



The Role and Potential Limitations of Contemporary Imaging Technologies to Aid Diagnosis and Management of Endodontics Cases

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Abstract

Aim: In endodontics, both clinical and radiographic examinations are important to be considered in terms of diagnosis and management of endodontics cases. The aim of this review is to discuss the different contemporary imaging technologies, including their role and limitations in diagnosis and management of endodontics cases as well as literature review and critical appraisal.

Methodology: Different types of studies were searched electronically from September 2016 to March 2017 through different well-known journals that include International Endodontic Journal (IEJ), Journal of Endodontics (JOE), and Journal of Endodontics, Oral Surgery Oral Medicine Oral Pathology Oral Radiology Endodontology (OOOOE) and Australian Dental Journal (ADJ).

Results: Literature review showed that several imaging technologies can be used in endodontics either for two-dimensional or three-dimensional image production. The most commonly radiograph used for different clinical applications in endodontics include diagnosis and treatment plan is the intra-oral periapical radiograph. It is used in three different phases which are preoperative, during treatment, and post-operative. However, there are some limitations of periapical radiograph and the use of 3D imaging technologies such as Cone-beam Computed Tomography (CBCT) overcome these limitations. Although CBCT has also some limitations such as scattering and beam hardening as well as a long scanning time in comparison to other imaging modalities, the limited field of view (FOV) CBCT was designed to improve diagnosis and management of endodontics cases. The overall result is that diagnosis and detection of periapical pathology is obtained by intra-oral periapical radiograph; nevertheless, the use of CBCT in some cases has improved that role significantly. In other words, there is no need to add or use a supplementary radiographic technique once the periapical radiograph gives the required information.

Conclusion: The use of intra-oral periapical radiograph is the first approach for diagnosis and management; however, limited FOV CBCT is used if it gives more and detailed information that aid diagnosis and management of endodontic problems.

Keywords: Endodontics; Radiography; Root canal treatment

Introduction

Population is exposed to radiation from natural background and medical sources primarily. Dental radiographs are responsible for only 0.26% of total exposure from medical imaging. Radiation has harmful effects on the public and occupationally exposed individuals; therefore, the International Commission on Radiological Protection (ICRP) established guidelines to limit the amount of radiation to be received. Radiation dose need to be kept as low as practical to all individuals. Dental exposure is reduced by following a three guiding principles in radiation protection including justification, optimization and dose limitation. Justification means that the dentist should distinguish situations where patients get benefits from a diagnostic radiographic exposure likely exceeds the risk of harm. Optimization means that every reasonable mean should be used to lower unnecessary radiation exposure to the dentist, dental staff and patients. This principle is also referred as the principle of ALARA [1]. According to the recommendations of the International Commission on Radiological Protection (ICRP), the radiation dose to patients should be as low as reasonably achievable (ALARA) while still offering image quality adequate to allow an accurate diagnosis [2]. Lastly, dose limitation gives dose limits to make sure that no individuals are exposed to unacceptable high doses [1]. In addition, radiation exposure is reduced by using patient selection criteria, physical methods and by adequate quality assurance programs [3].

Radiographic examination is an important component of endodontic management [4]. In the late 1970s, the transition from conventional x-ray films to digital ones using

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Radiographic source	Effective dose (μ SV)	Dose as percentage annual background radiation
Cone beam CT		
3D Accuitomo (1½ inch)	7.3	
i-CAT (12 inch FOV)	134.8	0.2
i-CAT (9 inch FOV)	68.7	5.4
Conventional CT		1.9
Conventional CT [11]	1 4 0 0	
	(maxilla)	38.9
	1 3 2 0	36.7
	(mandible)	
Conventional Radiography		
Periapical [11]		
Panoramic [11]		
Cosmic radiation on		0.14
Board an aircraft	5	0.2
Flying a round trip	6.3	4.2
Between paris-Tokyo	150	

CT: Computed Tomography

Table 1: A comparison of the effective dosages and back-ground equivalent of different sources of dental radiation [8].

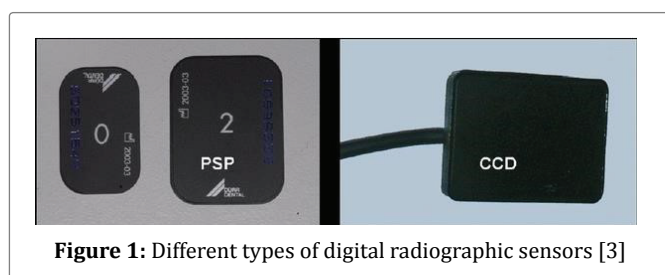


Figure 1: Different types of digital radiographic sensors [3]

intraoral sensors offered some advantages include less radiation exposure, improved x-ray resolution and quick processing [5]. Intra-oral radiographs allow clinicians to have an extra information that cannot be obtained by clinical examination such as the internal tooth anatomy, the bony contour around the tooth, and any associated pathology. Intra-oral radiographs captured on either x-ray films or digital sensors used for the endodontic problems management have limited information because of some reasons such as the two-dimensional nature of images produced, geometric distortion and the areas of interest are masked by overlying anatomy (anatomical noise) [6].

Extra-oral radiograph is a radiograph that makes diagnostic images of the larger craniofacial complex. It can be divided into extra-oral projection radiography and tomographic imaging [3]. Cone-beam Computed Tomography (CBCT) was specifically designed and developed in the late 1990s.. CBCT was introduced to produce three-dimensional images of the teeth and their surrounding tissues and undistorted three-dimensional information of the maxillofacial skeleton. Super-imposition of the anatomical structures is eliminated by the use of Sagittal, coronal and axial CBCT images [7]; however, CBCT has some limitations that include scattering and beam hardening as well as a long scanning time [8].

Radiation Exposure and Effective Dose

There are three types of radiation exposure that was categorized by the International Commission on Radiological Protection (ICRP): occupational exposures, public exposures, and medical exposures of patients. An occupational exposure is defined as (all radiation exposure of workers incurred as a result of their work). Public exposure is defined as (all exposures of the public due to natural sources other than occupational exposures and medical exposures of patients). Medical exposure is defined as all radiation exposures of patients occur in diagnostic, interventional, and therapeutic procedures) [9].

Radiation exposure is converted to effective dose that is a measure of the amount of radiation received by many radiosensitive organs during radiographic examination. Patient dose from dental radiography is reported as effective dose [1]. Cone-beam computed tomography (CBCT) has a low effective dose as a panoramic dental x-ray. Effective dose of CBCT and conventional radiography, including periapical and panoramic x-rays is significantly lower compared to conventional CT (Table 1) [10,11].

Intra-oral Radiography

Intra-oral radiography has three different configurations include periapical, bitewing and occlusal radiographs. Periapical radiograph is a type of intra-oral radiography that takes the image of the entire tooth with the bone surrounding the roots. Intra-oral periapical radiographs provide valuable information for the presence and location of peri-radicular lesions, root canal anatomy, and the adjacent anatomical structures proximity [3].

Bitewing radiograph is an intra-oral radiograph that takes the image of only the upper and lower teeth crowns and the alveolar bone crest. Therefore, interproximal caries that is not easy to be checked clinically or the presence of occlusal caries in the deep grooves of occlusal surfaces can be detected by using the intra-oral bitewing radiographs [2]. Occlusal radiograph is an intra-oral radiograph that is used to show an area of teeth and bone that is larger than periapical images [1].

Intraoral Periapical (IOPA) Radiography

Technology: A projection radiograph of a small region in the dento-alveolar process is gained by the use of an x-ray generator and intra-oral receptor. There are two speed groups of conventional intraoral x-ray films. Film of speed group E/F is twice faster than film of group D; therefore, it requires half of radiation exposure [1].

An F-speed direct exposure intra-oral x-ray film (InSight) was introduced by Kodak and stated that there is a 20% reduction in patient radiation exposure in comparison to its former E-speed film, (Ektaspeed Plus), without any sacrifice to the image quality [12].

Unlike conventional radiography, RadioVisioGraphy (RVG) is a digital imaging system that was introduced by Dr. Francis Mouyen (Trophy Radiologie, Vincennes, France). RVG uses an intraoral solid state detector as an X-ray receptor rather than uses a conventional x-ray film. An intensifying screen, fiber optic bundle, and a charge-coupled device (CCD) are inside the receptor [13]. CCD sensor produces an image as an array of pixels displayed on a computer monitor. CCD sensors have some drawbacks such as they are thick and the active area is relatively smaller [14].

There was an improvement in sensor technology from CCD sensors and newer sensors were discovered and called Complementary Metal Oxide Semi-conductor (CMOS) [15]. These changes increased resolution and processing speed as well as reduced power requirements [16]. Soredex (Orion Corp. Ltd, Helsinki, Finland) introduced an intra-oral computed radiography system (Digora) that uses a flat imaging plate with photosensitive phosphor granules [17] (Figure 1).

Immediate image generation and manipulation, elimination of chemical processing of radiographs, 50% radiation exposure reduction and enhancement of clinician's ability to educate patients are the advantages of digital dental imaging [18]. The diagnostic accuracy of detecting periapical bone defects/lesions in digital intra-oral radiographs is at least as high as that of conventional films [19]. In other words, several studies shown that there is no difference between digital and conventional intra-oral radiographs could be observed [20,21]. In the 1990s, several angulation techniques were studied and the paralleling technique was found as the most effective for endodontic use [22].

Role of periapical radiograph in Endodontics: The principal

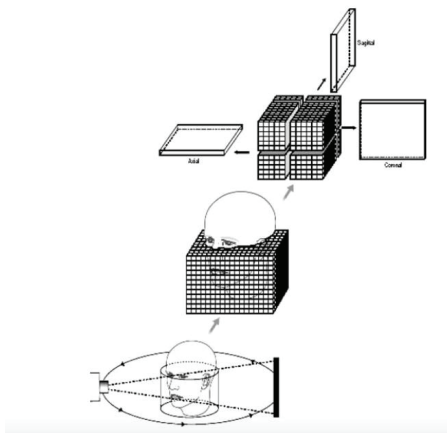


Figure 2: Diagram showing the basic concept of CBCT (Patel et al. 2007).

radiographic modality used for diagnosis and treatment planning before endodontic treatments is the intra-oral periapical radiography [23,24].

Intra-oral radiography has been the foundation for detection of periodontal disease, caries and periapical lesions [25]. In addition, using the intra-oral radiographs help in the visualization of bony tissues such as periodontal ligament space, lamina dura and bony trabecularisation. Moreover, another use of the intra-oral radiographs is the follow-up of dental lesions [3].

Detection of periapical pathology: In Endodontics, the diagnosis of the presence or absence of periapical lesion is based largely on periapical radiographic examination [17]. However, destruction of periapical bone may be minimal or be masked by adjacent anatomy in the early stages of apical periodontitis, so its presence cannot be seen on conventional radiographs [6]. Therefore, this can make to the diagnosis to be unclear, especially when the clinical signs and symptoms indicate irreversible pulpitis or pulp necrosis [26].

Determination of radiographic canal length: In addition to the use of intra-oral periapical radiograph to detect periapical pathology, it also can be used for radiographic canal length determination. In order to do an accurate root canal treatment, it is essential to determine the working length correctly. Therefore, over instrumentation of the root canals or insufficient root canal preparation due to underestimation of the working length won't occur [27]. According to the consensus report of the European Society of Endodontology (ESE) in 2006, the recommended methods to determine the working length are electronic apex locator and periapical radiograph.

Evaluation of root canal treatment outcome: In order to evaluate the success of root canal treatment, clinical evaluation and intra-oral periapical radiographs have been suggested as the traditional methods to be considered [28]. Reduction of the radiolucency size is the used radiographic criteria to determine successful treatment. This was considered to show the healing of the periapical pathology [29]. However, an overestimation of the success rate of the treatment could be given and this is due to the 2-dimensional (2D) images of tridimensional structures such as teeth and maxillary bones that provide a limited evaluation of the periapical lesion [28].

Periapical radiograph limitations: Although intra-oral periapical radiograph is the most common used in endodontics, it provides limited information for some reasons [6]. Limitations of intra-oral periapical radiograph include geometric distortion, the two dimensionality and anatomical noise [6].

First of all, geometric distortion of the radiographic image and this is caused by the lack of long axis orientation of the x-ray film or the digital sensor. In other words, improper positioning of the x-ray film. Ideally, the x-ray film or the digital sensor should be parallel to the long axis of the tooth, and the x-ray beam must be perpendicular to the image receptor for an accurate tooth anatomy reproduction [30].

Secondly, anatomical noise which means that anatomic structures obscuring structures of interest, so radiographic image interpretation is difficult. For instance, jawbone and other facial bones are at a close distance to the roots and apices, therefore it is unlikely to contain information of endodontic, diagnostic interest [31]. These structures that cause the anatomical noise can be either radiolucent such as the incisive foramen or the maxillary sinus or radiopaque such as the zygomatic buttress [6].

Extra-oral Radiography

Extra-oral radiography makes images of the larger craniofacial complex. It can be divided into conventional and modern techniques. Conventional techniques include skull projections, tomography and panoramic radiography, while modern techniques include computed tomography (CT) and cone beam computed tomography (CBCT) [3].

Frequently, the first diagnostic image of choice for routine radiologic examination is the Orthopantomogram (OPT) [32]. Panoramic radiograph is useful when doing examination of the jaw areas that cannot be imaged by using the intraoral radiograph such as the temporomandibular joints and the third molar regions. Panoramic radiograph has the ability to examine the entire lesion boundaries in the jaws. However, due to the numerous superimpositions seen on the panoramic image, it is needed to be supplemented by other advanced radiographic techniques such as computerized tomography, cone-beam computed tomography, and magnetic resonance imaging [33].

Magnetic resonance imaging (MRI) has many disadvantages such as images have poor resolution in comparison to simple radiographs, long scanning times, limited access only taken in radiology units and expensive hardware. In addition, the differentiation between different hard tissue types (e.g. enamel and dentine) cannot be done. Therefore, the use of MRI in endodontics has only a limited clinical application in relation to the management of endodontic disease. Moreover, Ultrasound (US) usage is also limited as its image interpretation requires an experienced radiologist who has received training in this field [6].

Computed tomography (CT) is an imaging modality that provides a three-dimensional image of an object by taking a series of two-dimensional sectional X-ray images. CT has many advantages and disadvantages. Advantages of CT include that it produces 3D images with a high contrast resolution in comparison to the conventional radiographs and eliminates the anatomical noise. However, CT has several disadvantages such as CT scans have high costs, CT scans limited only to be in radiology units, and metallic objects can cause scatter. Therefore, Cone-Beam Computed Tomography (CBCT) is the imaging technique to be used in diagnosis and management of endodontic problems rather than CT nowadays [6].

Cone-Beam Computed Tomography (CBCT)

Technology: Cone-Beam Computed Tomography (CBCT) is an imaging technology that has an advantage to make three-dimensional images of the teeth and their surrounding tissues and overcome some of the limitations of the two-dimensional images. By using a simple, direct relationship between sensor and source, the full 3D volume of data is obtained in the course of a single sweep of the scanner and this what makes CBCT differs from medical CT imaging. The X-ray beam is cone shaped and captures a cylindrical or spherical volume of data (Figure 2), described as the field of view (FOV) [7]. The field of view (FOV) size differs between CBCT scanners from 3 to 4 cm up to 20 cm, so there is a variation between scanners regarding the size of the field of view. There is a large volume of CBCT scanners

that take the image of the whole maxillofacial skeleton within a large spherical or cylindrical field of view (e.g. i-CAT, Imaging Sciences International, Hatfield, PA, USA). Also there are limited volume CBCT scanners that capture small volumes of data which include just two or three individual teeth (e.g. 3D Accuitomo, J Morita Corporation, Osaka, Japan) [7]. The resolution of the Image from the large size FOV scanner is typically lower than the image from the small size FOV scanner [34].

There are many CBCT scanners with a different field of view (FOV) size. Some scanners capture the entire maxillofacial skeleton, while other scanners only take the image of two to three teeth and named limited volume CBCT scanners [7]. For endodontic purposes, the appropriate CBCT image to be used is the one with a limited field of view (FOV) and this to limit the area to be irradiated (the area of interest) [35].

Moreover, the FOV is fixed in some scanners, while the FOV in other scanners can be changed to suit the clinical situation. Before installation of CBCT scanners, risk assessment must be for the need of personal dosimetry devices for staff involved in taking CBCT scans should be carried out, and this is because of the higher levels of scattered radiation [36].

The CBCT image data must be evaluated and reported on. This is to be performed by the practitioner who requested the scan, or the practitioner who has taken the scan. However, it is important to refer the CBCT image data to a competent person if the interpretation of the scan is beyond the competence of the clinician who has requested and/or taken the scan (SEDENTEXCT 2012). A maxillofacial radiologist is the one who normally would get this referral; however, national guidelines for the assessment of CBCT images should be followed [37].

Cone-beam computed tomography (CBCT) scan may only be considered after performing a comprehensive clinical examination and using appropriate conventional radiographs [8]. When planning to use CBCT, clinicians need to justify its use because of the risk of increased ionizing radiation [37]. Therefore, clinicians must have basic knowledge of CBCT radiography before they request CBCT scans as well as they must update that knowledge regularly [35].

Role of CBCT in Endodontics: The superimposition of anatomical structures is eliminated by sagittal, coronal and axial CBCT [7]. In addition to this advantage of the CBCT in which the adjacent anatomical noise can be avoided, CBCT allows to detect radiolucent lesions before they would be apparent on conventional radiographs [8]. A request for a CBCT scan should only be considered if the additional information from reconstructed three-dimensional images will potentially aid formulating a diagnosis and/or enhance the management of a tooth with an endodontic problem(s) and this is according to the ESE position statement [37].

Detection of periapical pathology: The detection of the presence or absence of periapical lesions is improved by using CBCT when compared to periapical radiographs and this has been confirmed by several Laboratory and clinical studies.

In 2007, the aim of a retrospective study was to compare intra-oral periapical radiography with 3D imaging modality for the diagnosis of periapical pathology. Among all the patients been referred to the Clinic of Oral and Maxillofacial Radiology at the Public Dental Health Service, Goteborg, Sweden, between April 2003 and July 2004, only 36 patients were selected. An examination of 46 teeth was done using two intra-oral periapical radiographs and a CBCT device (3D Accuitomo, J Morita Corporation, Osaka, Japan). The sample was maxillary/mandibular first or second molar, or maxillary premolar. In 53 cases, the presence of periapical lesions was related to individual roots rather than teeth. Those lesions were found at the same roots, in both radiographic modalities. Moreover, results showed that at an additional 33 roots, lesions that were not detectable in the periapical radiographs were detected in the Accuitomo images. It was concluded that when there is no detectable pathology in periapical

radiographs even though clinical tests indicate its presence, an additional radiographic assessment using a 3D technology, such as the 3D Accuitomo, should be considered [38].

This retrospective study has some drawbacks and gaps in its methodology. It is already known that CBCT images have better outcome in terms of detecting periapical pathology and in relation to the roots in specific than periapical radiographs. It's a retrospective study that has a lower quality as evidence and not as reliable as randomized controlled studies. Small sample size and the study included patients who were referred to the Clinic of Oral and Maxillofacial Radiology at the Public Dental Health Service; therefore, the study outcome does not reflect this in the general population. Regarding the radiographic interpretation, only three specialists in oral and maxillofacial radiology evaluated all radiographs together without specialists in endodontics. Moreover, a specific type of a CBCT device (3D Accuitomo) was used.

Another laboratory-based study (*in vitro*) that was published in 2009 with the objective to evaluate the diagnostic potential of two different CBCT units (i-CAT "Imaging Sciences International, Hatfield, PA, USA") and (Iluma ultra CBCT scanner "Imtec Imaging, Ardmore, OK, USA") and compare it with intra-oral digital and conventional film to detect chemically created periapical lesions. From 3 fresh cadaver mandibles from people who gave informed consent to donate their bodies for medical research and teaching, the sample size was 27 intact roots of 23 teeth (6 incisors, 4 canines, 6 premolars, and 7 molars) were selected. Intra-oral digital, conventional film, and CBCT images were obtained before and after the creation of periapical lesions. Results revealed that CBCT images were superior to 2D intraoral images and no difference between the two CBCT units as well as no difference between the two intra-oral radiographic techniques. Ozen et al concluded that both CBCT units (i-CAT and Iluma) performed better than intra-oral conventional and digital film radiography to detect chemically created periapical lesions [39]. This study has some weaknesses include that it's an *in vitro* study (chemically created periapical lesions) with a small sample size. Chemically created periapical lesions do not reflect periapical lesions that can be detected in patients' jaws. Although images were evaluated separately by three observers experienced in image interpretation, it wasn't stated in which specialty they are in. Are they specialist in oral and maxillofacial radiology or endodontics? Moreover, certain CBCT systems (i-CAT and Iluma) were used. Regarding the study outcome, it is already known that 3D images have better results than 2D images in detecting periapical lesions.

Detection of root fractures: Additionally, horizontal root fractures can be diagnosed and detected by using 2D imaging technique to be taken with different angles or using 3D imaging technology and based on the demonstration of a fracture line or lines. Frequently, horizontal root fractures occur in the maxillary anterior region of male patients due to trauma associated with fights, sports injuries, and automobile accidents [40]. An *ex vivo* study was conducted to compare the diagnostic accuracy of two different CBCT devices with several intra-oral radiography techniques to detect horizontal root fractures. The sample of this study was eighty-two extracted human maxillary incisors (centrals and laterals). An exclusion criteria include teeth without fractured, external or internal resorbed, acutely curved roots as well as those teeth did not undergone for root canal treatment. Twenty teeth were excluded from the sample because their roots were broken into many fragments during creation of horizontal fracture. The remaining 62 teeth were placed in sockets of a dry human maxilla and divided randomly into a control and test group. Images were taken by a 3D Accuitomo 170 CBCT, a NewTom 3G CBCT, a VistaScan PSP, a CCD sensor, and conventional film. Results showed that among the 5 radiographic modalities, 3D Accuitomo 170 has the highest sensitivity and diagnostic accuracy to detect horizontal root fracture [41]. The limitations of this study include that it's a laboratory-based study with a small sample size. No images were taken before the fracture was created.

Determination of radiographic canal length: In 2006, the

Cone Beam Computed Tomography with a limited FOV may be considered in the following situations:

- Diagnosis of radiographic signs of periapical pathosis when there are contradictory (nonspecific) signs and/or symptoms;
- Confirmation of nonodontogenic causes of pathosis;
- Assessment and/or management of complex dento-alveolar trauma, such as severe luxation injuries, suspected fracture of the overlying alveolar complex and horizontal root fractures, which may not be readily evaluated with conventional radiographic views;
- Appreciation of extremely complex root canal systems prior to endodontic management (for example, class III & IV dens invaginatus);
- Assessment of extremely complex root canal anatomy in teeth treatment planned for nonsurgical endodontic re-treatment;
- Assessment of endodontic treatment complications (for examples, [post] perforations) for treatment planning purposes when existing conventional radiographic views have yielded insufficient information;
- Assessment and/or management of root resorption, which clinically appears to be potentially amenable to treatment;

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Figure 3: Criteria for use of CBCT in endodontics [37].

recommended method by the European Society of Endodontology (ESE) to determine the canal working length is using an electronic apex locator and a periapical radiograph. On the contrary, according to the ESE position statement in 2014 (Figure 3), there are specific situations to use CBCT imaging technology [37] and up to the date, determination of canal working length is not included in the criteria of CBCT usage.

According to a recent *ex vivo* study with the aim of evaluating the accuracy of working length determination by using an electronic apex locator, periapical radiography, and cone-beam computed tomographic (CBCT) imaging. The sample was thirty freshly extracted human mandibular premolar teeth. The inclusion criteria included teeth without calcified canals and dental anomalies. Results showed that there was no significant difference between or within operators in intraoral radiographs. However, there were significant differences between and within operators for CBCT images. The conclusion was that available CBCT scans with different FOVs can be used for working length measurement [42]. This study has some limitations and gaps within the methodology. Mainly, it is an *ex vivo* study which considered as a weak evidence. The sample was approved by a local ethical committee; however, the sample size was small and only mandibular premolar teeth were selected. The inclusion criteria didn't include or exclude teeth status and condition in terms of root filing and coronal restoration. Also there is no information about who evaluated the radiographs and CBCT images. Finally, based on the ESE position statement [37] it is not indicated to use CBCT imaging system to determine the canal working length.

Preoperative diagnosis for apical surgery: Radiographs are important in combination with clinical examination for the preoperative diagnosis of teeth planned for apical surgery. The true extent of the periapical pathology and their spatial relationship to important anatomical landmarks can be evaluated by using computed tomography (CT) scans [43]. It was reported that the relationship of lesions to the mandibular canal before apical surgery is determined by using CT scans [44]. However, limited CBCT scan is used due to many advantages in comparison to CT scan; the most important advantage is fewer radiation administered to the patient

[45]. A retrospective study was conducted to compare using limited CBCT and conventional PA radiographs in order to detect periapical lesions and the dimensions of those lesions as well as the relationship of the mandibular canal to the mandibular molar teeth before apical surgery. The sample was 40 patients (21 female and 19 male), 38 molars with 75 roots included in the study. Periapical lesions that were detected on periapical radiographs were compared with the lesions seen on limited CBCT. It was concluded that limited CBCT has advantages to be used in treatment planning before apical surgery than PA radiographs [46]. This study has some limitations include that it's a retrospective study. In addition, a small sample size was included in the study and only molar teeth. Moreover, according to the inclusion criteria, teeth that were included in the study and planned for apical surgery already had been previously root canal treated. Actually, there was no consideration of non-surgical root canal re-treatment. A specific type of a CBCT device (3D Accuitomo) was used and the image evaluation was done by a postgraduate student.

Study of root canal morphology: For a successful root canal treatment, radiographic identification of the root canal morphology variations is considered as a basic requirement. For example, teeth with a complex root canal system such as teeth with C-shaped canals. According to a study by Jung et al in 2010, it was suggested that the recognition of C-shaped canals by means of OPT has a good surveying modality [47]. In 2014, the purpose of a retrospective study was to document the characteristics of C-shaped canal systems in permanent mandibular second molars using a combination of Orthopantomogram (OPT) and cone-beam computed tomographic (CBCT). The sample was 200 participants (94 men and 106 women, mean age = 35 years) who had both routine CBCT and OPT examinations of 339 mandibular second molars were enrolled. The presence of at least one well-developed mandibular second molar with a complete root formation was within the inclusion criteria, while the exclusion criteria were the existence of root canal fillings, PA lesion(s), or deep caries. All of the OPT and CBCT images were evaluated by one endodontist and one oral radiologist independently. Results showed that the use of OPT can assist in recognizing and diagnosing C-shaped root canal systems [49]. This study was approved by the Ethics Committee of Kocaeli University, Turkey. However, the drawbacks of this study include that it's a retrospective study that was conducted on a part of population (only patients who referred to the University of Kocaeli, Faculty of Dentistry, Kocaeli, Turkey). Moreover, a specific type of CBCT device (i-CAT scanner "Xoran Technologies, Ann Arbor, MI, and Imaging Sciences International, Hatfield, PA, USA") and OPT device (Vera-viewpocs "Morita, Kyoto, Japan") were used. Ultimately, the use of CBCT scanner should only be considered in specific cases or situations according to the ESE position statement (Figure 2) [14], but not as a routine examination such as the use of OPT.

CBCT was used in many studies to study the root canal morphology (number and configuration). For instance, Han et al studied the root canal morphology of the mandibular anterior teeth in a Chinese subpopulation and concluded that the prevalence of 2 root canals in the central incisors and the canines was lower than that in the lateral incisors as well as the largest proportion of central and lateral incisors had type 1 root canal configuration [49]. In Turkish population, it was recorded by Altunsoy et al that the most prevalent canal configuration of mandibular and maxillary anterior teeth was type 1. Type 5 was the most frequently observed canal configuration and in teeth with two canals [50]. Regarding the root canal morphology of molar teeth, Caputo et al used CBCT and evaluated differences in the anatomy of the mandibular first molars in a Brazilian population with respect to the patient's sex and the location of the tooth. It was found that 75.1% had 3 canals, 23.7% had 4 canals of the 342 mandibular first molars included in the study. In addition, women were more likely to have 2 canals on the distal root of the right side than men [52].

CBCT limitations: CBCT images may have minimal diagnostic value as a result of scattering and beam hardening that can be related to the tooth being assessed or close to it [38]. The cause of this

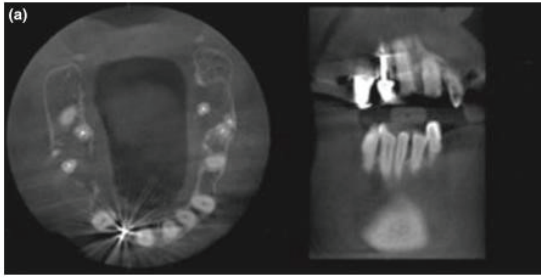


Figure 4: Scattering and beam hardening around metallic restorations [8].

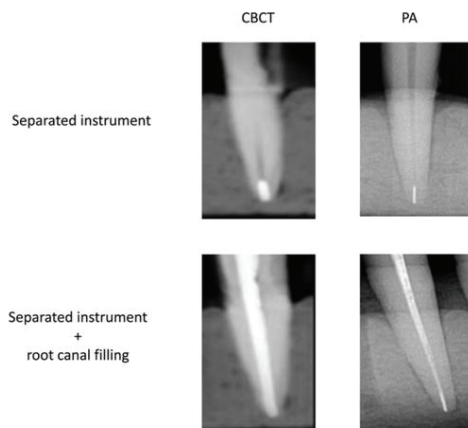


Figure 5: Periapical and CBCT images for a tooth with a separated instrument before and after root canal filling [54].

limitation is the high density neighboring structures, such as enamel, metal posts and restorations (Figure 4). Furthermore, patient need to stay completely still without moving for almost 15-20 s due to a lengthy CBCT scan time (Patel 2009). Therefore, certain types of patients, including children, elderly patients, and patients with neurological disorders such as Parkinson's disease are going to have a problem with CBCT [54].

Radiographs have the ability to identify broken instruments in the root canal. Preoperative diagnosis is important to consider treatment alternatives of teeth with broken instruments including endodontic surgery [53]. The objective of a recent *ex vivo* study in 2016 was to compare the diagnostic efficacies of cone-beam computed tomographic (CBCT) imaging and periapical radiography (PA) in the detection of retained broken instruments located at the apical third of filled root canals. The sample was sixty single-rooted extracted human teeth. In terms of inclusion criteria, the selected teeth were teeth with patent straight root canal and without any previous root canal treatment, root caries, root perforation, root resorption, or visible fractures or cracks. All sixty teeth were instrumented to size #25 and randomly divided to two groups. The first group was teeth with simulated 2-mm #30 K-file segment separation at the apical third of the canal ($n = 40$). The second group was teeth without a separated instrument (control group) ($n = 20$). Radiographs were taken for teeth with separated instrument in order to make sure that the separation occurred at the working length. The root canals were then obturated to the separated instrument or to the working length for the teeth without a separated instrument and subdivided into 6 groups of 10 teeth each based on file type (stainless steel or nickel-titanium) and sealer type (AH 26 or Roth). CBCT imaging and digital periapical radiography were taken for all teeth (Figure 5).

According to the study results, Rosen et al concluded that regardless of the instrument type or the sealer type and also under the limitations of this study, CBCT imaging is lower to periapical

radiography in the detection of retained separated instruments located at the apical third in extracted root filled teeth [54,55]. The limitations of this study include that it is an *ex vivo* study (on extracted teeth). A small sample size that was 60 teeth and those teeth were only single-rooted teeth. Also, no radiographs were taken initially before the instrument separation in the canal. Moreover, selected instrument and sealer types were used in this study.

Conclusion

Clinical and radiographic examinations are important to aid diagnosis and management of endodontic problems. Currently, there are several imaging technologies that can be used for many clinical applications in Endodontics. Some of these imaging modalities provide a two-dimensional image such as intraoral radiographs, while others have the ability to produce a three-dimensional image like cone-beam computed tomography (CBCT).

Although periapical radiography is the imaging modality that is most commonly accepted and used for diagnosis of presence or absence of periapical lesions, CBCT technique improved the detection of these lesions. Moreover, the use of limited volume CBCT allows to evaluate the true extent of the periapical pathology and its relation to any important anatomical landmark. Up to date, the recommended method by ESE for working length determination is the combination of electronic apex locator and periapical radiograph even though there was a recent study added the use of CBCT to determine the working length. Both periapical radiography and CBCT have limitations and that affect the image quality and subsequently diagnosis and management of endodontic cases.

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