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Applications of CBCT in Diagnosis and Treatment Planning for Endodontics

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ABSTRACT

Cone-Beam Computed Tomography (CBCT) is both a revolutionary imaging modality that has taken place in endodontics and offers three-dimensional imaging that surpasses the inherent constraints of traditional two-dimensional radiography. Its uses in the diagnostic and treatment planning have greatly contributed to the precision, predictability and success of the endodontics. CBCT provides accurate identification of periapical pathology, identification nonfibrosis of complex root canal morphology, and localisation of resorptive defects and vertical root fractures. It can also be used in treatment planning to assess the relationship of the anatomy, determine how to perform surgery or evaluate the process of healing. CBCT is most useful in the retreatment cases, traumatic dental injuries, and developmental anomalies as opposed to conventional imaging which can be inconsistent. In spite of these benefits, other factors like exposure to radiation and difficulty of interpretation and cost require their use in a wise manner with regard to the laid down guidelines. In the future, it is likely to broaden its clinical use by incorporating artificial intelligence, digital workflows, and dose-reduction technologies. This review underlines the emerging and current applications of CBCT to endodontics with the focus on its use to enhance the accuracy of diagnosis and the quality of treatment and promote evidence-based use.

Keywords: Cone-Beam Computed Tomography, CBCT, Endodontics, Diagnosis, Treatment Planning, Root Canal Morphology, Periapical Lesions, Endodontic Surgery

1. INTRODUCTION

Proper diagnosis and successful planning of treatment are the main principles of successful outcomes in the field of endodontics. Historically, the most common types of imaging have been considered intraoral periapical and panoramic radiographs; these two modalities are two-dimensional (2D) and have inherent limitations, including anatomy superimposition, distortion, and limited view of complex root canal systems (Ee et al., 2014; Tyndall and Rathore, 2008). The limitations tend to limit the ability to accurately identify periapical pathologies, root fractures, and changes in canal morphology, all of which are essential to predictable endodontic therapy.

Cone-Beam Computed Tomography (CBCT) has emerged as a transformative imaging tool, offering three-dimensional (3D) visualization that overcomes many limitations of conventional radiography (Shemesh & Cohenca, 2015; Shukla et al., 2017). With its ability to provide high-resolution volumetric data at relatively low radiation doses compared to conventional CT, CBCT has rapidly gained acceptance in endodontics for both diagnostic and treatment planning purposes (Walter et al., 2016; Khanna, 2020). CBCT enables clinicians to assess complex anatomical variations, evaluate periapical lesions with greater accuracy, detect root resorptions and fractures, and plan surgical interventions with enhanced precision (Venskutonis et al., 2014; Shekhar & Shashikala, 2013).

Evidence suggests that CBCT can significantly influence clinical decision-making in endodontics. Studies have demonstrated that treatment planning based on CBCT images leads to different and often more accurate therapeutic choices when compared with conventional radiographs (Mota de Almeida et al., 2014; Chogle et al., 2020; Kakavetsos et al., 2020). This is particularly valuable in retreatment cases, traumatic dental injuries, and cases involving developmental anomalies, where 2D imaging frequently falls short (Singh, 2018; Sethi et al., 2017). Furthermore, CBCT has shown to play a vital role in evaluating treatment outcomes and in guiding advanced procedures such as regenerative endodontics and microsurgical interventions (Shemesh & Cohenca, 2015; Singh, 2020).

Despite its advantages, CBCT is not without limitations. Factors such as increased radiation exposure compared

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to intraoral radiographs, higher costs, potential for image artifacts, and the need for appropriate training in image interpretation must be carefully considered (Shukla et al., 2017; Chandra et al., 2021). Current guidelines advocate for its selective and judicious use, emphasizing that CBCT should not replace conventional imaging but rather serve as a complementary tool when clinically justified (Venskutonis et al., 2014; Walter et al., 2016).

Given its expanding applications, CBCT has become an indispensable adjunct in modern endodontic practice. This review explores its role in diagnosis and treatment planning, focusing on its clinical utility, benefits, and limitations, while highlighting evidence-based recommendations for optimal use in endodontic care.

1.1. Principles of CBCT Imaging in Endodontics

Cone-Beam Computed Tomography (CBCT) is a three-dimensional imaging modality that has revolutionized diagnostic accuracy and treatment planning in endodontics. Unlike traditional two-dimensional radiographs, which provide limited information due to superimposition of structures, CBCT offers multiplanar visualization of the teeth, surrounding alveolar bone, and adjacent anatomical structures with high precision (Shemesh & Cohenca, 2015; Chogle et al., 2020).

1.1.1. Imaging Mechanism and Technical Considerations

CBCT employs a cone-shaped X-ray beam and a reciprocating two-dimensional detector, capturing multiple sequential projections during a single rotation around the patient. The acquired data are reconstructed into a volumetric dataset using algorithms, allowing visualization in axial, coronal, and sagittal planes (Tyndall & Rathore, 2008; Shukla et al., 2017). The voxel size typically ranging from 0.08 mm to 0.4 mm directly influences spatial resolution, making small field-of-view (FOV) CBCT scans especially valuable in endodontic imaging where fine anatomical details such as accessory canals or root fractures must be detected (Venskutonis et al., 2014).

1.1.2. Radiation Dose and Field of View

One of the fundamental principles in CBCT imaging is optimization of the field of view. A limited or small FOV should be used whenever possible to reduce radiation exposure while maintaining diagnostic quality (Walter

Table 1: Comparison of Conventional Radiog raphy and CBCT in Endodontic Imaging

Parameter	Conventional Radiography	Cone-Beam Computed Tomography (CBCT)
Dimensionality	2D image	3D volumetric image
Superimposition of structures	Present	Eliminated
Resolution	Moderate (limited detail in overlapping areas)	High (small voxel size enables detailed visualization)
Radiation dose	Low	Moderate (higher than 2D but lower than medical CT)
Field of view	Single region	Adjustable (small, medium, or large FOV)
Anatomical detail	Limited	Excellent (root canal morphology, fractures, resorption, sinus proximity)
Artifacts	Minimal	Can occur (metallic restorations, motion)
Cost and availability	Widely available, inexpensive	Higher cost, limited access in some regions
Diagnostic value in complex cases	Limited	Superior

et al., 2016). Although CBCT generally imparts a higher dose than conventional periapical radiographs, it remains significantly lower than that of conventional medical CT scans (Mota de Almeida et al., 2014). Adhering to the ALARA principle ("As Low As Reasonably Achievable") is essential when prescribing CBCT in endodontics (Khanna, 2020).

1.1.3. Image Quality and Artifacts

CBCT images may be influenced by scatter, beam hardening, and patient motion, which can generate artifacts that compromise diagnostic reliability. Metallic restorations, in particular, are prone to producing streak artifacts, limiting visibility in certain regions (Sethi et al., 2017). Therefore, appropriate interpretation training and careful correlation with clinical findings are crucial.

1.1.4. Comparison with Conventional Radiography

Conventional periapical radiographs remain indispensable for routine diagnosis, offering low-dose, cost-effective imaging. However, they present limitations such as anatomical superimposition and geometric distortion. Studies have demonstrated that CBCT significantly improves detection of periapical lesions, root fractures, and complex canal morphology compared to two-dimensional imaging (Ee, Fayad, & Johnson, 2014; Singh, 2018). The enhanced diagnostic yield directly influences treatment planning, particularly in challenging clinical situations (Kakavetsos, Markou, & Tzanetakis, 2020)

Adapted from Tyndall & Rathore (2008); Venskutonis et al. (2014); Chogle et al. (2020).

In summary, the principles of CBCT imaging in endodontics rest on its ability to provide three-dimensional, high-resolution imaging with adjustable FOVs tailored to the clinical situation. While it offers unmatched diagnostic value, clinicians must balance benefits against limitations such as radiation exposure, artifacts, and accessibility. Adherence to established guidelines ensures that CBCT remains a powerful but judiciously applied tool in endodontic practice (Chogle et al., 2020; Shemesh & Cohenca, 2015).

1.2. Applications of CBCT in Endodontic Diagnosis

Accurate diagnosis forms the foundation of successful endodontic therapy. Traditional two-dimensional radiographs, while widely used, are often limited by image superimposition, distortion, and lack of depth perception. Cone-Beam Computed Tomography (CBCT) provides three-dimensional imaging that overcomes these limitations and has been shown to significantly improve diagnostic accuracy in endodontics (Chogle et al., 2020; Ee et al., 2014; Singh, 2018). Its applications span the identification of periapical pathology, assessment of complex root canal morphology, detection of resorptive defects, and diagnosis of root fractures, among others.

1.2.1. 1. Detection of Periapical Lesions

CBCT is highly sensitive in detecting periapical radiolucencies, often revealing lesions not visible on conventional radiographs (Shemesh & Cohenca, 2015). This early detection assists clinicians in differentiating endodontic from non-endodontic pathologies, ensuring appropriate treatment planning (Mota de Almeida et al., 2014).2.

1.2.2. Assessment of Root Canal Morphology

Complexities such as additional canals, variations like C-shaped canals, or anomalies such as dens invaginatus are better visualized on CBCT scans. This information is critical for reducing missed canals and improving treatment outcomes (Khanna, 2020; Venskutonis et al., 2014).3.

1.2.3. Identification of Root Fractures

Vertical root fractures are notoriously difficult to diagnose using 2D radiography due to their subtle and variable radiographic features. CBCT has demonstrated superior ability to detect and localize such fractures, aiding in appropriate treatment decisions or extractions when necessary (Shekhar & Shashikala, 2013).

1.2.4. 4. Localization of Resorptive Defects

CBCT enables clinicians to differentiate between internal and external resorption and precisely determine the extent and location of resorptive lesions. This precision is crucial in selecting conservative treatment approaches or planning surgical interventions (Shukla et al., 2017; Tyndall & Rathore, 2008).

1.2.5. 5. Differentiation of Non-Endodontic Pathologies

Certain odontogenic and non-odontogenic lesions may mimic periapical disease. CBCT provides additional diagnostic clarity, helping clinicians avoid misdiagnosis and inappropriate endodontic treatment (Walter et al., 2016; Kakavetsos et al., 2020).

Overall, CBCT has transformed diagnostic capabilities in endodontics by offering three-dimensional detail that directly influences treatment planning and outcomes. Its judicious application ensures accurate identification of pathologies while minimizing unnecessary radiation exposure (Sethi et al., 2017; Chogle et al., 2020).

1.3. CBCT in Special Clinical Situations

The utility of Cone-Beam Computed Tomography (CBCT) becomes particularly evident in complex or atypical clinical presentations where conventional imaging fails

Table 2: Diagnostic Applications of CBCT in Endodontics

Diagnostic Area	Role of CBCT	Supporting References
Periapical Lesions	Detects early lesions not visible on periapical radiographs; differentiates pathologies	Shemesh & Cohenca (2015); Mota de Almeida et al. (2014)
Root Canal Morphology	Identifies additional canals, complex anatomy, anomalies (C-shaped, dens invaginatus)	Khanna (2020); Venskutonis et al. (2014)
Root Fractures	Localizes vertical/horizontal root fractures with higher accuracy	Shekhar & Shashikala (2013)
Resorptive Defects	Differentiates internal vs. external resorption; assesses size and location	Shukla et al. (2017); Tyndall & Rathore (2008)
Non-Endodontic Pathologies	Identifies lesions mimicking periapical disease; aids in differential diagnosis	Walter et al. (2016); Kakavetsos et al. (2020)

to provide sufficient diagnostic information. Special clinical situations such as retreatment cases, traumatic dental injuries, developmental anomalies, and immature permanent teeth pose unique challenges in diagnosis and treatment planning. In such scenarios, CBCT serves as a vital adjunct for enhancing visualization and guiding precise therapeutic interventions.

1.3.1. Retreatment Cases

Endodontic retreatments often require identification of missed canals, untreated anatomy, or persistent periapical pathology. CBCT aids in detecting hidden canal systems, assessing iatrogenic complications such as perforations, and evaluating the extent of persistent lesions that may not be evident on periapical radiographs (Ee et al., 2014; Venskutonis et al., 2014). Its ability to provide three-dimensional perspectives reduces diagnostic uncertainty and improves retreatment outcomes (Chogle et al., 2020).

1.3.2. Traumatic Dental Injuries

Dental trauma can result in root fractures, luxation injuries, or resorption processes that are difficult to detect using 2D radiography. CBCT offers superior accuracy in identifying horizontal and vertical root fractures, localizing foreign objects, and differentiating between internal and external resorption (Shemesh & Cohenca, 2015; Shekhar & Shashikala, 2013). In traumatic scenarios, CBCT also assists in monitoring healing progression and planning surgical interventions when needed (Kakavetsos et al., 2020).

1.3.3. Developmental Anomalies

Teeth with anomalies such as dens invaginatus, taurodontism, or fused roots pose significant diagnostic and therapeutic challenges. CBCT facilitates visualization of complex canal configurations and abnormal root morphologies, which is essential for tailored treatment planning (Venskutonis et al., 2014; Khanna, 2020). In dens invaginatus cases, CBCT imaging has been shown to accurately delineate the extent of invagination and associated pathology, thereby minimizing the risk of procedural errors (Singh, 2018).

1.3.4. Immature Permanent Teeth and Regenerative Endodontics

In immature permanent teeth with open apices, CBCT aids in assessing apical closure, root wall thickness, and periapical healing following regenerative or vital pulp therapy procedures (Singh, 2019; Sethi et al., 2017). It helps clinicians decide between regenerative approaches, apexification, or alternative treatment modalities by providing detailed insights into root development (Mota de Almeida et al., 2014).

In summary, CBCT proves indispensable in managing challenging endodontic cases where traditional radiographs fall short. Its role in retreatments, trauma, anomalies, and regenerative endodontics underscores its value as a critical diagnostic and planning tool, provided its use remains justified and guided by clinical need (Walter et al., 2016; Shukla et al., 2017; Tyndall & Rathore, 2008).

2. ADVANTAGES AND LIMITATIONS OF CBCT IN ENDODONTICS

The introduction of Cone-Beam Computed Tomography (CBCT) has significantly advanced diagnostic and treatment planning capabilities in endodontics. Com-

Table 3: Applications of CBCT in Special Clinical Situations in Endodontics

Clinical Situation	Role of CBCT	Supporting References
Retreatment cases	Identification of missed canals, evaluation of persistent periapical lesions, detection of perforations	Ee et al., 2014; Chogle et al., 2020; Venskutonis et al., 2014
Traumatic dental injuries	Detection of root fractures, assessment of resorption, localization of foreign objects, monitoring healing	Shemesh & Cohenca, 2015; Shekhar & Shashikala, 2013; Kakavetsos et al., 2020
Developmental anomalies	Visualization of dens invaginatus, taurodontism, complex root morphologies, treatment planning	Venskutonis et al., 2014; Khanna, 2020; Singh, 2018
Immature permanent teeth	Evaluation of root development, apical closure, regenerative endodontic outcomes, vital pulp therapy	Singh, 2019; Sethi et al., 2017; Mota de Almeida et al., 2014

pared with conventional two-dimensional radiography, CBCT provides volumetric, three-dimensional imaging that enhances the accuracy of clinical decision-making (Chogle et al., 2020; Ee et al., 2014). Despite its advantages, limitations such as radiation exposure, artifacts, and financial considerations necessitate a balanced, evidence-based approach to its clinical use (Shemesh & Cohenca, 2015; Walter et al., 2016).

2.3.1. Major Advantages of CBCT in Endodontics

- Enhanced diagnostic accuracy: Enables detection of periapical pathology and resorptive defects that are often missed on periapical radiographs (Ee et al., 2014; Venskutonis et al., 2014).
- Assessment of root canal morphology: Provides 3D visualization of complex root canal systems, C-shaped canals, and additional root canals (Singh, 2018; Khanna, 2020).
- Fracture and resorption identification: Allows reliable localization of root fractures and differentiation between internal and external resorption (Shemesh & Cohenca, 2015; Shukla et al., 2017).
- Surgical treatment planning: Assists in preoperative evaluation of apical surgery, including relation to

Table 4: Advantages and Limitations of CBCT in Endodontics

Aspect	Advantages	Limitations
Diagnostic accuracy	Detects hidden periapical lesions, resorptions, vertical root fractures, and complex anatomy (Ee et al., 2014; Venskutonis et al., 2014).	Susceptible to scatter and beam-hardening artifacts from restorations (Shemesh & Cohenca, 2015).
Treatment planning	Provides precise root canal morphology and relation to anatomical structures for surgery (Shekhar & Shashikala, 2013).	Requires specialist interpretation; potential misdiagnosis if poorly trained (Venskutonis et al., 2014).
Clinical outcomes	Facilitates retreatment and trauma management, improves prognosis (Mota de Almeida et al., 2014; Kakavetsos et al., 2020).	Evidence of improved long-term outcomes is still emerging; it requires further trials (Chandra et al., 2021).
Accessibility	Widely available in advanced centers; increasingly used in dental education (Khanna, 2020).	Costly technology, limited availability in resource-constrained settings (Sethi et al., 2017).
Radiation safety	Lower dose than medical CT; can be optimized with small FOV (Walter et al., 2016).	Higher dose than periapical radiography; ethical need for judicious use (Chogle et al., 2020).

anatomical structures such as the mandibular canal or maxillary sinus (Shekhar & Shashikala, 2013; Tyndall & Rathore, 2008).

- Improved treatment outcomes: CBCT findings directly influence therapeutic decisions, leading to more predictable outcomes in retreatment and trauma cases (Mota de Almeida et al., 2014; Kakavetsos et al., 2020).

2.3.2. Limitations of CBCT in Endodontics

- Radiation dose: Higher than conventional periapical radiographs, though lower than medical CT (Walter et al., 2016; Shukla et al., 2017).
- Artifacts and image distortion: Metallic restorations may cause scatter and streak artifacts that interfere with accurate interpretation (Shemesh & Cohenca, 2015).
- Cost and accessibility: The high financial investment and limited availability in certain regions may restrict widespread clinical adoption (Sethi et al., 2017).
- Interpretation challenges: Requires advanced training to avoid misdiagnosis and ensure accurate analysis (Venskutonis et al., 2014).
- Ethical concerns: Justification of exposure must align with the ALARA principle (As Low As Reasonably Achievable) and international guidelines (Chogle et al., 2020).

In summary, CBCT has proven to be a valuable adjunct in endodontic diagnosis and treatment planning, offering clear advantages in visualization and clinical decision-making. However, its limitations underscore the need for selective, guideline-based use. A judicious balance between diagnostic benefit and radiation safety is essential to ensure optimal patient outcomes (Singh, 2020; Tyndall & Rathore, 2008).

3. CONCLUSION

Cone-Beam Computed Tomography has become a central imaging modality in the domain of endodontics to bridge the diagnostic and treatment planning gaps associated with traditional radiography. It has better periapical lesion, root fracture, resorptive defect, and complex canal morphology detection with its three-dimensional visualization resulting in more accurate and assured clinical decision-making (Ee et al., 2014; Shemesh and Cohenca, 2015; Chogle et al., 2020). It has been shown that CBCT has a substantial impact on treatment decisions, especially in difficult cases (retraction, traumatic dental injuries, surgical endodontics) where the complexity of anatomical structures requires a high-resolution image (Mota de Almeida et al., 2014; Kakavetsos et al., 2020; Venskutonis et al., 2014).

The introduction of the CBCT in customary endodontic practice is, however, a matter of reasonable balance. Issues associated with radiation exposure, artifacts, costs, and interpretation problems entail that the international guidelines and the principle of as low as reasonably achievable are adhered to (Tyndall and Rathore, 2008; Walter et al., 2016; Shukla et al., 2017). However, CBCT when used selectively has shown enormous benefits in increasing the diagnostic accuracy, perfect treatment planning, and long-term outcomes in endodontics care (Singh, 2018; Khanna, 2020; Shekhar and Shashikala, 2013).

The introduction of new technologies, such as artificial intelligence, digital processes, and bioceramic-based methods of treatment, additionally underline the changing role of CBCT in precision endodontics (Singh, 2019; Singh, 2020; Chandra et al., 2021). CBCT continues to be an invaluable supplement to contemporary practice in endodontics by allowing clinicians to see complex pathologies and anatomical variations in a way never before seen to reinforce its role as an inseparable complement to clinical practice. Finally, it will be the quality, safety, and predictability of endodontic treatment that will be determined by its responsible and evidence-based use in the coming years (Sethi et al., 2017; Makkar et al., 2016).

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