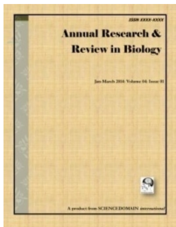

Annual Research & Review in Biology
4(5): 790-804, 2014

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Advanced Imaging Techniques in Endodontology: A Review

Aditya Shetty[1], Mithra N. Hegde[1], Raksha Bhat[1*], Uday Mahale[1], Ganesh Bhat[1] and Darshana Devadiga[1]

[1]Nitte University, Deralkatte, Mangalore-575018, India.

Authors' contributions

This work was carried out in collaboration between all authors. Author AS conceived the idea and wrote the manuscript. Author MH designed the review. Author RB and UM performed literature searches. Authors GB and DD contributed towards managing the analysis of the study. All authors read and approved the final manuscript.

Review Article

Received 3rd July 2013
Accepted 21st October 2013
Published 25th November 2013

ABSTRACT

Variations in the external morphologic features of the crowns of the teeth accord with variations in the shape and size of the head. The length of the crown varies with the size and sex of the person and is generally shorter in females than in males. As the external morphology varies from person to person, so does the internal morphology of the crown and root. Anatomical variability of the teeth is often a complicating factoring root canal treatment and many different methods have been used to investigate the tooth morphology. Every root canal has its own individual form, therefore guidelines are required in both endodontic practice and for the purpose of research. The currently accepted concepts of root canal treatment require knowledge of root canal length. The success of endodontic treatment depends on the identification of teeth requiring treatment and then the recognition of the root canal system, so that it can be cleaned, shaped and obturated. False assumptions about the root canal anatomy of the teeth may lead to misdiagnosis, missed canals, improper debridement and breakage of instruments during root canal treatment. However, in order to achieve this, it is imperative that the operator should have detailed knowledge of the root canal anatomy of the tooth being treated. This review article emphasizes on the various techniques used in endodontics for studying the root canal morphology.

**Corresponding author: Email: rkshabhat@gmail.com;*

Keywords: Experimental endodontology; root canal morphology; radiographic technique; dyes.

1. INTRODUCTION

Endodontics is that branch of dentistry that deals with the morphology, physiology of human dental pulp and periapical tissues. Its study and practice encompasses related basic and clinical sciences including prevention, etiology, diagnosis and treatment of pulpal diseases and their sequel. Internal complexities of the root canal necessitate the identification of methods that accurately determine the root canal morphology. As a cause of treatment failure, the lack of working knowledge of pulpal anatomy ranks second to the errors in accurate diagnosis and treatment planning. From the early work of HESS (1925) to the present studies demonstrating pulp space anatomy, it has been established that pulp space with a graceful taper and single apical foramen is an exception rather than a rule. In order to master the anatomic concept, the operator must develop a mental, three dimensional image of the internal anatomy of the tooth from the pulp horn to the apical constriction. A thorough understanding of the complexity of the root canal system is essential for understanding the principles and problems of shaping and cleaning, for determining the apical limits and dimensions of canal preparations, and for performing successful microsurgical procedures. This objective of this article is to describe and illustrate the various clinical techniques for root canal anatomy studies which help study tooth morphology, which in turn will help endodontic procedures.

2. RADIOGRAPHY

No single scientific advancement has contributed as greatly to improved dental health as the finding of the amazing properties of cathode rays by Professor Wilhelm Konrad Roentgen in November 1895. The first dental radiographs to aid in the diagnosis of hard tissue alterations of the teeth, to determine the location, shape, size and direction of root and root canals [1,2]. The two techniques which are most commonly used in dental radiography are the long cone technique and the bisecting angle technique. However the long cone technique is favored for diagnostic, follow up and a post-treatment photograph as it provides clarity in detail and minimal distortion for endodontic purpose. This provides adequate information about the tooth apices and surrounding structures in the area of interest [3].Walton et al made an important modification in the technique which helped visualize the third dimension by varying the horizontal angulation. This method helped in separating the overlapping canals [3]

X-ray films for general radiography consist of an emulsion of gelatin containing radiation sensitive silver halide crystals, such as silver bromide or silver chloride, and a flexible transparent, blue-tinted base.

The American National Standards Institute and the International Organization for Standardization have established standards for film speed. Film speeds available for dental radiography are D-speed, E-speed and F-speed, with D-speed being the slowest and F-speed the fastest. The use of faster film speed can result in up to a 50 percent decrease in exposure to the patient without compromising diagnostic quality. Film of a speed slower than E-speed should not be used for dental radiographs [4,5,6].

A study done by Pineda and Kuttler executed mesiodistal and buccolingual radiographic investigations of 7275 root canals in mandibular and maxillary teeth in vitro to study the curvature and the number of root canals,location of foramina,ramifications of the root canals and frequency of delta [7] Zilch and Dawson radiographically examined 1393 first mandibular molars and 938 second mandibular molars to determine the percentage of these teeth which had more than one root canal [8]. Another study was also done by Cunningham and senia where they radiographed teeth in the buccolingual and the mesiodistal directionsto study the degree and configuration of canal curves in the mesial roots of 100 randomly selected mandibular first molars [9]. A study was done by Khedmat et al to study the root canal morphology of 217 extracted human mandibular first premolars in an Iranian population using radiographs taken both in the mesiodistal and buccolingual directions and digital photographs of the cross section of their roots.around 88.5% of mandibular first premolars had a single canal and the remaining 11.5% showed 2 canals in atleast one cross section of their roots [10].

Radiography is essential to successful diagnosis of odontogenic and non odontogenic pathoses, treatment of the pulp chamber and canals of the root of a compromised tooth via intra coronal access, biomechanical instrumentation, final canal obturation, and assessment of healing. Imaging serves at all stages in endodontics [11]. Nevertheless Goldman et al. demonstrated the inherent and in built errors possessed in radiography [12]. With radiographs we get only a 2D view of a 3D structure. Improper techniques and processing errors can also cause distortion of the images.

From the advent of radiographs to date, several advanced imaging techniques have been developed. A few of them are being used for endodontic purposes are described below.

3. RADIOPAQUE CONTRAST MEDIA

Radiopaque contrast media has been in use in the medical field since a long time but the use of the same in the field of dentistry has been limited. The pulp space containing the contrast medium is enhanced in radiographs and can be visualized. Diatrizoate, a form of aqueous iodine salt solution has been injected to aid in the diagnosis of periapical lesions,to determine the pathways of pulp during apexification procedure [13]. The lateral canals are usually not detected in intra oral radiographs and in some instances can only be observed after obturation with radiopaque material [14]. A study was done by Alcam et al to evaluate the radiopaque properties of different iodine-containing contrast materials mixed in calcium hydroxide [15].

Ruddle Solution is an intracanal irrigant which has been formulated to provide a radiographically contrasted pulp space to aid in endodontic treatment planning. This irrigant is a "cocktail" containing 5% sodium hypochlorite (NaOCl), Hypaque and 17% EDTA. Hypaque is a water soluble, radiopaque, contrast solution which can be utilized to visualize root canal anatomy, monitor the remaining wall thickness during canal preparation procedures, detect pathological defects and manage iatrogenic mishaps Hypaque was used by Scarfe et al to detect accessory canals [13]. The composition of the ruddle’s solution simultaneously provides the solvent action with NaOCl, and visualization as it is nearly as radiopaque as gutta percha, and improved penetration as the tensioactive agent lowers surface tension.

Clinically, the contrast media is passively injected into the root canal once sufficient access has been made. The solvent action of this solution progressively clears out the contents of the root canal thus enabling the iodine portion to flow into those space.

The clearing technique and the canal staining technique are considered as benchmarks for studies. Neelkantan et al. performed a study to evaluate the accuracy of cone-beam computed tomography, peripheral quantitative computed tomography , spiral computed tomography , digital radiography , and contrast medium–enhanced digital radiographs in studying root canal morphology, wherein they concluded that CBCT and pQCT were as accurate as the modified canal staining and tooth clearing technique in identifying root canal configurations [16] Shearer AC et al in an in vitro study introduced a water soluble radiopaque contrast medium into the root canal systems of 30 first maxillary and mandibular molars. After comparision of radiographic images with and without the use of a contrast medium the evaluators concluded that with the use of a radiographic contrast medium, images of the root canal system with the radiopaque contrast medium are easier to read and interpret than plain radiographic images of the root canal system [17] Fan et al studied the c shaped root canal systems in mandibular second molars and their relationship to the root canal anatomy by using intraradicular contrast medium and micro computed tomographic scanning whereby they concluded that the radiographic features revealed by the intraradicular contrast medium, helped to identify the canal anatomy of the c shaped canal systems in mandibular second molars [18].

4. DIGITAL RADIOGRAPHY

The radiovisuography was developed in 1970 by Moyen [19]. In digital radiography, instead of the silver halide grain the image is constructed using pixels or small light sensitive elements. These pixels can be a range of shades of grey depending on the exposure, and are arranged in grids and rows on the sensor, unlike the random distribution of the crystals in standard film. The sensor is connected to the computer and the signal is sampled at regular intervals. The output of each pixel is quantified and converted to numbers by a frame grabber within the computer. The range of numbers is normally from 0 to 256 with 0 representing black, 256 representing white and all others are shades of grey. The number of grey levels relates to contrast resolution and the size of the pixels is related to spatial resolution. Resolution can also be expressed in line pairs per millimetre. Most conventional E speed films have a resolution of 20 LP/mm whereas with digital images the resolution ranges from 7-10 LP/mm.

Image is produced immediately on the monitor after the exposure and therefore also known as Direct digital Imaging.

The major advantage of digital imaging in studying root canal anatomy is *image manipulation.* It involves selecting the information of greatest diagnostic value and suppressing the rest. Manufacturers provide software programs with many different processing tools, however some are more useful than others and these include features like *contrast enhancement* which can effectively compensate for over or under exposure of the digital image. It has been shown that contrast enhancement of CCD devices were more accurate than E-speed film for detecting simulated caries under orthodontic bands. *Also* Digital calipers, rulers and protractors are some of the many tools available for image analysis. The images can also be superimposed onto each other and onto digital photographs. It also allows for *3-D reconstruction which* can be theoretically used to reconstruct intra-and extra-oral images. The uses range from profiling root canals to visualizing facial fractures in all three dimensions.

For accurate reproduction of anatomy, the image receptor (X-ray film or digital sensor) must 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 assessed. Lack of long-axis orientation results in geometric distortion (poor projection geometry) of the radiographic image. The ideal positioning of solid-state digital sensors may be even more challenging as a result of their rigidity and bulk compared with conventional X-ray films. Over-angulated or under-angulated radiographs (bisecting or paralleling technique) may reduce or increase respectively the radiographic root length of the tooth under investigation. Clark in 1909 introduced a SLOB (same lingual opposite buccal) technique of radiography which involves two radiographs taken at different horizontal angulations with the same vertical angulation. This technique is based on image size distortion; ie for a given focal spot film distance the objects further away from the image receptor film will be depicted more magnified than objects closer to the film [20].

For better radiographic image acquisition two or three radiographs at different angles should be taken. An intentional shift of the x-ray beam from the ortho radial position may provide additional information compared to the zero degrees projection.

The long cone paralleling technique is the technique of choice for endodontic radiography. It projects an accurate radiograph with minimal distortion and a high level of reproducibility [21].

Shearer et al compared the direct digital imaging to conventional films as in an in vitro study for working length determination of root canals. The results showed that greater length of file was imaged with conventional film than with digital imaging. Although enhanced digital images were not significantly different from conventional film images[19]. Simone et al used digital imaging to evaluate the incidence of root canal bifurcation in mandibular incisors which indicated the presence of bifurcation of root canals in 20% of teeth evaluated in vitro in the mesiodistal direction. In the buccolingual direction, 17.5% of teeth evaluated in vivo and 15% evaluated in vitro presented bifurcation [22]. Cesar et al used digital imaging to determine the effect of the apical preparation size and preparation taper on the volume of irrigant delivered at working length for different canal curvatures using apical negative pressure irrigation. He concluded that the degree of root canal curvature decreased the volume of irrigant at the working length for a given apical size and taper. An apical preparation of 40.06 significantly increased the volume and exchange of irrigant at the working length regardless of curvature [23].

In a study done on extracted permanent first molars from a Chinese population taken from a buccolingual and mesiodistal angulation wherein the digital radiographs were compared with the clearing technique showed the limited value of digital imaging when studyin the root canal type[22] .The limitations of this technique are mainly the investment costs ,the infection control measures as the detectors cannot be autoclaved and also the time which will take in mastering the software.

5. COMPUTED TOMOGRAPHY (CT SCAN)

Tomography was a term first used to describe sectional radiographic techniques. It is a term used to describe any imaging method that produces images of selected anatomical planes within a structure [23]. CT uses X-rays to create cross-sections of a 3D-object that later can be used to recreate a virtual model without destroying the original model. The first CT scanners took several hours to acquire the raw data for a single "slice" and took days to reconstruct a single image from this raw data. In the mid 1980's, the spiral or helical scanning was innovated. Later "multi-slice" spiral CT scanners have being developed. Cone

Beam CT was first introduced in the imaging of the dental and maxillofacial region in 1997.Recently a study done by Sushma et al studied the mesiobuccal canals in maxillary molars and distolingual canals in mandibular molars in a retrospective study using dental CT.They were able to gain additional information on the root canal anatomy and its relationship to vital structures such as the maxillary sinus using reconstructed axial slices and three-dimensional reconstruction of the CT data [24].

6. CONE BEAM COMPUTED TOMOGRAPHY (CBCT)

Nowadays a new technology known as cone beam computed tomography; CBCT scanners are widely used for various indications[25,26]Cone Beam Computed Tomography (CBCT) is a diagnostic imaging modality that provides high-quality, accurate three-dimensional (3D) representations of the osseous elements of the maxillofacial skeleton. CBCT systems are available that provide Small field of view images at low dose with sufficient spatial resolution for applications in endodontic diagnosis, treatment guidance, and post treatment evaluation [27]. Cone beam computed tomography (CBCT) has been used in dentistry since 19981. Unlike medical CT, which captures the image in slices, CBCT data are captured in a 3-D pixel unit called voxel. As these voxels are isotropic, the object is accurately measured in different directions. This enables the rendering of geometrically undistorted images of the maxillo-facial skeletal structure and allows viewing at different angles. In addition to providing higher resolution image,CBCT has a much reduced radiation dosage than medical CT [28]. This technology offers surprisingly low amounts of absorbed radiation while offering information never before available in clinical practice [29].

CBCT is accomplished by using a rotating gantry to which an X-ray source and detector are fixed. A divergent pyramidal- or cone-shaped source of ionizing radiation is directed through the middle of the area of interest onto an area X-ray detector on the opposite side of the patient. The X-ray source and detector rotate around a fixed fulcrum within the region of interest (ROI). During the exposure sequence hundreds of planar projection images are acquired of the field of view (FOV) in an arc of at least 180. In this single rotation, CBCT provides precise, essentially immediate and accurate 3D radiographic images. As CBCT exposure incorporates the entire FOV, only one rotational sequence of the gantry is necessary to acquire enough data for image reconstruction[29,30,31,32,33]CBCT is a complementary modality for specific applications rather than a replacement for 2D imaging modalities.

Cone beam computed tomography (CBCT) has been established to be superior to conventional intra and extra oral radiography in diagnostic accuracy. CBCT is capable of producing high contrast images with good resolution in a short period of time. In endodontics, this particularly relates to early diagnosis of periradicular disease with greater precision of lesion size, extent, nature and position [33,34,35,36,37]. Furthermore, 3 dimensional volume of information captured by CBCT can also aid clinicians in the diagnosis of root fractures, root resorption, perforations, obturation voids and defects and root canal morphology.

CBCT with large FOV provided more information about the presence of apical periodontitis, distortion of cortical bone, and identification of root compared with digital periapical radiography [38]. Jaffery et al conducted a study to compare digital periapical and cone-beam computed tomography (CBCT) images to determine the number of canals in the mesiobuccal root of maxillary molars and to compare these counts with micro computed tomography (µCT), which was also used to determine canal configuration. It was found that for cadaver maxillary molars, µCT canal counts were significantly different from digital periapical radiograph counts but not different from CBCT counts [39]. A study done to assess the diagnostic potential of 2 different cone-beam computerized tomography (CT) units and compare this with intraoral digital and conventional film in the detection of chemically created periapical lesions. The 2 cone-beam CT units tested performed similarly, and both performed better than intraoral digital and film radiography in detecting chemically created periapical lesions [40]. CBCT has been used to evaluate the close proximity between maxillary sinus floor and the posterior teeth root apices and also to evaluate the root configuration in mandibular molars in the Brazilian population giving significant results in turn proving CBCT to be a clinically useful tool for endodontic diagnosis and treatment[41,42]. CBCT imaging has also been reported to characterize the high prevalence of the distolingual canal in Taiwanese Individuals, highlight anomalies in the root canal system of mandibular premolars, and assist in the determination of root curvature [43].

A study was done to evaluate the presence or absence of periapical radiolucencies on individual roots of teeth with necrotic pulps, as assessed with digital PA radiographs and cone-beam computed tomography which concluded that unlike periapical radiographs, CBCT revealed a higher prevalence of periapical radiolucencies when endodontically untreated teeth with non-vital pulps were examined [44]. The benefits of the added diagnostic information provided by intraoperative CBCT images in select cases justify the risk associated with the limited level of radiation exposure [39].

The Limitations are that Despite the provision of the third dimension, the spatial resolution of CBCT images (0.4mm to 0.076mm or equivalent to 1.25 to 6.5 line pairs/rmm) is inferior to conventional film-based (approx. 20 lp/mm) or digital (ranging from 8-20 lp/.mm) intraoral radiography. Liedke et al. have recommended a minimal voxel resolution of 0.3mm for the detection of external root resorption. Observer inter rater reliability and detection of mesiobuccal canals increased substantially with increasing resolution with more than 93% accuracy with a voxel resolution of 0.12mm but accuracy barely over 60% with 0.4mm resolution [45].

CBCT evaluations identified an average of 3.58 root canals per maxillary molar, 1.21 per mandibular premolar, and 1.5 per mandibular incisor. Baratto Filho et al. investigated the internal morphology of extracted maxillary first molars by comparing detection rates obtained using an operating microscope and CBCT to ex vivo sections. They reported an ex vivo prevalence of a fourth canal in 67.14% of teeth and additional root canals in 92.85% of mesiobuccal roots. Clinical assessment provided slightly lower overall (53.26%) but higher (95.63%) MB2 detection rates whereas CBCT results showed the lowest overall (37.05%) detection rate. They indicated that CBCT provided a good method for the initial evaluation of maxillary first molar internal morphology but that the use of operating microscopes was optimal [46].

A study done to investigate the presence of second mesiobuccal canals in different thirds of the mesiobuccal roots of the first and second maxillary molars proved effective in mapping MB2 canals present in different thirds of the root[50.] For now CBCT should not be considered a replacement for standard digital radiographic applications. Rather, CBCT is a complementary modality for specific applications [47].

7. SPIRAL CT /MULTI SLICE CT/ MULTI DETECTOR CT

Spiral computed tomography has been recently introduced in endodontics as a diagnostic tool. This method helps access the internal morphology of the soft tissue and skeletal structures. This technique involves simultaneous translator movement of the patient with the x ray source so that continuous data acquisition occurs as the entire area of interest is scanned. It is then reconstructed into images representing transverse sections of the object using a 3D data set. With this technique it is possible to reconstruct the structures which overlap at arbiterary intervals and thus provides easier focus on small objects. Early generations of the CT scanner acquired 'data' in the axial plane by scanning the patient 'slice by slice' using a narrow collimated fan shaped X-ray beam passing through the patient to a single array of reciprocal detectors.

The Advantages over early generation CT is faster scan times, reduced radiation exposure to the patient, elimination of anatomical noise,high contrast resolution, allowing differentiation of tissues with less than 1% physical density difference to be distinguished. However The Disadvantages are its high effective dose, relatively low resolution of this imaging technique, high costs of the scans, scatter because of metallic objects and poor resolution compared with conventional radiographs. Tachibana & Matsumoto - were able to gain additional information on the root canal anatomy and its relationship to vital structures such as the maxillary sinus. Velvart et al. - found that CT detected the presence of an apical lesion and the location of the inferior alveolar nerve in all cases, compared with 78% and 39% respectively with periapical radiographs .Huumonen et al. - assessed the diagnostic value of CT and parallax periapical radiographs of maxillary molar teeth requiring endodontic retreatment.More periapical lesions were detected with CT compared with periapical radiographs.

8. HIGH RESOLUTION COMPUTER TOMOGRAPHY/MICRO CT/MICROTOMOGRAPHY

In Microtomography the term *micro* is used to indicate that the pixel sizes of the cross-sections are in the micrometer range. The first X-ray microtomography system was conceived and built by Jim Elliott in the early 1980s. The 3D Image Reconstruction works on the principle that as microtomography scanners offer isotropic, or near isotropic, resolution, display of images does not need to be restricted to the conventional axial images. Instead, it is possible for a software program to build a volume by 'stacking' the individual slices one on top of the other. The program may then display the volume in an alternative manner.

Using micro-CT, it is also possible to form three dimensional images of teeth and bone. It can reconstruct dental anatomy accurately and differentiate the enamel from dentin, as well as detects tooth disorders like attrision and caries accurately [48]. It is a promising tool in experimental endodontology. Qualitative and quantitative correlation between histological and micro-CT examination of root canal fillings was high [49] MicroCT has been used to calculate the volume of root canals in endodontic research [50] In a recent study, micro-CT scanning was used to compare the ability of manual and mechanical glide path to maintain the original root canal anatomy confirming that NiTi rotary pathfile instruments preserve the original canal anatomy and cause less canal aberrations [51].

9. TUNED APERTURE COMPUTED TOMOGRAPHY (TACT)

Tuned aperture computed tomography works on the basis of tomosynthesis. 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.

The Advantages of TACT over conventional radiographic techniques are the superimposition of anatomical noise over the area of interest (Webber et al., Tyndall et al.). The overall radiation dose of TACT is no greater than 1 -2 times that of a conventional periapical X-ray film as the total exposure dose is divided amongst the series of exposures taken with TACT [41]. Additional advantages claimed for this technique include the absence of artefacts resulting from radiation interaction with metallic restorations as observed in Computed tomography. The resolution is reported to be comparable with two dimensional radiographs [42]. Nance et al. compared TACT with conventional radiographic film to identify root canals in extracted mandibular and maxillary human molar teeth. Barton et al conducted a study to detect the second root canal in the mesiobuccal roots of the maxillary first molars using TACT. The frequency of detection of MB2 canals was 37.9% with TACT [52].

TACT can be used as a supplement to conventional radiography and as an alternative to other digital radiography techniques used in endodontics.

10. OPTICAL COHERENCE TOMOGRAPHY

During the last 20 years, optical coherence tomography (OCT) has evolved into a powerful technique for imaging of transparent and translucent structures.OCT is an attractive noninvasive, no touch imaging technique for obtaining high-resolution images. OCT is based on low-coherence interferometry and achieves micron-scale cross-sectional image. The first application in the biomedical optics field was for the measurement of the eye length [41].

There are two types of OCT; time domain (TDOCT) and spectrum domain (SDOCT)[53]OCT combines the principles of an ultrasound with the imaging performance of a microscope. It creates cross sectional images of biological structures using differences in the reflection of light. It achieves a depth resolution of the order of 10 micro and its plane resolution is similar to optical microscope. The light source has a wavelength of 1300 nm [54].

Shamesh et al. conducted an experiment to evaluate the ability of an optical coherence tomography system in imaging root canal walls after root canal preparation and to correlate these images to histological sections and concluded that OCT proves to be a reliable method to image root canals and root dentine in a non destructive way. This technique holds promise for endodontic imaging [55].

OCT can generate images of the boundaries of pulp and its relation to the dentin. The OCT image provides the insight into dentinal substrate about 0.65-mm deep (corrected for the dentin refractive index). OCT can be used in the future to prevent iatrogenic exposures of the pulp, complementing other existing methods, and will permit a more predictive prognosis of treatments.OCT is a promising nondestructive imaging method for the diagnosis of vertical Root fractures. OCT proves to be a reliable method to image root canals and root dentin in a nondestructive way.

This technique holds promise for full in vivo endodontic imaging [56]. Time Domain OCT has been used for evaluation of, apical micro leakage after endodontic treatment. Areas of apical micro leakage were detected between the gutta-percha cones and the root canal walls and the filling material of the root canal space.

11. MAGNECTIC RESONANCE IMAGING

An MRI scan is a specialized imaging technique which does not use ionizing radiation.

It involves the behavior of hydrogen atoms (consisting of one proton and one electron) within a magnetic field which is used to create the MR image. The patient's hydrogen protons normally spin on their axis. The patient is placed within a strong magnetic field, which aligns the protons contained within hydrogen atoms along the long axis of the magnetic field and the patient's body. A pulsed beam of radio waves which has a similar frequency to the patient's spinning hydrogen atoms is then transmitted perpendicular to the magnetic field.

This knocks the protons out of alignment, resulting in the hydrogen protons processing like tiny gyroscopes, moving from a longitudinal to a transverse plane. The atoms behave like several mini bar-magnets, spinning synchronously with each other. This generates a faint radio-signal (resonance) which is detected by the receiver within the scanner. Similar radio-signals are detected as the hydrogen protons relax and return to their original (longitudinal) direction. The receiver information is processed by a computer, and an image is produced.

Tutton & Goddard [56] performed MRI on a series of patients with dental disease. They were able to differentiate the roots of multi-rooted teeth; smaller branches of the neurovascular bundle could be clearly identified entering apical foramina. The authors also claimed that the nature of periapical lesions could be determined as well as the presence, absence and/or thickening of the cortical bone. Goto et al. compared measurements taken from three-dimensional reconstructed MRI and CT images of a dry mandible and hemi-mandible. They concluded that the accuracy of MRI was similar to CT. MRI scans are not affected by artifacts caused by metallic restorations which can be a major problem with CT technology (Eggars et al.) [57].

Cotti & Campisi suggested that MRI may be useful to assess the nature of endodontic lesions and for planning periapical surgery. Magnetic resonance imaging has several drawbacks. Different types of hard tissue cannot be differentiated from one another or from metallic objects; they all appear radiolucent. It is for these reasons that MRI is of limited use for the management of endodontic disease.

12. SWEEP IMAGING WITH FOURIER TRANSFORM (SWIFT*)*

Sweep Imaging with Fourier Transform (SWIFT) is fundamentally different approach to MRI. SWIFT MRI achieved simultaneous visualization of enamel, dentin and soft tissues in the pulp within clinically relevant scanning times and without the use of ionizing radiation. SWIFT images were able to identify 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 radiography techniques. Resolution of 100 jm (254 dpi) was obtained from *in vitro* teeth. The Problems found in vivo are the subject motion, proximity of intense signal from surrounding soft tissue, an enlarged field-of-view.

To solve these problems, authors developed an intraoral coil with radiofrequency shielding on the back of the coil to minimize signals from the cheek. But it compromised the resolution to 400 jm(63.5 dpi). The Advantages are that does not utilize ionizing radiation, image soft-tissue structures with great precision and detail and relatively insensitive to motion. The Disadvantages are that the equipment can be claustrophobic to many patients, the imaging process is extremely loud, typically takes 30 to 60 minutes and it requires several expensive and sensitive components.

13. VISUAL ENHANCEMENTS

Innovative advancements in fibre optic and rod-lens endoscope technology have allowed for the development and evolution of orascopic endodontics. Bahcall and Barss first reported on the use of orascopic visualization in 1999. The difference between an orascope and an endoscope is that an orascope utilizes fiber optics and is flexible, whereas the endoscope utilizes rods of glass and is rigid. The orascope is used to visualize within a root canal system, while the endoscope is used to visualize canal access in conventional endodontic therapy and in surgical endodontic treatment. A 0.8 mm lens diameter, 0°, 10K fiber optic orascope and a 4 mm lens diameter, 30°, 4 cm rod-lens endoscope are used for visualization in conventional endodontics. The 2.7 mm lens diameter, 70°, 3 cm long rod-lens endoscope is used for visualization in surgical endodontics.

The orascope and endoscope work in conjunction with a camera, light source, and monitor. The option of a printer or digital recorder can be added to the system for documentation purposes When compared to the microscope and loupes, the rod-lens endoscope provides the clinician with greater magnification without loss of focus or depth of field [21].

14. FIBER-OPTIC ORASCOPE

Limited intra-canal visualization during endodontic therapy was the catalyst for the development and application of fiber-optic technology in endodontics [57,58]. The device is small, lightweight, and flexible. This allows for ease of use in a non fixed treatment field of vision. The greater the amount of visual fibers in conjunction with a larger lens, the more image of a particular treatment field is captured by the camera and hence displayed on the monitor.

The fiber-optic orascope used for intracanal visualization has a 0.8-mm-tip-diameter, a 0° lens (a flat lens that does not have any angulations), and the working portion is 15mm in length. The orascope has 10,000 parallel visual fibers. Each visual fiber is between 3.7 and 5 um in diameter. To allow for illumination of the treatment field, a ring of larger, light-transmitting fibers surrounds the visual fibers.

Temperature and humidity differences between the dental operatory and the canal can result in moisture condensing on the orascope lens, resulting in fogging. The use of a sterile anti fog solution (Jedmed) eliminates this problem. The small fiber-optic size enables the orascope to actually go down into a canal. Prior to the placement of the 0.8mm fiber-optic scope, the canal must be prepared to a size No. 90 file in the coronal 15 mm of the canal. If the canal is not instrumented to this diameter, a wedging of the probe may occur, damaging some of the fibers within the scope. If a canal is curved, the orascope may not be able to visualize around the curve because of limited flexibility. The focus and depth of field of an orascope is zero mm to infinity. This allows the orascope to provide imaging of the apical third of the root without actually having to be positioned within this region of the canal.

15. CONCLUSION

The intricacy of the root canal morphology presents a challenging objective to endodontists. Conclusion During examination of the root canals have shown that we are not dealing with the canal alone nut with the complete root canal system with torturous turns, apical foramen, and at times with the accessory canals. However the recent improvements in digital radiographic imaging systems have brought about many benefits to endodontic practice. Nonetheless the use of these advanced digital systems has been limited because of cost and availability. With the development and rapid progress of technology towards the imaging of the maxillofacial region will definitely bring out success of endodontic treatment by providing accurate details about the root canal morphology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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