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Cone beam computed tomography implications in Dentistry

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Abstract
The commencement of cone beam computed tomography (CBCT) apparatus in dentistry changed the way of practicing oral and maxillofacial radiology. CBCT was embraced into the dental practice very rapidly because of its compact size, low cost, low ionizing radiation exposure as compared to medical computed tomography. CBCT also provides 3D evaluation of the maxillofacial area with minimal distortion, as similar to medical CT. This article gives an overview of basic principles of CBCT technology and reviews its implications and limitations in oral and maxillofacial region.

Keywords: Radiology, Cone beam computed tomography, Principle, Advantages, Limitations, Applications.

Introduction[1,2]
Diagnostic imaging over the past few decades, turned out to be rather more refined as a outcome of addition of various imaging technology with complex physical principles. The discovery of X – rays by Sir Wilhelm Conrad Roentgen (1895) was an incredible era in the history of medicine. Three dimensional imaging (3D) evolved to meet the demands of advanced technologies for delivering the treatment and at the same time responsible for the evolution of new treatment procedures. Considering the limitations (superimpositions, distortions etc.) of two-dimensional (2D) radiography which was the backbone of diagnostic imaging for many years, doubt exists that it will continue to contribute in the future. G.N. Hounsfield (1972) introduced computerized transverse axial scanning that lead to introduction of Computed Tomography (CT). However the high cost, limited access, and high radiation exposure, were the main downsides for under utilization of CT in dentistry. Arai et al. in Japan and Mozzo et al. in Italy working independently, introduced the Cone Beam Computed Tomography (CBCT) for the oral and maxillofacial applications and like CT, offered 3D exploration and more precise imaging compared to 2D imaging. The cost effective technology of CBCT, led to speedy entrances into dentistry with demand for commitment of dental professionals and dental educators to explore the applications of CBCT technology.

At first, CBCT gained popularity in the field of dental implantology. Recently, the uses of CBCT surrounds field of orthodontics, oral and maxillofacial surgery, endodontics, temporomandibular joint (TMJ) disorders, periodontics, sleep disorders, airway analysis along with dental implantology.

Principle[1]
A CBCT machine, employ a cone-shaped beam and a reciprocal solid state flat panel detector, that rotates once around the patient, 180-360 degrees, covering the outlined anatomical volume (complete dental/ maxillofacial volume) instead of slice-by-slice imaging found in conventional CT. This single scan capture data (180-1024 2D images, similar to lateral cephalometric images, each one is marginally offset), in contrast to stacked axial slices found in CT. Depending upon manufacturers, the scanning time of CBCT instrumentally differ from nearly 5 to 40 seconds. The X-ray parameters of CBCT similar to that of panoramic radiography with a usual operating range of 1-15 mA at 90-120 kVp, although that of CT is significantly higher at 120- 150 mA and 220 kVp. The captured 2D images are instantly conveyed to the computer, which reconstructs them, using modified Feldkamp algorithm program into the anatomical volume for viewing at 1:1 magnitute relation in axial, coronal, and sagittal planes (orthogonal planes). The information is in the Digital Imaging and

Communications in Medicine (DICOM) format, which enables ease of telecommunication and usage with other third party imaging software system.

Most of the CBCT instrumentation has user-friendly viewing software containing basic 3D imaging tools. Third party software are attainable at a wide range of cost, which offer considerable tools to research and do treatment plans. Apart from these, third party software are used to prepare surgical guides, virtual study prototypes, and laser generated resin models, alleviate the strategy of identification, treatment set up and delivery of the treatment.

Displaying modes of CBCT other than orthogonal views[1,3]

Oblique slicing: Non-orthogonal slicing of the CBCT images at any angle is practicable because of the isotropic nature of the datasets to supply non-axial 2-D planar images known as multiplanar reformations (MPR). This function creates 2D images at any angle by cutting across a set of axial images, that makes easy in evaluation of specific structures (Impacted teeth, TMJ).

Curved slicing: It permits to trace the jaw arch to display a trace read, providing acquainted panorama like view.

Cross-sectional (oblique coronal) view: It creates a group of sequential cross-sectional images perpendicular to curved slice with the choice of choosing the thickness and spacing. Such images are valuable in the examination of morphometric characteristics of alveolar bone for implant placement, the relationship of impacted mandibular third molar with mandibular canal, condylar surface and shape within the symptomatic TMJ or pathological conditions affecting the jaws.

Ray sum: It allows to display the thickened MPR slices by adding up adjacent voxels. The ensuing image 'ray sum' denotes actual volume of the patient which can be used for generating virtual projections, such as panoramic or cephalometric images identical to conventional radiographs without magnification and parallax distortion. However, they can be negatively affected by the superimposition of multiple structures analogous to 2D imaging.[3]

Volume rendering: It enables one to selectively display voxels in a data set to visualize volume. Direct volume rendering and indirect volume rendering are the two frequently used tools with this function. Direct volume rendering involves picking an arbitrary threshold of voxel values, below or above which all gray values are excluded. Most commonly used technique is maximum intensity projection (MIP). MIP images are ideal for locating impacted teeth, for TMJ assessment, for assessment of fractures, for craniofacial analysis, for surgical follow-up, and for visualization of soft tissue calcifications. Indirect volume rendering (IVR) requires selection of the density of the voxels to be displayed within an entire data set called segmentation, resulting in a volumetric surface reconstruction with depth. Two kinds of views are possible: views that are solid (surface rendering) and views that are transparent (volumetric rendering). IVR is ideal for visualization and analysis of craniofacial conditions and determination of relationships of various anatomic features, such as the inferior alveolar canal to the mandibular third molar.[3]

Advantages of CBCT[4]

CBCT is very suitable for imaging the craniofacial area. It gives clear images of highly contrasted structures and is exceptionally useful for evaluating bone.

1. *X-ray beam limitation:* Minimizing the size of the irradiated area by collimation of the primary X-ray beam to the area of interest minimizes the radiation dose. Most of the CBCT apparatus can be adjusted to scan small regions for certain examination. Others can scan the entire craniofacial complex if needed.
2. *Image accuracy:* CBCT apparatus consists of a volumetric data set comprises a 3D block of smaller cuboid structures called as voxels. Voxels size determines the resolution of the picture. Conventional CT comprises of voxels that are anistrophic ie. rectangular cubes where the longest dimension of the voxel is the axial slice thickness and is determined by slice pitch, a function of gantry motion. Although CT voxel surfaces can be as small as 0.625mm square, their depth is approximately 1-2 mm. All CBCT unit provide

voxel resolutions that are isotropic, equal in all 3 dimensions. This produces submilimeter resolution ranging from 0.4mm to as low as 0.125mm.

3. *Rapid scan time:* Scan time of CBCT machine is 10-70 seconds because CBCT obtain all basis images in single rotation and comparable with that of medical spiral system (MDCT system).
4. *Dose reduction:* Effective dose of radiation is 36.9-50.3µSv that can be significantly reduced by upto 98% compared with “conventional” fan-beam CT systems. For mandible average range is 1,320- 3,324 µSv and for maxilla 1,031-1420 µSv. This reduces the effective patient dose to approximately that of a film based periapical survey of the dentition ie. 13-100 µSv or 4-5 times that of a single panaromic radiographs 2.9-11 µSv.
5. *Display modes unique to maxillofacial imaging:* Reconstruction of CBCT data is executed originally by personal computer. Software can be made available for the user as well as for radiologists, either by direct purchase or innovative “per use” license from various vendors. The clinician gets the opportunity to use chair side image display, real time analysis and MPR (multiplanar) modes that are task specific by this. As the CBCT volumetric data is isotropic, the entire volume can be oriented so that the patient’s anatomic features are realigned.
6. *Reduced image errors:* By suppressing algorithms and increase in number of projections, CBCT images can result in low level of metal errors, particularly in second reconstruction designed for viewing the teeth and jaws.

Limations of CBCT[5]

It is essential that the dentist ensures that the radiological apparatus is calibrated and has appropriate contrast and sufficient brightness along with reduced required lighting. Educators should be aware that the referral to an oral and maxillofacial radiologist may be indicated for most cases for proper monitor, ambient lighting, and equipment settings may be available only in a specialist office.

CBCT produce relatively high scatter radiation during image acquisition and inherent flat panel detector related errors, this result in demonstration of limited contrast resolution. CBCT is not sufficient for soft tissue diagnosis, however it would not be a problem in diagnosing hard tissues.

A careful selection of parameters like patient size, field of view, region of interest, and resolution is required to optimizes examination data and lessen patient’s exposure. In adult patient, fatal malignancy related to CBCT is between 1/100,000 and 1/350,000 and when using CBCT in children this risk could be twice as much (according to 2009 ICRP reports).

Streaking and motion errors are limited in recent CBCT units, nonetheless it is not completely avoided.

Applications of CBCT[1,4,6-8]

Basic intensification in CBCT includes magnification and visual adaptations to narrow the range of displayed grey-scales and contrast level within these grey-scales, the ability to add annotation and cursor-driven measurement. All CBCT machines initially provide correted axial, coronal and sagittal perpendicular MPR images. The utility of CBCT in surgical assessment of pathology, implant planning, pre- and postoperative assessment of craniofacial fractures and TMJ assesement has been announced. CBCT is useful in assessment of growth and development, in orthodontics. The greatest advantage of CBCT in maxillofacial imaging is the ability of interacting with data and to generate images replicating those usually used in clinical practice.

Implantology: Missing teeth replacement by dental implant requires correct evaluation of the implant site for the successful implant placement and to avoid injury to surrounding vital structures. CBCT provides precise evaluation of dimensions and contours of the residual ridge in a buccolingual dimension. CBCT employ multiplanar and 3D images in implant planning to help in determining the exact height, width and alveolar ridge anatomy of the alveolar bone, also the relationship of the edentulous sites with adjacent anatomical structures. With the help of the CBCT data sets guided implant placement surgery can be performed. The clinician can determine pre-prosthetic surgery such as bone grafting or if sinus lift is needed prior to implant placement with the 3D potential of the CBCT.

Oral and maxillofacial surgery: As CBCT has extensive accessibility dentists are employing it in oral and maxillofacial surgeries. CBCT provides precise measurements of surface distance making it the choice for diagnosing and treating midfacial and orbital fractures also dentoalveolar fractures. Because of the intraoperative ability it has also been assessed in mandibular fracture fixation. CBCT is also aid to examine accurate location and extension of pathologies of jaw like odontogenic and non-odontogenic tumors, cysts as well as osteomyelitis. Pathologic calcifications like tonsilloliths, lymph nodes, salivary gland stones can also be acknowledged in terms of location distinguished from presumably notable calcifications, which occurs in carotid artery. The evaluation of impacted or supernumerary teeth and their association with vital structures has been indispensible.

Orthodontics: Due to the capacity of imaging a large field of view that includes all the landmarks for cephalometric analysis CBCT has been used in orthodontics. The 3D image needs to include the skull base, facial bones, and facial soft tissues for analyzing of skeletal jaw relationships. By exporting the DICOM files into specialized software programs, orthodontists are capable to perform cephalometric examination and treatment planning. In an orthodontic case with proposed orthognathic surgery a CBCT analysis will be helpful. Another utilization of CBCT in orthodontics is to find the precise location of any impacted teeth, along with the relationship of adjacent anatomical structures. This information can assist the clinician in determining the best approach for each case. The extent of the resorption may be evaluated through CBCT imaging if root resorption of teeth is present due to impacted teeth. The main advantage of CBCT on the top of other dental imaging is the cross-sectional view without superimposition, where the buccolingual position of the roots can be assessed.

Implications in TMJ disorders: To enable analysis and function of TMJ CBCT imaging gives multiplanar and possibly 3D images of the condyle and surrounding structures. Applicable TMJ imaging practices should comprise reformatted panoramic and axial reference images; corrected parasagittal and paracoronal crosssectional slices; and for cases during which spatiality is suspected or surgery is a contemplated, volumetric reconstruction. In revealing dislocation of the joint disk CBCT enables to diagnose the joint space and the exact position of the condyle within the fossa. In addition, CBCT enables to quantify the roof of the glenoid fossa and assists in locating the soft tissue around the TMJ, providing a practicable diagnosis and avoiding the necessity for Magnetic Resonance Imaging. These benefits drawn above have made CBCT the foremost imaging device for cases involving developmental anomalies of the condyle, trauma, fibro-osseous ankylosis, pain, dysfunction, and condylar cortical erosion, rheumatoid arthritis and cysts.

Implications in endondontics: For diagnosing periapical pathology CBCT is more accurate than periapical radiographs. In cases where clinical and conventional radiographic evaluations are inconclusive CBCT can be used to evaluate dentoalveolar trauma. Oblique fractures exact location can be diagnosed clearly in CBCT hence can be treated more appropriately. When the teeth are mobile or fractured, patients preferably find CBCT more comfortable. CBCT helps in assessment of complicated root canal anatomy that helps to gain desired standard of treatment. Fractured files and perforations can also be examined with the help of CBCT. CBCT is significantly more sensitive in detecting resorptive lesions and also in assisting dentists with chosing the correct treatment plan. CBCT is useful for planning surgical endodontic procedures, as it will provide precise information as to the size and location of the periapical lesion and root apex in relation to structures such as the maxillary sinus, inferior dental canal, and mental foramen.

Implications in periodontics: 2D imaging was the centerpiece in periodontal diagnosis for several decades,, however, their limitations led to underneath approximation of the bone loss. The literature has confirmed that morphometric analysis of periodontal diseases by CBCT to be as accurate as direct measurement using a periodontal probe. In addition, CBCT is much better than 2D radiographs in visualization of buccal and lingual defects due to absence of superimposition of the structures. CBCT offers accurate measurement of intrabony defects and lets clinicians to evaluate furcation involvement, dehiscence, fenestration defects, and periodontal cysts and to assess postsurgical consequences of regenerative periodontal treatment.

Implications in forensic dentistry: Age estimation is one of the significant part of forensic dentistry. Enamel is mostly resistant to alterations beyond normal wear and tear; conversely, the pulpodentinal complex displays physiologic and pathological changes with progressing age. Characteristically, to quantify these changes, extraction and sectioning of teeth is necessary, which is not always a attainable choice. CBCT, however, affords a non-invasive substitute.

Conclusion

This review article emphasize about basics and development of CBCT technology in maxillofacial region. It doubtlessly increase dental practitioner access to 3D radiographic examinations in clinical dental practice, it also improves treatment planning. CBCT is also cost effective, high resolution imaging apparatus that continues to be of value in oral and maxillofacial procedures. In comparison to alternative medical CT scans, dental CBCT can be recommended as a dose-sparing technique.

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Conflict of Interest

None.

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