RADIOGRAPHY IN ENDODONTICS

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ABSTRACT

Imaging in endodontics: an overview of conventional and alternative advanced imaging techniques Diagnosis, treatment planning and outcome assessment in endodontics depend to a large extent on radiographic examinations. Periapical radiographs, either captured on x-ray film or digital sensors, used for the management of endodontic problems provide limited information because of the combination of their two- dimensional nature, geometric distortion, anatomical noise, and temporal perspective. This review provides a summary of the limitations of periapical radiographs and the relevance of alternative advanced imaging techniques which are suggested as adjuncts to conventional radiographs in endodontic practice. Advantages and disadvantages of these imaging techniques are also briefly discussed.

KEYWORDS: Computed tomography, cone beam computed tomography, endodontics, magnetic resonance imaging, periapical radiograph, ultrasound.

INTRODUCTION

Since the report of the usefulness of visualizing a lead wire in a root-canal on a radiogram in establishing the length by Kells in 1899, radiography has been a fundamental tool in the practice of endodontics.[1,2] When combined with a thorough dental history, clinical examination and pulp-testing procedures; radiological examination is an integral and essential component of all phases of root-canal therapy from diagnosis and treatment planning to intra- operative control and assessment of treatment results.[3-5] Useful information about the presence, location and extent of periradicular lesions, the anatomy of root-canal(s) and the proximity of adjacent anatomical structures are limits its diagnostic performance.[3,4,6] The tooth and its surrounding structures are visualized in the horizontal (mesial-distal) and vertical (apical-coronal) plane, however the sagittal (buccal-lingual) plane (the third dimension) is not observed.[5] Periapical radiographs may not always be accurate in assessing the spatial relationship between the root(s) and their surrounding anatomical structures/associated periradicular lesions, and the location, nature and shape of structures within the root (e.g. root resorption).[6-8] However, in surgical planning, the accurate establishment of the angulation of the root to the cortical plate, the thickness of the cortical plate and the relationship between the root and adjacent anatomical structures such as the inferior alveolar nerve,

mental foramen or maxillary sinus is crucial; consequently, the diagnostic information in the missing "third dimension" is of particular importance.[9,10] Periapical radiographs from more than one direction should be taken to ensure that at least some 3D information is obtained.[4] Obtaining additional exposures with 10-15 degree changes in horizontal angulation (parallax principle) is a recommended method to achieve this.[4,7,11] In order not to subject the patient to unnecessary multiple radiation exposures; two images from different angulations are often sufficient.[11] But in some instances, multiple exposures may be necessary to determine the presence of multiple roots, multiple canals, resorptive defects, caries, restoration defects, root fractures, and the extent of root maturation and apical development.[11] However, taking multiple periapical radiographs does not guarantee the provided by periapical radiographs exposed during endodontic procedures.[5] Despite their widespread use, periapical images, either captured on x-ray film or digital sensors, provide limited information for several different reasons.[4,5] The aim of this review is to provide a summary of these limitations, and to assess alternative

advanced imaging techniques and their potential to overcome these problems.

Limitations of periapical radiography in endodontics
In periapical images three-dimensional (3D) anatomy is compressed into a two-dimensional (2D) image -in other words 2D image of a 3D object is produced; and this greatly limits its diagnostic performance.[3,4,6] The tooth and its surrounding structures are visualized in the horizontal(mesial-distal) and vertical (apical-coronal) plane, however the sagittal (buccal-lingual) plane (the third dimension) is not observed.[5]

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Another important limitation of periapical radiographs is that they do not always accurately reflect the anatomy being assessed because of the complexity of the maxillofacial skeleton.[4] In endodontic practice, radiographs should be taken using the paralleling technique (also known as the long-cone or right-angle technique), instead of the bisecting angle technique, as it produces more geometrically accurate images.[4,13,14] For accurate reproduction of anatomy in the paralleling technique, the image receptor (film or sensor) should be placed parallel to the long axis of the tooth, and the x-ray beam should be directed perpendicular both to the image receptor and the tooth being assessed.

The lack of long-axis orientation results in geometric distortion of the radiographic image. The ideal positioning of solid-state digital sensors (CCD/ CMOS) may be more challenging as they are more rigid and bulky in comparison to the conventional films and phosphor plate digital sensors (PSP).[7]

Over-angulated or under angulated radiographs may, respectively, decrease or increase the radiographic root length. [7,15] and increase or decrease the size - or even result in the disappearance – of eriradicular lesions.[16,17] Even under ideal conditions, approximately 5% of magnification in the radiograph should be anticipated; because while taking the radiograph using the parallelling technique, the tooth and the image receptor are slightly separated and the x-ray beam is slightly divergent[13,14] The use of a long focus-to-skin distance may limit, but will not eliminate this magnification .[7]

Another important principle in radiology is to display the structures of diagnostic interest onto a background as homogeneous as possible.[4] However, the anatomical structures surrounding the tooth may superimpose and cause difficulty in interpreting periapical radiographs.[4,18,19] Superimposition of the anatomical features is referred to as anatomical, structured or background noise and may be radiopaque (e.g. zygomatic buttress) or radiolucent (e.g. incisive foramen, maxillary sinus) (Figure 1).
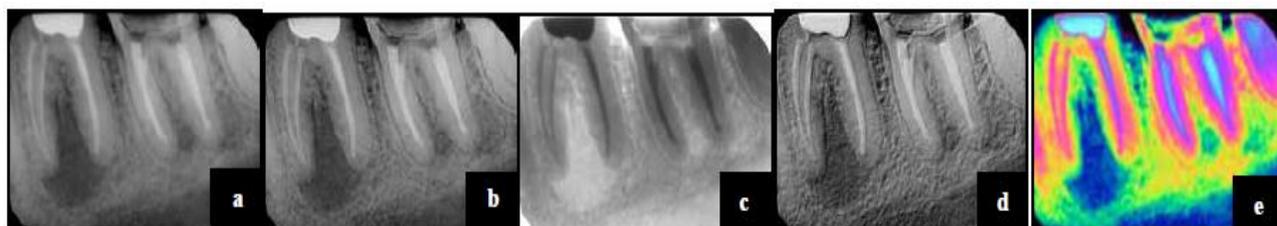

Figure1: Apical anatomy of the maxillary molar teeth is obscured by anatomical noise (the zygomatic arch).

The problem of anatomical noise in endodontics was first observed by Brynolf,[20] who noted that the projection of the incisive canal over the apices of maxillary incisors may complicate radiographic interpretation. Several studies have mentioned the difficulty of radiographically visualizing the periapical lesions confined to the cancellous bone, as the denser overlying cortical plate masks the area of interest.[16,21] Anatomical noise also accounts for some underestimation of the size of periapical lesion on radiographic images.[16,21,22]

Anatomical noise is dependent on several factors such as non-optimal irradiation geometry, overlying anatomy, the thickness of the cancellous bone and cortical plate, and the relationship of the root apices to the cortical

plate. Additional radiographs may once again be exposed in an attempt to overcome anatomical noise and to visualize endodontic lesions more clearly.[4,17]

The temporal perspective of the periapical radiographs is another limitation. To assess the outcome of endodontic treatment, radiographs exposed over a time period should be compared.[4,23] Pre-treatment, post-treatment and follow-p radiographs should be standardized to the utmost in respect to their radiation geometry, density and contrast in order to allow reliable interpretation of any changes in the periapical tissues that may have occurred as a result of treatment.[4]

Poorly standardized radiographs may lead to under- or over-estimation of the degree of healing or failure. Customized stents and elastomeric impression material have been used to ensure that the image receptor, tooth and x-ray beam are consistently aligned increasing the possibility of reproducing the radiation geometry when using paralleling technique.[24,25] Even with these techniques, serial radiographs will still show small inconsistencies.[25]

Contrary to film radiographs, digital periapical images may be changed through different types of image manipulation algorithms offered by software systems (Figure 2). Image enhancement –

Figure 2:

Alteration of brightness and contrast, and magnification being the most common - can greatly facilitate both diagnosis and treatment procedures. Colorization can also be used for diagnostic purposes by creating colorized images through assigning a color to a range of grays. However, this process actually discards some information and the diagnostic utility of this feature has not been demonstrated.[4] Digital systems also facilitate the measurements often needed when performing endodontic therapy or placing dowel post.

Densitometric image analysis and subtraction have also been applied to enhance especially the detection of osseous changes over time and to evaluate the healing process after root-canal treatment.[4] Unfortunately, these characteristics are not sufficient to eliminate these limitations.

Advanced imaging techniques for endodontic practice
In this section, advanced imaging techniques that have been suggested to overcome the fore mentioned limitations of periapical radiographs.[4-6,26] will be discussed. In endodontics, some of these techniques may improve the diagnostic yield and assist clinical management.

Computed tomography
Computed tomography (CT) is an imaging technique which produces 3D images of an object by using a set of 2D image data.[3,6] In addition to 3D images, CT has several other advantages over conventional radiography: it eliminates anatomical noise and high contrast resolution, allows differentiation of tissues with less than 1% physical density difference to be distinguished in

comparison to conventional radiography that requires 10%.[15]

When examining jaws, axial scans are usually acquired to avoid artifacts caused by posts, crowns, and metallic fillings.[4,6] Afterwards, multiplanar reconstructions are performed and viewed as images in the coronal, sagittal or cross-sectional planes from the axial slices depending on the diagnostic task.[4,6] The axial views provide possibilities for the interpretation of details of the anatomy/pathology in the buccal-palatinal/lingual direction, therefore they may be used to measure distances (e.g. between the mandibular canal and a periapical lesion) or the thickness of the buccal cortex in order to reveal information that can be of value before periapical surgery.[3,4,9] CT can even supply additional information about the morphology of the root-canal system provided that it does not contain metallic root-canal posts. [4,27] However, the geometric resolution of CT is insufficient to reveal the exact shape of the root-canals,[28] and a very high radiation dose is required to achieve a high enough resolution to assess root-canal anatomy in detail.[5]

CT may also be useful for the diagnosis of poorly localized odontogenic pain. In some circumstances in which periapical radiographs reveal nothing untoward, CT may confirm the presence of a periapical lesion.[9] The assessment of the 'third dimension' with CT imaging alsoallows the determination of the number of roots and rootcanals, as well as where root canals join or divide. This knowledge is extremely useful when diagnosing and managing failed endodontic treatment. CT can also be used to localize foreign bodies in the jaws such as gutta-percha and root-canal sealer (Figure 3).
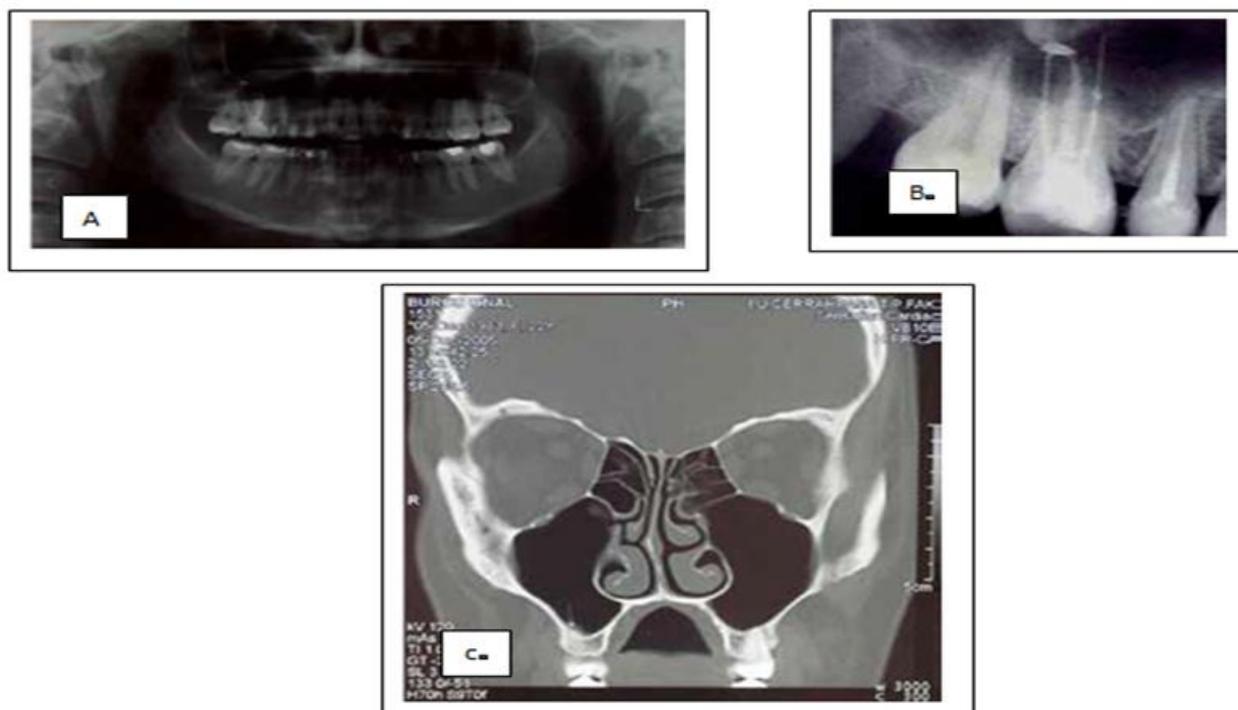
Figure 3: a, b: OPTG and periapical radiograph demonstrating the overfilled root-canal filling of maxillary right first molar. (c) Coronal CT images showing root-canal obturation, and extrusion of the gutta-percha and root-canal sealer into the maxillary sinus (white arrows).

Referral to CT in endodontics has been low for several reasons, including the high radiation dose and the high costs of the scans.[29] Other disadvantages of CT are scatter due to metallic objects, relatively low resolution in comparison to conventional radiographs, and the fact that these machines are only found in dedicated radiography units (e.g. hospitals).[5] In the management of endodontic problems, CT technology has now become superseded by cone beam computed tomography technology, which will be mentioned later on.

Tuned-aperture computed tomography (TACT) is a relatively new alternative CT technique. It creates 3D information from a series of 8-10 periapical radiographic images exposed at different projection geometries, using a programmable imaging unit with specialized software to reconstruct a 3D data set which may be viewed slice by slice.[4,5,30]

TACT has been proved to be an effective diagnostic tool in a variety of clinical conditions.[31] In respect to endodontic problems, studies have demonstrated that TACT is diagnostically more informative and has more impact on the potential treatment options than conventional radiographs. It is shown to significantly improve the detection rate of extra canals in molar teeth, and have superior diagnostic accuracy compared to 2D radiography for the detection of vertical root fractures even without displacement of the fragments.[31-34]

Claimed advantage of TACT over conventional radiographic techniques is that the images produced have less anatomical noise in the area of interest.[35,36] The overall radiation dose of TACT is not greater than 1 to 2 times that of a conventional periapical film as the total exposure dose is divided amongst the series of exposures taken.[33,37] Additional advantage of this technique is the absence of artefacts resulting from metallic restorations.

The resolution is reported to be comparable with 2D radiographs.[26] However, TACT is not, at least yet, commercially available for dental applications and it is currently a research tool on trial,[4,26] it appears to be a promising radiographic technique for the future.

Micro-computed tomography (micro-CT), another alternative CT technique, has also been considered in endodontic imaging.[38,39] Nevertheless, the use of micro-CT remains a research tool limited to *in vitro* measurements of small samples; due to the high radiation dose required, it cannot be employed for human imaging *in vivo*.[6,26] Experimental systems with reduced dose are still being tested.[6]

Magnetic resonance imaging
Magnetic resonance imaging (MRI) is a completely noninvasive specialized imaging technique which uses radio waves instead of ionizing radiation. It involves the behavior of hydrogen atoms (consisting of one proton and one electron) within a magnetic field.[8,15]

It performs best in showing soft tissues and vessels, whereas it does not provide great details of the bony structures.[6] The main dental applications of MRI to

datehave been the investigation of soft tissue lesions especially in salivary glands, investigation of the temporomandibular joint and tumour staging.[8,15,40] MRI has also been used for pre-surgical assessment for dental implants.[41,42] It was claimed that, with MRI, the roots of multi-rooted teeth might be differentiated, smaller branches of the neurovascular bundle entering apical foramina could be clearly identified, and the nature of periapical lesions could be determined as well as the presence, absence and/or thickening of the cortical bone.[6,43] MRI may be used for the investigation of pulpal and periapical conditions, and the specification of the extent of the pathosis and the anatomic implications in surgical decision-making.[6] MRI becomes the diagnostic technique of choice for the cases when an infective lesion like a periapical abscess is expanding fast in the jawbones and in corresponding soft tissues, degenerating into osteomyelitis.[44]

Although MRI scans are not affected by artefacts caused by metallic restorations (e.g. amalgam, metallic extracoronal restorations and implants) on the contrary to the CT technology,[45] it has several drawbacks. These include poor resolution compared with conventional radiographs and longer scanning times compared to CT, high hardware costs and limited access only in dedicated radiology units.

In MRI, different hard tissues (e.g. enamel and dentine) cannot be differentiated from one nother or from metallic objects as they all appear radiolucent. The strong magnetic field generated stricts its use in patients carrying a pacemaker or metal pieces in the areas to be investigated.

It is an expensive examination, and in most of the systems the patient must be placed in a narrow tube.[41,46] It is for these reasons that MRI is of limited use for the management of endodontic disease.

Ultrasound
Ultrasound imaging (US) is based on the reflection of sound waves (echoes), with a frequency outside the range of human hearing (1-20 kHz), at the interface of tissues which have different acoustic properties.[15,47] The echoes are detected by a transducer which converts them into an electrical signal, and a real-time black, white and shades of grey echo picture is produced on a computer screen.[15]

Tissue interfaces which generate a high echo intensity are described as hyperechoic (e.g. bone and teeth-white), whereas anechoic (e.g. cysts-dark) describes areas of tissues which do not reflect US energy. Typically, the images consist of varying degrees of hyperechoic and anechoic areas as the areas of interest usually have a heterogeneous profile.

The Doppler effect, which is the change of frequency of sound reflected from a moving source, can be used to detect the arterial and venous blood flow.[8] The application of US to the practice of endodontics has resulted with success.[48] The technique is easy to perform and may show the presence, exact size, shape, content and vascular supply of endodontic lesions in the bone.[6]

US was found to be a reliable diagnostic technique in the differential diagnosis of periapical lesions (granulomas versus cysts) with the aid of the echo picture (hyperechoic and hypoechoic) and through the use of the colour laser Doppler effect to provide evidence of vascularity within the lesion.[47,49] However, the ability of US to assess the true nature and type (e.g. true versus pocket cyst) of periapical lesions is doubtful.

Since sound waves are blocked by bone, US is useful only for assessing the extent of periapical lesions where there is little or no overlying cortical bone.[5] Whilst US may be used with relative ease in the anterior region of the oral cavity, positioning the probe is more difficult in the posterior region, and the thick cortical plate in this region prevents sound waves from traversing easily.[3,5] In addition, the interpretation of US images is usually limited to radiologists who have extensive training.[5]

US is considered to be a safe technique, but the energy of US waves should be controlled as it is absorbed by the tissues in the form of heat.[6] This potential adverse effect of the system depends on the duration of application of the energy, so the number and repetitions of the examinations should be limited.[50] In any case, the risk is much lower than the risk associated with radiographic investigations using ionizing radiation.[43,50]

Cone beam computed tomography
Cone beam computed tomography (CBCT) is a relatively new extra-oral imaging system which was specifically developed to produce undistorted 3D information of the maxillofacial skeleton with a substantially lower radiation dose compared to conventional CT.[5,51-53] CBCT differs from CT in that the entire 3D volume of data is acquired in the course of a single sweep of the scanner, using a simple, direct relationship between sensor and source which rotate synchronously between 180º and 360º around the patient's head.[5,53] The x-ray beam is cone-shaped instead of the fan-shaped beam used by the regular CT scanners, and it captures a cylindrical or spherical volume of data, identified as the field of view (FOV).[5,53] An optimal FOV can be selected for each patient based on disease presentation and the region designated to be imaged. In general, the smaller the voxel size, the higher the spatial resolution of the image is.

Its major advantage over CT scanners is the substantial reduction in radiation exposure[5,53] which is due to rapid scan times (typically 10 to 40 s long depending on the scanner used and the exposure parameters selected), pulsed x-ray beams (actual exposure time 2-5 s) and

sophisticated image receptor sensors.[5,53] CBCT scanners are simple to use and occupy the same space as panoramic machines, making CBCT scanners well suited for dental practice.[54] Typically, images are displayed in the three orthogonal planes; axial, sagittal and coronal simultaneously.[5,53]

Coronal and axial views of the tooth are readily produced, allowing the clinician to gain an accurate 3D view of the entire tooth and its surrounding anatomy.[5,53] The image quality of CBCT scans is superior to CT for assessing the dental hard tissues.[5,53,55,56] CBCT overcomes several limitations of conventional radiography.[5,53] Slices can be selected to avoid adjacent anatomical noise (superimposition of the anatomical structures, alveolar bone and adjacent roots).[4,5,53] The spatial relationship of the roots of multi-rooted teeth can be visualized in three-dimensions and the true size and 3D nature of periapical lesions can also be assessed.[4,5,53]

Unfortunately, at present, the images produced with CBCT technology do not have the resolution of conventional radiographs.[53] One significant problem, which can affect the image quality and diagnostic accuracy of CBCT images, is the scatter and beam hardening caused by high density neighbouring structures (such as enamel, metallic posts and restorations) lowering the diagnostic value for internal root resorption and root-canal perforations.[4,57-59]

Therefore, combining CBCT with periapical radiographs might be necessary.[4] Finally, scan times are lengthy at 15-20 s and require the patient to stay absolutely still.[53] CBCT technology is increasingly being used with success for the management of endodontic problems.

Potential applications in endodontics include the detection of apical periodontitis, pre-surgical assessment, evaluation of dental trauma and root fractures, determination of rootcanal configuration and internal-external root resorption.[3,4,53] Using CBCT, periapical disease may be detected earlier in comparison to periapical radiographs; and the true size, extent, nature and location of periapical and resorptive lesions can be assessed more accurately[10,58-62] The CBCT scans are desirable to assess posterior teeth prior to periapical surgery, as the thickness of the cortical and cancellous bone can be accurately determined, as well as the inclination of roots in relation to the surrounding bone.[52,53] The relationship between the anatomical structures, such as the maxillary sinus and inferior alveolar nerve, and the root apices may also be clearly visualized.[52,53] Apart from these, CBCT may be used in endodontics to assess the outcome of the treatment.[52] It provides a more objective and accurate representation of osseous changes (healing) over time [52,63] and assist in accurate determination of the prognosis of endodontic treatment.

It should be noticed that CBCT uses ionizing radiation and is not without risk.[52,53] It is critical to keep the patients' radiation exposure as low as reasonably achievable (ALARA principle). Each endodontic case should be judged individually in order to provide the condition where the benefits of a CBCT investigation outweighs any potential risks. [64] Until further evidence is available, CBCT should only be considered for situations where conventional imaging systems yield limited information and further radiographic details are required for endodontic diagnosis and treatment planning.[52,53]

CONCLUSION
Images acquired using periapical radiographs may not reveal adequate information for the detection and assessment of endodontic lesions and other relevant features. In certain situations, when 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.

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