REVIEW ARTICLE

Endodontics In 3d: A Paradigm Shift With Cbct

Ponung Perme[1], Navdeep[2], Priyanga M[1], Chingangbam Bindiya[1]

Abstract

Cone Beam Computed Tomography (CBCT) is a valuable imaging modality in endodontics that provides accurate three-dimensional visualization of teeth and surrounding structures, overcoming the limitations of two-dimensional radiography such as superimposition and distortion. It improves detection of complex canal anatomy, missed canals, root fractures, resorption, and traumatic injuries, and supports evaluation of treatment outcomes and surgical planning. Current guidelines recommend CBCT only when conventional imaging is insufficient and when diagnostic benefits outweigh radiation risks. Advances such as limited field-of-view scans, low-dose protocols, and artifact reduction have further improved image quality and patient safety.

***Keywords*:** Cone Beam Computed Tomography, Field of View (FOV), Application of CBCT in endodontics, DICOM.

1. Introduction

Radiographic imaging plays a crucial role in the diagnosis and management of diseases affecting the dental pulp and periradicular tissues. In Endodontics, radiology assists clinicians in diagnosis, treatment planning, and evaluation of treatment outcomes. [1]

Conventional intra-oral radiographs have long been the primary imaging method used in endodontic practice; however, their two-dimensional nature may result in limitations such as anatomical superimposition and distortion, which can reduce diagnostic accuracy. [2]

With advances in imaging technology, three-dimensional diagnostic modalities have been introduced to improve visualization of dental structures. Imaging techniques such as Magnetic Resonance Imaging and other advanced radiographic methods have expanded the possibilities for evaluating maxillofacial structures in dentistry. [3] Among these technologies, Cone Beam Computed Tomography (CBCT) has emerged as an important diagnostic tool because it provides high-resolution three-dimensional images of teeth and surrounding tissues. [4]

1. Post graduate student
2. Associate Professor

Department of conservative Dentistry & Endodontics

Corresponding Author:

Dr.Ponung Perme, Post graduate student

Ph: 9636223194.

Email: ponungperme37@gmail.com

Department of Conservative Dentistry & Endodontics

Maharaja Ganga Singh Dental College & Research Centre, Sri Ganganagar, Rajasthan.

CBCT enables detailed visualization of root canal anatomy and periapical structures, which significantly improves the detection and diagnosis of endodontic diseases.[5] In contemporary endodontic practice, CBCT has been increasingly used for evaluating complex root canal morphology, identifying periapical lesions, and assisting in treatment planning.[6] Studies have also demonstrated that CBCT may detect endodontic lesions more accurately than conventional intra-oral radiography in certain clinical situations.[7]

Despite its diagnostic advantages, the use of CBCT must be carefully justified due to factors such as radiation exposure and cost. Professional organizations such as the American Association of Endodontists and the American Association of Oral and Maxillofacial Radiology recommend the selective use of CBCT only when additional diagnostic information is required. [8] When used appropriately, CBCT provides valuable three-dimensional information that enhances diagnostic accuracy and supports more effective endodontic treatment planning. [9]

2. History

The foundation of CBCT lies in the development of conventional computed tomography by Hounsfield in **1967**, which introduced cross-sectional imaging in medicine. Later, the cone-beam principle was proposed to acquire an entire volume in a single rotation using a cone-shaped X-ray beam and a 2D detector, making imaging faster and more economical.[10,11]

In the late 1970s and early 1980**s**, foundation research on CBCT was conducted, laying the groundwork for later clinical and dental application.[10,12,13]

During the **mid-1990s**, advances in computer processing and flat-panel detectors enabled the development of compact CBCT machines suitable for maxillofacial imaging, marking the adaptation of CBCT for dental use.[11,14] In **1998**, Mozzo et al. introduced the **NewTom 9000** in Italy, the first commercial CBCT unit for maxillofacial imaging and the beginning of clinical CBCT in dentistry.[14,15] By the **early 2000s**, dental CBCT systems gained wider acceptance due to their ability to provide three-dimensional images with lower radiation dose than conventional medical CT.[16,17]

Between **2005** and **2010**, CBCT rapidly gained popularity in endodontics, orthodontics, and oral surgery due to its ability to provide accurate three-dimensional images with lower radiation dose and cost compared to medical CT.[18,19]

From **2020 onwards**, CBCT has been integrated with digital workflows, guided surgery, and artificial intelligence, improving diagnostic accuracy, automated interpretation, and treatment planning in dentistry.[20,21]

In **2021**, CBCT research focused on artificial intelligence and deep learning for automatic detection of periapical lesions, root fractures, and anatomical structures, improving diagnostic accuracy and reducing observer variability.[22,23]

In **2023**, CBCT was increasingly integrated with digital workflows such as guided endodontics, implant surgery and 3D printing, improving precision and predictability in treatment planning.[24,25]

By **2025**, research focused on integrating artificial intelligence with CBCT for automated detection, segmentation, and diagnostic interpretation, improving clinical decision support and efficiency.[26,27]

3.Classification of CBCT

Cone beam computed tomography systems are most commonly classified according to the dimensions of their field of view (FOV) or scan volume.[16,17,28] CBCT systems used in dentistry are commonly classified based on the field of view, which directly determines the anatomical coverage, radiation dose, and diagnostic application. According to Scarfe, Farman and Sukovic, CBCT machines are categorized into small/limited FOV (≤5 cm), medium FOV (5–10 cm) and large FOV (≥10 cm) systems.[13] Small FOV CBCT is preferred in endodontics because it provides high spatial resolution with minimal radiation exposure and is ideal for imaging individual teeth or a few teeth and their surrounding periapical structures.[16]

Based on the selected output volume level, CBCT units may also be described as follows: dentoalveolar (5–7 cm, single arch), interarch (7–10 cm), maxillofacial (10–15 cm) and craniofacial (>15 cm).[29]

Small FOV CBCT is preferred for endodontic diagnosis of periapical lesions, vertical root fractures, and resorptive defects, whereas medium and large FOV CBCT are used for assessment of multiple teeth and larger anatomical regions.[18,19,25]

4.ROLE OF IMAGING IN ENDODONTICS

Imaging has been fundamental to endodontics since Kells first introduced radiography in 1899 and it remains essential for accurate diagnosis, treatment planning and assessment of outcomes. Conventional intra-oral periapical radio-graphs continue to be the primary imaging modality because they are simple, accessible and provide crucial information about tooth and canal morphology as well as periapical status.[29,18] Cone beam computed tomography (CBCT) has expanded the role of imaging in endodontics by providing three dimensional visualization of teeth and surrounding structures, thereby improving the detection of periapical lesions, complex root canal anatomy, vertical root fractures and re-sorptive defects.[19,30,] Radiographic imaging is essential at all stages of endodontic treatment for diagnosis, canal access, instrumentation, obturation and healing assessment.[31]

Preoperative: It helps diagnose disease and shows tooth and root anatomy, number and position of canals, calcifications, fractures, caries, resorption and periapical lesions, guiding treatment decisions and possible surgical need.

Intraoperative: Working and master cone radiographs are taken to confirm file length and proper cone fit, ensuring complete cleaning and accurate obturation.

Postoperative: A radiograph taken after obturation evaluates the quality and extent of the root canal filling and serves as a baseline for follow-up healing assessment. It also helps assess previous treatment, delayed healing, retreatment challenges, and surgical needs.[32]

5.Criteria for use of CBCT in endodontics

A CBCT scan may only be considered after a comprehensive clinical examination has been carried out, and appropriate conventional radiographs have been taken and assessed [18]

A request for a CBCT scan should only be considered if the additional information from reconstructed three-dimensional images will potentially aid formulating a diagnosis and/or enhance the management of a tooth with an endodontic problem(s). Cone Beam Computed Tomography with a limited FOV may be considered in the following situations:[33]

- Diagnosis of radiographic signs of periapical pathosis when there are contradictory or nonspecific clinical signs and/or symptoms.
- Confirmation of non-odontogenic causes of pathosis.
- Assessment and/or management of complex dentoalveolar trauma, such as severe luxation injuries, suspected fracture of the alveolar bone and horizontal root fractures that are not readily evaluated with conventional radiographs.
- Evaluation of extremely complex root canal systems prior to endodontic treatment (e.g., Class III and IV dens invaginatus).

- Assessment of extremely complex root canal anatomy in teeth treatment planned for nonsurgical endodontic re-treatment.
- Assessment of endodontic treat-ment complications (e.g post perforations) for treatment planning when conventional radiographs provide insufficient information.
- Assessment and/or management of root resorption, which clinically appears to be potentially amenable to treatment.
- Pre-surgical assessment prior to complex periradicular surgery (for example posterior teeth).

6. Applications of CBCT in endodontics

Endodontic CBCT imaging requires exceptionally high detail and resolution to accurately capture the fine anatomical features of the periodontium and root canal system.[34]. However, it should not be considered a replacement for two-dimensional projection radiography rather, it serves as a complementary imaging modality for specific clinical applications.[35,36,37]

1)Evaluation of root canal morphology. Accurate identification of the root canal system is essential for successful treatment, as missed canals are strongly associated with apical periodontitis.[38-43] While periapical radiographs are routinely used, they may be insufficient in cases of complex anatomy, as noted by the American Association of Endodontists and American Academy of Oral and Maxillofacial Radiology.[44] CBCT shows high accuracy (about 90%) in detecting main canals and Vertucci configurations at 125–250 μm voxel sizes and improves MB2 canal detection.[45–47] However, its ability to detect fine accessory or lateral canals is limited due to spatial resolution constraints.[45,48,49] Although not required for routine cases, CBCT is particularly valuable in complex anatomical situations, improving treatment planning and reducing the risk of missed canals. [50,51,]

2) Three-Dimensional Evaluation of Periapical Pathology. Inflammatory lesions of the pulp and periapical tissues are the most common pathologic conditions affecting teeth. CBCT has been shown to provide higher diagnostic accuracy than conventional intraoral radiography for detecting periapical lesions.[52–54] Studies report that CBCT identifies significantly more affected roots compared with digital and film-based radiographs. Observer agreement is also higher with CBCT imaging.[54] Estrela et al. demonstrated a significantly greater prevalence of apical periodontitis detected with CBCT and introduced the CBCT periapical index (CBCTPAI).[30,55] Using this index, CBCT detected 54.2% more lesions than periapical radiographs.[55]Additional studies confirmed superior detection of lesions, including cases with sinus involvement and missed canals.[56,57] Ex vivo research further supports the higher sensitivity of CBCT compared with conventional radiography.[57] Overall, CBCT may be particularly be valuable in symptomatic cases where conventional imaging fails to reveal periapical pathology.[58,,59-60]

3) Assessment of pathosis of endodontic and non-endodontic origin. CBCT aids in distinguishing endodontic from non-endodontic lesions by showing detailed 3D lesion characteristics, bone destruction patterns, and root relationships.[61] It enables accurate evaluation of periapical healing or persistence after treatment, including post-apical surgery scenarios. This improved specificity helps avoid misdiagnosis and unnecessary procedures. Long-term follow-up is enhanced through reliable visualization of pathosis progression or resolution.

4) Identifying an untreated or missed canal. CBCT offers high sensitivity for detecting additional canals, such as the second mesiobuccal canal in maxillary molars, which are frequently overlooked on periapical radiographs. In vitro and clinical evidence shows superior identification of complex canal systems compared to traditional methods. Early detection reduces the risk of persistent infection and the need for retreatment. Targeted access and thorough disinfection become possible with this precise anatomical information.[62,63]

5) Visualizing over-extended root canal obturation material. Cone Beam Computed Tomography (CBCT) provides a three-dimensional view of extruded obturation material beyond the apical foramen. It overcomes the limitations of two-dimensional radiographs where overextensions may be underestimated. This helps clinicians evaluate complications and plan appropriate post-treatment management.[64]

6) Analysis of external and internal resorption.

Root resorption is a pathological loss of cementum and dentine that may be internal or external in origin.[65,66,67] Conventional periapical radiographs have limited ability to detect early lesions, identify perforations, and differentiate internal from external cervical resorption due to their two-dimensional nature.[68, 69–71]As a result, diagnostic accuracy with 2D imaging is inferior.[72]

CBCT demonstrates significantly higher accuracy for diagnosing and characterizing both internal and external resorptive lesions compared with periapical radiographs.[73,74,75] It provides improved visualization of lesion extent and perforations and supports three-dimensional classification systems that enhance prognosis and treatment planning.[76-80] Professional guidelines from the American Association of Endodontists and the European Society of Endodontology support the use of CBCT in evaluating potentially restorable resorptive defects.[44,51]

7) Evaluation of vertical and horizontal root fractures. Root fractures account for approximately 7% or fewer of dental injuries and are often difficult to diagnose using conventional radiography.[81,82,83] CBCT has demonstrated superior accuracy in detecting both vertical and horizontal root fractures compared with periapical radiographs.[84-87] Hassan et al. reported higher diagnostic accuracy for CBCT (0.86) than periapical radiographs (0.66), although visibility was slightly affected by root filling materials.[88] Similarly, Kamburoğlu et al. found significantly greater sensitivity for CBCT (0.92) compared with analog and digital radiographic systems.[89] Bernardes et al. further showed that CBCT detected fractures in 90% of suspected cases, whereas conventional periapical radiographs detected only 30–40%.[90] These findings support CBCT as a valuable adjunct to conventional radiography in the diagnosis of root fractures.

8) Traumatic dental injuries. Traumatic dental injuries require prompt and accurate diagnosis to prevent complications such as pulp necrosis and root resorption.[91-92] The International Association of Dental Traumatology recommends CBCT when 2D radiographs are inconclusive, particularly for root fractures, crown-root fractures, and alveolar fractures.[93] Horizontal root fractures may be missed on periapical radiographs due to their oblique orientation, whereas CBCT demonstrates superior diagnostic accuracy.[94,95] CBCT also improves detection of luxation injuries and cortical plate fractures compared with 2D imaging.[96] As these injuries commonly affect children and adolescents, radiation dose reduction and limited field-of-view protocols are essential.[97,98] Proper training in CBCT interpretation is also necessary to ensure accurate diagnosis and appropriate use.[51,99]

9) Surgical and Non-Surgical Retreatment Although primary root canal treatment has a high success rate, failures may require retreatment or apical surgery.[100,101] CBCT provides valuable three-dimensional information for assessing periapical lesions, iatrogenic errors, and proximity to vital structures. For surgical endodontics, the European Society of Endodontology and the American Association of Endodontists recommend CBCT for pre-surgical planning.[44,51] In non-surgical retreatment, CBCT improves detection of perforations and separated instruments and frequently influences treatment decisions in complex cases.[102-104]However, it should be used selectively when conventional radiographs are insufficient.[105]

10. Guided endodontics is most validated in the management of calcified or obliterated canals, were conventional access risks perforation and excessive dentin removal. By using CBCT-based digital planning and 3D-printed templates, a precise and conservative bur pathway can be achieved, preserving pericervical dentin and improving long-term tooth strength .[106] It is particularly beneficial in retreatment cases, where restorations or altered anatomy obscure canal orifices. Guided re-entry reduces iatrogenic errors such as perforation or ledging and improves detection of accessory canals, including the MB2 canal in maxillary molars .[107,108]

The application of guided principles has also expanded to periradicular surgery, such as guided apicoectomy and retrograde preparation .[106]

Accurate results depend on proper case selection, CBCT-based digital workflow, and stable 3D-printed guides. While highly effective in calcified and retreatment cases, its use in primary cases with extensive coronal destruction may be limited due to reduced guide stability.

11.Detection of Apical Periodontitis

Apical periodontitis is a common inflammatory condition affecting periapical tissues. CBCT is more sensitive and accurate than conventional periapical radiography for detecting, especially in early stages.[109] It can identify periapical bone destruction before it becomes visible on two-dimensional radiographs.

CBCT has been reported to detect lesions up to 62% more frequently than conventional radiography.[109] It also reveals additional findings such as maxillary sinus involvement, sinus membrane thickening, missed canals, and cortical or cancellous bone defects. [110] Comparative studies show significantly higher detection rates with CBCT (59.4%) than with periapical radiography (39.6%) ($P < 0.01$).[109]

7. ADVANTAGES OF CBCT

1. One of the advantages of CBCT is that the effective radiation dose is lower than that of conventional medical CT. However, the radiation dose of CBCT is generally higher than that of periapical and panoramic radiograph, depending on the field of view and exposure parameters. Panoramic x-ray and considerably less than a medical CT scan.[111,112]
2. Elimination of anatomical noise.
3. Accuracy of reproduction
4. Early detection of the size, position, and extent of periapical disease. CBCT could identify increased number of periapical lesions in maxillary and mandibular teeth as compared to conventional radiography.[113] Endodontic treatment is successful when managed before radiographic signs of periapical disease are evident, thus improving the endodontic outcome .[114]
5. Accurate detection of alveolar bone topography.
6. Geometric accuracy as compared to conventional radiography.[115]

7. CBCT can be used to detect periapical disease in patients with poorly localised symptoms with limited information revealed by clinical and periapical radiographs.[116]
8. Good appreciation of periapical lesions.[117]
9. CBCT can be a useful tool in periapical surgery to detect the proximity of anatomical structures such as inferior dental canal, maxillary sinus and mental foramen.
10. Conventional radiography can determine the approximation of the inferior dental canal to the root apices in only 40% of the cases.[118]

8. LIMITATION OF CBCT

At present, the spatial resolution and the contrast resolution of CBCT is lower than that of conventional film-based or digital intraoral radiography.[119] However, CBCT also has drawbacks, such as increased radiation exposure, susceptibility to artifacts and higher costs, which must be carefully weighed against its benefits.[120,121,7] As research evolves, our understanding of the potential clinical applications of CBCT imaging continues to expand. Therefore, this review aims to summarize the current evidence pertaining to clinical applications, benefits and limitations of CBCT in endodontics.[122] The presence of metallic restorations (e.g. amalgam restorations, metal posts and or crowns, and implants) or even gutta-percha can cause a radiographic artefact which compromises the details of root canal anatomy and relevant pathology such as root resorption and root fractures. Metal artefact reduction algorithms (MAR) are becoming more popular in operating and viewing software in order to overcome this loophole.[123,124] The scan time of CBCT devices can be as long as 20 s and is therefore significantly longer compared with that of an intra-oral radiograph (<0.3s),which increases the risk of patient movement and re-exposure.[125] If the voxel size of the CBCT machine is 0.3mm then it is not reliable for detection of vertical root fracture. The vertical root fracture is not diagnosed until the width of fracture is greater than 0.15mm.[126] Elsaltani in his study confirmed that voxel size of 0.35mm may not benefit the endodontist .[127]

9. FUTURE DIRECTIONS

The Digital Imaging and Communications in Medicine (DICOM) standards provide interoperability among various CBCT systems and promote seamless communication and data transfer with upcoming clinical applications, such as augmented and virtual reality enabled devices and technology based on artificial intelligence.[128] These solutions driven by artificial intelligence for clinical practice have already demonstrated successful applications, such as complete CBCT segmentation and periapical lesion detection,[129,130]the detection of cracks and fractures[131] or external cervical root resorption,[132] the identification of the mandibular nerve canal[133] or the classification of root canal morphology such as for the mesiobuccal root of first maxillary molars[134] or C-shapes in second mandibular molars.[135] Moreover, CBCT imaging will be indicated for treatment planning, outcome assessment[136] and prognostication and execution of clinical procedures supported by augmented reality, such as for nonsurgical[137] or surgical retreatment[138] or autonomous robotic procedures.[139] Future research could focus on assessing CBCT's impact on long-term treatment outcomes and developing integrated algorithms to optimise clinical practice (Abella et al. [140].. Kazimierczak et al. reported that an AI model showed over 90% diagnostic accuracy in detecting endodontic treatment outcomes on CBCT, with performance comparable to expert endodontists.[141] Likewise, Fontenele and Jacobs highlighted that AI can enhance diagnostic efficiency and consistency in endodontics, though it should be implemented cautiously with proper ethical oversight and professional training.[142]

10. CONCLUSION

Cone beam computed tomography (CBCT) has significantly enhanced diagnostic accuracy and treatment planning in endodontics by providing detailed three-dimensional visual-ization of root canal anatomy and periapical pathology. Although it overcomes many limitations of conventional radiography, its use should be justified on a case-by-case basis due to radiation exposure, cost, and potential artifacts. When applied judiciously in accordance with current guidelines, CBCT serves as a valuable adjunct that improves clinical decision-making and patient outcomes in modern endodontic practice.

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