Review Article

Cone-beam Computed Tomography: Three-dimensional Imaging in Periodontal Diagnosis

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Abstract

Cone beam computed tomography has been a diagnostic imaging modality, providing high-quality and accurate three dimensional representations of the hard tissues of the maxillofacial skeleton. This technology uses a low dose of radiation and provides increased precision of anatomical structures compared to computed tomography. Using 3-D imaging better diagnosis, treatment planning and surgical experience can be achieved to improve patient care. This review provides an overview of CBCT and highlights the potential application of CBCT in the field of periodontology and implantology.

Keywords: *Cone beam computed tomography, periodontal diagnoses, three-dimensional imaging*

Introduction

Diagnosis of periodontal disease mainly depends on clinical signs and symptoms. The radiographs are an adjunct to the clinical examination.[1] Conventional and Digital radiography is very useful in diagnosing the periodontal defects,[2] but they still possess unique inherent limitations including magnification, distortion, and superimposition[3] and provides only a two-dimensional (2D) image of three-dimensional (3D) structures which can lead to underestimation of bone loss and errors in identifying reliable anatomical reference points.[4] Thus, an imaging technique which would give an undistorted 3D image of teeth and surrounding structures is necessary to improve the diagnostic potential.[2]

Cone-beam Computed Tomography

Dental imaging techniques have advanced with the introduction of tomography.[3] Computed tomography (CT) using 3D imaging technique has frequently been used in medical speciality, but in dentistry, its application is limited to certain cases of maxillofacial trauma and diagnosis of head and neck diseases.[2] However, due to its high cost and high radiation dosage, routine use of CT in dentistry is not practically feasible.[4]

In the recent years, a relatively new imaging modality, cone-beam CT (CBCT) with dedicated CBCT scanners for acquiring remarkable 3D images of dentomaxillofacial structures has generated tremendous interest in dentistry and can be used for a variety of different clinical applications that include evaluation of dental implant receptor site; alveolar bone defect and bone reconstruction procedures; impacted teeth; orthodontics; endodontics; temporomandibular joint (TMJ) diagnostics; sinus augmentation procedures; and orthognathic surgical interventions.[5]

In periodontology as well as implantology, CBCT scanning has become a valuable imaging technique, for the diagnosis of intrabony defects, furcation involvements, and buccal/lingual bone destructions.[1] CBCT can display the image in all its three dimensions by removing the disturbing anatomical structures and making it possible to evaluate each root and surrounding bone.[2] It expands the role of imaging from diagnosis to image guidance of operative and surgical procedures.

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Principles of Cone-beam Computed Tomography

Cone-beam scanners use a 3D area detector digital array rather than a linear detector used in conventional CT scanners combined with 3D X-ray beam that is collimated by circular collimators so that the resultant beam is in the shape of a cone, hence the name "cone beam."[6]

During the scan rotation, the X-ray source emits radiation in a continuous or pulsed mode and many exposures at fixed intervals that produce projection radiographs or "basis images." The complete set of basis projection images is referred to as the projection data.[7] These image data are converted into 3D volumetric data set by sophisticated algorithms incorporated in software programs, which provide primary reconstruction images in three orthogonal planes (axial, sagittal, and coronal).[8] Since the X-ray beam exposes the entire field of view (FOV), only one rotational scan of the gantry is necessary to achieve enough data for image reconstruction.

Steps in Cone-beam Computed Tomography Image Production

Current cone-beam machines scan patients in three possible positions:[9]

1. Sitting
2. Standing
3. Supine.

Image production by CBCT involves four steps:

1. Image acquisition[10]
2. Image detection
3. Image reconstruction
4. Image display.

Image acquisition

Determinants of image acquisition:

1. Acquisition mechanics: Full/partial rotation scan
2. X-ray generation: Continuous/pulsed
3. FOV
4. Scan factor.

Acquisition mechanics

The CBCT technique involves a single scan from an X-ray source which can be a partial or full rotational scan, exposing a reciprocating area detector that moves synchronously around the patient's head.[11]

X-ray generation

During the scan rotation, X-ray beams are sequentially captured by the detector in which each projection image is made. Usually, a pulsed X-ray beam to coincide with the detector sampling, which minimizes the actual exposure time, thereby reduces patient radiation dose.[10]

Field of view

Ideally, the FOV should be adjusted in height and width which mainly depends on the size and shape of the detector, projection of the X-ray beam, and collimation of the X-ray beam.[10] CBCT systems can be grouped according to the available FOV or selected scan volume height as follows:

1. Localized region: Approximately 5 cm or less (e.g., dentoalveolar and TMJ)[12]
2. Single arch: 5–7 cm (e.g., maxilla or mandible)
3. Interarch: 7–10 cm (e.g., mandible and superiorly to include the inferior concha)
4. Maxillofacial: 10–15 cm (e.g., mandible and extending to nasion)
5. Craniofacial: >15 cm (e.g., from the lower border of the mandible to the vertex of the head).

Scan factor

Frame rate is the speed with which individual images are acquired. It is measured in frames, projected images per second.[6] The number of images comprising the projection data throughout the scan is determined by the frame rate, the completeness of the trajectory arc, and the speed of the rotation. A complete circular trajectory or a scan arc of 360° is used to acquire the projection data for adequate 3D reconstruction and reduce the scan time as short as possible.

Image detection

Based on detector type, CBCT units are categorized into two groups:[10]

1. Image intensifying tube/Charge-coupled device (IIT/CCD) combination
2. Flat-panel detectors.

Detector panels consist of two components, photodiodes that record the image and thin-film transistors that act as collators and carriers of signal information. In CBCT imaging, voxel dimensions primarily depend on the pixel size on the area detector, whereas in conventional CT, it depends on slice thickness. Therefore, CBCT units, in general, provide voxel resolutions that are isotropic (equal in all three dimensions).

Image reconstruction

The reconstruction process consists of two stages, and each stage consists of numerous steps.

Acquisition stage

Raw images from CBCT detectors exhibit spatial variations of dark image offset and pixel gain due to varying physical properties of the photodiodes and the switching elements in the flat panel detector and also due to variations in the X-ray sensitivity of the scintillator layer.[6] These raw images need systematic offset and gain calibration and a correction of defect pixels which is done by "detector preprocessing."

Reconstruction stage

After the correction of the images, the images are transformed into sinogram which is done by reconstruction filter algorithm, the modified Feldkamp algorithm,[13] that converts the image into a complete 2D CT slice. All the slices are finally recombined into a single volume for visualization.[10]

Image display

The volumetric data set comprises of collection of all available voxels and projected on the screen as secondary reconstructed images in three orthogonal planes (axial, sagittal, and coronal).[14]

Advantages of Cone-beam Computed Tomography

- Scan time is faster as compared with panoramic radiography[2]
- The image is a complete 3D reconstruction and displays in three orthogonal planes
- Limitation of X-radiation to the FOV can be done by collimation of X-ray beam
- Images accuracy can be produced voxel resolution ranging from 0.4 to 0.076 mm
- Patient radiation dose (29–477 µSv) is reduced when compared with conventional CT (approximately 2000 µSv).[15]

The exposure time is approximately 18 s in CBCT, that is, one-seventh the amount compared with the conventional medical CT. Thus, it is five times lower than normal CT.[2]

- CBCT units reconstructed images are provided in three orthogonal planes (axial, sagittal, and coronal)
- Multiplanar reformation can be done by nonorthogonal slicing of volumetric datasets
- Multiplanar image obtained in CBCT can be "thickened" by increasing the number of adjacent voxels included in the display, referred to as ray sum images
- It is possible to produce 3D volume rendering by direct or indirect method
- Positioning of the patient becomes easy by three positioning beams
- Reduced image artifacts: Rapid acquisition time and projection geometry result in a low level of metal artifact in primary and secondary reconstructions.

Limitations of Cone-beam Computed Tomography

Image noise

Noise is the nonlinear X-ray attenuation leading to image degradation. The major source of image degradation is scattered radiation. Scattered radiation arises from interactions of the primary radiation beam with the atoms in the object being imaged.[10] Scattered radiation increases with increase in object thickness and field size.

Scatter to primary ratio is as follows:
- For CT: 0.01–0.15
- For CBCT: 0.4–2.

Poor Soft Tissue Contrast

Two principal factors reduce the contrast resolution of CBCT:[6]

1. Scattered radiation from the X-ray beam adds background signals and reduces the subject contrast and thereby reduces image quality
2. Flat-panel detector-based artifacts that affect the linearity to X-radiation.
    1. Saturation: Nonlinear pixel effects above a certain exposure
    2. Dark current: Charge that accumulates over time with or without exposure
    3. Bad pixels: Pixels that do not react to exposure
    4. Pixel-to-pixel gain variation – variation in the sensitivity of different regions of the panel to X-rays.

X-ray beam artifacts

CT image artifacts result from the inherent polychromatic nature of the X-ray beam projection, what is known as beam hardening (i.e., its mean energy increases because lower energy photons are absorbed in preference to higher energy photons).[6]

This beam hardening results in two types of artifact:
- Distortion of metallic structures can be due to differential absorption, known as a cupping artifact
- Streaks and dark bands can appear between two dense objects.

Specific Application of Cone-beam Computed Tomography in Dentistry

Impacted teeth

CBCT has greatly improved the identification, treatment planning, and evaluation of potential complications of impacted or displaced permanent, supernumerary or supplementary teeth, such as third molars and canine supernumeraries.[16]

Orthodontics

CBCT images are used in orthodontics for evaluating palatal bone thickness, skeletal growth patterns, estimation of dental age, evaluation of upper airway, and visualization of impacted teeth.[17] It also helps in evaluating the bone density before, during, and after treatment.

Localization of inferior alveolar canal

Gives the accurate assessment of position of inferior alveolar canal in relation to the third molar which helps in better treatment planning and relatively low risks for surgical complications.

Fractured teeth

CBCT is considered to be superior to periapical radiographs for detecting vertical root fractures, horizontal root fractures, measuring the depth of dentin fracture, tooth luxation and/or displacement, and alveolar fracture.[18]

Endodontics

CBCT is an important investigative tool in diagnosing apical lesions and differentiating the lesions of endodontic and nonendodontic origin. It can be used to measure the number of roots, to determine morphology of roots, root canals, and accessory canals, and to establish their working lengths and angulations.

Root resorption

CBCT imaging helps in early detection of inflammatory root resorption. CBCT also helps to locate and differentiate external or internal root resorption and cervical resorption.[19] It can help in measuring the size and extent of the lesion.

Maxillofacial trauma

CBCT images are widely utilized to evaluate maxillofacial trauma. CBCT eliminates the structural superimpositions seen in panoramic images, thus helps in identifying the exact location and extent of fracture line.

Temporomandibular joint

CBCT provides necessary information for diagnosing various TMJ disorders such as osteoarthritis, inflammatory arthritis, trauma, and developmental disorder.[20] CBCT helps in examining the joint space and the exact position of the condyle within the fossa.

Forensic dentistry

Dental age estimation is a key element in forensic dentistry. CBCT provides a noninvasive method to estimate the age of a person based on the pulp–tooth ratio.[21]

Use of Cone-beam Computed Tomography in Periodontology

The proper diagnosis and treatment of periodontal disease depend on the accurate image of morphology of periodontal bone destruction. CBCT is considered the superior technique in accurate measurement of alveolar bone level in three dimensions and imaging of periodontal intrabony defects, dehiscence and fenestration defects, diagnosing furcation involvement in molars, and implant site imaging.[2]

Cone-beam Computed Tomography in Assessment of Periodontal Ligament Space

A break in the continuity of lamina dura and a wedge-shaped radiolucent area in the interproximal region are one of the earliest signs of periodontal disease.[1] Observation of periodontal ligament (PDL) space also helps in detection of occlusal trauma and the effects of systemic diseases on the periodontium.[2] The image quality of CBCT scans was found to be superior to CT scans in visualizing PDL space.

Cone-beam Computed Tomography for Periodontal Defect Measurements

The extent of periodontal marginal bone loss is necessary to determine the periodontal destruction. CBCT images provide better information on periodontal bone levels in 3D view than conventional radiography. CBCT produces accurate images as that of direct measurement using periodontal probe. CBCT is considered a superior technique in detecting the buccal and lingual defects and the interproximal lesions.

Radiographs play a major role in detecting the intrabony defects which are main cause for the tooth mobility and tooth loss. A proper diagnosis of interradicular bone loss is necessary for planning treatment options including apically positioned flaps with or without tunnel preparation, root amputation, hemi-/tri-section, or root separation.[1] CBCT provides high-resolution images in assessing the intrabony defects in three dimensions than the conventional radiograph and thus provides a better treatment outcomes.[22]

Soft Tissue Cone-beam Computed Tomography for the Measurement of Gingival Tissue and the Dimensions of the Dentogingival Unit

A new simple and noninvasive method called soft tissue CBCT (ST-CBCT) provides better visualization and measure distances corresponding to the hard and soft tissues of the periodontium and dentogingival attachment apparatus.[2] This technique helps to determine the relationships between

1. Gingival margin and the facial bone crest
2. Gingival margin and the cementoenamel junction (CEJ)
3. CEJ and facial bone crest.

During CBCT scans for the examination of various dentogingival unit, the tongues were retracted toward the floor of mouth and a plastic lip retractor was used to retract the soft tissues away from the teeth and gingiva and the images that were obtained.[1] CBCT helps in measuring the width of the facial and palatal/lingual alveolar bone and also the width of the facial and palatal/lingual gingiva.

Cone-beam Computed Tomography in Regenerative Periodontal Therapy and Bone Grafts

Bone grafting is mostly used in maxillary sinus lifting and for treating intrabony defects.[1] Assessment of bone healing after grafting during follow-up is difficult because of the overlapping of gaining and losing areas within the graft.[22] CBCT provides accurate images and helps in measuring the densities in small localized areas such as a vertical periodontal defect or an alveolar bone graft. Thus, it helps in quantifying the bone remodeling after bone grafting[2] and also avoids surgical reentry by providing accurate 3D images and measurement probably equivalent to direct surgical measurements.[1]

Cone-beam Computed Tomography for Diagnostic Imaging for The Implant Placement

Replacing the missing teeth by dental implants requires a radiographic image capable of producing highly accurate measurements of alveolar and implant site for treatment planning and to avoid damage to adjacent vital structures during surgery.[3] 2D film images using periapical and panoramic imaging films provide only limited information regarding bone density, bone width, or spatial proximity of vital structures, thus provide little information in diagnosing, treatment planning, placing, and restoring modern dental implants.[23] Determination of alveolar bone height and width is important for the proper placement of dental implants to avoid various complications.[1] CBCT provides more accurate images that help in preoperative planning and postoperative localization of dental implants.

CBCT images provide necessary information in implant planning such as evaluation of quality and quantity of bone available for implant placement, assessment of ridge topography, and identification of vital anatomical structures before implant placement such as the inferior alveolar, mental foramen, incisive canal, maxillary sinus, ostium, and nasal cavity floor. It also helps to determine whether or not there is a need for surgical procedures, such as sinus lifting and bone augmentation.[24]

CBCT is commonly utilized in postimplant and/or postgrafting evaluation to locate the implant after placement; to examine the bone-implant interfaces; and to assess the demineralized bone and bone transplants and also helps in identifying peri-implant defects.[25]

Conclusion

CBCT technology is increasingly available in dental practice. It greatly expands its possibilities in diagnosis and treatment planning for patients. However, CBCT should only be used after careful consideration, when conventional 2D imaging techniques are not sufficient or when approach to the technological processes such as guided surgery will improve patient management. While selecting the best CBCT examination for an individual, it is important to minimize radiation dose while aiming for an image that facilitates appropriate diagnoses and management. This requires an understanding the concepts behind CBCT and related technologies, making appropriate training essential for every member of the dental team.

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Conflicts of interest

There are no conflicts of interest.

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