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Pediatric phantom dosimetry using a hand-held portable dental radiology device

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Abstract

Background: The purpose of the study was to evaluate the radiation dose of the NOMAD Pro 2 device for different anatomical areas using a pediatric phantom.

Methods: Absorbed doses resulting from a maxillary anterior occlusal and bitewing projections of an anthropomorphic 10-year-old child phantom were acquired using optical stimulated dosimetry. Equivalent doses were calculated for radiosensitive tissues in the head and neck area, and effective dose for maxillary anterior occlusal and bitewing examinations were calculated following the 2007 recommendations of the International Commission on Radiological Protection (ICRP). In addition, the effective dose of backscatter radiation to the operator was recorded.

Results: Of the anterior occlusal scans, the salivary glands had the highest equivalent dose, followed by oral mucosa extra thoracic airway and thyroid gland. For the bitewing projection scan, the salivary glands had the highest equivalent dose followed closely by the oral mucosa. The operator had minimal recorded dose.

Conclusion: Compared to previous research, completed with the adult phantom, a child receives less radiation for bitewing and anterior occlusal projections using a hand-held portable device than when a traditional wall mounted device is utilized.

Introduction

Radiographic dental imaging serves an important role in determining overall dental health [1]. Dentists use radiographs, or X-rays, to aid in diagnosing dental caries, locating pathology, and assessing dental growth/development [2]. One of the more recent advances in dental imaging is the use of portable hand-held digital radiology [3]. Initially introduced to the market for use in emergency situations, these portable devices have also shown increased popularity in dental offices and operating rooms [4].

In pediatric dentistry specifically, several benefits for portable dental radiology have been documented including increased efficiency as well as good dental image quality and increased convenience [4]. While there are noted benefits, portable devices do have raised concerns for their increased equipment costs and possible increase in radiation exposure to the patient and operator [5]. Previous studies have shown that the housing tube shielding ineffectively protects the operator from back scatter radiation during the imaging process and may cause potentially

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high levels of radiation if the operator is not adequately shielded [6]. Even with their added convenience, concerns for these portable devices producing higher operator doses has resulted in a belief that these portable devices do not keep radiation exposure As Low As Reasonably Achievable (ALARA) and has even caused some to discourage their use in non-emergency situations [6]. The NOMAD portable dental radiology device is one of the more popular units [7]. According to the manufacturer, the NOMAD has special design features which provide additional radiation exposure protection, including increased shielding around the x-ray tube, built-in leaded acrylic shield to protect from backscatter radiation, and a shielded position indicating device, or collimator [8]. Other than those published reports completed by manufacturers, few studies have focused on determining the patient exposure problems or possible increased risk of use in pediatric patients [8,9].

One method of safely testing dosimetry and image quality is by using an imaging phantom. The imaging phantom is a device resembling a human head specifically designed with materials mimicking human tissue in thickness and response to imaging. The phantom houses 24 dosimeters strategically placed to target important structures irradiated in dental radiographs. Each dosimeter is encased in a light-tight plastic, which prevents any ambient lighting from reaching the dosimeter and, therefore, causing skewed data. Several studies have been published in the area of scatter radiation and operator exposure in using portable radiology devices in adult patients [8,9].

A previous study by Ludlow, comparing a traditional wall mounted device to the NOMAD hand-held radiology device (Airbex, Inc., Charlotte, NC) found there was an 18% difference between the two systems. While this is well within the variability of patient doses from one device to another regardless of the type of x-ray system, it is important to note this research was completed on an adult phantom [8,9]. There has been little research focusing on the use of portable dental radiology devices and their effect on radiation exposure to pediatric patients [10-13].

The aim of this study was to evaluate the effective dose, or the tissue weighted sum of the equivalent dose of specific organs or tissues, of exposing a pediatric phantom to right bitewing and maxillary anterior occlusal radiographs using the NOMAD PRO 2 Portable Radiology Device (Airbex, Inc., Charlotte, NC). A secondary aim of this study is to determine the amount of backscatter radiation affecting the operator of the NOMAD PRO 2 Portable Radiology Device.

Methods

Optically stimulated luminescent dosimeters (Nanodot, Landauer, Inc., Glenwood, IL) are plastic disks infused with aluminum oxide doped with carbon (Al_2O_3:C). The trace amounts of Carbon in the Al_2O_3 crystal lattice create imperfections that act as traps (F centers) for electrons or holes. After exposure to ionizing radiation, free electrons and holes are generated and trapped at the F centers in proportion to the amount of energy in the exposure. Energy captured by the F centers is reemitted as light when electrons or holes recombine. This occurs when the crystal is optically stimulated with a controlled exposure of 540 nm of light from a light emitting diode. The energy released from F centers can be distinguished from the stimulating light because it is emitted in the form of 420 nm photons. The intensity of the emitted luminescence depends on the dose absorbed by the OSLD and the intensity of the stimulating light. This intensity is proportional to the stored dose and is recorded by a photomultiplier tube that incorporates a filter that screens out photons from the stimulating light source. Each dosimeter is encased in a light-tight plastic holder measuring approximately 1 mm x 10 mm x 10 mm. This case prevents loss of energy through stimulation by ambient light. Dosimeters used in this study will be read with a portable reader (MicroStar, Landauer, Inc., Glenwood, IL). The reader is calibrated before use. Following calibration, photon counts from dosimeters may be recorded with an accuracy of ~+/- 2%. Photon counts are converted to dose using an energy specific conversion factor. The reader will be calibrated using dosimeters exposed to confirmed amounts of radiation from an 80 kVp source [9].

Dosimetry was acquired using a tissue equivalent pediatric phantom simulating the anatomy of a 10-year old child (Model 706 HN, CIRS Inc., Norfolk, VA). The phantom consists of nine 16cm diameter cylindrical slabs of plexiglass with polyvinyl chloride and air elements configured to permit measurements of Poly-methyl-methacrylate (PMMA) voxel, PMMA Noise, Homogeneity, Contrast, Contrast to Noise Ratio (CRN), Modulation Transfer Function (MTF) 10%, MTF 50%, and Nyquist frequency. Dosimeters were positioned at 24 locations corresponding to International Commission on Radiological Protection (ICRP) (2007) weighted tissues and other tissues of interest in the head and neck region. The phantom was modified by creating slots to accept Nanodot dosimeters at sites corresponding to internal tissues of interest (Figure 1). Neck and cheek dosimeters were positioned at the vertical center of the designated slice level and taped in position. Lens of eye dosimeters were centered over the anatomic location for the lens and taped in position. Internal dosimeters were positioned vertically with the upper edge of the dosimeter holder flush with the surface of the selected slice level and held in position by friction of the dosimeter case and the phantom material at the sampled anatomic location. For this experiment the NOMAD PRO 2 portable radiology device (Aribex, Inc., Charlotte, NC; item #ARU-06) was used and repeat exposures were taken simulating left/right bitewings as well as upper/lower anterior occlusal radiographs. Technique factors of 60 kVp and 7mA were used in all experimental trials. The child phantom underwent exposure times of 0.063 seconds. The NOMAD portable radiology device was maintained at a controlled angulation for the experiment in order to insure more consistent positioning between scans. A dental x-ray film positioning device was developed by the authors specifically for this study. The positioning device helps increase the dimensional accuracy and reproducibility of dental radiographs to ensure for more controlled angulation. An additional 2 dosimeters were placed on the operator in order to record possible backscatter radiation: (1) on the operator's forehead; (2) on the operator's hand. As per the recommendations of the manufacturer, the operator only wore a thyroid collar for protective shielding. Repeat exposures were utilized for each dosimeter run to provide a more reliable measure of radiation in the dosimeters. In order to ensure accurate baseline readings, the dosimeters were cleared prior to use and a separate set of dosimeters were utilized for each round of exposures. OSLD doses recorded by the reader were divided by the number of scans to determine the 'exposure per scan' for each dosimeter. Separate operator dosimeters were utilized for each part of the experiment. Ten exposures were completed for part of the study. The following process was utilized for completing the exposures:

- Right bitewing projection with the patient phantom wearing a thyroid collar.
- Right bitewing projection with the patient phantom not wearing a thyroid collar.
- Anterior occlusal projection with the patient phantom wearing a thyroid collar.
- Anterior occlusal projection with the patient phantom not wearing a thyroid collar.

Ten exposures were completed in each projection and the experiment was completed three times. Three additional sets of dosimeters were utilized. The first was used as a control to record any background radiation that might have been incurred during phantom transport. A second additional set of dosimeters was divided into pairs and utilized to record backscatter radiation to the operator. Thus, a total of 14 dosimeter sets were utilized. The test phantom was scanned with and without a thyroid collar in place [12,13].

After all scans were completed, the dosimeters were read with a commercial reader, MicroStar (Landauer, Inc. Glenwood, IL). This reader was calibrated prior to use. Again, the recorded value was divided by ten, which was the number of scans per trial completed. 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 was used to calculate the equivalent dose (H_T) in micro-Sieverts (μSv). A Sievert is a derived unit of ionizing radiation dose calculated in SI Units and is a measure of the health effect of low levels of ionizing radiation on the human body [15].

For bone, the equivalent dose to the whole-body bone surface was calculated using the summation of the individual equivalent doses to the calvarium, the mandible, and the cervical spine. The determination of these equivalent doses was based on the distribution of bone throughout the body [15]. The equivalent dose is used to calculate the overall effective dose, which refers to the tissue-weighted sum of equivalent doses in all specific tissues and organs of the human body [15]. It represents the stochastic health risk to the whole body, or the probability of cancer induction and genetic effects of low ionizing radiation levels [15].

A summary of statistical analysis was provided following completion of the experiment. Summary statistics (mean, standard deviation, standard error, 95% confidence interval for the mean, range) were calculated for the dosimetry parameters. Average and standard deviation of each set of dosimeters were calculated. Effective dose (μSv) was calculated by using the same methodology, published by Johnson et al., and applying 2007 ICRP tissue weighting factors [12].

Results

Dosimeter readings from 16 locations on the phantom and 2 locations (forehead/hand) on the operators were analyzed and recorded. Table 1 represents the average effective dose: One for right bitewing scans and the other for maxillary anterior occlusal scans. The average effective dose of the right bitewing scan with thyroid shielding was 0.2 μSv, compared with 1.4 μSv without thyroid shielding. The average effective dose of the maxillary anterior occlusal scan was 0.2 μSv both with thyroid shielding and 1.3 μSv without thyroid shielding. Figure 1 graphically depicts the average effective dose for right bitewings and maxillary anterior occlusal radiographs using the various methods.

OSL ID	Child Phantom Location (Level of OSLD Location)
1	Calvarium anterior (2)
2	Calvarium left (2)
3	Calvarium posterior (2)
4	Mid brain (2)
5	Mid brain (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)

Figure 1: Atom max pediatric tissue equivalent phantom and respective coresponding locations

Table 1: Average equivalent doses (e) for standard parameters of nomad pro 2

Upper Anterior Occlusal w/ Thyroid Shielding	0.2
Right Bite Wing w/ Thyroid Shielding	0.2
Upper Anterior Occlusal w/o Thyroid Shielding	1.3
Right Bitewing w/o Thyroid Shielding	1.4
*This is the E dose average over all exams.	

Table 2 shows the average equivalent doses of specific tissues for both right bitewing and maxillary anterior occlusal projections. Of the right bitewing scans, the largest equivalent dose per organ was seen in the oral mucosa followed by the salivary glands (parotid, submandibular, and sublingual), and thyroid gland. Of the maxillary anterior occlusal scans, the largest equivalent dose per organ was similarly seen in the salivary glands, and the thyroid gland. ANOVA test results showed that both of these projections are statistically significant. Thyroid shielding has significant effect at most of the locations in the right bitewing projection. For example: there was significant differences at bone marrow (p = 0.0002). The test results also showed that thyroid shielding has no significant effects at any of the locations with maxillary anterior occlusal projection (all p> 0.05). Figure 2 graphically depicts the tissue specific effective dose for right bitewings and maxillary anterior occlusal radiographs of three affected tissues (thyroid, bone surface, salivary glands).

Table 2: effective dose measurements for standard parameters of Nomad pro 2

Bone Marrow	0.0	0.1	0.4	0.5
Mandible				
Calvaria				
Cervical spine				
Thyroid	*0.3*	*0.3*	*1.2*	*2.0*
Esophagus	0.0	0.0	0.1	0.1
Skin	0.1	0.0	0.0	0.0
Bone surface	0.2	0.3	2.1	2.4
Mandible				
Calvaria				
Cervical spine				
Salivary glands	*6.0*	*5.3*	*40.0*	*42.6*
Parotid				
Submandibular				
Sub-lingual				
Brain*	0.7	0.7	1.7	1.0
Remainder	1.0	0.9	6.1	6.4
Brain†	0.7	0.7	1.7	1.0
Lymphatic nodes*	0.2	0.2	1.3	1.4
Extrathoracic airway*	6.1	5.6	29.2	30.6
Muscle*†	0.2	0.2	1.3	1.4
Oral mucosa*	6.6	5.9	47.0	49.8
†-ICRP 1990, *-ICRP 2007	0.0	0.0	0.0	0.0
Lens of eyes	1.6	1.3	1.0	1.2
Pituitary	1.2	1.5	3.7	1.8

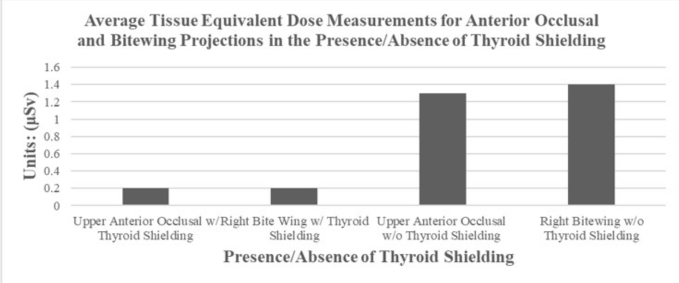

Figure 2: Average tissue equivalent doses for nomad pro 2.

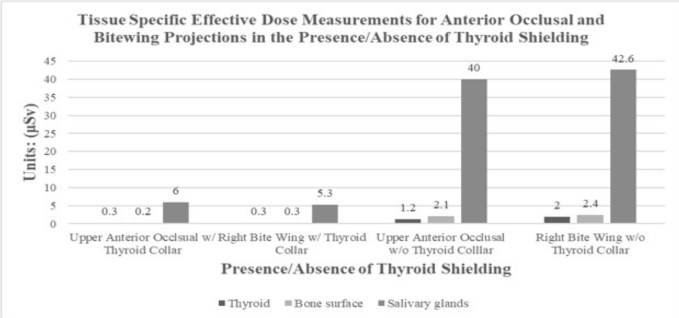

Figure 3: Tissue specific effective dose measurement for nomad pro 2.

Additional results were calculated comparing the backscatter radiation to the operator with the patient wearing/not wearing thyroid shielding, in other words, the average and standard deviation for tissue equivalent doses and total effective dose to the operator. ANOVA test results showed patient thyroid shielding has no significant effect at both locations for both right bitewing and maxillary anterior occlusal.

Discussion

Stochastic effects of radiation, or damage to the DNA causing cancer or other heritable defects, are an adverse outcome based on the frequency of radiation [15]. The larger the equivalent dose to a tissue, the more likely stochastic effects occur. However, for head and neck radiographs such as what is used in hand-held portable dental radiology, where the effective dose is less than 0.1 mSv (100 µSv), the risks of stochastic effects are negligible [13]. It is important to note that the effective dose of this study does not correlate to a specific patient but more to a reference patient of an average 10-year-old child, as there are known differences regarding age and sex [14].

Although no specific tests have been performed using portable handheld dental radiology in pediatric patients, salivary glands have consistently received the largest equivalent dose in adult phantom patients regarding standard radiographic technique studies as well as newer radiology methods. Pauwels et al. completed a study in 2012 using the adult phantom testing numerous CBCT machines. The radiographic testing specifically focused on the mandibular molar region, resulting in an effective dose of 40 µSv and an equivalent dose to the salivary glands of 709 µSv [16]. Compared to this study, the handheld portable dental radiology device resulted in almost forty times less effective dose and 20 times less equivalent dose to the salivary glands. While not the same method of radiology, it is important to note the differences in effective and equivalent dose when using various methods. In addition, until recently (2007) salivary glands were not incorporated into the ICRP calculation of effective dose. The 2007 ICRP guidelines include salivary glands and updated tissue-weighting factors for other organs [16]. A review of dosimetry literature prior to 2007 shows lower effective doses for both pediatric and adult phantoms. Ludlow et al. found an increased effective dose of 32 to 422 percent with the use of the 2007 ICRP guidelines compared to the previous guidelines [14,17,18].

To better understand how much radiation a child is exposed to while having radiographs completed using a handheld, portable dental radiology device, such as the Airebex NOMAD PRO 2 effective doses can also be compared to the effective doses of common intraoral radiographs (posterior bitewings). Johnson et al. calculated the average effective dose for a 12-year-old child using F-speed film and with a rectangular collimator at 5 µSv. We found that a 10-year-old child receives an average effective dose of 0.2 µSv with thyroid shielding (1.4 µSv without thyroid shielding). Additionally, the effective dose is less when undergoing portable handheld radiology methods compared with bitewings with round collimation [19,20].

Concerning the minimal backscatter radiation to the operator, previous research can aid in some explanation. According to Gray, occupational doses are lower with the NOMAD than with conventional intraoral x-ray systems [6]. This is probably due to the tube shielding design because the NOMAD is designed to be hand held and has significantly more shielding around the x-ray tube than a conventional system. Since the NOMAD has a built-in integral shield and shielded position indicating device collimator to protect the user from scattered radiation, this could explain why test results showed that patient thyroid shielding has no significant effect at both locations for both right bitewing and maxillary anterior occlusal.

Further studies need to be completed with other handheld portable dental radiology devices in the field of child phantom dosimetry. Due to the differing manufacturer settings of radiology machines and variable scanning options, more research is required to fully understand the amounts of radiation exposure in children.

Conclusions

Based on this study, the following conclusions may be made:

1. A child receives less radiation for bitewing and anterior occlusal projections using a hand-held portable device than when a traditional wall mounted device is utilized.
2. Thyroid shielding has no significant effect on backscatter radiation when taking bitewings on anterior occlusal radiographs using a handheld portable dental radiology device.

Acknowledgment

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