The third dimension of dentistry: Cone beam computed tomography - Its applications
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Abstract
Rapidly evolving advances in oral healthcare in the last 10 years has increased the need for various novel diagnostic imaging modalities that aid in formulating the early accurate diagnosis, and therefore, plan the treatment with the best prognostic value that is achievable. Cone beam computed tomography (CBCT) is a radiographic imaging technique that yields precise three-dimensional images of the maxillofacial region. For more than a decade now CBCT has been used for dental and maxillofacial imaging and its availability and use are increasing continuously. This has necessitated a review of the various application of CBCT in dentistry.

Introduction
Radiology has played revolutionary role in diagnosis, treatment plan, and prognostic value of various dental diseases ever since the invention of X-rays in 1895.
Two-dimensional radiographs are the most commonly employed techniques in dentistry. These radiographic techniques suffer from magnification, distortions, superimpositions, and misrepresentation of structures limiting its diagnostic accuracy. To overcome these diagnostic challenges three-dimensional (3D) radiographic techniques were incorporated after the discovery in the year 1972 by Sir Godfrey N. Hounsfield of the foremost commercial computed tomography (CT) scanner. Nevertheless due to its soaring radiation exposure and cost the use of CT in dentistry is limited. To combat these a newer generation of CT was developed in 1982 called cone beam CT (CBCT). The introduction of CBCT specifically dedicated to imaging the maxillofacial region heralds a true paradigm shift from 2D to an alternative 3D which compensates for the shortcomings of other 3D imaging options.1,2,3
CBCT imaging employs shaped source of ionizing radiation in the form of a divergent pyramidal or cone shape which is directed through the central point of the area of interest onto an area X-ray detector present on the opposite side. There is a stationary fulcrum inside the region of interest around which there is a rotating source of the X-rays and detectors that capture the image. Multiple sequential planar projection images of about 600 frames raw data is obtained within a solitary complete rotation from the desired field of view (FOV). Limited or small FOV units of <10 cm size are appropriate for dentoalveolar imaging and are largely beneficial for endodontic applications, diagnosis of cysts and tumors. FOV’s ranging between 10 and 15 cm are termed as medium FOV and are useful for imaging preimplant planning and pathological conditions in maxillomandibular region. FOV units range from 15 to 23 cm are called as large FOV which are useful in the diagnosis of maxillofacial trauma, orthodontic analysis, temporomandibular joint (TMJ) analysis and various pathologies of the jaws.3-5
These specific clinical applications are discussed ahead in detail.

CBCT in Implantology
Initial proof authenticates the capability of CBCT images to illustrate preoperatively the quantity and quality of bone available for placement of implant as well as to envisage the boundaries of vital structures significant in surgical preparation for dental implant planning for instance such as incisive canal, mandibular canal, maxillary sinus, and mental foramen.
The uses of this imaging modality in implantology are as follows:
1. Aids in locating and determining the distance of implant to vital anatomic structures
2. Measurement of alveolar bone thickness and appreciate bone contours to decide if a bone graft or sinus lift is desired
3. To conclude the most appropriate implant size and type for a particular patient
4. Identifies the ideal implant location and angulations.

The dental surgeon can approach all cases with the assurance of having all the best existing image information and technology have been used.\(^5\)

CBCT provides cross-sectional images in various planes of the alveolar bone height, width, and angulations. The science of CBCT in implantology has additional protection, precision and minimized errors. Further radiographic markers are used by inserting it as a tool at the time of scan which serves as a precise reference of the location of proposed implants.\(^7\)

With the assistance of DICOM data the computer-generated surgical guides (stereolithographic models) are being fabricated from the CBCT image data to remove the work and potential inaccuracy of impressions, conventional guide stents. Using technology minimally invasive surgery is performed without the need to raise a flap, thereby minimizing surgery time, post-operative pain and swelling, and recovery time. The dental laboratory uses the information stored in the surgical template to fabricate presurgically a master cast and short-term restoration that can be positioned instantly after surgery (teeth-in-an-hour).\(^7,8\) The use of computer-guided implant surgery has wholly enhanced the dental implant team’s ability to plan, place, and restore implants accurately with a level of precision.\(^6\)

**Impactions**

Cone beam scans afford more accurate 3D assessments to provide predictable management results along with dropping the risks associated with removal of impacted tooth. The site and root configuration of impacted and unerupted teeth can be visualized with incomparable precision. The periapical lesions extent, site, regions of bone destruction, and accurate assessment of the involvement of maxillary sinus are all distinctly defined. Even the “spots” seen on conventional radiography can be pinpointed, eliminating the intricacy of artifact and allowing the dentist to provide patients state-of-the-art diagnosis.\(^1,9,10\) The accurate assessment of the spot and the relation of the inferior alveolar canal to the roots of mandibular third molar may reduce the injuries to nerve in extraction of impacted third molar and during implant placement which avoids the everlasting loss of sensation to the lower lip. Although conventional panoramic imaging is possibly sufficient when the third molar is clear of the canal but it is advisable to employ 3D imaging approach in cases of radiographic superimposition of the structures. This has been achieved by CBCT at comparatively low radiation dose amalgamated either with the proprietary software accompanying the imaging device or with third party diagnostic software.\(^5,11\)

**Craniofacial Fractures**

Imaging of craniofacial fractures is a coherent application for CBCT. It is used to distinguish mandibular condylar fracture, fractures of the root of the teeth and the displacement of anterior maxillary teeth. Several additional reports have adorned the low-dose high-resolution principle of CBCT imaging in pre-operative depiction of mandibular and orbital floor fractures.\(^10\) In a study, the authors stated that although CBCT can exhibit clearly the orbital content herniation, due to its poorer contrast resolution it lacks the ability to build a distinction among the tissue components of the herniated materials.\(^14\)

**TMJ**

Congenital/developmental malformations, malocclusion, degenerative diseases, ankylosis, joint remodeling following diskectomy can be assessed more precisely in CBCT. CBCT in the recent past has been finding its place as a significant TMJ imaging modality through various ongoing researches, although introductory experiments have yet to transform into clinical studies. In a study by Alexiou et al.,\(^13\) the authors concluded that CBCT accurately assess periarticular bony defects, flattenings, osteophytes, and sclerotic changes.

Pathologic changes, such as osteophytes, condylar erosion, fractures, ankylosis, dislocation, growth abnormalities (like condylar hyperplasia), rheumatic disease, and degenerative joint diseases are optimally viewed on CBCT.\(^13-15\)

**Calcification in Sinus**

CBCT may be appropriate for specific imaging tasks in the circumstance of intraoperative and pre-operative low-dose assessment of paranasal sinus anatomy, surgical outcomes.\(^16\)

CBCT analysis provides us with volumetric data that can be used to visualize the complete airway path from both the nasal and oral entrances extending up to the laryngeal spaces for\(^12,16,17\):
1. Precise recognition of anatomical borders
2. Analysis of level of infection and existence of polyps
3. Assistance in airway studies for analysis and management of obstructive sleep apnea
4. Airway space assessment along with determining the actual volume
5. Bird’s eye view of the point of airway constriction.

**Cone Beam Computed Sialography of Sialoliths**

The advantage of CBCT sialography over conventional sialography is that 3D reconstruction can be performed and then viewed from any direction and in any slice thickness,
and from which cross-sectional slices may be obtained in any direction. In a study by Drage and Brown, the authors have stated that CBCT has proven useful in demonstrating areas of complex anatomy, such as the route of the submandibular duct over the posterior free margin of the mylohyoid muscle, the paths of the ducts to the deep pole of the parotid gland or the route of the anterior parotid duct over the anterior margin of masseter muscle.\[18\]

Orthodontics

CBCT offers a 3D image that can be used to aid in orthodontic tooth movement in all three planes of space. CBCT provides the display of position of impacted and supernumerary teeth and their relationships to adjacent roots and other anatomic structures facilitating planning of the subsequent movement.\[12,17\]

Structural and anatomic relationships can be visualized accurately due to the cross-sectional imaging that omits image overlay. The current criterion in orthodontics for imaging is still conventional CT. CBCT imaging has in recent past been largely explored in the field of orthodontics for evaluation of thickness of bone on the palatal aspect, skeletal growth patterns, age estimation by evaluating the dentition, upper airway assessment, and visualization of impacted teeth.\[5,12\]

CBCT imaging allows a more widespread orthodontic diagnosis and more correct treatment planning by:
1. Position and anatomy of impacted teeth precisely in 3D
2. One is to one imaging for treatment planning and growth assessments in orthognathic surgery cases
3. Airway assessments
4. Detailed planning for placement of orthodontic anchorage and temporary anchorage devices (TADs)
5. Assessment of level of skeletal asymmetry.\[9,20\]

Miniscule details about the root resorption, available bone width for the buccolingual movement of teeth, tooth inclination and torque can be obtained. There are numerous potential benefits to 3D cephalometry including accuracy of linear measurements, visual demonstration of dentoskeletal relationships and facial esthetics, and the potential for assessment of growth and development are perhaps the greatest potential benefits of CBCT in orthodontics.\[21,22\]

Endodontics

Periradicular surgical preparation, evaluation of periapical pathology, categorization of internal and external root resorption, and dentoalveolar trauma evaluation has all been proven to be more accurate to analyze using CBCT. CBCT has been proven to be finer to periradicular radiographs in the depiction of periapical lesions, signifying lesion immediacy to the maxillary sinus, sinus membrane connection, and lesion location relative to the mandibular canal.\[23\] However, CBCT has not proven its efficacy to assess’ caries accurately.\[33\] van Daatselaar et al. have stated that sensitivity increases with CBCT in detection of caries but does not alter the specificity.\[24,25\]

Periodontics

CBCT allows added precise evaluation of bone craters and furcation involvements than digital intraoral radiography. Kasaj and Willershausen have stated that these findings offer perspectives for further studies in balancing radiation dose and gather information for assessment of periodontal bone loss.\[26\]

Mengel et al.\[27\] compared the method of monitoring bone loss using the conventional periodontal probe and bitewing radiographs method with CBCT images. The authors concluded that CBCT promises to be superior to 2D imaging for the revelation of bone topography and lesion architecture but of similar efficiency as that of 2D for bone height investigation. Most of the CBCT software includes tools for evaluating and monitoring bone density, which aid to assess the efficiency, predict the results of treatment, and identify the prognosis of the condition.\[12\]

3D Virtual Models and Rapid Prototyping

The prospect of fabricating individual 3D models which clearly demonstrate the underlying skeletal pathology must certainly be ranked as representing significant progress in the planning of corrective maxillofacial surgery. Ongoing technical developments have contributed to the fact that contemporary surgery is computer assisted surgery, and such development is likely to continue. User-friendly interfaces which shorten operational procedures certainly improve the acceptance and distribution of this techniques.\[10\]

In 2007, Kim et al. used CBCT data to replicate dental models to manufacture drilling guides for orthodontic screws.\[28\] In 2008 Periago et al. concluded that CBCT datasets would be sufficiently accurate for clinical craniofacial analyses.\[21\]

Radiotherapy by CBCT

Image guided radiation therapy is in the recent past has been stated to use CBCT for patient positioning during radiation therapy.

With CBCT, a clear-cut repositioning of the patient to the isocenter of the radiotherapy machine is obtained with a single rotation immediately before delivering radiotherapy and is further reconstructed in <2 min for treatment planning. Other methods such as megavoltage (MV) imaging-based methods which comprises MV CBCT and helical tomography have also been researched religiously for verifying patient position before radiotherapy treatment in comparison to the regular CBCT equipment.\[12,17\]

CBCT in Forensic Odontology

CBCT is recently gaining importance in forensic dentistry. It provides a good, noninvasive alternative to view the physiological as well as the pathological changes of the pulpo-dental complex in antemortem and postmortem scans.\[29\] The usage of
CBCT in forensic dentistry mainly lies in age estimation, which is an integral part of forensic examination. There is high scope of CBCT for victim identification and age estimation. CBCT has also displayed its importance in skeletal age assessment, especially when analyzing the cervical vertebrae morphology. It provides a 3D approach to the biologic aging of ortho patients, by providing images of the cervical spine for age assessment.

**Future Trends in CBCT**

The future of CBCT is the enhanced CT scanner called as “ultra CBCT scanners” which has evolved into novel machines. Ultra CBCT imaging provides significant information concerning the 3D structure of vascular channels, nerve supply of the region imaged, soft tissue and bone.[12] Conventional cone CT imaging renders an 8-bit grayscale which yields 256 shades or 12-bit grayscale that provides 4,096 shades, whereas the recent IMTEC Imaging’s new ILUMA Ultra CBCT Scanner yields images in 14-bit grayscale, resulting in the shades of 16,384.[8,30]

The contrast-enhanced territories depicted by CBCT with selective intra-arterial contrast agent administration were employed to forecast allotment of microspheres. Such further studies are required in the future for maxillofacial region.[9]

These machines can also additionally provide information about tumor and tissue perfusion presently undetectable by digital subtraction angiography or 99mTc macro aggregated albumin imaging, which should optimize 90Y (yttrium-90) microsphere delivery and reduce nontarget embolization.[9,30] Captivating the lead in the growth of this technology is quantitative radiology, the pioneers in invention of CBCT for maxillofacial imaging is further researching in the same field.[2,8,30]

**Conclusion**

Since the time of its inception, CBCT imaging for the maxillofacial region has provided a new arena for the application of 3D imaging in all disciplines of dentistry as a diagnostic and treatment planning tool. CBCT today is capable of imaging hard-tissues and most of the soft-tissue structures.

The amalgamation of a third dimension into practical dental and craniofacial imaging has made this imaging modality an exciting and intrigue imaging of choice. The paradigm has shifted from landmarks, lines, and angles to flashing a volumetric narration of surfaces, areas, and volumes.

**References**


