STUDY OF EFFECTIVE DOSE OF VARIOUS PROTOCOLS IN EQUIPMENT CONE BEAM CT

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Abstract

Currently the cone beam computed tomography (CBCT) is widely used in various procedures of dental radiology. Although the doses values associated with the procedures of CBCT are low compared to typical values associated with dental radiology procedure in multi slices CT (MSCT). However can be high compared to typical values of other techniques commonly used in dental radiology. The present scenario is a very wide range of designs of equipment and, consequently, lack of uniformity in all parameters associated with x-ray generation and geometry. In this context, this study aimed to evaluate and calculate the absorbed dose in organs and tissues relevant and estimate effective dose for different protocols with different geometries of exposure in five CBCT equipment. For this, a female Alderson anthropomorphic phantom, manufactured by Radiology Support Devices was used. The phantom was irradiated with 26 dosimeters LiF: Mg, Ti (TLD-100), inserted in organs and tissues along the layers forming the head and neck of the phantom. The equipment used, in this present assessment, was: i-CAT Classical, Kodak 9000 3D, Gendex GXCB 500, Sirona Orthophos XG 3D and Planmeca ProMax 3D. The effective doses were be determined by the ICRP 103 weighting factors. The values were between 7.0 and 111.5 microSv, confirming the broad dose range expected due to the diversity of equipment and protocols used in each equipment. The values of effective dose per FOV size were: between 7 and 51.2 microSv for located FOV; between 17.6 and 52.0 microSv for medium FOV; and between 11.5 and 43.1 microSv to large FOV (maxillofacial). In obtaining the effective dose the measurements highlighted a relevance contribution of dose absorbed by the remaining organs (36%), Salivary glands (30%), thyroid (12%) and bone marrow (12%).

Key Words: CBCT, thermoluminescent dosimetry, effective dose and equivalent dose.

1. - INTRODUCTION

Since their introduction to dentistry, there is an increasing use of the technique of cone beam computed tomography (CBCT) for the various modalities of dental radiological examinations (Rottke, et al. 2013, Koivisto, et al. 2012, Pauwels, et al. 2012), including from the simplest procedures to the planning and evaluation of dental implants (Qu, et al. 2010, Rahman, Yue e Alam 2013).

The CBCT is an imaging technique that shows better three-dimensional spatial resolution with absorbed doses to organs and tissues exposed lower those usually obtained with computed tomography in medical applications in dentistry. After the introduction of CBCT in radiology, dental CT images were incorporated into routine dental radiology and cone beam CT scanner has replaced other equipment and / or other methods of dental radiology almost unrestricted way. However, the advantage presented in terms of lower doses compared with CT for medical use is not verified when compared to other methods within the own dental radiology and, thus changing the panorama of dental radiology.

Currently, there are on the market a considerable number of equipment models, with significant differences from the exposure parameters (kV, mA and current-time product), beam quality (filtration), field of view (FOV) and angle rotation. Several studies discuss the absence of uniformity among the various models and the difficulty of implementation of protocols and guidelines for dosimetric evaluation and quality control (Koivisto, et al. 2012, Pauwels, et al. 2012).

Given this versatility variety of equipment, there is a concern among experts in the field of dosimetry and quality control on necessity to estimate the effective dose for different patients and protocols and in addition the equivalent dose in tissue exposed to radiation, such as the thyroid, (Shaifulizan, Rahman and Mohammad 2013, Batista, Navarro and Maia 2013). In parallel to this need, there are studies that seek to develop phantoms and reproductive methodologies to perform quality control and determination of levels of exposure associated with the various protocols available in CBCT equipment (Shaifulizan, Rahman and Mohammad 2013).

Simultaneously with these dosimetric studies, usually performed with methodologies already applied to other radiological techniques, there is an effort of researchers to develop specific protocols and quality control tools for the CBCT technique CBCT (Pauwels, Theodorakou, et al. 2012, Batista, Navarro and Maia 2013, SEDENTEXCT Project 2011, Wu, et al. 2013). Thus, this study aims to assess the absorbed dose in organs and tissues relevant and consequently calculate the effective dose (International Commission on Radiological Protection, ICRP 103) using an anthropomorphic female phantom for typical protocols of exams in five different CBCT equipment .

2 - MATERIALS AND METHODS

2.1 Phantom anthropomorphic

Sections of the head and neck of a female Alderson anthropomorphic phantom representing a typical adult woman, manufactured by Radiology Support Devices have been used to perform this study. This phantom is composed of a human skeleton and soft tissue replacement by a resin with an equivalent atomic number to human tissue. 10 sections of the phantom were used, with a thickness of 2.5 cm each. Use of this region of the phantom is justified by the nature and purpose of dental radiology (Pauwels, Beinsberger, et al. 2012). Each section of the phantom, contain several cylindrical holes, filled with billets prepared for insertion of dosimeters (TLD), with dimensions of 3 mm x3 mm x1 mm in different positions. The phantom was exposed to clinical study protocols typically performed in the image service.

2.2 Equipment CBCT

All protocols were carried out exposing the phantom nearest possible a typical patient. In each equipment, various protocols used in the clinical practice were studied. The CBCT equipment used to perform this study were: i-CAT Classical, Kodak 9000 3D, Gendex GXCB 500, Sirona Orthophos XG 3D and Planmeca ProMax 3D. The parameters used in each equipment are given in Table 1. To simplify the citation were adopted reduced names to some equipment: Planmeca ProMax 3D equipment is the ProMax 3D, Gendex equipment GXCB 500 is the Gendex and the Sirona Orthophos XG 3D is Orthophos XG 3D.

To differentiate the size of FOV terms were used: maxillofacial, for a large FOV; dentoaveolar for a medium FOV; and mandible or maxilla for a located FOV (Pauwels, Beinsberger, et al. 2012) . For reasons of positioning phantom all protocols were performed of jaw dentoaveolar or the frontal region of the phantom.

Table 1 - Technical parameters of the selected protocols in CBCT

CBCT	Protocol	FOV (cm²)	Kilovoltage (kV)	Current (mA)
ProMax 3D	Maxillary	5 x 8	84	12
Gendex	Maxillofacial	14 x 8.5	120	5
	Dentoalveolar	8.5 x 8.5	120	5
	Maxilar	8.5 x 6	120	5
i-CAT Classical	Maxillofacial	14 x 8	120	3 – 7
	Maxillary	14 x 6	120	3 – 7
	Mandíbula	14 x 6	120	3 – 7
Orthophos XG 3D	Maxillary	5 x 5	85	7
	Mandible	5 x 5	85	7
	Dentoalveolar	8 x 8	85	7
Kodak 9000 3D	Maxillary	3.7 x 5	70	8

2.3 Thermoluminescent dosimeters

To perform the measurements, twenty six TLD-100 (LiF: Mg, Ti) dosimeters were used, . The calibration was performed by exposing each TLD TLD a beam of x-rays produced by the generator Pantak / Seifert model ISOVOLT 160HS and the known values of doses in the range of 1 to 15 mGy.. This X-ray equipment, belong to the Institute of Nuclear and Energy Research Laboratory – IPEN. The TLDs were calibrated to the qualities of computed tomography (RQT8, RQT9 E RQT 10), at a distance of 1.0 m from the focus. TLD for reading both for calibration and for performing reading of a TLD reader was used Harshaw, QS 3500 model, with the aid of WinREMS software, coupled to a data acquisition system.

2.4 Positioning of the TLD in the phantom

The selection of tissues and organs for placing TLDs in this study was based on the methodology presented by Ludlow et al (Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton B. 2006) and J. A. Roberts et al, (Roberts JA, Drage NA, Davies J, Thomas DW 2009). A total of twenty six TLDs were inserted in the phantom, the positions shown in Table 2. In total, 8 organs and tissues were selected for evaluation. The locations of the selected tissues were indicated by dental radiologists. To increase the dose and improve the TL signal, three exposures were carried out in each protocol and the response of the dosimeter was divided by three.

Table 2 - Location of the TLDs in the phantom

Nº TLD	Órgan(slice)
1	Surface of the left side (5) *
2	Posterior neck (5) *
3	Left thyroid (8) *
4	Right lens (3) *
5	Left lens (3) *
6	Posterior calvarium (2)
7	Calvarium right (2)
8	Calvarium left (2)
9	Previous calvarium (2)
10	Middle point of the brain (2)
11	Pituitary Gland (3)
12	Right Orbit (3)
13	Left orbit (3)
14	Center of the spinal column (5)
15	Right parotid (5)
16	Right branch (5)
17	Left parotid (5)
18	Branch left (5)
19	Center of the sublingual gland (6)
20	Right submandibular (6)
21	Left submandibular (6)
22	Right mandible (6)
23	Left mandible (6)
24	Esophagus (9)
25	Right thyroid (9)
26	Left thyroid (9)

* TLD located on the surface of the phantom

2.5 Equivalent dose, HT

For the determination of equivalent dose H_T, Equation 1 was used:

(1)

where w_R is the radiation weighting factor (w_R = 1Sv/Gy for X-rays), f_i is the fraction of the slice tissue T_i that has been irradiated and D_{Ti} the average absorbed dose to the tissue T in slice 2 (Koivisto, et al. 2012, Roberts JA, Drage NA, Davies J, Thomas DW 2009)

2.6 Effective Dose, E

To estimate the effective dose, E, the sum of the product of equivalent dose, H_T, by weighting the tissue, w_T, corresponding to T tissue was performed, according to Equation 2

(2)

The weighting factor, w_T, the tissues and organs is defined by the last recommendation published by the International Commission on Radiological Protection, ICRP 103 (Protection 2007), described in Table 3.

Table 1 - ICRP 103 (2007) Weighting Factor tissue *(Protection 2007)* .

Organ/Tissue	Weighting Factor
Gonads	0.08
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Breasts	0.12
Esophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remaining tissues [a]	0.12

[a] Adipose tissue, adrenals, extrathoracic (*ET*) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix.

3 - RESULTS

The results of equivalent dose, H_T found in the tissues studied are shown in Table 4, together with the estimated effective dose. It is observed in Table 4 the estimated effective dose varied between 7 and 111.5 microSv for the different study protocols.
By observing the protocols of localized procedures, jaw or mandible, there is an estimated effective dose ranging between 7 and 68 microSv. The estimated effective dose for the CBCT Gendex maxillofacial protocol is 33% lower than the ProMax 3D located (jaw). The equipment i-CAT Classical was the one with best predicted effective dose, 39% for the maxillofacial protocol, to be compared with the estimated effective dose of the second largest CBCT.

Figure 1 illustrates the average contribution of each tissue to estimating the effective dose. The largest contribution to the effective dose (36%) is due the whole organ termed as remaining. Then, the higher contribution in effective dose is due to the salivary glands (30%) followed by thyroid (14%) and bone marrow (12%). The contributions of the skin, brain, esophagus, and bone surface were low. The contributions of the skin, brain, bone surface and lower esophagus were individually without significant contributions in these percentages between the different sizes of FOV. For Kodak 9000, the largest contribution is given by the salivary glands (48%).

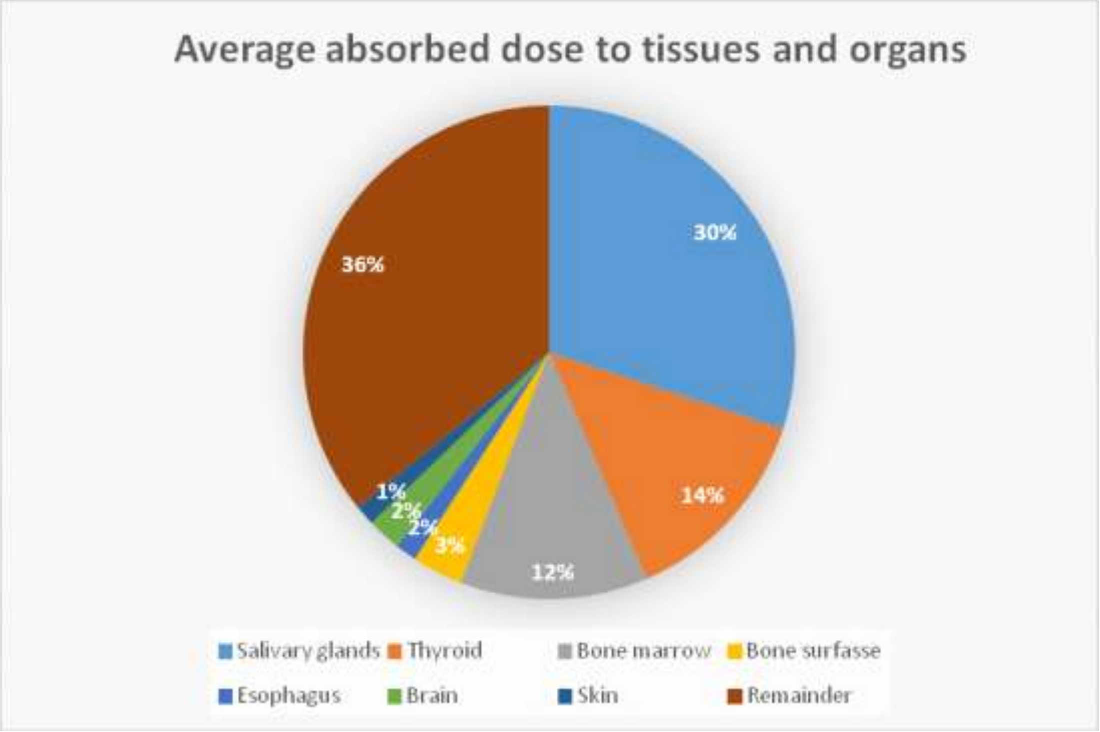

Figure 1: Values for the equivalent dose in tissues and organs studied

Table 4 - The organ absorbed dose and effective dose for the studied protocols

	ProMax 3D	**Gendex GXCB**			**I-CAT Classical**			**Orthophos XG 3D**			**Kodak 9000 3D**
Protocol	Jaw	Maxillofacial	Dentoaveolar	Jaw	Maxillofacial	jaw	Mandible	Jaw	Mandible	Dentoaveolar	jaw
Salivary glands	20.0	11.2	15.5	14.6	27.9	16.0	17.0	2.9	2.3	5.4	4.5
Thyroid	6.8	6.1	6.4	7.7	19.9	6.7	12.8	0.8	1.1	2.8	0.8
Bone marrow	8.7	6.5	6.5	6.1	15.7	12.4	6.8	1.7	0.5	1.6	0.6
Bone surfasse	2.3	1.7	1.8	1.7	4.2	3.3	1.8	0.5	0.1	0.4	0.2
Esophagus	0.8	0.6	0.6	0.8	2.1	0.6	1.2	0.1	0.1	0.3	-
Brain	1.7	1.3	1.2	0.9	2.6	2.5	1.2	0.2	0.1	0.2	-
Skin	0.9	0.3	0.6	0.4	0.9	0.7	0.5	0.2	0.1	0.3	0.3
Remainder	27.1	15.3	19.4	18.9	38.3	20.4	20.0	4.2	2.7	6.6	2.8
Effective dose	**68.3**	**43.1**	**52.0**	**51.2**	**111.5**	**62.7**	**61.3**	**10.5**	**7.0**	**17.6**	**9.3**

4 - DISCUSSION

The present study evaluated the effective dose for 5 different dental CBCT equipment, for various FOV, radiological procedures in clinical everyday through the measure for absorbed dose in internal positions.
To compare the results obtained in this study with results from other studies, one must consider the particular phantom used and the placement of dosimeters in each case (Qu, et al. 2010, R. Pauwels, J. Beinsberger, et al. 2012). Morant, et al., in their studies showed that the equivalent dose in the center of the brain in male and female are very close. In other tissues, because the dimensions, the equivalent dose is higher in organs and tissues of female phantom (Morant, et al. 2013). In this study, a female phantom was used. This fact helps both in estimating effective dose in women how much in the individual assessment of the contribution of absorbed dose to tissues in the radiation field or close to it.
The ProMax 3D CBCT for the FOV 5 cm x 8 cm, had an estimated effective dose of 68.3 microSv. This value is in accordance with studies conducted by Rottke, et al. (Rottke, et al. 2013) and Ruben Pauwels, et al. (R. Pauwels, J. Beinsberger, et al. 2012). In the study of Rottke et al., the effective dose for this equipment differed between 23 and 357 microSv. Already, in the other study, (R. Pauwels, J. Beinsberger, et al. 2012), there was an interval of variation between 28 and 122 microSv.
The ORTHOPHOS XG 3D CBCT equipment was the one with lowest effective dose estimation, 7 microSv protocol for localized jaw and 17.6 microSv for Dentoaveolar protocol with FOV of 8 cm x 8 cm. This result is justified by both the exposure parameters (kilovoltage and current), how much by the fact CBCT make a revolution of 180° image acquisition while the others use 210^{o} (ProMax 3D) or 360 ° (Gendex e Kodak 9000).
To assess the individual contribution, the remainder tissues contribute 36% of the effective dose, followed the salivary glands that have contributed on average 30% of the effective dose in protocols studied in CBCT. These results are in accordance with studies conducted by Ruben Pauwels, et all (R. Pauwels, J. Beinsberger, et al. 2012) , Koivisto, et all 2 (J. Koivisto, et al. 2012) and Roberts, et all (Roberts JA, Drage NA, Davies J, Thomas DW 2009), among other studies, where the remaining tissues were those who had their greatest contribution to the effective dose estimation, followed by salivary glands.
The Kodak 9000 3D CBCT has had the highest equivalent dose absorbed the salivary glands, 48% on in estimating effective dose, 9.3 microSv. Even with a low value when compared with other protocols, you must take into consideration that this equipment has the lower FOV 3.7 cm x 5 cm. When this value is compared with the CBCT ORTHOPHOS 3D with FOV of 5 cm x 5 cm, the same protocol jaw, the estimation of effective dose is 10.5 microSv, with an equivalent dose of the salivary glands microSv 2.9, equivalent to 27% of effective dose.
There should be careful in interpreting these results due to criteria related to image quality, the clinical purpose, the size of the FOV used, among other factors, (Rottke, et al. 2013). These differences make it difficult to undertake studies in general or comparative assessment between protocols and equipment CBCT (Pauwels, Beinsberger, et al. 2012). Besides reinforcing the need to estimate the effective dose in different equipment (Rottke, et al. 2013). The difference between the absorbed dose to various tissues may be due to the location of the TLD in the phantom, which has been reported punctually, and characteristics of the equipment, as the lack of a 360º, with the case of Orthophos XG 3D and ProMax 3D. One factor relevant to be observed in this study is that the equivalent dose may be changed an equipment relative to the other, even presenting the same exposure parameters (Araki, et al. 2013). This fact helps us to conclude how necessary it and crucial the need for studies that estimate the equivalent dose and effective dose.

5 - CONCLUSIONS

This study presents the effective dose values associated with different protocols and equipment. We conclude that the significant differences in the dose values, even when the protocols have the same purpose, are due to lack of uniformity among the equipment. It is concluded also by the need to be a minimum in terms of uniformity in basic parameters concerning the generation of x-rays and the radiation beam geometry without removing the ability to innovate each manufacturer.

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