Cone Beam Computed Tomography: A New Era in Maxillofacial Imaging

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ABSTRACT

Since decades, two dimensional (2D) imaging modalities such as cephalometrics, panoramic and periapical radiography have been the gold standard for diagnosing and treatment planning in dentistry. Nevertheless, this 2D representation has still left some queries unreciprocated which have set the goal towards three dimensional technologies. The advent of cone beam computed tomography is changing the vision of dentists towards the oral and maxillofacial complex. This article reviews this promising technology and its application in various fields of dentistry.
KEYWORDS: Cone Beam Computed Tomography; Field Of View; Multiplanar Reformation; Maxillofacial Imaging

INTRODUCTION

Radiology is an indispensable field in dentistry that facilitates the incidence of any disease, monitoring the progression and assessing treatment efficacy in patients for whom a thorough patient history and examination has been performed.

Ever since the first radiograph was taken in 1896, two-dimensional imaging modalities came into existence in dentistry.[1] Regardless of the technique; plain radiography provides only a 2D view of the complicated three-dimensional (3D) structures. The limitations of all 2D projections are magnification, distortion, superimposition and misinterpretation of structures. Copious efforts have been made towards 3D radiographic imaging, and although computed tomography (CT) has been available, its application in dentistry has been restricted because of cost, access and dose considerations.

The dawn of cone-beam computed tomography (CBCT) has been a colossal advance in dental imaging. CBCT was initially used in angiography, however more recent medical advancements have been put forward in radiotherapy guidance and mammography.[2] This technology is also well-known as dental volumetric tomography, dental CT, cone beam volumetric imaging and cone beam imaging.[3]

CBCT allows the conception in "real time" of images in the axial plane as well as 2D images in the coronal, sagittal and oblique or curved image planes - a process referred to as multiplanar reformation. Moreover, CBCT data are acquiescent to reformation in a volume, rather than a slice, providing 3D information.[4]

PRINCIPLE

Imaging is attained with the help of rotating gantry to which an x-ray source and detector are fixed. A divergent pyramidal or cone-shaped source of ionizing radiation is directed through the center of the area of interest against an x-ray detector on the opposite side. Both the x-ray source and detector revolve around a rotation fulcrum fixed inside the center of the region of interest. During the rotary motion, several (150 to 600 or more) sequential planar projection images of the field of view (FOV) are obtained in a complete, or at times partial, arc. Since CBCT exposure incorporates the entire FOV, only one rotational sequence of the gantry is necessary to acquire enough data for image reconstruction.[2]

CBCT systems can be categorized according to the available FOV or selected scan volume height as follows:[2,5]

- Localized region: approximately 5 cm or less (e.g., dentoalveolar, temporomandibular joint)
- Single arch: 5 cm to 7 cm (e.g., maxilla or mandible)
- Interarch: 7 cm to 10 cm (e.g., mandible and superiorly to include the inferior concha)
- Maxillofacial: 10 cm to 15 cm (e.g., mandible and extending to nasion)
- Craniofacial: greater than 15 cm (e.g., from the lower border of the mandible to the vertex of the head).

Once the basis projection frames have been acquired, data must be processed to create the volumetric data set by a process called reconstruction. Variations are seen in reconstruction depending on the acquisition parameters (voxel size, FOV, number of projections), hardware

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(processing speed, data throughput from acquisition to workstation computer) and software (reconstruction algorithms) used. A reconstruction filter algorithm is applied to convert the data into a complete 2D CT slice. Thus, all the reconstructed slices can now be recombined into a single volume for visualization.[3]

IMAGE ARTIFACTS

The fundamental factor that impairs CBCT image quality is image artifact.[3] They are induced by discrepancies between the actual physical conditions of the measuring set-up (i.e. the CBCT scanner's technical composition plus the composition, position and behavior of the object under investigation) and the simplified mathematical assumptions used for 3D reconstruction.[6] Artifacts can be classified according to their cause as acquisition artifacts**,** patient related artifacts**,** scanner related artifacts and cone beam related artifacts.[2,3]

Artifacts arise from the inherent polychromatic nature of the projection x-ray beam that results in beam hardening (i.e, its mean energy increases because lower energy photons are absorbed in preference to higher energy photons).[2] This is seen as distortion of metallic structures due to differential absorption, known as a cupping artifact and streaks and dark bands that can appear amongst two dense objects.[2,3]

Partial volume averaging is an artifact manifesting due to the beam projection geometry of the CBCT and the image reconstruction method. It is observed when the selected voxel resolution of the scan is larger than the size of the object to be imaged. It occurs in regions where surfaces are rapidly changing in the z direction (e.g., in the temporal bone).

Cone-beam effect is also a probable source of artifact, particularly in the peripheral portions of the scan volume. As the divergent x-ray beam, rotates around the patient in a horizontal plane, the projection data are collected by each detector pixel. The amount of data obtained is a result of the total amount of recorded attenuation along a specific beam projection angle as the scanner completes an arc.[2]

INDICATIONS FOR CBCT

CBCT is particularly useful in the following dental and maxillofacial areas:

- To investigate any jaw pathology such as cysts, tumors and fibro-osseous lesions;
- Investigation of the paranasal sinuses and bony components of the TMJ;[7,8]
- Assessment of pre and post-implant surgery;
- Assessment of orthodontic cases including dental and skeletal base relationship and orthognathic surgeries;
- Assessment of wisdom teeth, in particular, their relationship to the inferior dental canal and the antrum of Highmore;[8]
- Evaluation of facial trauma;
- Endodontics – 'hopeless teeth' can be saved by discovering untreated root canals;
- In addition, sleep disorders can also be diagnosed. Earlier to CBCT, it could only be assessed with a full cranial hospital CT scan.

Ultimately, 3D CBCT will become the **"Nivarna"** of the future.[7]

STRENGTHS OF CBCT

CBCT technology has been extensively used in clinical dental practice with the following advantages in maxillofacial imaging:

- CBCT being a smaller equipment, has a significantly reduced physical footprint and is approximately one quarter to one-fifth the cost of conventional CT.[3]
- Higher resolution and diagnostic potential.
- Rapid scan time between 10 and 40 seconds.
- Collimation of the CBCT primary x-ray beam enables restraint x-radiation to the area of interest.
- Images with submillimeter isotropic voxel resolution ranging from 0.076- 0.4 mm, their depth is usually in the order of 1−2 mm.[8]
- Reduced patient radiation dose equivalent to 5 to 74 times that of a single film-based panoramic X-ray.
- Reconstructs the projection data in three orthogonal planes (axial, sagittal, and coronal).[2]
- Reduced image artifact when compared to conventional CT.

LIMITATIONS OF CBCT

CBCT imaging and diagnosis is a great challenge to the dentist today due to lack of acquaintance with multiplanar imaging that is offered by this novel and exciting technology.

CBCT technology has limitations pertaining to the ''cone-beam'' projection geometry, detector sensitivity, and contrast resolution that produces images which are deficient in clarity and usefulness of conventional CT images. The precision of CBCT images is affected by image noise and poor soft tissue contrast.[2]

COMPARISON OF CBCT WITH CONVENTIONAL CT

CBCT machines differ from the conventional hospital CT scanners (helical, spiral, fan) in the following manner:

- CBCT uses a low-energy fixed anode tube analogous to dental panoramic radiograph machines.
- CBCT machines follow a single rotating arc around the patient, thus capturing the data using a cone-shaped x-ray beam.[9]
- The detectors used in modern CT scanners are arranged in parallel arrays, allowing up to 64 slices to be obtained concurrently with each rotation which reduces the scanning time.[7,8]
- Radiation exposure is equivalent to the exposure from a full mouth periapical series (~20% of the radiation of a helical CT).
- CBCT provides images with higher geometric

accuracy, spatial resolution and significantly less scattered radiation.

- CBCT equipment is smaller and cost effective than medical CT equipment and is particularly well suited to evaluate the jaws because of a lower level of metal artifacts in reconstructions versus its helical predecessor.
- On a CBCT image, the area around any metallic prosthesis is usually of diagnostic quality with minimal scattering and distortion.[9]

In the field of oral and maxillofacial radiographic imaging, dental CBCT can be suggested as a dose-sparing technique as compared to medical CT scans in routine dental practice.[10]

SPECIFIC APPLICATIONS IN DENTISTRY

CBCT technology has a significant impact on maxillofacial imaging. It has been applied to diagnosis in all areas of dentistry and is now expanding into treatment applications. It may be considered an alternative for panoramic or conventional projection radiographic applications but is relatively a complementary modality for specific applications.[3]

1) Oral and maxillofacial surgery: CBCT enables the analysis of jaw pathology, the assessment of impacted teeth, supernumerary teeth and their relation to vital structures, cases of cleft palate, orthognathic surgery, cortical and trabecular bone related changes in bisphosphonate-associated osteonecrosis of the jaw (BONJ) and the assessment of bone grafts.[11]

CBCT is chiefly used in planning of orthognathic surgery pertaining to facial orthomorphic surgery. It gives a detailed visualization of the interocclusal relationship in order to enhance the 3-D virtual skull model with a detailed dental surface.

In patients with suspected craniosynostosis, 3D shaded surface display may merge an open suture with the adjacent calvarial bone. This represents an overestimation of the condition or may not display peri-sutural sclerosis well, which may be seen in early sutural closure.

CBCT has also demonstrated significant differences in the airway volume and anterio-posterior dimension of the oropharyngeal airway amidst obstructive sleep apnea patients. Three-dimensional airway analysis is useful when sedation is planned for dental reconstruction. Preliminary studies show that three-dimensional image reconstructions are useful as ‘‘virtual laryngoscopy’’ in airway management during general anesthesia.[9]

2) Endodontics: CBCT imaging is apparently the most potential technology for improving the detection and depth of caries on proximal and occlusal surfaces. CBCT is a very useful tool in evaluation of root canal morphology and root fractures, diagnosis of endodontic & non-endodontic pathosis, analysis of external & internal root resorption, diagnosis of invasive cervical resorption, endodontic surgical planning and visualizing extruded root canal materials which are affecting anatomical structures.[5,12] It is also used in the diagnosis of dento-alveolar trauma since the precise nature and severity of alveolar and luxation injuries can be determined in a single scan. Recently, owing to its reliability and accuracy, CBCT has also been used to evaluate the canal preparation in different instrumentation techniques.[1,5]

Inflammatory root resorption can be detected in early stages with CBCT as compared to conventional 2-D X-ray. However, in cases of external root resorption, external cervical and internal resorption, both resorption as well as extent of the lesion can be identified significantly. Owing to its accuracy, it is very helpful in detecting the pulpal extensions in talon cusps and the position of fractured instruments. It is also a reliable tool for presurgical evaluation of the proximity of the tooth to adjoining vital structures, size, and extent of lesions. Moreover, the anatomy and morphology of roots can also be assessed with very true measurements. In cases of emergency and trauma, its application can aid in the derivation of a proper diagnosis and treatment approach.[5]

3) Implantology: Dental implants have increased demand in today’s dental practice for prosthetic rehabilitation. This was attainable with conventional CT as accurate measurements are needed to avoid damage to vital structures. Nevertheless, CBCT with new software gives more accurate measurements at reduced dosage and constructs surgical guide which prevents further damage. For example, defect size and shape form the basis for calculating the required graft material, predicting the probable stability of the postgraft arch, estimating quality of bone graft over time and in growing patients, predicting the prognosis. This leads to reduced implant failure, as case selection can be based on much more reliable information. CBCT facilitates the assessment of bone quality and quantity. It also helps to assess the relation of planned implants to neighboring structures, before ridge augmentation in anodontia, bone reconstruction, and sinus lifting.[1]

4) Orthodontics: Orthodontists can use CBCT images in cephalometric analysis and assessment of facial growth, airway function, disturbances in tooth eruption and age estimation.

CBCT imaging in orthodontics is mainly focused on the evaluation of impacted canines with a prevalence of approximately 0.9% to 3.0%. Various other teeth become impacted less often than canines but still pose a significant orthodontic challenge. Maxillary central incisors can be impacted and displaced subsequent to the presence of a mesiodens.

CBCT is an unswerving tool in the evaluation of the proximity to vital structures that may interfere with orthodontic treatment. Mini-screw implants serve as a temporary anchorage and CBCT is valuable for ensuring a safe insertion and to assess the bone density before, during and after treatment.[1]

5) Periodontics: CBCT is helpful in assessing a detailed morphologic description of the bone with minimal error margins. The measurements obtained have been proved to be as accurate as done with a periodontal probe. Furthermore, it also evaluates furcation involvements, buccal and lingual defects, which was formerly not possible with conventional 2-D radiographs. Due to its high accuracy, intra-bony defects can be accurately measured, and dehiscence, fenestration defects, periodontal cysts and determining the outcome of regenerative periodontal therapy. [1,12]

6) Pediatric dentistry: Besides other clinical implications, CBCT can as well evaluate eruption pattern of teeth along with any anomalies in number or shape. This can facilitate clinician's plan of eruption guidance, and serial extraction customized to individual patients. It also allows determining the exact site of resorption and is principally helpful in cases of resorption on the lingual or facial side of the tooth. It also determines cystic lesions along with their extent, various bony pathologies like tumors, fracture lines, condensing osteitis and focal apical osteopetrosis. CBCT can also be used in an identical approach as in adults for determining root morphology, root fractures, facilitating retrieval of broken instrument from canal and orthodontic tooth movement.

However, use of CBCT in children should be defensible depending upon the case such that its application prevails over the potential risks of radiation exposure and all the basic principles should be followed apparently.[13]

7) General dentistry –

- Temporomandibular joint disorder: CBCT has the ability to define the true position of the condyle in the fossa, the extent of condylar translation and visualize soft tissue around the TMJ. It is the imaging device of choice in cases of trauma, pain, dysfunction, fibro-osseous ankylosis and in detecting condylar cortical erosion and cysts. With the advent of 3-D features, the image guided puncture technique for TMJ disk adhesion cases can be carried out safely.[1]
- Influence of body mass index, age, implants and dental restorations: A study conducted by Ritter et al. (2009) affirmed that age and the amount of dental restorations may have a negative impact on CBCT image quality, whereas no such effect is seen in relation to gender and body mass index. The image quality of mental foramen, mandibular canal, and nasal floor has a negative influence due to age but not by the amount of dental restorations. Further studies are required to explicate influential factors on CBCT image quality.[14]

8) Forensic dentistry: A custom-made voxel counting software has been developed for calculating the ratio between pulp canal and tooth volume based on cone-beam CT tooth images, thereby helpful in age estimation in forensic odontology research.[15]

CBCT IN ENT IMAGING

Along with dental exploration, CBCT is helpful in assessing inflammatory and infectious sinus pathology. Effusion, mucosal thickening, ostial obstruction and tooth sinus relation are absolutely visible, with exactitude to or greater than that of CT. Assessment of traumatic bone lesions of the maxillofacial region without associated neurologic or cranial lesions can be carried out rapidly and easily on CBCT. For the ear, it is an exceptional substitute, with a lower radiation level and ideal for iterative examination, postoperative follow-up and pediatric examination.[16]

CONCLUSION

The development and rapid commercialization of CBCT technology dedicated for use in the maxillofacial region with increased diagnostic capability and lower radiation dose will help bring this expertise into the mainstream. If a drop in price occurs, then an era of this form of advanced dental imaging may emerge. Presently, CBCT imaging similar to conventional CT scanners have arisen as a highly useful and indispensable part of the dental imaging armamentarium.

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