A Review

Cone Beam Computed Tomography & Its Application in Periodontics

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Abstract

The presence of periodontal diseases is diagnosed on the basis of evaluation of clinical signs and symptoms followed by radiographs. Radiographs provide diagnostic information about the quality localization of the bone defect and the pattern of the bone resorption, changes in the bony trabeculae, condition of the lamina dura, length and shape of the root, furcation defects, subgingival calculus, and additional pathology. Two dimensional periapical and panoramic radiographs are routinely used for diagnosing periodontal bone levels.The amount of information obtained from conventional film and digitally-captured periapical radiographs is limited by the fact that the three-dimensional anatomy of the area being radiographed is compressed into a two-dimensional image. As a result of superimposition, periapical radiographs reveal limited aspects of the three-dimensional anatomy. Three dimensional imaging (3D) evolved to meet the demands of advanced technologies in delivering the treatment and at the same time responsible for the evolution of new treatment strategies. Cone beam computed tomography (CBCT) generates 3D volumetric images and is also commonly used in dentistry. All CBCT units provide axial, coronal and sagittal multi-planar reconstructed images without magnification. CBCT displays 3D images that are necessary for the diagnosis of intra bony defects, furcation involvements and buccal/lingual bone destructions. CBCT applications provide obvious benefits in periodontics, however; it should be used only in correct indications considering the necessity and the potential hazards of the examination.

Keywords: cone beam computed tomography (CBCT); 3D radiography; periodontal defects; periodontal diagnosis; furcation; intrabony defects

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Introduction

The periodontium is a functional unit of the tooth that consists of the gingiva, periodontal ligament, cementum, and alveolar bone. Radiographically, the periodontal ligament space appears as a dark line surrounding the root and an increased radio density of alveolar bone is visible adjacent to the periodontal ligament space, referred to as the lamina dura which is an extension of cortical bone into the alveolus.[1]

Periodontal diseases can be broadly classified as gingival diseases (gingivitis) and periodontitis. The bone destruction in periodontal disease occurs when the inflammation extends from the marginal gingiva into supporting periodontal tissues.

Although periodontitis is always preceded by gingivitis, gingivitis does not always progress to periodontitis.[2] The periodontium is first evaluated clinically followed by radiographic study.

Dental radiographs are a valuable non-invasive tool used as an adjunct to clinical examination for assessment of the periodontal conditions of the teeth.[3] Radiographs provide diagnostic information about the quality localization of the bone defect and the pattern of the bone resorption, changes in the bony trabeculae, condition of the lamina dura, length and shape of the

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root and the crown root ratio, plaque retention factors, caries, furcation defects, subgingival calculus, and additional pathology.[4]

Broadly, imaging techniques used in dentistry can be categorized as: intraoral and extraoral, analogue and digital, ionizing and non-ionizing imaging and two-dimensional (2-D) and three-dimensional (3-D) imaging. Traditional analog imaging modalities are two dimensional systems that use image receptors like radiographic films or intensifying screens. These include periapical views, panoramic, occlusal and cephalometric radiography.[5]

The interpretation of an image can be altered by the anatomy of both the teeth and surrounding structures. The amount of information obtained from conventional film and digitally-captured periapical radiographs is limited by the fact that the three-dimensional anatomy of the area being radiographed is compressed into a two-dimensional image. As a result of superimposition, periapical radiographs reveal limited aspects of the three-dimensional anatomy.[6] Three dimensional imaging (3D) evolved to meet the demands of advanced technologies in delivering the treatment and at the same time responsible for the evolution of new treatment strategies. G.N. Houns field, in 1972 introduced computerized transverse axial scanning which lead to introduction of Computed Tomography (CT). The high radiation dose, cost, availability, poor resolution and difficulty in interpretation have resulted in limited use of CT imaging in dentistry. These problems may be overcome using small volume cone-beam computed tomography (CBCT) imaging techniques.[7]

CBCT is also known as CBVT (Cone Beam Volumetric Tomography), CBVI (Cone Beam Volumetric Imaging) dental 3D CT, dental CT and DVT (Digital Volume Tomography) has touched every aspect of medical and dental profession. 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.

Principles of CBCT

The principal feature of CBCT is that multiple planar projections are acquired by rotational scan to produce a volumetric data set from which interrelation images can be generated.[8] Cone-beam scanners use a two-dimensional digital array providing an area detect or rather than a linear detect or as conventional CT does. This is combined with a three-dimensional X-ray beam with circular collimation so that the result ant beam is in the shape of a cone, hence the name "cone-beam". Because the exposure incorporates the entire region of interest (ROI), only one rotational scan of the gantry is necessary to acquire enough data for image reconstruction.[9]

Steps in Cone Beam Computed Tomography Image Production

Image production by CBCT involves four steps[10]:

A. Image Acquisition
B. Image detection
C. Image reconstruction
D. Image display

A. Image Acquisition

The cone-beam technique involves a rotational scan exceeding 180 degrees of an x-ray source and a reciprocating are a detect or moving synchronously around the patient's head. During the rotation, many exposures are made at fixed intervals, providing single projection images known as —basis", —frame" or "raw" images similar to lateral cephalometric radiographic images, each slightly off set from one another. The complete series of basis images is referred to as the projection data. Software programs incorporating sophisticated algorithms including back-filtered projection are applied to the projection data to generate a 3D volumetric data set that will provide primary reconstruction images in three orthogonal planes (axial, sagittal, and coronal).[11]

There are four components to image acquisition in CBCT:

1. Acquisition mechanics: Full/ partial rotation scan
2. X-ray generation: continuous/ pulsed
3. Field of view
4. Scan factor

1. 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.

2. X-ray generation

Although CBCT is technically simple in that, only a single scan of the patient is made to acquire a data set, a number of clinically important parameters should be considered in x-ray generation.

Patient Positioning:

CBCT can be performed with the patient in three possible positions: Supine, Standing and Sitting.

X-ray generator

During the scan rotation, each projection image is made by sequential single image capture of the remnant x-ray beam by the detector.

3. 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. 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., dento alveolar and TMJ)
2. **Single arch:** 5–7 cm (e.g., maxilla or mandible)
3. **Interarh:** 7–10 cm (e.g., mandible and superiorly toc 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).

4. Scan Factors

The speed with which individual images are acquired is called the frame rate and is measured in frames, projected images, per second. The maximum frame rate of the detector and rotational speed determines the number of projections that may be acquired. The number of projection images comprising a single scan may be fixed or variable. With a higher frame rate, more information is available to reconstruct the image; therefore, primary reconstruction time is increased. Higher frame rates are usually accomplished with a longer scan time and hence higher patient dose.[9,10,11]

A. Image Detection:

Current CBCT units can be divided into two groups on the basis of detector type:

- An image intensifier tube/ charge couple device combination (IIT/CCD)or
- Flat-panel imager.

B. Image Reconstruction

The reconstruction process consists of two stages:

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. 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, that converts the image into a complete 2D CT slice. All the slices are finally recombined into a single volume for visualization.[11]

C. 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.

Advantages of CBCT

CBCT technology in clinical practice has important advantages such as minimization of the radiation dose, image accuracy, rapids can time, fewer image artefacts, chair-side image display, and real-time analysis.

Disadvantages of CBCT

Although there has been enormous interest in CBCT, this technology has limitations related to the cone-beam projection geometry, detect or sensitivity and contrast resolution that produce images that lack the clarity and utility of conventional images. The patient must be motion less during the scanning to achieve a good image; other wise the image may display streaking.[12]

Diagnostic Application In Periodontics

The clinical applications of three-dimensional craniofacial imaging are one of the most exciting and revolutionary topics in dentistry.[13] (Figure1)

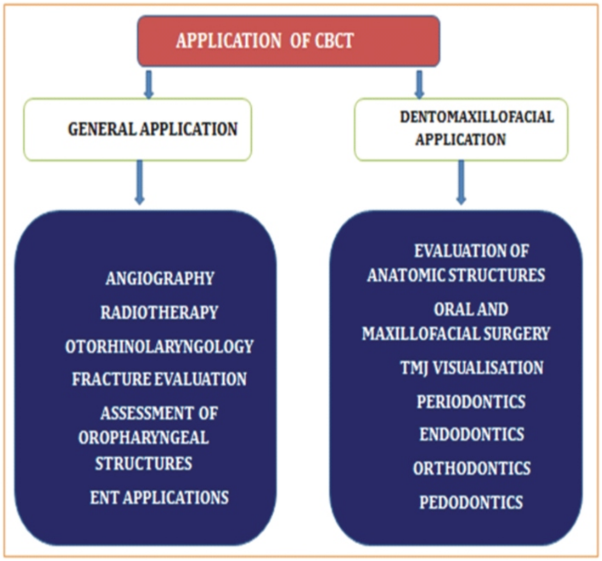

Figure 1: Application of CBCT

Role in Periodontics

Identification of periodontal landmarks

Periodontal Ligament Space

Radiographically lamina dura appears as a thin radiopaque line around the length of root. The space present between lamina dura and adjacent tooth is termed as PDL space. Any break in the continuity of lamina dura and a wedge shape radiolucenly at the mesial or distal aspect of the PDL space indicates periodontitis. Ozmeric et al did a study and compared CBCT with conventional radiography in terms of their ability to produce images of periodontal ligament space on a phantom model with artificially created periodontal ligament of various thicknesses and had found that the Periapical radiographs were superior to CBCT for the measurement of periodontal ligament space. But conflicting results were reported by the authors of another in vitro study that found CBCT to be better than conventional radiography in visualizing the periodontal ligament space. A phantom demonstrating variable periodontal ligament spaces was radiographed using CBCT and intraoral radiographs. This study found that CBCT provided better visualization of simulated periodontal ligament space in this phantom.[14]

Alveolar Bone Defect

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 is considered a superior technique in detecting the buccal and lingual defects and the interproximal lesions.Radiographs are mainly used to diagnose the amount and shape of alveolar bone destruction that affects treatment planning in periodontal therapy.[14,15]Two Dimensional radiographs can be insufficient for the detection of intrabony alveolar defects due to the obstruction of spongious bone changes by cortical plate. Thus, three-dimensional imaging is required for mapping of alveolar defects. Vandenberghe et al studied thirty periodontal bone defects of 2 adult human skulls using intraoral digital radiography and CBCT and concluded that the intraoral radiography was significantly better for contrast, bone quality, and delineation of lamina dura, but CBCT was superior for assessing crater defects and furcation involvements.[16]In Misch and colleagues study they demonstrated that CBCT was as accurate as direct measurements using a periodontal probe and as reliable as radiographs for interproximal areas.[17]Stavropoulos and Wenzel evaluated the accuracy of CBCT scanning with intraoral periapical radiography for the detection of periapical bone defects. CBCT was found to have better sensitivity compared to intraoral radiography.[18]

Furcation Involvement

Radicular bone assessment is anessential step in furcation involvement treatment planning procedures such as apically repositioned flaps with or without tunnel preparation, root amputation, hemi-/trisection or root separation. Conventional two dimensional radiographs can be deceptive in evaluating periodontal tissue support and inter radicular bone due to superposition of anatomical structures. However, 3D images provide detailed information about areas of multi rooted teeth. Intrasurgical furcation involvement measurements were compared by using CBCT images and it was reported that CBCT images demonstrated a high accuracy in assessing the loss of periodontal tissue and classifying the degree of furcation involvement in maxillary molars. In another study author had compared CBCT to intraoral radiography and concluded that the detection of crater and furcation involvements had failed in 29% and 44% for the intraoral radiograph, respectively, as compared to 100% detectability for both defects with CBCT.[19]

Regenerative periodontal therapy and bone grafts

Bone grafting is commonly used for maxillary sinus lifting and treatment of intra bony defects but evaluation of osseous defect regeneration with conventional radiography can be limited due to superimpositions. Furthermore, histological evaluation of a sample of the graft is not a preferred method due to its quite invasive procedure. CBCT was found to be significantly more accurate than digital intraoral radiographs when direct surgical measurements served as the gold standard for the evaluation of intra-bony defects' regenerative treatment outcomes. CBCT can replace surgical re-entry by providing 3D images and measurements that are almost equivalent to direct surgical measurements.[19,20] Dimensions of alveolar process should be examined in detail prior to dental implant placement to avoid various complications and evaluation of CBCT images has a major importance in preoperative planning and postoperative localization of dental implant.[21]

Role In Implant Site Assessment:

Implant placement requires technique which is capable of obtaining highly accurate alveolar and implant site measurement to assist with treatment planning and avoid damage to adjacent vital structure during surgery. Earlier alveolar and implant site measurement was done either using 2-D radiographs and in some instance using conventional CT (Figure 2). When compared, CBCT is preferable option for implant dentistry, providing greater accuracy in measuring with utilization of lower radiation dose.

Uses[22]

1. To assess the quantity and quality of bone in edentulous ridges.
2. To assess the relation of planned implants to neighboring structures.
3. To assess the success of implant osseointegration.
4. To provide information on correct placement of implants.
5. Before ridge augmentation in anodontia
6. Before bone reconstruction and sinus lifting
7. During planning and in designing a surgical guidance template.

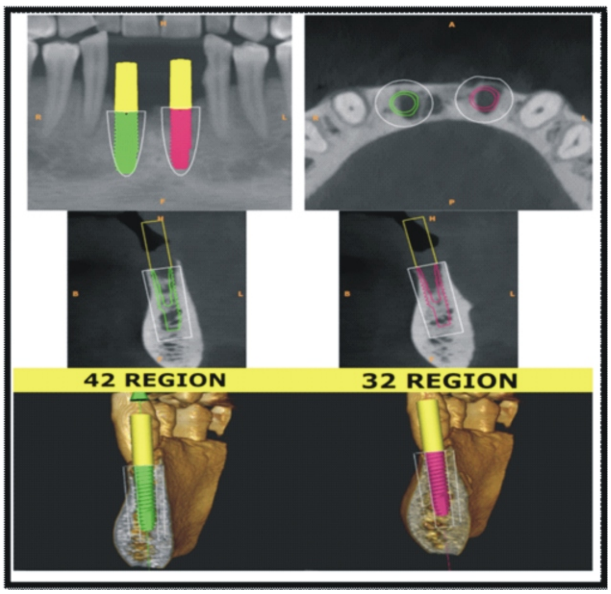

Figure 2: Implant site assessment

Role of CBCT in detecting anterior looping during implant placement:

Apostolakis D and Brown JE (2012) stated that the final part of the inferior alveolar nerve sometimes passes below the lower border and the anterior wall of the mental foramen.[23] After giving off the smaller mandibular incisive branch, the main branch curves back to enter the foramen and emerge to the soft tissues, as the mental nerve. The section of the nerve in front of the mental foramen and just before its ramification to the incisive nerve can be defined as the anterior loop of the inferior alveolar nerve. Selective surgery in the area of the anterior mandible such as implant installation in the interforaminal region or symphysis bone harvesting, may violate the anterior loop resulting in neurosensory disturbances in the area of the lower lip and chin. To avoid such a sequel a 5-mm safe distance to the most distal fixture from the anterior loop and a 5-mm distance from the mental foramen for chin bone harvesting have been proposed.[23,24]

Tolstunov identified and described four alveolar jaw regions—functional implant zones (Figure 3)[21] with unique characteristics of anatomy, blood supply, pattern of bone resorption, bone quality and quantity, need for bone grafting and other supplemental surgical procedures, and a location related implant success rate.

Four functional implant zones identified by Tolstunov[21,22,23]:

i. Functional Implant Zone 1 (Traumatic zone)consists of alveolar ridge of premaxilla and eight anterior teeth: 4 incisors, 2 canines, and 2 first premolars. Any bone loss in the anterior maxillary area is vital due to the esthetic implications on dental implant supported restorations. Loss of teeth in this area is mostly due to trauma and if the teeth are not replaced immediately following trauma, the bone loss continues, leading to difficulty in dental implant placement in a prosthetically favorable position.

ii. Functional Implant Zone 2(Sinus zone): bilateral maxillary posterior zone extends from the maxillary second premolar to the pterygoid plates and is located at the base of the maxillary sinuses.

iii. Functional Implant Zone 3 (Inter-foraminal zone): comprised of the area of the mandibular alveolar ridge between mental foramen and first premolar on each side. This zone is also associated with a thin alveolar ridge. There is abundant evidence in the literature reporting severe bleeding with the formation of expanding sublingual hematomas due to the perforation of the lingual cortex.

iv. Functional Implant Zone 4:- This zone of the alveolar process of the mandible behind the mental foramen on each side and extends from the second premolar to retromolar pad. The distance of the alveolar bone height from the inferior alveolar canal is evaluated when dental implants are considered in the posterior mandible. Careful assessment of the height must be made to avoid injury to the inferior alveolar canal. If there is a violation of the inferior alveolar nerve (IAN), depending on the degree of nerve injury, alteration in sensation, from mild paresthesia to complete anesthesia, is reported.

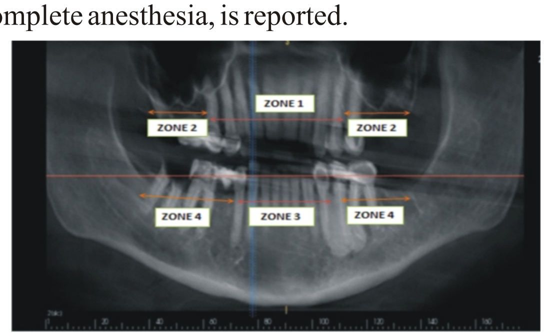

Figure 3: Functional implant zones identified by Tolstunov

Conclusion

Cone beam computed tomography is a diagnostic imaging technology that is changing the way dental practitioners view the oral and maxillofacial complex as well as the teeth and the surrounding tissues. CBCT has been specifically designed to produce undistorted three dimensional images similar to computed tomography (CT), but at a lower equipment cost, simpler image acquisition, and lower patient radiation dose. However the two-dimensional diagnostic imaging has served dentistry well and will continue to do so for the foreseeable future. Intraoral and panoramic radiographs are the basic imaging techniques used in dentistry and are quite often the only imaging techniques required for the detection of dental pathology.

For periodontal disease, CBCT promises to be superior to 2Dimaging for the visualization of bone topography and lesion architecture but no more accurate than 2D for bone height. This factor should be tempered with awareness that restoration in the dentition may obscure views of the alveolar crest. No doubt, future improvements in CBCT technology will result in systems with even more favorable diagnostic yields and lower doses.

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