Computed tomography: Will the slices reveal the truth

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Abstract

With the advances in the field of imaging sciences, new methods have been developed in dental radiology. These include digital radiography, density analyzing methods, cone beam computed tomography (CBCT), magnetic resonance imaging, ultrasound, and nuclear imaging techniques, which provide high-resolution detailed images of oral structures. The current review aims to critically elaborate the use of CBCT in endodontics.

Key words: *Cone beam computed tomography, endodontics, radiology*

INTRODUCTION

Radiographs in endodontics help in a proper diagnosis, correct treatment planning, and are an important tool in intraoperative procedures and outcome assessments. Conventional intraoral periapical radiography is the most widely used radiographic technique, which gives valuable information regarding the presence, nature and location of periradicular diseases, root canal morphology, and adjacent important anatomical structures.[1,2]

CONVENTIONAL TWO-DIMENSIONAL IMAGING AND ITS LIMITATIONS

Conventional two-dimensional periapical lack three-dimensional data and there is overlapping of important anatomical areas of concern due to superimposition.[3]

Conventional X-rays use an analog film or digital receptor to produce a two-dimensional image of a three-dimensional object.[4,5] The three-dimensional relation of the root(s) to their surrounding anatomical structures, associated periapical lesions, and the canal anatomy within roots may not be precisely assessed with conventional radiographs.[6-9]

The difficulty in positioning the radiographic film parallel to the long axis of the tooth can cause forelengthening and foreshortening.[9] Certain anatomical features such as zygomatic buttress and maxillary sinus may superimpose on the areas of interest, thus masking the minute diagnostic details.[10]

These can be overcome using three-dimensional imaging techniques, such as conventional computed

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tomography, and more recently cone beam-computed tomography (CBCT).

CONVENTIONAL COMPUTED TOMOGRAPHY

CT produces three-dimensional image of an object by using a series of two-dimensional image data to mathematically reconstruct a particular cross-section of the object. It is unique in that it provides images of a combination of soft tissues, bone, and blood vessels.[11] The technique of dental CT also known as dentascan was developed by Schwartz *et al*.[12] The dental CT can be performed with a conventional CT, a spiral CT, or a multislice CT scanner.

Applications of conventional computed tomography

Computed tomography can be applied in various aspects of dentistry.

- Assessing the root canal morphology[13]
- Accurately view the three-dimensional anatomy of the teeth[14]
- Detection of chronic apical periodontitis (AP) in the early and established stages[15]
- Detection of vertical root fracture which can be rarely detected on a periapical radiograh.[16]

Limitations of conventional computed tomography

CT in endodontics was not widely accepted due to its high effective dose and relative low resolution.[17]

CONE BEAM COMPUTED TOMOGRAPHY OR CONE BEAM VOLUMETRIC TOMOGRAPHY

In dentistry, where the need for three-dimensional imaging is increasing, CBCT is a promising tool.[18,19] CBCT volume tomography (DVT) is an extraoral imaging system, which can produce three-dimensional scans of the maxillofacial hard tissues.[20-22]

CBCT images are attained with the help of a rotating gantry to which an X-ray source and detector are attached. A divergent beam of cone-shaped ionizing radiation is then passed through the area of interest to an X-ray detector on the other side of the patient. The X-ray source and detector revolve around a fixed fulcrum that is immovable within the region of interest (ROI). At the time of exposure sequence, hundreds of planar projection images are generated of the field of view (FOV) in an arc of at least 180°. In a single rotation, CBCT can generate accurate, instant three-dimensional radiographic images. Because CBCT exposure involves the entire FOV, one rotational sequence of the gantry is sufficient to acquire adequate data for the purpose of image reconstruction.[23-25]

Its major advantage over conventional CT is the marked reduction in radiation exposure. This is due to rapid scan times, pulsed X-ray beams and state of the art image receptor sensors. CBCT scanners are very simple to use and are approximately the same size of the panoramic radiographic machines, which make them a practical choice for dental practice.[18]

Limited volume CBCT scanners scan relatively smaller data volume that cover just two or three individual teeth, for instance, the 3D Accuitomo (J Morita Corporation, Osaka, Japan) can even capture a 40 mm height by 40 mm diameter volume of data, which is almost similar in dimensions to a conventional periapical radiograph.

The majority of CBCT systems scan the patient in a seated position. Scan times are typically between 10–40 s which is based on the scanner employed and the selected exposure parameters. The actual exposure time is a fraction of this, only approximately 2–5 s.

Each mini-exposure produces a pixel matrix comprising 262,144 (512 × 512) pixels. The attained dataset of these CBCT contains up to 580 individual matrices, which are then reconstructed with the use of advanced configuration computers into three-dimensional datasets, containing almost 100 million voxels (5123).[3]

Sophisticated high-end software processes the obtained data into a format, which resembles those produced by medical CT scanners. Reconstructed images are generated within minutes. The data acquired by CBCT are captured in terms of volumes, which are made up of voxels. With digital imaging, the picture is composed of pixels. In the case of CBCT, voxels are basically three-dimensional versions of pixels. CBCT voxels are isotropic, which means that they are equal in all three dimensions.

Images can be displayed in the three orthogonal planes, axial, sagittal, and coronal simultaneously. Selection of a particular area and moving the cursor over one image also changes the other reconstructed slices. This allows an area to be investigated three-dimensionally in "real time." Surface rendering, which is a technique for visualizing a geometric representation of a surface from a three-dimensional volume dataset, makes it possible to produce three-dimensional images.

Numerous studies have reassured the geometric precision of CBCT in three dimensions.[26-30]

The quality of images from CBCT scans is better and far superior to helical CT in the assessment of important structures such as cancellous bone, periodontal ligament, lamina dura, enamel, dentine, and pulp.[25]

Cone beam CT scanners are simple to use, less complicated, and therefore less expensive than CT scanners.[31,32]

Limitations of cone-beam computed tomography

CBCT images only have a spatial resolution of 2 line pairs mm^{-1} compared to the 15–20 line pairs mm^{-1} of conventional packet film and digital sensors.[33,34] Still, the ability of this technique to reproduce geometrically accurate and reliable images in three dimensions and the elimination of anatomic noise facilitates the assessment of a large number of important features in endodontics.

One technical issue which may influence the quality of images and the diagnostic accuracy of CBCT images includes the beam hardening caused due to high density neighboring anatomical structures such as enamel, implants, metal posts, and metallic restorations.[35,36]

CBCT images are also highly prone to artifacts that affect image quality. X-ray beam that causes beam hardening (i.e. mean energy increases due to low-energy photons that are absorbed instead of high-energy photons) causes two types of artifact: (1) Distortion of metallic objects produced by differential absorption, which is termed as a cupping artifact, and (2) streaks and dark bands that usually appear between two thick objects. The presence of dental metallic restorations in the FOV can result in streaking artifacts. Owing to the fact that the CBCT X-ray beam is heterochromatic which contains lower mean kVp energy in comparison to conventional CT, this type of artifact is more prone to occur. In clinical scenario, CBCT scanners with a limited FOV may produce clearer images with better clarity because they can avoid structures out of the ROI, which are more prone to beam hardening.[37]

When this scattering and beam hardening is associated with the tooth being assessed, the resultant CBCT images may be of minimal diagnostic value.[38,39]

APPLICATIONS OF CONE-BEAM COMPUTED TOMOGRAPHY IN ENDODONTICS

Preoperative assessment

Root canal morphology: The outcome of endodontic treatment depends on the identification of all root canals so that it can be cleaned, shaped, and obturated effectively.[40]

- Abella *et al*., used CBCT to demonstrate a case of a mandibular first molar with a severely curved additional distolingual root (radix entomolaris). They concluded that CBCT imaging can be used for identifying the root canal system and the surrounding structures[41]
- Bauman *et al*. found that the reliability of detection of maxillary molar second mesiobuccal canal (MB2) canal in CBCT scans increased as the resolution improved[42]
- In a case report by Loannidis *et al*., it was concluded that the availability of three-dimensional images increased the opportunity for the precise description of the anatomy of 7 maxillary and mandibular molars with single roots and single canals[43]
- The results of an *in vitro* investigation by Blattner *et al*. showed that CBCT scanning is a reliable method to detect the MB2 canal when compared with the gold standard method of physical sectioning of the specimen[44]
- Fan *et al*. reported that CBCT method for negotiation combined with careful exploration may provide a reliable method for identifying the anatomy of the canal system and enhancing debridement in these complex canal anatomies[45]
- The CBCT scan is a reliable and noninvasive method, which can be used to assess the position of the mandibular canal. The variable position of this between patients suggests the need for CBCT to identify the proximity of the nerve bundle before initiating invasive treatment in this region. Potential differences in mandibular canal position when performing these procedures in this area should be considered[46]
- The use of a dental operating microscope (DOM) and CBCT imaging in endodontically challenging cases can facilitate a better understanding of the complex root canal anatomy, which ultimately enables the clinician to explore the root canal system and clean, shape, and obturate it more efficiently.[47]

Dental periapical pathology:

- CBCT was accurate in diagnosing the nature of periapical bone loss in chronic lesions, and the diagnostic information attained by CBCT was very useful for treatment planning.[48]

Stavropoulos and Wenzel compared CBCT to digital and film-based intraoral periapical radiography for the detection of periapical bone defects. They found that CBCT has a better diagnostic precision (61%) in comparison with digital (39%) and (44%) conventional radiographs.[49] In a similar study, Ozen *et al*. compared the detection of chemically-induced periapical lesions by three observers using digital and film-based conventional radiography to two CBCT systems. They concluded that, though detection rates for CBCT were higher, they did not recommend ignoring intraoral radiography for detecting periapical lesions in day-to-day clinical practice due to financial and radiation dose considerations.[50]

Estrela *et al*. compared the accuracy of CBCT, panoramic, and periapical radiographs from patients with endodontic lesions (1508 teeth) to detect apical periodontitis (AP). They showed that the prevalence of detection of AP was significantly better when CBCT is applied.[39] Estrela *et al*. formulated and proposed a periapical index using CBCT (CBCTPAI) for the detection of AP. They reported that CBCT imaging assessed 54.2% more AP lesions than using intraoral radiography alone.[51] Patel *et al*. reported a identification rate of 24.8% and 100% for intraoral radiography in comparison to CBCT imaging.[52]

Root fractures and perforations:

- According to Costa *et al*.,[53] small-volume CBCT scanning showed better accuracy in the detection of horizontal root fracture without a metallic post
- Edlund*et al*.[54] conducted a study which revealed the superior diagnostic accuracy of CBCT for detection of vertical root fracture (VRF)
- Shemesh *et al*. concluded that the risk to misdiagnose strip perforations was high with both CBCT and periapical radiography, however, CBCT scans showed a significant higher sensitivity than periapical radiography[55]
- Ozer *et al*. concluded that CBCT scans were more reliable in detecting simulated VRF, and a 0.2 mm voxel was the best protocol, considering the lower X-ray radiation exposure and good diagnostic accuracy[56]
- According to Bueno *et al*., the accurate management of CBCT images might reveal an abnormality that is unable to be detected in conventional periapical radiography. A map-reading approach reduces problems related to the detection of root perforations near metallic artifacts.[57]

Root resorption:

- CBCT provides useful information on the location, size, and nature of root resorptive defects in comparison with that achieved by conventional radiographs[58]
- Even though digital intraoral radiography has resulted in an acceptable level of accuracy, the statistically superior accuracy and reliability of CBCT may result in a review of the radiographic techniques that may be used for the assessment of the type of resorptive lesion.[59]

Intraoperative assessment:

- Based on the study by Janner *et al*., an already existing CBCT scan of teeth to be endodontically treated can be used to determine the working length in combination with clinical measurements such as the electronic apex locator (EAL). More studies should evaluate if intraoral radiography for measuring the length of root canals can be avoided when CBCT images are available.[60]

Postoperative assessment:

- Liang *et al*. stated that treatment outcome, length, density, and quality of root fillings, and outcome predictors, as determined with the help of CBCT, may vary from the corresponding values determined with conventional periapical radiography.[61]

Other applications:

- CBCT imaging revealed a lower-than-expected prevalence of mucositis adjacent to teeth with apical radiography[62]
- A study by Cymerman *et al*. showed the value of CBCT scanning in evaluating and assessing patients reporting with concurrent sinus and dental complaints[63]
- Changes in the maxillary sinuses seem to be associated with periapical pathology in more than 50% of the cases. Maxillary first or second molar teeth are most commonly involved and individual or multiple roots may be suspected in sinusitis. The use of CBCT can also identify changes in the maxillary sinus and possible causes of the sinusitis[64]
- A study by Bornstein *et al*. described the advantages of limited CBCT in treatment planning in mandibular molars prior to apical surgery[65]
- Thus, the application of new diagnostic tools, such as CBCT imaging, may provide detailed high-resolution images of oral structures, which may be pivotal in an initial diagnostic hypothesis as well as to plan surgery.[66,67]

EXAMPLES FOR CONE-BEAM COMPUTED TOMOGRAPHY USAGE IN CLINICAL ENDODONTICS

Kottoor *et al*.[68] reported the nonsurgical endodontic management of a left maxillary molar with three roots and eight root canals. This case of rare anatomic morphology was diagnosed with the help of DOM and confirmed with the use of CBCT images. CBCT axial images showed that both the mesiobuccal and distobuccal root contained a Sert and Bayirli type XV canal, whereas the palatal root showed a Vertucci type II canal configuration. This case report illustrates the importance of CBCT in managing cases with variation in root canal anatomy.

RADIATION DOSE FROM CONE-BEAM COMPUTED TOMOGRAPHY

To assess radiation risk, which is the chance of biological consequences after exposure to radiation in humans, the term effective dose is often employed. Effective dose is a quantitative measurement of the extent of harmful effects on humans when exposed to one kind of radiation. The international standard unit for the measurement effective dose is Sievert. In radiology milli or micro-sievert is generally mentioned.[69]

Effective doses from different CBCT units in comparison to other radiographic techniques in dentistry is shown in Table 1.[69]

In endodontics, small FOV is sufficient. It is clear from Table 1 that the effective dosage from a small FOV is almost nothing greater than an orthopantomography.

Table 1: Radiation dosage from different imaging modalities

Imaging technique	Effective dosage (μSv)
CBCT (Large FOV)- CB Mercuray	569
CBCT (Large FOV)- Kodak 9500	136
CBCT (Medium FOV)-classic i-CAT	69
CBCT (Medium FOV)-3D Accuitomo	54
CBCT (Small FOV) 3D Accuitomo	43
CBCT (Small FOV) Kodak 9000	19
Multislice spiral CT	1410
Panoramic radiography Digital-Planmeca	12
Panoramic radiography Film-Planmeca	26
Intra-oral periapical radiograph-Digital	0.65
Intra-oral periapical radiograph-Film	3.5

CBCT=Cone-beam computed tomography, FOV=Field of view

CRITICAL ANALYSIS OF THE USE OF CONE-BEAM COMPUTED TOMOGRAPHY IN ENDODONTICS

The benefits of CBCT should outweigh the potential risks of using it in the field of endodontics. CBCT should be considered only for complex endodontic cases where conventional imaging techniques are not sufficient for diagnosis, treatment planning, and execution. Though the effective dose used in CBCT is less compared to spiral CT, it is still quite high compared to other imaging techniques, and hence may not be free of risk. Multiple angled conventional intraoral digital radiographs are quite sufficient in most situations for understanding the root canal anatomy and its variation.

If a patient is still subjected to CBCT, the question to be answered is, does CBCT imaging give the clinician an accurate imaging of all the intricate details of the root canal system. In real time *in-vitro* studies, it has been proved that clearing and staining of teeth is a foolproof method to study the microanatomy of the root canal system. As shown in Figure 1, CBCT images are far inferior in dictating the intercanal communications, apical delta, lateral canals, etc., in comparison to Figure 1b. Thus, the justification has to be made for subjecting a patient to radiation exposure if it cannot match the clearing and staining technique used *in vitro*. In addition, due to beam hardening, CBCT is of limited value in diagnosing vertical root fractures, especially in teeth that are obturated due to the beam hardening caused by the radiopaque obturating material.[70]

CONTRAST ENHANCED CONE-BEAM COMPUTED TOMOGRAPHY

Ruddle *et al*.[71] injected a radio-opaque dye into the root canal system before subjecting it to a

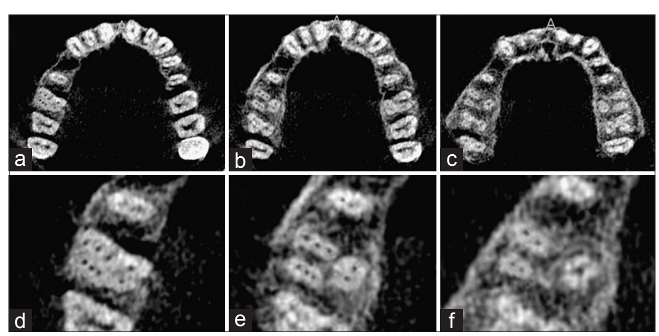

Figure 1: (a-c) Cone-beam computed tomography (CBCT) images of the maxillary arch showing axial sections at the (a) cervical, (b) middle, and (c) apical level. (d–f) Enlarged axial section CBCT images of tooth #14 at the (d) cervical, (e) middle, and (f) apical level showing three roots and eight root canals

conventional radiography. The authors of this article suggest a similar technique with a novel approach for achieving better images with CBCT. We have experimented the injection of a radio-opaque dye into the canals after cleaning and shaping procedure. The CBCT imaging is performed after this. The images obtained in our pilot study are shown in Figure 2. We could appreciate better visualization of the root canal anatomy including root canal aberrations and variations. Further studies are required before this technique could be recommended for clinical usage [Figure 2].

CONCLUSION

Thus, it can be concluded that CBCT is an invaluable diagnostic tool in the field of endodontics. It is especially indicated in situations where a two-dimensional image from a conventional intraoral radiography does not help in understanding the root canal anatomy and its complexity. Though the radiation exposure is less in CBCT, it should be used only in situations where a conventional radiographic technique is not sufficient. Hence, whether CBCT sections reveal the truth completely is still a mystery, but is certainly more valuable than conventional two-dimensional imaging.

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Conflicts of interest

There are no conflicts of interest.

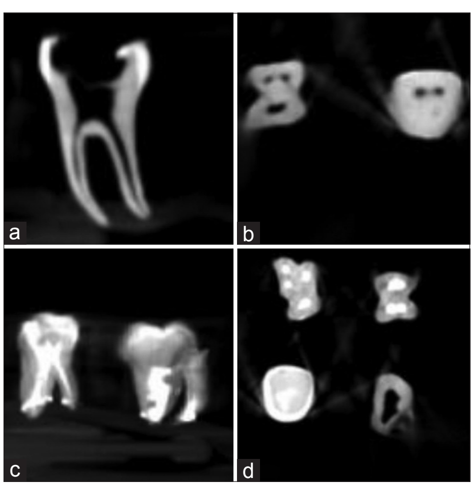

Figure 2: (a and b) Cone beam computed tomography. (c and d) Contrast media injected in the canal differentiates and highlights the complexity of the root canal system

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