

## REVIEW ARTICLE



# Cone beam computed tomography: Adding three dimensions to endodontics

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## Keywords

Cone beam computed tomography, effective dose, field of view

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Received 27 August 2015

Accepted 29 September 2015

doi: doi:10.15713/ins.idmjar.27

## Abstract

The need for evaluating the structures in three dimensions led to the revolutionary invention of cone beam computed tomography (CBCT). CBCT had found its application in various regions of dentistry. The literature demonstrates the use of CBCT for specific endodontic applications. The purpose of this article is to review the history and evolution of CBCT, its advantages over conventional radiography and to discuss the literature validating its application in endodontics.

## Introduction

All stages in endodontic practice essentially require radiographic evaluation. The first reported evidence of endodontic imaging was given by Kells in 1899. He tried to determine the root canal length by placing a lead wire in the root canal and visualizing it on a “radiogram.”<sup>[1,2]</sup> Since then, imaging has become an important tool in endodontic practice. Intraoral radiography produces two-dimensional (2D) image of the three-dimensional (3D) structures. Some of the limitations of 2D imaging include superimposition of the surrounding anatomic structures and probable errors in exposure or geometry.<sup>[3]</sup> Evaluation of the 3D structures based on the interpretation of conventional 2D imaging can compromise the endodontic diagnosis and treatment planning. Hence, the need for 3D imaging, which would help in the better assessment of an area interest, arose.

## Evolution of Cone Beam Computed Tomography (CBCT) Systems

Sir Godfrey Newbold Hounsfield invented CT scanner in 1972. His invention revolutionized the diagnosis in medicine and fetched him the honors of British Knighthood and the Nobel Prize in medicine in 1979.<sup>[4]</sup> Hounsfield used image

reconstruction developed by Alan Cormack for his invention in 1960's.<sup>[5]</sup> Using cone beam technology, a new volumetric CT machine was introduced by Mozzo *et al.* in 1998 for maxillofacial imaging.<sup>[6]</sup>

In 2001, the first CBCT unit for dental use was approved by the Food and Drug Administration (FDA) in the United States—the New Tom DVT 9000 (Quantitative Radiology srl, Verona, Italy). Later in the year 2003, the 3D Accuitomo (J. Morita Mfg. Corp., Kyoto, Japan), the i-CAT (Imaging Sciences International, Hatfield, PA), and the CB MercurY (Hitachi, Medical Corp., Kashiwa-shi, Chiba-ken, Japan) were the other FDA approved CBCT units in succession.<sup>[3]</sup> Since then a number of CBCT systems have been designed for dental use.

In 2013, during the “Festival della Scienza” in Genova, Italy, the research group members: Attilio Tacconi, Piero Mozzo, Daniele Godi, and Giordano Ronca received an award for the invention of CBCT which brought a paradigm shift in dental imaging.<sup>[7,8]</sup>

## How CBCT System Works

Imaging in CBCT is accomplished by using a rotating gantry to which an X-ray source and detector are fixed. A cone-shaped beam of ionizing radiation is directed through the center of the

area of interest toward X-ray detector which is placed on the opposite side of the patient.<sup>[9]</sup> The X-ray source and the detector rotate around a fixed fulcrum within the center of the region of interest (ROI). Several sequential planar images of the field of view (FOV) are obtained during the rotational exposure. A single rotational sequence of the gantry provides immediate and precise images of the entire FOV and also adequate data for 3D image reconstruction.<sup>[3]</sup>

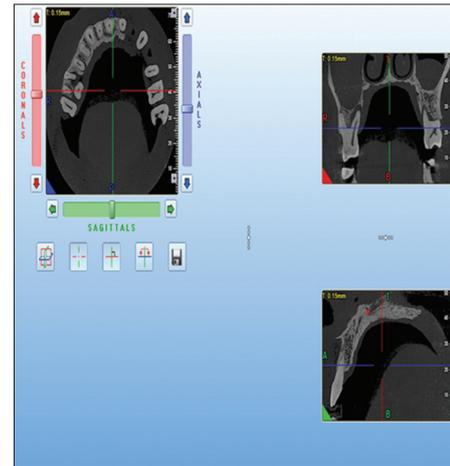
Pixels (picture element) are the unit measurements used for 2D imaging such as in computer screens and digital cameras. The image captured by CBCT is composed of voxels, the unit of measurement with 3D. In other words, the voxel is volume added to pixel or 3D pixel as the data is acquired by CBCT in volume in contrast to 2D image.

Unlike medical CT, CBCT voxels are isotropic, which means they are equal in all dimensions. This feature enables precise measurements of the area of interest and also 3D reconstruction for better evaluation. Standard viewing software allows the dentist to examine the selected area of interest in all the three planes; axial, coronal, and sagittal [Figure 1].

Based on the FOV CBCT systems are classified into full CBCT (FOV 100-200 nm) and limited CBCT (FOV 40-100 nm).<sup>[10]</sup> Full CBCT units are most useful in maxillofacial trauma evaluation, diagnosis, and treatment planning in orthodontics, temporomandibular joint analysis and pathologies of jaws. Limited CBCT systems are useful in dentoalveolar imaging and are most appropriate for endodontic applications. This is because higher spatial resolution of the image is obtained with smaller scan volume. Discontinuity of lamina dura and periodontal ligament (PDL) space widening are the earliest radiologic signs of periapical pathology. Thus, any CBCT system used in endodontics need to have an optimal resolution not exceeding 200  $\mu\text{m}$  (the average width of the PDL space).<sup>[3]</sup> The first of the small FOV systems which provided a resolution of 0.125 mm is the 3D Accuitomo (J. Morita, Corporation, Kyoto, Japan). Figure 2 shows ORTHOPHOS XG 3D system having a standard resolution of 160  $\mu\text{m}$  and a simple unit operation for 2D and 3D scans with automatic switching sensor.

### Accuracy of CBCT Systems

Unlike periapical radiography, CBCT demonstrates remarkable decrease in the superimposition of the surrounding anatomic structures. The geometric accuracy of CBCT is superior to 2D imaging.<sup>[11]</sup> Kobayashi *et al.*<sup>[12]</sup> compared the limited volume CBCT and spiral CT images of "lesions" that were made in cadaver mandibles. They concluded that limited volume CBCT accurately measured the distances. Pinsky *et al.*<sup>[13]</sup> studied the accuracy of 3D measurements in CBCT using cast acrylic blocks having holes of various sizes and simulated defects in the human mandible. CBCT errors were found to be clinically insignificant. Several investigators have demonstrated that CBCT allows for an accurate 3D representation of the area of interest.



**Figure 1:** Cone beam computed tomography image at different planes



**Figure 2:** ORTHOPHOS XG 3D (Sirona, Germany) system at JSD Techno dental, Bengaluru

### Advantages of CBCT

The use of CBCT in endodontics provides a number of advantages. It demonstrates the 3D anatomic features, unlike conventional 2D imaging. Multiplanar reformation (including oblique and curved) and serial transplanar reformation help in the improved assessment of the area of interest. Rapid scan time reduces the artifacts due to subject movement.<sup>[14]</sup> CBCT provides image accuracy and high resolution. Collimation enables X-ray beam limitation to the area of interest, and there is a reduction in the radiation dose. Geometrically, accurate images along with the elimination of anatomic noise provide a cutting edge to endodontic diagnosis and treatment planning.

### Limitations of CBCT

Omnidirectionally, produced scattered radiation is recorded by CBCT detector. These results in noise which is different

from the actual attenuation of the object present in the path of X-ray beam. Additional nonlinear X-ray attenuation results in image degradation when it is not eliminated by noise reduction algorithms. Graininess of the image due to remaining noise occurs in systems with large FOV, especially when a low signal is used in an attempt to reduce the radiation exposure.<sup>[3]</sup>

CBCT image artifacts are attributed to the following four sources: The patient, the scanner, artifacts specific to CBCT system (partial volume averaging, undersampling, and cone beam effect) and finally X-ray beam artifacts.<sup>[15]</sup> The cone beam effect occurs in the peripheral portions due to the divergence of X-ray beam. Less information is recorded for the peripheral structures than the central objects resulting in streaking artifacts, greater peripheral noise and image distortion. Image artifacts also occur due to inherent polychromatic nature of the projection X-ray beam is known as beam hardening (i.e. mean energy increases as the lower energy photons are absorbed in preference to higher energy photons). Two types of artifacts occur due to beam hardening: (1) Cupping artifact, i.e. the distortion of metallic structures due to differential absorption; and (2) streaks and dark bands can appear between two dense objects.<sup>[14]</sup> In endodontic practice, FOV can be reduced to avoid scanning structures outside the ROI susceptible to beam hardening.<sup>[3]</sup>

### Radiation Dose Considerations

Radiation dosages are of real concern for the patients. The effective dose (E) of radiation is the sum of weighted tissue or organ doses depending on the amount of specific tissue present in the FOV and their radiosensitivity.<sup>[3]</sup> International Commission on Radiological Protection has specified the tissues/organs to be used for effective dose calculation. The effective dose calculation for imaging of the head includes the skin, bone surface, bone marrow, brain, salivary glands, thyroid, esophagus, and "remainder" tissues.<sup>[16]</sup> The effective dose (E) of radiation is measured in Sieverts. CBCT has much lower effective dose of radiation when compared with traditional medical CT. CBCT dosages are largely determined by FOV, exposure beam type, technique settings (mA, kVp), beam geometry and amount of basis projections.<sup>[5]</sup> Published data on effective dose gives an indication of the radiation exposure level that is detrimental to health. Although there is a significant reduction in radiation dose with CBCT, it is important to follow the principles of as low as reasonably achievable, like any other dental imaging. It is equally important that the diagnostic benefit must outweigh the radiation exposure risk to the patient.

### Endodontic Applications of CBCT

CBCT has found its application in various fields of dentistry such as endodontics, implantology, oral and maxillofacial surgery, orthodontics, periodontics, and forensic dentistry. CBCT has limited application in restorative dentistry,

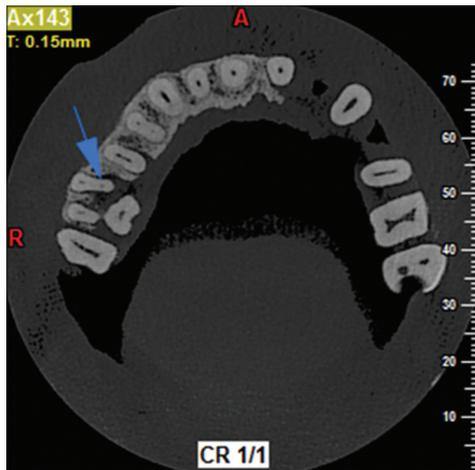
which may be attributed to its higher radiation dose and failure to provide additional diagnostic information than 2D radiography.<sup>[17]</sup> Tyndall and Rathore, in their article on CBCT diagnostic applications, stated that it is in the area of endodontic applications the literature had proved fruitful to date.<sup>[18]</sup> Literature review in this context has proved the efficiency of CBCT over conventional 2D imaging in many cases.

CBCT has been found to be effective in many endodontic applications, such as diagnosis of diverse canal morphology, periapical lesions due to odontogenic and non-odontogenic pathology, identification and localization of internal and external resorption, identification of root fractures and dentoalveolar trauma, evaluation of causes for non-healing root canals, invasive cervical resorption (ICR), assessment of procedural complications, and pre-surgical evaluation.

### Tooth morphology and internal anatomy

All the root canals are to be identified and thoroughly cleaned to achieve complete elimination of microbial flora. The presence of missed, undebrided canals lead to failure of endodontic treatment. Eliminating the anatomic noise and enabling to view the images in all planes make the CBCT system superior to intraoral periapical radiograph (IOPAR). Unrevealing the complex tooth morphology and internal anatomy with CBCT helps in rendering better treatment.

Prevalence of MB2 canals in maxillary first molars was found to be 51.5% by Weine *et al.*<sup>[19]</sup> They had stated that the difficulty to detect the extra canal with intraoral radiograph could result in an unexplained failure of the treatment. CBCT helps in confirming the presence of MB2 [Figure 3] and also determining its internal anatomy in relation to mesiobuccal canal. Degerness and Bowles<sup>[20]</sup> sectioned 150 maxillary molars to study the mesiobuccal root canal anatomy. It was found that 20% of mesiobuccal roots had one canal, 79.8% roots had two canals, and 1.1% had three canals. Neelakantan *et al.*<sup>[21]</sup> compared CBCT and other imaging modalities with modified canal staining and clearing technique to establish canal anatomy. They found 99.71% accuracy with CBCT imaging in canal identification. A study by Michetti *et al.*<sup>[22]</sup> showed a strong to very strong correlation when CBCT and histological sections were compared. They concluded that CBCT would be considered as a reliable tool and a non-invasive method to explore canal anatomy. Das *et al.*<sup>[23]</sup> reported a case management of dilacerated maxillary central incisor fused with the supernumerary tooth. They found that CBCT aided in 3D view of the area of interest which influenced the treatment outcome. Recently Almeida *et al.*<sup>[24]</sup> had reported an unusual case of maxillary first molar with 8 root canals confirmed with CBCT. In this case, both the mesiobuccal and distobuccal roots had 3 canals each and palatal root had 2 canals. The author concluded that the use of CBCT and dental operating microscope facilitated better understanding of anatomy and efficient cleaning, shaping and obturation of all canals.



**Figure 3:** Cone beam computed tomography image showing MB2

### Periapical lesions

CBCT has been found effective in diagnosing periapical lesions undetected on an intraoral radiograph as it eliminates the superimposition of cortical bone over the lesion.<sup>[25]</sup> Bender evaluated the factors affecting the radiographic appearance of lesions in the bone. He found that lesions in the cancellous bone having little or no cortical plate erosion were difficult to diagnose with an IOPAR. Bone loss of 30-50% was required for the lesion to appear on a radiograph.<sup>[26]</sup>

Lofthag-Hansen *et al.*<sup>[11]</sup> compared the efficiency of limited CBCT and intraoral radiography in the diagnosis of periapical pathology. CBCT identified 62% more apical lesions than intraoral radiographs. In a comparative study by Ma *et al.*<sup>[27]</sup> CBCT identified 59.4% and conventional radiography identified 39.6% of the apical periodontitis lesions. Rosenberg *et al.*<sup>[28]</sup> evaluated the efficacy of CBCT in differentiating periapical cysts from granulomas in contrast to histopathology. It was concluded that surgical biopsy and histopathology still remained as the standard procedure for identification of periapical cysts and granulomas. A systematic review by Kruse *et al.*<sup>[29]</sup> evaluated the diagnostic efficacy of CBCT for periapical lesions from the MEDLINE database from 2000 to July 2013. CBCT was found to have higher accuracy in detection of periapical lesions over 2D imaging. They concluded that none of the conducted studies justified the standard use of CBCT in this regard and at present, the use of CBCT for identifying periapical lesions had been assessed at low diagnostic efficacy levels. In contrast, Patel *et al.*<sup>[30]</sup> stated that CBCT allows for earlier detection of periapical lesion and helps in assessing the true size, extent, position of the periapical and resorptive lesions.

### Root fractures

The diagnosis of root fracture with 2D imaging may be quite difficult if the fracture line is not in line with X-ray beam. In such case, the clinician must carefully evaluate the signs and symptoms

to arrive at the diagnosis. Unless correct diagnosis is being made, it would be difficult to plan further treatment modalities.

Brady *et al.*<sup>[31]</sup> compared the efficacy of CBCT and IOPAR in detecting vertical root fracture (VRF) and also evaluated the impact of the width of VRF on their diagnostic accuracy. Two CBCT systems, 3D Accuitomo, i-CAT and IOPAR showed 27%, 28%, and 3% sensitivity, respectively. Complete fractures were detected more significantly than incomplete fractures by all the systems. VRFs of width  $\geq 50 \mu\text{m}$  were detected with higher accuracy by CBCT than those having the width  $< 50 \mu\text{m}$ . An *in vivo* study by Metska *et al.*<sup>[32]</sup> evaluated the diagnostic efficacy of two CBCT scanners in detecting VRFs in endodontically treated teeth. The sensitivity, specificity, and accuracy values for New Tom 3G were 75%, 56%, and 68%, respectively whereas for 3D Accuitomo, values were 100%, 80%, and 93%. They concluded that diagnostic accuracy in this regard depends on the type of CBCT system used and suggested the use of 3D Accuitomo for detection of VRFs in endodontically treated teeth.

Jones *et al.*<sup>[33]</sup> validated CBCT imaging as a reliable tool in detection of horizontal root fractures (HRFs). They found that the radiation dose could be reduced by alterations in the exposure parameters without affecting their diagnostic ability in detecting HRFs.

### Internal and external root resorption (ERR)

The loss of mineralized dental tissues due to odontoclastic activity is known as resorption. Internal and ERR are to be differentiated as they arise from the different pathologic process and require varied treatment modalities. Celikten *et al.*<sup>[34]</sup> presented a rare case report of multiple idiopathic external and internal root resorptions confirmed with CBCT imaging. In this case, CBCT was found beneficial in early detection and 3D analysis of resorptive lesions which led to better treatment outcomes. Xie and Zhang<sup>[35]</sup> had showed that the diagnostic ability of CBCT in assessing smaller ERR lesions was better when compared to multislice CT in simulated ERR defects. CBCT has been used to diagnose external apical root resorption which is a common iatrogenic consequence of undue orthodontic forces.<sup>[36]</sup>

### ICR

Careful radiographic evaluation of ICR has to be made as it is usually misinterpreted as internal resorption. The identification of portal of entry is crucial to establish the differential diagnosis. In two case reports of ICR by Vasconcelos Kde *et al.*,<sup>[37]</sup> CBCT was found beneficial in diagnosis of ICR by establishing the real extent of lesion and portals of communication with periodontal space.

### Presurgical evaluation

CBCT enables 3D evaluation of the lesion in terms of its location, extent and proximity to anatomic structures such as mandibular canal, mental foramen, maxillary sinus and nasal cavity. Kurt *et al.*<sup>[38]</sup> performed a prospective, clinical study comparing the

pre-surgical evaluation by CBCT and conventional radiography on the outcomes of periradicular surgery of maxillary first molars. It was found that CBCT evaluation resulted in shorter operative time and fewer sinus membrane perforations. The author concluded that pre-operative CBCT examination provides positive contributions to the surgical outcomes. International Congress of Oral Implantologists has supported the use of CBCT as an adjunct in implant dentistry. They concluded that CBCT would be beneficial in accurate linear measurements, 3D evaluation of the alveolar ridge, proximity to vital structures and fabrication of surgical guides.<sup>[39]</sup>

## Conclusion

Conventional radiography is an economical and accessible imaging technique which provides adequate diagnostic information for endodontic procedures. The literature revealed the specific applications of CBCT imaging in endodontics which required 3D analysis of the area of interest. The American Association of Endodontics and the American Academy of Oral and Maxillofacial Radiology had jointly discussed the use of CBCT in endodontics. They suggested that CBCT imaging should be considered when 2D imaging fails to provide adequate information. Every patient does not require 3D imaging, and it should not be used for screening purposes.<sup>[40]</sup> Thus, like any technology, CBCT has to be used judiciously for endodontic applications.

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**How to cite this article:** Patil S, Keshava Prasad BS, Shashikala K. Cone beam computed tomography: Adding three dimensions to endodontics. *Int Dent Med J Adv Res* 2015;1:1-6.