

Comparative Evaluation of Cone-Beam Computed Tomography and Conventional Radiography in Endodontic Lesion Detection

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Abstract

The successful diagnosis and treatment of periapical lesions are dependent on successful endodontic treatment and good diagnosis, with the correct technique for the accurate detection of periapical lesions. The standard two-dimensional radiographs have been employed for this purpose, but these radiographs have disadvantages in revealing complex anatomical structures and the presence of overlapping features that may reduce the accuracy of diagnosis. Now, with three-dimensional imaging, Cone Beam CT has come to be regarded as a superior tool in delineating the extent, position, and morphology of periapical pathology. This article comparatively evaluates CBCT and conventional radiography for the detection of endodontic lesions, bringing into focus their strengths, disadvantages, and clinical applications. The studies show that CBCT has greater sensitivity and specificity for detecting lesions, especially where multi-rooted teeth and complex anatomical variations are involved. Yet issues related to radiation dose, cost, and accessibility must be considered. From these findings, we see that CBCT cannot supplant conventional imaging but rather defines itself as an adjunct place with better diagnostic precision in present-day endodontology.

Keywords

Cone-Beam Computed Tomography (CBCT), Conventional Radiography, Endodontic Lesions, Diagnostic Accuracy, Periapical Pathology

1. Introduction

An accurate diagnosis of periapical and endodontic pathologies constitutes the precursor of effective treatment and successful clinical results in dentistry. Conventional radiographic two-dimensional techniques such as periapical and panoramic radiographs are considered an indispensable tool in the endodontic diagnostic field. They are easily accessible, economical, and present relatively low exposure to radiation. The drawback of these techniques is that the imaging could be distorted in a geometric way, could carry through anatomical superimposition, and could fail in showing the detailed three-dimensional morphology of dental and surrounding bone structures.

Cone-Beam Computed Tomography has fixed many limitations of conventional X-ray, providing a three-dimensional volumetric image that allows clinical visualization of minute details of root canal morphology, periapical lesions, and surrounding anatomical structures with more accuracy. Since its utilization in endodontics in the early 2000s, CBCT had gained recognition as a worthy diagnostic adjunct, particularly in cases with higher complexity wherein conventional radiographs are inadequate. Leading up to 2019, studies have developed a consensus that CBCT has a higher sensitivity and specificity in the detection of periapical lesions, identification of root resorptions, and assessment of canal complexities than conventional radiography.

The CBCT is still confronted with limitations despite having the diagnostic superiority. The considerations about radiation dose, accessibility, and cost still dictate decisions in routine clinical practice. Hence, CBCT is increasingly perceived as a complementary imaging modality-the aspect that gives the clinician all the power to make an accurate and well-informed decision-in endodontic diagnosis and treatment planning. This comparative evaluation highlights the diagnostic effectiveness of CBCT in contrast to conventional radiography, while stressing their role, advantages, and limitations in the contemporary setting of endodontics in 2019.

2. Limitations of Conventional Radiography

Conventional radiography has been regarded as the gold standard for endodontic and maxillofacial diagnosis, with periapical and panoramic imaging especially offered. However, despite this, several inherent limitations shroud their diagnostic reliability and most times clinical decision-making. Their affordable nature, availability, and low dosage of radiation-like characters ensure that they have been in use in general and specialty practices [1].

The most important limitation of any 2D radiographic image is anatomical superimposition; consequently, delimitation of the region of clinical interest is obstructed by the overlapping structures of anatomy. For example, the zygomatic arch,

floor of the maxillary sinus, nasal cavity, and dense cortical bone overlap with the roots of the posterior maxillary teeth, disabling uncomplicated visualization of periapical changes. This overlap can hamper the detection of early or small periapical lesions, root resorptions, or an extra canal; thus underdiagnosis or misdiagnosis prevails. Besides, in great clutters of anatomical sites like the posterior maxilla or mandibular molar region, the possibility of superimposition posing as radiographic artifacts of pathology may further confound clinical interpretation [2].

Another classic problem is geometric distortion. The correct angulation and positioning set the standard by which periapical and panoramic images attain diagnostic quality. Movement of the patient, improper sensor placement, or use of non-standard angulation can cause magnification, elongation, or foreshortening according to [3]. Such distortion weighs heavily upon the diagnostic ability of clinicians with regard to determining the size, location, or extent of periapical lesions, fractures, or anatomical variations. Surgical planning is, therefore, particularly disadvantaged, given that it requires proper spatial relationships between pathology and critical anatomical structures.

Secondly and equally important is the fundamental limitation of conventional radiography in that it entails the two-dimensional projection of a three-dimensional anatomical structure. This by itself possesses an impediment in the ability of the clinician to appreciate the true spatial complexity involved in the root canal morphology, root fractures, resorption defects, and periapical pathology. As an example, vertical root fractures usually develop along the buccolingual plane, and such fracture lines may remain undetected in a periapical radiograph due to the superimposition of adjacent structures. Accessory canals or lesions completely within the cancellous bone may also go unnoticed until the cortex gets sufficiently involved. Consequently, the clinician might think fewer lesions are present and that the disease would be less severe, thereby delaying intervention. [3].

Therefore, another limitation to the biological threshold for lesion detectability results from the studies showing that between 30 and 50% of mineralized bone must be resorbed before radiographic signs of periapical pathology appear. In other words, the radiographic evidence is found behind the disease process, and the beginnings of inflammatory or infectious disturbances of cancellous bones do not show up on conventional films. From that standpoint, if clinicians rely only on periapical or panoramic imaging, this may lead to interpreting continuing symptoms incorrectly or underacknowledging disease progression. This factor of diagnostic lag has rather made it a little problematic to monitor healing since on occasions, resolution of radiographic periapical lesions occurs behind histologic healing.

Besides this, technical sensitivity leads to variations with conventional radiography. Exposure factors, quality of the films or sensors, and maintenance technique by the operator are on maintenance of image sharpness or contrast, therefore altering the diagnostic perception they are given. Panoramic radiographs particularly with image magnification and lower resolution cannot detect slightly periapical or endodontic changes [4].

So, whilst conventional radiographs are still worthy first-line tools, their diagnostic limitations have led to an increased reliance on advanced three-dimensional imaging, mainly Cone-Beam Computed Tomography (CBCT). Along with the last decade, it was well established that for complex endodontic and maxillofacial cases, cases are better diagnosed with CBCT, especially for identifying periapical lesions, resorptive defects, root fractures, and defining the spatial relationships of lesions with adjacent anatomic structures [4]. However, while many of the deficiencies of 2D imaging are addressed by CBCT, it can only be justified if balanced against increased radiation dose and costs.

Queensland remains the most important ab initio imaging technique because it is inexpensive and easily accessible, although there exist diagnostic limitations that include such things as anatomical superimposition; geometric distortion; limited spatial representation; and threshold-dependent lesion visibility, all warranting additional CBCT imaging in difficult or unclear cases. In parallel to endodontic and maxillofacial surgical fields moving increasingly towards 3-D imaging, the restrictions of conventional radiography are a reminder that these adjunctive tools, though very useful, are insufficient when faced alone in the contemporary practice setting. As shown in Figure 1, the image provides a clear explanation.

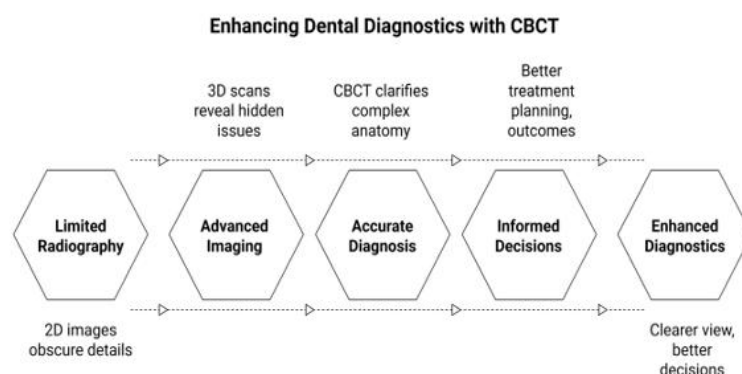


Figure 1. Limitation of conventional radiography.

3. Techniques Used in Periapical and Panoramic Imaging

Being able to discriminate between individual teeth and adjacent bony structures with high resolution has made periapical radiography one of the most widely employed intraoral imaging techniques in endodontics. Its principal function is to be able to ascertain details from the individual tooth in conjunction with the joining anatomy. The small film or digital sensor needs to be hands-on with the tooth for exposure, with the x-ray beam passing through the area of interest. Two principal methods are in use: the paralleling technique and the bisecting angle technique.

The paralleling technique is considered to be the best standard for periapical imaging. The film-holder apparatus allows for the sensor to be located parallel with the long axis of the tooth, while the x-ray beam is projected at a right angle with respect to both the tooth and the receptor. Such geometry decreases distortion in the image, lowers magnification, and allows for an accurate representation of tooth length, root canal morphology, and periapical status. Due to this, the paralleling technique has become the method of choice in endodontics, where exactitude is required for diagnosis and treatment planning.

Unlike in the parallel technique, the bisecting angle approach places the film or sensor close to the tooth so that the x-ray beam is directed perpendicular to an imaginary line bisecting the angle formed between the tooth's long axis and the receptor. It is a largely adaptable approach for difficult clinical situations-good in scenarios with small mouths, anatomical limitations, or gag reflex-but does suffer from geometric distortion, foreshortening, and elongation errors [5]. Hence, it is generally deemed to be less reliable in making accurate measurements or identifying subtle pathology.

The clinical use of periapical radiographs is highly essential for multiple diagnostic and evaluative purposes. They are used to check the periapical status, find changes in root canal anatomy, locate periapical lesions, identify root fractures, and examine the result of a treatment such as a root canal filling or apical healing [5,6]. Further, due to a low radiation dose and easiness of acquisition, they are the primary imaging options for localized endodontic diagnosis.

Compared with periapical imaging, panoramic is an extraoral technique that allows imaging of the region from a broad point of view: it can include both jaws, the dentition, and surrounding anatomical structures in a single exposure. The x-ray source and receptor rotate in synchrony around the patient's head, producing a wide-field tomographic image [6]. Panoramics are invaluable for general screening in dentistry and oral surgery, providing significant information on jaw relationships, impacted teeth, gross bone pathologies, and developmental anomalies.

For the same conclusion, panoramic radiography has limited worth in diagnosis within endodontics. Their relatively low spatial resolution and higher geometric distortion than for intraoral periapical radiographs make them inferior for detecting smaller periapical lesions, faint resorption defects, or finer details of root canals [6]. The diagnostics in endodontics is also hindered by the changing image sharpness from one region to another in panoramic radiography, with the anterior areas usually blurred because of the limitations in the focal trough.

By the year 2019, periapical and panoramic methods continued to remain among the essential first-line imaging modalities for endodontic procedures. Periapical radiography, as the name implies, was performed for localized, detailed examination of a particular tooth, while panoramic imaging retained its role as an adjunctive tool for generalized anatomical considerations, treatment planning, and screening purposes for systemic or structural anomalies. However, each bears with it, to some extent, a limitation, especially in situations wherein three-dimensional detail becomes paramount in exposing complex anatomy, hidden canals, or early pathological changes. Such diagnostic dilemmas have increasingly fostered the acceptance of Cone-Beam Computed Tomography-a three-dimensional imaging modality capable of giving higher resolution than any other imaging technique and offering superior diagnostic accuracy in complicated endodontic cases.

4. Applications in Detecting Periapical Lesions and Root Canal Complexities

Conventional radiography, periapical imaging above all, remains a means of diagnosing and following up endodontics. It would help give a particular role in the identification of periapical lesions, in evaluating root canal morphology, and in assessment of treatment outcomes. Radiographically evidenced periapical radiolucency is commonly interpreted as apical periodontitis, granulomas, radicular cysts, or abscesses, which are critical to treatment and prognosis estimations [7]. Periapical radiographs also allow validation of healing progression after root canal treatment, such that clinicians can record any future changes in lesion regression or persistence over time.

Though advantageous, periapical radiographs may have less sensitivity while detecting early periapical pathology. This kind of biological limitation is that radiographic changes, from Bender and Seltzer's point of view (1961), appear only when 30%-50% of the surrounding mineralized bone has been resorbed. A result of this mechanism is the undiagnosed perish of periapical lesions if they remain confined to cancellous bone or begin to develop there. The diagnosis is thereby delayed, and subsequently, the intervention is delayed, giving the possibility for the disease to progress beyond the threshold of radiographic visibility. Furthering this research are small lesions that can be obscured by superimposed anatomical structures or be mimicked as periapical pathologies, reducing diagnostic accuracy in radiographs due to their two-dimensional nature.

Apart from periapical lesion detection, conventional radiographs are often used in root canal anatomy determination. They help a clinician suspect the actual number, curvature, and direction of the canals before and during endodontic

treatment. However, the flat two-dimensional nature of the image rarely allows outcome achievement of the anatomy of various accessories of canals like isthmus, fins, or apical deltas. Overlapping structures possibly hide another canal, while mild variations could pass unnoticed, thus increasing the risk of missed anatomy. These limitations have a great clinical impact, for missed or untreated canal being one of the major causes of endodontic failures [8].

I'll go through the anatomy and structure of an endodontically treated tooth that illustrates how it can be used in detecting periapical disease. Radiographs are used in the evaluation of a number of other things such as root canal morphology, anomalies, apical constriction sizes, working lengths, etc. These definitions suggest that practitioners estimate the actual number, curvature, and direction of the canal even before the actual endodontic procedure [8].

Panoramic radiography appears to serve the need for a broad overview of the maxillofacial region. Since it has a wider field of view, it is able to locate extensive lesions involving more than one tooth; it is also able to assess the relationship of the tooth to some anatomical landmarks such as the maxillary sinus or the mandibular canal [8]. Therefore, treatment planning for complex or multisystem cases where there is an importance to identify surrounding anatomy will benefit from this type of imaging. However, panoramic imaging traditionally provides lower spatial resolution and higher distortion than the periapical counterpart. This evidently places such panoramic investigation as secondary and adjunct to the more focused image with reference to diagnostic considerations in endodontics.

Another consideration that must be kept in mind is that lesion detectability with conventional radiography depends on the projection geometry. Slight changes in angulation may alter the visibility of the lesion or canal structure, affecting the interpretation. Clinicians usually take views with variable horizontal or vertical angulation to overcome this limitation. However, increased radiation exposure is caused for the patient by this approach, and the basic two-dimensional limit remains unresolved. Another consideration is that such interpretation is subjective and that differing judgments by evaluators inherently pose an obstacle to consistent detection, especially in very subtle or borderline cases.

In the system of dental literature, consensus had emerged by 2019 that the ending of the crown is basically a very simple case. Radiographs like periapical and panoramic are essential lines of first diagnosis; however, their limitations should be addressed by more advanced three-dimensional modalities such as CBCT, especially in difficult endodontic cases. CBCT annihilates all forms of superimposition and geometric distortion and presents RCT anatomy and the viewpoint of periapical pathology in real 3D. The earlier the lesions can be picked up with it, the best, along with locating accessory canals and better characterizing cysts, granulomas, and other radiolucent lesions [8,9]. Not to mention that its provision of multiplanar and volumetric reconstructions makes it possible to localize and characterize pathology with great accuracy, which conventional films cannot.

Assuming that CBCT imaging may reveal early lesions or intracanal anatomical complexities hidden beneath normal-looking periapical radiographic findings, accurate diagnosis can be made accompanied by focused treatment. In retreatment cases where a missed canal or undetected resorption is suspected, CBCT provides a certainty that cannot be equaled by conventional imaging. Conventional radiographs remain the most readily available and least costly diagnostic tools in general dental practice, but complementing them with CBCT continues to provide a more exhaustive assessment of endodontic conditions.

The availability, simplicity, and ability to assess gross changes after some time in the conditions of pulp tissue at a relatively accessible level can be attributed to periapical and panoramic radiographic techniques fundamental in their work. Limitations of their incapacity to detect early periapical pathology or confirm complex canal morphology at present played out in front of us. CBCT integration into the diagnostic process remedies such shortcomings so that imaging in endodontics, which was traditionally 2-D, now recognizes the true 3-D complexity of dental anatomy and disease.

5. Diagnostic Accuracy in Lesion Detection

The reliability of imaging modalities in the identification of a periapical lesion stands as a nail on the head for an endodontic diagnosis and the treatment planning. The correct identification of the periapical pathology will not only determine whether the condition requires intervention, but it will also have a bearing on prognosis and the treatment modality used. For many decades, conventional periapical radiography has been the chief and widely accepted means of imaging used in the field of endodontics. But inherent biological and technical limitations seem to present a dimming effect on their diagnostic accuracy.

One of the highest limitations of a conventional radiograph method is the biological threshold of detectability. As established by research, it has been set that 30 to 50% of mineralized bone needs to be resorbed before an observation of a periapical lesion will visually come to light. This implies that smaller or incipient lesions, particularly those confined to cancellous bone, frequently go undetected until the disease is substantially well established. Thus, because of this, patients frequently appear with symptoms or even pathologies that persist despite radiographs having a normal look, thus complicating clinical decision-making and further delaying suitable treatment [10].

Yet another issue arises because periapical radiographs remain two-dimensional images representing complex three-dimensional structures. When bone, roots, or adjacent teeth superimpose anatomically, it may hide subtle lesions or create artifacts capable of simulating actual pathology. This results in false negatives (the absence of lesion detection when they are really present) or false positives (interpretation of natural anatomical variations as clinical pathology with

treatment). Though periapicals are still said to be more accurate than panoramic radiographs in lesion detection, their diagnostic sensitivity notably drops in posterior teeth with superimposed roots while also affecting multi-rooted mandibular molars [10].

Since these panoramic radiographs are excellent for scanning vast anatomical regions, they provide even less diagnostic ability when it comes to periapical lesions. They are less sensitive than periapical images in identifying apical pathologies, mainly due to much lower spatial resolution, frequent distortion, and the magnification errors produced. Hence, endodontic diagnosis almost never rests on panoramic radiography alone, which is more frequently deployed for general assessments of the maxillofacial skeleton or preliminary screening [11].

With the contrary, Cone-Beam Computed Tomography (CBCT) is considered by many to be the gold standard for the detection of periapical pathology. A true advantage lies in the fact that three-dimensional visualization is possible through CBCT, with no possibility of superimposition, thereby allowing the clinician to accurately judge the size, location, and extent of lesions. Its other major indication includes multi-rooted teeth and cases where the cortical bone is intact, resulting in lesions that cannot be detected on conventional radiographs. It has also been established through studies that CBCT detects periapical lesions invisible to periapical films, with demonstrating significantly higher sensitivity and specificity in clinical settings. In addition, CBCT is also used to determine whether there is any involvement of the cortical plate, the closeness of the lesion to important anatomical structures, or if it is a periapical cyst, periapical granuloma, or other types of radiolucencies-these are important for the prognosis and treatment plan.

The loss of professional consensus regarding routine placement of CBCT in endodontics is undoubtedly a result of limitation concerning radiation exposure, cost, and limited availability, which almost automatically restricts its use to selected cases. In 2019, it was already agreed by professional consensus that CBCT should be a complementary diagnostic tool rather than to replace conventional radiography. The guidelines considered that CBCT should be indicated when the conventional images are inconclusive, when lesions are suspected but the conventional radiograph does not allow for visualization, in complex retreatments, and in cases of trauma or atypical symptoms. This hybrid approach weighs factors of advanced diagnostic utility against patient safety and cost-effectiveness [12].

To sum things up, while conventional periapical and panoramic radiographs remain the first-line imaging option for endodontics, their diagnostic limitations have been widely described. Since CBCT could provide significant enhancement in lesion detection and diagnostic confidence in complex or equivocal cases, its judicious use will allow the clinicians to accomplish the highest degree of diagnostic accuracy without compromising responsible patient care.

6. Discussion

While diagnostic imaging in endodontics has kept pace, CBCT has emerged as a revolutionary imaging tool. Traditionally, periapical and panoramic radiographs have been the fundamental tools in endodontic diagnosis that rely on the clinician's judgment to assess periapical status, root canal morphology, and treatment outcomes-from an analytical perspective. However, their inherent 2D nature poses problems like distortion of images, superimposition of anatomical structures, and limited sensitivity for early or very subtle lesions. These shortcomings send a clarion call to adopt an advanced imaging method producing more accurate and detailed images.

CBCT has come to solve almost a majority of the diagnostic challenges, for it creates a three-dimensional visualization of the teeth and surrounding structures. By virtue of this ability to eliminate overlaps distorting the normal anatomy, clinicians can begin the identification of periapical lesions at earlier stages with greater precision. This is especially so with multi-rooted teeth or when complex root canal configurations exist, which traditional radiographs often fail to capture and display with regard to the decrease of the anatomical variation. Resolving the visualization problems, CBCT clearly improves treatment planning, so that missed canals may rarely occur, thus rendering endodontic therapy more predictable.

This presents another interesting advantage of CBCT: it allows more accurate determination of lesion size, assessment of spatial relationships, and cortical bone involvement when compared to conventional imaging. This carries further practical implications in evaluating the extent of periapical disease, differentiating healing from persistence of pathology, and also judging the outcome of treatment-whether surgical or non-surgical. Retreatments are, of course, the cases in which CBCT appears to be the most helpful in cases where conventional imaging gives inconclusive or conflicting findings.

There are, however, limitations to CBCT. Although radiation exposure is certainly less than that of medical CT, it still remains higher than conventional dental radiographs. Its cost, availability, and the necessity for proper training in interpretation of images may also affect the acceptance of this mode of investigation into clinical practice. Thus, CBCT certainly has shown potential diagnostic benefits; however, only in situations where conventional radiography falters or indeed fails should the use of CBCT be contemplated.

CBCT provides another tool in the imaging armamentarium of the endodontist. It does not replace traditional radiography but complements it. Appropriate use of CBCT routinely enhances diagnosis and treatment planning, which in turn improves the outcome for the patient, thus establishing CBCT as an important modality in the armamentarium of the modern endodontist.

7. Conclusion

Cone-beam computed tomography (CBCT) has revolutionized diagnostic imaging in endodontics by addressing many of the inherent shortcomings of conventional radiographic modalities. Unlike traditional periapical and panoramic radiographs, which are limited by two-dimensional representation, anatomical superimposition, and biological thresholds for lesion visibility, CBCT provides clinicians with comprehensive three-dimensional visualization. This advancement has allowed for earlier detection of periapical pathology, clearer assessment of complex root canal anatomies, and more accurate evaluation of treatment outcomes.

The clinical impact of CBCT lies in its ability to transform diagnostic uncertainty into diagnostic precision. Periapical lesions that remain undetectable on conventional radiographs due to their confinement within cancellous bone can be revealed clearly on CBCT scans. Similarly, anatomical variations such as accessory canals, isthmuses, and apical deltas features critical to endodontic success are more reliably identified, thereby reducing the risk of missed anatomy and treatment failure. For retreatment cases, CBCT enables clinicians to locate untreated canals, assess the extent of periapical pathology, and evaluate previous obturation quality with greater accuracy. In trauma cases, it assists in diagnosing horizontal or vertical root fractures, luxations, and resorptive defects, conditions that are often obscured or underestimated on two-dimensional imaging.

Despite these advantages, conventional radiographs retain an essential role in everyday clinical practice. Their ease of use, low cost, and relatively minimal radiation dose make them the first-line choice for routine diagnosis and follow-up. CBCT, while more powerful, requires careful and judicious integration into clinical workflows. The principle of ALARA“as low as reasonably achievable”remains central in dental radiology, underscoring the responsibility of clinicians to balance diagnostic benefits against radiation risks. Therefore, CBCT should not be viewed as a replacement for periapical and panoramic imaging but rather as a complementary tool that enhances diagnostic accuracy when traditional methods fall short.

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