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Cone Beam Computed Tomography for General Dentists

Shawn Adibi*, **Wenjian Zhang, Tom Servos and Paula O'Neill**

School of Dentistry, University of Texas, Houston, USA

Abstract

Recent advancements in Cone Beam Computed Tomography (CBCT) have identified the importance of providing outcomes related to the appropriate use of this innovative technology in dentistry. To assist in determining whether evidence exists, the authors conducted a PubMed search in September, 2012 using the key words "cone beam in Dentistry." This search revealed 1038 articles with 65 reviews recently published in national and international journals during last five years. The purpose of this article is to review the practical applications of CBCT in different dental disciplines, in order to update the general dental practitioners on the current status of this new imaging technology, and aid in their clinical decision-making process related to this imaging modality.

Keywords: Oral radiology; Dental radiology; Cone Beam Computed Tomography (CBCT); Clinical education; Oral pathology; Information technology

Radiology

Introduction of CBCT

The American Academy of Oral and Maxillofacial Radiology (AAOMR) has provided the rational for image selection for several areas of head and neck region [1,2]. For many areas of dentistry, the conventional panoramic and/or the full mouth survey would be adequate, but there may come a time when a multi-planar image such as Computed Tomography (CT) is needed [3].

CT was developed by Sir Godfrey Hounsfield in 1967, and there has been a gradual evolution to what is currently in use today. Two types of beams are commonly used in CT including fan-beam and cone-beam. In fan-beam scanners, a narrow fan-shape ray passes through the axial plan of the body contiguously. The final 3D images are produced by stacking all the two dimensional (2D) axial slices together [4]. In a multi-detector helical CT unit, multiple slices of two dimensional images can be produced by a single scan of the fan shaped helical X-ray source, which reduces exposure time and dosage [5]. A cone-beam scanner uses a cone shaped beam and the reciprocating detector, which rotates around the patient and acquires projection data. Using a back-filtered projection along with sophisticated computer software, a 3D image is produced. Both fan-beam and cone-beam 3D images can be reconstructed in axial, coronal and sagittal planes.

The cone beam technology has been given several names including cone-beam volumetric tomography and cone-beam volumetric imaging. The most frequently applied and preferred term is Cone Beam Computed Tomography (CBCT), because it is a digital analog of film tomography in a more exact way than is the fan-beam system [6].

CBCT has been around for many years, however, the recent advancements in this technology, i.e, reduced cost of production for the sophisticated X-ray source, a quality detector, the advancement in software design, and a more powerful computer system, have allowed its commercial production and practical application into today's dental offices. All CBCT units produce 3D images, although each manufacturer uses slightly different parameters and viewing software. These images are in the Digital Imaging and Communications in Medicine (DICOM) data format, which makes it convenient for imaging sharing, telecommunications, and postprocessings [7-13].

The standard of care for the use of diagnostic monitors has been set by medicine [14]. Dentistry is unique, in a sense that the practicing dentist is often the one reads the images. Gutierrez et al. [15] found that the usual desktop computer display is not adequate for accurate diagnostic purposes. Therefore, it is essential that the dentist ensures that radiologic/imaging equipment is calibrated such that adequate contrast and appropriate brightness along with a reduced ambient lighting is achieved when viewing the images.

Advantages of CBCT: CBCT produce isotropic volumetric image, which means the voxels generated have equal dimension in all three planes. CBCT can achieve a voxel size as small as 0.125 mm. A small voxel size, together with the isotropic feature, contributes to high resolution, accuracy, and reproducibility of CBCT images [4]. In a study published by Razavi et al. [8] using Accuitomo (J. Morita USA, Inc., CA; 888.566.7482) at a voxel size of 0.125 mm, the authors were able to produce images with better resolution and more accurate measurement of thickness of the thin cortical bone adjacent to dental implants than what can be achieved with an i-Cat NG (Imaging Sciences International, Inc., Hatfield, PA; 800.205.3570) system at a voxel size of 0.3 mm.

Clinical reports revealed that CBCT is superior to multidetector CT (MDCT) in reducing the level of metal artifact, especially in secondary reconstructions to view maxillary and mandibular dentitions [3].

Many CBCT units have options for selection of different field of view, which minimize tissue irradiation by exposing only the specific area of interest. Scan time for CBCT is approximately a minute or less. This allows for a quick collection of data from the patient thus reduces the possibility of motion artifacts.

The compact size and affordability have allowed CBCT to be suitable for the dental office setting. Moreover, CBCT images can be reconstructed into many formats that an oral care provider is familiar with. For instance, a CBCT image can be reformatted to a panoramic, cephalometric or bilateral multiple cross-sectional views for evaluation

***Corresponding author:** Shawn Adibi, DDS, FDOCS, MEd, Assistant Professor, School of Dentistry, University of Texas, Houston, USA, E-mail: shawn.adibi@uth.tmc.edu

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of a variety of oral & maxillofacial anomalies. These images, in turn, can be annotated, assessed, and measured electronically [1,13].

Disadvantages of CBCT: The dynamic range of CBCT for contrast resolution can only reach 14-bit maximally. To accurately read a soft tissue phenomenon, a 24-bit contrast resolution is needed. Even though CBCT is not the best imaging modality to evaluate soft tissues, there are situations that CBCT can help, such as analysis of soft tissue air way constrictions and obstructions for patient suffering from sleep apnea, and other soft tissue evaluation for orthodontic treatment [14,16]. In addition, unlike MDCT, the Hounsfield units of tissue density are not calibrated on CBCT, which makes it unreliable to compare tissue density based on CT numbers generated from different CBCT units [6].

Although great improvement has been made, streaking artifacts due to metal restorations and motion artifacts due to patient movement still exist on CBCT images. Manufacturers have developed their own specific filters to reduce these artifacts [6]. However, there is not enough evidence to show if the post-processing algorithm affects the diagnostic value of the images.

Several published reports indicate that the radiation effective dose of CBCT is within 36.9-50.3 microsievert, which is up to a 98% reduction when compared to MDCT systems [9,10]. Another study shows that the radiation effective dose of CBCT is between 6 to 477 microsievert, depending on the parameters used [11]. Based on the data from International Commission on Radiological Protection (ICRP), the effective dose from panoramic radiography is approximately 13 microsievert, from digital lateral cephalometric radiography is 1-3 microsievert, and from periapical radiography is 1-8 microsievert (Table 1). Roberts et al. [12] found that i-CAT (Imaging Sciences International, Inc., Hartfield, PA; 800.205.3570) CBCT delivers a higher dose to the patient than a typical panoramic radiography by a factor of 5-16. Apparently, the dose from a CBCT is low compared to a MDCT, but is higher than the conventional dental radiograph techniques.

According to a study conducted by Ludlow et al. [17], the risk of fatal cancers per million exams of full month series with F speed film and round collimation is 9, for panoramic radiograph with CCD detector is 0-1.3, and for large field CBCT is 4-59. Some CBCT systems have a similar fatal cancer risk as MDCT. Potential benefits of using CBCT in dentistry to assess and diagnose pathologies and to develop treatment planning are undisputed. However, due to the additional radiation exposure necessary to achieve the desired results, justification of increased benefit in diagnostic value should be provided.

In a study of the effective radiation dose of the ProMax 3D CBCT scanner (Planmeca Oy, Helsinki, Finland) using different dental protocols, Xing-min Qu et al. [18], have concluded that choice of patient size, field of view, region of interest, and resolution may affect patient dose by an order of magnitude. The authors advocate a careful selection of these parameters to optimize diagnostic information and minimize patient dosage at the same time [18,19].

Implantology: Dental imaging is an important tool for accurate treatment planning of a dental implant. Traditional 2D radiograph will provide adequate information about purposed implant sites in many clinical circumstances. However, limited size, image distortion, uneven magnification, and a 2D view restrict their use in many other cases [20]. Conventional CT in the past has also been used for pre-surgical planning of a dental implant. However, overlaid artifacts, high doses of radiation, and high cost of operation have been many of the relevant disadvantages.

CBCT	Panoramic	Cephalometric	Periapical
36.9-50.3 μSv[a]	13 μSv[c]	1-3 μSv[c]	1-8 μSv[c]
68-1073 μSv[b]			

Table 1: Dose comparisons of dental radiograph.

The ability of CBCT to produce cross-sectional images at reasonably low radiation exposure and cost makes it invaluable in coordination with a multidisciplinary implant treatment team [21]. Information important for implant planning, such as morphology and volume of alveolar bone, location and size of maxillary sinuses, incisive canal, mandibular canal, and mental foramina, can be easily assessed on CBCT images, which contributes to precise treatment planning and relatively low risks for surgical complications [1].

In a study published by Georgescu et al. [11] in 2010, CBCT was evaluated as a method of quantitative and qualitative analysis of the alveolar crest in the anterior mandible. It was concluded that CBCT provides the clinicians all the necessary information when planning dental implants [11]. Additionally, in a study published by Parnia et al. [22] in 2010, it was found that the depth of the submandibular fossa was more than 2 mm in 80% of patients. Therefore, this anatomical feature can be a contributory factor to an inadvertent perforation of the lingual cortical plate or injuries to the terminal branch of the sublingual artery during implant fixture placement, if a cross-sectional image is not obtained pre-surgically [22].

In another study on immediate implant placement in the posterior mandible, it suggests that a CBCT scan should be taken prior to tooth extraction, in order to evaluate all treatment options available, and try to avoid potential complications while fully informing the patient of the risks of each option [23,24]. When various imaging modalities for implant site assessment were compared, CBCT exceeded all others, with only the category of bone quality was inferior to MDCT. It was concluded that CBCT provides the anatomical information that help generate a collaborative treatment plan and achieve an optimal outcome for radiologist, surgeon, restorative dentist, and patient [21].

Even though the documentation is limited, CBCT provides the implant dentist with controlled surgical plan. This improved surgical plan increases the successful rate of the implant placement as well as reduces the possibility of surgical mishaps. Therefore, the general clinical outcome is improved [25-27].

Oral and maxillofacial pathology and surgery

A combination of low radiation dose, high quality bony definition, and compact design requiring minimum space has made CBCT desirable as an in-office imaging system for examination of the pathology in the head and neck, extra-cranial, paranasal, and temporal bone region. Examination of fractured teeth and bone seem to be a logical application of CBCT. Evaluation of post-surgical complications such as losing screws or broken mandibular fracture fixation can be achieved with CBCT due to the low level metal artifact [1].

CBCT is recommended when there is a need for diagnosis of a cyst, tumor or infections in alveolar process and jaw bone [28]. Many unusual and rare calcifying lesions such as Calcifying Cystic Odontogenic Tumor (CCOT) can be examined in CBCT images for their particular variations. CBCT is very useful for evaluation of intra-osseous lesions that are in close proximity to vital organs and vasculature in the head and neck region [28]. Although the reliability of CBCT to detect the invasion or erosion of oral malignancy such as Oral Squamous Cell Carcinoma (OSCC) is still under investigation, study has suggested that combination of Dynamic Contrast Enhanced (DCE)-Magnetic

Resonance Image (MRI) and CBCT may be a useful tool to delineate tumor boundary and develop appropriate surgical intervention [29].

Studies have shown that CBCT exams enable the surgeon to produce a more conservative treatment approach, which reduces iatrogenic damages and is more acceptable to the patients [24,25]. Researchers have made big strides to translate computer-assisted virtual treatment planning to actual clinical practices for orthognathic surgeries. Once being fully developed, CBCT and the 3D virtual software will become an excellent clinical tool for treatment planning of oral & maxillofacial deformities [26,27].

It would be safe to say that the application of CBCT for craniofacial pathology and surgery is in its infancy stage. Much more evidenced-based studies are needed to validate the role of CBCT in oral and maxillofacial pathology and surgery.

Orthodontics

The applications of CBCT in orthodontics include assessment of palatal bone thickness, skeletal growth pattern, severity of tooth impaction, and upper airway evaluation for possible obstructions [1,30,31]. CBCT is helpful in treatment planning of orthodontic cases which need buccal tooth movement and arch expansion [32,33].

Kumar et al. conducted an *in vivo* study to compare conventional vs. CBCT synthesized cephalograms. They find that synthesized cephalometric image can be used to delineate ambiguous visual landmarks such as porion, and avoid measurement inaccuracy occurred on conventional cephalogram. Cephalometric reconstruction can be used as an alternative to conventional cephalograms when a CBCT volume is already available, so as to reduces additional radiation exposure and extra examination cost [34,35].

Using CBCT 3D hard and soft tissue segmentation along with photographic superimposition, orthodontists and other related specialists are able to simulate virtual patient and interact directly with the disease model, which improves the therapeutic outcomes in many clinical sceneries [34].

Although CBCT has become more popular in orthodontics, further studies are needed to determine if it should be routinely ordered for orthodontic cases, especially because majority of the patients are young and the radiation dose associated with CBCT is much higher than the traditional plain film radiograph.

Temporomandibular joint

The advancement of CBCT technology has inspired many researches in TMJ imaging. Changes in TMJ can be evaluated using magnetic resonance imaging (MRI), CT, and conventional 2D radiographs. Studies are underway to evaluate the reliability of CBCT on clinical assessment of TMJ [1,36].

In a study published by Huntjens et al. [37] demonstrates that condylar shape and volume can be measured accurately using CBCT-based method, knowing that there are distortions and errors in conventional radiograph. Balasundaram and colleagues demonstrate that CBCT is able to diagnose maxillofacial anomalies such as synovial chondromatosis of the TMJ at a reasonably low dosage [38].

CBCT is not ideal for evaluation of cartilage and soft tissue of TMJ, because it has limited contract resolution and cannot distinguish soft tissue densities, where MRI may be the method of choice. However, when examining the hard tissues of the TMJ, such as articular eminence and condylar head, CBCT can provide invaluable information for diagnosis and treatment planning of TMJ diseases.

Endodontics

Conventional 2D periapical radiograph still plays a predominately role in the evaluation of periapical pathosis in today's endodontic field, because it provides clinicians with cost effective and high resolution imaging. For more complicated cases, the input from CBCT images is very essential and valuable, such as periapical pathology due to failed root canal therapy, dentoalveolar trauma, and pre-surgical planning [39,40]. CBCT is a precise imaging modality to measure the length and width of root canal, prevent iatrogenic exposure of the apex, and improves prognosis of root canal therapy [41]. CBCT has been suggested as superior to periapical radiographs when the radiolucent lesion is in close proximity to the maxillary sinus and/or the sinus membrane is involved, or when the lesion is in close proximity to the mandibular canal [1]. CBCT also plays an important role in early diagnosis of perforated defects due to internal root desorption which need nonsurgical endodontic management and long term follow up [39]. When ordering CBCT to evaluate a suspicious periapical lesion, or already failed root canal therapy, it is important to select the correct parameters, such as small volume and a voxel size of 0.125 mm, to achieve a diagnostic quality image.

Periodontics

CBCT has been used in the evaluation of intrabony defects and furcation involvements. It helps to select absorbable membrane with the optimal shape to fit into interproximal bony defects, and shorten the time required for the guided tissue regeneration [42]. However, studies on the evaluation of the periodontal ligament and lamina dura using conventional radiographs, MDCT, and CBCT have had mixed results [1].

Ethical and legal

Depending on the manufacturer and model, a CBCT can range from $90,000 to $300,000. It appears that at this time only the multi-provider offices can afford this technology for patient care. However, this may change in the near future. More than 3,000 CBCT units have been purchased in the U.S.A. and 800 units in Germany. Will this allow the practitioners to achieve a return on investment? Will it cause unethical over-prescription of procedures [6,43]? The belief that financial incentives have undermined the clinical decision-making process in an unethical way has triggered legislation on limiting Medicare payments for self-referral services.

CBCT allows the clinician to have an accurate 3D image of the teeth and areas of interest that aids their diagnosis and treatment planning. However, although CBCT is a useful tool in the clinician's armamentarium, it is essential that they are used when conventional means of radiograph is unlikely to provide the needed information [44].

Ethical and legal considerations on CBCT instruments do not differ from other technological trends such as laser and robotic surgery. Additionally, oral health professionals must embark on extensive training to meet the challenge of the emerging imaging technology in dentistry. Clinicians have legal responsibility to read the entire volume of images, and if they do not have adequate training and experience, they should refer to a qualified oral & maxillofacial radiologist.

Conclusion

Although many studies have favored the application of CBCT in dentistry, there are no multi-center double blind clinical trials for CBCT, which is known as the gold standard for evidence-based studies. CBCT appears to have a promising future, and its utility in dentistry will depend on the results of studies that are currently underway. The amount of existing literature from the past decade has been very encouraging for this imaging modality. Many questions have already been answered by virtue of these literatures documented. Authors of this article have acknowledged that by the time this article is published, many more findings and indications for application of CBCT in dentistry will come out.

Review of recent publications reveals that CBCT is here to stay and play an integral role in diagnosis and treatment planning for many dental disciplines. Additionally, at this point, we conclude that if used judicially, its benefits would outweigh the inherent risks. Finally, we should advocate more professional education and training on this emerging technology. Meanwhile, nothing should keep clinicians from continuing sound practices with appropriate aid of this extraordinary imaging technology.

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