Pediatric Phantom Dosimetry Evaluation of the Extraoral Bitewing

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Abstract: ***Purpose:*** *This study's purpose was to evaluate the effective dose (E) and equivalent dose (H_T) of exposing a pediatric phantom to the extraoral bitewing programs of the Planmeca ProMax 2D S3 (ProMax) and Instrumentarium Orthopantomograph OP30 (OP30) and compare these results with dosimetry associated with the intraoral bitewing and panoramic radiograph.* ***Methods:*** *Dosimetry was acquired by placing 24 dosimeters in tissues of interest in a 10-year-old phantom. Manufacturer child settings were used for all scans. Repeat exposures of 20 scans were utilized. The average values of E and H_T were calculated.* ***Results:*** *The E for the ProMax and OP30 units, respectively, were 16.84 μSv and 5.82 μSv. The highest E for both units was delivered to the thyroid, remainder tissues, and salivary glands. The highest H_T for both units was delivered to the oral mucosa, salivary glands, extrathoracic airway, and thyroid. The mean differences between units were statistically significant ($P<0.05$).* ***Conclusions:*** *The average effective dose of the ProMax was higher than for the OP30. The effective dose of the pediatric extraoral bitewing is three to 11 times higher than that of the intraoral bitewing and comparable to the traditional*

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panoramic radiograph of a pediatric phantom. Pediatric extraoral bitewing radiation protection guidelines are recommended.

KEYWORDS: DOSIMETRY, PEDIATRICS, EXTRAORAL BITEWING, PANORAMIC BITEWING

The pediatric population provides significant challenges to obtaining and accurately diagnosing radiographic images. Proximal tooth surfaces are difficult to visualize directly; therefore, caries is diagnosed with the aid of radiographs. However, studies have estimated that 24 to 42 percent of carious lesions remain undetected.[1] Improvements in diagnostic radiology technology have allowed dentists to use a variety of methods to maximize the diagnostic quality of imaging, minimize radiation dose, and maximize patient comfort. Select panoramic units offer extraoral bitewing programs that allow for an X-ray beam that is parallel to the interproximal contacts of the teeth, which produces bitewing-like images that include information on the maxillary sinus, mandibular canal, mental foramen, and periapical bone from ramus to canine.[2] Proposed advantages of this system are simplicity in obtaining images, less time requirement, greater patient comfort, comparable diagnostics, and lower radiation dose.[2,3] While the skills necessary to obtain accurate scans, the time required, and patient comfort are subjective advantages and difficult to ascertain, the diagnostic quality of extraoral bitewings has been tested.

Several studies have confirmed that the highest sensitivity and specificity for detection of interproximal caries is the intraoral bitewing.[1-5] However, diagnostic quality studies have shown that the improved extraoral bitewing and interproximal panoramic radiographs are superior to conventional panoramic radiographs, providing sufficient information to accurately diagnose posterior interproximal caries when an intraoral image is not possible.[2,3] Chan et al. showed extraoral imaging to have a higher caries detection rate but with a false positive rate of 38 percent.[5] This data suggest that extraoral bitewing imaging can offer acceptable diagnostic information in certain difficult populations, including pediatric patients and the medically compromised.

Radiation dosimetry is the science of determining the distribution pattern of ionizing energy and absorbed dose of radiation delivered to objects of interest.[6] Research has shown that dosimetry is best studied by using an imaging phantom, which is designed to be anatomically equivalent to a human in tissue size, thickness, and elemental composition.[6] Dosimeters placed

strategically in an anthropomorphic phantom measure the absorbed dose resulting from the X-ray unit scan/exposure. This allows researchers to study the relative safety and potential impacts on the body's most radiosensitive organs. Dosimetry is best expressed through the calculation of tissue-equivalent dose and total effective dose. Tissue equivalent dose (***H_T***) is the absorbed dose of a tissue, adjusted for the radiation weighting factor.[7] It is the product of absorbed dose (D_T) and the radiation weighting factor (w_R) and is expressed in units of microsieverts (**µSv**).[7,8] The International Commission on Radiological Protection (**ICRP**) uses the total effective dose (***E***) to compare differing exposures. *E* is a 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. *E*, expressed in microsieverts, is calculated using the equation: $E = \sum w_T \times H_T$, where *E* is the summation of the products of the tissue weighting factor (***w_T***), which represents the relative contribution of that organ or tissue to the overall risk, and the radiation weighted dose H_T.[7,8] This calculation reflects the most radiosensitive tissues; the higher the weighting factor, the more radiosensitive the organ is.

Studies have shown that posterior bitewings use rectangular collimation to deliver an effective dose of 5.0 µSv and an equivalent exposure of 0.6 days to natural background radiation.[9] Conventional panoramic radiographs deliver an effective dose of nine to 26 µSv and an equivalent background exposure of one to three days.[9] Some of the key radiosensitive organs of the head and neck are the thyroid, salivary glands, bone marrow, and brain.[10] Children are at greater risk of cancer induction from radiation exposure due to an increased radiosensitivity of tissues and a longer lifespan.[10] Therefore careful monitoring of radiation exposure to the pediatric population is of increased importance. There are no current dosimetry studies for the use of the extraoral bitewing image in the pediatric population. Despite the lack of published research, manufacturers claim up to a 25 percent dose reduction using the extraoral bitewing setting, making it comparable in dose to the intraoral bitewing.[11]

The purpose of this study was to evaluate the effective dose (*E*) and tissue equivalent dose (H_T) in microsieverts (µSv) of exposing a pediatric head and neck phantom to the extraoral bitewing programs of the Planmeca ProMax 2D S3 (**ProMax**; Planmeca, Helsinki, Finland) and Instrumentarium Orthopantomograph OP30 (**OP30; Instrumentarium,** Tuusula, Finland) and comparing these results to the effective dose measurements of pediatric intraoral bitewings found

by Branets et al. and to the pediatric rotational panoramic radiographs found by Hayakawa et al.[12,13]

Methods

Dosimetry was acquired using an anthropomorphic head and neck pediatric phantom simulating the anatomy of a 10-year-old child (ATOM model 706 HN, CIRS Inc., Norfolk, Va., USA; Figure 1). Tissues simulated in the ATOM phantom are average soft tissue, average bone tissue, spinal cord, spinal disks, brain, and sinus. Simulated bone tissue matches age-related density. A set of 24 optically stimulated luminescent dosimeters (**OSLDs**; Nanodot, Landauer, Inc., Glenwood, Ill., USA) were positioned in the phantom at locations corresponding to ICRP (2007) weighted tissues and other tissues of interest in the head and neck region.[14] Dosimeter anatomic locations and child phantom levels are seen in Table 1. Tissues simulated in the phantom are average soft tissue, average bone tissue, spinal cord, spinal disks, brain, and sinus. Simulated bone tissue matches age-related density. Doses from OSLDs at different positions within a tissue or organ were averaged to express the average tissue-absorbed dose in micrograys (μGy).

The products of these values and the percentage of a tissue or organ irradiated in a radiographic examination (Table 2) were used to calculate the equivalent dose (H_T) in microsieverts. The phantom was mounted on an articulating tripod and positioned appropriately using the laser positioning guides. The extraoral bitewing program was selected, and manufacturer settings for a small child were used. Technique factors of 62 kVp, five mA, and exposure time of 8.1 seconds were used in all experimental trials for the ProMax. Technique factors of 66 kVp, six mA, and an exposure time of five seconds were used in all experimental trials for the OP30. Repeat exposures were utilized for each set, totaling 20 scans (one run), to provide a more reliable measure of radiation in the dosimeters. Three runs were completed with each machine, changing the dosimeter sets each time. Seven dosimeter sets were used in this experiment: three for each unit and one as a control. Dosimeters were read with a calibrated commercial reader (MicroStarii, Landauer, Inc.). Doses recorded by the reader were divided by the number of scans to determine the “exposure per scan” for each dosimeter.

The average tissue-absorbed dose in micrograys was calculated from the doses at different positions within the target tissue or organ. The products of these values and the percentage of a tissue or organ irradiated in a radiographic examination were used to calculate the equivalent dose

in microsieverts.[14] The calculated equivalent doses were then used to calculate *E* in microsieverts for each dosimeter set. Comparisons of the dosimetry parameters between the OP30 and ProMax were made using two-sample *t*-tests by locations. A five percent significance level was used for each test. Summary statistics (mean, standard deviation, standard error, 95% confidence interval for the mean, and range) were calculated for the dosimetry parameters by locations.

Results

Table 3 summarizes the mean, standard deviation, standard error, 95% confidence interval for the mean, and range of tissue-equivalent doses in microsieverts delivered by the ProMax and OP30 units to the thyroid, salivary glands, remainder (which includes the brain, lymphatic nodes, extrathoracic airway, muscle, and oral mucosa), and bone marrow. The largest equivalent dose per organ for the ProMax was seen in the oral mucosa (357.13 μSv), salivary glands (306.53 μSv), extrathoracic airway (259.05 μSv), and thyroid (188.02 μSv). The largest equivalent dose per organ for the OP30 was seen in the oral mucosa (117.62 μSv), salivary glands (107.55 μSv), extrathoracic airway (90.55 μSv), and thyroid (57.33 μSv). The mean differences between units were statistically significant ($P<0.05$) at leach location.

Table 4 summarizes the mean, standard deviation, standard error, 95 percent confidence interval for the mean, and range of the weighted equivalent dose ($\mathbf{w_T H_T}$) in microsieverts delivered by the ProMax and OP30 units to the thyroid, salivary glands, remainder, and bone marrow. Table 4 also summarizes the mean, standard deviation, standard error, 95 percent confidence interval for the mean, and range of total *E* delivered by each unit. The largest average $w_T H_T$ per organ for the ProMax was seen in the thyroid (7.52 μSv), remainder (5.93 μSv), and salivary glands (3.07 μSv). The largest average effective dose per organ for the OP30 was seen in the thyroid (2.29 μSv), remainder (2.00 μSv), and salivary glands (1.08 μSv). The mean differences between units were statistically significant ($P<0.05$) at leach location. The total effective dose for the OP30 unit was 5.82 with a standard deviation of 0.335, while it was 16.84 with a standard deviation of 0.409 for the ProMax; this difference was statistically significant ($P<0.001$).

Discussion

This is the first study known to use a child anthropomorphic phantom consistent with ICRP (2007) recommendations to measure the absorbed dose in tissue for an extraoral bitewing. The damage to

DNA causing cancer or other heritable defects, or stochastic effects of radiation, is an adverse outcome based on the frequency of radiation and the amount of equivalent dose to a tissue.[15] Dosimetry studies are designed to allow practitioners to make educated decisions when prescribing radiographic examinations and follow the guidelines regarding radiation protection. When the principles of justification, optimization, and dose limitation are correctly followed, the exposure to radiosensitive target organs is reduced, therefore reducing the risk of radiation-induced pathology, health care costs, and patient mortality.[8] Of particular interest are children younger than 10 years old who are at three times the risk of developing fatal cancer due to ionizing radiation.[16]

To follow these principles appropriately, the dose delivered from different X-ray units and programs must be known. This study showed that there are significant differences in the effective dose delivered by these two X-ray units. This was due, in part, to variations in the manufacturer settings. In particular, five seconds (OP30) versus 8.1 seconds (ProMax) of exposure time likely contributed to the significantly higher doses delivered by the ProMax. Differences in the field of view in the image produced may also help explain differences in dose. ProMax reports a standard panoramic size at 230 by 110 mm, compared with an extraoral bitewing size of 164 by 83 mm. The field of view for the OP30 extraoral bitewing is approximately 115 by 100 mm using calibrated measuring software (Dentrix Enterprise, American Fork, Utah, USA). The overall larger field of view of the image produced by the ProMax corresponds with a greater effective dose. The larger height of the OP30 image corresponds to the higher dose delivered to the brain when compared with the ProMax. Despite the reduced field of view of the extraoral bitewing, the effective dose for both units remains comparable to that in a standard panoramic film.

Hayakawa et al. found that rotational panoramic radiography units using manufacturer child settings produced effective doses of 6.0 μSv using an Orthophos (Sirona Dental Systems, Bensheim, Germany) and 10.0 μSv using a PM 2002 CC (Planmeca) and a pediatric phantom.[13] They concluded that pediatric exposure settings reduce dose irrespective of the machine.[13] Branets et al. found a minimum effective dose of 1.5 μSv for a series of four intraoral bitewings in a 10-year-old phantom using rectangular collimation and digital imaging.[12] This data suggest that the effective dose of an extraoral bitewing is similar to a panoramic radiograph but three to 11 times that of an intraoral bitewing. The extraoral bitewing provides additional information to that obtained in an intraoral image; therefore, a higher dose of radiation is expected. Reducing the amount of radiation by using pediatric settings is indicated; however, additional studies on

diagnostic quality using child settings are needed. This study was completed without the use of a thyroid shield or lead apron. Thyroid carcinoma is one of the four most common cancers diagnosed in 15- to 19-year-olds.[17] Studies using panoramic radiographs suggest that a lead apron provides no statistically significant dose reduction; use of a thyroid collar has shown a 19 percent reduction of the thyroid dose and 33 percent reduction of the total effective dose.[18,19] Thyroid collars are typically not used in panoramic images due to diagnostic interference; however, they could be considered because of the image produced by the extraoral bitewing.

Current recommendations for prescribing dental radiographs in children and adolescents with caries risk include posterior bitewing images in six- to 12-month intervals.[20] Providers must consider radiation differences when considering prescribing extraoral bitewings over the lifetime of a patient. They must also be aware of the tendency toward false-positive diagnoses when using this method.[4,5] When indicated, the extraoral bitewing should be prescribed using child technique factors and based on case-specific needs, not as an alternative to an intraoral series.

It is important to note the limitations of this study. This study was not a direct comparison between extraoral bitewing, intraoral bitewing, and rotational panoramic radiography using the same reference patient/phantom. The effective dose of this study correlates to a reference patient representing an average 10-year-old child; there are known differences in absorbed dose regarding age and sex that could be considered.[21,22] There are several panoramic units with extraoral bitewing capabilities, each with unique manufacturer settings for pediatric exposures that would need to be studied to determine standard technique factors. Additional dosimetry studies including the use of radiation protection (thyroid shield, lead apron) and analyzing the diagnostic quality of extraoral bitewings with child settings are indicated. Guidelines on the prescription of the extraoral bitewing and use of radiation protection should be considered.

Conclusions

Based on this study's results, the following conclusions can be made:

1. The average effective dose (μSv) of an extraoral bitewing delivered from the ProMax was higher than for the OP30 using the manufacturer's settings for a small child.
2. The extraoral bitewing delivers an effective dose similar to a traditional panoramic radiograph and three to 11 times that of an intraoral bitewing series using a pediatric phantom.

3. Guidelines on the prescription of the extraoral bitewing and radiation protection should be developed.

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Table 1. LOCATION OF OPTICALLY STIMULATED LUMINESCENT DOSIMETERS (OSLD) IN PEDIATRIC PHANTOM

OSLD ID	**Child phantom location***
1	Calvarium anterior (2)
2	Calvarium left (2)
3	Calvarium posterior (2)
4	Midbrain (2)
5	Midbrain (3)
6	Pituitary (4)
7	Right orbit (4)
8	Right lens of eye (4-5)
9	Left lens of eye (4-5)
10	Right maxillary sinus (5)
11	Left nasal airway (5)
12	Right parotid (6)
13	Left parotid (6)
14	Left back of neck (6)
15	Right ramus (7)
16	Left ramus (7)
17	Right submandibular gland (7)
18	Left submandibular gland (7)
19	Center sublingual gland (7)
20	Center C spine (8)
21	Thyroid superior - left (8)
22	Thyroid - left (9)
23	Thyroid - right (9)
24	Esophagus (9)

**Value in parentheses corresponds to axial slice indicated in Figure 1.*

Table 2. ESTIMATED PERCENTAGE OF TISSUE IRRADIATED AND OPTICALLY STIMULATED LUMINESCENT DOSIMETERS (OSLD) USED TO CALCULATE MEAN ABSORBED DOSE TO A TISSUE OR ORGAN

Tissue	**Fraction irradiated child (%)**	**OSLD ID (Table 1)**
Bone marrow	15.4	
Mandible	1.1	15, 16
Calvaria	11.6	1, 2, 3
Cervical spine	2.7	20
Thyroid	100	21, 22, 23
Esophagus	10	24
Skin	5	8, 9, 14
Bone surface†	16.5	
Mandible	1.3	15, 16
Calvaria	11.8	1, 2, 3
Cervical spine	3.4	20
Salivary glands	100	
Parotid	100	12, 13
Submandibular	100	17, 18
Sublingual	100	19
Brain	100	4, 5, 6
Remainder		
Lymphatic nodes	5	12-13, 17-19, 21-24
Muscle	5	12-13, 17-19, 21-24
Extrathoracic region	100	10-13, 17-19, 21, 24
Oral mucosa	100	12-13, 17-19

**Values for 10-year-old child phantom following 2007 recommendations of the International Commission on Radiological Protection (ICRP).*[14]

†*Bone surface dose=bone marrow dose x bone/muscle mass energy absorption coefficient ratio=-0.0618 x 2/3 kV peak+6.9406 (using data taken from NBS Handbook no. 85)*[23]

Table 3. SUMMARY OF TISSUE EQUIVALENT DOSE (H_T) IN MICROSIEVERTS (μSv) BY LOCATION AND MEAN DIFFERENCE BETWEEN RADIOLOGY UNITS*

Location	**Unit**	**Mean±(SD)**	**Mean±(SE)**	**95% CI**	**Min/max**	**Mean difference (*P*-value)‡**
Thyroid	OP30	57.33 (4.99)	57.33 (2.88)	(44.92, 69.73)	(51.58, 60.65)	-130.70 (<0.001) OP30 < ProMax
	ProMax	188.02 (5.32)	188.02 (3.07)	(174.81, 201.23)	(184.22, 194.10)	
Salivary glands	OP30	107.55 (3.12)	107.55 (1.80)	(99.81, 115.29)	(104.16, 110.29)	-199.00 (0.002) OP30 < ProMax
	ProMax	306.53 (16.02)	306.53 (9.25)	(266.73, 346.34)	(296.40, 325.01)	
Remainder†	OP30	16.67 (0.46)	16.67 (0.26)	(15.54, 17.80)	(16.15, 16.96)	-32.75 (0.001) OP30 < ProMax
	ProMax	49.42 (2.27)	49.42 (1.31)	(43.78, 55.06)	(48.04, 52.04)	
Brain	OP30	3.03 (0.07)	3.03 (0.04)	(2.87, 3.20)	(2.98, 3.11)	0.96 (<0.001) OP30 > ProMax
	ProMax	2.07 (0.11)	2.07 (0.07)	(1.79, 2.36)	(2.00, 2.21)	
Lymphatic nodes	OP30	4.28 (0.18)	4.28 (0.11)	(3.83, 4.74)	(4.07, 4.41)	-8.86 (<0.001) OP30 < ProMax
	ProMax	13.14 (0.49)	13.14 (0.29)	(11.91, 14.37)	(12.79, 13.70)	
Extrathoracic airway	OP30	90.55 (2.28)	90.55 (1.32)	(84.88, 96.23)	(88.02, 92.45)	-168.50 (<0.001) OP30 < ProMax
	ProMax	259.05 (9.89)	259.05 (5.71)	(234.48, 283.62)	(252.04, 270.36)	

Muscle	OP30	4.28 (0.18)	4.28 (0.11)	(3.83, 4.74)	(4.07, 4.41)	-8.86 (<0.001) OP30 < ProMax
	ProMax	13.14 (0.49)	13.14 (0.29)	(11.91, 14.37)	(12.79, 13.70)	
Oral mucosa	OP30	117.62 (3.48)	117.62 (2.01)	(108.97, 126.27)	(113.75, 120.52)	-239.50 (0.002) OP30 < ProMax
	ProMax	357.13 (18.75)	357.13 (10.83)	(310.55, 403.70)	(345.76, 378.77)	
Bone marrow	OP30	2.20 (0.30)	2.20 (0.17)	(1.46, 2.94)	(1.87, 2.44)	0.85 (0.04) OP30 > ProMax
	ProMax	1.35 (0.04)	1.35 (0.02)	(1.26, 1.44)	(1.32, 1.39)	

**SD=standard deviation; SE=standard error; CI=confidence interval; min/max=minimum and maximum values in the data set*

†*Remainder includes brain, lymphatic tissues, extrathoracic airway, muscle, and oral mucosa.*

‡*Two-sample t-tests by location with a 5% significance level used to calculate the mean difference. A test was run on equality of variance. When P>0.05, the variances were equal and the pooled variance section of the results was read. When P<0.05, the variances were unequal and the Welch-Satterthwaite section was read.*

Table 4. SUMMARY OF WEIGHTED EQUIVALENT DOSE (W_TH_T) BY LOCATION AND MEAN DIFFERENCE BETWEEN UNITS AND TOTAL EFFECTIVE DOSE (*E*) IN MICROSIEVERTS (μSv)*

Location	**Unit**	**Mean±(SD)**	**Mean±(SE)**	**95% CI**	**Min/max**	**Mean difference (*P*-value)‡**
W_TH_T						
Thyroid	OP30	2.29 (0.20)	2.29 (0.12)	(1.80, 2.79)	(2.06, 2.43)	-5.23 (<0.001) OP30 < ProMax
	ProMax	7.52 (0.21)	7.52 (0.12)	(6.99, 8.05)	(7.37, 7.76)	
Salivary glands	OP30	1.08 (0.03)	1.08 (0.02)	(1.00, 1.15)	(1.04, 1.10)	-1.99 (0.002) OP30 < ProMax
	ProMax	3.07 (0.16)	3.07 (0.09)	(2.67, 3.46)	(2.96, 3.25)	
Remainder†	OP30	2.00 (0.06)	2.00 (0.03)	(1.86, 2.14)	(1.94, 2.04)	-3.93 (0.001) OP30 < ProMax
	ProMax	5.93 (0.27)	5.93 (0.16)	(5.25, 6.61)	(5.76, 6.24)	
Bone marrow	OP30	0.26 (0.04)	0.26 (0.02)	(0.18, 0.35)	(0.22, 0.29)	0.10 (0.04) OP30 > ProMax
	ProMax	0.16 (0.00)	0.16 (0.00)	(0.15, 0.17)	(0.16, 0.17)	
E						
Total effective dose	OP30	5.82 (0.34)	5.82 (0.19)	(4.99, 6.65)	(5.43, 6.02)	-11.02 (<0.001) OP30 < ProMax
	ProMax	16.84 (0.41)	16.84 (0.24)	(15.82, 17.85)	(16.43, 17.24)	

**SD=standard deviation; SE=standard error; CI=confidence interval; min/max=minimum and maximum values in the data set*

†*Remainder includes brain, lymphatic tissues, extrathoracic airway, muscle, and oral mucosa*

‡*Two-sample t-tests by location with a 5% significance level used to calculate the mean difference. A test was run on equality of variance. When P>0.05, the variances were equal and the pooled variance section of the results was read. When P<0.05, the variances were unequal and the Welch-Satterthwaite section was read.*