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WORD COUNT	2452	TIME SUBMITTED	24-JAN-2024 12:58PM
		PAPER ID	106392193

An evaluation of radiation dose from dental cone-beam computed tomography

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Abstract

Dental cone beam computed tomography (CBCT) has enormous features including better image quality, acceptable size, and a lower radiation dose than those of helical computerized tomography (CT) scanning. Moreover, CBCT is more suitable for dentists to obtain and analyse images and it is more comfortable for patients due to technological enhancements. CBCT produces three-dimensional (3D) images of the head and neck and is being used in the various fields of dentistry such as dental surgery, endodontic, trauma, implant dentistry, lesions and diseases in the head and neck and orthodontics. In this work, four protocols were examined. Three voxel size settings were evaluated: 420 µm, 380 µm and 320 µm. Field of view and voltage tube were constant at (13cmx15cm) and 90 kV. The absorbed doses and effective doses were calculated for each CBCT scan protocols. A direct relationship was found between effective dose and the resolution options with lower resolution yielding lower effective dose. Modification of resolution options leads to changes in effective doses. This study emphasized the importance of selecting exposure parameters in terms of voxel size settings or resolution options.

Keywords: Cone Beam, Computed Tomography, CBCT, Basrah Governorate

Introduction

Numerous studies have been carried out about cone beam computerized tomography (CBCT) scanners to calculate the dose of radiation that subjects received [1-6]. Most of these studies have used thermoluminescence dosemeters (TLDs) that are placed within phantoms made with tissues equivalent to human tissues to evaluate standard patient doses [1,7,8]. In 1998, CBCT was announced in dentistry by Mozzo et al. [4]. CBCT produces three-dimensional (3D) images on the head and neck and is being used in the various fields of dentistry such as dental surgery, endodontics, trauma, implant dentistry, lesions and diseases of soft tissue in the head and neck and orthodontics [2,4,9-11]. CBCT has been developed to be the most useful and important device in oral and maxillofacial diagnosis, oral treatment planning and radiation therapy [12-15]. CBCT examination has higher radiation dose than conventional panoramic imaging and it has lower radiation dose than conventional CT scanning [1,10]. Dental radiologists prefer cone beam computerized tomography (CBCT) to helical computerized tomography (CT) scanning because CBCT has enormous features including better image quality, inexpensive, acceptable size, its availability and a lower radiation dose. Moreover, CBCT is more suitable for dentists to obtain and analyse images and it is more comfortable for patients due to technological enhancements [3,4]. On the other hand, the examination dose of CBCT depends on its configurations and radiation protocols. CBCT has various FOVs options and VOX size settings to be convenient for dental examinations. Large, medium and small FOVs produce volumes satisfactory for covering the maxillofacial region, dentoalveolar and localized imaging, respectively. The radiation field of dentistry is the head and neck area including eyes, the thyroid gland and salivary glands [3,16-18]. Hence, It is significant to minimize the dose of CBCT that patients obtained to the lowest value because of radiological hazards [5,7]. However, the image quality should be produced as good as possible while the radiation dose is still low [17,18]. The purpose of this vitro study was (a) to evaluate the seven tissues doses for four scan protocols using CBCT (KaVo OP 3D Pro) scanner and (b) to investigate changes in resolution options with effective dose.

Materials and Methods

The measurement of this study was conducted with TLD-100 (LiF) dosimeters put in sealed plastic beaker and fixed in human phantom as shown in Figure 1. In total, 84 dosimeters (21 chips for each CBCT scan protocol) were placed in seven anatomical locations as illustrated in Figure 2 and reported in Table 1.

Figure 1. TLD-100

Figure 2. The image of phantom

Before radiation exposure, lithium fluoride dosimeters (TLD-100) were calibrated as described in Handbook of Thermoluminescence [19]. Hence, the relation between TLD data and X-ray doses was applied for the assessment of absorbed doses in the anatomical regions of phantom. In each radiation exposure, 21 dosimeters were applied. Three TLDs were used to estimate background radiation, which was measured as 0.013 mGy. The lowest TLD reading was three times greater than background values which were subtracted from TLD readings.

Cone beam computed tomography (CBCT) (KaVo ORTHOPANTOMOGRAPH (OP) 3D Pro CBCT scanner, Germany) was used in this study. The parameters of CBCT scan protocols are shown in Table 2. Table 2 indicates that protocol^1, protocol^2 and protocol^3 have the same field of view (13 cm x15 cm) which covers the most maxillofacial region. The resolutions of protocol^1, protocol^2 and protocol^3 are low resolution (420 µm voxel size), standard resolution (380 µm voxel size) and high resolution (320µm voxel size), respectively. Hence, the lower the voxel size the higher the resolution with low tube current.

The pre-irradiation annealing of all TLDs were carried out in Muffle furnace-Gallenkamp oven, for 1 h at 400°C followed by a low temperature thermal processing for 2 hours at 100°C . The post-irradiation annealing of TLDs were achieved for 10 min at 100°C [19]. The thermoluminescent reader was a Harshaw model 2000 B/C and it is manufactured by Harshaw Filtrol Partnership.

Table 1. Location of thermoluminescent dosimetry (TLD) chips in the phantom

Phantom location	TLD ID for each CBCT scan protocol
Throat	Protocol^{1}:1,2,3, Protocol^{2}: 22,23,24, Protocol^{3}: 43,44,45, Protocol^{4}: 64,65,66
Teeth	Protocol^{1}: 4,5,6, Protocol^{2}: 25, 26,27, Protocol^{3}:46, 47,48, Protocol^{4}: 67,68,69
Cheek	Protocol^{1}: 7,8,9, Protocol^{2}:28,29,30, Protocol^{3}:49,50,51, Protocol^{4}: 70,71,72
Eyes	Protocol^{1}: 10,11,12, Protocol^{2}:31,32,33, Protocol^{3}:52,53,54, Protocol^{4}: 73,74,75
Frontal (forehead)	Protocol^{1}: 13,14,15, Protocol^{2}:34,35,36, Protocol^{3}:55,56,57, Protocol^{4}: 76,77,78
Mid skull	Protocol^{1}:16,17,18, Protocol^{2}:37,38,39, Protocol^{3}:58,59,60, Protocol^{4}: 79,80,81
Occipital (back skull)	Protocol^{1}:19,20,21, Protocol^{2}:40,41,42, Protocol^{3}:61,62,63, Protocol^{4}: 82,83,84

Table 2. The parameters of CBCT scan protocols

CBCT scan protocol	VOX Size (µm)	FOV (cm)	Tube voltage (kV)	Tube current (mA)	Exposure time (second)
Protocol^{1}	420 (low resolution)	13x15	90	3.2	4.5
Protocol^{2}	380 (standard resolution)	13x15	90	5	8.1
Protocol^{3}	320 (high resolution)	13x15	90	8	8.1
Protocol^{4}	….	PAN	66	10	16

Effective dose (*E*) has been measured in Sievert (Sv), according to the ICRP60 as shown in the following equation [20]:

$$E = \sum_{i} H_i W_T \qquad (1)$$

where W_T is the tissue weighting factors for each tissue (T) or organ and H is equivalent dose (H (SV) = D (Gy) x W_R) where, w_R is a radiation weighting factor and D is absorbed dose. The value of w_R is one for x-ray [21]. Thus, the effective dose depends on absorbed dose (D) and tissue weighting factors (W_T). The tissue weighting factor values of different tissues or organs are summarized in Table 3.

Table 3. Tissue weighting factors values of different tissues or organs [21]

Tissue or organ	Tissue weighting factor, W_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

Results and Discussion

The measured absorbed doses (D) and effective doses (E) of several tissues including throat, teeth, cheek, eyes, frontal (forehead), mid skull and occipital (back skull) for CBCT scan protocol^{1} (low resolution), protocol^{2} (standard resolution), protocol^{3} (high resolution) and protocol^{4} (panoramic) are summarized in Table 4. Change in resolution options resulted in direct proportional with effective dose so that the greatest effective dose was calculated for the highest resolution. The findings of this work are consistent with the results of previous published study, in which reported that the effective dose is inversely proportional with voxel size settings [18]. Thus, there is unanimous agreement that variations in the CBCT exposure factors impact on effective dose. The data of protocol^{4} showed that result of panoramic imaging has lower radiation dose than other CBCT protocols.

Table 4. The absorbed (D) dose and effective dose for the various tissues based on each CBCT protocols

Tissue or Organ	Protocol^1		Protocol^2		Protocol^3		Protocol^4	
	D (mGy)	E (mSv)	D (mGy)	E (mSv)	D (mGy)	E (mSv)	D (mGy)	E (mSv)
Throat	0.473	0.023	7.719	0.385	1.565	0.078	0.138	0.006
Teeth	4.95	0.049	13.215	0.132	16.326	0.163	0.995	0.009
Cheek	5.378	0.053	12.684	0.126	25.053	0.250	0.271	0.002
Eyes	2.099	0.020	7.577	0.075	12.962	0.129	0.087	0.0008
Frontal (forehead)	3.46	0.034	5.104	0.051	8.465	0.084	0.055	0.0005
Mid skull	4.894	0.048	13.013	0.130	20.904	0.209	0.233	0.002
Occipital (back skull)	2.61	0.026	7.8	0.078	4.188	0.041	0.05	0.0005

These variations of findings are illustrated in Fig. 3 and Fig. 4. From Fig. 3, it can be seen that the highest absorbed dose was in cheek and teeth in CBCT scan protocols because these tissues are directly irradiated by the primary beam. Contrary, the throat and frontal (forehead) has the lowest absorbed dose during CBCT scan protocols, probably because these tissues are located out of the X-ray beam. The irradiation of tissues outside the X-ray beam is majorly because of X-rays scattered within the human phantom. The results of this study are in agreement with previous study which has identified the greatest and lowest absorbed doses in these tissues [15]. The effective (E) doses for the various tissues based on each CBCT protocols are shown in Fig. 4.

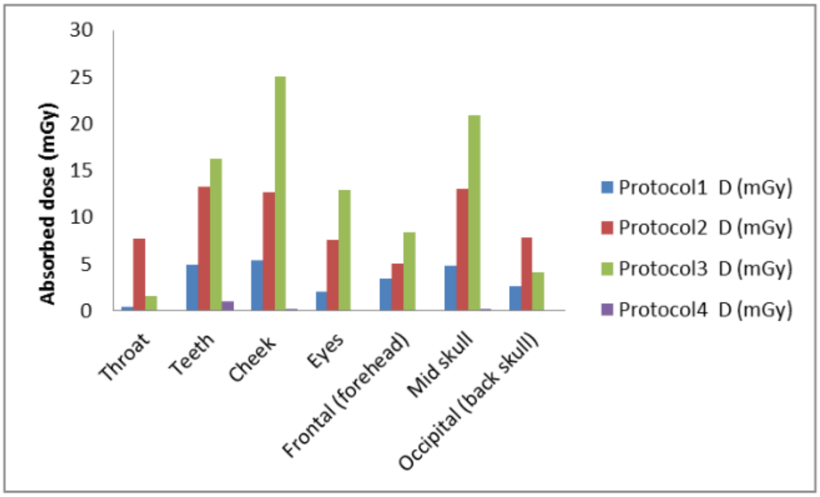

Fig. 3. The absorbed (D) doses for the various tissues based on each CBCT protocols

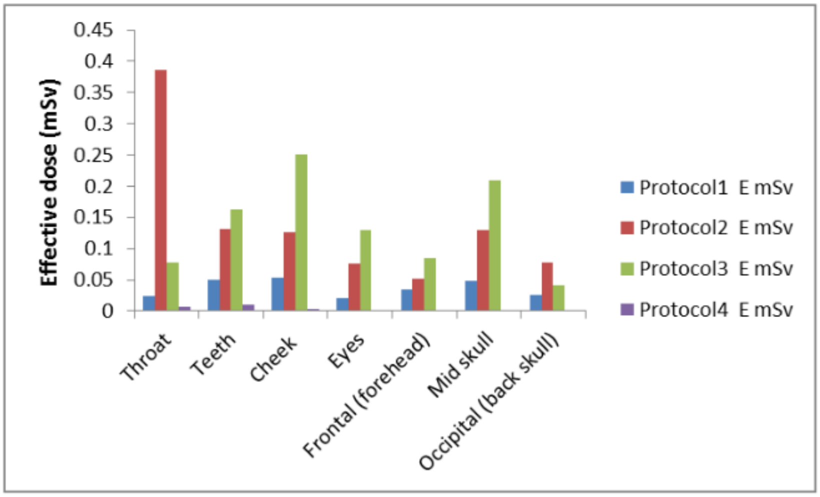

Fig. 4. The effective (E) doses for the various tissues based on each CBCT protocols.

This study compared various resolution types (low, standard and high) and their effect on effective radiation doses. As expected, the effective dose was directly proportional to the resolution and hence inversely proportional to the voxel size values. This is mainly because of the increase in exposure time which greater resolution images. This result agrees with numerous published studies, [18,22,23] and indicates the essential of the requirement for high-resolution images against the increase radiation hazard associated with these images. A number of studies have attempted to recognize suggestions for high accompanies increases in voxel settings to avoid image noise [24]. Thus, it is important to adjust compromise between radiation dose and image resolution.

Conclusion

It has been shown that variations in the CBCT exposure parameters impact on effective dose. Adjustment of resolution selections leads to variations in effective doses. This emphasizes the significance of choosing exposure factors in terms of voxel size settings or resolution options. Dentists should be pay attention in their choice of imaging parameters because this essentially impact on the patient.

Acknowledgment

The authors would like to knowledge all those contributed in declaring this issue.

Conflict of Interest

The authors declare that they have no conflict of interest.

Funding: No funding was obtained for this study

Acknowledgement: The authors would like to knowledge all those contributed in declaring this issue

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