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ORIGINAL ARTICLE

Entrance Surface Dose Measurement at Thyroid and Parotid Gland Regions in Cone-Beam Computed Tomography and Panoramic Radiography

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Abstract

Purpose: Ionizing radiation-absorbed doses is a crucial concern in Cone-Beam Computed Tomography (CBCT) and panoramic radiography. This study aimed to evaluate and compare the Entrance Skin Doses (ESD) of thyroid and parotid gland regions in CBCT and panoramic radiography in Yazd province, Iran.

Materials and Methods: In this cross-sectional study, 332 patients were included, who were then divided into two age groups (adult and pediatric) and underwent dental CBCT and panoramic radiography. Twelve Thermoluminescence Dosimeters (TLD- GR200) were used for each patient to measure the ESD of thyroid and parotid glands. The differences between the ESD values in CBCT and panoramic examinations as well as between the adults and children groups were evaluated by one-way ANOVA and Man-Whitney tests.

Results: The mean and Standard Deviation (SD) values of ESD in panoramic imaging were equal to 61 ± 4 and 290 ± 12 µGy for the thyroid and parotid glands of the adult groups, respectively. Notably, these values for CBCT were significantly higher (P<0.01), as 377 ± 139 and 1554 ± 177 µGy, respectively. Moreover, the mean ESD values in the panoramic examination were 41 ± 3 and 190 ± 16 µGy for thyroid and parotid glands for the children group, while they were 350 ± 120 and 990 ± 107 µGy in CBCT (P<0.01), respectively. The ESD values in the parotid gland were approximately 3.4 (2.8-4.1) and 4.7 (4.6-4.8) times greater than those for CBCT and panoramic examinations, respectively.

Conclusion: Although CBCT provides supplementary diagnostic advantages, the thyroid and parotid glands' doses are higher than panoramic radiography. Therefore, the risks and benefits of each method should be considered before their prescription.

Keywords: Cone-Beam Computed Tomography; Panoramic Radiography; Entrance Surface Doses; Thermoluminescence Dosimeter Dosimetry.

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1. Introduction

For the diagnosis of dental diseases, x-ray imaging is widely used to detect pathological changes or guide surgery operations [1–3]. Cone-Beam Computed Tomography (CBCT) and panoramic radiography are common diagnostic x-ray imaging techniques in dental practices [2, 4, 5]. Panoramic radiography is available at lower costs as well as uses low ionizing radiation in dental producers; however, CBCT has several advantages compared to panoramic examinations such as 3D view imaging, enhanced surgical preparation, and improved detection of pathologies [1, 3]. By contrast, ionizing radiation used in CBCT for imaging may lead to higher values of the effective dose and radiation toxicity compared to panoramic radiography [1, 6].

In general, although radiation doses from CBCT scans and panoramic radiographs are low, they irradiate radiosensitive organs like the thyroid and parotid glands in dental imaging. Consequently, the absorbed dose measurements are essential for patients' dose management during diagnostic radiography procedures [4, 7]. Many studies have reported the relationship between the absorbed dose to organs and cancer incidence risk [7–10]. Moreover, there are national and international reports, and also recommendations discussing this relationship [11, 12].

Exposure parameters such as tube voltage (kVp) and effective tube current-time product (mAs) are the factors, which have a specific role in determining the amount of radiation exposure and therefore patient dose. Also, the Field Of View (FOV) which defines the imaging region is another important factor in dental procedures and will affect the radiation dosage [13].

In previous studies, the researchers have confirmed that lifetime cancer risks are much higher in children compared to adults [11, 12]. Therefore, a particular concern is related to the children group. Moreover, the radiosensitive organs are almost totally involved in the examination field size in the pediatric group in addition to the fact that the majority of patients in dental radiography are in this group [2, 3].

Many approaches have been proposed to assess the absorbed dose in dental radiography [14, 15]. The National Radiological Protection Board (NRPB) [16] has introduced the dose-width product parameter to measure patient absorbed dose. Another proposed parameter is the ESD, or skin absorbed dose, which is the most remarkable measured parameter in orthodontic imaging [14]. It is defined as the amount of skin absorbed dose at the entrance of the beam [17].

Several investigations have been performed to determine and compare the absorbed dose during the CBCT and panoramic examinations [2, 4, 18–20]. The absorbed dose values are related to the exposure parameters and measurement settings in each modality. Therefore, specialized dosimetry is needed for different imaging procedures, and also the imaging modalities and absorbed doses to patients should be monitored over time [21].

Due to recent developments in both CBCT and panoramic modalities, it is essential to re-evaluate the dose because it is a vital aspect of justifying their use. The main aim of the current study is to measure and compare the regional distribution of ESD on the thyroid and parotid glands resulting from CBCT and panoramic radiography from adult and pediatric patients in Yazd province, Iran.

2. Materials and Methods

The National Ethics Committee with the ethical number of "IR.SSU.MEDICINE.REC.1398.118" and "IR.SSU.MEDICINE.REC.1398.119" approved this study. The informed consent was obtained from all participants (patients/parents) after the procedures were fully explained.

2.1. Data Collection and Imaging Protocols

The present cross-sectional multi-center study was carried out on 332 patients divided into two age groups. The participants consisted of two groups including children of 6-10 and adults over 18 years old. The recorded patients' demographic and anatomical data, including weight, age, height, and Body Mass Index (BMI) were measured and are presented in Table 1.

The patients were imaged in seven different dental clinics (among the twelve active clinics) from January to December 2019. The patients were randomly selected from the patients referring to the imaging departments for dental CBCT and panoramic radiography. The patients had normal craniofacial morphology (without congenital and acquired facial deformities), and none of the patients had a tumor and surgical procedures in their dental region in the past two years.

Table 1. Demographic data of patients

	CBCT		Panoramic	
	Pediatric	**Adult**	**Pediatric**	**Adult**
Number	30	101	60	141
Age (year)	9.3 ± 1.3 (6-10)	37.8 ± 12.2 (19-70)	9.2 ± 1.2 (6-10)	37.9 ± 10.2 (19-70)
Weight (kg)	35 ± 14 (28-38)	69 ± 14 (46-105)	39 ± 16 (32-40)	70 ± 19 (47-105)
Height (cm)	136 ± 7 (132-140)	175 ± 0 (149-183)	139 ± 12 (134-141)	170 ± 9 (149-183)
BMI (kg/m^2)	19 ± 7 (18-21)	22 ± 4 (17-33)	20 ± 5 (18-21)	24 ± 6 (17-33)

Three different CBCT machines and seven different panoramic systems were used in our study. The characteristic information of the panoramic and CBCT machines is summarized in Table 2. Furthermore, exposure parameters of each protocol used in the imaging centers, including kVp, mAs, and FOVs are listed in Table 3 for the adults and children. The scan range for panoramic and CBCT imaging devices was selected for all required volume sizes for diagnosing the maxillofacial region, from the smallest exceptional cases to images of the entire head. The scan time for panoramic and CBCT imaging was approximately 15-18 seconds and 12.5-20 seconds, respectively. The image quality and diagnostic value of all the images were reviewed and approved by a radiologist working in each center.

2.2. TLD Measurement Techniques

ESD measurements of the parotid and thyroid gland regions were performed using the TLD-GR200 (SDDML, China) chips and the TLD reader (TLD 7103 Reader, Imen Gostar Raman Kish, Iran). The size of TLD chips was 3×3×0.9 mm^3 consisting of LiF; Mg, Cu, and P.

Twelve TLDs were carefully installed as six TLDs in the parotid gland region (2 cm in front and bottom on both sides of the outer ear canal) and six TLDs in the thyroid gland region (in front of the neck and before the vertebrae of the lower neck) for each patient. The TLDs were embedded in numbered plastic covers and glued to the desired points with leucoplast glue (Figure 1). In each test series, three TLD chips were installed in the radiography roomaway from the radiation to determine the background radiation dose.

For minimizing the fading effect (signal loss with time after irradiation), we tried to read out the TLDs as soon as possible after the irradiation (2 hours after irradiation). The TLD calibration was done in similar circumstances. Furthermore, the region of the TLDs for glow readout in the calibration process was chosen in a way that has minimum fading as described in a study by Nikolovski *et al.* [22].

All TLDs were calibrated for an x-ray exposure according to the approach described by Hasanzadeh *et al.* [23]. Briefly, the first step of the calibration procedure was to obtain the ECC (Element Correction Coefficient)

Table 2. Information and technical specifications of the equipment

System		Model	Manufacture- country	Public/private	Year	kVp max	Type
Panoramic	A	PM2002CC	Planmeca-Finland	Public	2010	80	DR*
	B	Promax 3D	Planmeca-Finland	Public	2018	84	DR
	C	Promax 3D	Planmeca-Finland	Public	2018	84	DR
	D	Promax 3D	Planmeca-Finland	Private	2019	84	DR
	E	Ray Scan α-SC	South Korea	Public	2014	100	DR
	F	Soredex	Soredex-Finland	Private	2011	85	DR
	G	Promax XC	Planmeca-Finland	Public	2012	80	DR
CBCT	1	Promax 3D	Finland	Public	2009	84	DR
	2	CANON	France	Public	2019	80	DR
	3	HDX WILL DENTRI α	South Korea	Public	2017	90	DR

Table 3. Mean ± SD of kVp, and mAs, as well as field of value (FOV) for the children and adults in panoramic imaging at different institutions. Center 'C', no children were admitted for panoramic radiography

Institution (Device model)	Children			Adults		
	FOV (cm× cm)	kVp	mAs	FOV (cm× cm)	kVp	mAs
A (PM2002CC)	24×11	65.4 ± 0.7	101 ± 12	28×12	66.1 ± 1	108 ± 5.7
B (Promax 3D)	25×12	63.8 ± 1.5	98.4 ± 23.4	27×13	66.4 ± 0.8	129 ± 14
C (Promax 3D)	-	-	-	27×13	66 ± 0	102 ± 0
D (Promax 3D)	24×11	65.1 ± 1.8	106 ± 11	27×11	69 ± 1.2	142.4 ± 18
E (Ray Scan α-SC)	24×12	68.6 ± 1.3	79 ± 0	25×12	71.4 ± 1.2	133 ± 5.5
F (Soredex)	21×11	57 ± 0	86 ± 0	25×12	63 ± 0	110 ± 0
A(PM2002CC)	24×11	65.4 ± 0.7	101 ± 12	28×12	66.1 ± 1	108 ± 5.7
B (Promax 3D)	25×12	63.8 ± 1.5	98.4 ± 23.4	27×13	66.4 ± 0.8	129 ± 14

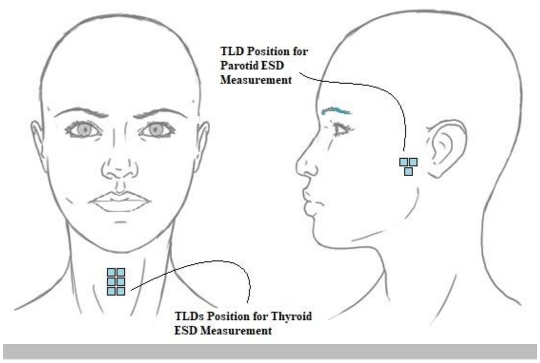

Figure 1. Installed TLD positions in the thyroid and parotid gland regions

values to increase the reproducibility for each TLD. Also, a semiconductor dosimeter (Barracuda, RTI Electronics, Sweden) calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) was used for the verification of the dose measurement. The TLDs were exposed (three folds) using an x-ray machine in similar parameter ranges used for panoramic radiography systems. The mean of the TLD responses was obtained, and finally, the ECC for each TLD was calculated using the following equation (Equation 1) [24]:

$$ECC_i = TLD_i \; / \, TLD_{average} \quad (1)$$

In the next step, to obtain the Calibration Factor (CF), 24 TLDs: seven groups of three TLDs and three TLDs for background radiation measurements were chosen. The TLDs were exposed three times to different selected doses, and then the mean TLD readout was measured. Then, the dose (mGy) versus TLD reading (nC) was plotted, and the slope of the curve obtained the CF. The dose delivered to organs was obtained by multiplying the mean values of the TLD readouts, ECC, and CF values.

2.3. Statistical Analysis

The measured ESD values resulting from CBCT were compared with the values of panoramic radiography using one-way ANOVA and Mann-Whitney tests. Furthermore, the ESD values in the thyroid and parotid gland regions were compared between the adult and pediatric groups using the tests mentioned above. Kolmogorov-Smirnov test was used to check the normality of data distributions before the comparison tests. The statistical analysis was performed with SPSS software (version 16, SPSS Inc, Chicago, IL, USA). P-values lower than 0.05 were considered as a significant difference between the assessed groups.

3. Results

The TLD calibration curve is demonstrated in Figure 2. Mean ± SD of ESD values for the thyroid and parotid gland regions in panoramic radiography examinations have been presented in Table 4 for the adults and children groups. According to the tables, it is evidence that the applied voltages are almost identical in all institutions

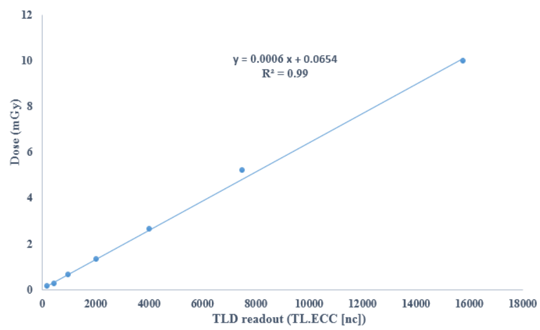

Figure 2. TLD calibration curve

Table 4. Mean ± SD of ESD values of thyroid and parotid gland regions for the children and adult groups in panoramic imaging at different institutions. Center 'C', no children were admitted for panoramic radiography

Institution (Device Model)	Parotid Gland (μGy)		Thyroid Gland (μGy)	
	Children	Adult	Children	Adult
A (PM2002CC)	204 ± 11	266 ± 25	46 ± 4	58 ± 4
B (Promax 3D)	248 ± 12	326 ± 26	57 ± 4	68 ± 9
C (Promax 3D)	-	319 ± 4	-	66 ± 3
D (Promax 3D)	259 ± 38	331 ± 4	57 ± 5	75 ± 7
E (Ray Scan α-SC)	224 ± 11	307 ± 17	42 ± 2	61 ± 4
F (Soredex)	100 ± 3	196 ± 2	24 ± 1	41 ± 1
G (Promax XC)	103 ± 20	285 ± 6	20 ± 1	57 ± 2
Total	190 ± 16	290 ± 12	41 ± 3	61 ± 4

and the mAs values have slight differences between the assessed clinics. The mean ± SD of ESD values for the panoramic examinations on the thyroid and parotid gland regions were 61 ± 4 and 290 ± 12 μGy, respectively, for the adult group, and they were 41 ± 3 and 190 ± 16 μGy for the children group. There was a significant difference in the ESD values between the adult and pediatric groups for both thyroid and parotid glands, with adult groups showing higher values ($P < 0.01$).

The mean ± SD values of ESDs for CBCT for the adult group were 377 ± 139 and 1554 ± 177 μGy for the thyroid and parotid glands, respectively, and 350 ± 120 and 990 ± 107 μGy for the children group (Table 5).

The ESDs in the parotid gland region resulting from CBCT and panoramic imaging had significantly higher values compared to the thyroid in both groups ($P < 0.01$). It was found that for both groups, the ESD values in the parotid region were approximately 3.4 (2.8-4.1) and 4.7 (4.6-4.8) folds greater than the thyroid values, respectively, for CBCT and panoramic examinations. There was a significant difference in ESD values between the two examinations, in a way that, the parotid and thyroid ESD values resulting from CBCT were found to be approximately 5.2 (5.3 for adults and 5.1 for children) and 7.3 (6.1 for adults and 8.5 for children) folds higher than the ESDs in panoramic imaging, respectively.

4. Discussion

In the present study, we measured the ESD values of the thyroid and parotid glands using TLDs from CBCT and panoramic examinations in two age groups of adults and children. These values for the parotid glands in the adult group were significantly higher compared to the children group ($P < 0.01$), but the difference was not significant in the thyroid glands.

The TLDs have several advantages such as their tissue-equivalent properties, less sensitivity to changes in radiation energy, small size, reproducibility, and lower cost, making them appropriate tools for ESD measurement [25]. The thyroid and parotid are radiosensitive organs, and ionizing radiations exposure on these organs could increase

Table 5. The mean (±SD) of kVp, mAs, and ESD values of thyroid and parotid gland regions for the children and adult groups in CBCT at different institutions

Institution (Device model)	FOV (cm × cm)	Children				Adult			
		kVp	mAs	Thyroid gland (μGy)	Parotid gland (μGy)	kVp	mAs	Thyroid gland (μGy)	Parotid gland (μGy)
1 (Promax 3D)	23 × 17	80 ± 0	108 ± 0	350 ± 120	990 ± 107	84 ± 0	147 ± 51.7	350 ± 135	1448 ± 175
2 (CANON)	16 × 14.4	-	-	-	-	80 ± 0	200 ± 0	400 ± 140	1646 ± 151
3 (HDX WILL DENTRI α)	20 × 20	-	-	-	-	90 ± 0	113 ± 2.5	380 ± 142	1586 ± 129
Total		80 ± 0	108 ± 0	350 ± 120	990 ± 107	84.6 ± 0	153.3 ± 18	377 ± 139	1554 ± 177

the risk of cancer [12]. Regarding the BEIR VII-phase2 report [12], the thyroid is highly radiosensitive for children but has an extremely low sensitivity for elderly patients (> 60 years old), this is unlike other organs for which there is residual cancer risk even at a very high age. For example, the thyroid cancer risk in females, for 0.1 Gy absorbed dose, changes from 0.42 % at the age of 5 years old to 0.001 % at the age of 60 years old. Therefore, thyroid protection is essential for children. Furthermore, the thyroid cancer risk in young women is significantly higher compared to young men. Thus, one of the appropriate techniques for protecting of thyroid is to use thyroid shields in children (especially in girls) during dental imaging [26].

The thyroid and parotid glands' surface dose values in CBCT and panoramic radiography have been investigated in several studies [6, 19, 27–31]. Although in some of the mentioned studies there is a good agreement with the current study, in some others the findings are different. There are some potential explanations for this discrepancy, such as the type of imaging system, dosimeter, exposure parameter conditions (kVp and mAs), and size of FOV.

Our findings are consistent with Suomalainen *et al.* [32] and Silva *et al.* [20] results showing higher ESD values for the parotid glands compared to thyroid glands. There are several reasons for this phenomenon; firstly, the parotid glands are entirely inside the radiation field and receive more primary radiation than the thyroid glands. Secondly, in the diagnostic radiology energy range (20-140 kVp), Compton scattering into the parotid position is more probable than the thyroid glands due to its closer location to the radiation field [33]. Furthermore, several studies have demonstrated that when the thyroid collar is used the effective doses to the thyroid gland and esophagus are reduced, but the other radiosensitive tissues like the parotid glands receive direct doses [34, 35].

The results showed that the ESD values for both age groups during CBCT were significantly higher compared to the panoramic radiography. The reason is related to the higher radiation parameters used in CBCT. In a previous investigation, the researchers expressed that the dose value in 3D imaging (like CBCT) is about 14 times higher than 2D projection imaging [36] because 3D imaging uses high working voltage and current, longer irradiation time, and broader FOV. Herein, following the results of the current study, the use of CBCT in dentistry should only be justified if it provides new information, which could not be acquired by the technique with a lower dose of radiation such as panoramic radiography.

However, in comparison with medical computed tomography, CBCT provides several potential advantages for maxillofacial imaging with lower absorbed doses to tissues [37]. Furthermore, the European Commission Report 172 [38] expressed the advancement of CBCT in dental radiology and published the radiation protection guidelines related to its safe use. In this report, the purpose is to acquire the primary scientific information on the clinical use of CBCT, and also to present the basic principles of radiological protection, like optimization of exposures, justification, user training, and quality assurance in CBCT.

Owning to the results, in the adult group, the ESD values for both parotid and thyroid glands were considerably higher in comparison to the children group, probably due to higher exposure parameters in the adult patients. The other reason is the larger organ size in the adult group, which causes the lower distance from the x-ray source to the entrance point, resulting in a higher entrance dose.

In almost all centers, the ESD values increased with the enlargement of the FOV. In a study by Pauwels *et al.* [39], they estimated doses for 14 various CBCT systems. They have expressed that the large size of FOV caused a higher effective dose (131 ± 91 µSv) than medium and small ones (88 ± 70 and 34 ± 14 µSv, respectively). Also, in another study [13], the authors reported that the effective dose from the Kodak 9500 system with the large FOV was higher compared to the Kodak 9500 medium FOV size. Iskanderani *et al.* [31] indicated that the use of two separate small FOVs (one for each temporomandibular joint), results in lower doses compared with one large FOV, with the same exposure parameters. As a result, the FOV seems a significant factor and should be chosen based on the purpose of the examination during the imaging process [39].

Overall, considering the different ESD values for various imaging machines, these variations can be explained by the different scan parameters, x-ray unit, clinical settings, and patient age. The exposure parameters, especially kVp, are one of the critical factors, because, photon dose is approximately proportional to a power function, kVpn, where n is approximately 2 in radiography and 2.6 in CBCT (with the variation related to differences in filtration and beam shape) [40, 41].

Notably one of the main limitations is that there are many different CBCT and panoramic machine models from various vendors as well as imaging techniques and that the dose is not consistent between these machines and techniques. We tried to compare all the CBCT machines and techniques with panoramic ones about ESD values in the local area where the study was conducted. However, a more wide-scale evaluation is needed to obtain a more representative sample of all the machines from all the vendors. In addition, in the current work, we measured the ESD values using only the TLD dosimeter. Thus, for future research, it is suggested that other dosimetric tools such as DAP (dose area product) meter, and film in different dental radiography systems should be used and the results compared with TLD.

5. Conclusion

Following the explanations given in this study, in both CBCT and panoramic examinations, the ESD values in the parotid gland region were higher compared to the thyroid region. In addition, the ESDs in the thyroid and parotid gland regions are higher in CBCT scans compared to panoramic x-ray equipment. s. Therefore, it is notable that clinicians should be aware of the absorbed dose from the CBCT technique and request dental examinations by considering their risks and benefits for the diagnosis and treatment producers. It is, therefore, suggested that the CBCT dose to children must be monitored more carefully regarding higher radiosensitivity of the thyroid and parotid glands in pediatric groups.

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