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ORIGINAL ARTICLE

Estimating the Entrance Surface Dose in the Eyes, Thyroid, and Parotid Gland Regions in Adult and Pediatric Groups: A Cone-Beam Computed Tomography Technique

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Abstract

Purpose: This study aimed to determine the Entrance Surface Dose (ESD) of sensitive organs in Cone-Beam Computed Tomography (CBCT) imaging of the maxillofacial region in the two age groups of adult and pediatric.

Materials and Methods: In this work, the measurements were performed using Thermo Luminescent Dosimeters (TLD-GR200). The imaging was performed using a PROMAX 3D CBCT scanner for 30 adults and 20 pediatric patients. The ESD value for each patient in the region of eyes, thyroid, and parotid glands was measured by 15 TLDs during CBCT of maxillofacial.

Results: The highest and lowest mean values of ESDs were related to the parotid and thyroid gland regions in adults, 4.77 ± 0.61 mGy and 0.37 ± 0.16 mGy, respectively. In addition, these values were obtained 2.97 ± 0.36 mGy and 0.35 ± 0.12 mGy in pediatric groups as the highest and lowest values in that order. The results showed that the ESD values of the parotid gland regions in maxilla and mandible examinations had a significant difference ($P < 0.05$). In addition, there was a significant difference between the ESD values of the parotid gland regions among the adults and pediatric groups ($P < 0.05$).

Conclusion: According to the results, the ESD values in both age groups were higher in the parotid gland region during maxillofacial CBCT examinations. Therefore, it is recommended to set radiation parameters like mAs as low as possible for reducing the patient dose, especially pediatric patients due to the more sensitive organs.

Keywords: Entrance Surface Dose; Cone-Beam Computed Tomography; Maxillofacial Imaging; Adult; Pediatric.

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1. Introduction

Today, the use of X-rays is widely increased regarding the easier and important tool in the diagnosis of lesions and diseases in medicine [1,2]. In addition, X-ray imaging has expanded significantly in dentistry in recent decades [3]. Three-Dimensional (3D) imaging of the maxillofacial region provides more details of the treatment area than two-Dimensional (2D) imaging due to the representation of the third dimension of anatomical structures [4].

In dental imaging producers, Cone-Beam Computed Tomography (CBCT) has better image quality and lower radiation time than conventional Computed Tomography (CT) [5]. In general, the patient dose in CBCT imaging is higher than panoramic and intraoral radiographies, and lower than conventional CTs [6,7]. According to Ludlow *et al.*'s [8] study, the radiation doses from a CBCT device are 2-4.5 times higher than those of conventional orthopantomography or lateral cephalometry. Furthermore, based on the previous studies, the radiation dose of CBCT varies greatly depending on the type of device and radiation factors/parameters [9].

CBCT is an important technique in diagnosing and monitoring the treatment process in implant dentistry and also as a leading treatment planning technology in oral and maxillofacial surgeries [10]. In maxillofacial imaging, eyes, parotid, and thyroid glands are the important/sensitive organs that are positioned inside or near the radiation field [11]. Although the amount of radiation used in dentistry is not remarkable, the main concern is related to the linear and non-threshold effects resulted from radiation dose [6,12,13]. It has been reported that one of the main disadvantages of the CBCT method is the ignoring of the effectiveness of demographic and anatomical factors during clinical conditions for each patient [14].

Entrance Surface Dose (ESD) is the dose that is absorbed by the skin at the entrance of X-ray, which can be measured directly or indirectly [15]. By measuring the ESD value, the number of radiation doses exposed to the organs can be estimated [16]. This study aimed to determine the ESD values in the sensitive organ regions, including eyes, thyroid, and parotid glands of the patients undergoing maxillofacial CBCT exams in two age groups of adult and pediatric.

2. Materials and Methods

2.1. Data Collection

All procedures were performed in accordance with the national ethical standards of the responsible committee on human experimentation (ethical code: "IR.SSU.MEDICINE.REC.1398.118"). In addition, informed consent was obtained from all patients.

In order to measure the ESD values, 30 adult patients and 20 pediatric patients (5-15 years old) underwent CBCT imaging participated. The patients' information, including their age and sex as well as the information related to radiographic examinations, including peak voltage and mAs were recorded. It is notable that maxillofacial imaging was performed using the PROMAX 3D CBCT device and the specifications of the device are shown in Table 1.

Table 1. Patients demographic information (adults and pediatrics) in CBCT of full, maxilla and mandible examinations (SA: average of both genders [sex averaged], M: male, F: female)

	Scan	**Sex**	**Number**	**Age**
Adults	CBCT FULL	SA	10	51 ± 12
		F	8	53 ± 12
		M	2	41 ± 1
	CBCT Maxilla	SA	10	43 ± 9
		F	7	45 ± 8
		M	3	39 ± 12
	CBCT Mandible	SA	10	51 ± 11
		F	8	53 ± 11
		M	2	42 ± 8
	Total		30	48 ± 11
Pediatrics	CBCT Mandible	SA	10	11 ± 3
		F	4	12 ± 1
		M	6	11 ± 4
	CBCT Maxilla	SA	10	12 ± 1
		F	7	13 ± 1
		M	3	11 ± 2
	Total		20	12 ± 3

Specifications of CBCT	
Vendor	FINLAND
Model	PROMAX 3D
Serial NO	TPP0900170
Production date	2009-06
mAs / FOV	147 / 50×50 (mm×mm)

2.2. TLD Characteristics

In this study, thermo luminescent dosimeters (TLD-GR200, LiF:Mg,Cu,P) with the dimensions of 3×3×0.9 mm^3 were used to measure the ESD value. This dosimeter has a very low detection threshold and is equivalent to soft tissue in physical characteristics. Before and after each application, the TLDs were annealed at 240°C for 10 min and then cooled to 35°C. Readouts were performed at 240°C for 10 seconds and pre-heating at 135°C for 5-10 seconds in the TLD reader (TLD 7103 Reader, Imen Gostar Raman Kish, Iran) (Figure 1) [17].

Figure 1. (a) TLDs and (b) Barracuda dosimeters

2.3. Determination of ECC (Element Correction Coefficient) of TLDs

The ECC values for each TLD were obtained to increase the reproducibility because of the individual differences between the TLD responses. In this process, a semiconductor dosimeter (Barracuda, RTI Electronics, Sweden) calibrated at the SSDL Lab of Iran Atomic Energy Organization, was used. The TLDs were exposed using an X-ray machine (76 kVp, 100 cm FFD, 100 mA, 0.01 S), and the output of the machine was measured by the Barracuda dosimeter. The exposure was repeated three times to reduce the error, and the mean of the TLD responses in nC (nano Coulombs) was obtained. The ECC for each TLD was obtained using the Equation 1 [18]:

$$ECC_i = TLD_i \ / \ TLD_{average} \qquad (1)$$

2.4. Calibration Process of TLDs

To obtain Calibration Factor (CF), 24 TLDs (with ECCs close to 1): seven groups of three TLDs and three TLDs for background radiation measurements were selected to be used for dosimetry. These TLDs were exposed three times to different doses (0.14, 0.28, 0.67, 1.31, 1.35, 2.72, and 5.45 mGy) measured by the Barracuda dosimeter, and then the mean TLD readout was calculated. After reading the TLDs, the dose (mGy) versus reading (nC) was plotted, and the CF was obtained by the slope of the curve.

2.5. Dosimetry with TLD Chips

For each patient, 15 TLDs were placed in different parts as follows: 6 TLDs in the area of the parotid gland region (3 TLDs for each outer ear canal), 6 TLDs on the skin of thyroid glands (in front of the neck), and 3 TLDs were located between the eyes. In each experiment, three TLDs were placed away from the radiation field to measure the peripheral background dose in the radiography room. To place the chips on the patient's body, the TLDs were first embedded in plastic covers with special numbers and then glued to the intended points. Finally, they were read by the TLD reader after 24 hours of exposure, and the amount of TLD readouts was multiplied by the ECC, CF, and R_{l0}/R_{li} to convert the reading to dose [15].

2.6. Statistical Analysis

Dispersion indices, including mean, median, standard deviation, minimum, maximum, first quarter, and third quarter were calculated using Microsoft Excel software. The Kolmogorov-Smirnov (KS) test was used to check the normality of data distributions before the comparison tests. The ESD values resulted from CBCT in the eyes, thyroid, and parotid gland regions were compared among the adult and pediatric groups using one-way ANOVA and Mann-Whitney tests. All of the statistical analyses were performed with SPSS software (version 16, SPSS Inc, Chicago, IL, USA). It is notable that P-values lower than 0.05 were considered as a significant difference.

3. Results

The TLD calibration curve is shown in Figure 2. The patient information, including age and sex is shown in Table 1 for both adults and pediatrics. The information related to radiographic testing, including voltage and mAs for both groups is indicated in Table 2.

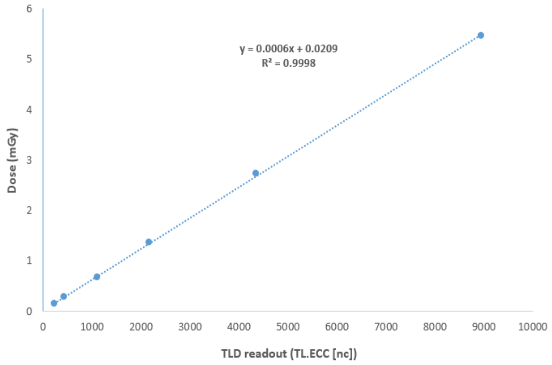

Figure 2. TLD calibration curve

Table 2. The information of exposure parameters for both investigated groups

	Scan	Sex	kVp	mA	Time (s)	mAs
Adults	CBCT FULL	SA	84 ± 0	12 ± 0	12.27 ± 0.02	147.25 ± 0.24
		F	84 ± 0	12 ± 0	12.27 ± 0.02	147.23 ± 0.26
		M	84 ± 0	12 ± 0	12.28 ± 0.01	147.31 ± 0.11
	CBCT Maxilla	SA	84 ± 0	12 ± 0	12.27 ± 0.03	147.22 ± 0.32
		F	84 ± 0	12 ± 0	12.26 ± 0.02	147.16 ± 0.29
		M	84 ± 0	12 ± 0	12.28 ± 0.03	147.36 ± 0.4
	CBCT Mandible	SA	84 ± 0	12 ± 0	12.28 ± 0.02	147.32 ± 0.27
		F	84 ± 0	12 ± 0	12.28 ± 0.02	147.34 ± 0.25
		M	84 ± 0	12 ± 0	12.27 ± 0.04	147.23 ± 0.43
	Total		84 ± 0	12 ± 0	12.27 ± 0.02	147.26 ± 0.27
Pediatrics	CBCT Mandible	SA	84 ± 0	10 ± 0	12.28 ± 0.04	122.79 ± 0.36
		F	84 ± 0	10 ± 0	12.28 ± 0.04	122.78 ± 0.38
		M	84 ± 0	10 ± 0	12.28 ± 0.04	122.8 ± 0.39
	CBCT Maxilla	SA	84 ± 0	10 ± 0	12.3 ± 0.07	122.96 ± 0.65
		F	84 ± 0	10 ± 0	12.3 ± 0.06	122.97 ± 0.63
		M	84 ± 0	10 ± 0	12.29 ± 0.09	122.92 ± 0.86
	Total		84 ± 0	10 ± 0	12.29 ± 0.05	122.88 ± 0.52

The mean and standard deviation of ESD (mGy) in each type of CBCT exam is shown in Tables 3 and 4, for adult and pediatric patients, respectively. According to Tables 3 and 4, in the CBCT exam, the highest mean value of ESD in adults was related to the parotid region (4.77 ± 0.61 mGy), and the lowest one was related to the thyroid region (0.37 ± 0.16 mGy). Similar results were observed for pediatric patients with the ESD values of 2.97 ± 0.36 mGy and 0.35 ± 0.12 mGy for the parotid and thyroid gland regions, respectively. It is considered that the highest ESD values for adults were allocated to the parotid gland region during maxilla examination, and the lowest ones were in the eyes' region during mandible examination, while in the pediatric patients the highest and lowest ESD values were observed in the parotid and thyroid gland regions, respectively, during maxilla examination. The statistical results showed that the ESD values of the parotid gland regions in maxilla and mandible examinations had a significant difference, P=0.02 (Figure 3.a). However, there was no significant variation between the thyroid and eyes' regions. In addition, as shown in Figure 3.b, there was a significant difference between the ESD values of the parotid gland regions among the adults and pediatric groups (P <0.05). But, there was no statistically significant difference between the ESD of the eyes and thyroid in the two age groups.

Table 3. Mean ESD values (mGy) of thyroid, parotid and eye regions in CBCT of full, maxilla and mandible in adult groups

Scan	Sex	DAP	Left Thyroid	Right Thyroid	Left Parotid	Right Parotid	Eyes	Thyroids	Parotids
CBCT FULL	SA	943 ± 98	0.34 ± 0.13	0.38 ± 0.12	4.26 ± 0.46	4.51 ± 0.66	0.38 ± 0.1	0.36 ± 0.12	4.38 ± 0.53
	F	935 ± 110	0.34 ± 0.15	0.36 ± 0.13	4.33 ± 0.47	4.49 ± 0.51	0.35 ± 0.08	0.35 ± 0.14	4.41 ± 0.48
	M	974 ± 0	0.35 ± 0.02	0.44 ± 0.12	3.99 ± 0.39	4.59 ± 1.45	0.46 ± 0.15	0.4 ± 0.05	4.29 ± 0.92
CBCT maxilla	SA	819 ± 164	0.32 ± 0.08	0.33 ± 0.1	5.04 ± 0.55	5.25 ± 0.56	0.52 ± 0.12	0.33 ± 0.09	5.14 ± 0.5
	F	796 ± 166	0.3 ± 0.08	0.31 ± 0.11	5.11 ± 0.64	5.4 ± 0.6	0.56 ± 0.12	0.3 ± 0.1	5.25 ± 0.57
	M	870 ± 180	0.37 ± 0.07	0.38 ± 0.02	4.89 ± 0.29	4.88 ± 0.16	0.44 ± 0.1	0.37 ± 0.04	4.89 ± 0.2
CBCT mandible	SA	725 ± 131	0.43 ± 0.23	0.44 ± 0.18	4.68 ± 0.37	4.89 ± 0.58	0.24 ± 0.07	0.44 ± 0.2	4.78 ± 0.42
	F	741 ± 144	0.44 ± 0.26	0.45 ± 0.2	4.68 ± 0.41	4.9 ± 0.62	0.24 ± 0.08	0.44 ± 0.23	4.79 ± 0.45
	M	663 ± 0	0.41 ± 0.07	0.42 ± 0	4.7 ± 0.2	4.82 ± 0.52	0.23 ± 0.06	0.41 ± 0.03	4.76 ± 0.36
Total		829 ± 158	0.37 ± 0.16	0.38 ± 0.14	4.66 ± 0.56	4.88 ± 0.66	0.38 ± 0.15	0.37 ± 0.15	4.77 ± 0.61

Table 4. Mean ESD values (mGy) of thyroid, parotid and eye regions in CBCT of full, maxilla and mandible in pediatric groups

Scan	Sex	DAP	Left Thyroid	Right Thyroid	Left Parotid	Right Parotid	Eyes	Thyroids	Parotids
CBCT mandible	SA	663 ± 0	0.45 ± 0.05	0.46 ± 0.05	2.88 ± 0.72	3.01 ± 0.69	0.36 ± 0.07	0.46 ± 0.05	2.94 ± 0.68
	F	663 ± 0	0.42 ± 0.07	0.45 ± 0.08	3.4 ± 0.68	3.29 ± 0.75	0.37 ± 0.05	0.44 ± 0.07	3.35 ± 0.69
	M	663 ± 0	0.47 ± 0.03	0.47 ± 0.03	2.53 ± 0.55	2.82 ± 0.63	0.35 ± 0.09	0.47 ± 0.02	2.68 ± 0.57
CBCT maxilla	SA	663 ± 0	0.24 ± 0.04	0.25 ± 0.03	2.85 ± 0.7	3.15 ± 0.63	0.45 ± 0.06	0.24 ± 0.03	3 ± 0.64
	F	663 ± 0	0.24 ± 0.04	0.25 ± 0.02	2.93 ± 0.71	3.18 ± 0.61	0.45 ± 0.06	0.25 ± 0.03	3.06 ± 0.63
	M	663 ± 0	0.22 ± 0.01	0.24 ± 0.04	2.67 ± 0.79	3.07 ± 0.8	0.43 ± 0.07	0.23 ± 0.02	2.87 ± 0.79
Total		663 ± 0	0.34 ± 0.12	0.36 ± 0.12	2.87 ± 0.69	3.08 ± 0.64	0.4 ± 0.08	0.35 ± 0.12	2.97 ± 0.36

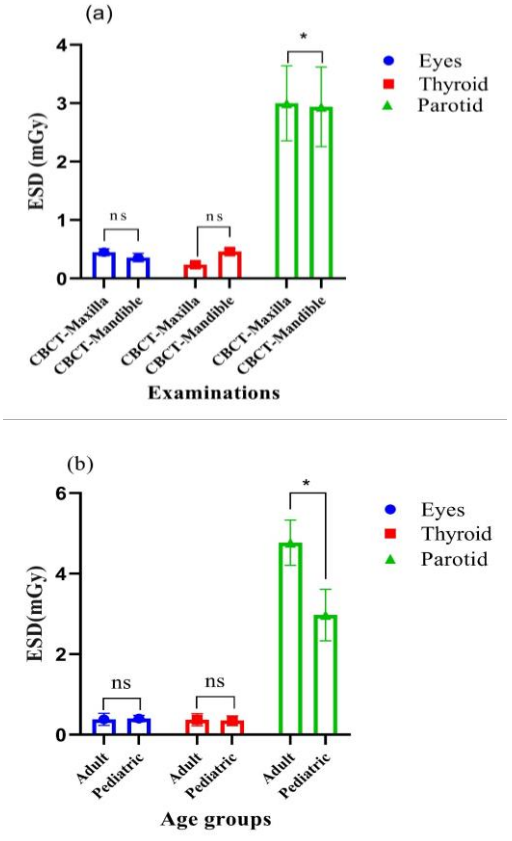

Figure 3. (a) Comparison of ESD values in maxilla and mandible examinations in eye, thyroid and parotid gland regions. (b) Comparison of ESD values among the adults and pediatric groups in eye, thyroid and parotid gland regions.* Significant difference at P<0.05. ^{ns}No significant difference

4. Discussion

Due to the widespread use of CBCT imaging, the radiation dose received by the sensitive organs during this method could be the main issue [16]. In the present study, the ESD value of the thyroid gland region in CBCT of the mandible is higher than that of the maxilla, because, in the mandible scan, the position of the head and radiation field is adjusted so that the thyroid receives more radiation compared to the mandible scan. In addition, the ESD value of the eyes and parotid regions during CBCT of the maxilla is higher than that of the mandible, in a way that, the ESD value was higher remarkably in parotid gland regions. The reason can be related to the position of the head during the maxilla examination, in other words, during this examination, eyes and parotid gland regions are placed in the radiation field and receive the initial radiation. Heiden *et al.* [19] showed that the thyroid and parotid glands are the organs that have the maximum radiation exposure in both panoramic and CBCT exams. Studies have shown that the risk of thyroid cancer through dental radiography is always a concern in adults and children [13,16]. However, due to the differences in patients' physical characteristics, biological sensitivity is a confounding factor in determining the dose and risk during CBCT examinations [20].

In the present work, fixed Field Of View (FOV) was used for all patients in both age groups which could be the main reason for increasing the surface dose [21]. In general, if the CBCT imaging centers do not follow specific instructions, the exposure adjusted by the technicians will not fit the diagnostic objectives and will lead to an additional dose to patients [20]. By reviewing 12 protocols for estimating the effective doses of CBCT ProMax 3D unit by Gang Li [22], it was shown that the larger FOV or higher spatial resolution leads to higher radiation dose to the patients when other exposure parameters (kV and mAs) are kept constant. Overall, the radiation dose for a large FOV of CBCT is estimated to be 3 to 7 times higher than that of panoramic radiography [23]. Comparison of the dose absorbed in children and adults (male and female) in small, medium, and large FOVs in both panoramic and CBCT exams by Saberi *et al.* [16] indicated that in panoramic (80 × 80) and CBCT (90 × 120), the adult dose is significantly higher than that of pediatric dose.

The results of ESD measurement in three imaging centers in the study of Pauwels *et al.* [24] have been reported that the maximum doses of ocular glands and thyroid gland regions were 2337 and 2559 µGy, respectively. Furthermore, in another study by Setti *et al.* [25], the absorbed dose of the thyroid gland was measured during the Newtom 3G-CBCT scanner using TLD-100 dosimeters in the head and neck phantom. The average surface dose of the thyroid was 0.48 mGy, which is higher in comparison with the amount of the present study. In addition, Farshi *et al.* [14] investigated NewTom VGi and Planmeca Promax 3D scanners to evaluate the doses received in 64 patients at two centers. The ESD values of the eyes, parotid, and thyroid gland regions were measured using TLD dosimeters. The maximum ESD belonged to the parotid gland regions, which is consistent with our study, which could be due to the more primary radiation in CBCT imaging.

The ESD values of the eyes and the thyroid gland regions were compared in pediatric patients. Although both are exposed to secondary radiation, the average dose in the thyroid region was higher than that of the eyes, which could be due to the shorter distance from the central beams [9]. In a study performed by Theodorakou *et al.* [26], the average effective doses for 10-year-old and adult phantoms were calculated. For both phantoms, the salivary glands received a higher dose than the rest of the organs. The smaller diameter and height of the 10-year-old phantom of the head place the thyroid gland closer to the primary beam, consequently, the thyroid dose was obtained more than other organs. Recent studies have shown that the use of thyroid protectors for children can help reduce the dose of the thyroid gland especially in large FOV [27, 28]. During the pediatric patients' imaging process, the optimization and dose limitation are the important factors, and knowing the technical aspects of the CBCT as well, although some of them are related to radiation parameters set by the manufacturer and are not adjustable for each patient [29]. If the radiation parameters such as kV, mA, and exposure time for pediatric patients will not reduce, the radiation doses for them may exceed the normal range for adults due to the differences in organ size and susceptibility to radiation [9].

All in all, in the present study, the surface dose of the eyes' region in both groups of adults and children was less than the recommended level [30]. The differences between the ESDs measured in the present study and other studies could be due to the type of CBCT devices, use of phantoms instead of the real patient, type and location of TLDs, anatomical differences of patients, and different exposure parameters (like kV and mAs). In addition, the other factors, which are affected the dose values during CBCT examinations are included; continuous or pulsed being of X-ray radiation, the amount of rotation angle of tube and detector, FOV size, beam filtration, and voxel size [31].

5. Conclusion

The findings of the present study indicated that the measured ESDs depend on a combination of patient demographic information such as patient age, as well as, scan parameters such as mA. The parotid gland region is the most sensitive region during maxillofacial CBCT imaging which has received the highest dose in both age groups. It is recommended to keep mAs as low as possible for the purpose of reducing the patient dose, especially for pediatric patients because their organs are more sensitive to radiation effects.

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