Review Article

Cone-beam computed tomography and its applications in dentistry

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ABSTRACT

It has been more than a century since William Conrad Roentgen first discovered the X-ray. Radiology has transformed itself from scientific curiosity to a medical and dental necessity. The evolution of radiographs from periapical to extraoral imaging, and cephalometric, and panoramic radiography has heralded major progress in dental radiology, providing clinicians with a single comprehensive image of the jaws and maxillofacial structures. Even though radiograph is useful in certain ways, it has its own pros and cons. Exposure to X-ray beam radiation for prolonged period can result in the development of cancer and other adverse effects. Cone-beam computed tomography (CBCT) is an advanced medical imaging technique that generates three-dimensional (3-D) image at a lower cost and absorbed dose compared to that of conventional CT. This technique is based on a cone-shaped X-ray beam centered on a two-dimensional (2-D) detector that performs one rotation around the object, producing a series of 2-D images. These images are reconstructed in 3-D using a modification of the original cone-beam algorithm developed by Kamp *et al*., in 1984. Interest in CBCT from all fields of dentistry has been unprecedented, as the results of a 3D visualization provided improved interpretation, diagnosis, and treatment planning. It also showed a tremendous impact in dental implant treatment planning, giving the arch and ridge configuration, and location of the nerve and maxillary sinus before the surgery, thereby decreasing surgical uncertainty. Many innovative software programs are useful in making customized surgical guides, virtual models, and laser-generated resins for treatment planning. This article describes CBCT generations, advantages, disadvantages, and the various applications of CBCT in dentistry.

KEY WORDS: Applications, Computed tomography, Cone-beam computed tomography, Craniofacial surgery, Dental implantology, Oral and maxillofacial pathology, Oral and maxillofacial surgery

INTRODUCTION

Cone-beam computed tomography (CBCT) is a modern radiographic imaging technique which is used to take three-dimensional image of an object. CBCT is a diagnostic tool that has helped dentists in diagnosis and treatment planning in the field of dentistry.[1] It is useful in almost every aspect of dentistry due to its accuracy, but the exposure to radiation is more in this technique. CBCT presents as a separate C-arm to CT imaging [Figure 1]. CT uses a comparatively less expensive radiation detector than conventional CT imaging. Table 1 describes about the various generations of CBCT.

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It is very useful in the field of dental implantology, oral surgery, orthodontics, endodontics, sleep apnea management, temporomandibular joint (TMJ) disorders, and periodontics.

DENTAL APPLICATIONS OF CBCT

Dental Implantology

For the overall success of implant treatment and to avoid post-operative implant complications, implantologists should have three-dimensional (3D) information of bone volume and topography before implant placement. Presurgical assessment of the implant site by imaging technique thus allows for the accurate assessment of the amount of bone volume available, bone density, and proximity to anatomical structures. The buccolingual ridge pattern cannot be viewed on 2D radiographs, but CBCT provides the advantage of identifying the type of alveolar ridge pattern present.[2]

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Table 1: Generations of CT

Generations of CT	Detectors	Type of beam	Tube detector movements	Duration of scan
1st generation	One	Pencil X-ray beam	Translate-rotate	25–30 min
2nd generation	Multiple	Fan-shaped X-ray beam	Translate-rotate	<90 s
3rd generation	Multiple, originally 288, newer ones used 700 arranged in an arc	Fan-shaped X-ray beam	Rotate-rotate	Approximately 5 s
4th generation	Multiple arranged in an outer ring fixed	Fan-shaped X-ray beam	Rotate-fixed	Few seconds

CT: Computed tomography

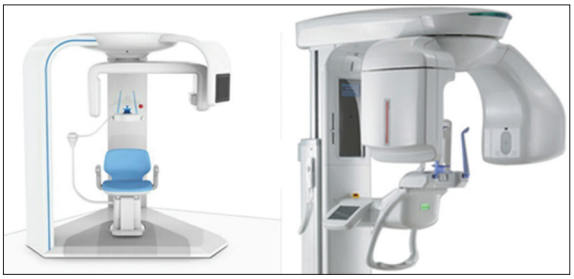

Figure 1: Cone-beam computed tomography machine

It can be used to identify the quality of bone at the implant sites. The term "bone quality" is commonly used in implant treatment based on implant success and failure. Bone quality is not only a matter of mineral content but also of structure. Bone quality comprises factors such as skeletal size, bone architecture, the 3D orientation of the trabeculae, and matrix properties.[3] Implant placed in poor-quality bone of thin cortex and low-density trabeculae (Type 4 bone) has a higher chance of failure compared with the other types of bones. This low-density bone is often found in the posterior maxilla and it has high chances of failure when placed at this region. Bone density can be expressed in terms of Hounsfield units. With more advanced CBCT software and methods, it should be possible to determine bone densities at implant sites. Thus, CBCT provides a subjective assessment of bone quality and not an objective assessment.[4]

CBCT-guided implant surgery is the widely used modality in dental implantology nowadays. With CBCT the type and size of the planned implant, its position within the bone, its relationship to the planned restoration and adjacent teeth or implants, and its proximity to vital structures can be determined before performing surgery.[5] Surgical guides are not indicated for every case, and some indications are as follows: Three or more implants in a row, proximity to vital anatomic structures, questionable bone volume, flapless implant placement, multiple unit or full-arch restorations, with or without extractions, and immediate replacement. With the use of computer-guided implant surgical guides, this anatomic relationship can be predictably established and considered before surgery. Gutta-percha, barium sulfate, and lead foils have been used for the fabrication of surgical guides.[6]

There are three types of computer-generated surgical guides: Tooth supported, mucosa supported, and bone supported. Tooth-supported guides are mostly used in partially edentulous cases. This surgical guide is designed to rest on other teeth in the arch for accuracy, for guide fit. Mucosal-supported guides are used primarily in fully edentulous cases and are designed to rest on the mucosa. Accurate interarch bite registrations are of utmost importance when using these guides to assure accurate surgical guide positioning and placement of securing screws/pins before the placement of implants. Bone-supported guides can be used in partially or fully edentulous cases, but they are used in fully edentulous cases which show significant ridge atrophy and good seating of mucosa-supported guides are questionable.[7]

Oral and Maxillofacial Pathology

Conventional CT is used routinely in the diagnosis of maxillofacial pathology. Three- dimensional imaging of cysts and tumors of the maxillofacial region can give the surgeon the vital information necessary for planning surgery. The volumetric analysis can help anticipate the need for and volume of a potential graft for reconstruction.[8]

TMJ Disorders

The imaging offered by current CBCT machines has been shown to provide a complete radiographic evaluation of the bony components of the jaw. The resulting images are of high diagnostic quality. CBCT shows significantly reduced radiation dose and cost compared with conventional CT.[9]

Craniofacial Surgery

CBCT allows better evaluation of dental age, arch segment positioning, and cleft size compared with traditional radiography. Volumetric analysis promises to offer better prediction in terms of the morphology of the defect, as well as the volume of graft material necessary for repair.[10] CBCT provides means to look and investigate these issues in depth.

Evaluation of Impacted Teeth

The identification, treatment planning, and evaluation of potential complications of impacted teeth are greatly

improved through CBCT. The site evaluation becomes not only less invasive and less time-consuming but also gives a complete overview. Using CBCT to locate and evaluate impacted third molars, cuspids and supernumerary teeth seem to make the surgical procedure more efficient and less invasive.[11] The adjacent structure against the area of interest can be seen in three dimensions. The relationship of impacted third molars to the mandibular canal, adjacent teeth, and cortical borders provides important diagnostic information that can directly impact the outcome of surgery.[12]

Orthodontics

Three-dimensional model can be reliably adopted for orthodontic and orthognathic analysis and surgical prediction. Extensive research is needed to differentiate the landmarks and relationships that this technology allows us to measure. CBCT machine can be adjusted to a small field of view specifically targeting an area of interest compared to regular CT, thereby assuring X-ray beam limitation. The effective dose of radiation ranges from 36.9 to 50.3 μSv and it records basic images in one rotation (scan time - 10–70 s), thereby making it a better adjunct than CT with relevance to orthodontic diagnosis and treatment planning. The effects on airway restriction can have profound effect on dentition, speech, and craniofacial development making it important to diagnose early during growth period. Airway space is better analyzed using CBCT. It can be used to make customized brackets and wires for individual patients, in digital modeling after constructing a physical model and for determining ideal site for mini-implant placement.[13]

Endodontics

CBCT has been shown to display the periodontal ligament space more accurately when compared to intraoral radiography, panoramic radiography, computerized radiography, and digital volume tomography. In general, the use of CBCT in endodontics should be limited to the assessment and treatment of complex endodontic conditions such as:

Identification of root canal system anomalies and determination of root curvature, diagnosis of dental periapical pathogenesis in patients who present with contradictory or non-specific clinical signs and symptoms, patients who have poorly localized symptoms associated with an untreated or previously endodontically treated tooth with no evidence of pathogenesis identified by conventional imaging, and in cases where anatomic superimposition of roots or areas of the maxillofacial skeleton is required to perform task-specific procedures.[14]

CBCT can be used for intracanal or post-operative assessment of endodontic treatment complications such as overextended root canal obturation material, separated endodontic instruments, calcified canal identification, and localization of perforations. It is also used in diagnosis and management of dentoalveolar trauma, especially root fractures, luxation and/or displacement of teeth, and alveolar fractures. It is useful in localization and differentiation of external from internal root resorption or invasive cervical resorption from other conditions. CBCT is indicated for presurgical case planning to determine the exact location of root apex/apices and to evaluate proximity of adjacent anatomical structures.[15]

CBCT reduces the risk of canal perforation, missed canal anatomy, or morphology, thereby, greatly increasing the chances for endodontic success and it is a precise modified canal staining and tooth clearing method to determine root canal morphology.

Dental Periapical Pathogenesis

The most common pathologic conditions seen in teeth are inflammatory lesions of the pulp and periapical origin. CBCT technology now provides the clinician to view the area in three different planes. Lesions confined to cancellous bone with little or no cortical plate erosion can be difficult to diagnose with intraoral film. CBCT technology provides an area of gray values which aids in the diagnosis of cysts versus granulomas. The higher detection rates afforded by CBCT are like those reported for conventional CT.[16]

Pedodontics

CBCT is used to evaluate morphological variations and eruptive disturbances in the permanent teeth which occur as sequelae to trauma in their predecessors. It is also used to assess the extent of dilaceration, palatal displacement of crown, root resorption, localization of impacted tooth, and a gradual curvature in the apical one-third of the root of permanent teeth following trauma to primary. It determines the close relationship between root apex of primary and permanent tooth germ which, in turn, explains the easy occurrences of disturbances in permanent teeth.[17]

Periodontics

CBCT has been used to obtain detailed morphologic descriptions of bone that is accurate than those obtained through direct measurement with a periodontal probe. CBCT provides accurate measurements of intrabony defects and allows clinicians to assess dehiscence, fenestration defects, and periodontal cysts. It can be used to assess the furcation involvement of periodontal defects and allows clinicians to evaluate the postsurgical results of regenerative periodontal therapy. CBCT is also helpful in identifying small osseous defects. Hence, CBCT is considered the superior most imaging modality in periodontics.[18]

Forensic Dentistry

Biologic aging of orthodontic patients can be assessed using images of the cervical spine. It also holds potential in studying disease processes such as spinal fractures, leading to osteoporosis.[19]

Innovations of CBCT

Fusion imaging is a process of combining relevant information from two or more images into a single image, linking anatomical and physiological image data, resulting in an image that is more informative, meaningful, and synergistic. Fusion imaging is more accurate in identifying the margins of a tumor, in locating primary lesions in unknown primary tumors, and helps in effective treatment planning in cases of many tumors.[20]

CONCLUSION

CBCT now plays a pivotal role in diagnosis, staging, and follow-up during treatment. Several innovative software programs have helped in making customized precision surgical guides, virtual models, and laser-generated resin models for advanced treatment planning. CBCT is an excellent diagnosis tool, providing significant advantages regarding the quality and quantity of anatomic information of the patient. Direct fabrication of dental appliances from the CBCT data using computer-aided design and computer-aided manufacturing systems would be the next progressive development.

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