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Dental Cone-Beam Computed Tomography: Are the Eye Lens and Thyroid at Risk?

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Abstract

Background: The purpose of this study was to assess radiation dose to the eye lens (EL) and thyroid gland (TG) from 22 protocols used in maxillofacial imaging with cone-beam computed tomography (CBCT).

Methods and Results: NanoDot optically stimulated luminescence dosimeters were used to assess scattered radiation to the EL and TG using a phantom. The dosimeters were secured at four sites around areas of interest. Mean eye radiation dose was significantly associated with field of view (FOV) size ($r=0.830$, $P<0.001$). Meanwhile, the mean thyroid radiation dose was found to be significantly associated only with exposure time ($r=0.464$, $P=0.030$). Mandible centralization was observed to be the most significant predictor for a greater effective thyroid dose; mandible FOV centralization had 0.236 odds of a higher thyroid dose than maxilla FOV centralization.

Conclusion: FOV size significantly impacted EL dose. Thyroid exposure was affected by FOV centralization and exposure time. Centering the FOV on the mandible resulted in a greater effective dose due to the proximity of the TG to the primary beam. **(International Journal of Biomedicine. 2024;14(1):77-82.)**

Keywords: cone-beam computed tomography • radiation dose • thyroid gland • eye lens

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Abbreviations

CT, computed tomography; **CBCT**, cone-beam computed tomography; **CTDI**, CT dose index; **DAP**, dose-area product; **EL**, eye lens; **FOV**, field of view; **OSL**, optically stimulated luminescence; **TG**, thyroid gland.

Introduction

The utilization of cone-beam computed tomography (CBCT) in dental practice has increased dramatically in the last decade to assess maxillofacial structures for diagnostic, treatment planning, and follow-up purposes. It is estimated that almost 4 million CBCT examinations are performed annually in the United States of America alone.(1) CBCT has become a useful tool for dentists worldwide and is gaining popularity in orthodontic clinics, where most patients are children or adolescents.(2) Of all the imaging techniques used in dentistry, CBCT is the newest and most closely associated with the highest radiation dose.(3) This modality consists of a cone-shaped beam rotating around the patient's head to acquire raw two-dimensional images reconstructed from several projections to form a three-dimensional volume.(4) The cumulative doses from CBCT machines can range from 5 µSv to 1073 µSv.(5) Ionizing radiation, which is used in CBCT, is associated with an increased risk of developing leukemia and other cancers over a patient's life span. Although CBCT is an extremely useful tool, the associated radiation risk is a significant public health hazard.(6)

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To express the risks associated with ionizing radiation exposures, the International Commission on Radiological Protection (ICRP) recommends using the effective dose, which considers the biological effect on radiosensitive tissue/organs using weighting factors depending on the degree of organ sensitivity.(7) Other exposure indicators specific to CT are the CT dose index (CTDI) or the dose-area product (DAP), which can be used to calculate the CBCT dose.(3)

The FOV size, image resolution, and other exposure parameters are important in the radiation dose received during CBCT examinations. According to the FDA, "radiation doses from dental CBCT exams are generally lower than other CT exams; dental CBCT exams typically deliver more radiation than conventional dental X-ray exams."(8)

The effective dose from CBCT examinations was reported to be between 46 µSv and 1073 µSv in adult phantom dosimetry studies. For child phantoms, however, standard protocols resulted in an effective dose that varied from 13 µS to 769 µS.(9,10) This large range in radiation doses is mainly due to the various exposure parameters that can be adjusted before each examination. Though the guidelines suggest that the dose from the CBCT modality is equivalent to doses from 2 to 10 panoramic radiographs, it has been reported that this dose can range from 2 to 200 panoramic radiographs.(11) This large variation emphasizes the need for practice standardization and justification of use.

The American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR) issued a joint position statement on dose considerations for CBCT, which includes the use of the smallest possible FOV size, largest voxel size, lowest current setting (mA), shortest exposure time, and pulsed exposure modes when possible.(12) This statement "recommended that the use of CBCT in endodontics be limited to certain complex conditions" to ensure that the benefit outweighs the risks associated with the exposure.(12) In addition to direct exposure, the scattered radiation is of concern, especially in head and neck imaging, where the eye lens (Els) and thyroid gland (TG) could receive an unnecessary dose.(13) The ICRP has dropped the yearly occupational eye dose considerably from 150 mSv to 20 mSv after epidemiological evidence proved damage to EL with radiation exposure. This has lowered the threshold for this sensitive organ, compared to the past.(14) The scattered radiation associated with CBCT usage can be affected by technique, including FOV size and centralization, which can decrease photon scattering and overall patient dose reduction.(15)

During abdominal CT, the dose of the scattered radiation reaching the TG was reported to be 214 µSv and the EL to be 57 µSv.(16) For comparison, the dose of the scattered radiation during a digital mammography screening could be 25 µSv and 2.5 µSv to the thyroid and lens, respectively.(17) A study by Alwasiah et al.(18) conducted in 2021 reported the mean absorbed dose to the eyes during a brain CT to be 33.6 mGy. Moreover, the authors indicated that these numbers are alarming, especially since damage could be induced in the eyes due to radiation doses "as low as 0.2 Gy and 0.5 Gy."

Since factors such as FOV size and the location of radiosensitive organs impact patient radiation dose, using a larger FOV exposes more tissue to radiation, resulting in more scattering to adjacent areas. FOV centralization (depending on the protocol used) also impacts the dose. A volume–dose model proposed by Pauwel et al.(19) in 2014 used various FOV sizes and centralizations to optimize patient doses and reduce scattering to radiosensitive organs. The results of this study demonstrated a significant dose reduction (up to 69%) when using the same FOV for the mandible instead of the maxilla. Additionally, in the mandible position, a dose reduction of more than 30% was achievable when changing the FOV from 17cm×2cm to 14cm×5cm. The authors also measured a higher scattered dose to the TG when using mandibular scans due to anatomic proximity. Most importantly, FOV should not be positioned inferiorly to achieve a reduction of the EL dose.(19) This, in turn, could increase the thyroid dose. Therefore, a reduction of EL dose is only achievable using a smaller FOV or decreasing mAs.

Studies propose patients use small leaded glasses during CBCT examination to spare the EL from unnecessary exposure.(20) In addition, since the thyroid is another area adjacent to the primary beam in CBCT, a high dose to the thyroid could result in radiation-induced damage. Epidemiological studies have provided some limited evidence of an increased risk of thyroid tumors resulting from dental radiography. During CBCT, the radiation dose to the TG can be reduced by 18% to 40% when using a front thyroid collar and up to 43% when using a front/back thyroid collar.(21) The use of leaded glasses and a thyroid collar during maxillofacial scans decreased the organ dose to the eye's lens by 62% and to the thyroid by 26%, respectively. Additionally, doses to the thyroid could also be reduced by 70% using collimation. In mandibular scans, using leaded glasses and thyroid collars decreased the dose to the eye's lens by 13% and to the thyroid by 33%. That study reported that doses to the EL were five times greater when leaded glasses were not used.(21)

This study aimed to assess radiation dose to the EL and TG during CBCT examinations using protocols developed for dental purposes. Optically stimulated luminescence (OSL) dosimeters, commonly used for dosimetry and to determine the radiation dose in diagnostic and therapeutic imaging modalities, were used in this study to measure the absorbed dose during CBCT dental examinations.(22,23)

Materials and Methods

This cross-sectional dosimetry study was conducted at the Oral Radiology Department of King Abdulaziz University Dental Hospital between September 2020 and September 2021. The study followed the methods of Jadu et al.,(24) except the nanodots were fixed securely to the phantom using fabricated straps at only four sites: the right and left eye surfaces and on the right and left side of the neck at the TG level.

Two similar CBCT machines (iCAT Imaging Sciences International, Hatfield, PA, USA) were used for data collection. Additionally, 22 different protocols covering the range of CBCT use for dentistry were used. The details of the protocols are outlined in Table 1. The exposure parameters for each protocol were as follows: FOV size, voxel size, which represents the image resolution, time, DAP, and FOV centralization. The kVp and mA for all the protocols were constant at 120 and 5, respectively.

The effective radiation doses (*E*) to the eyes and thyroid were calculated by multiplying the average absorbed radiation dose by the radiation- and tissue-weighted factors according to the following equation:

$$E\ (\mu Sv) = \sum W_T D_T X1$$

where W_T is the tissue (T) weighted factor, and the sum of all tissue-weighted factors is 1. The issue-weighted factors were based on the most recent ICRP guidelines.(14) D_T is the average absorbed dose measured in a particular organ or tissue, and the radiation-weighted factor for X-radiation is 1.

This study did not require ethical approval since no human subjects were enrolled. The experiment was conducted using a phantom. The data collected were analyzed and presented using IBM SPSS version 23 (IBM Corp., Armonk, N.Y., USA) and GraphPad Prism version 8 (GraphPad Software, Inc., San Diego, CA, USA).

Results

This study evaluated the effective radiation dose on the ELs and TG during CBCT examinations using a radiation phantom and 22 different protocols for dental purposes (Table 1).

The mean difference between the absorbed radiation dose to the right and left sides of each organ was assessed (Table 2). The results revealed no significant mean differences (P>0.05) between the average doses to the right and left eyes and between the right and left thyroid lobes, suggesting that the eyes and the thyroid can be considered unitary organs in further analyses.

The association between the mean organ dose and the imaging parameters of the different protocols was then evaluated (Table 3). The results revealed that the mean eye radiation dose was significantly associated with the FOV size (r=0.830, P<0.001), DAP (r=0.668, P=0.001), and voxel size (r=0.489, P=0.021). Meanwhile, the mean thyroid radiation dose was found to be significantly associated only with exposure time (r=0.464, P=0.030).

The association between the effective dose to the eyes and thyroid and the FOV centralization was investigated using a paired sample t-test. More specifically, a significant mean difference of -0.0437 (P=0.046) was found between the mean eye dose (0.24±0.0 mGy, N=3) and the thyroid dose (0.68±0.2 mGy, N=3) when the FOV was centered on the mandible and between the eye dose (0.76±0.4 mGy, N=12) and the thyroid dose (0.38±0.1 mGy, N=12) when the FOV was centered on the occlusal plane. No significant differences were observed between the mean eye and thyroid doses when the FOV was centered on the maxilla (P>0.05).

The significant imaging factors associated with the mean effective dose to the EL and TG were also determined (Table 4). The results revealed that only the FOV size was found to significantly predict the mean effective dose to the EL (SE=0.001, 95% CI: lower bound = 0.000, upper bound = 0.005, P=0.030) according to the general linear model (GLM) at the P<0.05 level, resulting in a 0.003 unit increase in the EL effective dose with every cm increase in FOV size.

Table 1.

The exposure parameters used for each of the 22 cone beam CT dental protocols explored.

No.	Indication	FOV (cm)	Vox (mm)	Time (sec)	DAP	FOV centralization
1	Single arch implant protocol (Protocol 1)	16 × 6	0.3	4.8	168.5	maxilla
2	Single arch implant protocol (Protocol 2)	16 × 6	0.3	8.9	302.9	maxilla
3	Single arch implant protocol (Protocol 3)	16 × 6	0.3	4.8	168.5	mandible
4	Single arch implant protocol (Protocol 4)	16 × 6	0.4	4.8	168.5	maxilla
5	Both arches implant (Protocol 1)	8 × 8	0.3	4.8	134.8	occlusal plane
6	Both arches implant (Protocol 2)	16 × 8	0.4	4.8	219.6	occlusal plane
7	Both arches implant (Protocol 3)	16 × 10	0.4	4.8	278.1	occlusal plane
8	Both arches implant (Protocol 4)	16 × 10	0.3	4.8	278.1	occlusal plane
9	Both arches implant (Protocol 5)	16 ×10	0.4	8.9	501.3	occlusal plane
10	Root resorption/root fracture/root canals assessment	8 × 8	0.25	14.7	275.1	occlusal plane
11	Apical periodontitis/ apical surgery	8 × 8	0.25	14.7	275.1	occlusal plane
12	Impacted third molars (single arches)	16 × 6	0.4	4.8	168.5	mandible
13	Impacted third molars (both arches)	16 ×10	0.4	4.8	278.1	occlusal plane
14	Impacted canines and supernumerary teeth	8 × 8	0.3	8.9	239	maxilla
15	Orthodontic planning	16 × 10	0.4	4.8	278.1	occlusal plane
16	Orthognathic surgery	16 × 13	0.4	4.8	349.4	occlusal plane
17	Cleft palate	16 × 13	0.4	4.8	349.4	occlusal plane
18	Craniofacial anomaly	23 × 17	0.4	4.8	458.6	occlusal plane
19	TMJ (closed)	16 × 8	0.25	14.7	444.3	maxilla
20	Pathosis (single arch)	16 × 8	0.3	4.8	219.6	occlusal plane
21	Pathosis (both arch)	16 × 10	0.3	4.8	278.1	occlusal plane
22	Maxillofacial trauma	16 × 13	0.3	4.8	349.4	occlusal plane

FOV, field of view; VOX, voxel; DAP, dose-area product; TMJ, temporomandibular joint.

Table 2.

Paired sample association of eyes lenses and thyroid lobes (N = 22).

Dose mGy		Mean ±SD	Mean Difference	95% CI of the Difference		P-value
				Lower	Upper	
Pair 1	RE	0.55 ± 0.3	-0.055	-0.116	0.005	0.072
	LE	0.60 ± 0.4				
Pair 2	RT	0.42 ± 0.2	0.011	-0.019	0.040	0.471
	LT	0.41 ± 0.2				

SD, standard deviation; CI, confidence interval; RE, right eye; LE, left eye; RT, right thyroid lobe; LT, left thyroid lobe. A P-value of < 0.05 was considered statistically significant.

Table 3.

Correlation between the mean organ dose and exposure parameters of the various protocols (N = 22).

Variables		Average dose mGy	
		Eye	Thyroid
FOV size	r	0.830	0.208
	P-value	<0.001	0.354
Vox size	r	0.489	0.184
	P-value	0.021	0.413
Time	r	0.103	0.464
	P-value	0.648	0.030
DAP	r	0.668	0.124
	P-value	0.001	0.582

FOV, field of view; VOX, voxel; DAP, dose-area product.
A P-value of < 0.05 was considered statistically significant.

More specifically, mandible centralization was observed to be the most significant predictor for a greater effective thyroid dose; mandible FOV centralization had 0.236 odds of a higher thyroid dose when compared to maxilla FOV centralization. In contrast, maxilla FOV centralization demonstrated an inverse relationship with dose. Another predictor was imaging time, for which a 0.021 increase in the thyroid effective dose with every unit increase in time was observed (Table 4).

Table 4.

Association between the imaging parameters and mean eyes radiation dose and thyroid gland dose (mGy)

Average EL dose (mGy)					
Parameter	B	SE	95% CI		*P*-value
			Lower Bound	Upper Bound	
Intercept	-0.134	0.451	-1.095	0.827	0.770
FOV size (cm)	0.003	0.001	0.000	0.005	0.030[a]
VOX size (mm)	0.699	0.993	-1.419	2.816	0.493
Time (sec)					
DAP	0.001	0.001	-0.001	0.002	0.351
FOV centralization=Maxilla	0.124	0.185	-0.270	0.519	0.512
FOV centralization=Mandible	0.033	0.200	-0.393	0.460	0.870

Average TG dose (mGy)					
Parameter	B	SE	95% CI		*P*-value
			Lower Bound	Upper Bound	
Intercept	0.266	0.040	0.182	0.351	<0.001[a]
Centralization=Maxilla	-0.101	0.045	-0.195	-0.008	0.036[a]
Centralization=Mandible	0.236	0.057	0.117	0.355	0.001[a]
Time	0.021	0.006	0.009	0.034	0.002[a]
[a]-Significant using General Linear Model (GLM) at <0.05 level.					

CI, confidence interval; B, B coefficient; SE, standard error.

Discussion

CBCT use in Saudi Arabia is neither monitored nor regulated. Local efforts are ongoing by national authorities to establish diagnostic reference levels, policies for practice justification and standardization, optimization of exposure, and quality assurance. Given the increased use of CBCT, there is a clear need for thorough justification criteria. This is especially important because of the current practice of "self-referral," in which a dentist performs CBCT examinations for patients based on their own clinical assessment.(3) Currently, CBCT use is highly dependent on self-awareness.

The Safety and Efficacy of a New and Emerging Dental X-Ray Modality (SEDENTEXCT) project, aiming to provide evidence-based guidelines for dental and maxillofacial use of CBCT, resulted in the publication of several dosimetry studies using Monte Carlo modeling of phantoms to estimate the effective doses and organs that contribute to these doses.(25) The results of these studies have confirmed that 19% of the average relative contribution of organ doses in CBCT maxillofacial examinations is from thyroid exposure.(26) Hence, radiation risk from CBCT examinations for dental purposes is generally higher than intraoral and panoramic modalities but lower than multidetector CT examinations of the same area.(25)

The purpose of this study was to assess radiation dose to the eye lens (EL) and thyroid gland (TG) from 22 protocols used in maxillofacial imaging with cone-beam computed tomography (CBCT).

Of all the imaging factors examined in this dosimetry study, the factor most significantly impacted the EL dose was the FOV size. This result is expected since the EL is more likely to be in the direct path of the primary X-ray beam in larger FOVs that extend above the maxilla—such as those used for orthodontic purposes, for example. Several previous studies have confirmed this finding and reported EL dose reductions that range between 26% and 67% with smaller FOVs.(19,27-29) Remarkably, no association was noted between EL doses and FOV centralization. It would have been plausible to record higher EL doses in CBCT examinations centered on the maxilla as opposed to the mandible; however, this was not the case. We hypothesize that this result is due to the anatomic distance from the eyes to both jaws being relatively similar. Hence, no significant difference in EL dose was detected when the FOV centralization was changed.

Cataract is a well-known and documented deterministic effect of eye lens radiation exposure during interventional procedures.(14,30) Not many studies quantify the radiation risk to the eye lens from diagnostic procedures such as CBCT. Yuan et al. evaluated the potential radiation risk to the EL from diagnostic CT imaging. Since the use of CBCT is growing, the authors cautioned that similar risks can be anticipated in patients undergoing CBCT, especially when the primary X-ray beam is closer to the eye.(31) There is growing evidence that the EL is likely to be affected by the levels of radiation used for diagnostic purposes, and this has prompted the change in the threshold for EL radiation-induced damage from 2.0 Gy to 0.5 Gy.(30) Consequently, caution must be exercised whenever the dental CBCT examination area is close to or includes the eyes.

The TG was most significantly affected by 2 imaging factors: FOV centralization and exposure time. The effect of FOV centralization on the effective dose has been well-documented in previous studies, such as the one by Jadu et al.(24) In agreement with the results of our study, the authors found that centering the FOV on the mandible led to a greater effective dose due to the anatomic proximity of the TG to the primary X-ray beam and, thus, a greater contribution of the thyroid dose to the overall whole-body effective dose. Jadu et al.(24) also found that the voxel size (i.e., the image resolution) affected the effective dose significantly; however, this was not the case in our study. This variation in results may be due to differences in the methods used to calculate the effective dose.

The effective doses to TG were also significantly influenced by the exposure time, with greater doses associated with longer exposure times. Despite the lack of publications that support this result, it seems plausible that a longer exposure time will result in a greater dose absorbed by the TG.

However, this result should be interpreted cautiously, as it cannot stand alone without considering the other exposure parameters.

The TG is of particular interest in dental imaging due to its proximity to the areas usually imaged and its sensitivity to the stochastic effects of radiation. The radiosensitivity of TG is especially relevant for children and adolescents. In fact, TG is still considered the most radiosensitive organ in the head and neck.(32) This has prompted several authors to strongly recommend using thyroid shields and collars, especially in children and adults until the age of 50.(32-34)

The CBCT maxillofacial imaging protocols are designed to ensure that the diagnostic purpose of the examination is met while exposing the patient to a relatively reasonable dose of radiation. This concept is known as the "as low as diagnostically achievable" (ALADA) principle. To follow this principle, there is usually a compromise between the various imaging parameters used. For example, protocol number 10 in Table 1 is used for assessing root resorption, root fractures, and root canals and, hence, utilizes a smaller voxel size to ensure that the images produced are of sufficiently high resolution to distinguish the delicate structures of the roots. This protocol is coupled with a smaller FOV size to offset the radiation dose to the patient to compensate for the increased radiation associated with these high-resolution images. Alternatively, larger FOV examinations are usually coupled with lower-resolution images (greater voxel size) to moderate the radiation risk to the patient. This explains the association we noted with only one or two—and not several—of the numerous imaging factors. This finding also highlights the importance of carefully selecting these parameters to balance the diagnostic task and radiation risk to the patient.

The results of this study may vary between different CBCT machines depending on other imaging factors, such as kVp, mA, filtration, rotation arc, and pulsed vs. continuous exposures. Future directions should include more CBCT dosimetry studies to improve our understanding and control of this significant public health risk. In addition, the use of CBCT should be monitored, and patient doses should be tracked and reported to establish reference levels for benchmarking and practice optimization.(35) Future research should especially focus on dosimetry involving vulnerable populations, such as children and adolescents, who often receive CBCT examinations for dental purposes.

Conclusion

We showed that radiation doses to the eye lens and thyroid gland from CBCT examinations of the maxillofacial region were most significantly affected by the FOV size and FOV centralization, respectively. Therefore, these parameters should be chosen carefully for the various CBCT dental indications. Every attempt to shield these sensitive organs using lead eyeglasses and thyroid collars should be made.

Competing Interests

The authors declare that they have no competing interests.

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