

REVIEW ARTICLE



Cone beam computed tomography functionalities in dentistry

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Abstract

The present article evaluates various clinical applications of cone-beam computed tomography (CBCT). Among scientific articles, research was conducted by PubMed on the dental application of CBCT, containing many articles, in general, among which most of them were clinically about dentistry and its related analyses. Different functionalities of CBCT, including oral and maxillofacial surgery, root treatment, implantology, orthodontics, temporomandibular joint dysfunction, periodontics, and forensic dentistry have been indicated in the study. The aim of this review paper is to summarize the CBCT applications in various fields of dentistry. Also, this review article illustrates that different CBCT indicators have been used concerning the need for the certain discipline of dentistry and the kind of conducted procedure.

Keywords: Application, cone beam computed tomography, dentistry, functionality, implant, maxillofacial, oral, orthodontics, perio

Introduction

Two-dimensional (2D) imaging techniques in dentistry have been employed since the first intraoral radiography was created in 1896. Since then, dental imaging techniques have evolved by the advent of tomography and panoramic imaging. While tomography makes it possible to divide the desired levels from an X-ray range, panoramic imaging provides a comprehensive observable image of maxillofacial structures.^[1] Recent developments of digital diagnostic imaging have been dealing with lower radiation doses and faster processing times, without affecting the diagnostic quality of intraoral and panoramic images. 2D images, however, have their own natural limitations (including enlargement, distortion, and folding images), which cause the structures to appear erroneously.^[1] Cone-beam computed tomography (CBCT) is capable of producing three-dimensional (3D) images, which leads to effective diagnosis, treatment, and further advances. By introducing dent alveolar imaging in 1998, CBCT could produce lower-cost and lower absorbed dose 3D data in comparison to conventional CT.^[2] CBCT imaging technique is based on a cone-beam X-ray, gathered on a 2D recognizer, with the privilege of achieving more radiation. In contrast to the

conventional CT, a parallel change from the recognizer system is not required during the spinning, which brings about a more efficient use of tube power.^[3] Being compared with the resultant slideshow images of the conventional CT, the cone-shaped radiation spins around a certain object once (in this case was the patient's head and neck) and is capable of producing hundreds of 2D images from a certain anatomical volume.^[4] Then, using different kinds of algorithms that are made by the Feldkamp in 1994, the images are reconstructed in a 3D observable data set.^[5]

Compared to a common 2D radiography, CBCT has various advantages, including no folded images, measuring ratio of 1:1, no geometric distortion, and 3D demonstration. It is worth mentioning that, by using a relatively low ionic radiation, CBCT provides a 3D representation from hard tissues along with little information from soft tissues.^[6] Common CT systems have similar advantages (in addition to providing information on soft tissues), however, they create the image call with higher levels of ionic radiation and longer scanning time. In total, larger CT units will cause them to be a weak alternative for the dental offices.^[7]

Applications in Oral and Maxillofacial Surgery

The resultant 3D CBCT images have been used to investigate the right place and the maxillofacial pathology area, as well as assessing the final impact or the additional tooth and its link with vital structures.^[8-23] These images have been utilized to look into the bone graft space, before and after the surgery and osteonecrosis of the jaw changes (such as those who were exposed to bisphosphonates), as well as the pathology and/or paranasal sinus defect.^[24-28] Moreover, CBCT technology was applied to assess patients with obstructive sleep apnea to adopt an appropriate surgery method (if required).^[29]

Since CBCT units were available extensively, dentists have made use of this technique increasingly to investigate maxillofacial injuries. In addition to preventing form folded images, which appear in panoramic images, CBCT made it possible to precisely measure the surface intervals, as well.^[30,31] This distinct advantage caused CBCT to become an established method for the evaluation and management of mid-face lesions and orbital fractures, assessment of fracture, observation of maxillofacial bones engaged in surgery, and routing during operation along the processes that are related to gunshot.^[32-37]

CBCT is widely used in orthognathic (orthodontic surgery) and orthomorphic surgeries, in a way that the details of intraocclusal relationships and the display of tooth surface are vital for adding a 3D skull model. Using advanced software, CBCT made it possible to slightly observe the soft tissues and enable the dentists to control post-treatment beauty, as well as assessing the outline of lips and bone area of the palate in patients with palatal split.^[38-43]

Applications in Root Treatment

While several studies have shown that high contrast CBCT images could be used to distinguish between apical granuloma and apical cysts with measuring dental trauma, yet CBCT imaging is an applicable tool for the diagnosis of periapical injuries.^[44-46] Other scholars use CBCT as a useful tool to classify the origin of damages, including root or non-root origin, which indicates another period of the treatment.^[47] The reliability of these labels (root or non-root) are doubtful. Consequently, they are the foundation of demand on (more) non-invasive techniques for the diagnosis of damages that are usually detected through non-invasive processes.

Several clinical sample reports have concentrated on using high-resolution CBCT images to diagnose the vertical fractures of the root.^[45,46,48,49] CBCT is considered a salient technique for periapical radiographs in diagnosing root vertical fractures, measurement of dentin fracture depth, and detecting the root vertical fracture.^[50,51]

CBCT imaging has made the early diagnosis of inflammatory root resorption possible, which is slightly detectable by 2D radiography.^[52,53] As well as detecting the root and cervical root resorption (internal and external), CBCT is also capable of recognizing the extent and progress of the injury.^[54-58]

CBCT could be used to identify the number and morphogenesis of roots and their related canals (both main and

supplementary), and also determine the functional length, type, and angle size.^[54-56] CBCT performs a more accurate evaluation of root canal resorption than 2D imaging.^[48] It also applies in identifying the extent of pulp in talon cusp and the position of damaged tools.^[59,60] Due to its simplicity and precision, CBCT is utilized in canal preparation with different tool techniques, as well.^[61,62]

CBCT is a pre-operation tool for figuring out the proximity of tooth to the adjacent vital structures, make the surface anatomy right size and cause extent determination to become possible.^[63-65] In emergency cases after the injury, in which it is vital to recognize the desired tooth status, CBCT images could help dentistry with a selection of the best treatment methods.^[66,67]

Applications in Dental Implants

As the need for dental implant, as an alternative to the lost tooth, increased helping the treatment plan and avoiding the damage to vital adjacent surfaces during the operation requires for a technique to get the right cavity and measure the position of implant. Previously, such measurement was generally provided by 2D radiographs (in special cases) that was obtained through conventional CTs. CBCT, however, is an appropriate option for a dental implant, which in comparison with 2D images, provides more precision in measurement and lower radiation dose at the same time.^[68-80] The new software lowers the chance of improper settling of accessories and damaged anatomic structures.^[81-84]

CBCT decreases the implant failure by providing information on bone density and cavity shapes, as well as the height and width of the proposed implanting space for patient.^[85,86] CBCT does not calculate the Hounsfield scale accurately; hence, the number of bone density through this technique could not be vertical through a group of CBCT units or patients. However, the effect of CBCT in measuring and evaluating the cavity shapes has brought about the selected improvements. By a prior notice about the complications, which could occur during a proposed treatment, the plan can be designed in a way that resolves them or results in an alternative treatment. CBCT is usually used in post-operation evaluation to assess the bone graft and implant position in the cavity.^[79]

Orthodontics Applications

Orthodontics, in introducing qualitative software of evaluation such as Dolphin (Dolphin Maging and Management Solutions) and *in vivo* dental (Anatmage), enables the dentists to fully exploit the CBCT images for cephalometric analysis. Moreover, it is an appropriate tool for investigating the amount of facial growth, age, function of the respiratory tract, and disrupting the destruction of the tooth.^[87-92]

CBCT is a reliable tool to evaluate the amount of damaged tooth proximity to the vital structure, which could interrupt the orthodontic procedure.^[93,94] When the mini-implant (Implant with < 3 mm diameter) is required as a temporary holder, CBCT provides the observable guidelines for accurate and

safe installation and thus, accidental and fatal injuries could be avoided.^[95-97] Accordingly, the evaluation of bone density before, during, and after the treatment indicates that whether or not the injury has decreased or remained unchanged.^[98,99]

CBCT illustrates different aspects of maxillofacial complications in one scan. In addition to 3D structure of skeleton bones, it enables the dentist to access anterior, crowns, and axial images. These images could be turned to allow the dentist to observe patterns and various angles of the image, including those that are not available in 2D radiography.^[100,101] CBCT images are capable of auto-correction for enlargements and creating vertical images by measurement ratio of 1:1. Consequently, CBCT is more accurate than panoramic and conventional 2D images.^[102]

Applications in Temporomandibular Joints (TMJ) Disorders

TMJ diagnostic images are vital for to detect accurately diseases and joints malfunction. According to Tsiklakis *et al.*, though CT is easily available, it is not prevalent in dentistry due to high-required costs and doses. Examining the right linking space and position of the condyle in the cavity has been made possible by CBCT, which is a tool for showing probable dislocation in a connecting disk.^[103]

CBCT precision and lack of folded images make the measurement of the roof of the glenoid fossa and observation of soft tissue around TMJ possible, which can provide a practical diagnosis and eliminate the need for magnetic resonance imaging (MRI).^[104-106] According to Tsiklakis *et al.*, MRI “is one of the most useful tests since it provides images from both soft and bone tissues.”^[103] While MRI is recommended for evaluation of TMJ soft tissues, CBCT has lower radiation dose. However, it is emphasized that CBCT technique, unlike CT and MRI, does not reveal the details of soft tissues.

The aforementioned advantages made the CBCT the best imaging tool for incurred injuries, fibrous ankylosis, pain, dysfunction, cortex erosion of Cortical condyle, and cyst.^[107-109]

Applications in Periodontics

As Vandenberghe *et al.* believe, 2D radiography is the most prevalent imaging used in the bone morphology, such as a defect in periodontal bones. The limitations of 2D radiography, as a result of probable errors and misconceptions in identifying reliable reference anatomic points, forced dentists to estimate the amount of lost or existing bone.^[110] These findings approve the observations achieved by Misch, in which the 2D radiography is for identification of alterations in bone level or the architecture of inefficient bone defect.^[111] CBCT provides an accurate measurement of intrabony defects, by which doctors are able to assess the amount of rupture, valve defects, and periodontal cyst.^[112-114] While CBCT and 2D radiography are compatible with revealing interproximal defects, it is only the 3D images, such as CBCT, which are able to illustrate the buccal and lingual defects.^[115]

To obtain the details of morphologic of bone features, CBCT is used with precision as the direct measurement with a periodontal probe.^[110,111] Moreover, CBCT could be utilized to express the performance derived from periodontal defects and enable the doctors to assess the results of post-periodontal surgeries.^[115]

Application in Forensic Dentistry

Age estimation is one of the significant aspects of forensic dentistry. In this process, it is vital for doctors to be capable of estimating the age of every person in a legal system (including those who have passed away). This is one of the specific cases in Europe and as Yang *et al.* declared in 2006, “every year thousands of under-aged people flee over the all European countries with no formal ID card to find a shelter and protection. On top of this, most of the crimes are committed by people, who seem to be under-aged. In either case, it is necessary to determine the chronological age and fill them in documents, similar to those we have seen in Belgian that are under-aged and want to enjoy ethnic and social benefits.” The text of the present article was published for age estimation in line with the relationship between tooth change and age. The tooth enamel, beyond a natural cover, is extremely safe against such major alterations. However, as the age raise the pulp complex (dentin, cementum, and pulp) illustrates the physiological and pathological changes.^[116]

Usually, the extraction and section cut is required to identify morphological changes, which are not always observable. Nevertheless, CBCT is a non-aggressive alternative.

Discussion

Since late 1990s, when this method entered dentistry, CBCT scanners have shown substantial advances in medicine and maxillofacial imaging.^[117] This review article indicated that recent articles were conducted on CBCT, most of which were designated to clinical applications. Most of these articles are about oral and maxillofacial surgery, root treatment, dental implant, and orthodontics. CBCT has limited functionality in restorative dentistry, which is due to its higher radiation dose than 2D radiography and its incapability in providing additional diagnostic information. Moreover, these researches are mostly in the field of restorative dentistry for exploring various privileges of CBCT.

Although this review did not assess any related articles to prosthetic applications of 3D scanners, yet the standard surveillances that were conducted in prosthetic treatment could be contingent to the use of CBCT with other dental specialties. For instance, dental implant prosthetic, maxillofacial prosthetic, and temporomandibular disorders evaluation are applicable, which in turn by unifying the resultant data of patients with treatment plan can increase the success of prosthetic treatment. CBCT images embrace issues with medical complications, especially in cases that several teeth and bone levels should be evaluated.

New CBCT systems can be utilized in specific dentistry applications. They have higher resolution power, as well as lower exposure and cost in comparison to the prior existing systems.

While CBCT has various advantages over 2D radiography, there are natural limitations to this technique that require more precise consideration in the selection of criteria and indices. For example, CBCT is sensitive to removable dentures (including removable dentures peculiar to CT technology) and stiffener bars around a compact object. Overall, CBCT has low contrast and limited strength in viewing internal soft tissues. Most modern CBCT units have flat panel detectors, which are mostly inclined to the bar of stiffening artifacts and are able to provide more information. However, due to the lack of compatibility between artifacts, CBCT is not capable of precise HU measurements; therefore the bone density measurement is not reliable.

We believe it is vital to take the principle of “As Low as Reasonably Achievable,” into consideration. The belief should not be mistakenly interpreted as a reason to avoid the use of high dose CBCT units, which provide us with credible information. There is no tough protocol concerning when the

technology must be used and every dentist, oral radiologist, and neuroradiologist, must actively assess his/her operational protocols. Image resolution needs an extensive knowledge of anatomy in the fields, which are commonly the domain of dentistry and neuroradiology. Accurate knowledge and experience is required for the clarification of scanned data that determines why imaging is needed. Furthermore, the clarification of implicit findings is illustrated, which are explicit in the scan beyond the common scopes of dentistry, including disorders that can be observed in any adjacent area. The fact that CBCT promotes the specialized knowledge and improves the standards of dental care is something that dentists must define case by case. Such an evaluation calls for continuous training and education for dentists and scholars.

The recent upsurge in the popularity of CBCT caused many units with low variation (sometimes important though) to be resulted in uncontrolled and unobserved report of the radiation amount. This unapproved report could be due to the limited technological knowledge of medical imaging apparatus in the new units. In response, the academy of European dentistry and maxillofacial radiography has established basic principles for dental applications of CBCT [Table 1].

Table 1: The required basic principles for using CBCT in dentistry^[118]

CBCT tests should not be taken, unless related history and clinical tests were provided	CBCT instruments should be tested regularly to make sure that protection against radiation is not critical for both technical/ medical users as well as patients
CBCT tests must be arranged individually to do more good than harm CBCT should not be normally repeated on a patient unless an updated evaluation is made from the range of risk/advantages When a dentist refers a patient for CBCT test, he must provide enough clinical information (results derived from the patient's history and test) which enables the CBCT operator to do the appropriate process	To protect the staff against CBCT equipment, the user manual is stated in of chapter 6 of protective equipment committee documentary against radiation 136. European user manual for protection against radiation must be followed in dental radiology All included issues in CBCT should take sufficient theoretical and practical trainings for radiology tests and related qualifications for protection against radiation
CBCT should be only used when the question concerning the type of required radiology was not answered properly by the (conventional) low dose radiography CBCT images provide a clinical evaluation (radiographic report) of the whole dataset Where soft tissue evaluation is required as a part of radiological assessment, appropriate imaging should be a usual CT or MRI, not CBCT CBCT equipment should illustrate the selection of volume sizes, and if the method has lower radiation dose for the patient, tests should use the less compatible volume with clinical status	Further education and learning is required after gaining qualification for using the technique, especially when new CBCT equipment or technique is adopted CBCT dentists, who previously did not receive “sufficient theoretical and practical trainings” should pass a related course, which is authorized by a higher education institute (university or equivalent). Where national specialists of dental and maxillofacial radiology are qualified, design and transference of CBCT training should be carried out by them
Where CBCT equipment indicates resolution selection, resolution adjustment with sufficient diagnosis and the lowest resultant radiation dose should be used A quality assurance plan should be existed and implemented for each CBCT facilities, including equipment, techniques, and quality control processes Always make sure that radiation indicator is appropriately set All installed modern CBCT equipment must be tested necessarily. All admission tests must be done prior to use to optimally protect staff, patients, and other people against radiation	For CBCT images of dentoalveolar tooth, their supporting structures, jaw, and maxillary under the nose (8 cm×8 cm or lower sight, for example), the clinical evaluation (radiological report) should be performed by a maxillofacial radiologist or, if possible, by a trained general dentist For small non-dentoalveolar areas (e.g. temporal bone) and all craniofacial CBCT images (broader dental sight, supporting structures, jaw [including temporomandibular joint] and maxillary under the nose) the clinical evaluation (radiological report) should be performed by a trained maxillofacial radiologist or a clinical radiologist (permitted by UK Radiology Institute)

CRCT: Cone beam computed tomography, MRI: Magnetic resonance imaging, CT: Computed tomography

Summary

Based on what has been proposed in this article, most dental CBCT applications are for oral and maxillofacial surgery specialists, root treatment, dental implant, and orthodontics. CBCT test should not be taken unless it is necessary and do more good than harm. While using this method, the whole image dataset (which is a radiology report from a dental surgeon, neurologist, or a general radiologist familiar with the head and neck anatomy) should be assessed completely to maximize the resultant clinical data and make sure that every significant implicit finding were reported.

Further researches should be concentrated on the resultant accurate data regarding doses of CBCT systems in which they comprise of a size detector and a background, limited from the scanned volume and sight. CBCT systems with larger background and less metal artifacts for orthodontic and orthognathic surgeries are not available yet. Further evaluations are required for better determination of CBCT applications in forensic dentistry.

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