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Review Article

Cone-beam Computed Tomography - A Boon in Periodontology: A Review

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Abstract

Diagnosis of periodontal disease is firstly based on clinical signs and symptoms, however, when bone destruction is involved, radiographic examination is the most conclusive diagnostic method. Conventional radiographs including intraoral and panoramic imaging are used very frequently for this purpose. Cone-beam computed tomography (CBCT) is a new era in the field of oral radiology making the innovation provide high-quality, thin-slice accurate imaging. CBCT comes to complete help in providing new data to diagnose periodontal lesions. It is an imaging modality which would give an undistorted three-dimensional (3D) vision of a tooth and surrounding structures which is essential to improve the diagnostic potential. It has got the advantage of less exposure of radiation to the patient and reduced scan time. In the field of periodontology, it best enables the clinician to evaluate the crestal alveolar bone architecture and helps in treatment planning for implant placement, hence providing 3D images that facilitate the transition of dental imaging from initial diagnosis to image guidance throughout the treatment phase along with guided implant placement.

Keywords: Cone-beam computed tomography, Periodontology, Three-dimensional imaging

INTRODUCTION

Periodontal disease is a chronic bacterial infection that affects the gingiva and bone supporting the teeth. Treatment of patients with advanced periodontal diseases requires not only extensive clinical recording but also radiological examination. Radiography provides key information on the amount and type of damage to the alveolar bone. The current diagnostic approaches including clinical probing and intraoral radiography have shown several limitations in their reliability.[1]

Intraoral radiography is the most commonly used imaging technique for the diagnosis of periodontal bone defects. However, intraoral radiography provides only a two-dimensional (2D) view of three-dimensional (3D) structures which can lead to underestimation of bone loss and errors in identifying reliable anatomical reference points. 3D diagnostic imaging of the jaws has been of interest from the introduction of computerized tomography (CT) as a clinical tool. However, due to the factors such as high cost and high radiation dosage, use of this technology in dentistry has been limited.[1]

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Cone-beam CT (CBCT) is a relatively new imaging modality and with the introduction of dedicated dentomaxillofacial CBCT scanners in the late 1990s, there has been an explosion of interest in these devices in the field dentistry. It has the obvious advantage of relatively low cost and low-dose.[1]

CBCT provides rapid volumetric image acquisition taken at different points in time that are similar in geometry and contrast, making it possible to evaluate differences occurring in the fourth dimension. In its various dental applications, images of jaws and teeth can be visualized accurately with excellent resolution, can be restructured three-dimensionally, and can be viewed from any angle. Most significantly, the patient radiation dose is 5 times lower than normal CT. Today, CBCT scanning has become a valuable imaging modality in periodontology as well as implantology. For the detection of smallest osseous defects,

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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. In implant treatment, appropriate site or size can be chosen before placement, and osseointegration can be studied over a period of time.[2]

PRINCIPLES AND IMAGE PROCESSING OF CBCT

CBCT uses a single, relatively inexpensive, flat-panel, or image intensifier radiation detector. CBCT imaging is performed using a rotating platform to which the X-ray source and detector are fixed. As the X-ray source and detector rotates around the object, it produces multiple, sequential, and planar images that are mathematically reconstructed into a volumetric dataset. A single rotational sequence would capture enough data for volumetric image construction. The entire scanning of the target region is performed in a single rotation thereby significantly reducing the radiation exposure. Further, the exposure is reduced by 50% (0.0037 mGy) if a 180° scan is performed instead of 360°. In comparison, the radiation exposure in a digital panoramic radiograph is around 0.0063 mGy and around 0.0012 mGy in a periapical radiograph. It has been reported that for an intraoral status of the entire dentition an effective dose ranging from 33 to 84 Sv is required.[1]

CBCT Image Production

CBCT machines scan patients in the following three possible positions: Sitting, standing, or supine. Despite patient orientation within the equipment, the principles of image production remain the same. The four components of CBCT image production are as follows.

Acquisition Configuration

Continuous or pulsed X-ray beam and charged couple device detectors moving synchronously around the fixed fulcrum within the patient's head.

Image Detection

It is determined by individual volume elements or voxels produced from the volumetric data set. CBCT units provide voxel resolutions that are isotropic (equal in all three dimensions).

Image Reconstruction

The processing of acquired projection frames to the volumetric dataset is done on the personal computer which is called as reconstruction.

Image Display

The compilation of all available voxels is presented to the clinician on the computer screen as secondary reconstructed images in three orthogonal planes.[2]

INDICATIONS/ADVANTAGES/ DISADVANTAGES OF CBCT

Indications

- 3D view of teeth position and structure
- Evaluation before the implant placement
- Endodontic evaluation
- Periodontal evaluation
- Evaluation of bone resorption
- Determination of anatomic bone sizes
- Study of the airways
- Positioning of temporary anchoring devices
- Cephalometric analyses
- 3D reconstructions
- Evaluation of jaw bones for
    - Pathology
    - Bony and soft tissue lesions
    - Recognition of fractures and structural maxillofacial deformities
    - Assessment of temporomandibular joint
    - Assessment of inferior alveolar nerve.

In short, CBCT is ideally suited for high-quality and affordable CT scanning of the head and neck in dentomaxillofacial applications.[1,3]

Advantages

Following advantages are offered by CBCT,[2,3]

- It has a rapid scan time as compared with panoramic radiography.
- It gives complete 3D reconstruction and display from any angle.
- Its beam collimation enables limitation of X-radiation to the area of interest.
- Image accuracy produces images with submillimeter isotropic voxel resolution ranging from 0.4 mm to as low as 0.076 mm.
- Reduced patient radiation dose (29–477 μSv) as compared with conventional CT (approximately 2000 μSv). Patient radiation dose is 5 times lower than normal CT, as the exposure time is approximately 18 s, that is, one-seventh the amount compared with the conventional medical CT.
- CBCT units reconstruct the projection data to provide interrelational images in three orthogonal planes (axial, sagittal, and coronal).
- Multiplanar reformation is possible by sectioning volumetric datasets nonorthogonally.
- Multiplanar image can be "thickened" by increasing the number of adjacent voxels included in the display,

referred to as ray sum.
- 3D volume rendering is possible by direct or indirect technique.
- The three positioning beams make patient positioning easy. Scout images enable even more accurate positioning.
- Reduced image artifacts: CBCT projection geometry, together with fast acquisition time, results in a low level of metal artifact in primary and secondary reconstructions.

Disadvantages

1. The high cost compared to that of standard 2D radiographies.
2. It cannot offer a resolution with increased contrast, and also it is not indicated in the exploration of soft tissues but only in the exploration of bone tissue in the maxilla-facial sphere.
3. A significant disadvantage of CBCT is represented by the artifacts that may be present on the image - not due to the scan, but to the presence of implants, restorations from the amalgam, metallic prosthetic restorations, or endodontic treatments. These artifacts are characterized by hyperdense lines and dark images, which affect the quality of the desired image.[2,3-5]

PERIODONTAL APPLICATIONS

CBCT in Assessment of Periodontal Ligament (PDL) Space

The earliest signs of periodontal disease in radiographs are fuzziness, break in the continuity of lamina dura, and a wedge-shaped radiolucent area at the mesial and distal aspect of the PDL space. In addition to this, the proper observation of PDL space may offer some potential regarding detection of occlusal trauma and the effects of systemic diseases on the periodontium.[2] Therefore, only a sensitive imaging technique would be able to detect the earliest changes in the PDL space. The conventional intraoral radiographs have some significant disadvantages including the overlap of anatomical structures due to the positioning of the X-ray tube. Furthermore, there could be errors related to the chemical processing and patient positioning.[1,4]

CBCT for Periodontal Defect Measurements

The extent of periodontal marginal bone loss is not always easy to determine and certainly not the extent with which furcation areas are involved with the conventional radiographic methods.[2] CBCT images provide better diagnostic and quantitative information on periodontal bone levels in 3D than conventional radiography [2].

The periodontal defects as seen in conventional radiography are short of accuracy in terms of 3D architecture of the bone morphology. In CBCT, the bony plates, buccal, and lingual can be visualized with accuracy and any discrepancy can be anticipated before surgical exposure. Furthermore, the defect morphology can be studied in all axial planes with the advent of CBCT modalities. Furthermore, the volumetric analysis of the defect depth preoperatively and postoperatively can lead to a better understanding of the functioning of bone graft eliminating the need of surgical reentry, which can also be useful for treatment planning.

Noujeim *et al.*[6] created periodontal lesions of different depths in dried human mandibles and analyzed them using intraoral radiography and CBCT. They found that CBCT was more accurate in detecting the defects than the conventional radiograph.

Stavropoulos and Wenzel[7] 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.

Leung *et al.*[8] evaluated the accuracy and reliability of CBCT in the diagnosis of naturally occurring bone defects by comparing the difference between the CBCT measurements and measurements made directly on the skulls. They reported that CBCT measurements were not as accurate as direct measurements on skulls. A certain discrepancy between direct measurements and estimated measurements on radiographs has to be considered as clinically acceptable.

Vandenberghe *et al.*[9] studied 30 periodontal bone defects of two adult human skulls using intraoral digital radiography and CBCT. Periodontal bone levels and defects on both imaging modalities were assessed and compared to the gold standard. The study 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.

CBCT in Measuring Periodontal Bone Levels

Sufficient alveolar bone volume and favorable architecture of the alveolar ridge are essential to obtain ideal functional and esthetic prosthetic reconstruction.[1]

Persson *et al.*[11] reported that conventional radiographic images provided a better resolution of the bone levels than what can be achieved from computer screen images.

Mol and Balasundaram[10] compared the image quality between CBCT and conventional radiography in the assessment of alveolar bone levels. They found that CBCT provided slightly better diagnostic and quantitative information on periodontal bone levels in three dimensions than conventional radiography.

Vandenberghe *et al.*[9] reported that CBCT images demonstrated more potential in the morphological description of periodontal bone defects, while the digital radiography provided more bone details.

Soft tissue CBCT for the measurement of gingival tissue and the dimensions of the dentogingival unit.

This novel method is based on CBCT technology called soft tissue CBCT, to visualize and precisely measure distances corresponding to the hard and soft tissues of the periodontium and dentogingival attachment apparatus. With this simple and noninvasive technique, clinicians are able 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.

The width of the facial and palatal/lingual alveolar bone and the width of the facial and palatal/lingual gingival also could be measured.[2]

CBCT Precision in Alveolar Bone Density Measurement

Radiographic follow-up of bone healing after grafting is challenging because of the overlapping of gaining and losing areas within the graft. The new volumetric imaging method, CBCT, offers an opportunity to see inside the bone and pinpoint and measure densities in small localized areas such as a vertical periodontal defect, or an alveolar bone graft. This precision would make it possible to reproducibly quantify the bone remodeling after bone grafting.[2]

CBCT for Diagnostic Imaging for the Implant Patient

Cross-sectional imaging modalities that include conventional X-ray tomography, computed tomography, and CBCT are valuable imaging modalities. Of all the three, CBCT scanning is the most successful, useful, and valuable imaging modality for 3D and cross-sectional evaluation of the implant patient. It has similar advantages and disadvantages as CT scanning. The most significant difference is that CBCT imaging requires much less radiation exposure. Location is the most important factor while placing an implant. From 3D planning to CT-directed placement, to take the advantage of available bone and avoid anatomic structures, the science of implantology has been revolutionized by 3D imaging. Not only has it added safety and accuracy, it has also minimized or eliminated the need for supportive procedures like bone and tissue grafting in many situations. Software and technology development trends suggest that in the near future, CBCT scans will be used to develop a patient-specific 3D model that will be used for implant diagnosis, treatment planning, treatment simulation, implant placement (surgery), and tooth replacement (restoration of implant).[2] Furthermore, the risk determination for osteoporotic patients can be predetermined by analyzing the density of bone. Clinicians have been diagnosing, treatment planning, placing, and restoring modern dental implants using periapical and panoramic imaging films to assess bone anatomy for several decades. Two-dimensional film images have been found to have limitations because of inherent distortion factors, and the noninteractive nature of film itself provides little information regarding bone density, bone width, or spatial proximity of key structures. Diagnostic imaging techniques must always be interpreted in conjunction with good clinical examination. Many factors influence the selection of radiographic techniques for a particular case, including cost, availability, radiation exposure, and case type. The decision is a balance between these factors and the desire to minimize risk of complications to the patient.

CONCLUSIONS

As CBCT scanning is finding more and more applications in dentomaxillofacial radiology, it stands as the privileged field of imaging in periodontics. Current methods of detecting alveolar bone level changes over time or determining 3D architecture of osseous defects are inadequate. This issue has been addressed by the recent low-cost CBCT machines, which has resulted in production of an affordable, low-radiation high-quality 3D data. CBCT is an essential diagnostic tool also for selection of implant design and its placement. CBCT provides high quality of diagnostic images that have an absorbed dose that is comparable with other dental surveys and less than a conventional CT and thus following the principles of radiation protection to reduce the radiations "as low as reasonably achievable" (ALARA). To conclude, CBCT with its high spatial resolution, affordability, smaller size, lower acquisition, and maintenance has made it as a natural fit in periodontal imaging.

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