Pediatric Phantom Dosimetry of the Portable Handheld Xray2Go®

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Abstract: ***Purpose:*** *The purpose of our study was to quantify radiation dose from the XTG (Xray2Go) Handheld X-ray device for bitewing and anterior occlusal projections using a pediatric phantom. The aim was to evaluate thyroid shielding effects on effective dose (E), tissue equivalent doses (H_T), and assess operator backscatter radiation.* ***Methods:*** *A pediatric phantom with 24 tissue site dosimeters was exposed to radiation from the Xray2Go. Projections included: Right and left bitewing (BW) without thyroid collar on phantom, BW with thyroid collar, maxillary anterior occlusal (AO) without thyroid collar, AO with thyroid collar. New dosimeters were used for each projection type, for 30 exposures. Operator wore dosimeters on forehead and right hand to quantify backscatter. Average values of H_T and E were calculated.* ***Results:***

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Thyroid shielding produced a statistically significant difference for posterior bitewing projections at thyroid (P<.001), lymphatic nodes (P=.04), and muscle (P=.04). Operator dose from the XTG was indistinguishable from background radiation. ***Conclusions:*** *Mean effective dose was less than 1 μSv for all projections. Thyroid shielding made a statistically significant difference for radiation dose with the Xray2Go for several tissue locations and for posterior bitewings effective dose. Radiation to the operator was low and indistinguishable from background radiation.*

KEYWORDS: DOSIMETRY, PEDIATRICS, HANDHELD, PORTABLE, X-RAY

Introduction

Radiographs are an essential component of dental practice, allowing dentists to diagnose dental caries, identify orofacial pathology, and evaluate dental development. Traditional dental radiograph systems are fixed, wall-mounted systems, but handheld alternatives have been developed in the last two decades.[1] Handheld digital radiography is a paradigm shift in the way dental radiographic images are obtained,[2] offering portability and cost advantages while still producing diagnostic quality radiographic images.[3] With this new technology, initial concerns arose regarding unintended exposure to backscatter radiation from the device for the operator due to proximity during operation of handheld devices,[4] as well as concerns about potential increased radiation exposure to patients.[5] These questions prompted numerous evaluations of one prominent handheld radiology device, the NOMAD (KaVo Dental Group, Brea, CA). Several radiation backscatter studies as well as phantom dosimetry studies have been completed, validating the NOMAD's safety for both patient and operator.[2, 4, 6-9]

Assessments of ionizing radiation can be accomplished by radiation dosimetry, in which a dosimeter registers the amount of radiation absorbed at a given target. To understand the associated health risk of the absorbed dose detected by dosimeters, studies often calculate the overall effective dose. The effective dose (E) is the preferred measurement, as stated by the International Commission on Radiologic Protection (ICRP), to compare risk from different radiographic exams. This value considers the variable radiation sensitivity of different tissues in our bodies and modifies the absorbed dose with a tissue weighting factor.[10] The effective dose (E) is a conceptual measurement of the whole-body risk of future health detriment, or possible cancer induction, from ionizing radiation exposure. An E of 1 sievert (Sv) represents approximately a 5.5% chance of developing cancer.[10]

Dosimeters that register absorbed dose can be worn by an operator or housed within an imaging phantom, a dummy apparatus designed to simulate the patient. A pediatric imaging phantom is composed of materials that approximate the density and responsiveness of tissues of an average 10-year-old pediatric human head and has slots designed to hold dosimeters in strategic positions within the anthropomorphic model.[11,12] When the phantom head is exposed to ionizing radiation, the encased dosimeters detect the absorbed dose of radiation at these orofacial sites of interest. Studies utilizing a pediatric phantom are important, as pediatric patients have

greater risk with ionizing radiation, due to developing organs' sensitivity to radiation and a longer remaining lifetime over which a radiation-induced cancer could present.[13]

Completion of phantom studies, particularly pediatric phantom studies, with handheld devices is important to assess patient safety and understand how their doses compare to existing research on traditional imaging equipment. Many handheld radiology units are currently available on the market. Some are non-FDA approved and may produce potentially hazardous amounts of radiation,[14] so it is imperative that providers verify the safety of their equipment.

The XTG (Xray2Go) Handheld X-ray (Digital Doc, LLC., El Dorado Hills, CA) is a new lightweight device that differs from other portable units in its ability to be operated like a camera, a familiarity of operation that may be beneficial for pediatric patients. The Xray2Go Handheld X-ray device has FDA approval, but there are no published independent evaluations of radiation exposure for pediatric patients nor on operator exposure to radiation.

The primary aim of this study was to quantify the effective dose (E) and tissue equivalent dose (H_T) in microsieverts (μSv) at tissue sites of interest within a pediatric anthropomorphic phantom head, with and without a protective thyroid collar, when exposed to left and right bitewing and maxillary anterior occlusal radiographs, using the XTG (Xray2Go) Handheld X-ray device. In addition, we evaluated the amount of backscatter radiation for an operator while using the device.

Materials and Methods

The dosimetry study was completed using a pediatric phantom modeling the anatomy of a 10-year-old child (ATOM model 706 HN, CIRS Inc., Norfolk, Va., USA; Figure 1). Modifications were made to the phantom, with pockets to hold dosimeters at 24 sites of interest (Table 1). The dosimeter pockets positioned in the head and neck corresponded to tissues of interest in the 2007 Recommendations of the International Commission on Radiological Protection (ICRP). Placement of the neck dosimeters were vertically centered to the slice and taped in place. Dosimeter placement for the lens of the eye corresponded to anatomical lens location and were also taped in position. Dosimeters housed within the phantom apparatus were standardized in position by maintaining the uppermost edge of the dosimeter at the level of the superior plane of the designated slice and retained in position by resistance of the dosimeter case within its designated slot.[12] Dosimeter placement within each axial slice is depicted in Figure 2. In addition to the dosimeters placed within the phantom head, two dosimeters were worn by the operator to record backscatter radiation. These dosimeters were placed on the center of the forehead and dorsal side of the right hand of the operator and taped into position.

The dosimeters used for this project were 1mm x 10mm x 10mm optically stimulated luminescent dosimeters (OSLDs; Nanodot, Landauer, Inc., Glenwood, Ill., USA), which were enclosed in opaque light-tight plastic holders to prevent ambient light exposure during transport. We used a calibrated portable dosimeter reader (MicroStarii, Landauer, Inc. Glenwood, IL) to process the dosimeters after exposure at the University of North Carolina, Chapel Hill.

We subjected the pediatric phantom head to radiographic exposures that are typical in pediatric practice: bitewings and upper anterior occlusal radiographs. The experiment was run with the Xray2Go unit's fixed settings of 60 kVp tube voltage and 2mA tube current, and an adjustable exposure time that was set at 0.06 seconds as recommended by the manufacturer for both of our chosen projections. The settings for the device are appropriate and fall within the optimal range of 60 to 70 kVp for dental radiographs, as stated by the American Dental Association.[15] Positioning of the Xray2Go was controlled with use of a customized XCP-like positioning device placed adjacent to the phantom head and stabilized by a tripod, to allow for more consistent angulation of the handheld x-ray device during operation. This device design had a circular ring indicating the aiming zone for the tube head of the device and was intended to

simulate a traditional XCP device. A control set of dosimeters was utilized to record the background radiation from phantom transport. Background radiation refers to the persistent low level of radiation found in our environment from both man-made sources and natural sources, such as minerals in the soil, water, and cosmic radiation. These control dosimeters functioned to give us a baseline of background radiation and were excluded from radiation exposure from our experiment.

A total of 14 dosimeter sets were used for the following: [Sets 1, 2, 3]: Thirty exposures on the patient's right for a right bitewing radiograph, and thirty exposures on the patient's left for a left bitewing radiograph with the patient phantom wearing a thyroid collar. [Sets 4, 5, 6]: Thirty right bitewing exposures, and thirty left bitewing exposures without the phantom wearing a thyroid collar. [Sets 7, 8, 9]: Thirty anterior maxillary occlusal radiograph exposures, with the phantom wearing a thyroid collar. [Sets 10, 11, 12]: Thirty anterior maxillary occlusal radiograph exposures, without the phantom wearing a thyroid collar. [Sets 13, 14]: A pair of dosimeters were used to record backscatter radiation potentially affecting the operator, placed on the forehead and the right hand. A full set of all 24 phantom dosimeters that could be housed within the model, as pictured in Figure 2, were in place for each set of exposures. The phantom's thyroid collar was wrapped around the cervical portion of the phantom and maintained in position with the collar's own Velcro attachment.

The operator stood at a designated point demarcated on the floor for each exposure. Floor markings indicated the foot position of the operator where, when standing at this position, the operator could comfortably hold the device's x-ray emitting cone flush with the positioning device. The operator's arms were slightly bent and the backscatter shield of the x-ray unit was parallel to the operator as recommended by the Xray2Go user manual. The operator wore a protective lead apron with a thyroid collar for all exposures. To prevent ambient light exposure to the dosimeters and inadvertent radiation exposure, dosimeters were kept in light-tight containers prior to and immediately after exposure, and during transport to the facility for dosimeter reading.

After completion of all exposure sets, dosimeters were processed by a MicroStarii commercial dosimeter reader (Landauer, Inc. Glenwood, IL) at the University of North Carolina, Chapel Hill.. Values obtained from each dosimeter were divided by thirty to indicate the average absorbed dose per exposure, in micrograys. Absorbed dose was translated to equivalent dose

(H_T), by multiplying absorbed dose by radiation weighting factor, value = 1, for x-rays. This incurred no numerical change but signified a unit change from micrograys (μGy) to microsieverts (μSv), reflecting the type of ionizing radiation used. Effective dose (E) was determined by multiplying equivalent doses by their appropriate tissue weighting factors as determined by ICRP 2007 and determining the whole-body sum of these values. Doses were compared between data sets with and without thyroid collar.

Dosimeter readings of Xray2Go from 16 locations of the phantom, derived from the 24 dosimeter sites, were analyzed using one-way ANOVA, with the factor for thyroid collar to identify its effect. All pair-wise group comparisons were made using Fisher's Protected Least Significant Differences used to control the overall significance level of pair-wise comparisons at 5%. Analyses were performed using SAS version 9.4 (SAS Institute, Inc., Cary, NC).

Results

Dosimeter readings from 16 tissue categories, derived from 24 dosimeters on the phantom and 2 locations on the operator were analyzed and recorded. Multiple dosimeter sites pertained to one tissue category. Some examples of these combinations of dosimeters include the salivary gland measurement, which combined the parotids, right and left submandibular, and sublingual glands, the lens of eye reading, which combined the right and left lens, and the brain reading which averaged dosimeters from the midbrain and pituitary. Table 2 summarizes the mean, standard deviation, standard error, 95% confidence interval for the mean, and range of tissue-equivalent doses in microsieverts delivered by the Xray2Go unit for the various projection types, with and without thyroid shielding. The overall average effective dose of the bitewing projections was 0.77 μSv (*SD*=0.05) with thyroid shielding and 0.96 μSv (*SD*=0.01) without thyroid shielding, a statistically significant difference (*P*=.003). The average effective dose of the anterior occlusal projection was 0.50 μSv (*SD*=0.02) with thyroid shielding and 0.46 μSv (*SD*=0.02) without thyroid shielding, however this difference was not found to be statistically significant (Table 3). Operator radiation registered from dosimeters on the forehead and hand was determined to be very low and indistinguishable from the dosimeter readings for background radiation. The value obtained from operator hand and forehead dosimeters did not differ significantly from the control dosimeters that were unexposed.

The highest average tissue equivalent dose from the BW without the phantom wearing the thyroid collar was for the salivary glands (*M*=20.66 μSv, *SD*=0.44), followed by the oral mucosa (*M*=19.14 μSv, *SD*=0.19), extrathoracic airway (*M*=13.23 μSv, *SD*=0.27), and thyroid (*M*=8.48 μSv, *SD*=0.31). The highest average tissue equivalent dose for the BW with the phantom wearing thyroid collar was for the salivary glands (*M*=20.30 μSv, *SD*=1.55), followed by oral mucosa (*M*=18.87 μSv, *SD*=1.38), extrathoracic airway (*M*=12.14 μSv, *SD*=0.88), and thyroid (*M*=4.67 μSv, *SD*=0.36). For the upper AO projection without the thyroid collar, highest average tissue equivalent dose was to lens of the eyes (*M*=54.76 μSv, *SD*=15.55), followed by the salivary glands (*M*=11.20 μSv, *SD*=0.47), extrathoracic airway (*M*=9.04 μSv, *SD*=0.62), and oral mucosa (*M*=8.17 μSv, *SD*=0.28). For the upper AO projection with the thyroid collar, highest average equivalent dose was to the lens of the eyes (*M*=40.56 μSv, *SD*=3.28), followed by the salivary glands (*M*=12.28 μSv, *SD*=0.47), extrathoracic airway (*M*=9.11 μSv, *SD*=0.11), and oral mucosa (*M*= 8.94 μSv, *SD*=0.28).

Figure 3 summarizes the exposure comparisons with and without thyroid shielding where a statistically significant difference in dose was detected. Thyroid shielding made a statistically significant difference in reducing radiation dose for select locations in the phantom during the posterior bitewing projection. These locations included the thyroid (*P*<.001), lymphatic nodes (*P*=.04), and muscle (*P*=.04), as well as for the overall effective dose (*E*) (*P*=.003). For the Upper AO projection, thyroid shielding did not produce a statistically significant difference for most tissue sites, except for the locations of the salivary glands (*P*=.05) and oral mucosa (*P*=.03). The dose in μSv with the phantom wearing a thyroid collar for the Upper AO projection was higher than without thyroid shielding at these two locations.

Discussion

This was the first study to evaluate the tissue equivalent dose and overall effective dose produced by the XTG device for an anthropomorphic pediatric phantom, with and without a thyroid collar present on the phantom. The principles of ALARA (As Low As Reasonably Achievable) guide us to make mindful decisions about radiation exposure, bearing in mind the stochastic effects of radiation with increased probability of a radiation-induced health effect over time. In the pediatric population, careful imaging techniques and practices are even more

important due to the increased radio-sensitivity of children.[13] A pediatric phantom study by Yepes et al. with the Kodak 9000 CBCT shows that children receive one to three times more radiation and up to ten times more radiation than adults for mandibular and maxillary CBCT scans, respectively.[11] It should be noted that dental radiation dose is low relative to other medical imaging such as CT scans, however with a lifetime frequency of dental imaging with higher regularity, minimizing the dose can mitigate some risk. With potential for additive effects over a longer lifetime, pediatric imaging decisions are especially important.

The adoption of portable radiology may be an opportunity to image wisely in terms of patient exposure, as compared to reported effective doses from similar projections with wall-mounted imaging devices. Pharaoh and White cite that the average effective dose for traditional wall-mounted imaging with bitewings with rectangular collimation and F-speed film is 5 μSv.[16] A 2018 study by Hedesiu et al. that contrasts risk from conventional intraoral radiography with CBCT cites a median pediatric effective and cumulative dose for conventional radiography as lower than 20 μSv. [17] A 2016 adult phantom dosimetry study by Granlund et al. evaluated both panoramic imaging and intraoral imaging and shows the effective dose of a four-bitewing projection from a wall-mounted device, the Gendex Oralix DC®, to be 3.4 μSv. The highest organ doses are found to be for the salivary glands and the mucosa, as was seen in our study.[18] An earlier study in 2014 with a pediatric phantom assessing the wall-mounted Gendex shows that effective dose for bitewings ranges from 1.5 to 2.7 μSv for a 10-year old anthropomorphic model.[19] These values contrast with values from our study. With the portable XTG unit, effective dose for posterior bitewings was 0.77 μSv (*SD*=0.05) with thyroid shielding and 0.96 μSv (*SD*=0.01) without thyroid shielding. The values from our study of the XTG unit for bitewing projections, even without thyroid shielding, were far less than estimates from traditional imaging devices.

It is important to note that we cannot make direct comparisons, as there are factors that contribute to these differences, including technique factor settings of different devices, projection strategy, and phantom type. The Gendex studies had settings of 60 kVp and 7 mA or 65 kVp and 7 mA, respectively, for exposures, different exposure times, and performed exams on different imaging phantoms.[18, 19] Our device had fixed settings of 60 kVp and 2 mA and was consistently operated at 0.06 seconds, a time setting that fell within a manufacturer recommended range for exposures for digital imaging for these projections with the XTG device. Acknowledging the

inherent differences between these studies, the values reported for pediatric imaging from our device are lower than those from traditional imaging devices and appear to support patient safety of the XTG.

Thyroid shielding is a simple way to reduce dose to the patient, as shown in the bitewing assessment in our study. Thyroid shielding significantly reduced the overall effective dose for the bitewing projections and was also strongly reflected in specific tissue site equivalent doses as well, including the thyroid, lymphatic nodes, and muscle. With the thyroid noted as one of the most radiosensitive organs in the head and neck area[10], implementing this precaution to limit exposure to this area is a simple modification with significant benefits. When it comes to our results regarding the anterior occlusal projection, several variables could account for our unexpected findings of higher doses with thyroid shielding rather than without. Non-ideal placement of the thyroid collar against the phantom model could have impacted radiation dose. In addition, although efforts were made to standardize operator position for the anterior occlusal projection during the XTG study, inevitable operator positioning shifts could have occurred between exposures. A 2018 study by Worrall et al. which examined the effect of thyroid collar on dose reduction for an anterior occlusal view and shows that suboptimal examination position can increase thyroid dose significantly, even with a phantom wearing a collar. In those scenarios, the thyroid was in the path primary beam, while shielded, due to angulation. [20] The factor of suboptimal operator positioning and angulation could account for some of the difference we observed for certain tissue sites, where values registered for some tissues showed a higher reading with the thyroid collar than without the thyroid collar. While the difference between effective dose for the anterior occlusal projection with the thyroid collar, at 0.5 μSv, and without the thyroid collar, at .46 μSv, was determined not to be statistically significantly different, we postulate that operator angulation could have contributed to unexpected higher readings. The thyroid shield may be rendered less effective at reducing dose when operator beam angulation circumvents the collar's area of protection, such as in the case of an anterior occlusal projection taken at a more upright angle. Future studies with a custom thyroid collar that fits the phantom ideally and fixing the device on an immobile tripod, rather than with an active operator, could optimize the study by fixing the beam position at a more optimal angle that avoids direct projection towards the thyroid, although these changes would not reflect the true clinical application of the device, where patient position could also inevitably require variability of

operator position. Clinicians should be aware of the benefits of thyroid shielding but mindful of their position when imaging, so as not to inadvertently include the thyroid in the primary beam.

There are very few dosimetry studies of handheld radiology devices that assess patient dose using anthropomorphic phantom dosimetry currently, however multiple studies exist that discuss operator safety. Further investigations need to be completed with other portable dental radiology devices as well as repeat studies to validate previous findings. We would benefit from a uniform investigation of multiple devices to understand how the estimated patient effective dose of the XTG compares to those from other devices.

Operators carry the highest risk with dental radiography due to their frequency of exposure, and a handheld device requires the operator to be near the beam. Scatter radiation occurs when x-rays bounce off objects and travel in multiple directions. Backscatter radiation pertains to radiation directed back towards the tube source, and in the case of a handheld device, also back towards the operator. Studies on backscatter dose have supported the safety of handheld devices for the operator. Studies of the NOMAD and other portable dental x-ray devices have shown that portable units satisfy the principles of ALARA for operator exposure, with doses well below 1 mSv per year, or 2% of the annual occupational dose limit.[7] A 2012 study by Gray corroborates this idea, stating that doses to dental staff for handheld devices are far lower than those from a wall mounted system.[8] This contrasts with a 2019 study by Smith et al., which states concerns with stray radiation to the operator and recommended limited handheld device usage to cases where accessibility demands portable device use. The study by Smith et al uses a large plane of 63 dosimeters to assess operator exposure from multiple handheld devices, which contrasts significantly with the 2 operator dosimeter locations used in our study.[21] Our study reported that dose to the operator from the XTG was indistinguishable from background radiation, which is promising, but we note the need for a more robust operator assessment with greater numbers of dosimeters to assess operator exposure. The XTG unit has a built-in safety features that include a collimator cone and 6-inch diameter backscatter shield that likely contributed to the low operator dose.

While our study was able to quantify the absorbed, equivalent, and effective dose from the XTG unit for a pediatric phantom, it did not assess the diagnostic quality of images produced by our device. An image quality study by Pittayapat et al. finds that portable dental x-ray units show good diagnostic imaging for a variety of devices, including the NiRay, AnyRay, Rextar,

and NOMAD devices.[3] Similarly, a 2020 comparative study by Nitschke et al. shows that the NOMAD Pro2 device delivers comparable image quality as a wall mounted device.[22] These studies did not include the XTG device. More studies on image quality of portable devices including the XTG device should also be completed to understand this aspect of its comparison to wall mounted devices, however it appears that when it comes to reducing operator and patient radiation risk, the XTG device is a sensible option for imaging.

CONCLUSIONS:

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

1. Mean effective dose to a pediatric phantom from the Xray2Go was less than 1 μSv for bitewing and anterior occlusal projections, with and without thyroid shielding.
2. Operator backscatter radiation dose to the forehead and right hand from the Xray2Go was minimal and indistinguishable from background radiation.
3. Thyroid shielding made a statistically significant difference in reducing radiation dose from bitewing projections for the thyroid, lymph nodes, muscle, and overall effective dose, when using the Xray2Go.

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

OSLD ID	**Child phantom location (Slice Level)**
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. SUMMARY STATISTICS OF TISSUE EQUIVALENT DOSE (H_T) IN MICROSIEVERTS (μSv) BY LOCATION AND PROJECTION TYPE

Projection Type	Location	Thyroid shielding	N	Mean (SD)	Mean (SE)	Confidence Interval
BW	Bone Marrow	with	3	0.39 (0.03)	0.39 (0.02)	(0.31, 0.47)
BW	Bone Marrow	without	3	0.48 (0.05)	0.48 (0.03)	(0.37, 0.60)
BW	thyroid	with	3	4.67 (0.36)	4.67 (0.21)	(3.77, 5.56)
BW	thyroid	without	3	8.48 (0.31)	8.48 (0.18)	(7.71, 9.24)
BW	esophagus	with	3	0.15 (0.01)	0.15 (0.01)	(0.12, 0.18)
BW	esophagus	without	3	0.24 (0.06)	0.24 (0.03)	(0.09, 0.38)
BW	skin	with	3	0.04 (0.00)	0.04 (0.00)	(0.03, 0.05)
BW	skin	without	3	0.05 (0.00)	0.05 (0.00)	(0.04, 0.06)
BW	bone surface	with	3	2.08 (0.17)	2.08 (0.10)	(1.66, 2.49)
BW	bone surface	without	3	2.58 (0.27)	2.58 (0.16)	(1.91, 3.25)
BW	Salivary glands	with	3	20.30 (1.55)	20.30 (0.90)	(16.45, 24.15)
BW	Salivary glands	without	3	20.66 (0.44)	20.66 (0.25)	(19.57, 21.75)
BW	brain*	with	3	0.42 (0.06)	0.42 (0.04)	(0.27, 0.58)
BW	brain*	without	3	0.44 (0.01)	0.44 (0.00)	(0.42, 0.46)
BW	remainder	with	3	2.48 (0.18)	2.48 (0.10)	(2.03, 2.93)
BW	remainder	without	3	2.60 (0.04)	2.60 (0.02)	(2.51, 2.68)
BW	brain†	with	3	0.42 (0.06)	0.42 (0.04)	(0.27, 0.58)
BW	brain†	without	3	0.44 (0.01)	0.44 (0.00)	(0.42, 0.46)
BW	lymphatic nodes*	with	3	0.61 (0.04)	0.61 (0.02)	(0.51, 0.71)
BW	lymphatic nodes*	without	3	0.69 (0.01)	0.69 (0.00)	(0.67, 0.70)
BW	extrathoracic airway*	with	3	12.14 (0.88)	12.14 (0.51)	(9.95, 14.33)
BW	extrathoracic	without	3	13.23 (0.27)	13.23 (0.15)	(12.56, 13.89)

Projection Type	Location	Thyroid shielding	N	Mean (SD)	Mean (SE)	Confidence Interval
	airway*					
BW	muscle*†	with	3	0.61 (0.04)	0.61 (0.02)	(0.51, 0.71)
BW	muscle*†	without	3	0.69 (0.01)	0.69 (0.00)	(0.67, 0.70)
BW	oral mucosa*	with	3	18.87 (1.38)	18.87 (0.80)	(15.44, 22.30)
BW	oral mucosa*	without	3	19.14 (0.19)	19.14 (0.11)	(18.66, 19.62)
BW	lens of eyes	with	3	0.99 (0.15)	0.99 (0.09)	(0.62, 1.36)
BW	lens of eyes	without	3	1.14 (0.08)	1.14 (0.05)	(0.95, 1.34)
BW	Pituitary	with	3	0.69 (0.07)	0.69 (0.04)	(0.52, 0.85)
BW	Pituitary	without	3	0.73 (0.08)	0.73 (0.04)	(0.54, 0.92)
BW	Effective Dose (2007)	with	3	0.77 (0.05)	0.77 (0.03)	(0.64, 0.89)
BW	Effective Dose (2007)	without	3	0.96 (0.01)	0.96 (0.01)	(0.93, 0.98)
Upper AO	Bone Marrow	with	3	0.26 (0.02)	0.26 (0.01)	(0.21, 0.32)
Upper AO	Bone Marrow	without	3	0.26 (0.02)	0.26 (0.01)	(0.23, 0.30)
Upper AO	thyroid	with	3	3.18 (0.12)	3.18 (0.07)	(2.89, 3.48)
Upper AO	thyroid	without	3	2.59 (0.47)	2.59 (0.27)	(1.42, 3.77)
Upper AO	esophagus	with	3	0.23 (0.08)	0.23 (0.05)	(0.04, 0.43)
Upper AO	esophagus	without	3	0.24 (0.02)	0.24 (0.01)	(0.20, 0.29)
Upper AO	skin	with	3	1.36 (0.11)	1.36 (0.06)	(1.09, 1.63)
Upper AO	skin	without	3	1.84 (0.52)	1.84 (0.30)	(0.55, 3.12)
Upper AO	bone surface	with	3	1.39 (0.11)	1.39 (0.07)	(1.10, 1.67)
Upper AO	bone surface	without	3	1.39 (0.08)	1.39 (0.05)	(1.18, 1.59)
Upper AO	Salivary glands	with	3	12.28 (0.47)	12.28 (0.27)	(11.10, 13.45)
Upper AO	Salivary glands	without	3	11.20 (0.47)	11.20 (0.27)	(10.04, 12.36)
Upper AO	brain*	with	3	0.58 (0.04)	0.58 (0.02)	(0.47, 0.68)
Upper AO	brain*	without	3	0.60 (0.04)	0.60 (0.02)	(0.49, 0.70)

Projection Type	Location	Thyroid shielding	N	Mean (SD)	Mean (SE)	Confidence Interval
Upper AO	remainder	with	3	1.44 (0.03)	1.44 (0.02)	(1.37, 1.51)
Upper AO	remainder	without	3	1.37 (0.05)	1.37 (0.03)	(1.25, 1.48)
Upper AO	brain†	with	3	0.58 (0.04)	0.58 (0.02)	(0.47, 0.68)
Upper AO	brain†	without	3	0.60 (0.04)	0.60 (0.02)	(0.49, 0.70)
Upper AO	lymphatic nodes*	with	3	0.31 (0.01)	0.31 (0.01)	(0.28, 0.35)
Upper AO	lymphatic nodes*	without	3	0.28 (0.02)	0.28 (0.01)	(0.25, 0.32)
Upper AO	extrathoracic airway*	with	3	9.11 (0.11)	9.11 (0.06)	(8.83, 9.38)
Upper AO	extrathoracic airway*	without	3	9.04 (0.62)	9.04 (0.36)	(7.51, 10.57)
Upper AO	muscle*†	with	3	0.31 (0.01)	0.31 (0.01)	(0.28, 0.35)
Upper AO	muscle*†	without	3	0.28 (0.02)	0.28 (0.01)	(0.25, 0.32)
Upper AO	oral mucosa*	with	3	8.94 (0.28)	8.94 (0.16)	(8.24, 9.63)
Upper AO	oral mucosa*	without	3	8.17 (0.28)	8.17 (0.16)	(7.48, 8.86)
Upper AO	lens of eyes	with	3	40.56 (3.28)	40.56 (1.89)	(32.42, 48.70)
Upper AO	lens of eyes	without	3	54.76 (15.55)	54.76 (8.98)	(16.13, 93.39)
Upper AO	Pituitary	with	3	0.88 (0.12)	0.88 (0.07)	(0.58, 1.18)
Upper AO	Pituitary	without	3	1.04 (0.03)	1.04 (0.02)	(0.96, 1.13)
Upper AO	Effective Dose (2007)	with	3	0.50 (0.02)	0.50 (0.01)	(0.45, 0.54)
Upper AO	Effective Dose (2007)	without	3	0.46 (0.02)	0.46 (0.01)	(0.41, 0.51)

Table 3. SUMMARY OF MEAN EFFECTIVE DOSE (E) IN MICROSIEVERTS (μSv)

Projection Type	Mean Effective Dose μSv (SD)
Upper AO with thyroid shielding	0.5 (0.02)
Upper AO without thyroid shielding	0.46 (0.02)
BW with thyroid shielding	0.77 (0.05)
BW without thyroid shielding	0.96 (0.01)

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