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Review Article

Endodontic practice management with cone-beam computed tomography

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Abstract

Traditionally, conventional periapical radiology formed the backbone of endodontics for diagnosis, treatment planning, and management. One of the major associated gripes being the technique created two-dimensional images of three-dimensional (3D) structures, suffered magnification, superimposition, and distortion, leading to compromised diagnostic information. The need to analyze the area of interest in all the possible planes led to the introduction of cone-beam computed tomography (CBCT), a novel modality specifically designed to produce precise, undistorted 3D reconstructed images of the maxillofacial skeleton. CBCT is increasingly being embraced by various fields in dentistry, remarkably in endodontic practice. A systematic literature-based and book-based review was conducted using the keywords "CBCT in endodontics" and "endodontic applications of CBCT." This article hereby discusses the prospects of CBCT in endodontics with an emphasis on its application in diagnosis and management along with treatment outcome assessment.

Key Words: Cone-beam computed tomography, dental radiography, endodontics, oral diagnosis, three-dimensional imaging

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INTRODUCTION

Conventional radiology is the fundamental tool of endodontic practice and needed for the successful management of any endodontic crisis. It comprises the basis of all the stages of endodontic treatment starting from diagnosis, intraoperative procedure assessment, treatment planning, and evaluation of treatment outcome.[1] Although two-dimensional (2D) imaging is still the most routinely followed modality in practice, it comes with the precinct of being a planar imaging technique. Hence, arose the need for a three-dimensional (3D) imaging system which could give a better assessment of the area of interest.[2,3] Cone-beam computed tomography (CBCT) is the current modality of choice with emphatic results, especially

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in endodontic imaging. The aim of this paper is to review the pertinent literature focusing on applications of CBCT in contemporary endodontic practice, also highlighting the merits and demerits of CBCT.

ENDODONTIC COMPLICATIONS

While routinely performing endodontic cases, clinician may face a variety of intraoperative complications such as missed canals, unusual complex root canal anatomy and its variations, fractured instruments, asymptomatic nonhealing periapical and resorptive lesions, perforations, root fractures, cortical bone fractures, presence of apicomarginal communication, expansion of lesions into the maxillary sinus and sinus membrane thickening, and poor root canal obturation systems. Postoperative complications such as persistent symptoms of pain and swelling around the treated tooth and the surrounding soft tissue areas are well documented as well. Till date, conventional periapical radiography was the tool of choice to assess pre-, intra-, and post-operative stages of the treatment.[4] Despite its notable contribution, the technique does possess certain innate limitations that have been discussed herewith.

True assessment of the spatial relationship of the roots of the teeth to their surrounding anatomical structures in three dimensions such as inferior alveolar canal, mental foramen, and maxillary sinus cannot be achieved by periapical radiography.[5] Furthermore, the anatomical complexities, the extent of resorptive lesions, as well as iatrogenic procedural errors may not be truly appreciated.[6,7] Evaluation of the angulation of the root to the cortical plate and thickness of cortical plate for presurgical evaluation is extremely difficult as the diagnostic information is missing in the third dimension. Even multiple radiographs with different horizontal or vertical angulations do not always guarantee complete detection of all the relevant structures or the pathoses.[8,9]

Conventional periapical radiographs cause geometric distortion of the image mostly due to the lack of proper orientation of the film/sensor to the long axis of the tooth. The resultant images may be foreshortened or elongated causing variations in the radiographic length of the tooth, and the extent of the periapical lesions and magnification of up to 5% is still expected to be present.[10] Geometric distortion is also particularly evident in the roots of the posterior teeth which are divergent or convergent in nature, and it becomes challenging to satisfactorily separate the roots radiographically.[11,12]

Among the two prevalent techniques used in conventional and digital intraoral imaging, namely the bisecting angle and paralleling technique, the latter is considered to be more accurate. In this, the receptor is placed parallel to the object (tooth) and X-ray is directed perpendicular to the arrangement. Although distortion gets minimized, parallelism is governed by local anatomy.[13] Paralleling technique works well with flat 2D structures, but it is imperfect for the multirooted teeth.[9] Furthermore, magnification happens to be inherent to the central projection principle used in intraoral radiography.[13]

The anatomic features such as incisive foramen, maxillary sinus, or zygomatic buttress obscure the region of interest (ROI) which may hamper the proper interpretation of 2D images caused by the superimposition of these features over any pathology. More complex the anatomic noise results, greater is the reduction in contrast in the ROI.[14] Periapical lesions limited to cancellous bone cannot be easily visualized in plain radiographs causing underestimation of the actual size and extent of the lesion.[15,16] Various factors which influence the visualization of periapical lesions and resorptive defects are overlying anatomy, thickness of the cancellous bone along with the cortical plate, trabeculae, bone marrow spaces, and the relationship of the apices of the roots with the cortical plate. Hence, keeping in consideration all the above factors, it could be concluded that periapical radiography provides suboptimal diagnostic information.[17,18]

In endodontics, radiographs depicting pretreatment, posttreatment, and follow-up stages should have standard density, contrast, and radiation geometry.[18] Of equal importance is the fourth dimension - time, series of radiographs to be comparable over a period of time should be standardized with respect to the above three factors.[18] Poorly standardized radiographs can lead to erroneous judgment of the degree of healing in certain cases. All this is difficult to attain with conventional planar imaging techniques and warranted the need of new techniques to be introduced into dentistry. This led to the evolution of limited CBCT, which is fast becoming the standard of care in endodontic and dental imaging.[19]

INTRODUCTION TO CONE-BEAM COMPUTED TOMOGRAPHY

One of the earliest 3D modalities to be introduced in medical imaging was the computed tomography (CT) system. However, the associated limitations of CT unit were a cost factor, lengthy scanning procedure, and high radiation dose to the patient. Each image slice of the CT machine required a separate scanning and reconstruction.[20] These shortcomings were addressed by the introduction of a novel technique, the CBCT. The first version of CBCT machine was developed for angiography, in 1982 by Richard Robb at the Mayo Clinic.[21] The technology was later refined over the next two decades and around 1988, CBCT unit was developed that could be used specifically for dentomaxillofacial imaging. In the early 1990s, manufacturers launched improved office-based CBCT scanners that offered the advantages of CT scanning with far fewer disadvantages.

CBCT is a fairly recent modality in which a pyramidal or cone-shaped X-ray beam is focused at the center of the ROI onto a detector on the opposite side [Figure 1]. The X-ray source and detector rotate and multiple sequential planar projections of the field of view (FOV) are acquired in a complete or partial arc. This 2D data are then converted with the help of algorithms into a 3D volume by a computer. CBCT aids in rapid acquisition of data with a smaller radiation exposure, and it is less expensive than CT. The volume data obtained in CBCT scans are in the form of isotropic voxels which are more precise than CT machines.[22,23]

APPLICATIONS OF CONE-BEAM COMPUTED TOMOGRAPHY IN ENDODONTICS

Assessment of root canal morphology and its variations

Recognition of the variations in the root canal anatomy is important for the success of endodontic diagnosis and treatment. Periapical radiographs may reveal only up to 50% information about all the canals within the root, especially in the buccolingual plane. Such missed canals are responsible for reinfection and failure of the endodontic treatment. Most commonly missed canal causing reinfection and necessitating retreatment is the second mesiobuccal canal (MB2) present in maxillary first molars. The prevalence of MB2 canal can vary from 69 to 93%. CBCT can help in identifying MB2 canal with much more precision as compared to a conventional radiograph.[24,25] CBCT imaging can also be used to detect additional distolingual canals, "C"-shaped canal, and in assessment of canal curvature. It has been shown that CBCT reports a higher incidence of distolingual canal (33%) as compared to conventional radiography (21%).[26,27] Matherne *et al*. compared different techniques and established the supremacy of CBCT in detecting the number of root canals over charged couple device detectors and photostimulable phosphor plate digital radiography.[28] CBCT scans have also proved to be useful in diagnosis and treatment planning of anatomic variations of the teeth such as dens invaginatus, dilacerated teeth, talon's cusp, and fused roots as it can provide precise 3D information about the anatomy without any geometric distortion.[29,30]

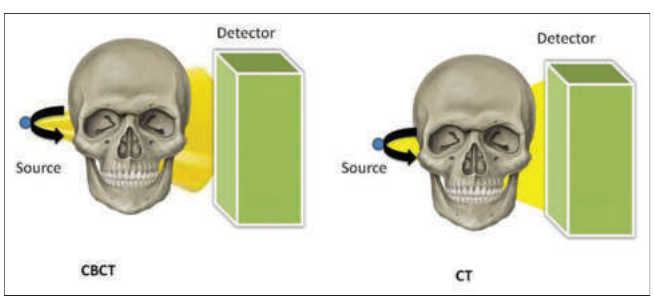

Figure 1: Comparison of the geometric configuration of incident X-ray beam projection and detector for cone-beam computed tomography and multidetector computed tomography

Detection of periapical pathosis

Routinely used periapical radiographs often fail to completely reveal the true nature and extent of progression of a periapical lesion. The lesions can be detected only when the buccal and lingual cortical involvement is present producing a distinct bone loss (30–50%) and an area of rarefaction.[31,32] Further, the details may get obscured by the presence of anatomical structures such as zygomatic arch or maxillary sinus and any radiolucent periapical lesions in these areas might go unnoticed.[33] CBCT helps overcome such limitations by providing 3D reconstructed images in the axial, sagittal, and coronal planes without the overlying anatomical noise [Figures 2 and 3]. CBCT imaging is also an accurate method for measuring the volume of artificially created bone cavities using an *ex vivo* model thus providing a valuable tool for monitoring the healing rate of apical periodontitis (AP) as compared to conventional radiography.[34,35] A new periapical index system (CBCT-periapical index) for the identification of AP has been proposed by Estrela *et al*., and they concluded that CBCT imaging detected 54.2% more AP lesions than intraoral radiography.[36] CBCT was also useful in assessing endodontic treatment outcome (a 1-year posttreatment follow-up) (17.6%) by evaluating if any periapical radiolucency existed which was commonly undiagnosed by periapical radiographs (1.3%). This was useful for identifying cases which required retreatment.[37]

Assessment of intraoperative iatrogenic errors

Intraoperative assessment such as unexpected anatomic findings, location of calcified and missed canals in endodontic retreatment, curvature of roots before using rotary instrumentation, and iatrogenic errors such as fractured instruments, overextended obturation materials, and perforations can be effectively performed with limited FOV CBCT scans which greatly influences the outcome of endodontic treatment.[27,38]

Assessment of dentoalveolar trauma

Traumatized teeth pose a clinical challenge with regard to their diagnosis, treatment plan, and prognosis. Periapical radiography provides poor sensitivity in the detection of minimal tooth/root displacements and alveolar fractures mostly due to projection geometry, processing errors, and the superimposition of various anatomic structures. CBCT is the imaging modality of choice for the evaluation of facial traumas, identification, and characterization of fractures with their associated complications, degree and direction of luxation injury, and in assessment of outcome.[39,40] Root fractures, classified under dentofacial trauma, form an important endodontic concern as their correct diagnosis mandates an accurate establishment of the fracture line location which in turn will determine the therapeutic possibilities.[41]

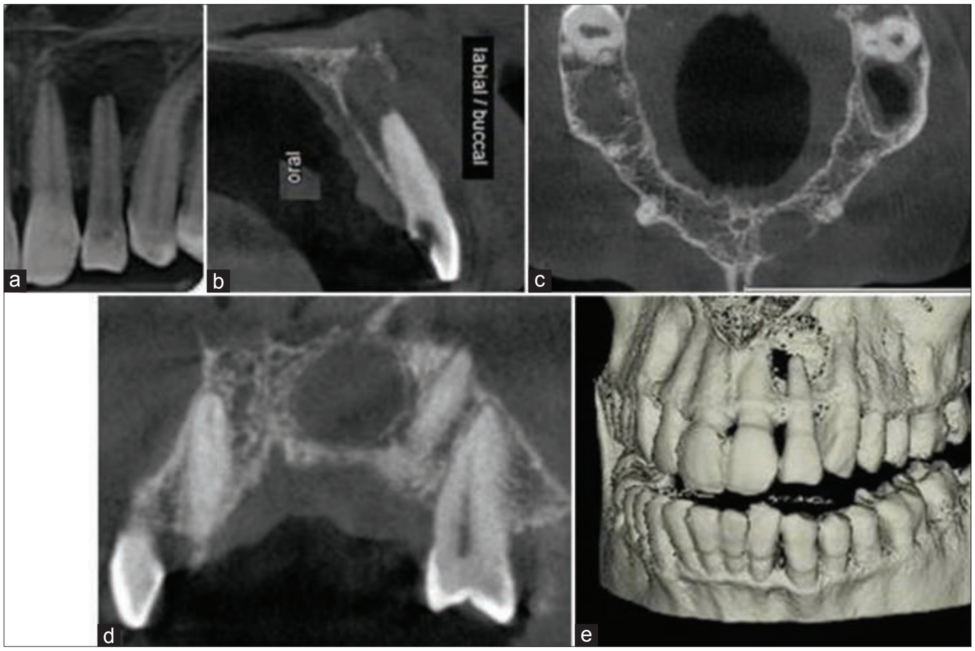

Figure 2: Periapical lesion. (a) Conventional intraoral periapical radiograph of tooth 22. (b and c) Cross-section and axial cone-beam computed tomography image of the same tooth revealing the loss of palatal cortex. (c and d) Tangential and three-dimensional reconstruction image showing the dramatic extent of lesion. (e) Three dimensional reconstruction (surface volume) depicting the loss of bone in the labial cortex and the proximity of the lesion to the floor of the nasal fossa

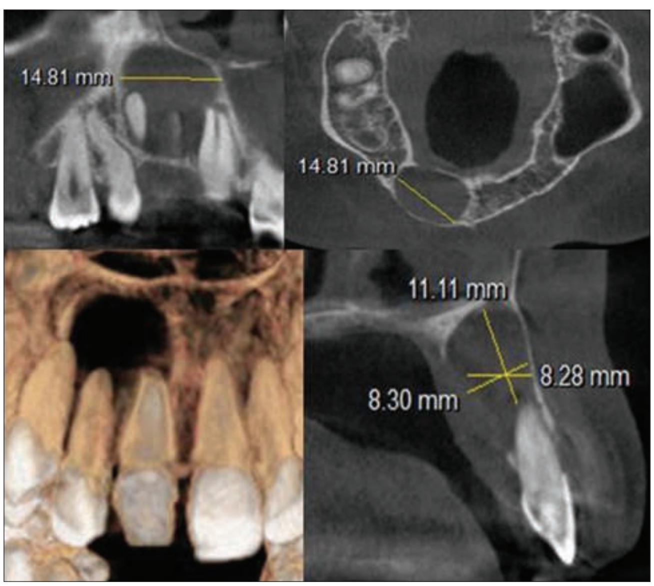

Figure 3: Various sections depicting the cystic pathology in the maxillary anterior region. The dimensions of the cyst, extent of bone loss, labial cortical plate expansion, and thinning are markedly seen hence giving a clear picture about the lesion

Vertical root fracture (VRF) is more common than the horizontal fractures and are characterized by a "through-and-through" crack connecting the pulp space and periodontal ligament. It manifests with nonspecific clinical features such as a localized deep periodontal pocket, sinus tracts, or a lateral radiolucency which complicates the diagnosis if only plain conventional radiographs are used.[42] For horizontal fracture detection, on the other hand, the vertical angle should be changed, and the central beam should be focused on the fracture plane as well as be perpendicular to the film.[41]

CBCT, in this context, can provide undistorted, cross-sectional views of the fracture line without any noise and help in viewing the desired area in several orthogonal planes [Figure 4].[43] Hassan *et al.* observed that the detection of VRFs in root canal filled teeth had a higher sensitivity with CBCT in the buccolingual and mesiodistal planes (87 and 63.5%).[44] External inflammatory root resorption is also very common sequelae of luxation injury (5–18%) and avulsion cases (30%). Its diagnosis is based solely on the radiographic demonstration of the process, and CBCT alone can suffice for it.[45]

Assessment of root resorptions and perforations

Root resorption is a pathological event causing loss of dental hard tissues as a result of osteoclastic activities. Internal root resorption (IRR) within the root canal is usually asymptomatic and a serendipitous finding on routine radiographic examination, often confused and misdiagnosed with external root resorption (ERR). CBCT can be used in confirming the presence of IRR and differentiating it from ERR. The external resorption defect presents with irregular border of radiolucency and intact root canal, whereas internal resorption has clearly defined borders with no canal radiographically visible in the defect.[45,46] It is also useful in differentiating between invasive cervical resorption and IRR by assessing the real extent of the root defect and possible points of communication with the periodontal space.[47] CBCT has the highest accuracy among the different imaging modalities in detecting perforations since there is 3D visualization of the perforation site without superimposition of neighboring structures.[48]

Assessment of outcome of endodontic treatment

3D CBCT scans are also significant in the evaluation of healing of periradicular tissues and endodontic outcome assessment. Paula-Silva *et al*. evaluated the periapex of 83 root canal treated and untreated teeth using periapical radiography, CBCT, and histological analysis. It was observed that CBCT detected AP in 86% of the cases. This proved that many cases which were considered completely healed might show a slight degree of persistent infection requiring immediate attention.[49]

Assessment of potential surgical sites

CBCT has been an extremely useful tool in the planning of surgical endodontic treatment. Rigolone *et al*., in 2003, studied 43 upper first molars using for microsurgery of palatal root and concluded that CBCT provided enough information for a minimally invasive microsurgical technique via the buccal side rather than the palatal approach.[50] Low *et al*. assessed 37 premolars and 37 molars in the maxilla, referred for apical surgery. They reported that CBCT was able to identify clearly the sinus membrane thickening, expansion of the lesion into the maxillary sinus, apicomarginal communications, pattern of root morphology, and bony topography (cancellous bone pattern and fenestrations).[33] CBCT also allows for virtual implant planning and placement of implants using the reconstructed data to fabricate a surgical guide that transfers the information to the surgical site [Figure 5].[51]

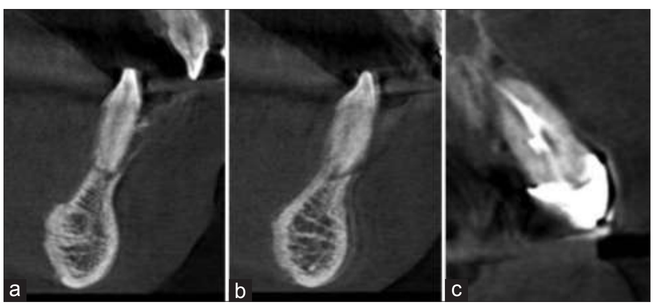

Figure 4: (a-c) Cross-sectional cone-beam computed tomography images of tooth number 31, 41, and 21, respectively, showing vertical fracture lines

CONCLUSION

The success of endodontic treatment results from an accurate diagnosis and proper debridement of the root canal space. Radiographic examination continues to remain the essential part of the diagnosis and management of endodontic treatment. Although intraoral periapical radiography is an economical and accessible technique readily available to the clinicians for routine treatment procedures, CBCT imaging helps in overcoming the inherent limitations of intraoral radiography. The all-encompassing and readily available 3D data result in an accurate identification of canal morphology, early monitoring and differential diagnosis of periapical lesions, management of dentofacial trauma, analysis of resorptive lesions, and presurgical assessment, thus making CBCT the forerunner of endodontic treatment planning and outcome assessment. However, the flip side of the coin being limited availability and cost factor associated with the modality. Hence, endodontic cases should be scrutinized thoroughly, and CBCT imaging should be considered in situations where conventional radiography cannot yield adequate information for the appropriate management of endodontic problems.

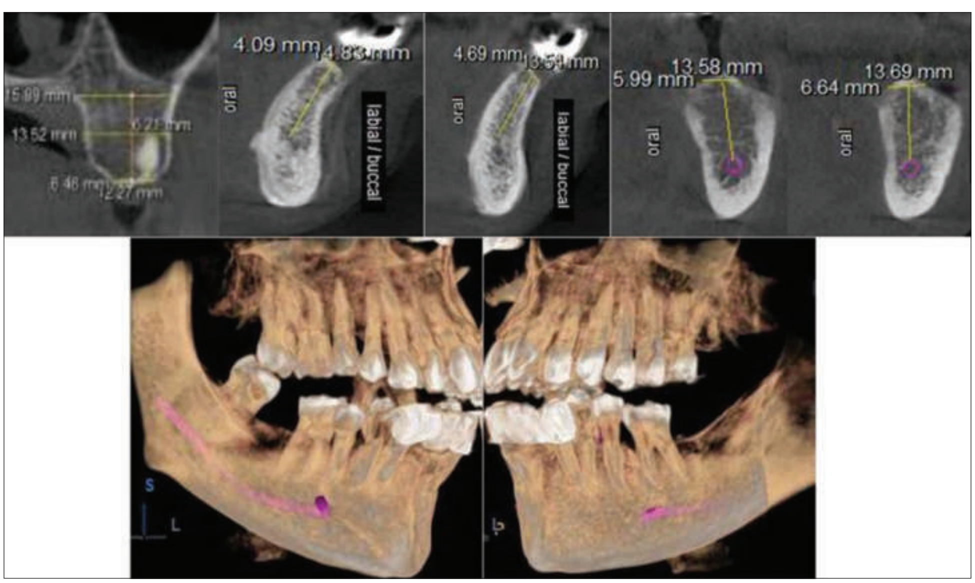

Figure 5: Cone-beam computed tomography imaging providing multiple views for the presurgical evaluation and measurement for placement of implant

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Conflicts of interest

There are no conflicts of interest.

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