

Cone Beam Computed Tomography (CBCT): A New dimension of Imaging with Basics and Clinical applications in Dentistry

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Abstract

For the clinical assessment of the dental patients, imaging is an important diagnostic adjunct. Cone-beam computed tomography (CBCT) systems have been designed for three dimensionally imaging of hard tissues of the maxillofacial region including the teeth and surrounding tissues. CBCT is a new application of computed tomography (CT) that generates image data at lower cost and absorbed doses than conventional CT used for medical radiology. Most of the attention regarding CBCT imaging has focused on applications for dental implant placement, oral surgery, endodontics, orthodontics and temporomandibular joint imaging.

The purpose of this article is to provide an overview of this CBCT technology and an understanding of its basics and the clinical applications in dentistry.

Key Words: CBCT, Imaging, Conventional CT, Voxel, Three dimensional, Radiograph

Introduction

Problem of clear visibility is the main disadvantage of conventional intraoral and panoramic imaging¹, which is largely the result of representation of a three dimensional (3D) structure as a two-dimensional (2D) image. This limitation becomes clear when considering the caries² and periodontal³ and endodontic applications¹. Since the first intraoral radiograph obtained in 1896, dentistry has been involved in to the same method of 2D imaging. Since then, only one or two significant advances in dental radiographic imaging have been made apart from this including panoramic imaging and tomography.

However, intraoral and extraoral radiography, used separately or in combination, could not avoid some inherent limitations of 2D projections such as magnification, distortion, superimposition, and misrepresentation of structures. Numerous efforts have established 3D radiographic imaging as a possible technique (e.g. stereoscopy, tuned aperture computed tomography), still, the application of computed tomography (CT) in dentistry is limited because of cost, access, and dose considerations.⁴

A new imaging technology based on cone-beam has existed since the 1980s⁵. However, the advancement of technology, its applications and advantages has justified the use of cone-beam

volumetric tomography (CBVT)^{6,7} or cone-beam computed tomography (CBCT) for dentistry.⁸

Cone-Beam CT Technology

Basic principle: In this technology, a cone-shaped beam of radiation acquires a volume in a single 360-degree rotation, similar to panoramic radiography^{6,7}. Just as a digital image is made of basic unit pixels, the volume acquired by a CBVT is composed of *voxels*. Basically, a *voxel* is a 3-D pixel. Compare to the slices, here, the data are captured in a volume (voxels) which are isotropic in nature, enabling the accurate measurement of objects in different directions. However, the medical CT voxels are anisotropic in nature and are determined by the slice thickness or pitch (1–2 mm thick)⁹. In general, as compared to CBCT voxel, a medical CT voxel does not represent a perfect cube, and their measurements made in different planes are not accurate. Apart from increased accuracy, the CBCT also provide higher resolution, low scan-time, low radiation dose, and reduced cost for the patient⁹⁻¹¹.

Using a special viewer software¹², the operator can scroll and go through the whole volume and at the same time, can visualize the axial, coronal, and sagittal 2-D sections that range from 0.125–2.0 mm thickness. The axial and proximal (sagittal in the anterior, coronal in the posterior) views are of main importance, as they

cannot be generally visualized with conventional IOPA radiographs.

The incorporated special software processes the volumetric data into a format that closely resembles to that of medical CT scanners. Generally, a pixel matrix consisting of 262144 (512 x 512) pixels are produced by each mini-exposure or projection image. The resulting dataset obtained can have up to 580 individual matrices, which are then reconstructed into 3D data sets with the help of software, consisting of over 100 million voxels (512³). This reconstruction is generated very shortly within minutes. To achieve an increased resolution, the number of pixels per matrix may be increased from 512² to 1024². The final reconstructed 3D data volume will have 1024³ voxels, and each voxel turns in to half its original size. But it may require two to three fold increase in radiation exposure for this enhanced resolution.⁴

Depending on type of scanner used and exposure parameters, scan times for CBCT ranges from 10 to 40 s long. The actual exposure time is limited to only 2–5 s, since the pulsed X-ray beam results in up to 580 individual ‘mini-exposures’ or ‘projection images’ during entire scan. This property makes the CBCT superior and advantageous over CT scanners. The speedy scanning time and the advanced image receptor sensors used for CBCT result in further reduction of radiation dose.¹³

Types of CBCT Scanners

Depending on field of view (FOV), CBCT systems can be divided into 2-categories, limited (dental or regional) CBCT or full (ortho or facial) CBCT. The limited category has FOV ranges in diameter from 40–100 mm, whereas the FOV of full category ranges from 100–200 mm. Also, a voxel is generally smaller for the limited category than the full CBCT (0.1–0.2 mm vs 0.3–0.4 mm). Hence, the limited CBCT systems generates higher resolution and they may have better application in endodontic.¹⁴

Recently, with the development of inexpensive x-ray tubes, high-quality detector systems and powerful personal computers, there are some affordable commercially available systems. Such systems may include New Tom QR DVT 9000 (Quantitative Radiology, Verona, Italy), CB MercuRay (Hitachi Medical Corp., Kashiwa-shi, Chiba-ken, Japan), 3D Accuitomo – XYZ Slice View Tomograph (J. Morita Mfg

Corp., Kyoto, Japan) and i-CAT (Xoran Technologies, Ann Arbor, Mich., and Imaging Sciences International, Hatfield, PA).

These units can be divided based on their x-ray detection system^{15,16}. Most CBCT units for maxillofacial applications have an image intensifier tube (IIT) -charge coupled device. Recently, a system consisting of a flat panel imager (FPI) was introduced (i-CAT).^{17,18} The FPI consists of a cesium iodide scintillator applied to a thin film transistor made of amorphous silicon. The basic difference between these two is that images produced with FPI generally result in lesser noise than images from an IIT and also to overcome geometric distortions inherent in the detector configuration of IIT, preprocessing need to be done.^{15,16}

Cone-beam CT image production⁴

Present cone-beam machines provide three possible positions to scan patients: (1) sitting, (2) standing, and (3) supine. Machines that utilize the supine or sitting units have some demerits like inability to adjust with physically disabled or wheelchair-bound patients. While on other hand, seated units are the most comfortable; still, fixed seats may not able to scan physically disabled or wheelchair-bound patients. Because scan times are often greater than those of panoramic imaging, the head restraint mechanism becomes more important than patient orientation. Despite patient orientation within the machine, the principles of image production remain the same which consist of four components i.e. (1) acquisition configuration, (2) image detection, (3) image reconstruction, and (4) image display.

Radiation Dose of CBCT

The effective radiation dose for CBCT is considered to be much lower as compared with medical CT and comparable to that received from routine diagnostic imaging^{19,20}. Various brands and its array of settings determines effective doses of different CBCT equipments. Effective doses of digital panoramic radiography range from 4.7–14.9 microsieverts (μ SV) per scan²¹. The effective dose for the New tom 9000 (Verona, Italy) was found to be 50.3 μ SV²⁰ while the effective dose for a full mouth series has been reported to range from 33–84 μ SV²², depending on different variables.

Advantages of CBCT⁹

CBCT technology used for dentistry offers several advantages over conventional CT:

Low radiation dose: Radiation dose is minimized due to reduction in the size of the irradiated area by collimation of the primary x-ray beam to the area of interest.

Enhanced resolution & image accuracy: The resolution of the image is determined by the size of the voxels. Because of isotropic voxels of CBCT, it produces sub-millimeter resolution ranging from 0.4 mm to as low as 0.125mm (Accuitomo).

Fast scan time: Because CBCT acquires all basis images in a single rotation, scan time is rapid and comparable with that of medical CT systems.

Diminished image artifact: With manufacturers' artifact suppression algorithms and increasing number of projections, CBCT images can have a low level of metal artifact, particularly in secondary reconstructions designed for viewing the teeth and jaws.

Unique display modes for maxillofacial imaging: Because of isotropic voxels of CBCT, the entire volume can be reoriented in order to realign the patient's anatomic features. In addition, cursor-driven measurement algorithms have made the real-time dimensional assessment possible.

Limitations of CBCT¹³

- **Diminished resolution than conventional radiographs:** The spatial resolution of conventional radiograph and digital sensors is in the order of 15–20 line pairs/mm as compared to CBCT images which have a spatial resolution of 2 line pairs/mm only.
- **Beam scattering and beam hardening:** It is generally resulted by high density neighboring structures, such as enamel, metal posts and restorations. If such scattering and beam hardening occurs close to or with the tooth being assessed, the final CBCT images may have minimal diagnostic value.
- **Lengthy scan time:** It requires lengthy scan time compared to conventional radiograph and require the patient to stay absolutely still.

Application of CBCT Imaging to Clinical Dentistry: The discussion below will focus on the diagnostic and treatment-planning applications of CBCT in clinical dentistry:

Dento-maxillofacial Imaging: Advanced CBCT imaging techniques are used in dentomaxillofacial imaging to solve complex diagnostic and treatment-planning problems, such as those involving the craniofacial fractures, endosseous dental-implant planning, orthodontics and endodontics etc.²³

Implantology: It is an invaluable tool during preoperative planning for complicated endosseous dental implantation procedures²⁴. Previous articles have documented the ability of CBCT images to characterize mandibular and alveolar bone morphology, as well as to visualize the maxillary sinuses, incisive canal, mandibular canal, and mental foramina, all structures particularly important in surgical planning for dental implantation.²⁵⁻²⁷

Craniofacial Fractures: Imaging of complex high-contrast bony structural pathology such as craniofacial fractures is a logical application for CBCT. There was a case series²⁸, which reported two patients with facial trauma for whom CBCT was used to evaluate the mandibular head fracture, dental root fractures, and the displacement of anterior maxillary teeth. Since that time, several additional reports have confirmed the low-dose high-resolution properties of CBCT imaging in preoperative evaluation of mandibular and orbital floor fractures.²⁹⁻³¹

The intraoperative uses of C-arm CBCT systems have been evaluated for fractures of the zygomatico-maxillary complex (ZMC), demonstrating the feasibility of CBCT use in surgical navigation, localization of bony fragments, and evaluation of screw anchorage and plate fittings with low levels of metal artifact.^{32,33}

Orthodontics: Low-cost CBCT imaging can also be used for orthodontic applications, such as assessment of palatal bone thickness, skeletal growth patterns, dental age estimation, upper airway evaluation, and visualization of impacted teeth.³⁴⁻³⁶ Although initial reports are promising, these cross-sectional techniques provide superior image quality of dental and surrounding structures for advanced orthodontic treatment planning.³⁷

Temporomandibular Joint (TMJ): CBCT has recently promoted the research in field of TMJ imaging, though initial results have yet to be proven for its efficacy into clinical cases. Several

cadaveric series have explored the use of CBCT to assess periarticular bony defects, flattening, osteophytes, and sclerotic changes in TMJ.³⁸⁻⁴⁰

Endodontics: CBCT has great promising results to become a valuable diagnostic and treatment planning tool in the modern endodontic practice. Potential endodontic applications of CBCT include diagnosis of endodontic pathosis and canal morphology, assessment of pathosis of non-endodontic origin, evaluation of root fractures and trauma, analysis of external and internal root resorption and invasive cervical resorption, and presurgical planning.

CBCT becomes superior to periapical radiographs in the characterization of periapical lucent lesions, reliably demonstrating lesion proximity to the maxillary sinus, sinus membrane involvement, and lesion location relative to the mandibular canal.⁴¹⁻⁴³ The role for CBCT in early detection of periapical disease could lead to better endodontic treatment outcomes.¹³

Periodontics: The first reported applications of CBCT in periodontology were for diagnostic and treatment-outcome evaluations of periodontitis.⁴⁴ In-vitro studies later demonstrated the ability of CBCT to accurately reconstruct periodontal intrabony and fenestration defects, dehiscences, and root furcation involvements in comparison with radiography, MDCT and histologic measurements.⁴⁵⁻⁴⁷

Although CBCT can better visualize the periodontal bony defects, the conventional radiography still provide higher quality bony contrast and delineation of the lamina dura.⁴⁷

Conclusion

CBCT is a new imaging dimension of CT technology, which has potential applications for imaging of high-contrast structures in the dentomaxillofacial regions. When compared with medical CT, CBCT has increased accuracy, higher resolution, reduced scan time, a reduction in radiation dose, and reduced cost for the patient. When indicated, three-dimensional CBCT scans may supplement conventional 'two dimensional' radiographic techniques, which at present have higher resolution than CBCT images.

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