SAR Journal of Dentistry, Oral Surgery and Medicine

Abbreviated Key Title: *SAR J Dent Oral Surg Med*
Home page: http://sarmedjournals.com/sjdom/home

ISSN 2707-7772 (P)

Research Article

Cone Beam Computed Tomography: Systematic Review on Justification of Exposure Based on ALADA Principle

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Article History: | Received: 22.12.2020 | Accepted: 08.01.2021 | Published: 15.01.2021 |

Abstract: ***Introduction***: Imaging is an important diagnostic adjunct in the clinical assessment of the dental patient. Cone beam computed tomography (CBCT) is new innovative imaging modality which provides additional information and low radiation dose than conventional CT, but results in higher radiation doses than conventional imaging procedures such as intraoral and panoramic radiography especially to pediatric patients. ***Aim:*** The aim of this review was to compile evidence based clinical trials on effective doses of dental Cone beam computed tomography (CBCT) with focus on measurement methods and compare the effective doses of CBCT, multidetector computed tomography, panoramic radiography and intraoral radiography. This review would also highlight radiation protection measures to be taken while performing CBCT scan. ***Materials and Methods:*** The English literature on effective dose of Cone beam computed tomography from October 2000 to January 2019 was reviewed. Data sources included: PUBMED [MEDLINE], SCOPUS, COCHRANE DATABASE, EMBASE and SCIENCE DIRECT. A model was developed to underpin data extraction from 36 included studies. ***Results****:* The effective dose showed variations across studies and among CBCT scanners and on average the effective dose ranged from 10 – 425.84 µSv. Exposure from Dental CBCT is lower than conventional CT but it is ten times higher than conventional radiographs (intraoral and panoramic) used in dentistry. In one study, with CBCT effective dose of a 10-year-old phantom was around 116 µSv which was high as compared to adolescent phantoms at 79 µSv. Use of thyroid shielding devices to protect thyroid gland and lead glasses to prevent cataract should be reinforced while performing scan. CBCT scan when performed with use of lead glasses in conjunction with thyroid shielding devices resulted in (42 %) reduction of the effective dose to patient. ***Conclusion:*** The review suggests that although, effective dose varies from one CBCT unit to other, it increases with larger Field of View used for scanning. More direct comparison trials are required in future to estimate the effective doses from CBCT and conventional radiographs .Even studies using pediatric phantoms should be encouraged as these patients are at higher radiation risk than adults. During CBCT scanning lead glasses and thyroid collars should be worn by the patients to prevent unnecessary exposure to thyroid gland and lens of eye. CBCT should be used as an additional imaging modality and not as a substitute to conventional imaging. In 2014, new concept emerged in which there was movement from ''as low as reasonably achievable'' (ALARA) to ''as low as diagnostically acceptable ''(ALADA). Now it's time to implement this concept into clinical practice.

Keywords: imaging, radiation, dosage, phantom, dosimetry.

INTRODUCTION

Imaging is an important diagnostic adjunct in the clinical assessment of the dental patient. Two dimensional (2D) imaging modalities have been used in dental practice since the first intraoral radiograph was obtained in 1896. Since, then dental imaging has advanced with the introduction of tomography and panoramic radiography. But these conventional 2D imaging modalities possess various limitations such as magnification, distortion and superimposition of structures [1]. Dental Cone beam computed tomography (CBCT), provides three dimensional (3D) information via multiplanar and 3D reconstructed images which are adapted to clinical requirements for correct diagnosis and treatment planning [2].

CBCT allows acquisition of 3D volumes of the dental arches and the surrounding tissue and this imaging modality is also known as digital volume tomography (DVT) [4-6]. CBCT scanners are used in various dental specialties such as orthodontics, periodontology, implantology, trauma and dental surgery [7-9]. Even though studies have shown that CBCT doses (30-80 μSv for restricted anatomical volumes in the maxillofacial region and 0.2 mSv for imaging of paranasal sinuses) are less than conventional CT, but when compared with conventional imaging procedures (intraoral and panoramic) effectives doses are higher [10, 11]. Another concern from CBCT unit is higher radiation dose to pediatric patients than adults. In 2010, an article entitled "Radiation worries for children in dentist's chair" was published in The New York Times newspaper. It was the first time a major newspaper brought the radiation dosage of CBCT to the attention of the public [12]. Therefore, radiological protection from CBCT is essential and the aim of this review was to compile evidence based clinical trials on effective doses of dental CBCT with focus on measurement methods of effective doses and to compare the effective doses of CBCT, multidetector computed tomography (MDCT), panoramic radiography and intraoral radiography. This review would also highlight on radiation protection measures to be taken while performing CBCT scan and future software advancements to reduce the radiation dose to patient from CBCT as nowadays, advent of digital technology, computer-aided design/computer-aided manufacturing (CAD/CAM) systems and low dose protocols have optimized the old CBCT scanners to detect and plan treatment at relatively low dose.

MATERIALS AND METHODS

Literature Searches

A review of scientific literature concerning effective dose measurement of CBCT for maxillofacial region was done in this manuscript. The electronic retrieval systems and databases searched for the relevant articles were PUBMED [MEDLINE] database (National Library of Medicine, NCBI), COCHRANE DATABASE, SCOPUS, EMBASE and SCIENCE DIRECT. The search was performed from October 2000 till January 2019 and it was based on MESH terms. The PUBMED Search yielded 1179 articles, SCIENCE DIRECT yielded 1065 articles and COCHRANE DATABASE, SCOPUS and EMBASE yielded 167 articles.

Authors searched and reviewed the full title and abstract of the articles retrieved in the initial literature research. Differences among the reviewers, in the eligible studies were reviewed and resolved by mutual agreement. The articles that were not matching eligibility criteria and duplicate articles were removed from the study. Later, the authors screened the abstracts of the remaining papers individually. The authors tried to obtain the full papers for all the potentially eligible studies. The studies that met the eligibility were included in this review.

Inclusion criteria were all articles published in English in the scientific literature, publications reporting primary studies related to CBCT dosimetry, articles including information regarding scanner used, FOV size, exposure parameters, phantom type, dosimeter used, effective doses of CBCT and MDCT, effective doses of CBCT and conventional radiography(panoramic and intraoral), and articles on radiation protection shielding devices. Articles not meeting the inclusion criteria were excluded. Case reports, narrative reviews and articles in other languages were excluded.

Data extraction

The following data were extracted from selected articles on radiation doses of dental CBCT: year of publication, method of effective dose measurement, phantom type, scanning protocol, effective doses, and author's conclusion in the manuscript. When information of the CBCT unit was insufficient, it was searched on the manufacturer's website. Authors extracted the mentioned data from the included articles and the second author cross checked it. Any disagreement was resolved with discussion between authors until a consensus was reached.

RESULTS

Figure 1 shows number of publications identified excluded and included. From the initial search strategy, the PUBMED Search yielded 1179 articles, SCIENCE DIRECT yielded 1065 articles and COCHRANE DATABASE, SCOPUS and EMBASE yielded 167 articles. In the first phase of selection, observers screened the articles by reading titles and abstracts. Of the retrieved publications, 1076 were discarded after reviewing the abstracts, as these publications did not meet the inclusion criteria. The full text of remaining 88 publications was examined, and 36 satisfied the inclusion criteria (Table 1- Table 5).

Methods used to measure and estimate radiation dose from CBCT

The methods used to measure radiation doses varied across the studies (Table 1). The following measuring methods were used: thermoluminescent dosimeter TLD 100 and TLD 100 H (Three studies) [11, 13, 15]. TLD chips (ten studies) [16-24], glass dosimeter (one study) [25], gafchromic film (one study) [26], optically stimulated luminescence dosimeter (one study) [27], Montecarlo technique (two studies) [17, 18], and measured quantities to calculate effective dose i.e dose area product, DAP (two studies) [29, 30] and computed tomography dose index, CPDI (one study) [29]. Also there was variation in type of phantom used, number of slices, exposure parameters among studies. The number of phantom slices ranged between 11 and 32. The number of TLDs used ranged from 2 to 148. It could be observed that most TLD studies used commercially available anthropomorphic phantom whereas Monte Carlo studies used International Commission on Radiation Protection (ICRP) Adult Male (AM), Adult Female (AF) reference computational phantoms. One study used paediatric phantom and found that effective doses of 10-year-old phantom to be approximately 116 μSv which were higher than adult phantoms [18]. Overall, the effective dose ranged from 10 – 425.85μSv and it was highest for Somatom Sensation 10 and lowest for Promax 3D, FOV 4x5 cm (10 μSv).

Comparison of effective dose between CBCT, multidetector computed tomography (MDCT), panoramic Radiography, Intraoral radiography

Table 2 shows various literature clinical trials that compared the effective doses of CBCT and Multidetector Computed Tomography (MDCT) and suggested that CBCT has lower radiation dose than MDCT. The effective dose of MDCT could be markedly decreased by using the low-dose technique [13, 16, 31-33].

In market, numerous CBCT devices are available and new models are introduced on a continuous basis. Ludlow *et al*. [31] and Pauwel *et al*. [14] determined the effective doses of 8 and 14 CBCT units respectively. The results are summarized in Table 3. They determined the effective dose by using TLD chips and ART phantoms. It was found that effective doses in two studies were different, irrespective of FOV. In a study by Ludlow *et al*. [3], for maxillofacial region highest effective dose was for CB Mercury Maximum quality (1073 μSv) and in a study by Pauwel *et al.* [14], highest was for Illuma Elite (368 μSv). FOV is also important factor in the assessement for effective dose. When all the exposure parameters (kVp, mA) are kept constant, larger the FOV, more the effective dose. In Table 3, in a study by Ludlow *et al*. [31], for CB Mercury, effective dose was 1073 μSv for large FOV, 560μSv for medium FOV and 407 μ Sv for small FOV. Hence, effective dose varies from one CBCT unit to other, but it increases with larger FOV used for scanning.

For intraoral Periapical Radiographs, the effective dose is influenced by number of factors, especially film sensitivity and type of collimation (circular or rectangular). Table 3 summarizes effective doses for intra oral radiographs from studies by Ludlow *et al*. [34] and Gibbs SJ [35]. The average effective dose in a study by Ludlow *et al*. ranged from 1.25-21.6 μ Sv. It was highest for D speed film and round collimation whereas in a study by Gibbs SJ the effective dose ranged from 0.65 -5.6 μ Sv, it was lowest for rectangular collimation, 4 E Speed Bite wing Films and highest for round collimation 18 E speed films [34, 35].

Gijbels *et al*. in their study reported that effective dose of different panoramic machines with head phantoms ranged from 4.7μSv to 14.9μSv [36]. Other studies demonstrated that effective dose of panoramic radiograph was 3.85 -38.0 μSv (Table 3) [12, 37-39]. There are few studies on the direct comparison of effective doses of CBCT and conventional dental radiography. The range of effective doses for CBCT ranged between 65 -428 μSv, for panoramic radiography it was 6.39 -22μSv (Table 4) [40, 41], for lateral cephalogram it ranged between 1.1-5.6 μ Sv, for posteroanterior cepahlograph it was 5.1 μ Sv. It could be demonstrated that the exposure from CBCT is ten times higher than the conventional radiographs. Therefore radiation protective measures are needed while carrying out CBCT especially for pediatric patients.

Radiation Dose to pediatric patients

Theodorakou C *et al*. [18] used five dental CBCT units (New Tom VG, I CAT NG, 3D Accuitomo 170, Promax 3D and Kodak 9000 C 3D) and anthropomorphic phantoms to estimate effective doses in paediatric patients. They found effective doses of 10-year-old phantom to be approximately 116 μSv which was 1.5 times higher as compared to adolescent phantoms (79 μSv) (Table 2). A survey was conducted in United Kingdom on young adults and children less than 18 years over 24 month period. From their CBCT examinations, Region of Interest (ROI), FOV, exposure factors and incidental findings were recorded. It was observed that CBCT scans were performed > 13 years of age for localization of unerupted teeth in anterior maxilla and optimization of X ray exposures were not consistent [42]. Whenever planning CBCT examination especially for young adults and children, smaller FOV machines would be appropriate as it would result in proper evaluation of scans and optimization of radiation doses.

Radiation protection to patients

Table 5 represents various shielding devices employed to reduce the dose to thyroid, esophagus and eye while performing CBCT examinations. Two studies used leaded eye glasses during CBCT scan to limit the dose to lens of eye, thus preventing cataract [43, 44]. In a study by Prins *et al*. [43] radiation dose to eye lens could be reduced by over 60 % without having any effect on image quality and in a study by Goren *et al*. [44] there was 74 % dose reduction to internal eye. Three Studies [44-46] used thyroid collar shielding, two studies suggested that thyroid collars when used tightly in front and back of the neck provided the more effective results of dose reductions to thyroid [45,46] Goren *et al*. suggested that there was 42 % dose reduction when both lead shielding devices are used together while scanning[44].

Table-1: Summarizes clinical trials for measurements and estimation of radiation dose in cone beam computed tomography (CBCT) of maxillofacial region

Study (Year)	Intervention	CBCT Scanners	Dosimetry Method	Phantom Type	Effective Dosage	Comments
Tsiklakis K *et al*. [11]	To estimate the effective dose in radiographic imaging of the jaws using low dose CBCT	Newtom, Model QR-DVT 9000, Verona, Italy	TLD-100 Two techniques: i) there was no shielding device used ii) a shielding device (EUREKA! TRIX) was applied for protection of the thyroid gland and the cervical spine.	RANDO phantom	In the non-shielding technique effective dose, E (ICRP), was 0.035 mSv and the E(SAL) was 0.064 mSv. In the shielding technique effective dose, E(ICRP), was 0.023 mSv and E(SAL) was 0.052 mSv.	The use of CBCT for maxillofacial imaging results in a reduced absorbed and effective dose. The use of lead shielding leads to a further reduction of the absorbed and effective doses to the thyroid and cervical spine.
Loublele *et al*. [13]	To calculate effective doses of three CBCT scanners	Accuitomo 3D, New Tom 3G and i-CAT	TLD-100 TLD-100H(Li F: Mg, Cu, P)	ART phantoms, 20 slices corresponding to head and neck region	13-82 µSv	CBCT dose levels were lowest for Accuitomo 3D and highest for i-CAT.
Lofthag Hnasen S [29]	To calculate effective dose on a CBCT device	3D Accuitomo 3D Accuitomo FPD	DAP value measurement and CTDI measurements	CT Head dose phantom	11-77 µSv	DAP measurement was better for estimating effective dose for accuitomo than CTDI measurements
Hirsch E *et al*. [20]	To compare tissue-absorbed and effective doses of the CBCT units, the Veraviewepocs 3D and the3DAccuitomo, in different protocols.	Veraviewepocs 3D FOV:(anterior 4x4 cm scan, anterior 8x4 cm scan and panoramic + anterior 4X4 cm) 3DAccuitomo FOV((anterior 4x4 cm scan and anterior 6x6 cm scan)	TLD	ART phantoms	i)3D Accuitomo 4x4 cm (20.02 mSv), 3D Accuitomo 6x6 cm (43.27 mSv) ii) Veraviewepocs 3D was 39.92 mSv for the 8x4 cm scan, 30.92 mSv for the 4x4 cm scan and 29.78 mSv for the panoramic + 4x4 cm scan protocol	Smaller FOV should be used for dental images, whereas a larger FOV should be employed in cases where larger or wide view I required.

Qu XM *et al.* [21]	To compare effective doses resulting from different scan protocols for CBCT	ProMax 3D CBCT	TLD chips	Human equivalent phantom	Effective doses for default patient sizes from small to large ranged from 102 to 298 μSv.	ProMax 3D provided a wide range of radiation dose levels. Reduction in radiation dose could be achieved when using lower settings of exposure parameters.
Cheng HCY *et al.* [15]	To compare the image quality and dosimetry on the Varian CBCT system between software Version 1.4.13 and Version 1.4.11	Varian CBCT	TLD	Two standard cylindrical Perspex CT dosimetry phantoms with diameter of 16 cm (head phantom) and 32 cm (body phantom)	1.72 mSv	The new Varian CBCT provided volumetric information for image guidance with acceptable image quality and lower radiation dose.
Pauwels *et al.*[14]	To estimate effective doses of 14 CBCT scanners	3D Accuitomo 170, Galileos Comfort, i-CAT Next Generation, Iluma Elite, Kodak 9000 3D, Kodak 9500, NewTom VG, NewTom VGi, Pax-Uni3D, Picasso Trio, ProMax 3D, Scanora 3D, SkyView, Veraviewepocs 3D	TLD100 TLD100H	Two ART phantoms, upper 11 slices corresponding to head and neck region	19 and 368 μ Sv	Distinction is mainly needed between small-, medium-, and large-field CBCT scanners and their scanning protocols, as they are applied to different indication groups and the dose received being is strongly related to field size.
Jeong *et al.* [16]	To estimate effective doses of three CBCT units and MDCT	AZ3000CT, Implagraphy and Kavo 3D eXaM MDCT: Somatom Sensation 10, Somatom Emotion 6	Three TLD chips	ART phantoms,32 slices	The effective dose was highest for for Somatom Sensation 10 (425.84 μSv), followed by AZ3000CT (332.4μSv), Somatom Emotion 6(199.38μSv), and 3D eXaM (111.6μSv), lowest for Implagraphy (83.09 μSv)	The effective dose of MDCT was comparable to CBCT imaging.
Morant JJ *et al.* [17]	Validation of a Monte Carlo simulation for dose assessment in dental CBCT examinations	i-CAT CBCT	58 TLDs	Anthropomorphic phantom (Remab system)	Absolute differences between measured and simulated outcomes were ≤2.1% for free-in-air doses; ≤6.2% in the 5	The devised MC simulation program can be a emerging tool to optimize protocols and to estimate patient doses

					cavities of the CT dose head phantom; ≤13% for TLDs inside the primary beam	for CBCT units in oral and maxillofacial radiology
Theodorakou C *et al.* [18]	To estimate pediatric organ and effective doses using five dental CBCT units	New Tom VG, I CAT NG, 3D Accuitomo 170, Promax 3D and Kodak 9000 C 3D	TLD	10-year-old and adolescent phantoms	10-year-old phantom: 116 µSv Adolescent phantoms :79 µSv Paediatric Phantom Dose was 1.5 times higher than adolescent phantom	CBCT examinations on children should be fully justified over conventional X-ray imaging and should be optimized by FOV.
Moon YM *et al.* [25]	To measure the effective dose delivered to a patient from CBCT	XVITM, Elekta (mainly used in radiotherapy)	glass dosimeter	RANDO® phantom	3.37±0.29 mSv per scan	Glass dosimeters are useful in determining effective dose with absence of directional dependence
Morant JJ *et al.* [28]	Dosimetry of CBCT device for oral and maxillofacial radiology	i-CAT CBCT	Monte Carlo technique	ICRP Adult Male (AM), Adult Female (AF) reference computational phantoms	. For 360º effective doses were in range of 25-66 µSv and46 µSv for full head. DAP values were between 181 mGycm² to556 mGycm² for 360º. For 180™, dose to organs , effective dose and DAP was 40% lower.	Dose to organs varies for different FOVs, it is usually higher in AF phantom Organ and effectivedoses varies according to field size, acquisition angle and positioning of the beam relative to radiosensitive organs.
Okshi AA *et al.* [26]	To estimate effective dose from dental CBCT and panoramic radiography by using Gafchromic film	CBCT: Veraviewepoes, 3De, Promax 3D and New Tom VGi	Gafchromic film	RANDO phantom	10 -129 µSv	The lowest effective dose was for Promax 3D, FOV 4x5 cm (10 µSv) and highest for New Tom VGi, FOV 8x8 cm(129 µSv).
Rottke D *et al.* [22]	To evaluate the spans of effective doses of ten different CBCT devices	-3DAccuitomo FP -3D exam -KODAK 90003D -KODAK 9500 3D -Galileos Comfort - Promax 3D - Orthophos XG 3D - Scanora 3D	48 TLDs	RANDO Head Phantoms	Effective doses were between 17.2 mSv and 396 mSv for the ten devices.	Different CBCT scanners showed wide range and variations in effective doses depending on the selected exposition parameters, required spatial resolution and

		-Master 3D -Pax Duo 3D				many other factors.
Kim *et al.* [30]	Conversion coefficients (CC) for the estimation of effective dose dose in CBCT	Alphard VEGA	DAP measurement using DIAMENTOR M4-meter selectable by operator in C mode (200x179mm), Pmode(154mmx154mm),Imode(102 mmx102mm), and D mode (51mmx51mm), Effective dose measurement also by 22 TLD chips	ART phantom	The CCs ranged from 0.038 μSv/mGycm^2 to 0.146 μSv/mGycm^2	The CCs were highest for D mode at mandibular molars.
Wu J *et al.* [19]	To evaluate the level of effective dose of CBCT using anthropomorphic adult head phantom	----------------	TLDs	ART phantom	The effective doses measured using the proposed phantom at 65, 75, and 85 kVp in the D-mode were 72.23, 100.31, and 134.29 μSv, respectively. In the I-mode, the effective doses were 108.24, 190.99, and 246.48 μSv, respectively	The proposed anthropomorphic adult head phantom can be utilized for assessing the radiation dose resulting from clinical dental CBCT.
Pauwels R *et al.* [23]	To quantify the effect of FOV and angle of rotation on radiation dose in dental CBCT	3D Accuitomo 170 dental CBCT unit using six FOVs as well as fullrotation (360°) and half-rotation (180°) protocols.	148 TLDs	ART phantoms	-For the 360° rotation protocols, effective dose ranged between 54 mSv (43 4 cm, upper canine) and 303 mSv (173 12 cm, maxillofacial). An empirical relationship between FOV dimension and effective dose was derived. -The use of a 180° rotation resulted in an average dose reduction of 45% compared with a 360°rotation. -Eye lens doses ranged between 95 and 6861 mGy.	-Significant dose reduction can be achieved by reducing the FOV size, particularly the FOV height, of CBCT examinations to the actual region of interest. - 180° rotation can be preferred in some cases , as it has the added value of reducing the scan time. - Eye lens doses should be reduced by decreasing the height of the FOV rather than using inferior FOV positioning, as the latter would increase the effective dose considerably.

Chambers D *et al.* [27]	To determine the effective dose and CTDI for a range of imaging protocols using the Sirona GALILEOS® Comfort CBCT scanner	Sirona GALILEOS® Comfort CBCT scanner	Calibrated optically stimulated luminescence dosimeters	modified RANDO phantom	i)ForFull maxillomandibular scan- At 42 mA: 102 ± 1 mSv At varying contrast and resolution:remains unchanged ii)For maxillary scan at 42 mA: 71 mSv High contrast and resolution settings) iii)For mandibular scan at 42mA: 76 mSv(High contrast and resolution settings)	mAs and beam collimation changes have a significant influence on effective dose than contrast and resolution settings.
Signorelli L *et al.* [24]	To determine radiation doses of different CBCT scan modes in comparison to a COR by means of phantom dosimetry.	--------------	TLD chips (3 × 1 × 1 mm)	Adult male Phantoms	Scanning Mode of CBCT: i)Portrait-131.7 µSv ii)Fast Landscape- 77 µSv iii)Normal landscape- 91 µSv COR: 35.81 µSv i) PA: 8.90 µSv ii)OPG: 21.87 µSv iii) LC: 5.03 µSv	CBCT should not be recommended for use in all orthodontic patients as a substitute for a conventional set of radiographs.

ART, Alderson Radiation Therapy; DAP, dose –area product ; ICRP, international commission on Radiation Protection; TLD, Thermoluminescent Dosimeter; CC, Conversion coefficient ;FOV, Field of View; MC , Monte Carlo; CTDI, computed tomography dose index; COR, conventional set of orthodontic radiographs; PA, Posterior anterior; LC, Conventional lateral; OPG, Digital Panoramic radiograph

Table-2: Comparison of effective doses of cone beam computed tomography and multidetector computed tomography

	CBCT	**Effective Dose (µSv)**	**MDCT**	**Effective Dose (µSv)**
Ludlow *et al.* [31]	-CB Mercury Pan -Next Generation iCAT -Classic i-CAT standard -Galileos default -Galileos maximum	264 36 29 28 52	Somatom 64 slice	453
Loubele *et al.* [13]	-Accuitomo 3D - i-CAT -New Tom 3G	44 77 30	-Somatom Volume Zoom 4slices - Somatom Sensation 16 slice -Mx8000 IDT	1110 995 1160
Suomalainen *et al.* [32]	-3D Accuitomo CCD -3DAccuitomo FSP -Promax 3D -Scanora 3D	27 166 674 91	GE 4slice GE16 slice	685 1410
Jeong *et al.* [16]	-AZ3000CT -Implagraphy -Kavo 3D eXaM	332 83 111	-Somatom Sensation 10 - Somatom Emotion 6	425 199
Kadesjo N *et al.* [33]	-Promax 3D	92	LightSpeed VCT	124

CBCT: Cone Beam Computed Tomography, MDCT: Multidetector computed tomography

Table-3: Studies illustrating effective doses for cone beam computed Tomography

CBCT Study	Maxillofacial Region (large FOV)		Dentoalveolar region (medium FOV)		Localised region (small FOV)	
Author	**CBCT**	**Effective Dose (µSv)**	**CBCT**	**Effective Dose(µSv)**	**CBCT**	**Effective Dose (µSv)**
Ludlow *et al.* [31]	CB Mercury maximum quality	1073	CB Mercury Panoramic FOV	560	CB Mercury IFOV maxilla	407
	CB Mercury standard quality	569	Classic i-CAT standard scan	69	Promax 3D small adult	488
	Next generation i-CAT	74	Next Generation i-CAT landscape mode	87	Promax 3D large adult	652
	Illuma standard	98	Galileos default exposure	70	PreXion 3D standard exposure	189
	Illuma Ultra	498	Galileos maximum exposure	128	PreXion 3D high resolution	388
Pauwel *et al.* [14]	**CBCT**	**Effective Dose (µSv)**	**CBCT**	**Effective Dose(µSv)**	**CBCT**	**Effective Dose (µSv)**
	Galileos Comfort	84	3D Accuitomo 170	54	3D Accuitomo 170(lowe jaw, molar region)	43
	i-CAT N.G.	83	i-CAT N.G.	45	Kodak 9000 3D (upper jaw, front region)	19
	Illuma Elite	368	Kodak 9500	92	Kodak 9000 3D (lower jaw, front region)	40
	Kodak 9500	136	New Tom VGi	265	Pax-uni 3D (upper jaw,front region)	44
	New Tom VG	83	Picasso Trio(high Dose)	123		
	New Tom VGi	194	Picasso Trio (Low Dose)	81		
	Scanora 3D	68	ProMax 3D (High Dose)	122		
	Sky view	87	ProMax 3D (low Dose)	28		
			Scanora 3D(upper jaw)	46		
			Scanora 3D (lower jaw)	47		
			Scanora 3D (Both jaws)	45		
			Veraviewepocs 3D	73		

FOV: Field of View; SPP: Storage phosphor plate; CCD:Charged Couple Device

Table-4: Direct Comparison of effective doses of CBCT and panoramic radiography

	Panoramic Machine		CBCT	
Ludlow *et al.* [12]	Orthophos Plus DS	22	New Tom 9000	77.9
Grunheid *et al.* [40]	OP100	21.5	i-CAT 0.3voxel landscape i-CAT 0.2 voxel landscape	65 134.2
Shin HS *et al.* [41]	Panorama	6.39	Alphard 3030 -C Mode -P Mode -I Mode -D Mode Rayscan Symphony -Facial -Wide -Jaw -TMJ	 428 350 273 81 158 160 153 154

C: Cephalo, D: Dental, I: Implant, P: Panorama

Table-5: Summarizes various clinical trials conducted to evaluate the effect of shielding devices for dose reduction during cone beam computed tomography examination

Author (year)	Intervention	CBCT scanner	Phantom Type	Method of measurement	Radiation Shielding Measure	Comments, Dose Reduction
Prins R *et al.* [43]	To investigate the effect of leaded eyeglasses worn during dental CBCT procedures on the radiation absorbed dose to the eye	Imtec, Ardmore, OK, 120 kVp, 3.8 mA, 7.8 s	male (ARTphantom), female (CIRS), and juvenile male (CIRS)	TLD, optical luminescent dosimetry	leaded eye glasses	Leaded glasses worn by adult and pediatric patients during CBCT scans may reduce radiation dose to the lens of the eye by as much as 67% (from 0.135 ± 0.004 mGy to 0.044 ± 0.002 mGy in pediatric patients).
Qui X *et al.* [46]	To evaluate the radiation dose level during CBCT scanning for the different oral and maxillofacial regions with and without thyroid collar shielding	DCT PRO CBCT	ART phantoms	TLD chips	Thyroid collar shielding	i)No thyroid collar used: Large FOV-254.3 µSv Middle FOV-249.0 µSv Small FOV-180.3 µSv ii) Applying one thyroid collar in front of neck Large FOV-208.5 µSv Middle FOV-149.1µSv Small FOV-110.5 µSv iii) Two thyroid collars in front and back Large FOV-219.1 µSv Middle FOV-142 µSv Small FOV-105.5 µSv The dose reduction becomes more significant when middle or small FOV was chosen.
Qui XM *et al.* [45]	To evaluate the influence of thyroid collars on radiation dose during CBCT scanning.	New Tom 9000 CBCT	ART adult phantom	TLD chips	Thyroid collar	i)Without thyroid collar: Thyroid gland- 31.0 µSv Oesophagus-2.4 µSv ii)Thyroid collars used loosely around neck, no effective dose reduction iii) One thyroid collar used tightly in front of neck Thyroid gland- 15.9µSv Oesophagus-1.4µSv and a similar dose reductions Two collars used tightly in front and back
Goren AD *et al.* [44]	Effect of lead glasses and thyroid shielding on cone beam CT radiation dose in an adult female phantom.	i-CAT platinum CBCT scanner, 120kVp and 5mA	Anthropomorphic female phantom	Optically stimulated luminescent dosimeters	Thyroid shielding, lead glasses and collimation	Dose to internal eye i)without lead glasses or thyroid shield: 0.450 cGy ii) with glasses and thyroid shield 0.116 cGy (74% reduction) iii) Thyroid dose without glasses or thyroid shield-0.158 cGy iv) with both thyroid shield and lead glasses thyroid dose reduced to 0.091 cGy (42 % reduction). Lead glasses, thyroid collars, and collimation minimize the dose to organs outside the FOV.

ART, Alderson Radiation Therapy; CIRS, Computerized Reference Imaging System; FOV, Field of View

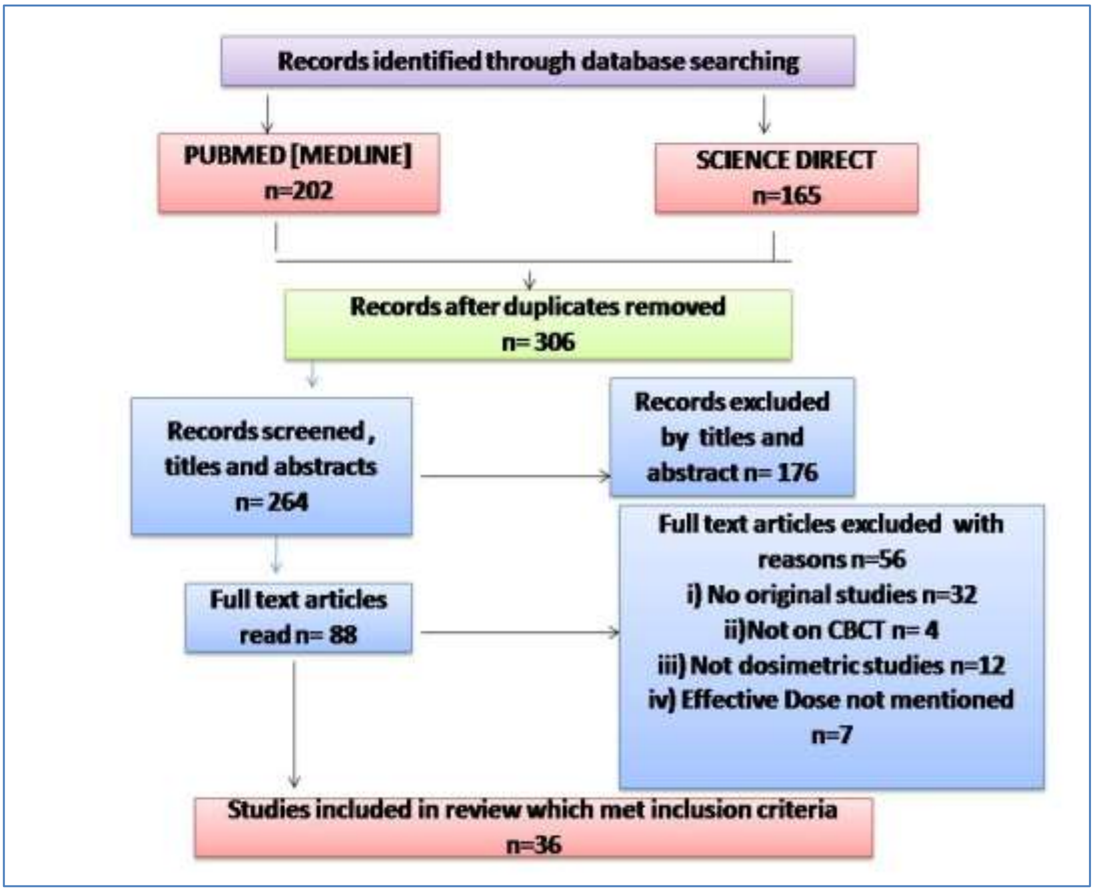

Fig-1: Flowchart presenting study selection process with number of publications identified, excluded and included for review of effective dose of cone beam computed tomography of oral maxillofacial region

DISCUSSION

In this review for effective dose assessment, TLD-100 was used in most studies.TLD -100 is a routine clinical method not only in the field of dosimetry but also for monitoring personnel radiation doses [11-24]. The TLD 100 consists of Li F: Mg, Cu, P which has a lower intrinsic dose detection limit (˜10μSv) [13, 14]. The T100 H was used for dose measurements in organs which were expected to receive minimal dose. The main advantages of TLD 100 are sampling uniformity, nearly tissue equivalence and simple calibration procedures using common radionuclide sources. Thermoluminescent response of dosimters could be affected by roughness of TLD surface; therefore TLD chips should be kept clean [13]. Gafchromic film was used in one study by our search, it produces high resolution images, requires no chemical processing. These films are easier to adjust on the phantom in relation to radiation field and present an analog like dose distribution [26]. CT dose index (CTDI) [29] or the DAP are the two quantitative methods used to calculate effective dose [29, 30]. DAP was found better to determine effective dose as CTDI fails to measure the scatter radiation outside the scan region. The type and number of slices of phantom varied across studies. In most TLD studies, Rando and Alderson Radiation therapy Phantom (ART) were used whereas Monte Carlo studies used International Commission on Radiation Protection (ICRP) Adult Male (AM), Adult Female (AF) reference computational phantoms. The phantom can be made with a real human skull covered with soft tissue equivalent materials. Study was conducted using pediatric phantom corresponding to the age of 10 years as these patients are at higher risk to radiation [18].

Effective dose of CBCT was found to be higher than conventional radiography although it was less than MDCT. For intraoral radiographs, the effective dose depends upon film speed and type of collimation. The dose for the digital/Fspeed complete intraoral exam with rectangular collimation (34.9 μSv) is 4.9 times lower than circular collimation (170.7 μSv) [33]. National Council on Radiation Protection and Measurements (NCRP) and the American Dental Association recommended rectangular collimation for periapical and bitewing radiographs, the use of a thyroid protector and the avoidance of using films lower than E-speed (preferably F-speed/digital)[47].

Effective dose usually vary among different CBCT machines. These devices differ in exposure parameters such as peak voltage (kVp), filtration, x-ray exposure (mA and number of projections) and FOV [48]. In the literature studies it was found, FOV is also important factor in assessment for effective dose. In a recent study conducted by Ludlow *et al*. on CBCT dosimetry using various CBCT machines from various manufacturers and different FOV settings, it was found that increasing the FOV height brings new and potentially radiosensitive tissues into the area of direct exposure, while increasing the width of the beam simply increases the dose to tissues already being exposed [33]. When all the exposure parameters (kVp, mA) are kept constant, larger the FOV, more the effective dose. In contrast, Schilling R, compared effective doses from two CBCT units: Ka Vo 3D eXam and Ka Vo Pan 3D eXam. Effective doses from the 3D eXam ranged between 32.8 μSv and 169.8 μSv, and for the Pan eXam Plus effective doses ranged between 40.2 μSv and 183.7 μSv; these were measured using ICRP 103 weighting factors in each case. According to their study, effective doses could be reduced significantly with the choice of lower resolutions and mAs settings as well as smaller FOVs. They suggested that larger FOVs do not necessarily lead to higher effective doses [49].

Pediatric patients aged less than 10 years old have higher risk than adults because the number of dividing cells promoting DNA mutagenesis is higher and they have more time to show any radiation induced effects, such as cancer [50]. Furthermore, a substantial proportion of dental x ray procedures are performed in pediatric patients for orthodontics. In the initial orthodontic radiographic procedures, which includes full mouth intraoral radiographs, panoramic and lateral cephalograph, the total dose varies between 43.2 and 200.6 μSv[18]. But future demands more research on effective doses of pediatric dental CBCT, using anthropomorphic phantom.

CBCT optimatization is important and for proper optimization following are necessary : i) collimation should not exceed detector size ii) laser guidance of needles in various local interventional procedures such as biopsy of small lesions with13-42% patient dose reduction by CBCT guidance than CT guidance according to Braak *et al*. [51]. But in comparison to CT, CBCT guidance leads to higher operator dose which emphasizes the use of appropriate shielding devices for reduction of operator hand dose, thus needle guidance devices such as laser guidance could be used. All personnel intending to use CBCT for interventional purposes should be trained in the same manner as for interventional CT. iii) minimization of dose wastage by mechanical components for example scattered radiation should be reduced and measured by placing stationary beam blocker between the x ray source and object, result is scatter free and low dose CBCT images [52]. Before CBCT equipment is put into clinical use, Quality Assurance (QA) test is carried out on a monthly basis which includes the following measurements: image noise, image density values, image uniformity, distance calibration and high contrast artifacts. It is also recommended that regular checks are made on image viewing monitors including monitor condition, distance calibration and resolution. Some of these tests require use of test phantoms also [53]. Unlike conventional radiography, which should be checked at intervals not exceeding 3 years, CBCT equipment should be subjected to an annual full radiation safety check [54]. The results of both routine and annual tests should be recorded in radiation protection file and should be compared against baseline levels at the time of installation [53, 54].

There are three ways by which radiation dose can be reduced to patient during X ray examination from CBCT devices i) concept of moving from ALARA to ALADA has reduced the patient dose ii) By decreasing the FOV, as CBCT scanners provide different FOV. To determine FOV, ROI should be determined first. iii) Use of lead aprons and thyroid collars to avoid unnecessary radiations. These all measures also lead to the development of sharper images with good contrast. Shielding devices include lead apron for protection of body, thyroid collar for protection of thyroid gland, lead glasses for protection of eye to avoid cataract, lead hat for protection of brain. The use of lead apron for patients is not considered essential as only patients head should be exposed to primary x ray beam. There is some research that indicated thyroid shields could provide a dose saving in some circumstances. Use of thyroid collars should be recommended for all dental x rays when they do not interfere with the examination according to American Thyroid Association. Even use of lead glasses should be reinforced to prevent the cataract. Dental practitioners should consider that the size of lead glasses could interfere with the identification of lacrimal duct for orthodontic tracings and decrease the image quality at axial levels between maxillary sinus floor and the orbit which could be solved by using smaller lead glasses. Thus use of both shielding devices (thyroid collar and lead glasses) together should be practiced during CBCT scan for better reduction of exposure [45, 46].

Occupational radiation exposure is expected to be small in case of clinic based CBCT systems. For reduction of exposure there should be i) provision for shielding of doors, floors and ceilings ii) provision of suitable shielding of operator iii) use of radiation warning lights outside the radiography room and iv) Providing dosimetry to staff [55]. CBCT should be used as an additional imaging modality when conventional imaging modalities are insufficient to arrive at a diagnosis or in planning treatment procedures. We as Oral and Maxillofacial radiologists should convey about the radiation hazards to the patients and referring practitioners. It is vital for us to evaluate the detrimental effect of diagnostic information against the expense and risk of the imaging procedure [56].This has brought us to a new concept of ALADA "as low as diagnostically acceptable", which is a modification of ALARA, "as low as reasonably achievable [57]". Depending upon the area of interest, the appropriate FOV, mAs, and kVp settings and high definition/high resolution parameters should be selected to obtain a diagnostically acceptable and interpretable image. ALADA would require the strict regulation of guidelines on CBCT referrals followed by an evidence-based appraisal of image quality for explicit diagnostic tasks with exposure and doses associated with a given level of image quality [54]. The main limitation of this review is that it included few trials on effective doses on pediatric patients and broader explanation of concept of ALADA is required in near future.

CONCLUSION

CBCT is a new emerging technology which provides 3D information about facial skeleton and teeth. But just as every good thing has limitations, so does CBCT technology. Dose levels of CBCT imaging by far remained below those of clinical MDCT protocols, but higher than conventional radiography. The increasing use of CBCT use in dentistry carries the risk of overdose in patients, which is becoming dentist's major concern. New methods of dose reduction to patient during CBCT such as lead glasses and thyroid collar were found to be more effective than collimation and filtration. Radiation dose needs to be kept as low as possible at all times, optimizing its balance with image quality.

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