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EVALUATION OF CONE-BEAM COMPUTED TOMOGRAPHY FOR DIAGNOSIS: ACCURATE DETECTION AND DIAGNOSIS: NARRATIVE REVIEW

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Abstract
Understanding root canal morphology is crucial for successful endodontic treatment. Accessory canals, isthmuses, documented curvatures, bifurcations, and even early apical pathologies that are found in posterior teeth, are some of the complex anatomical features found in such teeth which are difficult to appreciate in planar radiography. Such features are often missed in the periapical and panoramic radiographs, resulting in incomplete debridement, persisting infection, and treatment failure. With the advent of CBCT, diagnostic imaging has been revolutionized because it allows detailing of tooth structures from multiple angles in 3D, as well as offering high-resolution imaging and minimal distortion, thus CBCT enhances acuity of diagnosis and optimizes treatment planning. This review evaluates CBCT's posterior tooth imaging focuses on the diagnosis of additional canals, assessing root curvatures, diagnosing vertical root fractures, evaluating root resorptive defects, and characterizing periapical lesions. When evaluating the diagnostic accuracy and utility of conventional radiography and CBCT, it is clear that the performance of conventional radiography is rather suboptimal. However, factors such as CBCT's costs, limited availability, the necessity of specialized training, and radiation exposure must be taken into account. Important endodontic organizations have advocated CBCT as an additional imaging method, but it should not be used as a substitute to the standard images which have to be done in every case. CBCT is recommended for complex cases, cases with uncertain diagnosis, cases with treatment challenges, and cases with complication-prone treatment. Provided that evidence-based guidelines and ALARA are respected, the diagnostic precision of endodontic treatment greatly improves, refining the treatment plan and boosting the overall patient outcome.

Keywords: Cone-beam computed tomography, posterior teeth, root canal morphology, endodontic diagnosis.

1. Introduction

1.1 Background and Clinical Significance

The success of endodontic therapy hinges on the ability of the clinician to meticulously identify, access, clean, shape, and obturate all the root canals within the affected teeth. This goal becomes even more challenging with posterior teeth, particularly molars and premolars, which show a high degree of anatomic complexity and significant heterogeneity between individuals. These teeth often contain complex canal systems, which include additional canals, sharp three-dimensional curvatures, canal bifurcations and reunifications, lateral canals, apical deltas, and isthmus connections between root canals.[1]

One of the clinically important examples of frequently missed anatomy is the second mesiobuccal (MB2) canal in maxillary molars. It is reported that this canal is present in 60–96% of maxillary first molars depending on the population studied, and it is one of the most frequent reasons of post treatment disease when left untreated.[2,3] Mandibular molars are also found to present with middle mesial canals, C shapes in the case of the mandibular second molars, and three rooted forms in certain ethnic groups. Premolars also show significant diversity, as maxillary first premolars often have two or three roots, and mandibular premolars sometimes contain multiple canals in a single root.

For the past more than a century, simple two dimensional radiographs such as periapical and panoramic imaging have been the cornerstone of diagnostics and treatment in the field of dentistry. Nevertheless, these techniques have unavoidable shortcomings due to their projection nature. The reduction of 3D anatomical structures into 2D images will always cause anatomical feature superimposition, distortion of geometry, and loss of spatial relations.[4] Thus, critical anatomical parts, and especially those aligned to the x-ray beam, are at risk of being entirely hidden or poorly defined.

Clinical studies using ex vivo teeth, micro-computed tomography, and surgical reconstructions show that conventional radiography 'detects' MB2 canals in 30-50% of cases in which they actually do exist.[5] This problem is not confined to missed canals, as root fractures, resorptive lesions, anatomical variations, and the degree of periapical pathological assessment are also problematically overlooked.

The ability to perform Cone-Beam Computed Tomography (CBCT) in dental practices has dramatically changed the previously established diagnostic framework in endodontics. Unlike medical computed tomography, which subjects the patient to higher irradiation, volumetric datasets obtained through the rotational acquisition of several projection images results in the isometric representation of dental and maxillofacial tissues. The spatial resolution of these images is as good as that obtained through conventional radiography.[6,7]

1.2 Objectives and Scope

The review focuses on the areas where the greatest gaps exist in knowledge – the gaps in the efficiency of CBCT in endodontics, and the gaps in the anatomical intricacies of the posterior teeth where treatment success is most periled. It also takes into account the following factors: (I) the clinical and technical skills that form the basis of CBCT systems and the functions that can be performed in the context of different use cases, (ii) the comparison of the diagnostic performance of CBCT with conventional radiography pertaining to an array of endodontic tests, (iii) the reputational risks, clinical threshold, and the evidence-focused framework of clinical practice in the context of substantiated and overstated claims within the discipline, and (iv) the head, neck, and teeth CBCT and 2D X-ray volumetric imaging diagnostics in endodontic diagnostics.

2. Literature Review

2.1 Limitations of Conventional Two-Dimensional Imaging

Although it still holds the primary position as the first imaging technique used for the endodontic assessment of the dentition, periapical radiography suffers basic projection radiography problems. All images contain loss of information, which in the case of radiography, it is two-dimensional projection of a three-dimensional structure. In the case of the x-ray, it is radiography, two-dimensional, projection of a three-dimensional structure, invariably creating loss of information. Structures positioned perpendicular, crosswise, or transverse to the imaging plane, receive optimal visualization, while structures situated in parallel, parallel to, or in line with the beam direction, may be completely absent .[8]

In practice, some of the results of the said limitations will include the following:

Missed Canal Systems: The MB2 canal in maxillary molars is one of the more strikingly, both in clinical practice as well as in the literature, difficult diagnostic problems. Histologic, as well as micro-CT studies, will in fact show that MB2, depending on the population as well as the methodology used to detect it, with ranges between 60 to 96 percent, do exist in the first maxillary molars. Conventional radiography, on the other hand, is falsely positive, as it will show only 30 to 50 percent. [3,5] The middle mesial canals in mandibular molars as well as C-shaped configurations equally exist and go undetected on standard radiographs.[9]

Poor Visualization of Fractures: One of the leading reasons for failure after treatment, vertical root fractures, is poorly demonstrated in radiographs. Research shows that in less than half of the documented cases, radiographs identify vertical root fractures. Although it is less than half, it still is dependent on how the fracture fragments are oriented and the amount of separation of the fractures.9

Underestimation of Periapical Pathology: There is little doubt that two dimensional X rays underestimate the prevalence and the size of the apical lesions. There are studies that have shown that lesions have a size 20 to 50% greater in CBCT than in periapical radiographs, and that in endodontically treated teeth, CBCT captures over 35 to 60% more periapical rarefactions in teeth that are considered to be normal in traditional radiographs.[10,11]

Increased Clinical Detection Threshold: In the case of external and internal early resorptive lesions, there is significant loss of tooth structure and it becomes increasingly radiographically visible. The later the detection, the more it compromises the treatment and the post treatment prognosis.

Superimposition of Anatomy: Densely Cortical bone of the and the overlying roots, zygomatic process, maxillary sinus, and important concise structures is to a great degree obscured more than root maxilla. The fissures posses root bones of the teeth in the maxilla that have more confidentiality.

These limitations are important, as they lead to incomplete instrumentation of the canals, a persistent infection and the condition known as periapical pathology. This culminates in the retreatment or extraction of the tooth, as treatment failure occurs.

2.2 Technical Principles and Clinical Applications of CBCT

The acquisition physics of Cone Beam Computed Tomography (CBCT) differ fundamentally from that of traditional radiography. Instead of just creating a single projection image, CBCT systems capture around 150–600 basis projection images in a 10–40 second time frame as they rotate around a patient's head. During a single rotation sweep of a patient's head, sophisticated reconstruction algorithms are able to generate a three-dimensional volumetric dataset CBCT systems isotropic voxels, which are typically 75–400 μm in dimension, depending of the selected field of view and imaging protocol.[7]

Some of the capabilities that the volumetric dataset provides are as follows:

- Multi-planar reconstruction in the axial, coronal, sagittal, and oblique axes.
- Volume rendering in 3D with spatial orientation.
- Curvilinear reformation in the axial planes which follows the canal roots.

• Advanced geometric measurement of the volume with minimal geometric distortion.
• Digital enhancement, contrast and zoom adjustment, and geometric distortion measurement.

Current Clinical Applications in Endodontics:

1. **Complex Anatomy Identification:** CBCT is better in identifying the MB2 canal and the C shaped configurations, radix entomolaris in the mandibular molars and in premolar multi-canal variations, with a sensitivity of 78-90%.[1,5]
2. **Root Curvature Assessment:** The ability to see in 3D helps in assessing curvature preoperative. It helps in understanding the level of curvature and its location, which is vital during the selection of instruments and in anticipating challenges.[12]
3. **Detection of Vertical Root Fracture**: Meta-analyses show that for the diagnosis of vertical root fracture, the sensitivity of CBCT is 80–88% and specificity 86–92%.[9]
4. **Resorption Evaluation:** CBCT permits the early diagnosis and accurate description of external cervical resorption and internal and external apical root resorption, enabling prompt and accurate treatment.[13]
5. **Assessment of Periapical Pathology:** CBCT determines accurate lesion size, differentiates between perforation of the cortex and lesions of the bordering vital structures, and assesses post-treatment healing.[10,11]
6. **Surgical Endodontics:** CBCT is one of the primary tools for preoperative imaging for the accurate location of root apices, bone structure evaluation, and locating surgical targets (maxillary sinus, inferior alveolar nerve, mental foramen, etc.) for approach planning.
7. **Planning Retreatment:** CBCT aids in the investigation of the reasons for treatment failure, such as missed canals, insufficient obturation, and treatment-related sequelae such as perforations, separated files, or canal transportation.

3. Methodology

3.1 Search Strategy and Study Selection

This is a narrative review To construct a well-documented history of a subject, publications need to be consolidated. As such, a combination of electronic literature databases such as Pubmed/MEDLINE, Scopus and Web of Science provided a foundational border within which literature spanning January 2010 to September 2024 can be accrued. As a consequence, literature encapsulating the basis of incorporation of CBCT is endodontics alongside the latest within the field is thoroughly reviewed.

The search devised utilized Boolean Phrases and comprised of the terms:

• (“CBCT” OR “cone beam computed tomography” OR “cone beam CT”) AND (“root canal morphology” OR “endodontic diagnosis” OR “root canal anatomy”)
• (“CBCT”) AND (“posterior teeth” OR “molars” OR “premolars”) AND (“endo” “dentics”)
• (“three-dimensional imaging”) AND (“missed canals” OR “MB2” OR “root fracture” OR “periapical lesion”)

3.2. Inclusion and Exclusion Criteria

The parameters for inclusion contained the following:

• Primary original research articles (clinical, in vitro and comparative studies of diagnostic accuracy)
• Systematic reviews and meta-analyses
• Position papers and consensus-based guidelines produced by professional societies
• Literature in the English language
• Studies specifically addressing diagnostic applications of CBCT in endodontics

• Research that specifically examined the role of 3-dimensional imaging in endodontics

The exclusion criteria were:

• Case reports without comprehensive and systematic diagnostic assessment
• Research limited to the study of anterior teeth
• Non-peer review publications
• Research papers which lacked a clear research design and rigorous statistical assessment

The reference lists of selected papers were manually reviewed for potential additional relevant publications which were not retrieved by the database search. In total, 87 articles were identified in the first instance, out of which 45 articles were selected based on the defined criteria after the review of the abstracts and full texts. The final analysis and synthesis is on the best available evidence relevant to the diagnosis of the posterior teeth.

4. Results – Synthesis of Diagnostic Evidence

In depth evaluation of the given works point towards a pervasive reality regarding the diagnostic prowess of CBCT: it performs well for a multiplicity of functions within the field of endodontics.

4.1 Detection of Additional Canals

Increased Detection Rates of the Oftentimes Missed Canals

Tooth Type	Anatomical Feature	2D Radiography Detection	CBCT Detection	Key Studies
Maxillary 1st molar	MB2 canal	30–50%	78–92%	Baratto-Filho 2009; Zhang 2011
Mandibular molar	Middle mesial canal	15–25%	65–78%	Patel 2015
Mandibular 2nd molar	C-shaped configuration	35–45%	88–95%	Vertucci 2010
Maxillary premolar	Three-canal system	20–35%	75–85%	Scarfe 2009

4.2 Root Curvature and Morphologic Complexity

Information regarding angulations of curvature and the existence of several curvature planes within a single root is CBCT appreciable data and is beyond the reach of information retrievable from 2D radiographs. Literature states 35–45% of posterior roots have clinically significant curvatures that lie outside the visibility range of vertical angulations utilized in standard peri-apical radiographs. [12]

4.3 Vertical Root Fracture Diagnosis

Data synthesis from systematic reviews including 18 studies and over 2,000 (n=18 studies, >2,000 teeth) indicates that:

- CBCT is sensitive to the fractures for 84 percent (95% Confidence Intervals: 78–88%).
- CBCT is 92 percent specific to vertical root fractures (95% Confidence Intervals: 88–95%).
- 2D Radiographs shows a sensitivity of 52 percent (95% Confidence Intervals: 45–59%).
- 2D Radiographs have a specificity of 76 percent (95% Confidence Intervals: 70–82%).

Furthermore, diagnostic accuracy is markedly improved with smaller voxel sizes, ≤150 µm, with appropriate windowing and/or leveling.[9]

4.4 Resorption Detection and Characterization

CBCT is superior in the identification and classification of resorptive lesions by:

- The early clinical detection of external cervical resorption in the early stages before the patient develops clinical symptoms.
- Internal resorption: 3D volume and extent accurately gauged.
- 88% accuracy in differentiating resorption from carious lesions compared to 2D with 65%.[13]

4.5 Periapical Pathology Assessment

Research reveals time and time again these main findings:

• Enhanced diagnostic capability: CBCT finds peri-apical lesions in 35 to 60% of endodontically treated teeth incorrectly assumed as normal based on conventional (panoramic) x-rays.

• Morphometric analysis: CBCT measures lesions 20 to 50% bigger

• Cortical bone perforation: Correctly identified in 82% of cases (as compared to 45% with 2D).

• Healing assessment: Significantly better post-treatment bone regeneration assessment than previous studies. [10,11]

5. Discussion

5.1 Clinical Advantages and Effects on Treatment

The diagnostic benefits of CBCT are translated into clinical benefits by the following mechanisms:

Better Treatment Plans: Knowledge of the number of canals and their canal locations and curvatures and morphologies beforehand assist clinicians in choosing the proper instruments, predicting procedural hurdles, modifying the design of the access cavity, and setting realistic objectives for the treatment. There are studies which indicate a 25-35% reduction in iatrogenic complications associated with treatment guided by CBCT in challenging cases.[12]

Better Success Rates in Retreatment Cases: In cases of retreatment, CBCT helps uncover canals that have been missed in 40-55% of cases termed failed. There is critical information for intervention. Thorough imaging of separated instruments, strip perforations, and vertical fractures in their various forms, aids in proper case selection and technique alteration.[2]

Available Evidence for Diagnosis of Vertical Root Fractures: Advanced imaging helps prevent needless attempts of retreatment, which spares the patient from added discomfort and allows for quick extraction and implant planning, when necessary. The ability to predict the fracture with high specificity 92% ensures that collapse of the architecture which could lead to loss is highly controlled and the loss of the tooth is avoided.[9]

Informed communication with the patient: is made easier with 3D imaging. Patients are more equipped to discuss treatment possibilities and have better-informed consent, as they have clear comprehension of the treatment rationale, prognosis, and risks involved.

5.2 Limitations and Considerations

Radiation Exposure: While taking a CBCT scan, the effective doses CBCT are 19-1073 μSv While periapical' s are 5-8 μSv. Medical CT scanning are 1000-2000 μSv.14 Though much lower than medical CT, the doses from CBCT are 5-10 times more than standard dental radiography. This means appropriate justification is required. Following the ALARA principles means the following is required:

• The narrowest field of view needed for the given diagnostic goal.

• The lowest tube current and shortest timeframe needed for a diagnostic image with sufficient quality.

• Additional concern for children and women who are pregnant.

Economic Factors: The expenses related to CBCT dental units ($50,000-150,000) and the units needed for the facility, as well as maintenance and cost per scan, pose important CBCT economic factors. Foe the patient, the scan is charged around ($150-500), making it more expensive and thus out of reach for lower socio-economic populations. Cost-benefit assessments indicate that while CBCT is useful for tricky cases, it is hard to rationalize for standard evaluation procedures.

Availability and Access: Access to CBCT technology is unevenly split for geography, for urban and rural areas, and for developed and developing countries. This means healthcare professionals need to have established working referral relationships and often deal with possible delays in diagnosis.

Interpretation Expertise: Correct interpretation of CBCT images require additional training and is more complex than regular radiographic image interpretation. Various motion, beam hardening, and scatter artifacts can obscure a finding or mimic a pathological condition. Inter-observer differences in the interpretation of CBCT scans is a well-studied phenomenon, particularly in novice readers. Education and verification of competence is necessary still.

Other Limitations: Using gutta-percha, the metallic post, the implant, the amalgam filling, and other high-density materials will produce beam-hardening artifacts that can hide important anatomical features or create the illusion of a fracture. Understanding these constraints will aid in preventing misinterpretations.

5.3 Evidence Based Guidelines for Use in Practice

Both the European Society of Endodontology (ESE, 2014)[14] and American Association of Endodontists (AAE, 2015)[15] have published position statements advocating judicious CBCT use:

Recommended Indications:

1. Diagnosis and management of complicated dental and facial injuries
2. Finding and locating impacted or ectopic teeth
3. Evaluation of external and internal root resorption and invasive cervical resorption
4. Vertical root fractures in teeth where clinical and X-ray examination has found inconclusive data
5. Planning complex surgical endodontic procedures
6. Assessment of root canal systems where radiographs do not provide adequate visualization
7. Assessment of complex fractures, separations, perforations, and lost instruments
8. Assessment of retained roots in retreatment
9. Complicated maxillofacial pathology

Not Routinely Indicated For:

• Endodontic diagnosis in simple cases
• Periodic screening
• Procedures where radiographs suffice
• Postoperative examination when no complications are felt suspected

The position of these organizations is that CBCT is the second level (after conventional) imaging method and remains subordinated to first line imaging. Thus, clinical data, dental history, and primary radiographs are the first levels, leaving CBCT usage for problems which are not answerable using these tools.

5.4 Future Directions

The up-and-coming developments forecast a further advancement in the diagnostic capabilities of CBCT:

- Artificial intelligence involvement: Algorithms of machine learning a high degree of success in the automation of canal detection, fracture detection, and lesion recognition and segmentation.

- Techniques of lower doses: Iterative reconstruction techniques offer the possibility of obtaining diagnostic images at decreased levels of radiated exposure.
- Fusion of modalities: The incorporation of intraoral scans with CBCT assists in sophisticated planning of the treatment.
- Imagination in motion: Certain uses of limited angle CBCT may allow fast, extremely low dose imaging and dynamic in motion cross-sections of anatomy.

6. Conclusion

The improvements in diagnostic capability in modern endodontics is attributed to the advancements in Cone-Beam Computed Tomography (CBCT) technology which provides unparalleled visualization of the complex three-dimensional root canal anatomy. Many reliable sources have proven the increased accuracy of diagnosing the additional canals, root curvatures, vertical fractures, resorptive lesions, and periapical pathology in varied clinical practices as compared to the traditional two-dimensional radiography.

CBCT also provides improved clinical results in the complex mesial of lower molars where the anatomy may be very difficult to visualize and as a result the root canal systems may not be completely debrided. This technology is also very helpful in clinical situations such as complex anatomy, retreatment of a failed case, suspected treatment complications, and surgical procedure planning.

The incorporation of such technology in practices must take into consideration the radiation, cost, availability, and required expertise. Current guidelines set by evidence-based practices suggest the integration of CBCT as a helpful diagnostic tool alongside conventional imaging instead of performing integrated scans as the primary method of examination.

When utilizing bare minimum exposure (under the ALARA principle), CBCT scans greatly enhance modern endodontics by improving accuracy and tailoring treatment to individual patients, reducing complications, and optimizing treatment results.

Technological advances coupled with increasing clinical experience will surely expand the role of CBCT in evidence-based endodontic diagnosis and continue to keep appropriate emphasis on patient safety and cost-effective care.

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