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Effective Dose Computation for Dental Cone-Beam CT: A Comparison with MSCT and Panoramic Imaging

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Abstract— Cone beam CT was recently developed and introduced in the medical field, it utilizes a low-power, medical fluoroscopy tube that provides continuous imaging throughout the scan while Traditional CT uses a high output rotating anode X-ray tube. Whereas Panoramic is performed routinely for patient assessment. The aim of this study was to calculate the effective doses for CBCT compared to multi-slice CT and panoramic imaging performing similar Dentomaxillofacial examination. . The systems used were an Iluma CBCTs. The Multi-slice CT used was a Light speed VCT 64 slices (GE) ,and digital panoramic Orthoslice 1000 C (Trophy). Measurement of the patient radiation dose was performed using thermo-luminescent dosimeter on 30 patients, 10 patients undergoing CBCT, 10 patients undergoing head scanning using Multi-slice CT. and 10 patients undergoing panoramic imaging. the absorbed dose is then recorded. The effective radiation dose as defined by the International Commission on Radiological Protection was then calculated with inclusion of the salivary glands, parotid and submandibular glands, mandibular bone, thyroid gland, skin, and brain. Data is then analyzed, statistical calculations were performed with SPSS plus software. Effective radiation doses ranged between 7.3 μSv' and 3380 μSv for one exposure. Thyroid , bone marrow , Salivary glands and maxilla absorbed the most radiation for all panoramic, CBCT and MSCT units. When digital Panoramic unit, CBCT and MSCT systems were compared, the effective dose of panoramic digital unit (49.1 μSv), the effective doses for the CBCT digital unit (2376 μSv), , and the effective doses for the MSCT digital unit (7020 μSv). Calculated doses from CBCT is 30% of the MSCT whereas Panoramic imaging is 2% of CBCT. CBCT doses are significantly higher than those digital panoramic unit. whereas MSCT is the highest dose among all modalities. the potential benefits of CBCT in maxillofacial disciplinary are undisputed ; however , it is imperative that their use be fully justified over conventional technique before they are carried out.

Keywords: Cone beam CT, Panoramic radiography; Effective dose, Multislice CT, Radiation dose

I. INTRODUCTION

In recent years, cone beam computed tomography (CBCT) has become a widely accepted radiographic tool for diagnosis, treatment planning and follow-up in dentistry. CBCT allows the acquisition of three-dimensional volumes of the dental arches and surrounding tissues at a high spatial resolution and a low radiation dose. There are a number of different dental applications that bene- fit from the use of CBCT, each with specific requirements regarding the size of the acquired volume and the image quality in terms of spatial and contrast resolution [2].

When patients undergo X-ray examinations, millions of photons pass through their bodies. These can damage any molecule by ionisation, but damage to the DNA in the chromosomes is of particular importance. Most DNA damage is repaired immediately, but rarely a portion of a chromosome may be permanently altered (a mutation). This may lead ultimately to the formation of a tumour. The latent period between exposure to X-rays and the clinical diagnosis of a tumour may be many years. The risk of a tumour being produced by a particular X-ray dose can be estimated; therefore, knowledge of the doses received by radiological techniques is important. While doses and risks for dental radiology are small, a number of epidemiological studies have provided some limited evidence of an increased risk of brain [3],[4], salivary gland and thyroid [3],[18], tumours for dental radiography.[6]

Three-dimensional (3D) craniofacial imaging techniques have changed how professionals approach diagnoses in dentistry and orthodontics. Although computed tomography (CT) is still used in many clinical situations when 3D information is needed, its use has been limited in dentistry due to its high cost, low vertical resolution, and high dose of radiation. The cone-beam CT (CBCT) scanner is intrinsically 3D in its acquisition of images and provides usable images from equipment that is compact and affordable for small diagnostic centers. CBCT has been considered the examination of choice in many instances, since it provides high-resolution imaging, The radiation dose to the patient with CBCT is markedly lower than that of multi-slice CT; and CBCT doses are 3 to 7 times more than panoramic doses a and 40% less than conventional CT. However, orthodontic assessment with CBCT should follow the “as low as reasonably achievable” (ALARA) principle. Other studies have shown a dose reduction of 50% in orthodontic practice with digital direct15 or indirect16 ceph alometric radiography or the collimated lateral beam for cephalometric images.[12].[14] Radiation doses between conventional and CBCT images for orthodontic practices have not been compared. The aim of this study was to compare the absorbed radiation and effective doses for conventional panoramic imaging, CBCT unit, and a multi-slice CT unit in orthodontic practice.

A very effective measure of both protection to both the staff and the patient of course is applying less radiation. There is always a trade-off between radiation dose and image quality. A higher x-ray dose leads to a clearer picture. Modern software technology can improve image quality during post-processing, such that the same image quality is reached with a lower dose. Image quality thereby is described by contrast, noise, resolution and artifacts. In general, the ALARA principle (as low as reasonably achievable) should be followed. Dose should be as low as possible, but image quality can only be reduced to the level that the diagnostic benefit of the examination is still higher than the potential harm to the patient.[2],[11]

The effective dose is designed to provide a single number proportional to the radiobiological "detriment" from a particular, often inhomogeneous, radiation exposure, with detriment representing a balance between carcinogenesis, life shortening and hereditary effects. It is commonly used to allow a comparison of the risks associated with different spatial dose distributions produced by different imaging techniques. The effective dose represents questionable science: two of the most important reasons for this are that the tissue-specific weighting factors used to calculate effective dose are a subjective mix of different endpoints, and that the marked and differing age dependencies for different endpoints are not taken into account.[5]

Effective dose, referred as Sieverts, it takes into account where the radiation dose is being absorbed and attempts to estimate the whole-body dose that would be required to produce the same risk as the partial-body dose that was actually delivered in a localized radiologic procedure. It is currently the best measurement available as it allows comparison with other types of radiation exposure, including natural background radiation.[16]

Effective dose is calculated for any X-ray technique by measuring the energy absorption in a number of 'key' organs/tissues in the body. Each organ dose is multiplied by a weighting factor that has been determined as a reflection of its radiosensitivity. These are added together, so that the final figure is a representation of 'whole body' detriment.

It is clear that the range of devices and imaging protocols that are available will result in different absorbed radiation doses for the patient with, to some extent, the amount of dose being reflected in the image quality of the scan. Radiation dose and image quality, together with the size of the field of view (FOV), determine whether or not a certain CBCT imaging protocol from a given device is suitable for a specific dental application by following the generally applied ALARA (As Low As Reasonably Achievable) principle of radiation exposure [10]. To measure the radiation risk for patients from a radiographic modality, the effective dose is still accepted as the most suitable figure of merit,

II. MATERIALS AND METHOD

The study included 30 adult patients (16-54 years), 10 patients had CBCT imaging at the dental X-ray department, Maadi Hospital, 10 patients undergoing head scanning using Multi slice CT, and 10 patients undergoing panoramic imaging were compared. . The CBCT used in the examinations was the ILUMA CBCT Scanner (Ortho CAT™ Model: Monoblock E-40R-HF X20PL). It is an X-ray device that acquires a single 360° rotational sequence of the head and neck including the dentomaxillofacial and ear, nose and throat areas for use in diagnostic support. The Iluma Ultra CBCT is powered by flash CT technology. The X-ray source is a low-energy fixed anode tube emitting a cone-shaped X-ray beam Model Mono-block E-40R-HF X20PL. The CBCT machine is provided with an Ortho CAT™ Sensor. Amorphous Silicon Flat Panel; the resulted image is Cylindrical Scan Volume with a Height: 19.5 cm Diameter: 14 cm in the Vertical Mode a Height: 14 cm Diameter: 19.5 cm Horizontal Mode Light Field. The Sensor used is an amorphous Silicon Flat Panel, Ortho CAT™ with a Height of 19.5 cm a Diameter: 14 cm Vertical Mode Height: 14 cm Diameter: 19.5 cm Horizontal Mode. Two lasers at 90° to each other intersecting at the center of the sensor plate are used to center the patient. During scanning, the patient was seated on a motion-controlled chair. The patient is centered with the help of a laser positioning system. The scanner has two acquisition settings namely 20 and 40 seconds. The scanner acquires data by a volumetric reconstruction of the area of interest. This area is calculated by the software as a stack of axial slices. The Multi-slice CT used was a Light speed VCT 64 slices (GE), operated at 120KV, 100 mA and 4 s. And digital panoramic Orthoslice 1000 C (Trophy) ; operated at 70 KV, 10 mA and 12 s. Measurement of the patient radiation dose was performed The same methods as described above was used for measurements of patient dose by TLD located 5 cm from the focal point of the head.

The patient dose exposure was measured by thermo-luminescent dosimeters (TLDs) Model Monitor 4, S.E. International Instrumentation Division with an Accuracy ± 10%. The TLD was located on the head support approximately 5 cm from the focal point of the head. The Iluma CBCT was set at 120 kV and , 3.8 mA, for a 40-second. A patient was positioned in the machine for scanning. This setting was fixed for all the patients. The machine was operated for ten different patients with the same parameters The TLD was exposed and read.

Data is then analyzed, statistical calculations were performed with SPSS plus software the mean +/- SD were used to describe the continuous variables The differences between the means were tested for by either the t or F tests. The relation between the exposures were tested for by linear regression. Differences at $P<.05$ was considered significant.

The dose was separately measured by means of the dosimeters placed around the surface of the face and head, where the primary beam entered. Exposure was performed ten times to gain enough doses to ensure proper measurement, and a mean exposure was then obtained. The effective dose E expressed in µSv was calculated by multiplying the tissue weighting factor W_T by the mean absorbed dose at the irradiated area. And summed over all of the tissue /organ exposed; $E = \Sigma W_T \times H_T$. The tissue weighting factors as defined by the ICRP in 2007 are shown in table(I), it represents the relative radiosensitivities of the organ and therefore the contribution of that organ to overall risk . The effective dose E allows the risk to the whole body to be expressed , thereby giving a broad indication of the level of detriment to health from the exposure The effective dose as defined by the ICRP was then calculated .for the salivary glands, parotid and submandibular glands, mandibular bone, thyroid gland, skin, bone marrow and brain .

Table I: Tissue weighting factors as defined by ICRP 2007

Table (1) : Tissue weighting factors as defined by ICRP 2007		
Organ	W_T	ΣW_T
Thyroid	0.04	
Bone marrow	0.12	
Oesophagus	0.04	
skin	0.01	
bone surface	0.01	
brain	0.01	
salivary glands	0.01	
bone marrow , maxillary scan		0.13
salivary glands , brain , skin , bone surface		0.04
thyroid ,oesophagus		0.08
salivary gland, mandibular scan		0.02

W_T= tissue weighting factor. $\Sigma W_{T=}$ sum of tissue weighting factors.

III. RESULTS

The measured absorbed dose using the panorama , CBCT and MSCT techniques were summarized in table (II) the exposure in mGy is that reported for the patients examined The absorbed doses were persistently higher in case of the MSCT compared to the CBCT the magnitude was around 30 times and the CBCT compared to the Panorama the magnitude was around 50 times whereas MSCT compared to the Panorama the magnitude was around 140 times . The difference was as expected was highly significant the P is shown in the table <.001 between the CBCT and Panorama , whereas MSCT and both CBCT and Panorama show no significance. P>0.05.

The coefficient of correlation (0..937) was high and it had a positive sign. It could be concluded that the exposure to the radiation was much lower in case of the panoramic image compared to the CBCT and the risk should be weighted against the benefit of expected from the better quality of the image resulting from the use of CBCT. Whereas The coefficient of correlation (0..415 and 0.449) between MSCT to the Panorama and CBCT respectively was medium and it had a negative sign. Table (III) It could be concluded that the exposure to the radiation was much higher in case of the panoramic image and the CBCT to the MSCT and the risk should be weighted against the benefit of expected from the better quality of the image resulting from the use of MSCT.

Dose Comparison of the exposure to the X-ray using the conventional and the Cone Beam machines with). The mean, +/- the Sd, the minimum and maximum values are shown in the table (II) ; the exposure in case of the CBCT (8.831+/-0.26 mGy) is almost one third (30.7%) of the mean received in case the conventional machine MSCT (26.098 +/-0.5 mGy) and the mean received in case of the panoramic unit (0.182 +/-0.005 mGy) is almost (2%) of the CBCT used. The relation of the minimum and maximum values was also kept constant.

The effective dose according to the specific organ in µSv is summarized in table (IV), the organs shown in the table are those in the head and neck region. The weighting factors are those assigned by the ICRP in 2007. The sum of the total exposure amounted to 2112 , 43.8 and 6240 µSv using the CBCT imaging , panorama and MSCT respectively. The percentage distribution is shown in the table based on the CBCT figures are shown in the table. The major contributor was the bone marrow (50.0%) with the thyroid and the esophagus contributing 17% of the total dose. It is interesting to note that the skin, bone surface brain and the salivary gland were contributing equal portions (4%) each. The overall mean amounted to 6.25, 301.7 and 891.429 µSv using the panorama , CBCT and MSCT imaging respectively.

The effective dose for the combined groups of organs is summarized in table (V), the sum of the dose for the panoramic imaging amounted to 49.1 µSv ,that for the CBCT 2376 µSv, and for the MSCT 7020 µSv The major contributor to the dose was that from the bone marrow maxillary salivary gland, brain and skin, contributing almost half of the total (48.1%).

Table II: The absorbed dose of radiation from the use of Panorama and CBCT imaging

	Absorbed dose		
Scan No	Panorama	CBCT	MSCT
	mGy	mGy	mGy
1	0.187	9.02	26.11
2	0.187	9.00	25.6
3	0.186	8.98	26.00

4	0.183	8.92	26.31
5	0.182	8.87	26.35
6	0.182	8.76	25.9
7	0.181	8.76	25.89
8	0.180	8.70	26.6
9	0.179	8.78	25.7
10	0.177	8.52	26.52
max	0.187	9.02	26.6
min	0.177	8.50	25.6
range	0.010	0.520	1,0
Mean	.182	8.831	26.098
SD	.003	.157	.340

Table III: Correlation between different image modalities

Correlation		Panorama	CBCT
Panorama	Pearson Correlation r	[redacted]	.937**
	p_value	[redacted]	.001
CBCT	Pearson Correlation r	[redacted]	[redacted]
	p_value	[redacted]	[redacted]

The effective dose received by the thyroid and Esophagus amounted to 2080 µSv for the MSCT, 704 µSv in case of the CBCT and much less than that in case of the panorama 14.6 µSv, however the relative contribution was the same for the three imaging modalities (29.6%). The effective dose to the bone surface was of the amounted to 1040 µSv , 7.3 µSv and same magnitude 352 µSv for the MSCT, panorama and the CBCT imaging systems. The effective dose to the salivary glands and mandible was almost half that to the thyroid and esophagus (520, 3.6 and 176.0 µSv for the three imaging modality.

Table IV: The Effective dose of radiation from the use of Panoramin and CBCT imaging Organs

organ	Panorama	CBCT	MSCT	%
	µSv	µSv	µSv	Contrib
Bone marrow	21.9	1056	3120	50
Thyroid	7.3	352	1040	17
Esophagus	7.3	352	1040	17
Skin	1.82	88	260	4
bone surface	1.82	88	260	4
brain	1.82	88	260	4
Salivary glands	1.82	88	260	4
Sum	43.78	2112	6240	100
mean	6.254	301.714	891.429	
Sd	7.367	355.129	1049.245	

Table V: The Effective dose of radiation from the use of Panorama and CBCT imaging Combined

organ	Panorama	CBCT	MSCT	%
	µSv	µSv	µSv	Contrib
Bone marrow, maxillary scan	23.6	1144	3380	48.1

salivary glands , brain , skin , bone surface	7.3	352	1040	14.8
Thyroid, Esophagus	14.6	704	2080	29.6
Salivary gland and Mandibular scan	3.6	176	520	7.4
Sum	49.1	2376	7020	100
Mean	12.28	594	1755	
Sd	8.83	427.35	1262.63	

IV. DISCUSSION

The results should be interpreted carefully, due to the inter- play between image quality, size of the scanned volume and absorbed radiation dose to different tissues. Therefore, the main goal of the study was not only to compare the effective dose of different imaging modalities but to understand the radiation dose from these devices can be seen as a function of the diagnostic application. From that per- spective, a key paradigm for dose optimisation is to ensure that patient scans are made using an exposure protocol which leads to an acceptable image for their specific indication [13].

It is useful to compare the results to those published. Most of the following values are based on the ICRP 60 (1990) ; tissue weighting factors the effective dose from panoramic radiography is 2.7-23 µSv [12];[13];[16], cephalometric radiography 1-3 µSv [17] periapical radiography 1-8 µSv [14] and occlusal radiography 8µSv [14]. CT maxillo- mandibular (2100 µSv) [12],[13],[16]. Other studies therefore indicates that the i-CAT CBCT delivers a higher dose to the patient (48-206 µSv) than a typical panoramic radiograph by a factor of 5-16. for the Mercuray (283-1073 µSv) ; Galileos (70-128µSv) NewTom (30-78µSv) [11] the range difference in the effected dose is due to That Studies are divided into those in which “dento-alveolar” CBCT (fields of view smaller than the facial region) and “craniofacial” CBCT, in which the field of view routinely includes at least the maxilla and mandible.

The ICRP suggest a nominal probability coefficient for all radiation-induced fatal averaged over the whole population to be 5% per Sievert [10]. Therefore, the risk of fatal malignancy from a CBCT of the jaws is between 1 in 100 000 and 1 in 350 000. the risk is based on an adult patient. In orthodontics, many of the patients are children and the risk is higher. The risk to a peadiatric patient is approximately twice that of an adult patient. Therefore, these examinations must be fully justified before they are performed, and it is hoped that evidence-based selection criteria will be produced soon to aid the clinician is requesting these examinations. This study has calculated the effective dose of the the salivary glands, parotid , submandibular glands, mandibular bone, thyroid gland, skin, bone marrow , maxilla and brain. . Some other tissues and organs were not measured in this study, but they would not significantly affect the effective dose because most of them would be irradiated by very low doses , it shown that the results of the effective dose of the CBCT and MSCT are higher than those published by Okano et al [13] , based upon publication 103 (2007) due to the large field of view of the ILuma CBCT , whereas it is similar to studies of effective dose of the panorama [14] ; The dose in case of CBCT was significantly lower than that resulting from the Multi-slice CT. The overall mean exposure in case of CBCT was almost one third that of the Multi–slice CT. This is in line with many reports [15] . The higher effective doses calculated in this study were higher than other studies, is caused by the differences in scanner models , imaging protocols and the modification to the tissue weighting factors in Publication 103 (2007) than of the ICRP 60 (1990) that had affected the data of the effective dose calculated. Boetticher et al [1] evaluated circumstances under which the application of the new model yields relevant dose differences compared to the prevailing model. As an example the Effective doses were calculated and compared from the measured organ doses according to ICRP 60 and ICRP 103, respectively. The change of the weighting factor for the thyroid from 0.05 to 0.04 leads to a noticeable increase in the effective dose by (19%) . Further reduction in the dose is feasible with further optimization of examination protocols and the development of newer techniques which is lower than the finding in the present study. The Iluma exposures are higher than the doses from the tradition views used in dentistry of other cone beam volumetric imaging this was interpreted due to the difference in the modalities and FOV of other CBCT ranges from (6 – 13 cm) and in our experiment the CBCT used was 24x19 cm, a cost benefit analysis should be carried out before a CBCT investigation is carried out for dental application. This large spread in reported doses mainly caused by differences in scanner models imaging protocols and Field of View . The results demonstrate that the direct TLD dosimetry measurements for the Multi – slice CT 16 detector (22.2 mSv) were slightly higher than those using NRPB, Monte Carlo Estimation techniques (18.8 mSv)[9] and 2000 µSv The figures are very close to the finding in the present investigation (26.1 mSv), this is expected since the data provided by the other studies [8] was based on 16 detectors where as the present data came from a 64 slice detector

Therefore theses examinations must be fully justified before they are performed and an evidence based selection criteria should be produced to aid the clinician in requesting these examinations.

V. CONCLUSION

CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose Panoramic radiography; Nonetheless, when 3D imaging is required, CBCT ought to be weighted over MSCT.

Additionally studies should be conducted to set protocols and clinical application of each modality to balance between the risk assessment and the diagnostic information needed.

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