Ministry of Higher Education
& Scientific Research
University of Baghdad
College of Dentistry
Department of Conservative Dentistry

Cone Beam Computed Tomography in Endodontics

By

Dahlia Adel Farhan

Supervised by:

Dr. Nassr Al-Nuaimi

B.D.S., M.Sc., PhD (UK)

2018 A.D. 1439 A.H.

بسم الله الرحمن الرحيم

﴿قَالُوا سُبْحَانَكَ لا عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا
إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيم﴾

صدق الله العظيم

Declaration

This work is dedicated to my family, my father The Big teacher (Dr. Adel Frahan) and mother and my friends for their great support and for always believing in me.

To my supervisor for his care and guidance

Thank you from all my heart.

Dahila

Certification of the Supervisor

This is to certify that the organization and preparation of this project has been made by the under graduate student **Dahlia Adel Farhan** under my supervision in the College of Dentistry, University of Baghdad, in partial fulfillment of the requirements for the degree of B.D.S.

Dr. Nassr Al-Nuaimi
B.D.S., M.Sc., PhD (UK)

List of Contents

1. Introduction

Cone beam computed tomography (CBCT) is a relatively new method to visualize an individual tooth or dentition in relation to surrounding skeletal tissues and to create three-dimensional (3D) images of the area to be examined. The use of CBCT in Endodontics is rapidly increasing worldwide. Compared with traditional radiographic methods, which reproduce the three-dimensional anatomy as a two-dimensional (2D) image, CBCT is a three-dimensional imaging method that offers the possibility to view an individual tooth or teeth in any view, rather than predetermined 'default' views. Therefore, CBCT can be a powerful tool in endodontic diagnosis, treatment planning and follow-up. At the same time CBCT has limitations, and radiation dose to the patients must always be taken into consideration when selecting the modes of diagnostics (Cotton *et al*. 2007, Patel 2009).

Because CBCT has the ability to create precise, superimposition and distortion-free images of structures, in dentistry it is most commonly used for oral surgery problems. High-resolution dental CBCT images are being increasingly applied in other areas of dentistry as well, such as Periodontology, Prosthetics, Orthodontics, and Endodontics (Weber *et al*. 2015).

Although CBCT has been available, its application in dentistry still limited because of cost, access, and dose considerations. Since its inception, conventional radiography has remained the mainstay of imaging in Endodontics. In recent decades, however, advances in medical imaging have been applied, with varying success, to the various dental disciplines. Among the specific imaging techniques, which have been researched as potential diagnostic and treatment planning tools in Endodontics, are digital subtraction radiology (DSR), tuned aperture computed tomography (TACT), ultrasound (US), magnetic resonance imaging (MRI) and computed tomography (CT) (Patel *et al*. 2009).

These imaging techniques have been slow to gain acceptance in Endodontics, for an array of different reasons. As such, conventional radiography, despite its inherent limitations, remains the default imaging system in the field. However, the development of cone beam computed tomography (CBCT) has highlighted the inadequacies of conventional radiography when assessing the unique anatomy of the maxillofacial skeleton (Patel *et al*. 2009).

2.Cone Beam Computed Tomography

Background

Cone beam computed tomography (CBCT) is a contemporary, three-dimensional, diagnostic imaging system designed specifically for use on the maxillofacial skeleton (Arai *et al*. 1999). It has its origins in conventional medical CT. However, CBCT differs from the latter in a number of fundamental ways; differences which optimize its suitability for dental imaging.

Image Acquisition and Reconstruction

The CBCT hardware consists of an X-ray source and detector, or sensor, mounted on a rotating gantry. During imaging, a cone-shaped X-ray beam is emitted from the X-ray source and is directed through the area of interest in the patient’s maxillofacial skeleton. Having passed through the area of interest, the beam is projected on to the X-ray detector, as both it and the X-ray source rotate synchronously 180°-360° around the patient’s head, in a single sweep. The scan time typically ranges from 10-40 s depending on the equipment and exposure parameters employed. However, many CBCT systems employ a pulsatile X-ray beam and with these systems the actual patient exposure time can be as low as 2-5 s.

The reconstructed, three-dimensional data set will comprise 5123 three-dimensional pixels, or voxels. Reconstructed CBCT images can be displayed in a variety of ways. A commonly used option is for the images of the area of interest to be displayed, simultaneously, in the three orthogonal planes (axial, sagittal and coronal), affording the clinician a truly three-dimensional view of the area of interest (Patel *et al.* 2009).

3. Limitations of conventional radiographic image

3.1. Compression of Three-Dimensional Structures

A. Conventional radiography compresses three-dimensional structures on to a two-dimensional image. The radiograph provides a visualization of the anatomy under examination in the mesio-distal plane, whilst affording very little appreciation of structures in the third (bucco-lingual) dimension (Patel *et al*. 2009).

B. Parallax radiographic images with changes in the horizontal angulation of the X-ray beam, in relation to the area of interest, have been shown to contribute to an improved depth of perception and appreciation of spatial relationship in dental radiographic imaging (Brynolf *et al*. 1976).

3.2. Geometric Distortion

Intraoral periapical radiographs should be taken using a paralleling technique. This provides a more accurate geometric representation of the object of interest than do techniques such as the “bisecting angle” method (Forsberg *et al*. 1987). To obtain paralleled images, the image receptor should be positioned parallel to the tooth under investigation, and the X-ray beam should be perpendicular to both (Whaites *et al*. 2007).

The anatomical confines of the oral cavity mean that this ideal is seldom achieved, despite the availability of paralleling film holders. The use of rigid image receptors, such as those used with charged couple device (CCD) digital systems, adds to the difficulty. A minimum 5% magnification of the object being radiographed can be expected in the final image, even when the paralleling procedure is executed perfectly (Vande *et al*. 1969). This is due to the unavoidable separation between the image receptor and the object, and the divergent nature of the X-ray beam during imaging.

The ultimate result is that the geometry of the area being assessed is rarely reproduced with complete accuracy using conventional intraoral radiography (Patel *et al*. 2009).

3.3. Anatomical Noise

Anatomy in, or projected over, the area of interest during conventional radiographic imaging may impair visualization of the object under investigation, and complicate interpretation of the radiograph. These anatomical interferences can vary in radiodensity and are referred to as anatomical noise (Revesz *et al*. 1974).

Anatomical noise caused by features of overlying alveolar bone such as the cortical plate, trabeculae and marrow spaces have been specifically reported as complicating factors in the accurate detection of simulated periapical lesions (Bender *et al*. 1966) and external root resorption (ERR) (Schwartz *et al*. 1971).

3.4. Temporal Perspectives

Intraoral periapical radiographs of a particular area or tooth need to be compared over time to assess the development or progression of a disease. The radiographs should be standardized with respect to the X-ray beam angle, the object to image receptor distance and all of the radiation exposure parameters. Furthermore, the positional relationship between the image receptor and the object should be reproduced for each radiograph. In this manner all variables, other than the one under investigation, i.e. the disease process, are kept constant (Gröndahl *et al*. 2004). Poorly-standardized radiographs may result in a misinterpretation of disease onset or progression. This is particularly salient in the assessment of ERR, which can commence and progress rapidly (Durack *et al*. 2011). Even when customized bite blocks attached to the paralleling device are used to take serial radiographs, the images will never be identical (Rudolph *et al*. 1987).

4. Classification of CBCT

CBCT systems are most commonly classified in accordance with the scan volume or dimensions of their field of view (FOV), which are primarily depend on the detector size and shape, beam projection geometry and the ability to collimate the beam. The shape of the FOV can be either cylindrical or spherical. Collimation of the primary X-ray beam limits the radiation exposure to the region of interest. Therefore, the limitation of field size ensures that an optimal FOV can be selected based on disease presentation and the region of interest to be imaged for each patient. Based on available or selected scan volume height, the use of units can be classified as follow:

1. Small volume or localized region; also called as focused, small field, limited field or limited volume systems have a maximum scan volume height of 5 cm.
2. Single arch; CBCT scans have a FOV height ranging from 5-7 cm within one arch.

3. Inter arch; CBCT scans have a FOV height ranging from 7-10 cm.
4. Maxillofacial; CBCT scans have a FOV height ranging from of 10-15 cm.
5. Craniofacial; CBCTs have a FOV height greater than 15 cm.

Less popular methods of classifying CBCT systems are based on the patient position during the scan (supine, sitting or standing) and the functionality of the systems; some systems are multimodal and have a digital panoramic tomograph (DPT) function (Scarfe *et al.* 2009).

In general, the smaller scan volume causes the higher spatial resolution of the image. It is favorable that the optimal resolution of any CBCT imaging system used in Endodontics does not exceed the average width of the periodontal ligament space (200 μm), considering the earliest sign of periapical pathology being the discontinuity in the lamina dura and widening of the periodontal ligament space (Tyndall *et al*. 2008).

In addition to reducing capital costs, CBCT units with small FOV offer many advantages in Endodontics. First, a small FOV means that high resolution images with a spatial resolution as low as 0.076 mm isotropic voxel size can be acquired at very low exposure dose. Also, the image is taken without extensive reconstruction times that would be required with larger FOV systems due to the greater file sizes to be processed. Second, a limited FOV reduces the volume examined that the practitioner is responsible to interpret. CBCT systems are also classified by less popular methods based on the patient position (Durack *et al*. 2012).

5. Effective Dose of CBCT.

The radiation dose produced by a given CBCT system is dependent on a number of factors. The nature of the X-ray beam i.e. whether it is continuous or pulsatile, the degree of rotation of the X-ray source and detector and the size of the FOV will all have a bearing on the radiation dose. So too will the amount and type of beam filtration and the kV, mA and voxel size settings.

Collectively, these factors are referred to as the exposure parameters (Scarfe *et al.* 2009). The effective dose takes into account the radiation dose produced by the imaging system and the radiation sensitivity of the tissues that the X-ray beam is passing through during the exposure sequence. Effective dose is measured in Sieverts (Sv) and is often expressed in micro Sieverts (Sv) (ICRP Publication 2007).

The effective doses associated with CBCT scans, using this device, ranged from 13 μSv (anterior mandible) to 44 μSv (maxillary canine/premolar region) respectively (Loubele *et al.* 2009). By comparison, the effective dose of a single intraoral periapical radiograph ranges from 1-5 μSv, depending on the area of interest and the type of beam collimation employed (Gijbels *et al.* 2002).

6. Dose reduction and optimization

To ensure patient safety, personnel who use a CBCT scanner must have appropriate training and knowledge of patient radiation doses related to the specific CBCT scanner they are using. For endodontic purposes, the FOV should be limited to the region of interest, that is, the FOV should encompass the tooth (or teeth) under investigation and its surrounding structures. This is an effective way to reduce the patient dose. The tube current (mA) selected should be as low as possible, so that the image produced is of sufficient diagnostic yield even though there may be a degree of noise. The effective dose is also dependent on the region of the oral cavity being scanned (Loubele *et al*. 2009, Pauwels *et al*. 2012). Radiosensitive tissues, (e.g. salivary and thyroid gland) will be irradiated when certain areas of the jaws are being scanned.

7. Advantages of CBCT

CBCT is well suited for imaging the craniofacial area. It provides clear images of highly contrasted structures and is extremely useful for evaluating bone. The use of CBCT technology in clinical practice provides a number of potential advantages for maxillofacial imaging compared with conventional CT:

I. X-ray beam limitation: Reducing the size of the irradiated area by collimation of the primary X-ray beam to the area of interest minimizes the radiation dose. Most CBCT units can be adjusted to scan small regions for specific diagnostic tasks. Others are capable of scanning the entire craniofacial complex when necessary.

II. Image accuracy: The volumetric data set comprises a 3D block of smaller cuboid structures, known as voxels, each representing a specific degree of X-ray absorption. The size of these voxels determines the resolution of the image. In conventional CT, the voxels are isotropic rectangular cubes where the longest dimension of the voxel is the axial slice thickness and is determined by slice pitch. Although CT voxel surfaces can be as small as 0.625 mm square, their depth is usually 1-2 mm. All CBCT units provide voxel resolutions that are isotropic equal in all 3 dimensions. This produces sub millimeter resolution (often exceeding the highest grade multi-slice CT) ranging from 0.4 mm to as low as 0.125 mm (Scarfe *et al*. 2006).

III. Rapid scan time: Because CBCT acquires all basis images in a single rotation, scan time is rapid (10-70 seconds) and comparable with that of medical spiral MDCT systems. Although faster scanning time usually means fewer basis images from which to reconstruct the volumetric dataset, motion artifacts due to subject movement are reduced (Scarfe *et al*. 2006).

IV. Dose reduction: reports indicate that the effective dose of radiation is significantly reduced by up to 98% compared with “conventional” CT systems. This reduces the effective patient dose to approximately that of a film-based periapical survey of the dentition or 4-15 times that of a single panoramic radiograph (Ludlow *et al*. 2003).

V. Display modes unique to maxillofacial imaging: Access and interaction with medical CT data are not possible as workstations are required. Although such data can be converted and imported into proprietary programs for use on personal computers, this process is expensive and requires an intermediary stage that can extend the diagnostic phase. Reconstruction of CBCT data is performed natively by a personal computer. In addition, software can be made available to the user, not just the radiologist, either via direct purchase or innovative “per use” license from various vendors. This provides the clinician with the opportunity to use chair-side image display and real-time analysis (Cohnen *et al*. 2002).

VI. Reduced image artifact: With manufacturers’ artifact suppression algorithms and increasing number of projections, our clinical experience has shown that CBCT images can result in a low level of metal artifact, particularly in secondary reconstructions designed for viewing the teeth and jaws (Hu *et al*. 2000).

8. Limitation

Metal restorations, metal posts and root fillings and to some extent adjacent dental implants typically cause artefacts to the reconstructed images (Scarfe& Farman 2008). The potentially deleterious impact this may have on reconstructed images should be considered before considering a CBCT scan (Sogur *et al*.2007, Bueno *et al*. 2011) (Fig. 1).

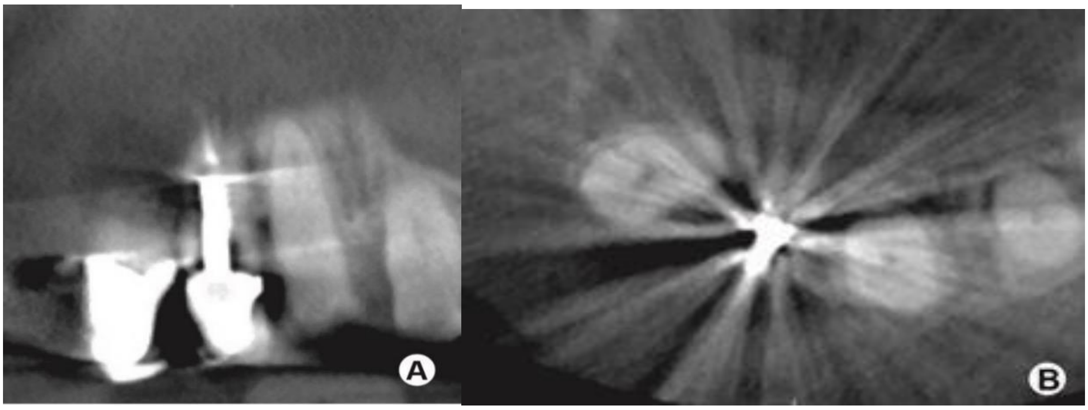

Figure 1. (a, b) Coronal (a) and axial (b) CBCT slices through a maxillary left central incisor tooth restored with a post-retained crown. Beam hardening caused by the metallic post has resulted in the appearance of streaks and bands, impairing the quality of the images.

The scan time of CBCT devices can be as long as 20 s and is therefore significantly longer compared with that of an intra-oral radiograph (<0.3 s). Therefore, even the slightest movement of a patient during the scan may render the resulting reconstructed images of minimal diagnostic use. Therefore, this may be a problem with children, elderly patients and those with neurological disturbances, for example Parkinson’s disease.

The spatial resolution of even the smallest voxel size may be too low to identify small objects, such as fractured instruments, or diagnostically challenging problems, for example incomplete vertical root fractures (VRFs) (Brady *et al*. 2014, D’Addazio *et al*. 2011, Patel *et al*. 2013).

9. Benefits and Risks

9.1. Benefits (https://www.fda.gov/Radiation).

1. The focused X-ray beam reduces scatter radiation, resulting in better image quality.
2. A single scan produces a wide variety of views and angles that can be manipulated to provide a more complete evaluation.

3. CBCT scans provide more information that conventional dental X-ray, allowing for more precise treatment planning.
4. CBCT scanning is painless, noninvasive and accurate.
5. A major advantage of CBCT is its ability to image bone and soft tissue at the same time.
6. No radiation remains in a patient's body after a CBCT examination.
7. X-rays used in CBCT scans should have no immediate side effects.
8. Dental CBCT images provide three-dimensional (3D) information, rather than the two-dimensional (2D) information provided by a conventional X-ray image. This may help with the diagnosis, treatment planning and evaluation of certain conditions.

9.2 Risks (https://www.fda.gov/Radiation).

1. There is always a slight chance of cancer from excessive exposure to radiation. However, the benefit of an accurate diagnosis far outweighs the risk.
2. CBCT scanning is, in general, not recommended for pregnant women unless medically necessary because of potential risk to the baby in the womb.
3. Because children are more sensitive to radiation, they should have a CBCT exam only if it is essential for making a diagnosis and should not have repeated CBCT exams unless absolutely necessary. CBCT scans in children should always be done with low-dose technique.

Although the radiation doses from dental CBCT exams are generally lower than other CT exams, dental CBCT exams typically deliver more radiation than conventional dental X-ray exams. Concerns about radiation exposure are greater for younger patients because they are more sensitive to radiation (i.e., estimates of their lifetime risk for cancer incidence and mortality per unit dose of ionizing radiation are higher) and they have a longer lifetime for ill effects to develop.

The FDA has launched a pediatric X-ray imaging website that provides specific recommendations for parents and health care providers to help reduce unnecessary radiation exposure to children. The FDA's Center for Devices and Radiological Health defines the ages of the pediatric population as birth through 21 years.

10. Patient selection criteria

It was suggested that small FOV units are better suited to Endodontics because their inherent small voxel sizes result in higher resolution images (down to 0.076 mm) and less radiation dosages than the larger FOV options. An important consideration is patient selection criteria.

CBCTs should not be used for screening purposes and not every patient needs a 3D image. Cases should be chosen on an individual basis depending on the patient's history, clinical examination and inability to obtain adequate diagnostic information from 2D images. As stated previously, it is important that the diagnostic benefit to the patient exceed the risk of radiation. CBCT should be limited to difficult endodontic cases such as:

- Identification of accessory canals, complex morphology, root canal system anomalies including determination of root curvature, such as in the case of maxillary molars.
- Cases of contradictory or non-specific signs and symptoms.
- Poorly localized symptoms associated with a previously treated tooth.
- Anatomic superimposition unresolved with 2D imaging.
- Diagnosis of non-endodontic pathology.
- Assessment of intra or postoperative complications.
- Diagnosis of dentoalveolar trauma (AAE and AMOR guideline 2011).

11. Interpretation

Clinicians ordering a CBCT are responsible for interpreting the entire image volume just as they are for any other radiographic image. Any radiograph may demonstrate findings that are significant to the health of the patient. There is no informed consent process that allows the clinician to interpret only a specific area of an image volume. Therefore, the clinician can be liable for a missed diagnosis so, any questions by the practitioner regarding image data interpretation should be referred to a specialist in oral and maxillofacial radiology.

Perhaps the most important advantage of CBCT in Endodontics is that it demonstrates anatomic features in three dimensions that intraoral and panoramic images cannot. CBCT units reconstruct the projection data to provide inter relational images in three orthogonal planes (axial, sagittal and coronal). In addition, because reconstruction of CBCT data is performed natively using a personal computer, data can be reoriented in its true spatial relationships. Due to the isotropic nature of the constructed volume elements (voxels) constituting the volumetric dataset, image data can be sectioned non-orthogonally. Most software provides for various non-axial 2D images in multi planar reformation. Such MPR modes include oblique, curved planar reformation (providing “simulated” distortion-free panoramic images) and serial transplanar reformation (providing cross-sections), which can be used to highlight specific anatomic regions for diverse diagnostic tasks. Enhancements including zoom magnification, window/level adjustments, and text or arrow annotation can be applied (Kavitha and Prabhat 2015).

12. Uses of CBCT

12.1 Detection of Apical Periodontitis

Cone beam computed tomography is significantly more sensitive than conventional radiography in the detection of apical periodontitis in humans (Estrela *et al*. 2008).

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 (Paula-Silva *et al*. 2009) (Fig. 2).

Comparison of the prevalence of apical periodontitis in maxillary and mandibular posterior teeth in a small human population using conventional periapical radiography and CBCT. They found that CBCT detected 62% more periapical lesions than conventional radiographs, although the assessment of the subject teeth was increased by parallax views in the latter technique (Lofthag *et al*. 2007). These findings were corroborated in similar studies with much larger sample sizes (Estrela *et al*. 2008).

The findings of these human in vivo experiments have been validated using ex vivo human (Patel *et al*. 2009) and animal models (Stavropoulos *et al*. 2007) in which periapical lesions were artificially created at verified healthy sites. The sensitivity of CBCT in the detection of simulated lesions of apical periodontitis was 1.0 (100% accuracy). Intraoral periapical radiographs, on the other hand, detected the simulated lesions in only 24.8% of the cases (Patel *et al*. 2009).

Earlier detection of apical periodontitis can be expected, with potentially better anticipated outcomes for non-surgical root canal treatment.

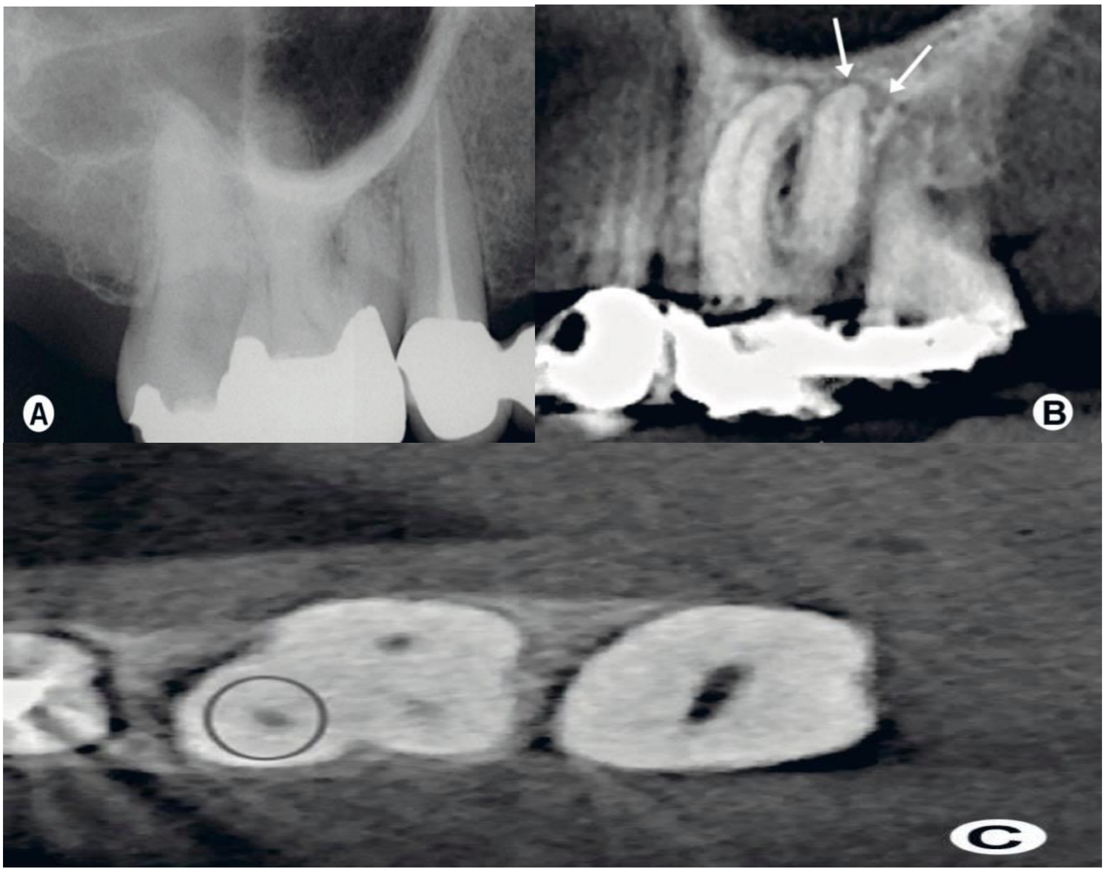

Figure 2. (a) Periapical radiograph of a symptomatic maxillary left first molar tooth. There is no evidence of a periapical radiolucency associated with the roots of this tooth. (b) Sagittal CBCT slice through the same tooth demonstrating the periapical bone destruction (white arrows) not evident on the periapical radiograph. Anatomical noise, caused in part by the zygomatic buttress, has obscured the area of interest on the periapical radiograph, reducing the diagnostic yield. Compression of this three-dimensional structure on the periapical radiograph, is also partly responsible. By examining the axial CBCT slices (c) of the tooth, it is evident that only one MB canal (circle) is present in the tooth. Advanced knowledge of this eradicates the need for excessive dentine removal to search for a supplemental canal.

12.2 Assessment of Potential Surgical Sites

Cone beam computed tomography has been highlighted as an extremely useful tool in the planning of surgical endodontic treatment (Rigolone *et al*. 2003). 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 (Lofthag *et al*. 2007).

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 (Fig. 3).

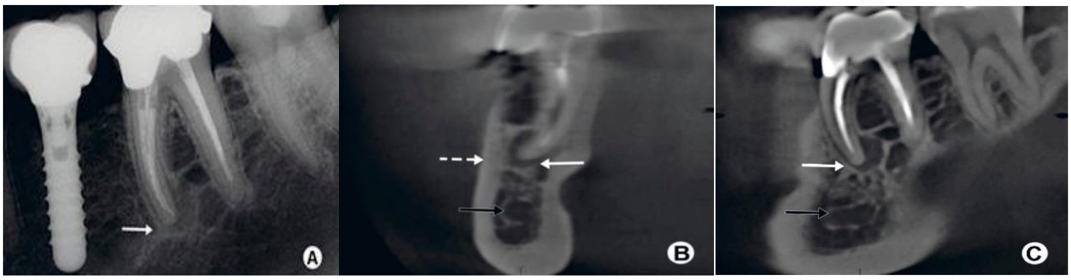

Figure 3. (a) Periapical radiograph of a mandibular left first molar tooth. The tooth has remained symptomatic and there is radiographic evidence of persistent apical periodontitis (solid white arrow) one year after non-surgical root canal treatment.

(b, c) Coronal (b) and sagittal (c) CBCT slices through the same tooth. The spatial relationship of the mesial root-end (solid white arrows) to the buccal cortical plate (dashed white arrow) and the inferior dental canal (black arrows) can be assessed and measured accurately prior to apical root-end surgery.

12.3 Assessment and Management of Dental Trauma

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 confidently implemented. The degree and direction of displacement associated with luxation injuries can be evaluated easily using CBCT (Patel and Durack 2011) (Fig.4).

Furthermore, CBCT has been shown to be far more sensitive than multiple periapical radiographs in the detection of horizontal root fractures (Kamburuglo *et al*. 2009) (Fig. 5). Failure to identify the presence of root fractures following dental trauma may lead to inappropriate treatment and poorer prognoses for these teeth.

External root resorption is a common complication after dental luxation (Andreasen *et al*. 1970) and avulsion (Andreasen *et al*. 1966) injuries. Of the three types of ERR described by Andreasen, external inflammatory root resorption (EIRR) is the only one which is responsive to endodontic treatment.

The prevalence of EIRR following luxation injuries, regardless of the specific type, ranges from almost 5% (Andreasen *et al*. 1985) to 18% (Crona *et al*. 1991). It affects 30% of replanted avulsed teeth. EIRR is the most common form of ERR following luxation and avulsion injuries. Diagnosis of EIRR is based solely on the radiographic demonstration of the process (Andreasen *et al*. 1966).

The process can have a rapid onset and aggressive progression, such that complete resorption of an entire root can occur within 3 months. The diagnosis of EIRR at an early stage following traumatic dental injuries (TDI) is, therefore, critical to the survival of the affected tooth.

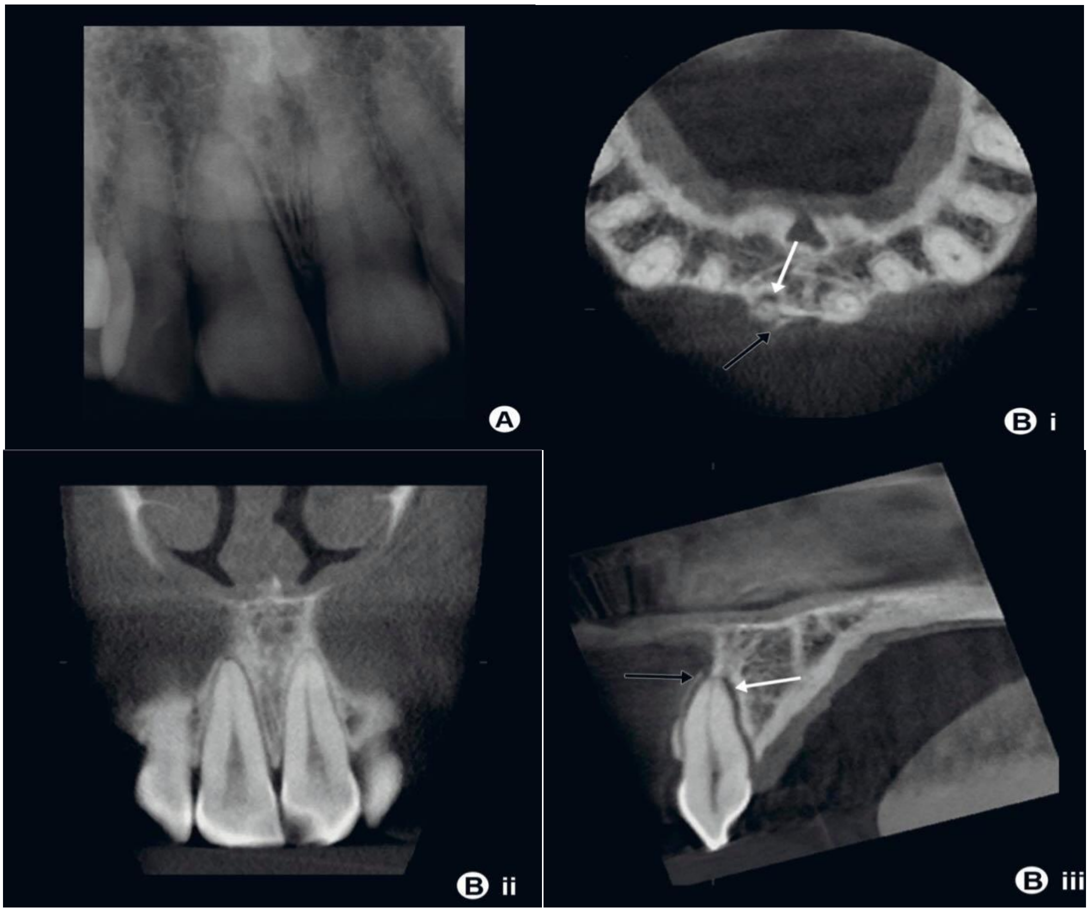

Figure 4. (a) Periapical radiograph of a luxated maxillary right central incisor tooth, following a traumatic dental injury. The radiograph reveals little about the nature and extent of the injury. (b) Axial (i), coronal (ii) and sagittal (iii) CBCT slices through the injured tooth. The crown of the tooth has been luxatedpalatally resulting in the labial displacement of the root of the tooth through the buccal cortical plate (black arrows). This has resulted in a widening of the periodontal ligament space on the palatal aspect of the root (white arrows).

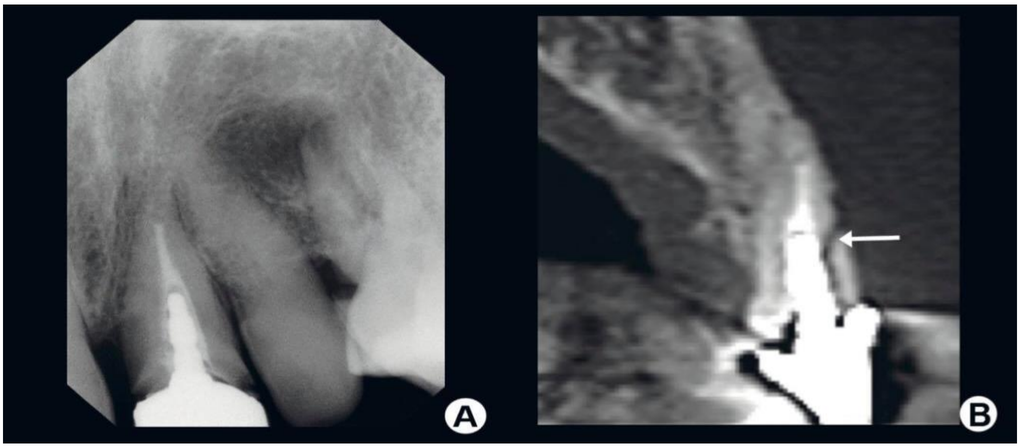

Figure 5. (a) Periapical radiograph of a maxillary left central incisor tooth restored with an ill-fitting crown retained by a cast post and core. There is no evidence of a root fracture on the radiograph. (b) Sagittal CBCT slice through the same tooth. A horizontal root fracture (arrow) is clearly evident. (Images courtesy of Steve Jones; Pentangle Specialist Dental Practice, Newbury, Berkshire, UK).

12.4 Assessment of Root Canal Anatomy and Morphology

Conventional radiographs frequently fail to disclose the number of canals in teeth undergoing non-surgical root canal treatment. Failure to identify and treat accessory canals can negatively influence treatment outcome (Wolcott *et al*. 2005).

The superiority of CBCT over conventional radiography in detecting the presence of supplemental canals (Matherne *et al*. 2008) (Figs. 2 and 6). Cone beam computed tomography 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 (Estrela *et al*. 2008). The availability of this information preoperatively reduces the chances of the aberrations outlined above occurring. In addition, CBCT has proved a useful assessment and treatment planning tool when teeth with anatomical and morphological anomalies, such as dens invaginatus and fused teeth require endodontic treatment (Patel *et al*. 2010).

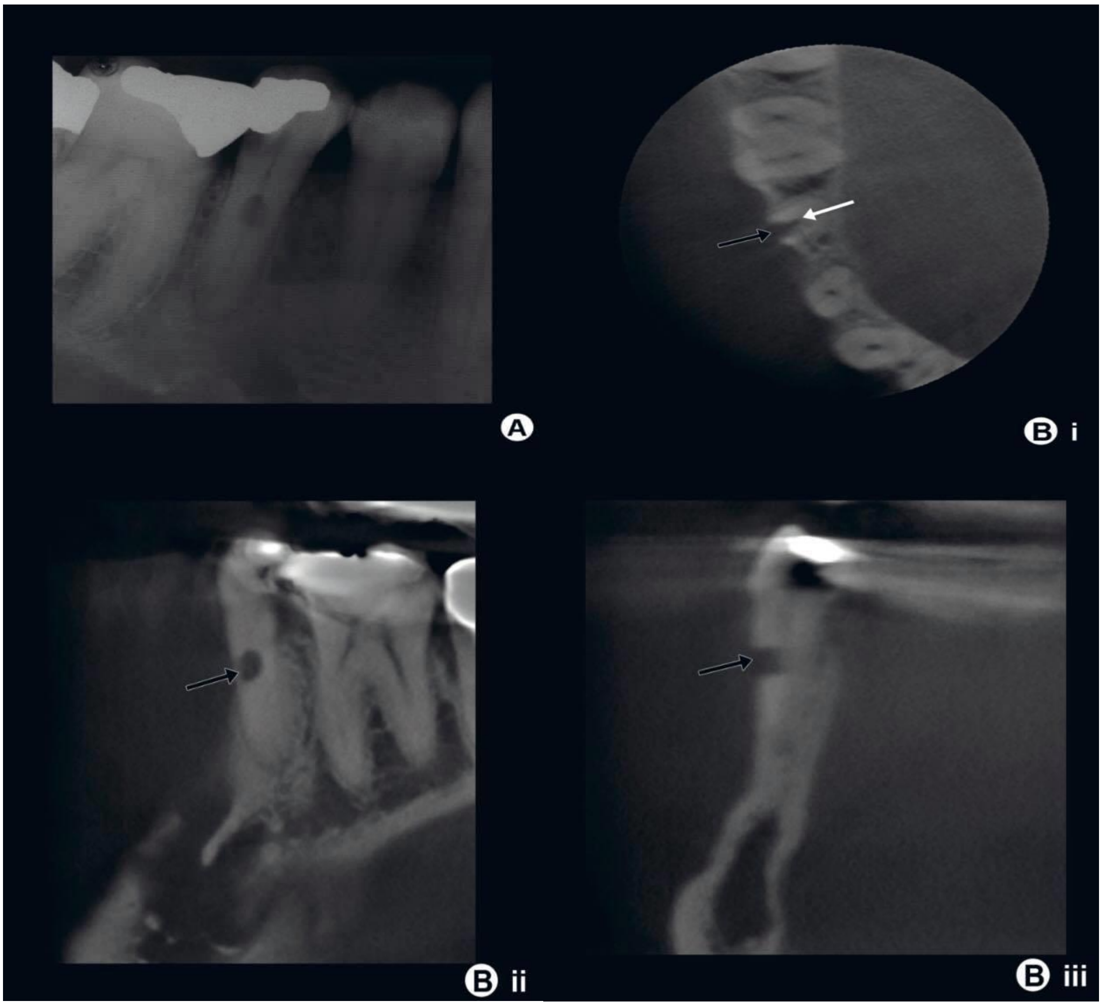

Figure 6. (a) Periapical radiograph of a mandibular second premolar tooth, which appears to be affected by root resorption. It is unclear from the radiograph whether the root resorption is internal or external or if the resorptive process has perforated the root canal wall. (b) Axial (i), coronal (ii) and sagittal (iii) CBCT slices through the tooth in the area of interest. It is clear from the CBCT images that the resorption originated on the external surface of the root (black arrows) and has perforated the root canal wall. The root canal shows no signs of ballooning enlargement associated with internal resorption (white arrow).

12.5 Diagnosis, Assessment and Management of Root Resorption

The clinical diagnosis of root resorption relies on the radiographic demonstration of the process (Andreasen *et al*. 1987).

The sensitivity of conventional radiography is significantly poorer than CBCT in the detection of ERR in its early stages and significant hard tissue damage may have potentially occurred to the affected tooth before the resorption becomes evident on conventional radiographs (Durack *et al*. 2011). 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 resorption (Patel *et al*. 2010).

Differentiating between external cervical resorption (ECR) and internal resorption can be particularly difficult (Gulabivala *et al*. 1995) (Fig. 7).

The authors reported CBCT to be 100% accurate in the diagnosis of the presence and type of the root resorption and the overall sensitivity of intraoral radiographs was lower than CBCT. (Fig.8). It was concluded that CBCT is an effective and appropriate method for identifying and differentiating between incipient, simulated ECR and IRR cavities, whilst conventional radiography is not. along the periodontal defect sometimes means this sign is missed. Radiographic features suggestive of VRF such as J-shaped and halo-shaped radiolucencies do not appear until significant bone destruction has occurred and similarly shaped radiolucencies may manifest themselves in cases of apical periodontitis not associated with VRF (Tamse *et al*. 2006). CBCT is more sensitive than conventional radiography in the detection of vertical fractures in roots. 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 (Hassan *et al*. 2009).

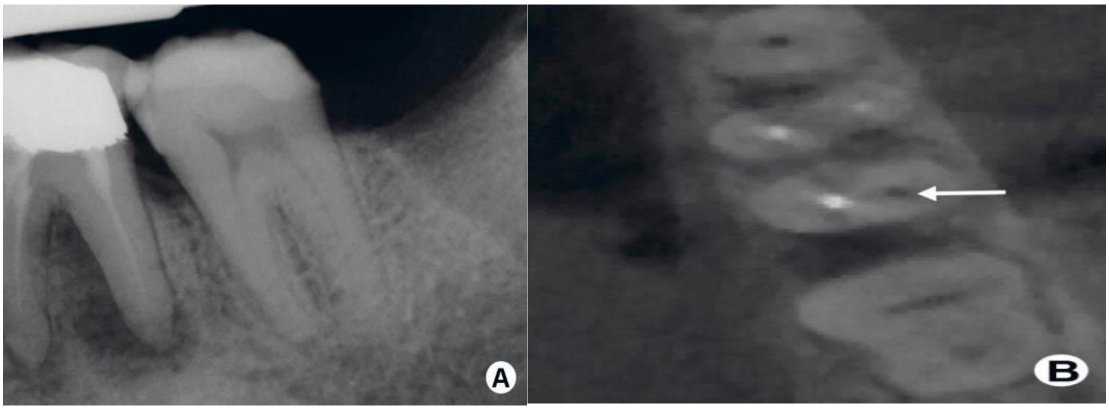

Figure 7. (a) Periapical radiograph of a mandibular left first molar tooth with a 10o horizontal shift in the angle of the X-ray tube head. There is no evidence of a second distal canal on this image despite the oblique view taken. (b) Axial CBCT slice through the same tooth clearly demonstrating the presence of an uninstrumented disto-buccal canal (white arrow).

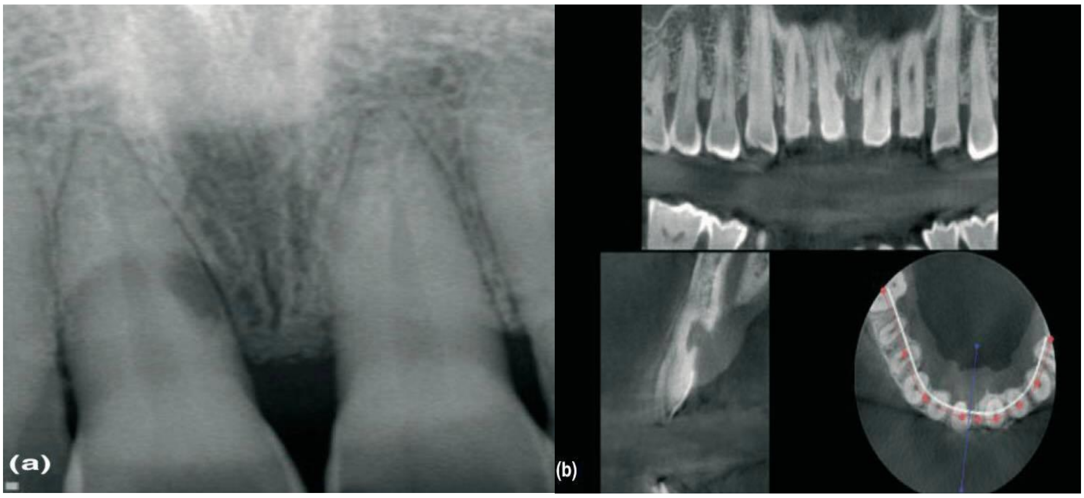

Figure 8. Periapical radiograph showing external root resorption (a). The CBCT of the tooth in question showed the exact location and extent of the lesion and guided the treatment plan (b).

12.6 Assessment of the Outcome of Endodontic Treatment

The radiographic outcome of root canal treatment is higher when teeth are treated before obvious conventional radiographic signs of periapical disease are detected (Friedman 2002). Thus, earlier identification of periapical radiolucent changes with CBCT may result in earlier diagnosis and more effective management of periapical disease. (Fig.9).

Cone beam computed tomography should result in a more objective and accurate determination of the prognosis of root canal treatment (Liang *et al.* 2011 Patel *et al.* 2011). A comparison between CBCT and conventional periapical radiographs in assessing the outcome of endodontic treatment in dogs. Six months after treatment, the success rate was deemed to be 79% when the teeth were assessed with conventional radiographs, while the success rate was 35% when CBCT was used to assess outcome (Paula-Silva *et al*. 2009).

These findings have been reflected in a recent prospective clinical outcome study, compared \\radiography and CBCT, 1 year after treatment. The healed rate (absence of radiolucency at review) of the treated teeth was 87% and 62.5% when assessed using periapical radiographs and CBCT, respectively (Patel *et al.*2012).

The healing rate (a reduction in the size or absence of the associated apical radiolucency) was 95.1% and 84.7% when assessed using conventional means and CBCT, respectively. These findings were significantly different. Failure rates for teeth with no preoperative radiolucencies were higher when outcome was assessed using CBCT compared with periapical radiography at 1 year.

In a clinical study, Liang *et al.* 2011 compared the outcome of endodontic treatment in humans, the success rate was deemed to be 87% when the cases were assessed using periapical radiographs and 74% when CBCT was used (Liang *et al*. 2011).

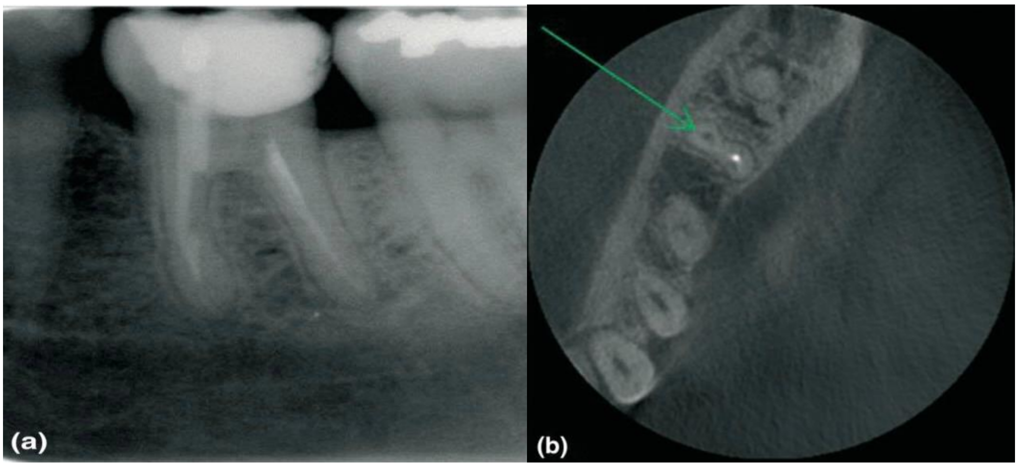

Figure 9. Periapical radiograph of a previously root canal treated tooth (36) with continued symptoms (a). The CBVT revealed an unfilled mesio-buccal canal indicated by the green arrow (b).

13. References

1. American Association of Endodontists and American Academy of Oral and Maxillofacial Radiology. Use of cone-beam computed tomography in Endodontics. Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 2011; 111:234–237.
2. Andreasen JO, Hjørting-Hansen E. Replantation of teeth. I. Radiographic and clinical study of 110 human teeth replanted after accidental loss. ActaOdontolScand 1966; 24:263-286.
3. Andreasen JO, Ravn JJ. Epidemiology of traumatic dental injuries to primary and permanent teeth in a Danish population sample. Int J Oral Surg 1972; 1:235-239.
4. Andreasen JO. Luxation of permanent teeth due to trauma. A clinical and radiographic follow-up of 189 injured teeth. Scand J Dent Res 1970; 78:273-286.
5. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. DentomaxRadiol 1999; 28:245-248.
6. Bender IB, Seltzer S, Soltanoff W. Endodontic success – are appraisal of criteria Part I. Oral Surg Oral Med Oral Pathol 1966; 22:780-789.
7. Brady E, Mannocci F, Wilson R, Brown J, Patel S. A comparison of CBCT and periapical radiography for the detection of vertical root fractures in non-endodontically treated teeth. Int Endod J 2014; 47(8): 735-46.
8. Brynolf I. A histological and roentenological study of the periapical region of human upper incisors. Odontologisk Revy 1967;18:Supplement 11.
9. Bueno MR, Estrela C, Figueiredo JAP, Azevedo BC. Map-reading strategy to diagnose root perforations near metallic intracanal posts by using cone beam computed tomography. J Endod 2011; 37:85–90.

10. Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler WG. Endodontic applications of cone-beam volumetric tomography. J Endod 2007; 9: 1121–32.
11. Crona-Larsson G, Bjarnasan S, Norén JG. Effect of luxation injuries on permanent teeth. Endod Dent Traumatol 1991; 7:199-206.
12. D'Addazio PS, Campos CN, Ozcan M, Teixeira HGC, Passoni RM, Carvalho ACP. A comparative study between cone-beam computed tomography and periapical radiographs in the diagnosis of simulated endodontic complications. IntEndod J 2011; 44:218–24.
13. Durack C, Patel S, Davies J, Wilson R, Mannocci F. Diagnostic accuracy of small volume cone beam computed tomography and intraoral periapical radiography for the detection of simulated external inflammatory root resorption. Int Endod J 2011; 44:136-147.
14. Durack C, Patel S. Cone beam computed tomography in endodontics. Braz Dent J. 2012; 23(3):179–91.
15. Durack C, Patel S. The use of cone beam computed tomography in the management of dens invaginatus affecting a strategic tooth in a patient affected by hypodontia: a case report. IntEndod J 2011; 44:474-483.
16. Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic radiography for the detection of apical periodontitis. J Endod 2008; 34:273-279.
17. Estrela C, Bueno MR, Sousa-Neto MD, Pécora JD. Method for determination of root curvature radius using cone-beam computed tomography images. Braz Dent J 2008; 19:114-118.
18. Forsberg J. Radiographic reproduction of endodontic 'working length' comparing the paralleling and the bisecting-angle techniques. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 1987; 64:353-360.
19. Friedman S. Prognosis of initial endodontic therapy. Endodontic Topics 2002; 2: 59–98.

20. Gijbels F, Jacobs R, Sanderink G, De Smet E, Nowak B, Van Dam J, et al. A comparison of the effective dose from scanography with periapical radiography. DentomaxRadiol 2002; 31:159-163.
21. Gröndahl H-G, Huumonen S. Radiographic manifestations of periapical inflammatory lesions. Endod Topics 2004; 8:55-67.
22. Gulabivala K, Searson LJ. Clinical diagnosis of internal resorption: an exception to the rule. Int Endod J 1995; 28:255-260.
23. H Hu, HD He, WD Foley, SH. Fox Four multidetector-row helical CT: image quality and volume coverage speed. Radiology 2000; 215:55-62.
24. Hassan B, Metska ME, Ozok AR, va der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. J Endod 2009; 35:719-722.
25. https://www.fda.gov/Radiation , EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm315011.htm#benefitsrisks, U.S. Food and Drug Administration,
26. ibular molars. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 2006; 101:797-802.
27. ICRP (2007) The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Annals of the ICRP* **37,** 1-332.
28. JB Ludlow, LE Davies-Ludlow, SL. Brooks Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac Radiol 2003;32:229-34.
29. Kamburuglo C, Cebeci AR, Gröndahl HG, Effectiveness of limited cone-beam computed tomography in the detection of horizontal root fracture. Dent Traumatol 2009; 25:256-261.
30. Kavitha**,** and Prabhat Singh**.** Cone Beam Computed Tomography in Endodontics. IOSR Journal of Dental and Medical Sciences (IOSR- JDMS)

2015; 14: 18-21.

31. Liang Y-H, Li G, Wesselink PR, Wu M-K. Endodontic outcome predictors identified with periapical radiographs and cone-beam computed tomography scans. J Endod 2011; 37:326-331.
32. Lofthag-Hansen S, Huumonen S, Gröndahl K, Gröndahl H-G. Limited cone beam CT and intraoral radiography for the diagnosis of periapical pathology. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 2007; 103:114-119.
33. Loubele M, Bogaerts R, Van Dijck E, Pauwels R, Vanheusden S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. Eur J Radiol 2009; 71:461-468.
34. M Cohnen, J Kemper, O Mobes. Radiation dose in dental radiology. EurRadiol2002; 12:634-7.
35. M.T.Weber,N. S. J. Fleiner, D. Schulze, and C. Hannig. Possibilities and limits of imaging endodontic structures with CBCT.SWISS DENTAL JOURNAL 2015; 125 (3):293-302.
36. Matherne RP, Angelopoulos C, Kulilid JC, Tira D. Use of cone-beam computed tomography to identify root canal systems in vitro. J Endod 2008; 34:87-89.
37. Patel S, Brady E, Wilson R, Brown J, Mannocci F (2013) The detection of vertical root fractures in root filled teeth with periapical radiographs and CBCT scans. Int Endod J 46, 1140–52.
38. Patel S, Durack C. Section 7. Case 7.2. Lateral luxation. In: Pitt Ford’s Problem Based Learning in Endodontology. Patel S, Duncan HF (Editors). 1st ed. Chichester: Wiley Blackwell, 2011, 256-263.
39. Patel S, Wilson R, Dawood A, Foschi F, Mannocci F. The detection of periapical pathosis using digital periapical radiography and cone beam

computed tomography – Part 2: a 1-year post-treatment follow-up. Int Endod J 2012; 45:711–23.

40. Patel S. New dimensions in endodontic imaging: Part 2. Cone beam computed tomography. Int Endod J 2009; 42:463-475.
41. Patel S. The use of cone beam computed tomography in the conservative management of dens invaginatus: a case report. IntEndod J 2010; 43:707-713.
42. Paula-Silva FWG, Hassam B, da Silva LAD, Leonardo MR, Wu M-K. Outcome of root canal treatment in dogs determined by periapical radiography and cone-beam computed tomography scans. J Endod 2009; 35:723-726.
43. Pauwels R, Beinsbergera J, Collaert B et al. Effective dose range for dental cone beam computed tomography scanners. European Journal of Radiology 2012; 81:267–71.
44. Revesz G, Kundel HL, Graber MA. The influence of structured noise on the detection of radiologic abnormalities. Invest Radiol 1974; 6:479-486.
45. Rigolone M, Pasqualini D, Bianchi L, Berutti E, Bianchi SD. Vestibular surgical access to the palatine root of the superior first molar: “low-does cone-beam” CT analysis of the pathway and its anatomic variations. J Endod 2003; 29:773-775.
46. Rudolph DJ, White SC. Film-holding instruments for intraoral subtraction radiography. Oral Surg Oral Med Oral Pathol 1988; 65:767-772.
47. Scarfe WC, Levin MD, Gane D, Farman AG. Use of cone beam computed tomography in endodontics. Int J Dent 2009; 634567.
48. Schwartz SF, Foster JK. Roentgenographic interpretation of experimentally produced bony lesions. Part 1 Oral Surg Oral Med Oral Pathol 1971; 32:606-612.

49. Sogur E, Baksi BG, GröndahlH-G. Imaging of root canal fillings: a comparison of subjective image quality between limited cone beam CT, storage phosphor and film radiography. Int Endod J 2007; 40: 179–85.
50. Stavropoulos A, Wenzel A. Accuracy of cone beam dental CT, intraoral digital and conventional film radiography for the detection of periapical lesions: an ex vivo study in pig jaws. Clin Oral Invest 2007; 11:101-106.
51. Tamse A, Kaffe I, Lustig J, Ganor J, Fuss Z. Radiographic features
52. of vertically fractured endodontically treated mesial roots of mandibular molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:797-802.
53. Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. Dent Clin North Am. 2008; 52(4):825–41.
54. VandeVoorde HE, Bjorndahl AM. Estimated endodontic ‘‘working length’’ with paralleling radiographs. Oral Surg Oral Med Oral Pathol 1969; 27:106-110.
55. W.C. Scarfe, A. G. Farman, and P. Sukovic**.** Clinical Applications of Cone-Beam Computed Tomography in Dental Practice. J Can Dent Assoc 2006; 72(l):75-80.
56. WC Scarfe, AG Farman, P. Sukovic Clinical Applications of Cone-Beam Computed Tomography in Dental Practice. J Can Dent Assoc 2006; 72:75-80
57. Whaites E. Periapical radiography. In: Essentials of Dental Radiology and Radiography. Whaites E (Editor). 4th ed. Churchill Livingston Elsevier; 2007.
58. Wolcott J, Ishley D, Kennedy W, Johnson S, Minnich S, Meyers J. A 5-year clinical investigation of second mesiobuccal canals in endodontically treated and retreated maxillary molars. J Endod 2005; 31:262-264.