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Comparison of pediatric doses of cone beam computed tomography and panoramic radiography in three age groups

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ABSTRACT

Background: A wide variety of radiation dose values can occur in Cone Beam Computed Tomography (CBCT) devices with different field of view (FOV) sizes. Radiation dose of current CBCT devices have been considerably reduced. This study compared effective radiation doses and organ absorption doses obtained from panoramic and CBCT imaging at various FOV sizes in children aged five, ten, and fifteen years. ***Materials and Methods:*** To calculate the organ doses and effective doses, a dose calculation software PC-based Monte Carlo (PCXMC) 2.0 based on Monte-Carlo simulation was used for CBCT and panoramic exposures. Both absorbed and effective doses were calculated for the simulated phantoms of 5, 10 and 15 years old separately. ***Results:*** The organ doses of thyroid and salivary glands measured with 6*6 ECO Scan CBCT were found to be lower when compared with panoramic radiography organ doses. Panoramic radiography effective doses were lower than all other CBCT modes in all age groups. ***Conclusion:*** Although it is stated that this study does not have diagnostic data, it is thought that 6×6 ECO Scan Mode of Newtom CBCT can be chosen instead of panoramic radiography in children aged 5 years due to the dose differences.

INTRODUCTION

Panoramic radiography, an imaging technique that is widely used in the daily practice of pediatric dentistry allows examination of both the jaw and surrounding structures and tissues in a single image [1]. Because studies have shown that the radiation dose can be significantly reduced for children, many of today's panoramic devices have child-specific settings for children [2, 3]. Therefore, the use of cone beam computed tomography (CBCT) has become an increasing trend in recent years, especially in children, increasing the need for radiation protection [4]. Referral guidelines in radiology have been developed, particularly for the pediatric population, to identify the techniques in by which radiographic examination can provide the most accurate diagnostic observation while adhering to the “as low as diagnostically acceptable” (ALADA) principle. These guidelines do not provide a definitive judgment on which radiological method to use in clinical diagnosis. Instead, they provide recommendations based on the best available evidence that can be considered for the patient's specific needs [5-10]. SedentexCT guidelines have indicate that CBCT examinations should be recommended in clinical situations in which the information they provide could change the diagnosis or improve the treatment plan [11]. CBCT has proven beneficial when combined with two-dimensional (2D) imaging techniques [11-13]. Therefore, a preliminary radiological assessment is typically required for pediatric CBCT imaging, often involving panoramic imaging in practice. However, panoramic radiography is not an imaging method that can be routinely applied in every clinical situation, especially for children [14]. The most important criterion determining the choice of imaging method is the radiation dose.

It is generally acknowledged that CBCT radiation doses are higher than those of other 2D dental imaging method [11-15]. However, a wide range of radiation dose values can be used in CBCT devices with different field of view (FOV) sizes, and even among different–brands [16]. Therefore, selecting the imaging method should be based on the clinical condition of the patient by conducting dose studies on as many different devices as possible. We have not yet come across previous studies examining children's CBCT and panoramic doses with different FOVs across various age groups. This study aims to provide a clear understanding of the differences between CBCT and panoramic doses in different FOVs for children of various age groups. The clinical benefit of this study is that it provides an overview of the most appropriate combination of radiological imaging that can be applied in pediatric patients.

MATERIALS AND METHOD

This study compares the organ absorption and effective radiation doses obtained from CBCT imaging at different FOV sizes with panoramic imaging in different pediatric age groups, and also reveals differences between doses resulting from three-dimensional (3D) imaging techniques and panoramic imaging doses. In selecting the image sizes used for this purpose, FOVs were preferred that could cover the dentoalveolar region for 3D imaging and the parameters of the panoramic images recommended for each age group by the manufacturer.

PC-based Monte Carlo simulation (PCXMC)

To determine organ doses and effective doses for CBCT exposure, dose calculations were performed using PCXMC 2.0 Rotation (STUK, Helsinki, Finland), a Monte-Carlo simulation-based program. In this in vitro study, a distinct approach was taken for panoramic radiography compared to CBCT simulations. Specifically, dedicated software, PCXMC 2.0 was utilized for 2D imaging.

Initially, imaging units were modeled in the software to reflect the characteristics of the respective imaging machines. Subsequently, scanning protocols were simulated by the software. The parameters for these simulations are detailed in table 1. Following the simulation of imaging units and scanning protocols, virtual phantoms were employed to calculate both absorbed and effective doses for three age groups; 5-year-olds, 10 -year-olds, and 15-year-olds. PCXMC 2.0 applied standard height and weight information for the phantoms, with values of 109.1 cm and 19 kg for 5-year-olds, 139.8 cm and 32.4 kg for 10-year-olds, and 168.1 cm and 56.3 kg for 15-year-olds [17]. Dosages were computed in organs and tissues based on the International Commission on Radiological Protection (ICRP) dosimetry recommendations, as well as the effective doses with tissue weighting factors based on ICRP publication 103 [10]. FOV areas large enough to examine both jaws were selected ~~in~~ from the different age groups evaluated for CBCT. Thus, it is possible to calculate radiation doses for images comparable to panoramic radiography in all examinations.

Imaging units

In CBCT exposures, CBCT volumes were centered on the jaws to cover the dentoalveolar region bilaterally for simulated phantoms of the three age groups. The NewTom CBCT Machine (Newtom 5G XL; QR Systems; Verona, Italy) was used in this study. Its standardized FOVs are 6 × 6, 8 × 5, 8 × 8, 10 × 10, 12 × 8, 15 × 5, 15 × 12, 18 × 16, and 21 × 19 mm in NewTom CBCT Machine. Since we were examining different age groups, we preferred FOV dimensions that would cover the dentoalveolar region of each age group according to the common physical characteristics of that group. While making these choices, the researcher, who had more than 10 years of maxillofacial radiology experience, decided to, evaluate the FOVs of the images taken in our clinic according to age ranges. The CBCT machine was used at 360° rotation with a a 6 × 6 cm^2 and 8 × 8 cm^2 FOV for 5-year-olds, 8 × 8 cm^2 and 10 × 10 cm^2 for 10- year-olds, and 12 × 8 cm^2 and 15 × 12 cm^2 for 15- years -olds in different imaging modes of CBCT. The parameters for the CBCT exposures are summarized in Table 1. The focal spot image receptor distance (FID) of the CBCT device which is the distance from the focal point to the sensor, was 97 cm, and the distance from focus to reference point (FRD), which is the distance from the focal point to the center of the FOV, was 48.50 cm. The cranio-caudal angle, which is a required parameter to calculate radiation doses, was adjusted ~~as~~ to 0° for CBCT exposures, accordance with manufacturer's recommendations. A single 360° scan was split into 36 equal portions in 10° increments, each of which served as a single record for computing absorbed doses in the PCXMC rotation modification software. Ozaki *et al.* determined that a simulation of every 5° and 10° would be sufficient to estimate the effective dose in accordance with TLD [17]. For this reason, we carried out our study with 10° angles. For each analyzed trial, the absorbed dosage values of all 36 sections were summed after calculation.

The coordinates for CBCT exposures were set as follows:

0 cm Xref, –4 cm (6 × 6 FOV), –5 cm (8 × 8 FOV) Yref, and 47.50 cm Zref for 5-year-olds
0 cm Xref, –5 cm (8 × 8 FOV), –6 cm (10 × 10 FOV) Yref, and 58.50 cm Zref for 10-year-olds
0 cm Xref, –7 cm (12 × 8 FOV), –8.5 cm (15 × 12 FOV) Yref, and 74 cm Zref for 15-year-olds

In panoramic radiography, exposure geometry was simulated according to the manufacturer's recommendations. Planmeca ProMax® 2D S3 (Planmeca, Helsinki, Finland) device parameters were used to simulate panoramic exposures as XS mode for 5-year-old phantoms and S mode for 10- and 15-year-old phantoms (table 1). FRD and FID were inserted as 35 cm and 50 cm, respectively, for all ages. In addition, X-ray beam width was set to 0.6 cm for all ages and X-ray height was set to 11.7 cm for 5-year-old simulations and 13.8 cm for 10- and 15-year-old simulations. The cranio-caudal angle was adjusted to –7°-for panoramic radiography exposures according to the manufacturer's recommendation. Unlike CBCT exposures, a single 180° scan for XS mode was split into 18 equal portions in 10° increments, and a single 210° scan for S mode was split into 21 equal portions, each of which served as a single record for computing absorbed doses in the rotation modification of PCXMC dose calculation software. For each analyzed trial, the absorbed

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dosage values of all separated sections were summed after calculations.

The Xref, Yref, and Zref coordinates for panoramic exposures were 0 cm, –4 cm, and 47.5 cm for five-year-olds; 0 cm, –5 cm, and 58.5 cm for 10-year-olds; and 0 cm, –8.5 cm, and 74 cm for 15-year-olds, respectively. Simulated exposure protocols is shown in figure 1.

RESULTS

The highest recorded organ doses were observed during CBCT imaging in the 15-year-old group, primarily attributable to the utilization of a larger FOV. The maximum organ dose measured occurred in the 15-year-old group, specifically on the bone surface during RS scanning (3.6 s exposure time; 10.81 mAs). Across all scans and organ doses, the tissues receiving the highest doses are followed by total bone surface, oral mucosa, and salivary glands. The mean absorbed doses for each organ of interest in CBCT and panoramic radiographies by age group are presented in table 2.

Table 1. The parameters of panoramic imaging technic (Planmeca ProMax® 2D S3, Helsinki, Finland) and CBCT exposures (Newtom 5G XL; QR systems; Verona, Italy).

	5-years old					*10 years old*					*15 years old*				
	ES		**RS**		**PAN**	**ES**		**RS**		**PAN**	**ES**		**RS**		**PAN**
FOV size (cm)	6×6	8×8	6×6	8×8	XS	8×8	10×10	8×8	10×10	S	12×8	15×12	12×8	15×12	S
Tube kV	75	75	75	75	62	75	75	75	75	64	75	75	75	75	64
Total Filtration (AL-mm)	11.2	11.2	11.2	11.2	2,8*	11.2	11.2	11.2	11.2	2,8*	11.2	11.2	11.2	11.2	2,8*
Exposure time (s)	0.9	1,4	3.6	3.6	13.8	1.4	1.4	3.6	3.6	15.8	1.4	1.4	3.6	3.6	15.8
mAs	2.70	4.05	10.81	10.81	69	4.05	4.05	10.81	10.81	99.54	4.05	4.05	10.81	10.81	99.54
Axial thickness (mm)	0.2	0.2	0.2	0.2	-	0.2	0.2	0.2	0.2	-	0.2	0.2	0.2	0.2	-
DAP (mGy.cm^2)	35.6	88.1	113.5	187.1	40	88.11	132.43	113.58	281.26	73	124.98	220.77	265.42	470.78	73

*According to the manufacturer's manual, total filtration values given at 84 kV for the panoramic device
ES: Eco Scan; RS: Regular Scan; PAN: Panoramic Radiograph

Table 2. The mean absorbed doses (µSv) for each organ of interest in CBCT and panoramic radiographies according to age groups.

TİSSUE	**5 years old**					**10 years old**					**15 years old**				
	6 x 6 FOV		**8 x 8 FOV**			**8 x 8 FOV**		**10 x 10 FOV**			**12 x 8 FOV**		**15 x 12 FOV**		
	ES	**RS**	**ES**	**RS**	**PAN**	**ES**	**RS**	**ES**	**RS**	**PAN**	**ES**	**RS**	**ES**	**RS**	**PAN**
Oral Mucosa	579.5	1837.4	1362.0	2893.1	320.1	1130.8	2401.7	1567.3	3332.4	458.0	1285.6	2743.0	2281.6	3440.9	395.5
S.G.	246.3	786.6	683.7	1449.8	349.1	778.6	1653.7	1005.2	2129.0	511.7	707.2	1501.0	1248.5	2054.6	297.3
Bone marrow	19.6	62.5	51.3	108.9	21.7	32.7	69.5	51.9	110.3	23.0	38.1	80.9	67.2	119.3	19.7
Bone surface	885.8	2877.1	2012.5	4279.1	1116.8	1610.4	3420.3	2316.8	4925.6	1294.2	1606.0	3410.3	2836.6	5005.7	853.0
Esophagus	4.5	13.7	11.0	23.3	6.5	6.5	13.9	9.4	20.6	5.7	2.9	6.3	5.3	9.9	1.7
Thyroid	58.9	186.7	146.1	301.5	105.0	118.8	252.4	175.1	372.7	148.0	59.1	125.1	104.0	203.9	31.7
Brain	27.7	87.9	65.9	139.5	45.4	41.6	88.3	59.6	126.4	41.9	40.3	85.7	71.3	133.8	18.7
Skin	15.0	48.1	38.1	81.0	22.4	25.6	54.4	40.2	85.5	25.6	27.4	58.4	48.5	101.4	18.0
Remainder Tissues*	809.7	1668.9	1468.0	2723.6	649.5	763.3	1621.2	1199.8	2548.0	461.1	536.9	1133.3	942.7	1982.8	217.8

*Remainder tissues: Adrenals, extra thoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀). BM: Bone Marrow; SG Salivary Gland. ES: Eco Scan; RS: Regular Scan; PAN: Panoramic Radiography Organ doses resulting from RS (3.6 seconds exposure time; 10.81 mAs) in all age groups exhibit elevated values compared to ES (for the 5-year-old age group, exposure times are 0.9 sn [6 × 6 FOV] and 1.4 sn [8 × 8 FOV], and mAs are 2.70 [6 × 6 FOV] and 4.05 [8 × 8 FOV]; for 10- and 15-year-old age groups, exposure time is 1.4 and mAs is 4.05). However, in every age group, when the FOV is increased, the ES imaging technique results in lower organ doses than RS imaging at a lower FOV. This highlights the potential for performing imaging with lower organ doses by adjusting imaging parameters when the FOV needs to be expanded in diagnostically suitable pediatric patients.

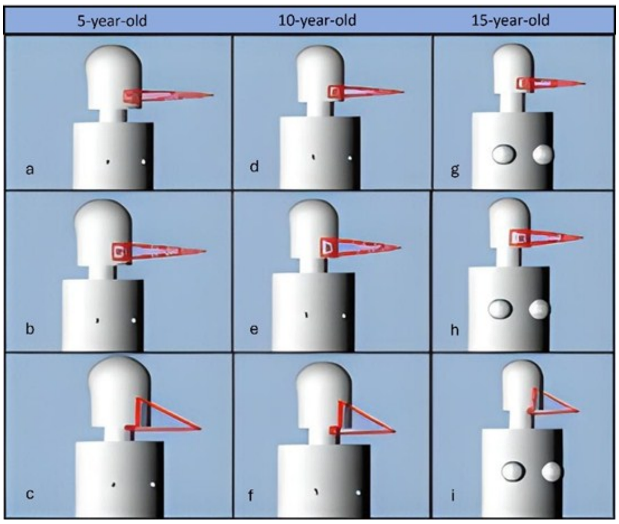

Figure 1. Simulated exposure protocols of 6*6 cm2 **(a)** and 8*8 cm2 **(b)** FOV for CBCT and XS mode **(c)** for panoramic radiograph on 5 years old; 8*8 cm2 (d) and 10*x10 cm2 **(e)** FOV for CBCT and S mode **(f)** for panoramic radiograph on 10 years old; and 12*8 cm2 **(g)** and 15*12 cm2 **(h)** FOV for CBCT and S mode **(i)** for panoramic radiograph on 15 years old mathematical phantoms are demonstrated.

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In examinations of the 10- and 15-year age groups, all organ doses were significantly lower in panoramic images compared to CBCT doses. Nevertheless, in the case of 5-year-olds, a substantial decrease in organ doses was observed with a parallel reduction in FOV, mAs, and exposure time. As a result, CBCT doses are reduced to levels comparable to panoramic doses when imaging is performed with a 6 × 6 FOV, an exposure time of 0.9 seconds, and acquisition parameters of 2.70 mAs. This observation underscores the feasibility of achieving lower organ doses through modification of imaging parameters when a larger FOV is required in diagnostically appropriate pediatric patients.

The mean absorbed doses of all organs except oral mucosa were seen to be lower when 6 × 6 ECO scan CBCT was compared with panoramic radiography in the 5-year-old group. In addition, organ doses of thyroid and salivary glands measured with 6 × 6 ECO Scan CBCT were found to be lower when compared with panoramic radiography organ doses. Absorbed organ doses of remainder tissues also represent a significant contribution to effective doses in all imaging modes, including panoramic radiography. Meanwhile, although the oral mucosa was classified under the heading of remainder tissues in ICRP 103, in our study, it was removed from remainder tissues, and the absorbed dose is indicated in table 2. This is because the oral mucosa is overexposed to radiation in all irradiations. Furthermore, the lowest absorbed organ doses of remainder tissues in all age groups were measured on panoramic radiography. Table 3 shows the measured effective doses of imaging modalities in the different age groups. Based on organ absorption doses, panoramic radiography effective doses were lower than all the other CBCT modes in all age groups. Nevertheless, 6 × 6 ECO scan CBCT effective dose was found to be almost the same with panoramic radiography in the 5-year-old group. Effective doses of CBCT regular scan modes were higher than those of Eco scan modes in all age groups. Panoramic radiograph effective doses were lower in the 10- and 15-year-old groups.

Table 3. Effective doses of imaging modalities according to different age groups.

Age	FOV	Imaging Mode	Effective Dose ICRP103 (µSv)
5	6 x 6	Eco	19.695
		Regular	62.432
	8 x 8	Eco	50.639
		Regular	107.319
	XS	Panoramic	19.068
10	8 x 8	Eco	37.385
		Regular	79.401
	10 x 10	Eco	54.077
		Regular	114.978
	S	Panoramic	24.911
15	12 x 8	Eco Scan	33.572
		Regular Scan	71.325
	15 x 12	Eco Scan	59.327
		Regular Scan	102.007
	S	Panoramic	13.688

DISCUSSION

Currently, there are more than 50 CBCT units with different FOV sizes and exposure parameters, such as mAs, kV, and collimators, and these parameters can be controlled by technicians based on patient size and image quality requirements [15]. Also, each CBCT unit produces different radiation doses for each specific exposure protocol. The same feature applies to panoramic devices. The present study included radiation doses of the NewTom CBCT Machine (Newtom 5G XL; QR systems; Verona, Italy) and Planmeca ProMax® 2D S3 (Planmeca, Helsinki, Finland) panoramic device. The NewTom CBCT unit exhibits a distinct advantage over other units by allowing image acquisition while the patient is in the supine position. This advantage might be useful for imaging pediatric patients, which can reduce artifacts arising from patient motion, especially a factor with this patient group.

The present study includes-a comparison of absorbed and effective radiation doses obtained from panoramic and CBCT devices using the Monte Carlo simulation method. In particular, radiation doses of different CBCT scan modes were measured in different age groups, which can be considered adolescent and child patients. To compare the CBCT scan modes with panoramic radiography in the same age group, two different CBCT FOVs were used for each age group to capture the dentoalveolar region of both the maxilla and mandible.

Although it is not the same as the panoramic exposure area, a very similar field of view has been provided by CBCT. Therefore, because different FOV areas were preferred in different age groups, the radiation doses obtained for CBCT from each age group could be compared with the panoramic radiation doses. A prior study, sharing a similar perspective as this study, compared doses based on the anatomical regions encompassed by various FOVs, but the comparison was not specific to pediatric subjects. Nevertheless, as in our results, they reported that radiation doses were generally lower with smaller FOVs [18]. Similar to our methodology, a previous systematic review compared pediatric doses of CBCT and panoramic in a 10-year-old age group with an adult group. The study utilized a minimum of 8 × 8 FOV for ProMax 3D Max (Planmeca, Finland) and 15 × 15 FOV for NewTom 3G (Cefla Dental Group, Imola, Italy) in children. The study indicated an elevated radiation risk associated with CBCT for individuals under the age of 15 [15].

In addition, two exposure settings, ECO and regular, were used in each CBCT exposure mode, so the radiation doses of different exposure settings in the same FOV in each group could be compared. Van Acker *et al.* systematically reviewed articles on children's doses published up to December 2018 and wrote a summary guide for the reduction of the

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exposure dose [16]. According to the dose reduction guideline suggested by Van Acker *et al.*, the radiation doses measured with CBCT's ECO scan mode were lower than the CBCT regular scan mode in all age groups [16]. Thus, especially in pediatric patients, choosing the low-dose exposure mode that actually reduces the absorbed dose by lowering the mAs in the CBCT device used reduces the effective dose by half.

Few studies in the literature have addressed the determination of effective doses of different kinds of CBCT units for pediatric patients. Ludlow et al. reviewed effective doses of 34 CBCT units and found the mean effective dose for 10-year-old phantoms-to be 103 μSv in small FOVs [19]. The effective doses ranged from approximately 37 μSv to 115 μSv for 10-year-old simulated phantoms. Thus, in each CBCT device, the amount of radiation applied to the pediatric patient and the effective dose showing associated risks differ. In our study, the lowest effective doses were measured in the 5-year-old group in panoramic and 6 × 6 ECO Scan mode CBCT. However, upon examining the FOV–ECO dose relationship from a diagnostic standpoint, particularly by assessing the outcomes of the NewTom VGI EVO with the tube current modulation option (QR Verona, Verona, Italy), no statistical difference was reported, indicating that the diagnostic accuracy of lamina dura in the 5 × 5 ECO mode compared to the regular 5 × 5 scan [20]. Consequently, we can say that the 5 × 5 ECO mode may be a preferred choice in instances for which detailed images are not critical for diagnosis [20].

In our study, the results show that the effective dose decreases in the same FOV area as age increases. That is, the effects of radiation increase as age decreases. In a study conducted by EzEldeen *et al.*, 18 CBCT exposure protocols were employed for ages 5, 8, and 12 across three CBCT machines-3D Accuitomo 170 (Morita, Kyoto, Japan) (2 protocols), the ProMax 3D MAX with an ultra-low-dose option (Planmeca, Helsinki, Finland) (10 protocols), and the NewTom VGI EVO with the tube current modulation option (QR Verona, Verona, Italy) (6 protocols). Similar to our study, the researchers discovered that the lowest recorded average effective dose was 6.3 (± 0.9) μSv (NewTom 50 × 50 with Eco mode), while the highest was 166.3 (± 23.6) μSv (ProMax with normal-dose high-dose) [20]. Similar to our results, Choi *et al.* found in their study that, 5-year-old and 12-year-old phantoms absorbed approximately 1.2 to 1.7 times more radiation than adult phantoms in the same exposure conditions [21]. The fact that radiosensitive organs move away from the irradiated area as a result of growth and development causes this outcome [22]. Moreover, Theodorakou *et al.* reported the effective dose of a different CBCT unit (Planmeca ProMax 3D Max) for 10-year-olds as 24 μSv in 8 × 8 FOV size, while Pauwels *et al.* reported an effective dose for the same CBCT unit (Planmeca ProMax 3D Max-in the same age group as 28 μSv in the same FOV size [23, 24]. Both–studies determined radiation doses with thermoluminescence dosimeters (TLD), so it is understood that even when measurement methods are the same, different results can be obtained. As a result, dose measurement studies are mutually consistent, but each is unique. In this respect, meta-analyses on the subject may yield more valuable results.

A study performed by Lee *et al.*, compared TLD measurements with Monte Carlo simulation methods and concluded that the Monte Carlo method was comparable with TLD measurements for obtaining effective dose estimates in pediatric panoramic radiography, and it was clinically applicable [25]. The Monte Carlo method was preferred in our study because it takes less time and requires less equipment. Lee *et al.*'s study was performed on an Instrumentarium OP100 panoramic device with a 5-year-old phantom. They found an effective dose of 3.850 μSv and 3.474 μSv for individual methods. Compared to the 5-year-old panoramic effective dose obtained in our study, the results of this study differ significantly. As in CBCT, the device ~~in~~ to be used for panoramic imaging is important in determining the radiation dose. In another study in which Davis *et al.* measured the pediatric doses of the Instrumentarium OP200 panoramic device, the effective dose was 11.4 μSv and 7.7 μSv for long and short collimators, respectively [26]. This result is higher than the results obtained by Lee *et al.*, which measured the effective doses of another panoramic device produced by the same company, further supporting the fact that device differences have an effect on the radiation dose [25, 26]. Thus, the differences between studies are due to device differences rather than measurement methods.

Results of this study showed that the highest organ absorption doses were measured from the bone surface, including skull bones within FOV, salivary glands, oral mucosa, thyroid gland, and remainder tissues except oral mucosa, for all CBCT and panoramic exposures in all age groups. The presence of especially muscle and lymph nodes in remainder tissues made us suspect that this had caused the result. Moreover, it was expected that the organs that absorb the most irradiation in the maxillofacial region were—bone surface, salivary glands, and oral mucosa. Another remarkable result was that while the absorbed dose of the bone surface was found to be high, the absorbed dose of the bone marrow was found to be very low. The reason for this may be preservation of substantial bone marrow by cortical bone absorption.

Thyroid gland, which is known to be highly sensitive to the harmful effects of radiation [27], was the organ that absorbed the highest radiation dose after salivary glands and oral mucosa except bone

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surface and remainder tissues. Our results showed that although the CBCT effective doses were higher, the thyroid gland received less radiation in the 5-year-old and 10-year-old age groups compared to panoramic radiography in small FOVs and low-dose CBCT protocols. A panoramic study comparing organ doses between adults and children reported that the organ dose in children was 40.7±2 μGy for the thyroid gland and 189.3±11.5 μGy for the parotid gland. Researchers observed that the organ doses absorbed by the adult thyroid and parotid were significantly higher than those in children. As a result, they established correlations between surface absorbed dose values and radiation parameters [28].

In our study, the dose area product (DAP) values taken as a reference value for dose calculations were the DAP values calculated by the CBCT device used. Jose *et al*. assessed DAP as a reference level for panoramic radiography in pediatric patients, and they compared machine DAP and calculated DAP in 75 panoramic devices, which included the device used in our study [29]. They concluded that the difference between the calculated and measured DAPs complied well within ±18% [29]. Because the DAP value calculated by the device was thought to be reliable, no additional measurement was needed in our study. A previously reported study showed that most dentists and dental students underestimate the actual radiation doses of dental imaging techniques [30]. In a study assessing the cancer risks associated with CBCT and panoramic radiography in individuals aged 6–10 and those over 18 years old, it was reported that the risk of exposure-induced death was statistically higher in the pediatric group and during CBCT imaging [31].

For this reason, we concluded that dose studies are essential, in accordance with ALADA principles, in terms of choosing the most appropriate radiography technique for clinical applications. The major limitation of our study is that the panoramic imaging area and the FOV area of CBCT are not exactly equivalent. Instead, FOV sizes were selected in which only both jaws could be viewed together, but the surrounding anatomical structures were out of view. However, it should be taken into account that CBCT imaging is not an imaging modality that can be used directly as a substitute for panoramic imaging.

In conclusion, CBCT can be employed safely, in terms of dose, for 5-year-old patients with CBCT indications. This is attributed to the advantage of offering a 3D image, as opposed to panoramic radiography, facilitated by the utilization of a 6 × 6 FOV and a dose-reduction application.

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Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Ethical consideration: As this study was conducted in a virtual environment, ethical considerations were deemed unnecessary.

Author contribution: (1) conception and design, or analysis and interpretation of data: H.E., Y.D., G. C.A., R.S.; (2) drafting the article or revising it critically for important intellectual content: H.E., Y.D., G.C. A., R.S.; (3) final approval of the version to be published: H.E., Y.D.

REFERENCES

1. Sabbadini G (2013) A review of pediatric radiology. *CDA J 2013, **41 (8)**:575-81.*
2. Pakbaznejad Esmaeili E, Waltimo-Siren J, Laatikainen T, Haukka J, Ekholm M (2016) Application of segmented dental panoramic tomography among children: positive effect of continuing education in radiation protection. *Dentomaxillofac Radiol*, ***45**:20160104.*
3. Benchimol D, Koivisto J, Kadesjö N, Shi XQ (2018) Effective dose reduction using collimation function in digital panoramic radiography and possible clinical implications in dentistry. *Dentomaxillofac Radiol, **47**:20180007.*
4. Alamri HM, Sadrameli M, Alshalhoob MA, Sadrameli M, Alshehri MA (2012) Applications of CBCT in dental practice: a review of the literature. *Gen Dent, **60(5)**:390-400.*
5. Council of the European Union (1996) Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. Official Journal of the European Communities N° L 159, http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/9629_en.pdf. Accessed 10 October 2022.
6. Council of the European Union (1997) Council Directive 97/43/Euratom of 30 June 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure, and repealing Directive 84/466/Euratom. http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/9743_en.pdf. Accessed 10 October 2022.
7. Espelid I, Mejàre I, Weerheijm K (2003) EAPD guidelines for use of radiographs in children. *Eur J Paediatr Dent, **4**:40–8.*
8. European Commission (EC) (2004) Radiation protection 136. European guidelines on radiation protection in dental radiology: the safe use of radiographs in dental practice. Luxembourg: Office for Official Publications of the European Communities. http://ec.europa.eu/energy/nuclear/radioprotection/publication/doc/136_en.pdf. Accessed 10 October 2022.
9. American Academy of Pediatric Dentistry (2012) Guideline on Prescribing Dental Radiographs for Infants, Children, Adolescents, and Persons with Special Health Care Needs Revised 2009 *Reference Manual **37(6)**: 319–21.*
10. International Commission on Radiological Protection, ICRP (2013) Radiological protection in paediatric diagnostic and interventional radiology. ICRP Publication 121. *Ann ICRP **42(2)**: 21-36.*
11. European Commission, Radiation Protection 172 (2012) SEDENTEXCT Cone Beam CT for Dental and Maxillofacial Radiology: Evidence-based Guidelines. European Commission. Available from: http://www.sedentexct.eu/files/radiation_protection_172.pdf. Accessed May 2012.
12. Guerrero ME, Noriega J, Castro C, Jacobs R (2014) Does cone-beam CT alter treatment plans? Comparison of preoperative implant planning using panoramic versus cone-beam CT images. *Imaging Sci Dent, **44(2)**:121-8.*
13. Mota de Almeida FJ, Knutsson K, Flygare L (2014) The effect of cone beam CT (CBCT) on therapeutic decision-making in endodontics. *Dentomaxillofac Radiol, **43(4)**:20130137.*
14. Tsiklakis K, Mitsea A, Tsichlaki A, Pandis N (2020) A systematic review of relative indications and contra-indications for prescribing panoramic radiographs in dental paediatric patients. *Eur Arch Paediatr Dent, **21(4)**:387-406.*
15. Hedesiu M, Marcu M, Salmon B, Pauwels R, Oenning AC, Almasan O, *et al*. (2018) Irradiation provided by dental radiological procedures in a pediatric population. *Eur J Radiol, **103**:112-7.*
16. Van Acker JWG, Pauwels NS, Cauwels RGEC, Rajasekharan S (2020) Outcomes of different radioprotective precautions in children

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undergoing dental radiography: a systematic review. *Eur Arch Paediatr Dent, **21(4)**:463-508.*

17. Ozaki Y, Watanabe H, Kurabayashi T (2021) Effective dose estimation in cone-beam computed tomography for dental use by Monte -Carlo simulation optimizing calculation numbers using a step-and-shoot method. *Dentomaxillofac Radiol, **50(7)**:20210084.*
18. Mutalik S, Tadinada A, Molina MR, Sinisterra A, Lurie A (2020) Effective doses of dental cone beam computed tomography: effect of 360-degree versus 180-degree rotation angles. *Oral Surg Oral Med Oral Pathol Oral Radiol**, 130(4)**:433-446.*
19. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, Scheske MJ (2015) Effective dose of dental CBCT-a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol, **44(1)**:20140197.*
20. EzEldeen M, Stratis A, Coucke W, Codari M, Politis C, Jacobs R (2017) As low dose as sufficient quality: optimization of cone-beam computed tomographic scanning protocol for tooth autotransplantation planning and follow-up in children. *Journal of Endodontics*, ***43*(2)**: 210-217.
21. Choi E and Ford NL (2015) Measuring absorbed dose for i-CAT CBCT examinations in child, adolescent and adult phantoms. *Dentomaxillofac Radiol, **44(6)**:20150018.*
22. Brenner DJ (2002) Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative. *Pediatr Radiol, **32**:228–3.*
23. Theodorakou C, Walker A, Horner K, Bogaerts R, Jacobs R (2012) SEDENTEXCT project consortium: estimation of paediatric organ and effective doses from dental cone beam CT using anthropomorphic phantoms. *Br J Radiol, **85**:153–160.*
24. Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, Cockmartin L, Bosmans H, Jacobs R, Bogaerts R, Horner K (2012) SEDENTEXCT project consortium: effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol, **81**:267–271*.
25. Lee C, Park B, Lee SS, Kim JE, Han SS, Huh KH, Yi WJ, Heo MS, Choi SC (2019) Efficacy of the Monte Carlo method and dose reduction strategies in paediatric panoramic radiography. *Sci Rep, **9(1)**:9691.*
26. Davis AT, Safi H, Maddison SM (2015) The reduction of dose in paediatric panoramic radiography: the impact of collimator height and programme selection. *Dentomaxillofac Radiol, **44 (2)**:20140223.*
27. Paro JN and Zavisić BK (2012) Iodine and thyroid gland with or without nuclear catastrophe. *Med Pregl, **6**5:489-495.*
28. Zamani H, Parach AA, Razavi SH, Shabani M, Ataei G, Zare MH (2021) Estimating the radiation surface dose and measuring the dose area product to provide the diagnostic reference level in panoramic radiography. *International Journal of Radiation Research*, ***19(4)**: 963-970.*
29. Jose A, Kumar AS, Govindarajan KN, Manimaran P (2020) Assessment of regional pediatric diagnostic reference levels for panoramic radiography using dose area product. *J Med Phys, **45**:1826*.
30. Özkan G, Sessiz Ak R, Akkaya N, Öztürk H (2021) Awareness level of dentists and dental students about radiation doses of dental imaging methods. *International Journal of Radiation Research, **19 (3)**:729-736.*
31. Zamani H, Falahati F, Omidi R, Abedi-Firouzjah R, Zare MH, Momeni F (2020) Estimating and comparing the radiation cancer risk from cone-beam computed tomography and panoramic radiography in pediatric and adult patients. *International Journal of Radiation Research*, ***18(4)**: 885-893.*

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