

Effective dose from direct and indirect digital panoramic units

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ABSTRACT

Purpose: This study aimed to provide comparative measurements of the effective dose from direct and indirect digital panoramic units according to phantoms and exposure parameters.

Materials and Methods: Dose measurements were carried out using a head phantom representing an average man (175 cm tall, 73.5 kg male) and a limbless whole body phantom representing an average woman (155 cm tall, 50 kg female). Lithium fluoride thermoluminescent dosimeter (TLD) chips were used for the dosimeter. Two direct and 2 indirect digital panoramic units were evaluated in this study. Effective doses were derived using 2007 International Commission on Radiological Protection (ICRP) recommendations.

Results: The effective doses of the 4 digital panoramic units ranged between 8.9 μ Sv and 37.8 μ Sv. By using the head phantom, the effective doses from the direct digital panoramic units (37.8 μ Sv, 27.6 μ Sv) were higher than those from the indirect units (8.9 μ Sv, 15.9 μ Sv). The same panoramic unit showed the difference in effective doses according to the gender of the phantom, numbers and locations of TLDs, and kVp.

Conclusion: To reasonably assess the radiation risk from various dental radiographic units, the effective doses should be obtained with the same numbers and locations of TLDs, and with standard hospital exposure. After that, it is necessary to survey the effective doses from various dental radiographic units according to the gender with the corresponding phantom. (*Imaging Sci Dent* 2013; 43: 77-84)

KEY WORDS: Radiography, Dental, Digital; Radiography, Panoramic; Radiation Dosage

Introduction

Panoramic radiography has been widely used as a diagnostic tool because it is easy to provide a radiographic overview of the teeth and surrounding anatomical structures.^{1,2} Recently, a number of dental practitioners have come to prefer digital radiography over conventional film radiography.³⁻⁶ One of the main advantages of digital radiography compared with conventional film radiography is the possibility of reducing the radiation dose to patients.⁷ Diagnostic benefits and possible dose hazard trade-offs

are important considerations in the choice of radiographic procedures. Since X-ray risks are cumulative, the choice of radiographic unit should be considered in examining all patients for dose reduction.⁸ Digital panoramic equipment requires the evaluation of the radiation dose to patients according to the machines, and in maxillofacial panoramic imaging, the radiation dose of the machines should follow the principle of keeping the dose as low as reasonably achievable (ALARA).

The effective dose (E) is a concept and approach recommended by the International Commission on Radiological Protection (ICRP) to estimate the damage from radiation to the exposed population.⁹ E is a widely used calculation that permits comparison of the detriment of different exposures, including specific area exposure,¹⁰ to ionizing radiation to an equivalent detriment produced by a full body dose of radiation.⁸ White¹¹ used this approach in 1992 in

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assessing the radiation risk from various dental radiographic examinations. The unit of the effective dose is the sievert (Sv) and it is calculated by the equation: $E = \sum H_T \times W_T$, where E is the product of the tissue weighting factor (W_T), which represents the relative contribution of each organ or tissue to the overall risk, and the equivalent dose (H_T).¹² The whole-body risk is acquired by the summation of the weighted equivalent doses to all exposed tissues or organs. The earlier 1990 ICRP tissue-weighting factors,¹³ 2005 weighting factors, and the new 2007 weighting factors¹² were used to calculate the effective dose.^{7,8,14} Newly adopted recommendations from the ICRP provide revision of tissue-weighting factors and inclusion of salivary glands as a weighted tissue. These changes resulted in an upward reassessment of the effective dose from oral and maxillofacial radiographic examinations.¹²

The studies of the absorbed dose or effective dose from each exposure program of the film-based panoramic machine with a limbless whole body phantom and a head phantom were reported by Lecomber et al in 2000¹⁵ and Choi et al in 2001,¹⁶ respectively. The tissue-absorbed dose and the whole-body effective dose (E) for a new generation film-based panoramic machine (Planmeca PM 2002 CC Proline, Planmeca, Helsinki, Finland), operating in the panoramic examination mode with a head phantom, was studied by Danforth et al in 2000.¹⁴ Gijbels et al⁷ reported that the effective radiation doses ranged from 4.7 μ Sv to 14.9 μ Sv for various digital panoramic units with a head phantom using the 2005 recommendations of the ICRP.

Few studies have reported the difference in radiation dose between direct and indirect digital panoramic units. Also, to our knowledge, no studies have been published addressing the difference in the assessment of the effective dose using a head versus a whole body phantom.

Ludlow and Ivanovic⁸ reported that there was large difference in the radiation dose between the “standard” and “ultra” exposure in the Iluma CBCT unit. They also mentioned that a substantial difference in the effective dose was found according to variations in technique even when they evaluated the same CBCT unit. Therefore, it is neces-

sary to prepare standardized conditions for calculation of the effective dose to compare the radiation risk from various dental radiographic examinations.

The aim of the present study is to provide the comparative measurements of the effective dose from direct and indirect digital panoramic units according to phantoms and exposure parameters. The average tissue-absorbed dose, weighted (equivalent) radiation dose, and effective dose were calculated for the anatomy of the head and neck area and the whole body with the corresponding phantom, respectively.

Materials and Methods

Exposures

The digital panoramic units used for this study were the ProMax (Planmeca, Helsinki, Finland), Orthopantomograph OP100 (Imaging Instrumentarium, Tusula, Finland), and 2 ProlineXC units (Planmeca, Helsinki, Finland). Table 1 shows the technical and phantom parameters for the direct and indirect panoramic units used. Both the radiation exposure dose and the latitude of the TLD are too small to be measured with reliability; therefore, the TLD loaded phantom was exposed to radiation by the dosimeters ten times. Then, the obtained values were divided by ten to obtain one individual value for each region, subtracting each background dose. The phantom was positioned in accordance with the manufacturer’s specifications for each machine, following the reference lines and head rests. The standard examination was carried out for each unit and the dosimetry was performed for each technique in order to ensure reliability.

Dosimetry

Dose measurements were carried out using two anthropomorphic phantoms. The head phantom (Rando ART-210, Alderson Research Laboratories, Long Beach, CA, USA) representing an average man (175 cm tall, 73.5 kg male) (Fig. 1) and the limbless whole body phantom (Rando ART-300, Alderson Research Laboratories, Long

Table 1. Exposure and phantom parameters for the panoramic units

Type	ProMax Direct	ProlineXC Direct		ProlineXC Indirect	OP100 Indirect		
kVp	70	70	70	70	72	72	83
mA	10	12	12	12	12	12	12
Time (s)	16	18		18	17.6		
Phantom	Head	Body	Head	Head	Body	Head	Head



Fig. 1. The limbless female whole body phantom.



Fig. 2. The head phantom representing a man.

Beach, CA, USA) representing an average woman (155 cm tall, 50 kg female) (Fig. 2) consisted of 9 and 31 transverse sections, respectively. The reservoirs for the placement of radiation dosimetry measuring devices were prepared to correspond to the anatomic sites of interest. Lithium fluoride thermoluminescent dosimeter (TLD) chips (Harshaw TLD-100, Thermo Electron Co., Oakwood Village, OH, USA) were used as dosimeters. The absorbed doses at the selected locations, corresponding to the radio-

sensitive organs of interest, were measured using two sets of 60 and 96 TLDs. The 30 and 48 phantom sites both inside and on the surface of each phantom can be seen in Table 2. Two dosimeters were placed in each anatomical site to calculate the mean value of each location, while retaining the same dosimeters in the same positions for each exposure. A set of dosimeters were kept separately to record the background radiation. Before the study, all of the dosimeters were calibrated using the same type and range of radiation that would be used during the experiments. Prior to every exposure, the dosimeters were annealed at 100°C for 1 hour, 400°C for 2 hours, and then cooled to 35°C. All of the TLDs were read in accordance with the manufacturer's directions after each exposure using a Harshaw 3500 TLD Reader (Harshaw/Bicron, Solon, OH, USA).

Dose calculations

After reading, an individual sensitivity value was applied for each TLD. Exposure doses were recorded in nanocoulombs (nC) and, after the application of energy calibration factors (RCF, reader calibration factor; and ECC, element correction coefficient), the dosimetry data were converted into micrograys (μGy) and subsequently recorded. The standard deviation of the readings from the TLDs was less than 30%. Doses from two TLDs located at different points in the same tissue or organ were averaged, resulting in the average organ absorbed dose. The weighted dose for bone marrow of the whole body phantom was calculated using the sum of the radiation from the calvarium, mandibular body and ramus, cervical, thoracic, and lumbar vertebrae, and sacrum. The weighted dose for the bone marrow of the head phantom was calculated using the sum of the radiation from the calvarium, mandibular body and ramus, and cervical vertebra. Sublingual, submandibular, and parotid salivary gland doses were used for calculating the weighted dose for the salivary glands. The thyroid gland dose was individually calculated taking its specific weighted factor into consideration. For the skin surface area, fifteen points were measured: the posterosuperior surface of the head, thyroid surface, back of the thorax, and both sides of the right and left of the temporal region, lens of the eye, cheek, back of the neck, axilla, and breast (Table 2).

The products of these average organ absorbed doses and the percentage of a tissue or organ irradiated (Tables 3 and 4) in a radiographic examination were used to calculate the equivalent dose (H_T) in microsieverts (μSv).¹²

Table 2. Locations of TLD chips in phantoms

Head and Neck	ID	Body	ID
Posterosuperior surface	1	Right lung (13)	31
Right temporal surface (2)	2	Left lung (13)	32
Left temporal surface (2)	3	Thoracic spine (13)	33
Calvarium anterior (2)	4	Back (13)	34
Calvarium right (2)	5	Right axilla (14)	35
Calvarium left (2)	6	Left axilla (14)	36
Calvarium posterior (2)	7	Right breast surface (15)	37
Mid brain (2)	8	Left breast surface (15)	38
Pituitary (3)	9	Heart (15)	39
Right lens of eye (3)	10	Stomach (18)	40
Left lens of eye (3)	11	Liver (18)	41
Right orbit (4)	12	Right kidney (22)	42
Left orbit (4)	13	Left kidney (22)	43
Right cheek (5)	14	Lumber vertebra (24)	44
Left cheek (5)	15	Sacrum (27)	45
Right parotid (6)	16	Right ovary (29)	46
Left parotid (6)	17	Left ovary (29)	47
Right ramus (6)	18	Gall bladder (31)	48
Left ramus (6)	19		
Center C spine (6)	20		
Right back of neck (7)	21		
Left back of neck (7)	22		
Right mandible body (7)	23		
Left mandible body (7)	24		
Right submandibular gland (7)	25		
Left submandibular gland (7)	26		
Center sublingual gland (7)	27		
Midline thyroid (9)	28		
Thyroid surface (9)	29		
Esophagus (9)	30		

The effective dose was calculated by multiplying actual organ doses (equivalent dose; H_T) by 'risk weighting factors' as follows: $E = \sum H_T \times W_T$. The tissue weighting factor (W_T) represents the contribution that each specific tissue or organ makes to the overall risk. The whole-body risk was found by the summation of the tissue weighted equivalent doses to all tissues or organs exposed. Effective doses were derived using 2007 ICRP recommendations¹² (Table 5). This dose was expressed in microsieverts (μSv). The obtained effective dose from each panoramic unit was compared with the dosimetric values calculated from the 24 anatomical sites of the phantoms used by Ludlow and Ivanovic⁸.

Results

Table 6 shows the dosimetric results. The equivalent doses and the effective doses were expressed in μSv . The greatest individual organ doses for all examinations were measured in the salivary tissue.

The effective radiation doses ranged between 8.9 μSv

and 37.8 μSv for the 4 digital panoramic units. By using a head phantom, the effective doses from the ProMax (37.8 μSv) and ProlineXC (27.6 μSv) direct digital panoramic units were higher than those from the Orthopantomograph OP100 (8.9 μSv) and ProlineXC (15.9 μSv) indirect units.

The effective dose from the same panoramic unit (Orthopantomograph OP100) using the same head phantom was higher at 83 kVp than at 72 kVp.

Comparison of effective doses with parameters; the exposure, phantom (gender), and calculation method can be found in Table 7.

The effective dose from the ProlineXC (direct) with an exposure of 70 kVp and 12 mA was 36.8 μSv by the calculation for the head region of the whole body phantom and 27.6 μSv by the head phantom. The effective dose from the Orthopantomograph OP100 (indirect) with an exposure of 72 kVp and 12 mA was 13.6 μSv by the calculation for the head region of the whole body phantom and 8.9 μSv by the head phantom. The effective doses from the direct and indirect digital units were both higher with the female phantom than with the male one.

Table 3. Estimated percentage of tissue irradiated with the head phantom

Head and Neck	ID	%
Bone marrow		16.5
Mandible	18, 19, 23, 24	1.3
Calvaria	1-7	11.8
Cervical spine	20	3.4
Thyroid	28, 29	100.0
Esophagus	30	10.0
Skin	1-3, 10, 11, 14, 15, 21, 22, 29	9.0
Bone surface*		16.5
Mandible	18, 19, 23, 24	1.3
Calvaria	1-7	11.8
Cervical spine	20	3.4
Salivary glands		100.0
Parotid	16, 17	100.0
Submandibular	25, 26	100.0
Sublingual	27	100.0
Brain	8, 9	100.0
Remainders		
Lymphatic nodes	16-20, 23-28, 30	10.0
Muscle	16-20, 23-28, 30	5.0
Extrathoracic airway	12, 13, 16-20, 23-28, 30	100.0
Oral mucosa	16-19, 23-27	100.0

*Bone surface dose = bone marrow dose \times bone/muscle mass energy absorption coefficient ratio = $-0.0618 \times 2/3$ kV peak + 6.9406 using data.⁸

The effective doses calculated by the method of Ludlow and Ivanovic were lower than those calculated by the authors from each panoramic examination.

Discussion

The equivalent dose is used to compare the effects of different types of radiation on tissues or organs, presented in sieverts (Sv). The equivalent dose (H_T) was calculated according to the equation: $H_T = \sum W_R \times D_T$, where the equivalent dose (H_T) for a tissue or organ is the product of the radiation weighting factor (W_R) and the average absorbed dose (D_T) measured for that specific organ.¹³ The products of these values and the percentage of a tissue or organ irradiated (Table 3) in a radiographic examination were used to calculate the equivalent dose (H_T) in microsieverts (μ Sv).¹²

The equivalent doses from the indirect and direct digital panoramic units were highest in the remainders and salivary glands (Table 6). The next highest equivalent doses to other organs were the following, in order: bone surface, thyroid gland, and bone marrow. Several studies on panoramic units have pointed out that the salivary gland tissue is one of the organs receiving the highest individual organ doses during maxillofacial imaging^{7,15,17} and our

Table 4. Estimated percentage of tissue irradiated with the whole body phantom

Whole body	ID	%
Bone marrow		
Mandible	18, 19, 23, 24	1.3
Calvaria	1-7	11.8
Cervical spine	20	3.4
Thoracic spine	33	14.1
Lumbar vertebra	44	10.9
Sacrum	45	13.9
Colon	41-43, 48	100.0
Lung	31, 32, 39	100.0
Stomach	39, 40	100.0
Breast	37, 38	100.0
Gonads	46, 47	100.0
Bladder	48	100.0
Liver	41	100.0
Thyroid	28, 29	100.0
Esophagus	30, 39	100.0
Skin	1-3, 10, 11, 14, 15, 21, 22, 29, 34-38	36.0
Bone surface*		16.5
Mandible	18, 19, 23, 24	1.3
Calvaria	1-7	11.8
Cervical spine	20	3.4
Thoracic spine	33	14.1
Lumbar vertebra	44	10.9
Sacrum	45	13.9
Salivary glands		100.0
Parotid	16, 17	100.0
Submandibular	25, 26	100.0
Sublingual	27	100.0
Brain	8, 9	100.0
Remainders		
Lymphatic nodes	16-20, 23-28, 30, 35, 36, 39	40.0
Muscle	16-20, 23-28, 30, 33, 44, 45	43.9
Extrathoracic airway	12, 13, 16-20, 23-28, 30	100.0
Oral mucosa	16-19, 23-27	100.0
Adrenals	40	100.0
Gall bladder	41	100.0
Heart	39	100.0
Kidneys	42, 43	100.0
Pancreas	40	100.0
Small intestine	42, 43	100.0
Spleen	40	100.0
Thymus	39	100.0
Uterus/cervix	48	100.0

*Bone surface dose = bone marrow dose \times bone/muscle mass energy absorption coefficient ratio = $-0.0618 \times 2/3$ kV peak + 6.9406 using data.⁸

results confirmed these findings. Lecomber et al¹⁵ indicated that the influence on the calculated effective dose of treating the salivary tissue as a remainder organ deserved discussion in 2000. Ludlow and Ivanovic⁸ explained this by the fact that the rotational centers of panoramic units for the jaws coincide with the location of the salivary glands. Because anatomy at the rotational center is continuously

exposed, effective doses from dental panoramic imaging will be larger than imaging procedures that produce a more uniform distribution of absorbed energy within the scanned region. It seems reasonable to include salivary gland exposures in calculations of effective dose until these exposures could be shown not to be significant.¹⁸ The effective doses in this study were calculated with inclusion of the salivary gland tissue using 0.01 according to the 2007 ICRP tissue

weights.¹² Dental radiographic examinations resulted in negligible doses to the gonads, and hereditary doses were not effective for the calculation of detriment in this study. The use of a head phantom or only the head region calculation of the whole body phantom is thought to be reasonable for the calculation of detriment from dental radiographic examinations.

The effective dose is the product of the ICRP's tissue weighting factor (W_T) for the type of tissue or body and the human-equivalent dose for tissue (H_T). The effective dose is calculated by multiplying actual organ doses by 'risk weighting factors' (associated with individual organ sensitivities) and represents the dose that the total body could receive and that would provide the same cancer risk as the application of different doses to various organs.¹³ One sievert of effective dose carries with it a 4.1% chance of developing fatal cancer in an adult worker and a 5.5% chance in a whole population, and a 0.8% chance of hereditary defect in future offspring.¹² The ICRP recommends limiting artificial irradiation of the public to an average effective dose of 1 mSv per year, not including medical and occupational exposures.¹²

The effective doses from the ProMax (37.8 μ Sv) and ProlineXC (27.6 μ Sv) direct digital panoramic units were higher than those from the Orthopantomograph OP100 (8.9 μ Sv) and ProlineXC (15.9 μ Sv) indirect units by using the head phantom (Table 7). Gijbels et al⁷ reported that comparable results (9.35 μ Sv for CCD, 8.1 μ Sv for storage phosphor) were found for the various digital panoramic

Table 5. Tissue weighting factors for calculation of effective dose 2007 recommendations¹²

Tissue/Organ	Weighting factor (2007)
Bone marrow	0.12
Breast	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Esophagus	0.04
Gonads	0.08
Liver	0.04
Thyroid	0.04
Bone surface	0.01
Brain	0.01
Kidney	Remainder
Salivary glands	0.01
Skin	0.01
Remainder tissues	0.12 [†]

[†]: Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, and uterus/cervix. Italicized text represents remainder tissues used for calculation of maxillofacial dose.

Table 6. Equivalent dose (H_T) to tissues/organs and effective doses from direct and indirect digital panoramic units (unit; μ Sv)

kVp (mA) Phantom	ProMax	ProlineXC		ProlineXC	OP100		83 (12) Head
	Direct 70 (10) Head	Direct 70 (12) Head	Body	Indirect 70 (12) Head	Indirect 72 (12) Head Body		
Bone marrow	33.4	18.5	24.6	14.2	8.2	8.9	8.1
Colon			1.0			0.0	
Lung			3.4			0.7	
Stomach			2.0			0.0	
Breast			0.8			0.0	
Gonads			2.4			0.0	
Bladder			2.3			0.0	
Liver			0.2			0.0	
Thyroid	73.7	37.5	41.8	26.9	28.8	14.9	25.0
Esophagus	10.6	4.4	22.3	4.6	4.4	7.0	3.5
Skin	10.2	7.0	10.2	5.7	3.4	3.8	3.7
Bone surface*	135.6	75.0	99.8	57.7	32.7	35.3	28.6
Salivary glands	1161.1	880.9	1214.6	522.5	203.0	447.1	414.0
Brain	29.2	14.9	25.0	1.6	5.2	9.2	6.5
Remainders	1853.2	1510.9	2036.2	761.8	451.3	754.2	652.9
Effective dose	37.8	27.6	39.0	15.9	8.9	13.9	12.7

Table 7. Comparison of effective doses with parameters

	Type	kVp	mA	Phantom		Effective dose
ProMax	Direct	70	10	Man	Head	37.8
ProlineXC	Direct	70	12	Woman	Body	39.0
				Man	Head (cal)	36.8
ProlineXC	Indirect	70	12	Man	Head	27.6
				Man	Head	15.9
OP100	Indirect	72	12	Woman	Body	13.9
				Woman	Head (cal)	13.6
		83	12	Man	Head	8.9
				Man	Head	12.7

Head (cal): calculation of only head portion of whole body phantom.

units when the effective dose data of the direct panoramic units were averaged and compared with the indirect units. The effective doses from both types of digital panoramic unit evaluated in this study were larger than the results of Gijbels et al.

Given that comparison of the effective doses from the different panoramic units was difficult because of the different exposure settings, Gijbels et al⁷ reported that by considering per unit of exposure (mAs), the Orthoralix yielded the lowest dose per mAs ($0.10 \mu\text{Sv mAs}^{-1}$), but the Veraviewepocs the highest ($0.17 \mu\text{Sv mAs}^{-1}$), and that the influence of the tube potential was less clear. Actually, for the comparison of the effective doses from the different units having different exposure settings recommended for the preservation of diagnostic image quality, the doses per unit of exposure are thought not to be significant. In the present study design, the X-ray parameters used were those for an adult as usual in the hospital. The results obtained are thought to be reasonable for the comparison of effective doses from several digital panoramic units considering the respective technical aspects of each radiation unit for good image quality, such as the size of the radiation field and shape of the focal trough.

Considering the phantom parameters, the effective dose from the indirect digital panoramic units by the calculation for the head region of the whole body phantom ($13.6 \mu\text{Sv}$) was higher than that of the head phantom ($8.9 \mu\text{Sv}$). The effective dose from the direct units by the calculation for the head region of the whole body phantom ($36.8 \mu\text{Sv}$) was also higher than that of the head phantom ($27.6 \mu\text{Sv}$) (Table 7). In addition, the effective dose was higher with the female phantom than with the male phantom in both types of digital units. This is because the absorbed dose at each TLD dose in the phantom depends on the skull size¹⁹ and soft tissue morphology of the phantom, which simu-

late an actual man and woman.

The effective dose calculated from the 24 anatomical sites of the phantom used by Ludlow and Ivanovic⁸ was lower than the obtained effective dose from each panoramic unit in this study. The numbers of anatomical sites of the phantoms for their calculation of the effective dose were less than the numbers of anatomical sites in this study. Furthermore, the difference in the location (left, center, right) and numbers of sites for the TLDs at the same selected organs can account for the small difference in effective dose between the calculations of the present study and their study.

Besides, small variations in collimator adjustment or phantom position within the unit may account for the very nearly 23% difference seen between the dosimeter values for the 2 modes of one unit.⁸ The slight discrepancy in the location of the TLD or phantom position are magnified as the TLD is positioned inside or outside of the field of direct radiation.¹⁸

The effective doses from direct digital panoramic units were higher than from the indirect units. Even the same panoramic unit showed a difference in effective doses according to the gender of the phantom, number and locations of TLDs, and kVp. To reasonably assess the radiation risk from various dental radiographic units, the effective doses should be obtained with the same number and locations of TLDs, and with usual hospital exposure. After that, a survey on the effective doses from various dental radiographic units must be performed according to the gender with corresponding phantoms.

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