Cone-Beam Computed Tomography as a Tool in Endodontic Detection and Diagnosis

Krishnan Hari, G Anuradha

ABSTRACT

Radiographic imaging is essential in diagnosis, treatment planning and follow-up in endodontics. The interpretation of a periapical radiograph can be confounded by various factors including the root canal anatomy, superimposition of multiple roots of a particular tooth to be treated as well as the surrounding dentoalveolar structures. As a result of superimposition, periapical radiographs reveal only limited aspects, a two-dimensional (2D) view, of the true three-dimensional (3D) anatomy. These problems can be overcome by utilizing small- or limited-volume cone-beam computed tomography (CBCT) imaging techniques, which produce accurate 3D images of the teeth and surrounding dentoalveolar structures. The purpose of this paper is to review the current literature on various clinical applications, advantages and limitations of intraoperative CBCT in the field of endodontics.

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INTRODUCTION

Cone-beam computed tomography (CBCT) is a diagnostic imaging modality that provides high-quality, accurate three-dimensional (3D) representations of the osseous elements of the maxillofacial skeleton with a lower effective radiation dose than computed tomography (CT). Since, the first cone-beam volumetric tomographic unit was approved for dental use in the United States in 2000, numerous endodontic applications of this technology, along with CBCT, have been described in the literature. Most of the applications in the field of endodontics are primarily focused on preoperative assessment and treatment planning and include diagnosis and canal morphology, assessment of internal and external root resorption, treatment planning and assessment of traumatic dental injuries, assessment of root fractures, presurgical anatomic assessment, and treatment planning for tooth anomalies, such as dens invaginatus. Studies reveal CBCT to be more precise than conventional radiographs in measurements of the length of root canal fillings, diagnosing the presence of bone defects, resorption lesions, root fractures and perforations.

BASIC COMPARISON OF MEDICAL CT AND CBCT

The medical CT scanner was developed in the late 1960s, and subsequently patented by Hounsfield (1973). Early generations of the CT scanner acquired ‘data’ in the axial plane by scanning the patient slice by slice, by passing a narrow fan shaped X-ray beam through the patient to a single array of reciprocal detectors. Current CT scanners have a linear array of multiple detectors, allowing multiple slices to be taken simultaneously, resulting in faster scan times and often less radiation exposure to the patient (Sukovic 2003). The slices of data are then ‘stacked’ up and can be re-formatted to obtain 3D images. The interval between each slice may also be varied; approximated slices will give better spatial resolution, but will result in an increased dose to the patient. CT scanners are large and very expensive and therefore are usually only found in hospitals with dedicated medical imaging departments. They are not designed for general dental practice.

In the late 1990s, Italian and Japanese groups (Arai et al 1999, Mozzo et al 1998), working independently of each other, developed a new tomographic scanner known as CBCT or digital volume tomography (DVT) specifically for maxillofacial and dental use. CBCT differs from medical CT imaging, in that the whole 3D volume of data is acquired in the course of a single sweep of the scanner, using a simple, direct relationship between sensor and source. The X-ray beam is cone-shaped (hence the name of the technique), and captures a cylindrical or spherical volume of data, described as the field of view (FOV) (Fig. 1). The size of the field of view is variable, large volume CBCT scanners (e.g. i-CAT, Imaging Sciences International Hatfield, PA, USA and NewTom 3 G, QR, Verona, Italy) capture the entire maxillofacial skeleton within a large cylindrical or spherical FOV. Limited volume CBCT scanners capture small volumes of data that can include just two or three individual teeth (Fig. 2). For example, the 3D Accuitomo (J Morita Corporation, Osaka, Japan) captures a 30 mm high by 40 mm diameter cylindrical volume of data which is similar in overall height and width to a periapical radiograph. The most important and clinically useful aspect of CBCT scanners is their highly sophisticated software that allows the huge volume of data collected to be broken down and processed or re-constructed into a format which closely resembles that produced by medical CT scanners. The data are re-constructed to form small (e.g. 0.125 mm) isotropic cubic voxels (3D pixels). Typically, one scan contains over 100 million voxels.
**FIELD OF VIEW**

The dimensions of the FOV or scan volume are primarily dependent on the detector size and shape, beam projection geometry and the ability to collimate the beam. Collimation of the primary X-ray beam limits x-radiation exposure to the region of interest. Field size limitation therefore ensures that an optimal FOV can be selected for each patient based on disease presentation and the region designated to be imaged. In general, the smaller the scan volume, the higher the resolution of the image and the lower the effective radiation dose to the patient. As the earliest sign of a periapical radiographic finding suggestive of pathosis is discontinuity in the lamina dura and widening of the periodontal ligament space, it is desirable that the optimal resolution of any CBCT imaging system used in endodontics not exceed 200 $\mu$m—the average width of the periodontal ligament space. The principal limitation of large FOV cone beam imaging is the size of the field irradiated. Unless the smallest voxel (volumetric pixel) size is selected in these larger FOV machines, there will be reduced resolution compared to intraoral radiographs or limited-volume CBCT machines. For most endodontic applications, limited or focused FOV CBCT is preferred over large volume CBCT for the following reasons:

1. Increased resolution to improve the diagnostic accuracy of endodontic-specific tasks such as the visualization of small features including calcified/accessory canals, missed canals, etc.
2. Highest possible resolution.
3. Decreased radiation exposure to the patient.
4. Time savings due to smaller volume to be interpreted.
5. Smaller area of responsibility.
6. Focus on anatomical area of interest.

**ROLE OF CBCT IN ENDODONTICS WITH CLINICAL EXAMPLES**

In general, the use of CBCT in endodontics should be limited to the assessment and treatment of complex endodontic conditions, such as:

1. Identification of root canal system anomalies and determination of root curvature and extra root canals. Conventional radiographs frequently fail to disclose the number of canals in teeth undergoing nonsurgical root canal treatment. Failure to identify and treat accessory canals can negatively influence treatment outcome. CBCT has been shown to be a reliable tool to accurately assess the degree of curvatures associated with the roots of teeth with normal anatomical forms. The availability of this information preoperatively reduces the chances of the aberrations outlined above occurring. In addition, CBCT has proved a useful assessment and treatment planning tool when teeth with anatomical and morphological anomalies, such as dens invaginatus and fused teeth require endodontic treatment.
2. Diagnosis of dental periapical pathosis in patients who present with contradictory or nonspecific clinical signs and symptoms, who have poorly localized symptoms.

**Fig. 1:** The basic concept CBCT where a cone-shaped X-ray beam orbits around the patient obtaining information in cylindrical volume

**Fig. 2:** Images produced by limited volume CBCT
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3. Diagnosis of pathosis of nonendodontic origin in order to determine the extent of the lesion and its effect on surrounding structures.

4. Intra- or postoperative assessment of endodontic treatment complications, such as overextended root canal obturation material, separated endodontic instruments, calcified canal identification and localization of perforations.

5. Diagnosis and management of dentoalveolar trauma, especially root fractures, luxation and/or displacement of teeth and alveolar fractures. The exact nature and extent of the injuries to the teeth and the alveolar bone can be assessed accurately by eliminating anatomical noise and image compression, thereby allowing appropriate treatment to be confidently implemented. The degree and direction of displacement associated with luxation injuries can be evaluated easily using CBCT. Furthermore, CBCT has been shown to be far more sensitive than multiple periapical radiographs in the detection of horizontal root fractures. Failure to identify the presence of root fractures following dental trauma may lead to inappropriate treatment and poorer prognosis for these teeth.

6. Localization and differentiation of external from internal root resorption or invasive cervical resorption from other conditions, and the determination of appropriate treatment and prognosis. The sensitivity of conventional radiography is significantly poorer than CBCT in the detection of external root resorption in its early stages and significant hard tissue damage may have potentially occurred to the affected tooth before the resorption becomes evident on conventional radiograph.

7. Presurgical case planning to determine the exact location of root apex/apices and to evaluate the proximity of adjacent anatomical structures. CBCT has been highlighted as an extremely useful tool in the planning of surgical endodontic treatment. The spatial relationship of the specific roots undergoing the surgical procedure (and the associated bony destruction) can be accurately related to adjacent anatomical structures, such as the maxillary sinuses, the inferior dental nerve canal and the mental foramen.

CLINICAL EXAMPLES USING CBCT

1. Interpretation of second mesiobuccal canal of maxillary second molar (Figs 3A to D).

2. Detection of anatomy of taurodontism and the presence of maxillary mucositis in relation to maxillary first molar (Figs 4A to E).

3. Evaluation of the extent of calcification of buccal canals in maxillary first premolar (Figs 5A to D).

4. Determining the location of separate instrument to enable its bypass and removal (Figs 6A to F).

5. Assessment of vertical root fractures. Images obtained on conventional periapical radiographs and 3D scans for the diagnosis of vertical root fractures have been compared. Twenty cases with suspected vertical root fractures were subjected to radiographic imaging. They found that CBCT was significantly better than conventional radiographs in the diagnosis of vertical root fractures.

6. Location of mesiolingual perforation and mesiobuccal root canal in mandibular second molar.
Figs 4A to E: Sagittal view showing extent of pulp chamber extension and axial view showing c-shaped canal with four-canal system.

Figs 5A to D: (A) Depicts preoperative radiograph with a large carious lesion under an onlay, (B) and (C) show completely calcified buccal canal in CBCT and (D) shows obturated lingual canal.
LIMITATIONS OF CBCT

A significant issue that can affect the image quality and diagnostic accuracy of CBCT images is the scatter and beam hardening artifacts caused by high density adjacent structures (Fig. 7), such as enamel and radiopaque materials, such as metal posts, restorations and root filling materials (Mora et al 2007; Soður et al 2007). If the scattering or the beam hardening is associated close to or with the tooth being assessed, the resulting CBCT images may be of minimal diagnostic value. The scan times are absolutely lengthy at 15 to 20 seconds and require the patient to be absolutely still. The spatial resolution of CBCT is approximately 2 line pairs per mm and is inferior to conventional dental radiography, which has a spatial resolution in the order of 15 to 20 line pairs per mm. In addition, the contrast resolution of CBCT is poor and is inferior to CT, which has a high contrast resolution.

CONCLUSION

Conventional intraoral radiography provides clinicians with cost-effective, high-resolution imaging that continues to be the front-line method for dental imaging. However, it is clear that there are many specific situations where the 3D images produced by CBCT facilitates diagnosis and influences treatment. The usefulness of the CBCT cannot be disputed. It is a valuable task-specific imaging modality, producing minimal radiation exposure to the patient and providing maximal information to the clinician.
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ABOUT THE AUTHORS

Krishnan Hari (Corresponding Author)
Reader, Department of Conservative Dentistry and Endodontics, Mar
Baselios Dental College, Kothamangalam-686691, Kerala, India
e-mail: lordkrish18@hotmail.com

G Anuradha
Reader, Department of Oral Medicine and Radiology, Madha Dental
College, Kundrathur, Chennai, Tamil Nadu, India