IN VITRO STUDY

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Pediatric Phantom Dosimetry of Kodak 9000 Cone-beam Computed Tomography

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Abstract: ***Purpose:*** *The purpose of the study was to evaluate the radiation dose of the Kodak 9000 cone-beam computed tomography (CBCT) device for different anatomical areas using a pediatric phantom.* ***Methods:*** *Absorbed doses resulting from maxillary and mandibular region three by five cm CBCT volumes 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 and mandibular examinations were calculated following the 2007 recommendations of the International Commission on Radiological Protection (ICRP).* ***Results:*** *Of the mandibular scans, the salivary glands had the highest equivalent dose (1,598 microsieverts [μSv]), followed by oral mucosa (1,263 μSv), extrathoracic airway (pharynx, larynx, and trachea; 859 μSv), and thyroid gland (578 μSv). For the maxilla, the salivary glands had the highest equivalent dose (1,847 μSv), followed closely by oral mucosa (1,673 μSv), followed by the extrathoracic airway (pharynx, larynx, and trachea; 1,011 μSv) and lens of the eye (202 μSv).* ***Conclusion:*** *Compared to previous research of the Kodak 9000, completed with the adult phantom, a child receives one to three times more radiation for mandibular scans and two to 10 times more radiation for maxillary scans.* *(Pediatr Dent 2017;39(3):229-32) Received June 8, 2016 | Last Revision January 5, 2017 | Accepted January 5, 2017*

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There are several documented uses for cone-beam computed tomography (**CBCT**) in the pediatric dental field. CBCT has been used to localize developing dentition, visualize resorption in relation to an unerupted tooth, and determine severity of facial trauma. CBCT has also aided in surgical applications of bony pathoses. Thirty-three percent of 313 cases in pediatric dental patients were for localization of teeth, 19 percent for presence of root resorption, 11 percent for bony pathoses visualization, and four percent were facial trauma patients.[1]

In a recent retrospective publication, Isman et al. investigated the most common reasons for authorizing 329 CBCT in children. They found that dentomaxillofacial anomalies followed by localization of impacted teeth were the most common indications for a CBCT.[2] Dentists and physicians can also benefit from CBCT by visualizing the extent of a cleft palate, craniofacial morphology, and abnormalities and analyzing airways needed for sedation cases.[3] Studies published regarding pediatric usage of the CBCT mention that, in the pediatric population, a smaller field of view (**FOV**) can satisfy the needs of the prescribing physician or dentist. The smaller the FOV used, the less effective dose the patient receives.[3]

Previous research suggests that children are more radiosensitive compared to adults while undergoing dental radiography. Ludlow et al. reported effective doses 36 percent higher in children compared to adults when undergoing a CBCT.[4] They show average effective doses for the maxilla at 53 microsieverts (**μSv**) and average effective doses for the mandible at 102 μSv for an adult phantom. For a child phantom, average effective doses for the maxilla were 67 μSv and average effective doses for the mandible were 128 μSv.[4] Dosages of common dental radiographs, including bitewings and panoramic radiographs, range from one to 20 μSv and four to 30 μSv, respectively.[5] Therefore, a patient receives a larger amount of radiation while undergoing a CBCT compared to other dental radiographs. Several studies have been published in the area of dosimetry using CBCT with an adult phantom, but there is a lack of publications with pediatric phantoms.

The purpose of this study was to evaluate the radiation dose of the Kodak 9000 CBCT on different anatomical areas using a pediatric phantom, with the hypothesis that the child will receive more radiation compared with previous similar studies using an adult phantom.

Methods

Dosimetry is best expressed in terms of tissue equivalent dose and total effective dose. Tissue equivalent dose (**H_T**) is the absorbed dose of the tissue adjusted for the radiation weighting factor. It is calculated by the product of absorbed dose (**D_T**) and the radiation weighting factor (**W_R**) and expressed in millisieverts or microsieverts. Total effective dose is the calculation the International Commission on Radiological Protection (**ICRP**) chooses to use to compare differing exposures.[4] It is calculated by taking the sum of the products of the tissue weighting factor (**W_T**) and the H_T. According to Ludlow et al., this calculation reflects the most radiosensitive tissues; their weighting factor, expressing a degree of sensitivity for each tissue, is commonly expressed in millisieverts or microsieverts.[4] The higher the weighting factor, the more radiosensitive the organ is.

A device used for evaluating dose, due to exposure from ionizing radiation during dental radiographic examination, is an imaging phantom. For this study, an anthropomorphic head and neck phantom (ATOM Max, CIRS, Inc., Norfolk, Va., USA), simulating the approximate size, body type, and

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Figure 1. ATOM Max Pediatric Tissue Equivalent Phantom.

Table 1. LOCATION OF DOSIMETERS INSIDE THE PEDIATRIC PHANTOM	
Optically stimulated luminescence ID	**Child phantom 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)

* Axial slice indicated by ( ).

mass of an average 10-year-old child, was used to acquire dosimetry data (Figure 1). The phantom contains materials of varying densities that provide attenuation characteristics representative of the varying human tissues, glands, and organs located within the head and neck. The phantom is sectioned into axially oriented slabs (25-mm thick), which permits access to specific tissues and anatomical locations of interest (Table 1). Slabs are modified to accept dosimeters at each of the internal and external sites. During the imaging process, the phantom was oriented so that the sectioned planes were parallel to the floor.

Dosimetry was recorded using optically stimulated luminescence (**OSL**) dosimeters (Nanodot, Landauer, Glenwood, Ill., USA). OSL dosimeters respond to ionizing radiation by storing energy in proportion to the amount of X-ray energy to which they are exposed. Each dosimeter is encased in a light tight plastic holder measuring approximately one mm by 10 mm by 10 mm. This case prevents any ambient lighting from reaching the dosimeter and, therefore, causing skewed data. Sets of 24 dosimeters, each corresponding to a specific organ or tissue of interest, were grouped and coded for identification. Each set was cleared of stored energy using a light source (LED light pad) for at least 24 hours prior to establishing baseline readings. Seven dosimeter sets were used during the study; one served as a control set.

The Kodak 9000 (Carestream Dental LLC, Atlanta, Ga., USA) has one FOV: 50 mm by 37 mm. The voxel size used was 0.076 mm. This voxel size will provide better image resolution and detail compared with a bigger voxel size (0.4). However, the radiation with smaller voxel sizes is higher. For maxillary techniques, 12 scans were completed using the same dosimeter set with the FOV focused on the permanent maxillary left first molar (no. 14). This procedure was repeated two more times, each time utilizing a different set of dosimeters with the same FOV location. Each dosimeter set was averaged to calculate the dose per examination. The same technique was used for mandibular exposures with the FOV focused on the permanent mandibular left first molar (no. 19). Since the Kodak 9000 has a smaller FOV compared to other CBCT units, more exposures were completed. Smaller FOVs require more exposure repetitions because more dosimeters are outside of the field of direct exposure and absorb only small quantities of scatter radiation.[4] All scans were acquired using the same child setting, set by the manufacturer as 75 kV and 8 mA.

Dosimeters were read with a portable reader (MicroStarii, Landauer). The reader was calibrated initially with a set of dosimeters, supplied by the manufacturer, which had been exposed to known amounts of energy. Reader performance was checked before each use. 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.[6]

Results

Table 2 represents the tissue equivalent doses and total effective dose for each scan: three for mandibular scans and three for maxillary scans. Table 3 represents the average and standard deviation for tissue equivalent doses and total effective dose for mandibular and maxillary scans. The average effective dose of the mandibular scans was 65.4 μSv plus 3.2 μSv. The average effective dose of the maxillary scans was 53.2 μSv plus 2.5 μSv. Figure 2 shows the average equivalent doses of tissues for both mandibular and maxillary scans. Of the mandibular scans, the largest equivalent dose per organ was seen in the salivary glands (parotid, submandibular, and sublingual; 1,598.5 µSv plus 107.9 µSv), followed by oral mucosa (1,263.3 µSv plus 104.3 µSv), extrathoracic airway (pharynx, larynx, and trachea; 859.4 µSv plus 55.1 µSv), and the thyroid gland (578.9 µSv plus 73.4 µSv). Of the maxillary scans, the largest equivalent dose per organ was seen in the salivary glands (parotid, submandibular, and sublingual; 1,847.8 µSv plus 61.4 µSv), followed by oral mucosa (1,673.0 µSv plus 82.7 µSv), extrathoracic airway (pharynx, larynx, and trachea; 1,011.4 µSv plus 45.4 µSv), and the lens of the eye (202.5 µSv plus 16.1 µSv).

Table 2. TISSUE EQUIVALENT DOSES AND EFFECTIVE DOSE FOR STANDARD PARAMETERS OF KODAK 9000

Exam/location (µSv)	Mandible 1	Mandible 2	Mandible 3	Maxilla 1	Maxilla 2	Maxilla 3
Bone marrow	28.5	32.5	28.3	19.5	15.1	20.6
Thyroid	525.5	661.3	550.0	145.1	128.8	101.6
Esophagus	15.4	20.4	16.4	6.8	6.1	6.7
Skin	3.9	3.2	4.4	30.3	31.3	31.9
Bone surface	133.7	152.8	131.5	88.7	68.7	94.7
Salivary glands	1559.0	1515.8	1720.5	1889.8	1777.4	1876.3
Remainder	164.0	162.2	184.8	221.7	202.5	217.8
Brain	12.7	12.1	16.4	38.1	36.5	37.2
Lymphatic nodes	43.5	45.1	48.5	50.9	46.3	49.6
Extrathoracic airway	823.9	831.5	922.9	1050.0	961.4	1022.7
Muscle	43.5	45.1	48.5	50.9	46.3	49.6
Oral mucosa	1221.1	1186.7	1382.1	1730.6	1578.3	1710.2
Lens of eyes	54.2	40.1	56.0	187.2	219.3	201.0
Pituitary	22.8	20.8	29.6	71.0	68.5	67.8
Effective dose	61.8	67.5	67.0	55.5	50.6	53.3

Table 3. AVERAGE AND STANDARD DEVIATION FOR TISSUE EQUIVALENT DOSES AND EFFECTIVE DOSE FOR STANDARD PARAMETERS OF KODAK 9000

Exam/location (µSv)	Mandible average	Mandible standard deviation	Maxilla average	Maxilla standard deviation
Bone marrow	29.8	2.4	18.4	2.9
Thyroid	578.9	73.4	125.2	22
Esophagus	17.4	2.6	6.6	0.4
Skin	3.8	0.6	31.2	0.8
Bone surface	139.4	11.7	84.1	13.6
Salivary glands	1598.5	107.9	1847.8	61.4
Remainder	170.3	12.5	214	10.2
Brain	13.8	2.3	37.3	0.8
Lymphatic nodes	45.7	2.5	48.9	2.3
Extrathoracic airway	859.4	55.1	1011.4	45.4
Muscle	45.7	2.5	48.9	2.3
Oral mucosa	1263.3	104.3	1673	82.7
Lens of eyes	50.1	8.7	202.5	16.1
Pituitary	24.4	4.6	69.1	1.7
Effective dose	65.4	3.2	53.2	2.5

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.[5] The larger the equivalent dose to a tissue, the more likely stochastic effects occur. However, for head and neck radiographs such as CBCT, where the effective dose is less than 0.1 mSv (100 µSv), the risks of stochastic effects are negligible.[7] 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.[7]

Pauwels et al. completed a study in 2012 using the adult phantom testing numerous CBCT machines, including the Kodak 9000. The FOV of the Kodak 9000 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.[8] Compared to this study, the child phantom with the FOV focused in the same location resulted in 1.6 times greater effective dose and 2.3 times greater equivalent dose to the salivary glands.

In a meta-analysis completed by Ludlow et al., numerous CBCT machines were analyzed based on FOV size and default or standard settings set by the machine's manufacturer, some utilizing the adult and child phantom. The Kodak 9000 (CS 9000) machine was analyzed only using the adult phantom with standard adult settings for both maxillary and mandibular scans. Among those findings, the maxillary effective dose ranged five to 19 µSv and the mandibular effective dose ranged from 22 to 40 µSv.[4] These reported effective doses, when compared to this study of the child phantom, reveal that the child receives 2.8 to 10 times and 1.6 to 2.9 times greater dose for the maxillary and mandibular scans, respectively. Therefore, the child receives roughly two to 10 times more radiation overall when undergoing a scan of the maxilla and one to three times more radiation when undergoing a scan of the mandible compared to an adult.

Salivary glands were also the organ to receive the largest equivalent dose of the adult phantom, based on the meta-analysis of the Ludlow et al.[9] The salivary glands specifically received 130 to 523 µSv with scans of the maxilla and 633 to 1,037 µSv with scans of the mandible. This is 3.5 to 14.2 times more radiation to the salivary glands of a child undergoing a maxillary scan and 1.5 to 2.5 times more radiation to the salivary glands of a child undergoing a mandibular scan.

The salivary glands were not incorporated into the ICRP calculation of effective dose until 2007. The 2007 ICRP guidelines include salivary glands and updated tissue-weighting factors for other organs.[10] 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.[11]

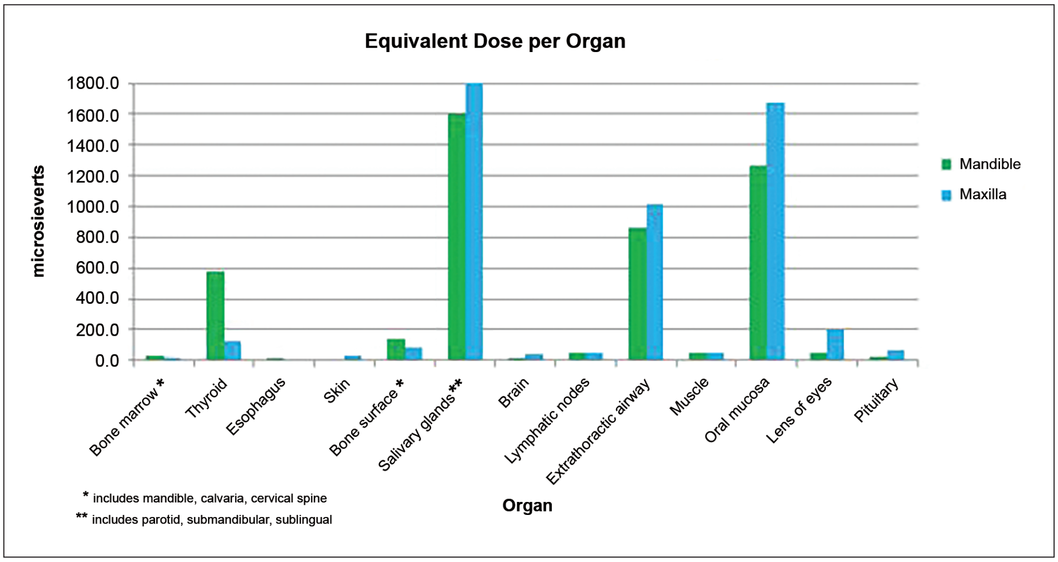

Figure 2. Average tissue equivalent doses for standard parameters of Kodak 9000.

To better understand how much radiation a child is exposed to while having a CBCT with the Kodak 9000, effective doses can be compared to the effective doses of common intraoral radiographs (posterior bitewings). Johnson et al. calculated the effective dose (μSv) for a 12-year-old child using F-speed film and with a rectangular collimator at five μSv.[6] We found that a 12-year-old child receives an average effective dose of 65 μSv with CBCT limited to the mandible. The effective dose is ten times greater when undergoing CBCT compared with bitewings with rectangular collimation.

Further work needs to be completed with other CBCT machines in the field of child phantom dosimetry. Due to the differing manufacturer settings of CBCT machines and variable scanning options of CBCT machines, more research is required to fully understand the amounts of radiation a child is exposed to. This study is limited to one CBCT machine with one FOV option. Future dosimetry research can be completed using other machines that have been studied with the adult phantom for additional comparisons to be made.

Conclusions

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

1. Pediatric patients receive up to 10 times more radiation, when compared to adult patients, undergoing a cone-beam computed tomography session with the Kodak 9000.
2. Pediatric patients receive the most radiation to the salivary glands with both maxillary and mandibular scans using the Kodak 9000.
3. CBCT should be used judicially in pediatric patients due to the overall amount of radiation exposure.

Acknowledgment

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