Advanced Imaging modalities in Endodontics – A Review

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Abstract: Introduction
Introduction: Radiography is used to diagnose or treat diseases by recording the internal structures of the human body. Ever since Radiology was introduced in Dentistry, its use has been extended to all the disciplines of Dentistry. With advancements in technology, various imaging modalities are being used to better enhance diagnostic ability in the field of Dentistry especially with regard to Endodontics.
Aim: With every step of root canal treatment relying on radiographs, this article aims to explore the various imaging modalities that are used in Endodontics. The purpose of this review paper is to assess the limitations of periapical radiographs in endodontics and to clearly articulate three-dimensional imaging technology that have been envisaged as adjuncts to conventional radiographs. These include micro-computed tomography, tuned aperture computed tomography, spiral computed tomography, magnetic resonance imaging, ultrasound, and cone beam computed tomography.
Materials and methods: Several articles from literature were studied and have been utilized in this review to highlight the different imaging modalities, their advantages and limitations in the field of Endodontics.
Conclusion: This article states that advanced imaging techniques help in obtaining precise images and specific information for accurate diagnosis and help errors during the treatment, leading to predictable endodontic therapy.

Keywords: Advanced imaging techniques, Endodontics, CBCT, CT, TACT, SCT, OCT.

1. Introduction

Since Kells' 1899 report on the utility of envisioning a lead wire in a root canal on a radiogram in determining length, radiography has been a cornerstone in the discipline of endodontics.[1] Endodontic management relies on radiographic examination to endorse facets of diagnosis, treatment planning, intraoperative control, and outcome assessment. Intra-oral periapical radiographs are still the most often exposed during endodontic procedures, and they provide valuable information for the existence and position of periradicular lesions, root canal anatomy, and the vicinity of adjoined anatomies.[2]

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2. Materials and Methods

A systematic literature review based on synthesis methodology was used in this review article. Several studies related to advanced imaging modalities in endodontics were analysed. The results, strengths and weaknesses of the literature review have been collated.

3. Discussion

Limitations of Conventional Radiography in endodontics

Amidst their ubiquitous usages, periapical images, whether captured on x-ray film or digital sensors, provide limited information due to the limitations listed below.

Three-dimensional anatomy compression: It may be hard to determine the site, nature, and shape of structures within the root under investigation.[3] The angulation of the root to the cortical plate, the cortical plate's thickness, and the root's relationship to pivotal adjoining anatomical structures such as the inferior alveolar nerve, mental foramen, or maxillary sinus should all be comprehended in surgical planning.[4]

Geometric distortion: The image receptor should ideally be parallel to the long axis of the tooth, and the x-ray beam should be perpendicular to the image receptor and the tooth being evaluated.[5]The shallow palatal vault in the maxilla prevents this positioning of the image receptor. Due to the obvious lack of long-axis orientation, the radiographic image is geometrically distorted. Over or under angulated teeth can substantially reduce the radiographic root length of the tooth under consideration.[6] It is impossible to completely avoid geometric distortion and magnification in multi-rooted teeth with divergent or convergent root anatomy, notably in the posterior maxilla.[7]

Anatomical noise: Anatomical features can conceal the area of interest, finding it challenging to interpret radiographic images.[8] These features can be radiopaque (e.g., the Zygomatic buttress) or radiolucent (eg. Incisive foramen, maxillary sinus). The greater the complexity of anatomical noise, the greater the reduction in contrast within the area of interest.[9]

Temporal Perspective: To appraise the output of endodontic treatment, radiographs taken at different times should be compared using standardisation of radiation geometry, density, and contrast to allow for reliable comparison. Poorly standardised radiographs result in an under- or overestimation of the degree of healing or failure.[10]

The deleterious effects of improper film processing on diagnostic quality and the difficulty of maintaining high-quality chemical processing are quite well documented issues in dental radiography.[11]

4. Alternative and advanced Imaging modalities in endodontics

I. Micro-Computed Tomography The micro-CT is a noninvasive and non-destructive method to obtain two- and three-dimensional images.[12] Scanning electron microscopy, stereomicroscopy and confocal laser microscopy can be used for superficial analysis but do not provide 3D images without the requisite of sectioning the samples. Contrary to these, micro-CT allow the use of the same sample for different tests without destruction of the sample.[13]This characteristic is very important particularly when is required to evaluate volume pre and post instrumentation, quality of root canal obturation or removal of the material in retreatment.

Some applications of micro-CT in endodontic research include the analysis of internal anatomy of teeth,[14] instrumentation of root canal,[15] root canal fillings,[16] retreatment,[17] physical and biological properties of materials. Micro-CT has been proposed to evaluate the quality of obturation techniques. The percentage of volume of voids and gaps in the root canal can be calculated. The analyses include demarcation of voids and gaps in the two-dimensional slices and then the reconstruction in a three-dimensional image. This process is considered prolonged and difficult, but very accurate.[18]

Other advantages of micro-CT are the possibility of repeated scanning and the manipulation of image using specific software.[19] On the other hand, a limitation of micro-CT is the impossibility of using it for in vivo studies due to the radiation exposure. Moreover, micro-CT permits the examination of specimens of limited size, which restrict some analysis. Instead, cone beam computed tomography could be used in patients despite its lower resolution.[20]

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II.Tuned aperture computed tomography in Endodontics

Tuned aperture computed tomography(TACT) works on the basis of tomosynthesis.[21] A series of 8-10 radiographic images are exposed at different projection geometries using a programmable imaging unit, with specialized software to reconstruct, a three-dimensional data set which may be viewed slice by slice. TACT was more diagnostically informative and had more impact on potential treatment options assessing patients who required minor oral surgery than conventional radiographs. The diagnostic accuracy of TACT was superior to conventional radiography for the detection of vertical root fractures.[22] Nance et al compared TACT with conventional radiography to identify root canals in extracted mandibular and maxillary human molar teeth. With TACT, 36% of second mesio-buccal (MB2) canals were detected in maxillary molar teeth and 80% of third (mesio-lingual) canals were detected in mandibular molars.[23]

Claimed advantage of TACT is that the images produced have less superimposition of anatomical noise over the area of interest.[21,24] The overall radiation dose of TACT is no greater than 1-2 times that of a conventional periapical radiograph as the total exposure dose is divided amongst the series of exposure taken with TACT.[22,23] Additional advantages claimed include the absence of artifacts resulting from radiation interaction with metallic restorations. The resolution is reported to be comparable with two dimensional radiographs.[23]

III. Spiral CT in endodontics

The scope of spiral computed tomography (SCT) in endodontic diagnosis is becoming broader day by day. Spiral CT provides a better resolution as compared with other scanning methods, such as cone beam CT. Chandra *et al* successfully employed SCT in managing the middle distal canal in the mandibular first molar.[24]
The use of SCT scans in dentistry has increased dramatically in the past 2 decades. SCT scans acquire raw projection data with a spiral sampling locus in a relatively short period. Without additional scanning time, these data can be viewed as conventional transaxial images such as multiplanar reconstructions or as three-dimensional reconstructions. With SCT scans, it is possible to reconstruct overlapping structures at arbitrary intervals; therefore the ability to resolve small subjects is increased. It provides axial,panoramic, paraxial and 3d volume rendering which helps in diagnosis. Its operator-friendly software allows the dentist to assess the images in the dental office. They have drastically reduced scan time and effective dosages.[25] The only disadvantage with the spiral CT technique can be its cost effectiveness for the patient.[26]

IV. Flat panel-based volume computed tomography (fpVCT)

Compared with multidetector CT, fpVCT is superior in its spatial resolution. The high resolution is a distinct advantage for many clinical applications, such as imaging calcified atherosclerotic plaque, clipped aneurysms, and endovascular stents. In addition, it has a wide 2D field of view that can be refreshed at the video frame rate. Coupled with its ability to image at any arbitrary angle, fpVCT functions like a conventional fluoroscopic device. Volumetric scanning and continuous rotation also make dynamic imaging, such as whole-organ perfusion studies, feasible.[27] fpVCT is found appropriate for non-destructive volumetry of large numbers of teeth in experimental laboratory studies.[28]

V. Peripheral Quantitative CT

pQCT shows promise for allowing qualitative and quantitative analysis of endodontic procedures.[29] It allows 3D reconstruction of the root canal anatomy and the assessment of the extent of canal enlargement during root canal instrumentation with lateral displacement of canal walls.

VI. MRI in endodontics

Magnetic Resonance Imaging(MRI) is a non-invasive method to detect internal structures and differentiate between soft and hard tissues within the body. The principle behind MRI is the use of non-ionizing radiofrequency electromagnetic radiation in the presence of controlled magnetic fields, to obtain high quality cross-sectional images of the body.[30] In order for MRI to be applied to endodontic clinical practice, it is necessary to scan at the microscopic level, i.e. with voxel resolutions better than 100 mm^3. Magnetic resonance microscopy chambers are generally small, typically less than 1 cm3. With a resolution of about 100–300 mm, magnetic resonance microscopy could lead to a better understanding of processes that occur inside the teeth.[31] The obtained microscopic images allow for adequate visualization of the pulp chamber, pulp, and root canals. A study used MRI as an imaging examination complementary to the electrical pulp test for the evaluation of pulp health and of pathological processes occurring within the dental pulp tissue.[32]

The disadvantage is that, to obtain a sufficient resolution for clinical evaluation in vivo, it takes up to 90 min. It is expected that with technological development, the time will be reduced, making it fast enough to facilitate

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clinical use. The visualization of hard tissues, such as enamel and dentin that do not have MRI signals, considering the low content of protons, remains the real technical challenge to be faced in making MRI a routine diagnostic method in dentistry.[33]

VII. SWIFT MRI in Endodontics

Specific interest in this area has focused on a recently developed method, magnetic resonance imaging with fourier transform, or **SWIFT**. At the centre of developing studies, research of the SWIFT technology has shown great promise for advancements, especially in the field of endodontics. SWIFT identified the presence and extent of dental caries and fine structures of the teeth, including cracks and accessory canals, which are not visible with existing clinical radiographic techniques. SWIFT MRI offers simultaneous three dimensional hard and soft tissue imaging of teeth without the use of ionizing radiation. Furthermore, it has the potential to image minute dental structures within clinically relevant scanning times. This technology has implications for endodontists due to the fact that it offers a potential method to evaluate teeth where pulp and root structures have been regenerated.[34]

VIII. Ultrasonography in endodontics

In endodontics, ultrasound estimates the extent of periapical lesions and also provides accurate information on the pathological nature of the lesion.

Cystic lesion- a hypoechoic well-contoured cavity surrounded by reinforced bone walls, filled with fluid and no evidence of internal vascularization on color Doppler examination.

Granuloma – a poorly defined hypoechoic area, showing rich vascular supply on color Doppler examination.

Mixed lesion- predominantly hypoechoic area with total anechoic area, showing vascularity in some areas on color doppler examination.[35-36]

Cotti et al have reported the use of ultrasound in the examination of bone lesions of endodontic origin, it can differentiate between cysts and granulomas by revealing the nature of the content of a bony lesion.[37] A study determined the efficacy of high-resolution ultrasound and color power doppler as a viable and nonhazardous tool for monitoring the healing of periapical lesions.[38] It was also proposed that ultrasound with power doppler flowmetry can be an additional diagnostic tool, where treatment option is non surgical.[39]

IX. CBCT in Endodontics

In Endodontics, CBCT has been used for several applications, including periapical diagnosis, evaluation of root canal anatomy, assessment of resorption defects, suspected perforations and in planning endodontic surgery.[40] A major advantage of CBCT is its three-dimensional geometric accuracy. Sagittal, coronal and axial CBCT images eliminate the superimposition of anatomical structures. For example, the roots of maxillary posterior teeth and their periapical tissues can be visualized separately and in all three orthogonal planes without superimposition of the overlying zygomatic buttress, alveolar bone and adjacent roots.[41](Figure 1-3)

i)Detection of Apical Periodontitis

Cone beam computed tomography is significantly more sensitive than conventional radiography in the detection of apical periodontitis.[42] Periapical bone destruction associated with endodontic infection can be identified using CBCT before evidence of the existence of these lesions presents itself on conventional radiographs.

ii)Assessment of Potential Surgical Sites

CBCT has been highlighted as an extremely useful tool in the planning of surgical endodontic treatment.[43]The spatial relationship of the specific root(s) undergoing the surgical procedure (and the associated bony destruction) can be accurately related to adjacent anatomical structures such as the maxillary sinuses, the inferior dental nerve canal and the mental foramen.[44] By arming themselves with this information, clinicians can assess the appropriateness of individual cases for treatment. Identifying and excluding unsuitable cases can reduce surgical morbidity. In cases deemed appropriate for treatment, accurate preoperative measurements that are relevant to the surgical procedure (e.g. root length and angulation, thickness of the cortical plate, root-end to mental foramen distance) can be made and applied to the surgical site during treatment, thereby enhancing case management and reducing the potential for iatrogenic damage.

iii)Assessment and Management of Dental Trauma

The benefits of CBCT in the assessment and management of dento-alveolar trauma have been highlighted in the literature.[45]The exact nature and extent of the injuries to the teeth and the alveolar bone can be assessed accurately by eliminating anatomical noise and image compression, thereby allowing appropriate treatment to be

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confidently implemented. The degree and direction of displacement associated with luxation injuries can be evaluated easily using CBCT.[46] Furthermore, CBCT has been shown to be far more sensitive than multiple periapical radiographs in the detection of horizontal root fractures.[47] Failure to identify the presence of root fractures following dental trauma may lead to inappropriate treatment and poorer prognoses for these teeth. Single teeth are rarely traumatized in isolation. Small volume CBCT scanners, which are the most appropriate for the assessment of endodontic problems, capture all teeth and surrounding anatomy in a 4 cm x 4 cm FOV. Therefore, multiple teeth can be assessed without geometric distortion in a single scan.

iv)Assessment of Root Canal Anatomy and Morphology

Conventional radiographs frequently fail to disclose the number of canals in teeth undergoing root canal treatment.[48] Failure to identify and treat accessory canals can negatively influence treatment outcome. Undetermined canal morphology enhances the possibility of peri-operative mishaps such as ledge formation, canal transportation or even perforation, potentially compromising the treatment outcome.[49] CBCT has been shown to be a reliable tool to accurately assess the degree of curvatures associated with the roots of teeth with "normal" anatomical forms.[50]The availability of this information preoperatively, reduces the chances of the above mentioned aberrations. In addition, CBCT has proved a useful treatment planning tool when teeth with morphological anomalies, such as dens invaginatus and fused roots require endodontic treatment.[51]

v)Diagnosis, Assessment and Management of Root Resorption

The clinical diagnosis of root resorption relies on the radiographic demonstration of the process.[52] The sensitivity of conventional radiography is significantly poorer than CBCT in the detection of external root resorption (ERR) in its early stages. Furthermore, when a diagnosis of root resorption is made based on conventional radiographic findings it must be remembered that ERR superimposed on the root canal may mimic internal root resorption(IRR).[53] Differentiating between the two can be particularly difficult.

vi)Assessment of the Outcome of Endodontic Treatment

There is limited data in the literature pertaining to the outcome of endodontic treatment using CBCT as the assessment tool. The outcome of endodontic treatment can be expected to be better when it is executed prior to the development of conventional radiographic signs of the disease.[54] When the diagnosis is made using CBCT and the treatment outcome is assessed using conventional radiographs, a true appreciation of treatment outcome cannot be obtained. For a more accurate assessment using CBCT, preoperative scans and postoperative review scans should be compared.

vii)Diagnosis of Vertical Root Fractures

Identifying the presence of vertical root fractures (VRF) is often an endodontic challenge. Even with longstanding VRF, clinical signs may be only a draining buccal sinus, which is certainly not pathognomonic of the problem. While a deep, isolated, thin periodontal pocket is suggestive of VRF, difficulty aligning the periodontal probe along the periodontal defect sometimes means this sign is missed. Radiographic features such as J-shaped and halo-shaped radiolucencies do not appear until significant bone destruction has occurred and similar radiolucencies may manifest themselves in cases of apical periodontitis not associated with VRF.[55] Ex vivo studies have demonstrated that CBCT is more sensitive in the detection of VRF. However, care should be taken when assessing root filled teeth for VRF using CBCT as scatter produced by the root filling or other high-density intraradicular material may incorrectly suggest the presence of a fracture.[56]

X. Optical Coherence Tomography (OCT)

Optical Coherence Tomography (OCT) is a relatively recent development in diagnostic medical imaging technology that was first introduced in 1991.[57] OCT uses infrared light from a source with a short coherence length. The light is scattered by the internal microstructure inside the specimen. A reflectivity profile is recorded along the scanned direction using an interferometer: constructive interference occurs if the lengths of sample and reference arms are equal to within the coherence length of the source.[58] OCT achieves a depth resolution of the order of 10 μm, with an in-plane resolution depending on the imaging optics, but possibly similar to the optical microscope. An image is formed from the envelope of the interferogram. By scanning the probe along the imaged specimen while acquiring image lines, a two- or three-dimensional image is built up. In endoscopic OCT imaging, near-infrared light is delivered to the imaged site (a blood vessel or a section of the gastrointestinal tract) through a single-mode fiber. The imaging tip contains a lens-prism assembly to focus the beam and direct it toward the lumen wall. The imaging beam is scanned along the wall by rotating the fiber. The fiber can be retracted inside a catheter sheath to perform a so-called "pullback," allowing the user to make a stack of cross-sections. OCT proves to be quite effective in diagnosing VRF. Fractures may appear as a bright line extending

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outward from the lumen, a separated cleft through the dentin if the root has actually split, or as small notches in the canal wall. These small cracks were seen mostly higher up in the canal, where the dentin is optically thicker and the light does not penetrate as deeply. Cracks usually originate in the canal, or are adjacent to it, but several examples were encountered where the fractures separated from the canal deeper into the dentin.[59]

5. Conclusion

The improvements in imaging technology have helped in obtaining a near perfect image for accurate diagnosis. In certain situations, it is important to evaluate the real extension, content, precise relationship to anatomic landmarks, vascularization, pattern of bone destruction and evolution in time; advanced imaging techniques may be extremely useful for providing detailed and specific information.

Some of the results of selected advanced imaging modalities in endodontic studies are summarized in Table 1.

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Table 1

Summary of selected advanced imaging studies	
Analysis of root canal anatomy	Oshishi et al[60] demonstrated the root anatomy and canal morphology of paramolar tubercles using CT.
	Nance et al reported that TACT detected a fourth canal in the maxillary molar and a third canal in the mandibular molars, 36% and 80% of the time, respectively in the extracted human molars.23
	Aggarwal found out that 2 palatal canals with separate orifices and apical foramen have been confirmed with the help of a spiral CT.[61]
	Zormechhingi et al.demonstrated that CT images show the complexities of the pulp space in primary molars.[62]
	Blattner et al. stated that CBCT scanning is a reliable method to detect the mesiobuccal (MB)2 canal, when compared to the gold standard of the physical sectioning of the specimen.[63]
Assessment of root canal preparations	Peters et al analyzed the efficacy of different techniques of root canal preparation and concluded that micro-CT was an indispensable tool in the research on the effectiveness of preparation instruments and techniques *in*

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	vitro.[64]
	Janner et al. reported that CBCT scan of the teeth can be useful to determine the endodontic working length in combination with clinical measurements.[65]
	Sonntag et al reviewed the evaluation of root canal curvatures before and after root canal preparation. It was realized that only graphical representation and mathematical formulae existed for the analysis of root curvatures.[66]
Detection of periradicular lesions	Estrela et al demonstrated that the prevalence of apical periodontitis was significantly higher when CBCT was used as the diagnostic method. [67]
	Sekerci et al reported two cases where CBCT was employed to diagnose an anatomical variation of the maxillary sinus that mimicked a periapical cyst, thereby avoiding unnecessary intervention.[68]
	Tutton and Goddard performed MRI on a series of patients with dental diseases and also claimed that the nature of periapical lesions could be determined as well as the presence , absence and/or thickening of the cortical bone.[69]
Presurgical assessment	Yoshioka et al. demonstrated that CBCT accurately identified the type of periapical bone defect in persistent lesions, which could not be identified by periapical radiography.[70]
Post surgical assessment	Aseem et al. reported that Ultrasound and color doppler imaging have the potential to supplement conventional radiography in monitoring the postsurgical healing of periapical lesions of endodontic origin.[71]
Diagnosis of dental trauma	Edlund et al determined the diagnostic accuracy of the CBCT detection of suspected VRFs in endodontically treated teeth with a sensitivity of 88% and specificity of 75%, CBCT proved to be a superior diagnostic tool in the detection of VRF.[72]
	Costa et al. reported that CBCT scanning showed high accuracy in detecting horizontal root fracture without a metallic post, however, the presence of a metallic post significantly reduced the specificity and sensitivity.[73]
	Youssefzadeh et al. demonstrated that CT is superior to dental radiography in the detection of vertical root fractures.[74]
	Bechara et al demonstrated that CBCT with smaller fields of view had higher accuracy and sensitivity for detecting VFR than CBCT with larger fields of view as well as photostimulated phosphor plates.[75]

Figures

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Figure 1: Coronal view of CBCT shows Endodontic treated 11,12.

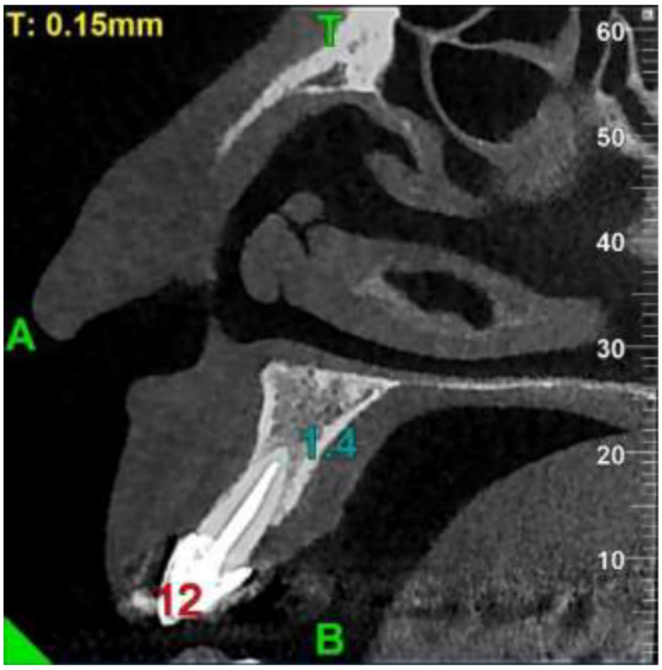

Figure 2: Saggital view of CBCT eliminates the superimposition of anatomical structures.

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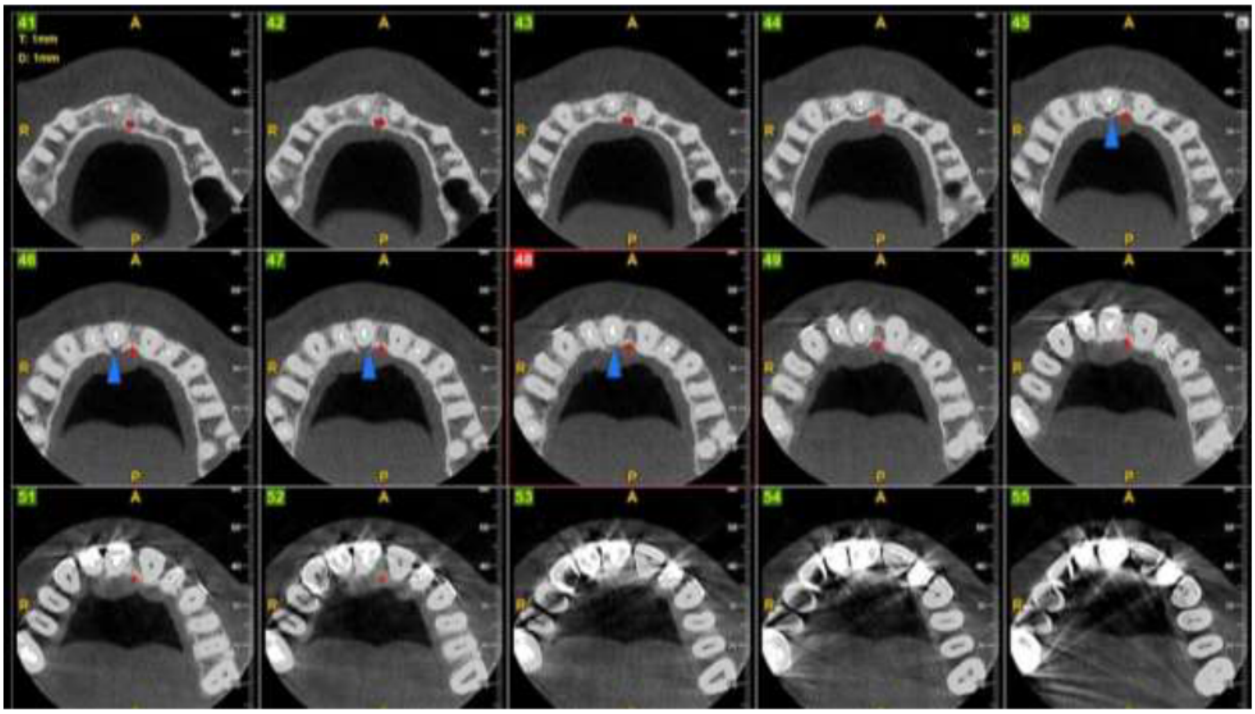

Figure 3: Axial view of CBCT shows root morphology and its associated structures.

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