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Cone-beam computed tomography in endodontics: Historical development, technical principles, clinical applications and operative outcomes (Review)

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Abstract. Cone-beam computed tomography (CBCT) has transformed diagnostic and therapeutic approaches within endodontics by providing practitioner-accessible three-dimensional visualization of dentoalveolar anatomy with high spatial resolution and comparatively low radiation dose. Conventional two-dimensional radiography, while essential and routinely used, suffers from inherently limited perspectives caused by projection, geometric distortion, and anatomical superimposition; these limitations can obscure complex root canal systems, periapical pathology and subtle fractures. CBCT fills these diagnostic gaps by producing isotropic voxel datasets that permit multiplanar reconstructions, accurate measurement, and volumetric assessment of osseous and dental structures. The present review traces the historical development of dental radiology leading to dental CBCT, summarizes fundamental technical considerations including voxel size, field of view and reconstruction algorithms, and discusses the principal advantages and limitations of CBCT relative to conventional imaging. Emphasis is placed on endodontic indications: The pre-operative evaluation of canal morphology and anomalous anatomy, the detection of vertical and horizontal root fractures, assessment of internal and external resorption, intra-operative localization of separated instruments and perforations, and objective postoperative outcome appraisal. Practical considerations, such as radiation dose, artifact generation and interpretation challenges are discussed, and suggested practice guidelines for appropriate use are provided. The intent is to present an integrated, evidence-informed perspective that assists clinicians in selecting and applying CBCT appropriately to enhance diagnostic accuracy and treatment outcomes in endodontic care.

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Key words: cone-beam computed tomography, endodontics, imaging, root morphology, periapical lesions

Contents

1. Introduction

Radiographic imaging has been integral to dental diagnosis and treatment planning since the dawn of dental radiology. Conventional periapical and panoramic images have long supported clinical decision-making through straightforward depiction of dental and osseous structures in the mesiodistal plane (1). However, these two-dimensional projections compress three-dimensional anatomy into a flat image, limiting detection and characterization of buccolingual features, canal complexity, and subtle periapical changes (2). The introduction of volumetric imaging modalities, culminating in compact cone-beam computed tomography (CBCT) systems suitable for dental clinics, has enabled clinicians to visualize and quantify anatomy in three orthogonal planes, enhancing diagnostic confidence and enabling more precise treatment planning (3) (Fig. 1). CBCT has the ability to produce multiplanar images enabling more precise assessment of anatomical structures and pathology. CBCT is increasingly becoming an invaluable tool in endodontics, significantly improving patient care and treatment decisions (4).

2. History of dental radiology and CBCT development

The discovery of X-rays by Wilhelm Röntgen in 1895 initiated a rapid succession of innovations that placed radiography at the heart of medical and dental diagnostics (5). Early dental exposures were technically demanding and prolonged, but progressive improvements in film technology, tube design and processing rapidly reduced exposure time and improved image quality (6). With the conceptual foundation for tomographic reconstruction articulated by Johann Radon and the practical realization of clinical computed tomography by Hounsfield and Cormack, three-dimensional reconstruction became possible (3). However, early medical CT systems remained prohibitive in cost, size and dose for routine dental use. The emergence of true dental CBCT systems in the late 1990s and early 2000s, pioneered by commercial units, such as the NewTom series and later by i-CAT, Accuitomo and others, made volumetric imaging accessible to dental practitioners by combining cone-beam geometry, dedicated detectors and more efficient reconstruction algorithms (7,8). The iterative improvement in detector technology, software and choice of field of view (FOV) has driven the wider adoption of CBCT across endodontics, implantology and orthodontics (1).

3. Limitations of conventional radiographic imaging

Despite their ubiquity, intraoral and panoramic radiographs are constrained by a number of limitations. Projected compression conceals information in the buccolingual dimension, geometric distortion and unavoidable magnification introduce measurement errors, and anatomic noise arising from superimposed structures compromises lesion detection and morphological assessment (5). Serial radiographs require strict standardization to be comparable, and small pathoses may remain radiographically occult until progression reaches cortical bone (9). These limitations particularly affect endodontic tasks, such as the identification of accessory canals, locating missed anatomy, and distinguishing between odontogenic and non-odontogenic radiolucencies.

4. CBCT: Technical considerations

Voxel size. In CBCT imaging, the voxel represents the smallest volumetric element and determines the achievable spatial resolution. CBCT provides voxel resolution which is isotropic, i.e., equal in three orthogonal dimensions. Commercial units provide voxel sizes that range from ~0.076 mm for high-resolution small-FOV scans to 0.2-0.4 mm for larger FOVs. The selection of voxel size represents a practical trade-off between image resolution, image noise and radiation dose (10). For endodontic applications where fine canal anatomy or fracture lines need to be resolved, smaller voxel sizes are preferred, albeit at the cost of higher radiation exposure and increased reconstruction time. Positioning the tooth in the center or closer to the anterior periphery of the FOV and selecting small FOV sizes improves the detection of root fracture and decreases artefact interference.

FOV. FOV selection is central to optimizing diagnostic yield, while limiting radiation exposure. Modern CBCT devices offer selectable FOVs, from localized segments that cover a few centimeters to craniofacial volumes encompassing the entire maxillofacial skeleton (11) (Fig. 2). Clinicians should tailor the FOV to the diagnostic question: Localized endodontic concerns demand small FOVs (tooth or single-arch coverage), whereas complex trauma or multi-tooth pathoses may justify larger volumes. Proper collimation and FOV selection reduce effective dose and limit unnecessary anatomical imaging.

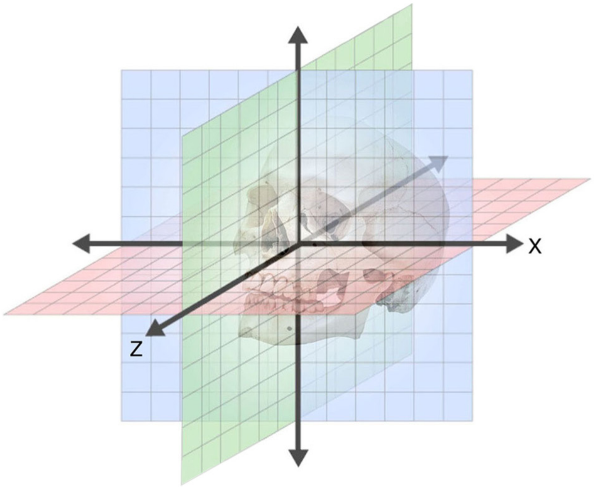


Figure 1. Three orthogonal planes in cone-beam computed tomography.

Image reconstruction and algorithms. CBCT reconstruction has historically relied on filtered back projection algorithms adapted for cone-beam geometry, such as the Feldkamp-Davis-Kress (FDK) method. While computationally efficient, FDK can produce cone-beam artifacts and limitations for objects located away from the central source plane (12). Iterative reconstruction techniques, increasingly available with modern systems, allow for analysis of the physics of photon interactions and detector response more accurately, allowing improvements in noise suppression and artifact reduction at an equivalent or reduced dose. Clinicians should be aware that different post-processing approaches and reconstruction kernels of manufacturers influence image appearance and diagnostic performance (13).

Patient positioning and scan volume. Patient orientation, i.e., in a sitting, standing or supine position, affects comfort and motion artifact susceptibility. Effective head stabilization and short scan times minimize motion-induced degradation. The shape of the captured volume (cylindrical vs. spherical) and detector size determine the maximum scan height; certain units use offset detectors or multiple rotations to extend the FOV (14). Operators need to ensure that the region of interest is centrally located within the volume to minimize truncation artifacts and to maximize the image (12).

CBCT vs. conventional radiographs. Intraoral radiographs of D-speed yield greater radiation dose of 170.7 μSv than the E/Fspeed and digital films which is 34.9 μSv (15). In extraoral radiographs, according to ICRP 2005/2007 (https://www.icrp.org/publication.asp?id=ICRP%20Publication%20103), the doses

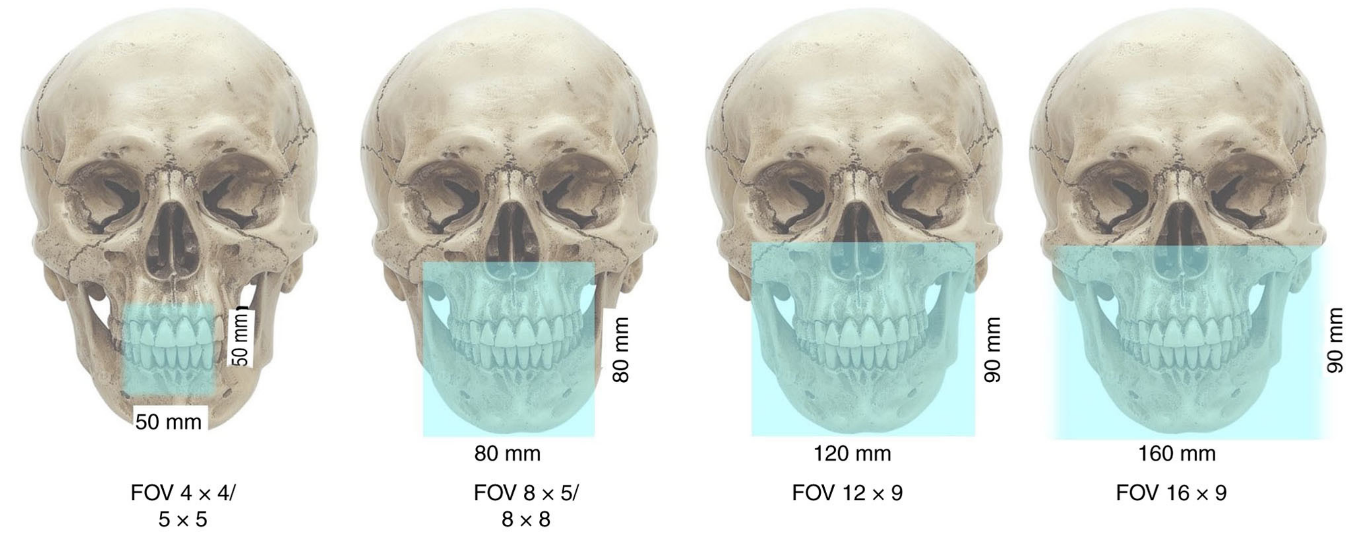


Figure 2. Different FOVs for cone-beam computed tomography. FOV, field of view.

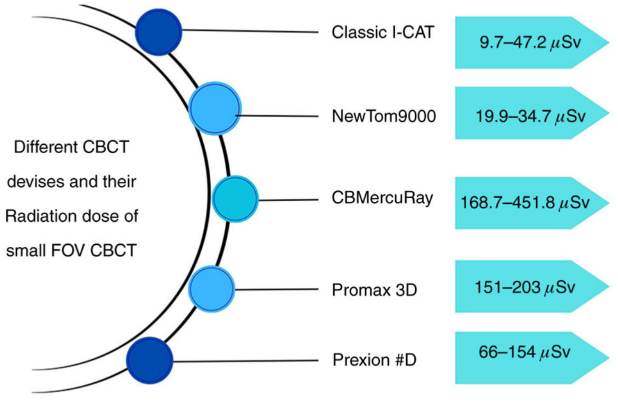


Figure 3. Radiation doses for small FOVs in different CBCT devices. FOV, field of view; CBCT, cone-beam computed tomography.

are between 2.7 and 24.3 μSv for the panoramic and 5.6 μSv for the lateral cephalometric. For full mouth series of intraoral radiographs, panoramic and lateral cephalometric radiographs, the total dose varies between 43.2 and 200.6 μSv, whereas the large FOV CBCT requires 30 to 68 μSv for the NewTom 3G, 74 μSv for the Next Generation i-CAT, 82 to 182.1 μSv for the Classic i-CAT, 87 μSv for the SkyView, 93 to 260 μSv for the Kodak 9500, and 98 to 498 μSv for the Iluma (16).

Comparison between different CBCT devices. Endodontic treatment usually uses smaller FOVs. Radiation doses for small FOV CBCT from different devices are illustrated in Fig. 3 (17-19).

In their study, Kim *et al* (20) compared I-CAT Gendex CB-500 and Orthopantograph OP300 in the detection of mechanically simulated peri-implant buccal bone defects in dry human mandibles. The result of their study suggested that the selection of CBCT systems with their respective commonly used acquisition protocols does not significantly affect diagnostic performance (20). However, the study by Rathee *et al* (21) compared the VelocityAI™, SmartAdapt® and PerFraction™ methods based on dosimetric analysis and demonstrated that the the VelocityAI™-based method using fraction N CBCT was most similar to the reference plan, whereas the other two methods had significant differences.

Clinical efficiency. Tsai *et al* (22), in an *in situ* study, demonstrated higher accuracy in CBCT than intraoral radiography. This was supported by the meta-analysis by Leonardi Dutra *et al* (23) which stated that digital and periapical radiographs were effective diagnostic tools for the detection of apical periodontitis; however, CBCT imaging had an excellent accuracy value.

5. Advantages of CBCT in dentistry and endodontics

CBCT confers multiple advantages: A lower radiation dose relative to medical CT, higher spatial resolution than panoramic imaging for bone and dental structures, and interactive multiplanar visualization that facilitates accurate measurement and surgical planning. Rapid single-rotation acquisition reduces motion artifacts compared with multi-pass fan-beam techniques, and the relatively compact footprint and lower cost have made CBCT widely deployable in dental offices (24). Further clinical benefits include the precise assessment of periapical lesions, improved detection of root fractures and the ability to localize anatomical landmarks critical to surgical planning. The isotropic nature of CBCT voxels enables distortion-free measurement across planes, a feature that is particularly useful for implant planning and endodontic assessment (Fig. 4).

6. Pre-operative assessment using CBCT

Root canal morphology and anatomical variants A primary use of CBCT in endodontics is the detailed pre-operative assessment of complex canal anatomy. Variants such as C-shaped canals, dens invaginatus, taurodontism and additional roots or canals can be accurately characterized in three dimensions, assisting the clinician in access design, negotiation strategy and selection of instruments. The precise knowledge of canal curvature and cross-sectional shape reduces the risk of instrument separation

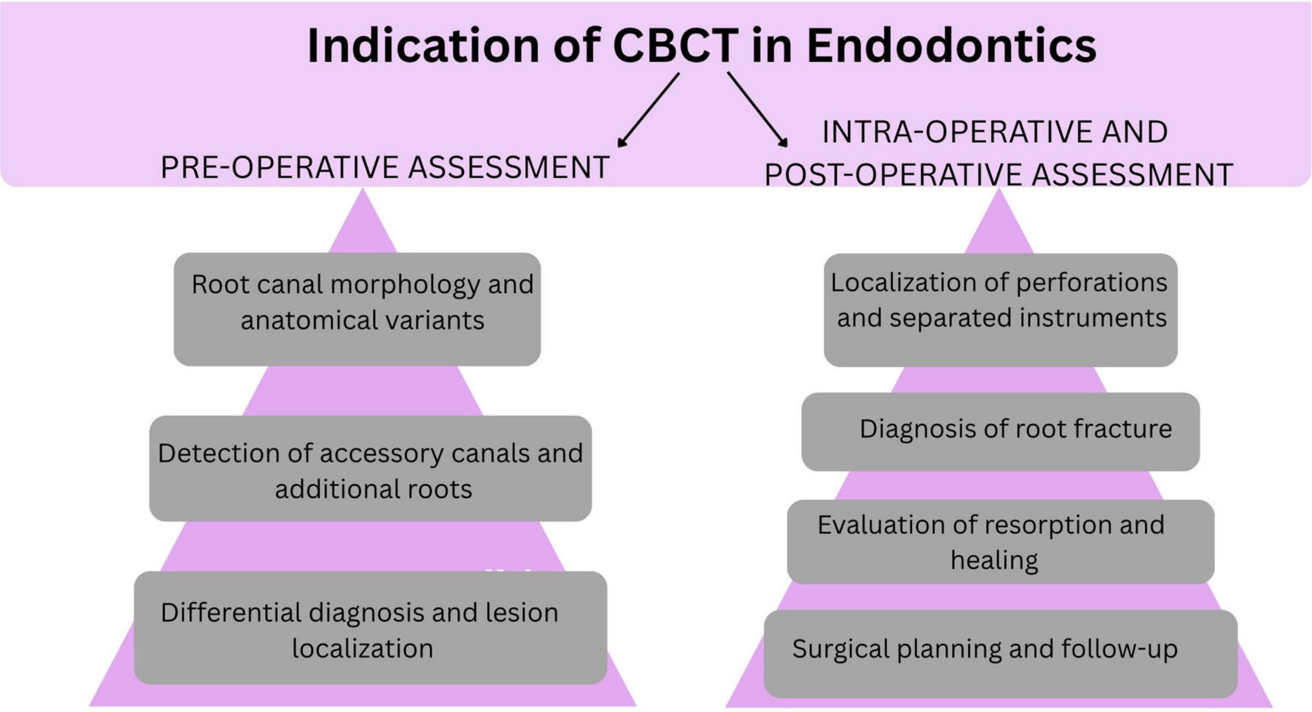


Figure 4. Indications for CBCT in endodontics. CBCT, cone-beam computed tomography.

and canal transportation (25). Case-based studies and population surveys using CBCT have documented a higher detection rate of accessory canals and unusual root configurations compared with conventional radiography are discussed below.

Detection of accessory canals and additional roots. High-resolution CBCT imaging improves the sensitivity for identifying accessory canals, second mesiobuccal canals (MB2) in maxillary molars and additional distolingual roots in mandibular molars. These anatomical discoveries directly affect treatment strategy: Locating and treating missed canals often changes prognosis (26). The study by Sukovic (24) stated that employing CBCT have revealed clinically significant canal systems that are not evident on two-dimensional radiographs, underscoring the value of the modality in complex endodontic cases. In their study, Aung and Myint (27) stated a sensitivity and specificity of 94 and 93.1%, respectively for the detection of second canal in permanent teeth. A sensitivity of 96.6% for MB2 was followed by a sensitivity of 88.8% for maxillary and mandibular premolars and 81% for mandibular molars. The specificity of 97.6% for premolars was trialed by a specificity of 85% for mandibular molars and MB2. For permanent mandibular canines, a sensitivity of 67% and specificity of 100% were estimated. CBCT exhibited greater agreement in detecting the second canal with micro-CT, with an estimated sensitivity of 100% and specificity of 95.6%. The highest prevalence of the second canal comprised the highest sensitivity of 99.1% and the lowest specificity of 77.5%. Following the exclusion of case-control studies, a 3% drop of sensitivity from the summary estimate was observed. Multiple spectrum of the second canal had a higher sensitivity of 8.6% and a lower specificity of 4.4% than a single spectrum (27).

Differential diagnosis and lesion localization. CBCT aids the differentiation of odontogenic from non-odontogenic radiolucencies, determines communications between lesions and the maxillary sinus, and clarifies the association between pathology and adjacent anatomical structures (25). For ambiguous cases with non-specific symptoms or inconclusive periapical radiographs, CBCT provides additional diagnostic confidence and helps avoid unnecessary or inappropriate endodontic interventions (6).

7. Intra-operative and post-operative assessment

Localization of perforations and separated instruments. Endodontic mishaps, such as root perforations and separated instruments are challenging to locate precisely using two-dimensional imaging. CBCT provides volumetric localization, assisting in decision-making regarding conservative repair, surgical intervention, or tooth extraction (7). Pre-operative CBCT can also assist in planning retrieval strategies for fractured instruments and in determining the proximity of procedural errors to vital structures (9).

Diagnosis of root fractures. Vertical root fractures (VRFs) and horizontal root fractures are often radiographically occult on conventional films unless the X-ray beam aligns closely with the fracture plane (6). CBCT improves the diagnostic accuracy for VRF by revealing fracture lines, associated radiolucent halos and adjacent bone changes in three dimensions (13). In the study by Hassan *et al* (28), the sensitivity and specificity of CBCT and periapical radiograph was compared for detecting vertical root fracture. The sensitivity and specificity were 79.4 and 92.5%, respectively for CBCT and 37.1 and 95%, respectively for periapical radiographs (28). However, the presence of root fillings or metallic posts can create beam-hardening artifacts that reduce sensitivity; thus, clinicians need to interpret suspicious findings within the clinical context and consider supplemental evidence (25).

Evaluation of resorption and healing. CBCT enhances the detection and characterization of internal and external resorptive defects, including the extent, perforation status and communication with the periodontal ligament or oral cavity (26). In post-operative follow-up, volumetric assessment permits the more objective measurement of lesion volume and bone fill compared with planar radiography, enabling a more accurate appraisal of healing progression. Nevertheless, the higher sensitivity of CBCT may reveal radiolucencies that represent cicatricial changes rather than active pathology, and the clinician should integrate clinical findings when making decisions (2).

Surgical planning and follow-up. For periapical surgery and other endodontic surgical procedures, CBCT is invaluable in delineating the association between apical pathology and adjacent structures, such as the maxillary sinus, nasal floor and mandibular canal (29). The accurate assessment of bone thickness, lesion extent and root apex orientation supports surgical access planning, resection angulation, and the selection of appropriate retrograde filling materials. Additionally, CBCT is useful in post-operative surveillance to evaluate bone regeneration and detect persistent pathologies (29).

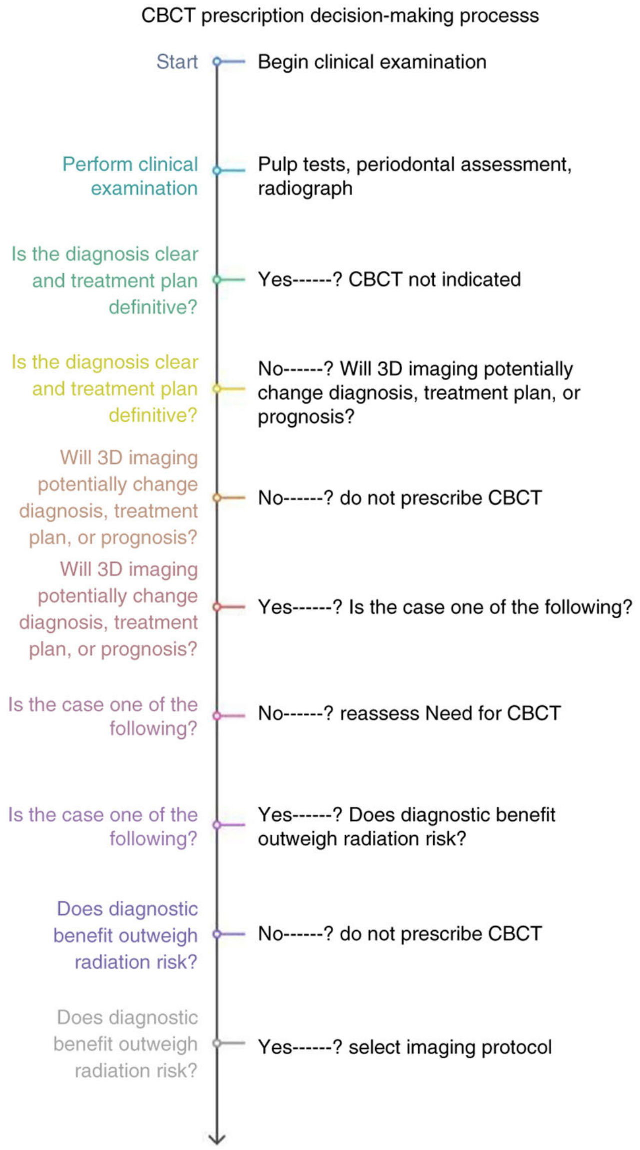
8. CBCT in pediatric endodontics

Given the potential risks associated with radiation exposure in children, it is imperative for clinicians to have a robust understanding of the applications of CBCT in pediatric patients. The most common indications for CBCT referrals in the pediatric population are impacted or unerupted permanent teeth, endodontic treatment and orthodontic assessments. Endodontic treatment uses smaller FOVs, such as 8x8 and 5x5, which are primarily of first permanent molars and traumatized upper central incisors (30).

CBCT provides associate increased read in locating incomprehensible canals, calcified canals, and curvature of roots in pediatric patients (31). CBCT is capable of providing submillimeter resolution in images of high diagnostic quality, with short scanning times (10-70 sec) and radiation dosages reportedly up to 25-30-fold lower than those of conventional CT scans (head) (32). The radio density and thickness of the tissue formed after pulp capping can also be studied using CBCT (33). The positioning of FOV in the vertical plane with the lead protection of thyroid and eye lens has the largest impact on local dose reduction in pediatric patients (34).

9. Limitations, artifacts and radiation considerations

While CBCT provides numerous diagnostic advantages, clinicians need to be mindful of its limitations. Metal artifacts from posts and restorations can obscure anatomy and generate false-positive or false-negative appearances (26). Image noise, motion artifacts and truncation artifacts arising from incomplete coverage reduce interpretability (35). A CBCT protocol with a higher kVp with metal artefact reduction can improve the image quality in CBCT scans when subjectively analyzed. However, these factors did not improve the diagnosis of VRF (36).



CBCT prescription decision-making processs

Figure 5. Decision-making flowchart.

The study by Torabinejad *et al* (37) demonstrated that 1 out of 5 patients successfully treated with root canal based on periapical X-ray and no clinical symptoms, will have 1 mm CBCT radiolucency. There is no information to determine whether these radiolucencies are complete healing, persistent disease, or fibrous scar tissue; thus, the dentist should be cautioned in retreatments to avoid overtreatment (37).

The radiation dose, although generally lower than medical CT, is higher than standard intraoral radiography; therefore, justification and optimization principles need to be followed (35). FOV selection, shielding and ALARA principles (https://www.cdc.gov/radiation-health/safety/alara.html) guide the responsible application of CBCT imaging. Comparative dosimetry exhibits a large range in effective doses across devices and protocols; therefore, practitioners should be familiar with the radiation characteristics of their unit and adhere to national and local regulations (38).

Radiation safety. According to the study by Pauwels *et al* (39), by decreasing mA values, one can proportionally decrease radiation dose with a fixed tube voltage (kV); however, CBCT scans acquired with low mA and kV may present higher artefact intensity. A smaller FOV size presents the highest sensitivity, specificity and accuracy for the detection of root fracture and the lowest artefact intensity; therefore, one could assume that larger FOVs may impair that diagnostic task (40). Although small voxel sizes are indicated for root fracture assessment, some other diagnostic tasks in endodontics may not be jeopardized by scans acquired with larger voxel size, with the benefit of dose reduction (41).

ALARA has been revised throughout time to the 'as low as diagnostically acceptable' (ALADA) approach, which aids medical practitioners in selecting the optimal FOV based on the region of interest (42). In panoramic charge-coupled devices, the effective dose observed was 16.1 μSv, 5.6 μSv in postero-anterior cephalometric photo-stimulable phosphor (PSP), 5.1 μSv in lateral cephalometric PSP, 68 μSv in New Tom 3G-Large FOV, and 569 μSv in CB Mercuray-'Facial' FOV (43).

In the study by Qu *et al* (44) on the New/Tom 9000 CBCT scanner, the effective organ doses to the thyroid and esophagus were 31.0 and 2.4 μSv, respectively, with a collarless CBCT scan. The effective organ dosage for the thyroid gland and esophagus were decreased to 15.9 Sv (48.7 % reduction) and 1.4 Sv (41.7% reduction), respectively, when a single thyroid collar was worn snugly in front of the neck, and 46.5 and 41.7% reduction when two collars were used (front and rear of the neck) (44).

10. Practical recommendations and appropriate use criteria

Practical guidance for CBCT in endodontics emphasizes targeted, case-specific use. Indications where CBCT is likely to change management include: teeth with unresolved symptoms despite negative or ambiguous radiographs; suspected complex morphology or additional canals not visualized on 2D images; suspected root fractures that cannot be confirmed by periapical radiographs; pre-surgical planning for apicoectomy; assessment of persistent or recurrent periapical pathology; and evaluation of resorption. Conversely, routine screening CBCT for all endodontic cases is not justified due to cost and radiation considerations (45). A decision-making flowchart for the use of CBCT in endodontic practice is presented in Fig. 5. Clinicians should document the diagnostic rationale and obtain informed consent mentioning radiation risks and benefits. The AAE and AAOMR guideline (https://aaomr.org/common/Uploaded%20files/Position%20Papers/aaomr-aae_position_paper_cb.pdf) states that CBCT in endodontics should be limited in endodontics to assess and treat complex endodontic-related issues, such as the identification of accessory canal, root curvature, periapical pathoses, intra and the post-treatment assessment of complicated endodontics (46).

11. Conclusion

CBCT represents a significant advancement in endodontic imaging, providing three-dimensional visualization that improves the detection of complex root anatomy, periapical pathology, fractures and resorptive defects. When used judiciously with appropriate FOV selection and dose optimization, CBCT provides diagnostic insight that can materially alter treatment planning and improve outcomes. Clinicians need to balance diagnostic benefits against artifact risk and radiation exposure, integrating CBCT findings with clinical examination and other diagnostic tests. Continued improvements in detector technology and reconstruction algorithms promise to enhance image quality while reducing dose, further strengthening the role of CBCT in endodontic practice.

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Authors' contributions

AS was involved in the conceptualization of the study and in the drafting of the manuscript. SR was involved in the literature synthesis, figure planning, critical revisions, technical editing, formatting and references. All authors have read and approved the final manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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