PRESCRIPTIVE PATTERN AND CLINICAL DECISION MAKING IN COMPLICATED ENDODONTIC CASES USING CONE-BEAM COMPUTED TOMOGRAPHY

by

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Abstract

Purpose: Cone Beam Computed Tomography (CBCT) is an advanced but new imaging technique used in dentistry. Although it already has acquired a substantial literature, that literature does not include evidence-based evidence both for its indications-for-use and for its efficacy in comparison to the conventional approach to diagnosis and treatment planning.

Aims: To determine the pattern of prescription of CBCT by all UBC dental programs with particular regard to the field-of-view (FOV). To determine whether the CBCT prescriptions by the Graduate Endodontics Program were compliant with the joint American-Academy-of-Oral-and-Maxillofacial-Radiology and American-Academy-of-Endodontics (AAOMR/AAE) position statement (viz guidelines). To determine by reference to the EPR whether CBCT changed the original diagnosis and/or treatment plans based on the initial clinical examination and the conventional radiographic.

Methods: Ethics approval certificates **H14-02191** and **H15-03507** were granted for this retrospective study. All CBCT prescriptions were audited. The audit revealed that CBCT prescriptions by the Graduate Endodontics program were for a wide range of clinical reasons and worthy of further study. The pattern of prescription of CBCT was reviewed, by reference to electronic patient record (EPR), to determine whether it was compliant with the AAOMR/AAE guidelines. The statistical test, Chi-square was used.

Results: All but one CBCT in the audit were for small and medium sized FOVS. All 128 CBCT prescriptions (in 110 consecutive patients) were AAOMR/AAE-guidelines compliant. CBCT identified significantly more features than conventional radiography **($p<0.001$)**, particularly with regards to the identification of periapical lesions (**$p = 0.002$),** missed canals (**$p < 0.001$)**, vertical root fractures (**$p = 0.004$)** and complex anatomy (**$p = 0.008$)**. The significant results were seen with respect to change in diagnosis **($p<0.001$**), change in treatment plan **($p< 0.005$)**. The AAOMR/AAE recommendations were found to be incomplete.

Conclusion: CBCT permitted the identification of more numbers of periapical lesions, missed canal, complex anatomy and vertical root fracture than initially observable on conventional radiography. This study is perhaps the first to 'road-test' the AAOMR/AAE guidelines in an authentic clinical environment. It identified an important hiatus in these guidelines; they did not consider missed/extra canals in teeth which required endodontic re-treatment.

Lay Summary

Cone Beam Computed Tomography (CBCT) is an advanced imaging technique commonly used in dentistry. It provides a three-dimensional image as compared to two-dimensional image in conventional radiography. The use of advanced imaging techniques has a risk of high radiation dose or radiation injury; hence its use should be justified with clinical evidence. Our study was a retrospective review of the electronic patient records (EPR) of all patients who received a CBCT during the study period. The first part was an audit of all such CBCTs. This revealed that the CBCT prescribed by the Graduate Endodontics program were for a wide range of clinical reasons and worthy of further study, the second part reviewed the entries in the EPR of that program to determine if there were any significant changes to diagnosis and the treatment plan when the CBCTs were compared with the original periapical radiographs. The pattern of prescription of CBCT was reviewed to determine whether it was compliant with the American Academy of Oral and Maxillofacial Radiology / American Academy of Endodontists position statement 2015.

Preface

I conducted this retrospective research under the valuable guidance and support of my supervisor, Dr. David MacDonald. My committee members included Dr. J. Coil, Dr. B. Chehroudi and Dr. A. Esteves.

I was responsible for collecting all the data of Part 1 and Part 2 of this study. Part 1 mainly dealt with audit of CBCT cases in Faculty of Dentistry for quality assurance.

Part 2 included only the endodontic cases sent for CBCT examination. I reviewed all the cases from the electronic patient record in the study thoroughly. Dr. Coil provided me the guidance and direction in reviewing the endodontic records, whenever I was in doubt. I performed all the statistical analysis under the guidance of Dr. Chehroudi. Dr. Esteves gave invaluable feedback during committee meeting pertaining to electronic record keeping and other details.

Ethics approval certificate was granted for this study, which was done in two parts, from UBC Clinic Research Ethics Board (Certificate number: H14-02191 and H15-03507).

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List of Abbreviations

AAE	American Academy of Endodontists
AAOMR	American Academy of Oral and Maxillofacial Radiologists
CBCT	Cone Beam Computed Tomography
CT	Computed Tomography
EPR	Electronic Patient Record
ER	Emergency Room
FOV	Field of View
Gp. 1	Group 1
Gp. 2	Group 2
Gp. 3	Group 3
IADR	International Association for Dental Research
MDCT	Medical Computed Tomography
OMFR	Oral and Maxillofacial Radiology
OR	Operating Room
PID	Position Indicating Device
PRIO	Periapical radiolucency of inflammatory origin
TACT	Tuned-Aperture Computed Tomography
VRF	Vertical Root Fracture

Acknowledgements

I would like to express my sincere and deepest gratitude to my supervisor Dr. David MacDonald. This work would not have been possible without his valuable guidance, positive feedback and long hours put into reviewing my thesis. I am lucky to have him as my supervisor and consider him my “guru”. Apart from being a great supervisor, Dr. David MacDonald is a generous and kind-hearted person. I thank him for his early morning meetings to discuss my thesis and late evenings going through my text, reviewing radiographs and scans, despite his busy schedule.

I would like to deeply thank Dr. Chehroudi for his prompt help and answering all the questions related to statistics. He was always available whenever I needed him and helped me in the initial stages of my research, when I needed him the most, to guide me through the process.

I am grateful for all the valuable time that Dr. Coil spent with me in reviewing some relevant and complicated cases from electronic records, which helped me in completing my research smoothly.

I greatly appreciate Dr. Esteves’ invaluable feedback in committee meetings.

I also appreciate the informative discussion I had with Dr. Jolanta Aleksejuniene concerning statistics.

I thank, my husband Vibhor for spending long hours at night helping in formatting this thesis. Last, but not the least I would like to thank my parents Manju and Narayan Datt Bhatt for believing and instilling in me the spirit of pro-active hard work, patience and perseverance. They played a strong role in building my basics and foundation. They taught me to work hard,

celebrate and share my successes with others. My go-getter attitude is the result of their perseverance.

Dedication

This thesis is the outcome of my literary training and research. I dedicate this work to my precious husband Vibhor. He not only teaches me the essence of "balance in life" but also instills joy, positivity and perception.

He is my best friend and mentor for life. He is my first and only love and without his constant support, none of my accomplishments would have been possible. He is my biggest critique which has helped me to hone my skills. I have learnt some of the most important lessons of life from him. He is my rock, and I can trust him, no matter what.

I thank him in supporting me to follow my dreams, keeping them alive and never stop dreaming.

Chapter 1: Introduction on Endodontic Imaging

1.1 Importance of Radiology in Endodontics

After the discovery of X-rays in 1895 by Roentgen, C. Edmund Kells introduced X-rays to the dentistry in 1896 (Jacobsohn & Fedran, 1995) thus making the display of lesions affecting the skeleton of the face and of the jaws easier. Before this introduction of radiology most of the diagnoses and treatments of intra-osseous lesions were performed in the “dark”. Today clinicians are able to identify the exact location of lesions and determine their extent, with more precision.

In common with other dental specialties, the use of radiological imaging became an important investigative tool in endodontics. This initially was by conventional radiography and now more recently by cone-beam computed tomography (CBCT). In endodontics, the most relevant and commonly used conventional radiograph is the periapical radiograph. This has been complemented by the advent of CBCT, which made its clinical debut in 2000. CBCT has now been used the pre-operative, intra-operative and post-operative assessment stages of endodontic treatment (Cohen, 2016, p. 43).

Pre-operative assessment

One of the most important factors that contributes to the success of endodontic treatment is pre-operative diagnosis (Molven et al., 2002). In pre-operative endodontic assessment, imaging permits assessment of the root form, the length of the root, the canal anatomy and the periradicular status of the tooth in question. These structures cannot be assessed without radiography. If radiographic information is not available the diagnosis of endodontic problems becomes challenging (Cohen, 2016, p. 43). Pre-operative assessment also reveals the difficulties which the clinician might encounter during treatment, such as calcified canals, curved roots, complex canal anatomy and proximity of lesions to important anatomical landmarks such as the mandibular canal or the floor of the maxillary sinus.

For better diagnosis and treatment, the region of interest should be adequately imaged to determine the need of further investigation or treatment planning. An adequate periapical radiograph should display at least 3-5 mm of peri-radicular area of the tooth in question. An image helps the clinician to correlate the radiographic findings with the clinical examination to make an accurate diagnosis (Ee et al., 2014).

Intra-operative assessment

In intra-operative assessment, the radiographs help in determining the size of the pulp canal, accessory canals and the location of the apex. It also assists in determining the working length of the canal and the type of obturation material to use. After the advent of CBCT in endodontics, it is believed that the intra-operative use of this imaging technique can prevent the iatrogenic mishaps (Cohenca & Shemesh, 2015), such as the removal of excess dentine and other healthy tooth structure in an attempt to locate the canal. The judicious use of CBCT intra-operatively can minimize the tissue loss in such events, affecting a better treatment outcome. American Academy of Oral and Maxillofacial Radiology (AAOMR) American Academy of Endodontists (AAE) published their most recent joint AAOMR/AAE position statement in 2015. This is clearly indicated the use of CBCT intra-operatively for location of calcified canals. Other benefits of intra-operative CBCT use are the identification of perforations and unusual anatomy otherwise not evident on conventional radiography (Cohenca & Shemesh, 2015).

Post-operative assessment

Post-operative assessment determines the quality of treatment performed and the healing process. It helps in determining the quality of obturation done or whether it is over or under filled. Post-operative radiographs also help in deciding whether any further treatment is required or not. The presence of a new periapical lesion or the increase or decrease in size of the initial lesion determines whether the initial treatment was successful or not. In North America, the post-operative radiography assessment ranges from 6 months to at-least two years after the initial treatment. It should be noted that a nearly three-decades of follow-up of a case series of endodontic cases, all initially with periapical radiolucencies treated by undergraduates in a Norwegian dental school, revealed the onset of late failures and successes (Molven et al., 2002).

The studies concluded that the initial healing outcome is low in endodontically-treated teeth, when evaluated by CBCT (Fernández et al., 2013; Patel et al., 2012). Since these studies some authors now suggest that CBCT can overestimate the endodontic failures (Petersson et al., 2012). So more long-term follow-up studies are required to assess the healing outcome.

1.2 Conventional Radiographs

The most important radiograph to the endodontists is the periapical radiograph (Cotti-& Campisi, 2004). The term ‘periapical’ is derived from the Greek *peri*, which means "around," and *apex* which means "tip". In addition to this periapical area, a periapical radiograph of adequate quality would include the entire tooth, including the crown and also a few millimeters of alveolar bone in which the tooth is invested. The periapical radiograph is needed for the establishment of a diagnosis, for the formulation of a treatment plan and for post-treatment follow up.

The main advantage of the periapical radiograph is its superior spatial resolution (MacDonald, 2011 Figure 1.3 p. 59). Apart from providing superior spatial resolution the periapical radiographs, in comparison to CBCT, are low cost, impart a low radiation dose and the equipment to produce them is both ubiquitous and easily accessed. Despite being widely used in endodontic practice, the periapical radiograph has limitations.

1.2.1 Limitations of conventional radiographs

Superimposition of anatomy

The periapical radiograph is a 2-dimensional (2-D) image representation of a 3-dimensional (3-D) structure. Although periapical radiographs optimally display the mesio-distal plane of an region of the jaws (Patel et al, 2009), all anatomy captured between the distal end of the cone and the periapical detector in the bucco-lingual plane, be it digital (Phospher plate or solid state) or analog (film), are superimposed on each other. In multi-rooted teeth the buccal, lingual or palatal roots are superimposed on each other obscuring the exact location of the periapical lesions (Davies et al., 2015). In maxilla, the evaluation of bucco-lingual width of the sinus floor is of utmost importance when performing endodontic surgery in order to determine the proximity of the apices to the sinus floor. The evaluation of this important relationship by periapical radiographs (Chien & Chen, 2014) in not possible because of their 2-D nature.

Apart from an inability to interpret bucco-lingual anatomy, periapical radiographs are also limited in permitting the accurate evaluation of spatial relationship of the periapical lesions to other adjacent structures (Cotti & Campisi, 2004; Patel et al., 2009), such as the mandibular canal, the aforementioned maxillary sinus and the cortical bone (Patel et al., 2016).

Geometric distortion

The two periapical radiographic techniques used are the bisecting technique and the paralleling technique. The former is associated with more image distortion. In order to achieve a geometric image that best represents the object (in this case the tooth), the image receptor (also called detector and occasionally sensor) and the long axis of the tooth should be parallel to each other and the incident beam should be perpendicular to both (White & Pharoah, 2014 p.93).This geometric accuracy can be achieved by paralleling technique to a large extent. Although the paralleling technique is best recommended for endodontic purposes (Forsberg & Halse, 1994), it may be impossible in some cases to position the image receptor parallel to the long axis of the entire tooth (Durack & Patel, 2012; Patel et al., 2016) like a shallow palatal vault or tori. Furthermore, optimal positioning of the image receptor is also affected by patient-related factors such as a gagging reflex and any other inability to tolerate placing of the image receptor and its accompanying position-indicating device (PID). Operator-related causes are over- and under-angulated tube head. These factors result in image distortion. It has been observed that there is at least 5% of magnification of the structures radiographed using paralleling technique (Forsberg, 1987). These limit diagnostic accuracies and may contribute to endodontic treatment failure.

Furthermore, the superimposition of the opaque root filling materials in already endodontically-treated teeth also hinder the exact location of the lesion or extra canals, more commonly in multi-rooted teeth (Davies et al., 2015). Additional images at different angulations can be produced for non-surgical endodontic treatment to enhance the diagnostic accuracy and to allay the above factors resulting in better endodontic treatment (European Society of Endodontology, 2006)

1.3 Advanced Imaging in Endodontics

In order to overcome the limitations of traditional imaging techniques, the advanced imaging modalities have gained much importance recently in endodontic practice. They have proved to be useful in enhancing diagnosis with respect to endodontic problems (Cotti & Campisi, 2004) and thus increasing the diagnostic accuracy. A wide range of advanced imaging modalities like magnetic resonance imaging (MRI), computed tomography (CT), ultrasound, digital subtraction radiology, cone beam computed tomography (CBCT) and tuned aperture computed tomography (TACT) which have been used for endodontic diagnosis and treatment planning (Durack & Patel, 2012; Patel et al., 2009) .

Magnetic Resonance Imaging

MRI is a non-invasive and non-ionizing imaging technique (Ibrahim et al., 2014), which uses various sequences of radio waves to communicate with the patient's normal and diseased tissues within a magnetic field (MacDonald 2011, p. 67).

MRI has been used to assess the disorders or lesions involving soft tissues pertaining to face and jaws (MacDonald, 2011, p. 67; MacDonald et al 2017.). In dentistry MRI is mostly prescribed to assess the stages of oral cancers or neoplasm of maxillofacial area and disorders involving temporal mandibular joint (MacDonald, 2011, p. 67). Recently MRI was employed to evaluate a non-Hodgkin lymphoma that first came to the clinician's attention when performing endodontic-treatment. This was quickly followed by CBCT then CT and finally MRI (MacDonald et al 2017). MRI is also used to investigate the soft tissue lesions involving salivary glands (Goto et al., 2007) and implant placement (Choël et al., 2014)

MRI has several drawbacks such as its poorer spatial resolution, in ability to display bone (bones is rendered black as is air) (MacDonald, 2011; p.68) , long scanning time and cost (Patel et al., 2009). It is contraindicated in patients with older *cardiac implantable electronic device* (CIED' also known as a pacemaker or *implanted cardiac defibrillator* (ICD) which remain *MRI-incompatible*. (Cadieu et al., 2017; Strom et al., 2017) performed MRI on patient with MRI incompatible CIEDs "under strict protocol demonstrated excellent short- and medium-term safety while providing interpretable imaging that frequently influence clinical care." Although only one patient suffered a loss of pacing, there were no deaths or system revisions.

Another contraindication for MRI is for those patients who suffer from claustrophobia, particularly in view of MRI's long scanning time of about an hour on average.

Ultrasound

Ultrasound (US) is the imaging technique which high frequency sound waves in order to create a picture from their return to the transducer and their interaction with the patients tissues (MacDonald, 2011, p. 88). The frequency of sound waves ranges between 1 to 20 MHz (MacDonald, 2011, p. 88). Although US has been used to detect periapical lesions based on their contents (Cotti et al., 2003), it still has a very little use in endodontic practice. The main problem is that a thick intact cortex is a major barrier to the US waves.

Computed Tomography

Computed Tomography (CT) was first used in 1990 in endodontics (Tachibana & Matsumoto, 1990). It was used to determine complicated root canal systems, complicated pre-surgical assessments and in diagnosis of dental trauma (Mao & Neelakantan, 2014). CT uses a fan-shaped radiation beam which rotates around the area of interest multiple times (MacDonald, 2011, p. 51). Although CT have been used in endodontic research to study the root canal systems and anatomical variations (Mao & Neelakantan, 2014). it has a very limited use in endodontics mainly due to its high radiation and costs, (Ngan et al., 2003). the need for highly trained technicians and low spatial resolution when compared to periapical radiographs (MacDonald, 2011).

1.4 Cone-Beam Computed Tomography

Although medical physicists have long been aware of CBCT, it has only relatively recently been introduced to clinical dentistry. Although its first clinical application was for osseo-integration implants three decades ago (Schwarz et al, 1987) it did not make a commercial impact until 17 years ago. The first formal paper on a commercially-available machine was that by (Hatcher et al., 2003). Since there has been a deluge of publications addressing the use of CBCT in a wide range of dental specialties (De Vos et al., 2009; MacDonald, 2015). The recently published displayed the near exponential annual growth in publications on CBCT and osseo-integrated implants.

Year of publication*	Number of publications that year
2003	1
2004	0
2005	0
2006	1
2007	6
2008	14
2009	15
2010	33
2011	44
2012	65
2013	46
2014	70

Table 1: The number of publications that first presented in PubMed annually from 2003 until 2014 on CBCT and pre-implant planning CBCT data set.

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Unfortunately, very few of these publications or those addressing other uses in dentistry have attempted to adduce evidence for CBCT's efficacy. This was recently remarked on by (Horner 2013). Furthermore, the use of CBCT in the diagnosis of lesions affecting the face and jaws was addressed only recently (MacDonald, 2015; MacDonald 2016).

In common with all technologies using X-rays, CBCT consists of an x-ray source and a detector (Durack & Patel, 2012). CBCT uses a cone-shaped beam of X rays (Fig.1) (MacDonald, 2011 p. 60; MacDonald-Jankowski & Orpe 2006) which are projected onto the detector. The detector and x-ray source rotate up to 360° in a single rotation (MacDonald, 2011 p.59). The spatial resolution is recorded as voxel/mm^2 (Kruse et al., 2015). Standard voxel sizes in many current CBCT units vary from 0.076mm voxel size (Yepes et al., 2017) 0.20 mm voxel size (Kajan & Taromsari, 2012). In all the more recent unit patient is most often seated or standing in a panoramic radiographic-like gantry. The patient lay supine only in the first original commercially-available Newton 3G units (MacDonald, 2011, p. 60). The only CBCT patients which assume a supine position are those in some emergency room (ER) or operating room (OR) scenarios where CBCT units with C-arms are only used.

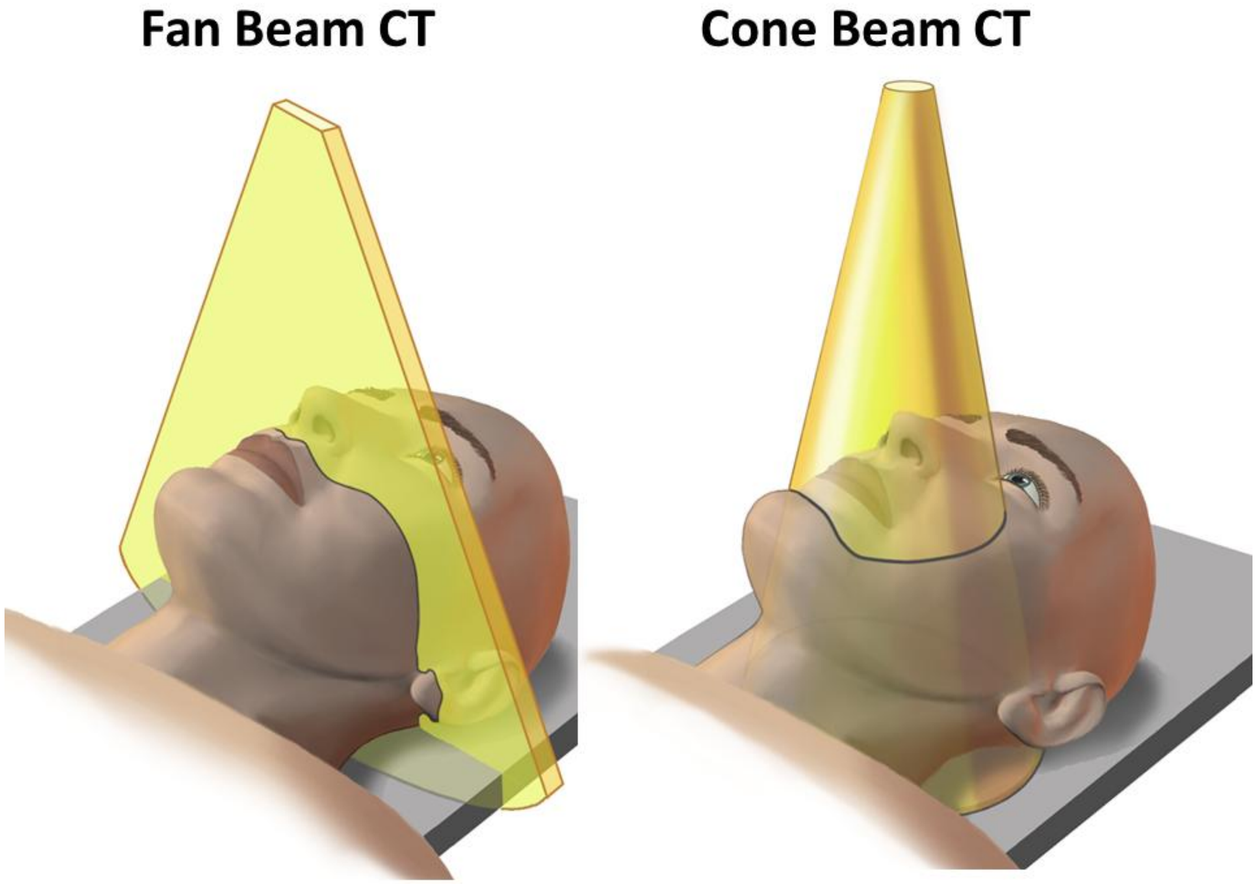

Figure 1: Fan Beam CT Vs Cone Beam CT

The fan beam upon which medical computed tomography is based interrogates only a slice of tissue, whereas the cone beam of cone-beam computed tomography interrogates a three-dimensional region within a single 360° rotation (now often less). (Reprinted with permission from MacDonald-Jankowski DS, Orpe E. Computed tomography for oral and maxillofacial surgeons. Part 2: Cone-beam computed tomography. *Asian Journal of Oral Maxillofacial Surgery* 2006; 18:85–92.

The CBCT dataset can be reformatted in a multi-planar reformat (MPR), in three planes (namely sagittal, axial and coronal) or in a 'curved' format broadly similar to the 'dentoscan' software first developed, prior to the advent of CBCT, to facilitate medical CT's use in producing cross-sectional images for pre-implant planning. The curved reformations are axial, panoramic and trans-axial reconstructions.

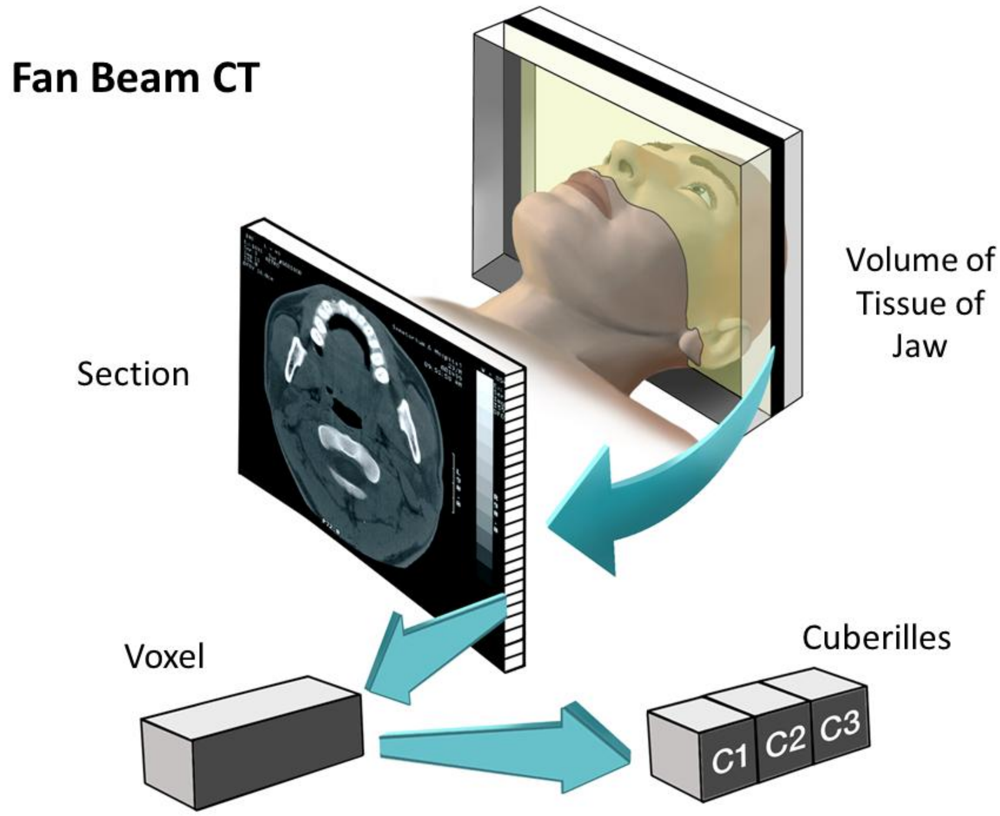

Figure 2: Fan Beam CT

The fan-beam (medical) computed tomography achieved three-dimensional reconstruction by slicing the voxel into cuberilles, each with the same attenuation coefficient as the original voxel. As these cuberilles are arrayed in the *z* axis) resolution would be, poorer in that axis. (Reprinted with permission from MacDonald-Jankowski DS, Li TK. Computed tomography for oral and maxillofacial surgeons. *Periapical radiographrt 1: Spiral computed tomography. Asian Journal of Oral and Maxillofacial Surgery 2006;18: 68-77)*

The use of a single rotation of a cone-beam interrogating a volume of the patient reduces the dose irradiated on the same volume interrogated by multiple rotations of a thin-slice fan beam (MacDonald, 2015). Indeed, many modern CBCT units use only an arch of rotation of 220 degrees; CBCT units with C-arms in ER and ORs use only a 180-degree arc. The latter covered the whole volume by multiple rotations or subsequently encapsulating that volume by multiple detectors. This last solution has been applied globally as multi-detector computed tomography (MDCT), which reduces the radiation dose further when compared to a single-slice CT of the same volume. Another advantage of CBCT as compared to MDCT is the better spatial resolution (MacDonald, 2011). Although, CBCT overcomes the limitations of conventional radiography, the general dentist or the specialist must justify the use CBCT. S/he must determine that the radiation risk is outweighed by the hoped-for clinical benefit to the patient. It is the responsibility of the clinician to acquire a functioning knowledge about CBCT and to update that knowledge continually (Brown et al., 2014; MacDonald, 2015).

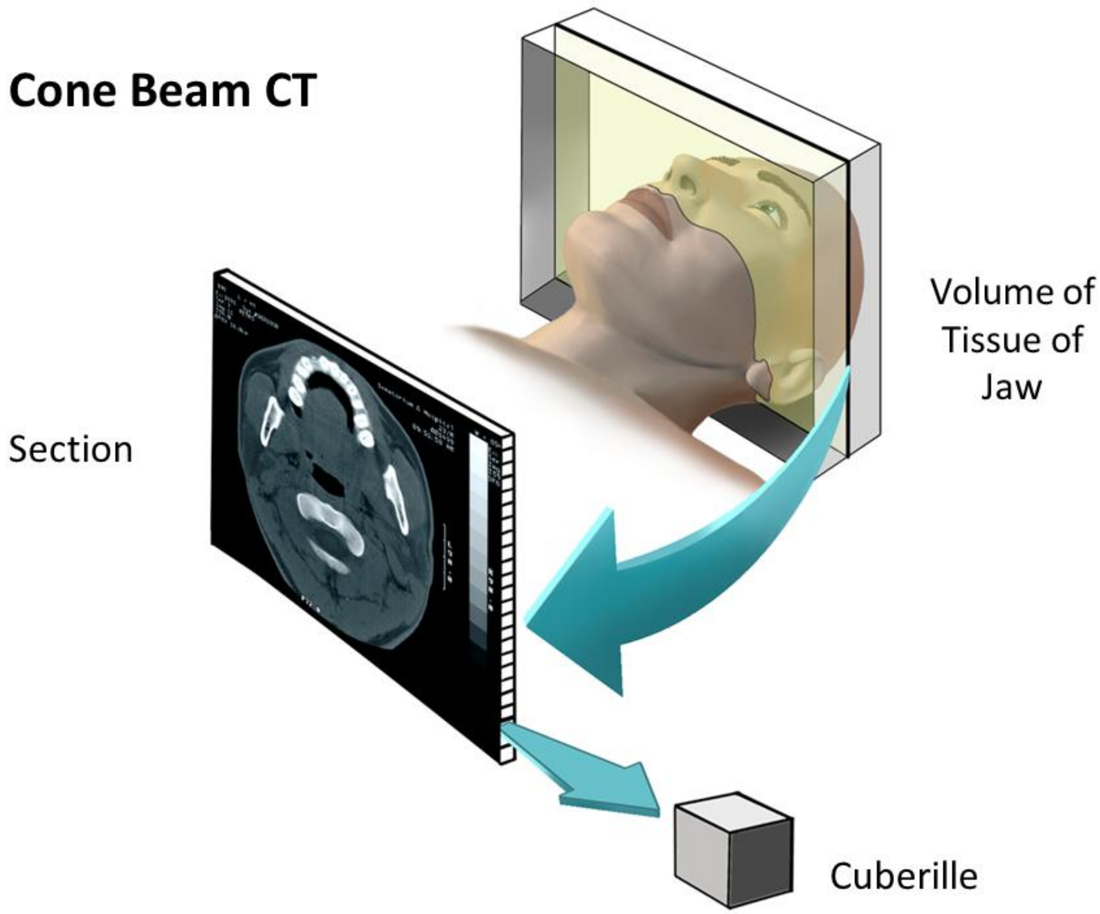

Figure 3: Cone Beam CT

Cone-beam computed tomography reconstructs the three-dimensional images by generating cuberilles directly, each with its own attenuation coefficient. This allows three-dimensional reconstructions with better resolution in the *z* axis.) in addition to the axial (XY) plane. *Reprinted with permission from MacDonald-Jankowski DS, Orpe E. Computed tomography for oral and maxillofacial surgeons. Periapical radiographrt 2: Spiral computed tomography. Asian Journal of Oral and Maxillofacial Surgery 2006;18: 85-92.*

After the acquisition of CBCT dataset, the whole volume of the image should be evaluated essentially by the referring or prescribing dentist (Patel et al., 2014). But if the referring or prescribing dentist is not competent in evaluating the whole volume of the image, the dataset can be referred to oral and maxillofacial radiologist (Patel et al., 2014)or failing that a medical radiologist (MacDonald 2016). The last point is relevant when large fields of view are used as these encompass the base of the skull, brain and vertebral column which are outside the dentist's area of especial expertise, the face and jaws (MacDonald 2011 p.256). Nevertheless, the presentation of the anatomy and the most frequent and important lesions on CBCT (MacDonald, 2015; MacDonald, 2016) will be unfamiliar to most dentally-trained clinicians and therefore should be supported by additional training.

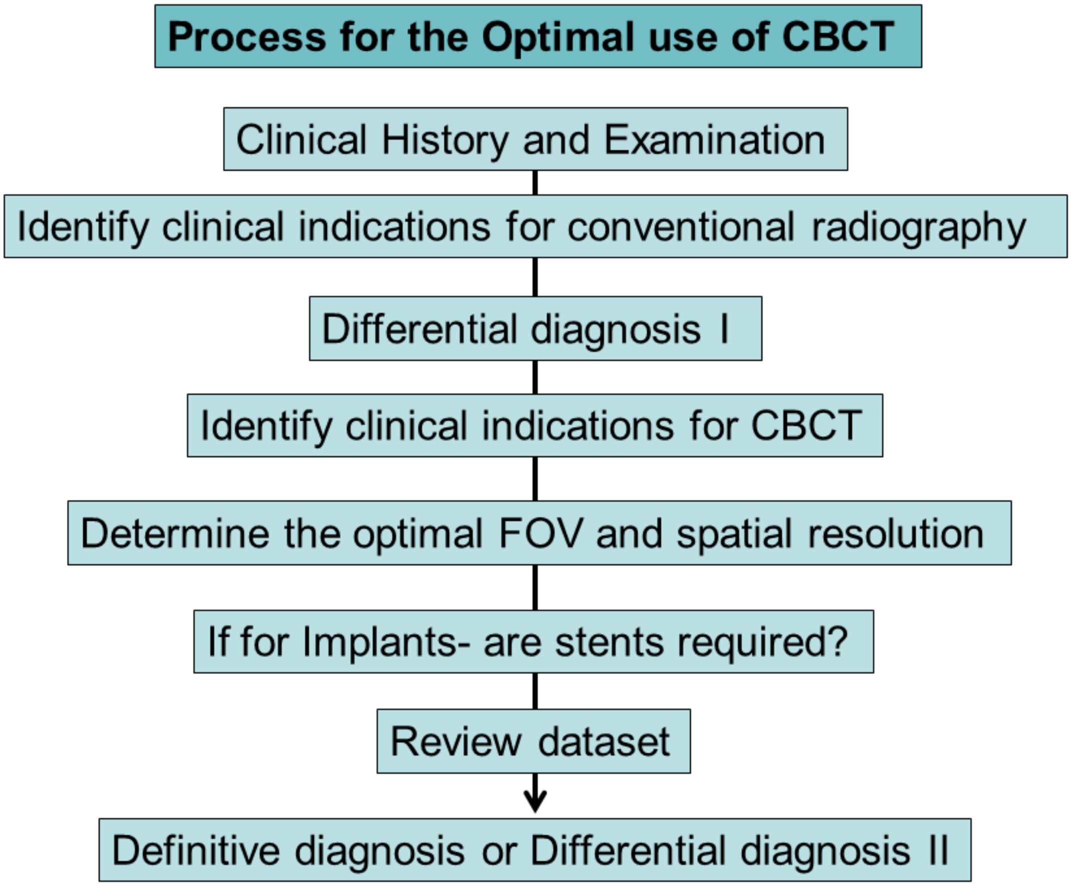

Figure 4: Process for the optimal use of CBCT

Conventional radiography, in addition to producing images of the best resolution (image detail), a significantly lower radiation dose to the, especially important for the child due to its greater vulnerability to radiation-induced injury. The requirement that the entire image be reviewed, well-established for conventional radiography, is just as relevant for a CBCT dataset. *Reprinted with permission from MacDonald D. Cone-beam computed tomography and the dentist Journal of Investigative and Clinical Dentistry. 2017;8. doi: 10.1111/jicd.12178. 18: 85-92.*

European Academy of Dento-Maxillofacial Radiology (EADMFR) had observed that dentists receive little or no training in the application and evaluation of CBCT imaging (Brown et al., 2014). In order to maintain a high standard in health care, justifying the appropriate use of CBCT, dentists should undergo training for CBCT use. This can be achieved by specifying training requirements from professional organizations dealing with radiology (Brown et al., 2014). CBCT should be used as a supplement when conventional radiography fails to provide information that is essential to diagnosis and to treatment planning.

Though there has been considerable use of CBCT, there is lack of studies showing the benefit of CBCT to the patient with respect to quality of life and radiation dose (Horner et al., 2014). Furthermore, the guidelines for CBCT use in dentistry are written in a very broad and general way, most of these guidelines are expert opinions rather than based on evidence (Horner et al., 2014). In order to ascertain the justified use, “high quality research evidence is needed particularly with regard to assessing whether using CBCT improves patient’s outcome” (Horner, 2013). More research is required to prove its efficacy and efficiency related to various referrals made.

The consensus guidelines of CBCT from EADMFR also reported that there is a risk of injudicious use of technology without a radiologist’s input (Horner et al., 2009). CBCT has been widely embraced by dental clinicians, these days many of the dental clinics own a CBCT unit or have relatively easy access to one. The main reasons for the acquisition of a CBCT unit by dentist in general are the availability of a wide selection of suitable units which are reasonably priced and require no special modification to dental offices that is in addition to that required for panoramic radiographic units. Namely no special floor strengthening or high-tension electricity is required that is required for medical CT units (MacDonald 2011, Chapter 15.). Furthermore, the dentist can reformat cross-sectional or 3-D reconstructions. Clinicians fail to understand that only a small proportion of patients require cross-sectional imaging. Furthermore, other than the attractiveness of 3-D images for the purposes of presenting the treatment plan to the patient, parents and colleagues, there is very little evidence that it has contributed to diagnosis and treatment planning itself. This misunderstanding and a lack of sufficient knowledge is related to the overuse of CBCT as well as inexperience in interpreting the data sets which might also lead to medico-legal issues. This lack of knowledge among CBCT users is likely to be wide-spread. Although, the two recent national questionnaire surveys Norway (Hol et al., 2015) ; Switzerland (Dula et al., 2015), enquired about the use of CBCT in their respective countries, no specific questions were directed about the field of view (FOV) and spatial resolution used. These two parameters are central to the radiation dose delivered. Both parts of this study directed users to using the smallest FOV and lowest spatial resolution appropriate to their clinical need for that particular patient. Figure 5 sets these out in accordance to the clinical problem.

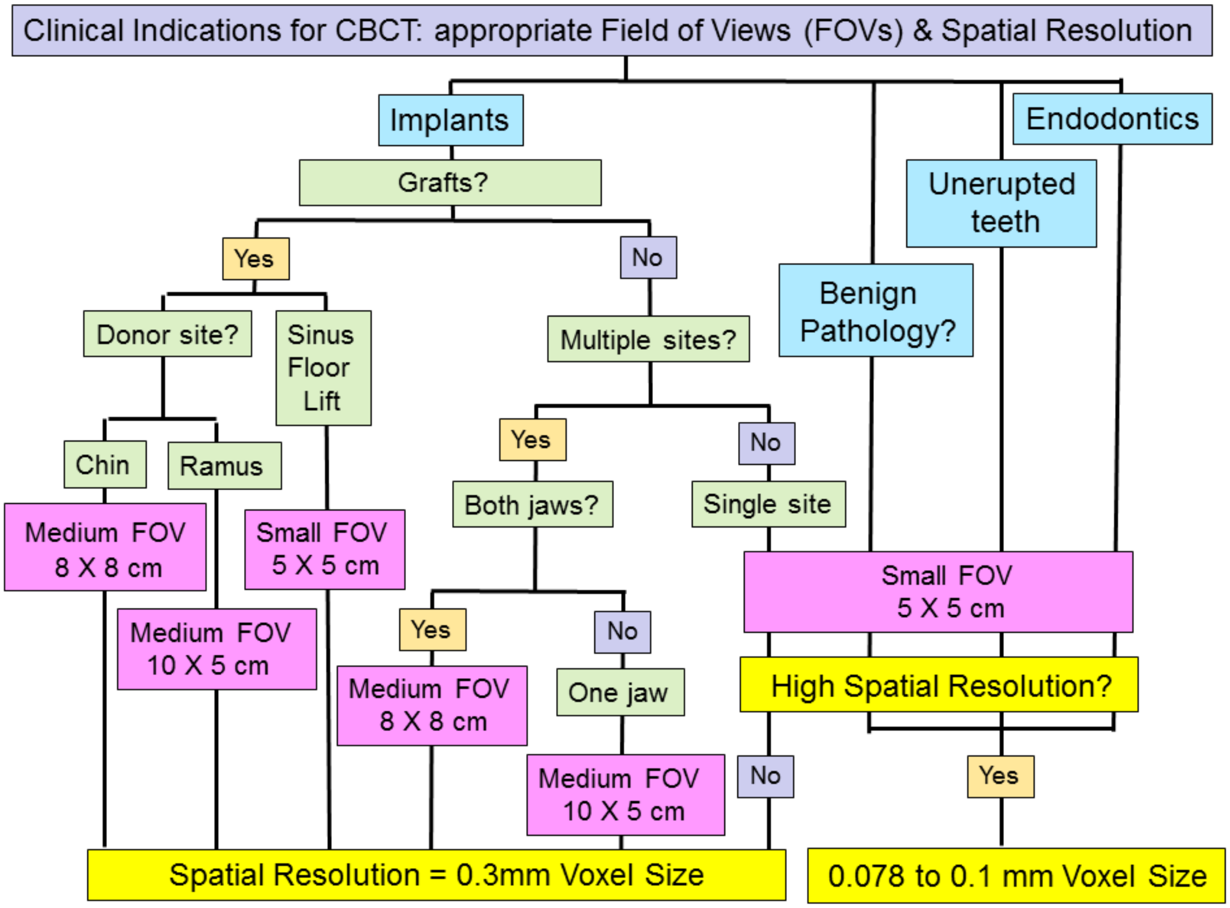

Figure 5: Clinical indications for CBCT

A balance must be struck between minimizing the risk of radiation-induced harm and the need to obtain images of diagnostic quality appropriate for the clinical procedure that is being contemplated. The flowchart reveals that the spatial resolution (degree of detail seen) and size of *field-of-view* (FOV) vary with clinical indications. Note! The FOVs selected for the flowchart are those available on a Carestream 9300 CBCT unit, other units may offer different FOVs. Nevertheless, the smallest FOV possible is used to reduce the radiation dose. Any lesions that cannot be fully displayed within a small FOV (with better spatial resolution) should be referred to an oral and maxillofacial surgeon or radiologist or to a medical clinic or hospital for a MDCT as intravenous contrast [media] may be required. The FOVs selected for the flowchart are those available on a Carestream 9300 CBCT unit, other units may offer different FOVs. Nevertheless, use the smallest FOV possible to reduce the radiation dose. *Reprinted with permission from MacDonald D. Cone-beam computed tomography and the dentist Journal of Investigative and Clinical Dentistry. 2017;8. doi: 10.1111/jicd.12178. 18: 85-92.*

Without evidence-based guidelines each individual case requires a considered determination as to whether the presence of those features central to diagnosis and treatment-planning, which are still unclear after the clinical examination and the review of the conventional radiographs may be confirmed or not by CBCT. In order to assist this determination evidence-based clinical research is needed. This evidence in turn should enhance the quality of patient care with an improvement in treatment predictability. Keeping this in mind the evidence-based qualitative research was begun at University of British Columbia, Faculty of Dentistry in 2014. The first phase of this study was the audit of CBCT for all dental specialties, including that from the Doctor of Dental Medicine (DMD) program.

The prescription form was found under the function marked ‘referrals.’ The terms ‘referral’ and ‘prescription’ when applied to CBCT may be considered synonymous in most situations. The term prescription was considered more appropriate as it more accurately reflected the degree of detail that had to be included in the decision making as to whether a CBCT was required for a particular case at UBC’s Faculty of Dentistry.

1.4.1. CBCT and endodontics

In endodontics, periapical radiographs play an important role in the diagnosis, the treatment planning and the prognosis of the tooth in question. It is still the first line of imaging tool for diagnosing the endodontic problems. But as already remarked upon earlier, one of the major drawbacks of periapical radiographs is the superimposition and anatomical noise of anatomical structures which decreases its diagnostic sensitivity as compared to CBCT (Petersson et al., 2012). Therefore clinically-useful information may be lost by using periapical radiography as the sole imaging modality (Ee et al., 2014). These limitations have prompted clinicians to consider cross-sectional images. But as these, until relatively recently, could only be achieved with medical CT, which besides being sighted in a medical facility, most usually a hospital, and imparted high radiation doses and produced images of such poor spatial resolution, they were of little use to endodontists. Nevertheless, it should be noted that such images were of value to dental implantologists whose cross-sectional imaging needs were less demanding with regard to spatial resolution.

The recent advent of easily-accessible high-spatial resolution CBCT which imparts a generally much lower radiation dose than MDCT provides the endodontist with a feasible cross-sectional imaging modality. CBCT's multi-planar assessment of anatomy removes the superimposition and anatomical noise (Patel, 2009). The introduction of the third dimension increases the diagnostic accuracy and contributes to the improved management of complex endodontic cases (D'Addazio et al., 2011). Even though the use of CBCT is increasing in endodontics because of high diagnostic accuracy due to multi-planar imaging, a systematic review on diagnostic accuracy of CBCT concluded that the systematic review-included publication were too varied and too inconclusive to justify its use as a standard care for diagnosis in endodontics (Kruse et al., 2015). More *in vivo* clinical studies are required to provide this evidence.

CBCT helps in determining the initial changes in the periapical status thereby increasing the diagnostic accuracy in complex or contradictory endodontic problems (Nair & Nair, 2007;). CBCT has proved to be more beneficial to diagnose apical periodontitis in the endodontically-treated tooth (Balasundaram et al., 2012). But it cannot yet be used as a standard care due to the lack of evidenced based clinical studies (Petersson et al., 2012).

The gold standard for diagnosing the presence of periapical lesions is histological examination (Kruse et al., 2015). This necessarily requires surgery to remove the periapical lesion, which in a large retrospective study derived from the pathology files of a major British dental school accounted for only 107.6 radicular cysts and 56 granulomas per year (Jones & Franklin, 2006) is reserved only for a small number of such lesions (Nair, 2006). The majority of such cases are treated by dentists working in the community at large by simply extracting and immediately disposing of the extracted tooth or by orthograde endodontics. Both of which do not produce a surgical specimen for a histopathological diagnosis. Furthermore, medical ethics prohibits any surgery to harvest a surgical specimen which is not primarily indicated in the best interests of that particular patient. Therefore, the histopathological gold standard can only be met by taking the biopsy specimen at the time of clinically indicated endodontic apical surgery for that particular patient (Petersson et al., 2012).

Due to these limitations, an appropriate gold standard in such studies was in effect impossible to establish (Dutra et al., 2016). Therefore, many studies conducted to compare the diagnostic efficiency of radiographs and CBCT, have been *in-vitro* studies for example the study by (D'Addazio et al., 2011), which used 'simulated' lesions. The limitations of such simulated lesions if made by rotary instruments is that borders are sharp unlike the more diffuse borders found in natural periapical lesion. Furthermore, the simulated lesions made by acid may have diffuse borders but it's difficult to determine the actual size of these lesions (Petersson et al., 2012). Furthermore, *ex vivo* studies do not give account of the effect of surrounding soft tissue and changes in surrounding alveolar tissues(Chavda et al., 2014). Another limitation of artificially induced fractures is that width of the simulated fracture can get wider than the actual width of the fine fracture and therefore more likely to be detected by imaging modalities (Chavda et al., 2014). Therefore, from the very outset, such studies would not be considered or discussed to any degree, because they were not likely to reflect an authentic clinical process.

Studies performed in animals are not clinically relevant in the human situation due to the interspecies anatomical difference (Dutra et al., 2016).

At this stage, what is required is more clinical-based studies with good sample sizes. These most be performed before CBCT becomes the standard care in endodontics with regards to diagnostic and treatment outcome. Consideration should also be given to radiation dose and to cost effectiveness of such a procedure.

Recommendations for CBCT use in endodontics

In 2010 a joint statement by AAE/AAOMR was announced, which was published in 2011 ("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," 2011). A web based survey by AAE members in USA and Canada found out that 34.2% of endodontists use CBCT for diagnosis and treatment purposes. This could be the main reason to develop a position statement for CBCT use. The main objective of these recommendations was to provide research based evidence and guidance to use multi-planar imaging for endodontic treatment. The recommendations were updated in 2015, as more studies were published. The 2015 update provided more detailed criteria or rationale for CBCT use in endodontic diagnosis and treatment planning.

For this study, only selected recommendations were used (Table 2). The 2015 joint statement recommendations were broadly divided into 5 criteria for CBCT use. These 5 considerations for CBCT use were- diagnosis, initial treatment, non-surgical re- treatment, surgical re-treatment and special conditions. The uses of CBCT for initial treatment were further subdivided into pre-operative, intra-operative and post-operative. Under diagnosis criteria the study team recommended the use of CBCT when signs and symptoms are contradictory and non-specific. The tooth under this criterion can either be previously endodontically treated or untreated; this is 'recommendation 2'. Under initial treatment criteria, the subpart pre-operative had 'recommendation 3' which states that CBCT can be considered for initial treatment of teeth suspected for complex morphology or extra canals. For intra-operative considerations, the study team recommended 'recommendation 4' to use CBCT for intra-operative identification of calcified canals. Post-operative CBCT use has not been recommended in the position statement. For post-operative purposes the study team recommends the use of intraoral radiographs for imaging, which is 'recommendation 5'. The non-surgical retreatment criterion has three recommendations. Under this criterion the position statement recommends use of CBCT for identification of vertical root fracture, when clinical and intra-oral imaging is inconclusive, this is 'recommendation 6'. Recommendation 7 under non-surgical retreatment states the use of CBCT to evaluate the status of non-healing previous endodontic treatment to help in determining the further need of treatment and recommendation 8 states the use of CBCT for overextended root canal obturation material, separated endodontic instruments, and localization of perforations. The use of CBCT for surgical criteria is 'recommendation 9' which states the need for CBCT to locate the proximity of the apices of the roots to the adjacent anatomical structures pre-surgical treatment planning. Lastly, under special conditions criteria the use of CBCT is recommended for implant planning, traumatic injuries and resorptive defects which is recommendation 10, 11 and 12 respectively. For resorptive defects 'recommendation 12' CBCT use is intended to distinguish between internal and external root resorption and to determine the treatment and prognosis.

Recommendation 2 - (R2)	Limited FOV CBCT should be considered the imaging modality of choice for diagnosis in patients who present with contradictory or nonspecific clinical signs and symptoms associated with untreated or previously endodontically treated teeth.
Recommendation 3 - (R3)	Limited FOV CBCT should be considered the imaging modality of choice for initial treatment of teeth with the potential for extra canals and suspected complex morphology, such as mandibular anterior teeth, and maxillary and mandibular premolars and molars, and dental anomalies.
Recommendation 4 - (R4)	If a preoperative CBCT has not been taken, limited FOV CBCT should be considered as the imaging modality of choice for intra-appointment identification and localization of calcified canals.
Recommendation 6 - (R6)	Limited FOV CBCT should be considered the imaging modality of choice if clinical examination and 2-D intraoral radiography are inconclusive in the detection of vertical root fracture.
Recommendation 7 - (R7)	Limited FOV CBCT should be the imaging modality of choice when evaluating the non-healing of previous endodontic treatment to help determine the need for further treatment, such as nonsurgical, surgical or extraction.
Recommendation 8 - (R8)	Limited FOV CBCT should be the imaging modality of choice for nonsurgical retreatment to assess endodontic treatment complications, such as overextended root canal obturation material, separated endodontic instruments, and localization of perforations.
Recommendation 9 - (R9)	Limited FOV CBCT should be considered as the imaging modality of choice for pre-surgical treatment planning to localize root apex/apices and to evaluate the proximity to adjacent anatomical structures.
Recommendation 12 – (R12)	Limited FOV CBCT is the imaging modality of choice in the localization and differentiation of external and internal resorptive defects and the determination of appropriate treatment and prognosis.

Table 2: AAOMR/AAE position statement recommendations 2015 used in this study

As more and more evidence based studies will be published in the coming years, the position statement will be updated accordingly to formulate the clinical based guidelines for CBCT use in endodontics. After going through the previous researches and as per 2015 position statement by AAOMR/AAE this research was carried out to determine the diagnosis and treatment alteration after CBCT examination.

Chapter 2: Introduction to Endodontic Diagnosis and Problems

2.1 Diagnosis of Endodontic Problems

Diagnosis is described as "The art and science of detecting and distinguishing deviations from the health and the cause and nature thereof" ("AAE Glossary of Endodontic Terms," 2012). Knowing the correct diagnosis should lead to appropriate treatment and outcome. The correct diagnosis can be reached after thorough examination and collection of appropriate data. This can be achieved by well planned, systematic approach and correct interpretation of the problem (Cohen, 2016, p. 2). The final diagnosis is made after combining the clinical and radiographic presentations. Apart from diagnosis, the radiographs also play an important role in treatment planning and follow up.

2.1.1 Chief complaint and history taking

The process of formulating a correct diagnosis starts with the chief complaint from the patient. The chief complaint is as important as other investigative tests performed by the clinician (Cohen, 2016, p. 2). Investigating the chief complaint of a patient often is the foundation of the diagnostic process. The chief complaint is followed by medical and dental history of the patient. The chronological events which led to the patient's problem interpreted with investigative tests often leads to the identification of the main cause of the problem.

Medical and dental history taking is another important step in formulating the diagnosis. By taking these histories, clinician can determine whether the problem is a pure dental problem or the consequence of the systemic health of a patient. Medical history is important as it can change or modify the treatment.

The dental history is often described as the chronological events which led to the chief complaint (Cohen, 2016, p. 6). Systematic approach is taken by the clinician when investigating the chief dental complaint. It usually starts with the localization of the affected area (Cohen, 2016, p. 6). This is followed by commencement, intensity, provocation and duration of the symptom (Cohen, 2016, p. 6).

2.1.1.1 Examinations and investigative tests

Based on chief dental complain, dentist follows up by examining the area of concern. This includes palpation or percussion and other chair side tests like cold test, heat test, pulp testing and periodontal examination. Even though the clinical examinations help in narrowing down the chief cause of the problem, the examinations like percussion, palpation, electric pulp test or heat or cold test are not accurate enough to determine the diagnosis of the apical periodontitis (Cohen, 2016, p. 636).

These examinations are most often followed by radiographic examination. The radiographs further help to determine the periapical status of the area of concern. The presence of apical periodontitis or healing after non-surgical root canal treatment cannot be determined by absence of signs and symptoms and radiographic findings. The absence of signs and symptoms and radiographic findings does not mean complete histologic diagnosis of healing or presence of apical periodontitis (Cohen, 2016, p. 636).

2.1.1.2 Radiographic diagnosis

Periapical radiographs are still the first imaging modality in endodontic treatment and management and forms the radiographic backbone in endodontic practice (Cotti & Campisi, 2004).

The radiographs help endodontist to determine the root canal anatomy, periapical tissues and related problems. The main advantage of using periapical radiographs are its superior spatial resolution (MacDonald, 2011, p.249). Apart from providing superior spatial resolution the radiographs have low cost and low radiation dose as compared to advanced imaging modalities. Despite being widely used in endodontic practice, the digital/conventional radiographs have some limitations. These limitations can be overcome by advanced imaging techniques. But before referring the patients for advanced imaging, its use should be justified.

2.2 Apical Periodontitis

Apical periodontitis is the inflammation of periodontal tissues around the apex of the root. There is a high prevalence of apical periodontitis in patients above 60 years (62%) (Cohen, 2016, p. 631). Prevalence depends on the age and location of the population (Patel et al., 2016, p. 79). apical periodontitis is a disease of inflammatory origin (White & Pharoah, 2014, p. 315). It can be caused by exogenous or endogenous factors with microbial infection being the most common causative agent (Huumonen & Ørstavik, 2002). These factors can elicit the inflammatory responses that activate osteoclasts (Stashenko, 1990). The diagnosis of apical periodontitis is most commonly based on clinical signs and symptoms, duration and clinical examinations (Cohen, 2016, p. 635) and radiographic presentation.

Apical periodontitis can present as an acute or chronic condition. The acute apical periodontitis is mostly commonly depicted with distinct signs and symptoms while the chronic apical periodontitis is routinely diagnosed by the radiographic presentation (Patel et al., 2016, p. 79). Radiographic findings presents the pathology at tissue level unlike histology which detects pathology at cellular level (Cohen, 2016, p. 636). Therefore, absence of radiographic periapical periodontitis does not mean that there is no inflammation of the tissues (Paula-Silva et al., 2009). In the absence of symptoms, well timed radiographic diagnosis is important in determining apical periodontitis (Dutra et al., 2016) for better treatment and outcome.

Apical periodontitis in periapical image.

Apical periodontitis on a radiograph classically presents as radiolucency at the apex of the root, indicating periodontal bone loss, (Cohen, 2016, p. 631)but only sometime after the onset of signs and symptoms. The earliest radiological indication of apical periodontitis is a widening of the periodontal space of the affected tooth apex (White & Pharoah, 2014, p317) in comparison with those of adjacent teeth, particularly if the affected tooth is painful on percussion. Later onset periapical radiolucencies of inflammatory origin (PRIOs) are detected in radiographs when there is at least 30% of the mineral loss of the bone (Balasundaram et al., 2012; Miguens et al., 2008).

In most cases, it presents as a radiolucent area at the apex of the tooth. Some cases also show the sclerosing pattern in the vicinity of the radiolucency. This periapical sclerosis was a common finding in a study composed of several consecutive series of an East Asian and Western communities (MacDonald-Jankowski 1999). The radiolucent area has an ill-defined border (White & Pharoah, 2014, p. 316) presented at the apex of the root. This radiolucency is the response of the local bone to the inflammatory reaction induced by toxic metabolites from the necrotic pulp (White & Pharoah, 2014, p. 315). Microscopically, the specimen from the radiolucent lesion has shown infiltrate of lymphocytes and neutrophils confirming it to be of inflammatory origin.

The initial or early signs of inflammation in the periapical region are difficult to diagnose in radiographs. As the inflammation progresses the bone resorbs due to the osteoclastic activity thus decreasing the mineral content which is presented as radiolucency. Most, commonly the lesions cannot be detected if they are present in the cancellous bone. The thickness of the cortical bone can superimpose on the periapical lesions, thus hindering its visualization in a radiograph. Therefore, in many instances there may be no radiographic evidence of bone resorption (Dutra et al., 2016).

To enhance the evaluation of the periapical status, additional angled radiographic images can be prescribed (European Society of Endodontology, 2006b). But a recent clinical study has shown that there is no significant difference when single parallel and additional angulated images were compared to determine periapical lesions (Davies et al., 2015). The result of this clinical study also agrees, that additional radiographs at an angle do not improve the diagnostic accuracy in radiographs, with another study performed on simulated periapical lesions within mandible (Soğur et al., 2012).

Though there are certain limitations of conventional radiography to detect apical periodontitis, it is still widely used as a radiographic choice for diagnosing apical periodontitis. Apart from this; there are several other factors which determine the presence of apical periodontitis radiographically. The factors on which radiographic detection of apical periodontitis depends on are the position of the apical lesion, the thickness of the cortical and cancellous bone, amount of resorption , angulation of the x-rays, exposure parameters and the nature of the lesion (Patel et al., 2016, p. 79). There is no significant difference in the ability to detect apical periodontitis using conventional and digital radiographs (Ozen et al., 2009).

Apical periodontitis in CBCT

Several studies have concluded that CBCT is more accurate in diagnosing apical periodontitis *ex vivo* being more numerous. The advent of CBCT in dentistry and its ongoing researches in endodontics so far have concluded that CBCT have better sensitivity in detecting periapical lesions, and it can be used as an aid to diagnose and assess treatment options for periapical lesions. A recent systematic review and meta- analysis concluded that CBCT has excellent diagnostic accuracy in determining apical periodontitis (Dutra et al., 2016).

An *in vivo* study on root filled teeth found that CBCT images are useful in viewing periapical areas in multi-rooted teeth, thereby increasing the diagnostic ability in these teeth (Davies et al., 2015). Another clinical study (Fernández et al., 2013) also found the high sensitivity of CBCT in detecting periapical lesions. A more recent clinical study (Karabucak et al., Setzer, 2016) concluded that the majority of periapical lesions were associated with the missed canal in previously endodontically treated teeth. But this study (Karabucak et al., 2016) only included pre-treated molars and premolars.

The information about the periapical status of a tooth is an important aspect for a dental clinician. It determines the condition of the tooth in question, and its related treatment options and prognosis (Kruse et al., 2015) and the success rate of surgical or non-surgical endodontic treatment and outcome. Due to its multi-planar quality, CBCT can detect initial or early periapical changes, which might get unnoticed in radiographs. The studies (Abella et al., 2012; Tsai et al., 2012) found that initial periapical lesions can be seen more readily in CBCT scans as compared to radiographs. Early diagnosis of apical periodontitis can also change the treatment plan from pulp capping to root canal treatment (Patel et al., 2016, p. 86) leading to better prognosis and preventing the initial treatment failure.

There is a lack of clinical studies to determine the effectiveness of CBCT in determining the true clinical relevance of apical periodontitis and the outcome. The evidence supporting effectiveness of CBCT is very limited (Fernández et al., 2013). A more recent SR looking at the diagnostic efficacy of CBCT in determining periapical lesions concluded that the studies have been assessed at a very low diagnostic efficacy (Kruse et al., 2015). There are few studies determining the endodontic treatment outcome based on CBCT evaluation.

A recent systematic review (Kruse et al., 2015) analyzing CBCT studies on diagnostic efficacy concluded that even though the studies show that CBCT has high sensitivity in detecting periapical lesions, no studies have been done so far that justify the standard use of CBCT in diagnosing periapical lesions. In order for CBCT examination to become the standard of care to diagnose apical periodontitis there are several points which should be addressed ranging from predicting the positive and negative values of CBCT to treatment planned and its outcome (Kruse et al., 2015).

2.3 Root Fractures

Break in the integrity of a tooth root can be defined as a ‘root fracture.’ Root fractures have causes. Two important causes are over-instrumentation and too much compaction (Kajan & Taromsari, 2012). Excessive removal of dentine during root canal treatment weakens the root increasing the susceptibility to root fractures (Kajan & Taromsari, 2012). Another reason for root fractures can also be attributed to differences in diet and chewing habits in certain population. Tang et al suggested that those factors causing VRF which are under the control of a dentist should be avoided (Tang et al., 2010). These factors include over instrumentation of sound tooth structure, in appropriate selection of posts, inadequate precautions taken during access cavity preparation, and coronal preparation (Tang et al., 2010).

There are two types of root fractures vertical root fracture (VRF) and horizontal root fracture (HRF).

Horizontal Root Fractures

Horizontal fracture is defined as the fracture of the cementum, dentine and pulp in a horizontal plane (Kamburoğlu et al., 2009). These fractures are commonly associated with trauma sustained during sports, road accidents and fights (Kamburoğlu et al., 2009). There are very few studies which have focused on the detection of horizontal root fractures in CBCT scan. This is because horizontal root fractures are easily diagnosed in periapical radiographs as compared to vertical root fractures. This is due to the fact that there is less superimposition of root filling materials and the X-rays are parallel to the horizontal fracture line (Kajan & Taromsari, 2012; Kamburoğlu et al., 2009). The study (Kamburoğlu et al., 2009) comparing the diagnosis of horizontal root fractures in CBCT and radiographs concluded that although CBCT detected more horizontal root fractures the results were not significant.

Vertical root fractures

Vertical root fracture (VRF) is defined as a longitudinal fracture of the root (Chang et al, 2016). The fracture line may involve proximal surface and extends from root canal to the periodontium ("Colleagues for Excellence : Cracking the Cracked Tooth Code: Detection and Treatment of Various Longitudinal Tooth Fractures. American Association of Endodontists," 2008; Talwar et al., 2016). VRF is not only challenging to diagnose but if missed leads to poor treatment outcomes (Chang et al., 2016). VRF is most commonly seen in endodontically treated teeth (Tamse, 2006). Approximately 32.1% of root canal treated teeth are extracted due to VRF (Chen et al., 2008).

The VRF can be divided into complete or incomplete fracture. The complete VRF has two separate root fragments as compared to incomplete which consists of partial separation of root fragments (Patel et al., 2016, p. 133). Even though the complete VRF are comparatively diagnosed more readily under the operating microscope than the incomplete VRF (Patel et al., 2016, p. 133), they have poor prognosis. An accurate diagnosis of VRF is not only important to prevent treatment with little chance of success but rather to extract the tooth in question (Edlund et al., 2011). One of the main reasons for presence of VRF in endodontically treated teeth is over instrumentation. The most common teeth affected with VRF are mandibular molars and maxillary premolars (Cohen et al., 2003).

The clinical examinations suggestive of VRFs are bite test, presence of single surface deep pocket probing, transillumination, radiographs and presence of sinus tract but these signs are only suggestive of VRFs not conclusive. A clinical study (Edlund et al., 2011) found that the correlation between the symptoms, radiographic signs and presence of VRF were not significant. The only reliable or gold standard method to detect VRF is exploratory method or direct visual examination. The systematic review (Tsesis et al., 2010) concluded that the diagnostic accuracy of VRF in endodontically-treated teeth based on clinical and radiographic features are lacking the evidence based data.

VRF and Periapical radiographs

VRFs can only be detected in periapical radiographs when primary beam is within 4 degree angle (Chang et al., 2016) or parallel to the plane of the fracture (Talwar et al., 2016). Radiographically, the VRF presents as a ‘J’ shaped radiolucency around the fractured root in a radiograph (Tamse et al., 2006). This ‘J’ shaped radiolucency is an extensive peri-radicular radiolucency around the length of the root. There is no difference in detecting VRF in digital or analog films (Tofangchiha et al., 2011). The detection of VRF in conventional radiographs depends on the position of the fracture line in the root , degree of displacement of the fragments (Patel et al., 2016, p. 133) and the amount of separation of the root fragments. Complete fractures are most readily detected in conventional radiography, than incomplete fractures, due to the separation of root fragments (Patel et al., 2016, p. 133).

CBCT and VRF

The main advantage to use CBCT for VRF diagnosis is the orientation of anatomy in three planes (Talwar et al., 2016). This allows the dentist to visualize the fracture line from different angles (Talwar et al., 2016). In practice, the referral for CBCT in determining VRF should only be made after thorough clinical examinations and clinical features which are highly suggestive of VRF (Chang et al., 2016). Apart from this, the need for CBCT in determining VRF in endodontically filled teeth also remains questionable.

CBCT have low specificity in detecting VRF in the presence of orthograde root fillings as compared to periapical radiographs (Talwar et al., 2016). Studies have shown that image artifacts or beam hardening from root filled materials hinder the diagnostic accuracy of CBCT to diagnose the presence of VRF. Diagnosing VRF after orthograde root-canal treatment also becomes important for clinician because of the liability claim and medico legal considerations (Rosen et al., 2012). Even though CBCT is recommended to diagnose VRF, but the two recent systematic reviews concluded that there is insufficient evidence which proves that CBCT is not a reliable method in detecting VRF in endodontically treated teeth (Chang et al., 2016; Talwar et al., 2016).

There is very limited and very few *in vivo* studies conducted to determine the diagnostic accuracy of CBCT for VRF. One of the important points summarized in the two recent systematic reviews was the variation of CBCT systems used and their ability to diagnose VRF (Chang et al., 2016; Talwar et al., 2016). These studies also exhibited significant variability with respect to voxel size, field of view, and exposure parameters. The study (Metska et al., 2012) concluded that 3D Accuitomo 170 with a voxel size of 0.08 mm was superior in detecting VRF in endodontically-treated teeth as compared to New Tom 3G with a spatial resolution of 0.30mm voxel size. This study also showed that small FOV and small voxel size enhance the detection of VRF in previously orthograde root-filled teeth. Axial plane are more accurate in detecting VRFs than sagittal or coronal plane (Hassan et al., 2009; Kajan & Taromsari, 2012). The study (Neves et al., 2014) suggests that low dose mode can be recommended in the presence of metal post or gutta-percha, whereas high dose can be recommended in the absence of root filing or fiber posts to increase the diagnostic performance in detecting incomplete VRFs. The diagnostic accuracy to detect incomplete VRF increases with high spatial resolution (Neves et al., 2014) . The study (da Silveira et al., 2013) looking into the influence of different voxel size in detecting VRFs observed that the VRF is better detected when 0.20 mm voxel size is used in previously endodontically treated teeth.

The meta-analysis and systematic review (Long et al., 2014) mentions that diagnostic accuracy of CBCT in determining VRF is higher in non-endodontically-treated teeth than in endodontically-treated teeth. The detection of VRF is also varied and unpredictable if the width of the fracture is less than the voxel size , due to partial volume averaging (Chavda et al., 2014). (Chavda et al., 2014) concluded that CBCT can be used as an aid to detect early subtle changes in peri-radicular bone a s a supplement to clinical features rather than actually detecting a fracture line. CBCT should be used in detection of root fractures when conventional radiographs are inadequate and clinical features are highly indicative of root fracture (da Silveira et al., 2013).

In horizontal fracture there is no masking of root fillings (Kajan & Taromsari, 2012) et al). CBCT voxel sizes vary from 0.125 to 0.20mm (Kajan & Taromsari, 2012). Excessive removal of dentine during root canal treatment weakens the root increasing the susceptibility to root fractures (Kajan & Taromsari, 2012). “CBCT shows good potential for use in the detection of root fracture as it ensures a high level of diagnostic score accuracy. Reconstructed axial views were more effective in confirming specific diagnoses than other reconstructed views.” (Kajan & Taromsari, 2012) Combining the clinical and radiographic findings further improved the results Edlund et al also showed that limited FOV and small voxel size enhance the detection of VRF in previously endodontically-treated teeth. (Edlund et al., 2011)

CBCT should be used in detection of root fractures when conventional radiographs are inadequate and clinical features are highly indicative of root fracture (da Silveira et al., 2013). In practice, the referral for CBCT in determining VRF should only be made after thorough clinical examinations and clinical features which are highly suggestive of VRF (Chang et al., 2016).

To date there is no clinical study that compares the detection of VRF by CBCT in single-rooted and multi-rooted teeth.

2.4 Root Resorption

Root resorption is the result of the osteoclastic activity of cell causing the removal of cementum and dentine of the root (Creanga et al., 2015; Patel & Ford, 2007). The root resorption is classified into external and internal depending on the site of occurrence (Patel et al., 2016, p. 119). Root resorption can be temporary or it can be continuous (Kamburoğlu et al., 2011). Continuous root resorption leads to poor prognosis of the tooth. Internal resorption affects the pulp requiring at least some vital pulp (Gabor et al., 2012) and external resorption occurs on the outer surface of the root (Patel et al., 2016, p. 119). The external root resorption is further classified based on the location of resorption and the etiology causing it (Bernardes et al., 2012). External root resorption is classified as inflammatory, replacement or cervical resorption (Kamburoğlu et al., 2011).

The common causes of external root resorption are orthodontic treatment and pressure from impacted teeth, cysts or tumors (Creanga et al., 2015; Patel et al., 2016, p. 120). Other causes of root resorption are trauma and pulpal and periodontal inflammation (Bernardes et al., 2012). It is important to diagnose root resorption in early stages to increase the better prognosis of the tooth (Gabor et al., 2012; Kamburoğlu et al., 2011).

The internal root resorption is most commonly associated within the inflammation of the pulp (Gabor et al., 2012). Inter root resorption is a rare pathology (Gabor et al., 2012) sometimes not routinely detected in radiographs because of its small size. It is asymptomatic and associated with the necrosed pulp (Patel et al., 2009), if not small in size, it is most often seen as an incidental finding in radiographs. Internal root resorption can sometimes be confused with external cervical resorption (Cohen, 2016, p. 58). The study (Estrela et al., 2009) concluded that CBCT detected all (100%) internal root resorptions whereas periapical radiographs only detected 68.8% of the internal resorptions.

Root resorption and periapical radiographs

Like any other endodontic problem, conventional radiography is the imaging choice for diagnosing root resorptions. The primary aim of imaging in dentistry is to aid in diagnostic accuracy and also to reduce radiation exposure (Ren et al., 2013). Root resorptions are asymptomatic and not easily detected in conventional radiographs (Bernardes et al., 2012). This makes it difficult to diagnose especially in its early stages. In most instances root resorptions are incidental findings (Creanga et al., 2015). There is no diagnostic gold standard for external root resorption (Ren et al., 2013). The periapical radiography underestimates the presence of external root resorptions (Ren et al., 2013). The radiographic appearance of root resorption is very varied and depends on the type of resorption (Patel et al., 2016, p. 120). The appearance can vary from radiolucent saucer shape, concave shape to complete destruction of the root surface. It is easier to detect external root resorptions as compared to internal root resorptions.

The lesions located on the buccal or lingual surfaces remain undetected in radiographs due to the superimposition of anatomical structures or varying root thickness (Creanga et al., 2015).

CBCT and root resorption

Majority of the studies on the diagnostic ability of CBCT in detection of root resorption are in vitro which does not display the exact imaging features that are seen clinically (Creanga et al., 2015). The improved diagnostic ability of CBCT in detection of root resorption is due to the multi-planar imaging of the anatomy (Da Silveira et al., 2015). CBCT showed better diagnostic ability in detecting simulated external root resorptions as compared to periapical radiographs (Bernardes et al., 2012; Creanga et al., 2015; Kamburoğlu et al., 2011; Ren et al., 2013). Different exposure parameters can influence the identification of the internal root resorptions (Da Silveira et al., 2015). CBCT can detect the true size and position of all resorptive defects (Patel et al., 2009). The study (Patel et al., 2009) showed the accurate diagnostic accuracy of CBCT by receiver operative characteristic (ROC) curve in determining root resorptions.

High resolution scans increase the diagnostic ability in determining external root resorptions (Ponder et al., 2013). Better imaging quality is associated with small voxel size (Da Silveira et al., 2015). Different voxel size influence the diagnostic ability of CBCT in detecting internal root resorptions but there is little influence of field of view in detecting internal root resorptions (Da Silveira et al., 2015).

2.4 Complex Anatomy

Root canal anatomical variation not only depends on tooth type, but also in population type. Differences in ethnic background, gender, age, are associated with varied root canal anatomy (Cleghorn et al., 2006). Different ethnicities have different root and root canal anatomical variations (Mao & Neelakantan, 2014). An incidence of 2.5% or more than two canals in maxillary first premolar was observed in a Brazilian population (Pécora et al., 1992), Chinese have a higher incidence of accessory canals in anterior teeth whereas Indians' maxillary first molar canal morphology differs when compared to other Indo-European and east Asian populations (Neelakantan et al., 2010). Felsypremila et al reported that the root canal arrangement of maxillary second molar exhibited great variation in Indians (Felsypremila et al., 2015).

Therefore, each patient should be analyzed with reference to his/her ethnicity and its related anatomic teeth variations (Estrela et al., 2015). This knowledge of variance is of utmost importance in very multiethnic countries like Canada. CBCT imaging can help in understanding complex root canal systems which is as accurate as digital operating microscope (Toubes et al., 2012). The variations like accessory canals, curvature of the root or calcifications within the canals increase the difficulty in treatment and are significant in determining the treatment outcome. These variations often result in incomplete healing if not diagnosed during treatment. Therefore, a thorough knowledge of root canal systems is required.

Canal anatomy and periapical radiographs

Periapical radiographs are still used as first line of diagnostic imaging for the assessment of canal anatomy. However, the two-dimensional perspective, superimposition of the anatomical features and previous dental work hinders the visualization of the exact anatomy.

The diagnostic ability of the periapical radiographs is improved by taking additional parallax radiographs (Davies et al., 2015). But, additional parallax radiographs do not always provide sufficient information (Toubes et al., 2012).

Successful non-surgical endodontic treatment results when all the canals have been successfully debrided. In order to achieve this it is important to know the anatomy of root canals and its anatomical variations (Mao & Neelakantan, 2014). Many methods have been employed in endodontic research to analyze the root canal systems and variations. Some of these methods are canal staining, clearing technique, CT scans, CBCT and contrast medium enhanced digital radiography (Neelakantan et al., 2010). Out of all these methods the most accurate technique for identifying root canal systems in endodontics is CBCT (Neelakantan et al., 2010).

Missed Canal

Accurate detection of number of canals present in the root system in a tooth is an important aspect while performing endodontic treatment. Information about exact location, number of canals and tooth anatomy may prevent extra patient appointments, unnecessary dentine removal and inadvertent perforations (Ee et al., 2014). A missed canal can also lead to the failure of the initial non-surgical endodontic treatment and poor outcome (Wolcott et al., 2005). Maxillary first molar has the high clinical failure rate as these teeth have most complex anatomy (Hartwell, Appelstein, Lyons, & Guzek, 2007). The presence of a periapical lesion is most commonly associated with a missed canal (Fernández et al., 2013; Karabucak et al., 2016).

The majority of missed canal was located in maxillary 1st molar. The prevalence of MB2 in maxillary first molars has been reported to vary from 69% to 93% depending on the type of study used (Scarfe et al., 2009). Teeth which have high incidence of missed canal are maxillary molars.. This MB2 is often missed during initial endodontic treatment due to the excessive deposition of dentine at the canal opening (Betancourt, Navarro, Muñoz, & Fuentes, 2016). The detection of MB2 can also be attributed to the clinical experience of the operator (Stropko, 1999).

CBCT and complex anatomy/missed canal

Using CBCT as a diagnostic tool to analyze the missed canal, Karabucak et al's study confirmed that the majority of the missed canals was in maxillary first molars (Karabucak et al., 2016) . The CBCT identified 23.04% of missed canal in pretreated molars and premolars (Karabucak et al., 2016). Vizzotto et al reported CBCT has high sensitivity and specificity than periapical radiographs in identification of MB2 canals (Vizzotto et al., 2013), which confirmed earlier studies(Lofthag-Hansen et al., 2007; Matherne et al., 2008).

Davies et al.'s clinical study, using the microscope as gold standard reference for comparing the number of canals, showed that CBCT detected more number of root canals as compared to periapical radiographs and parallax images (Davies et al., 2015). There was no significant difference between CBCT and endodontic microscope in identifying the canals (Davies et al., 2015). This suggests that the operating microscope should be the next diagnostic instrument to be employed prior to prescribing a CBCT in those cases where missed canals are suspected.

Resolution of CBCT scans also play an important role in analyzing any missed canal (Bauman et al., 2011). The detection of missed canal increases as the resolution is increased (Bauman et al., 2011). Root canal filling material can reduce the detection of the exact number of canals in a tooth. This ability to detect canals is further reduced if the spatial resolution is decreased (Vizzotto et al., 2013). Vizzotto et al. declare that a high resolution is required for the detection of missed canal if the tooth is root filled (Vizzotto et al., 2013), whereas a spatial resolution as low as 0.3 mm voxel size in those circumstance where there is no root filling material present (Vizzotto et al., 2013).

2.5 Hypothesis

After literature review on endodontic imaging and endodontic diagnosis and treatment plan in previous chapters we formulated the hypothesis for this study:

Hypothesis: CBCT examination can change the diagnosis and treatment plan previously determined by periapical radiographs in endodontically-involved teeth.

Null Hypothesis: CBCT examination cannot change the diagnosis and treatment plan previously determined by periapical radiographs in endodontically-involved teeth.

Chapter 3: Methods and Materials

3.1 Part 1 - Audit of CBCT Referrals

This is a retrospective study performed in two parts. Part 1 was an Audit of the prescriptions for CBCT referrals for quality assurance at UBC, Faculty of Dentistry). This was in part a quality assurance exercise and in part an exercise to determine the clinical sources of these prescriptions.

An online referral system of CBCT was set up in UBC Dentistry in January 2012. Oral Health Centre's database was reviewed from the 16th January 2012 until the 31st August 2014 for all the patients who were investigated by CBCT. Ethics approval certificate H14-02191 was granted for this study. All the prescriptions were made within the Faculty of Dentistry. The prescriptions to CBCT were initiated by graduate students who had been competency tested in CBCT technology, diagnosis and technique. In addition, the graduate students were supervised by already credentialed specialist faculty teaching in their appropriate specialty. A prescription was only valid when it was approved by appropriately-credentialed faculty. The prescription in addition to identifying clinical indication also had to specify field-of-view (FOV) and whether a high spatial resolution was necessary or not. The FOV and spatial resolutions were based on the following flow chart. These were chosen from those available on the Carestream 9300.

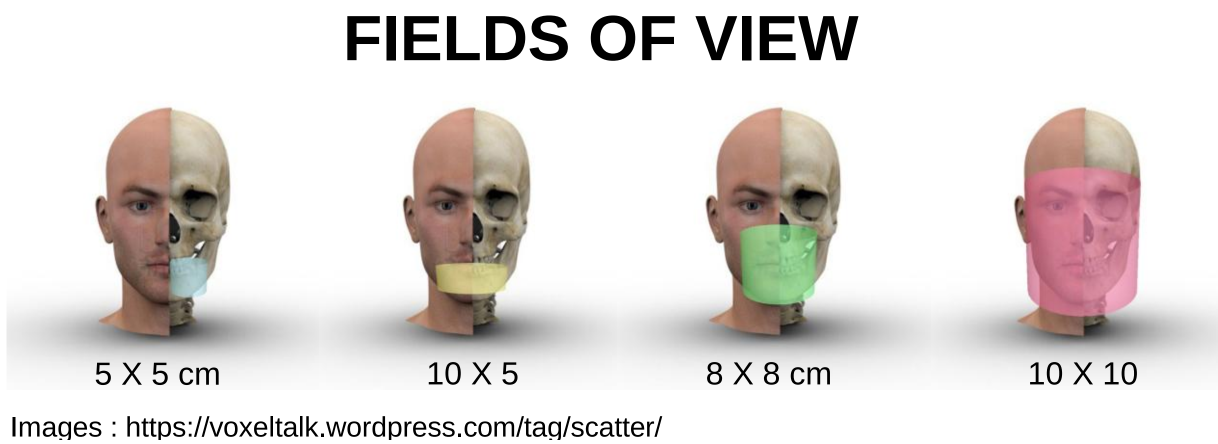

Figure 6: Fields of view used at UBC

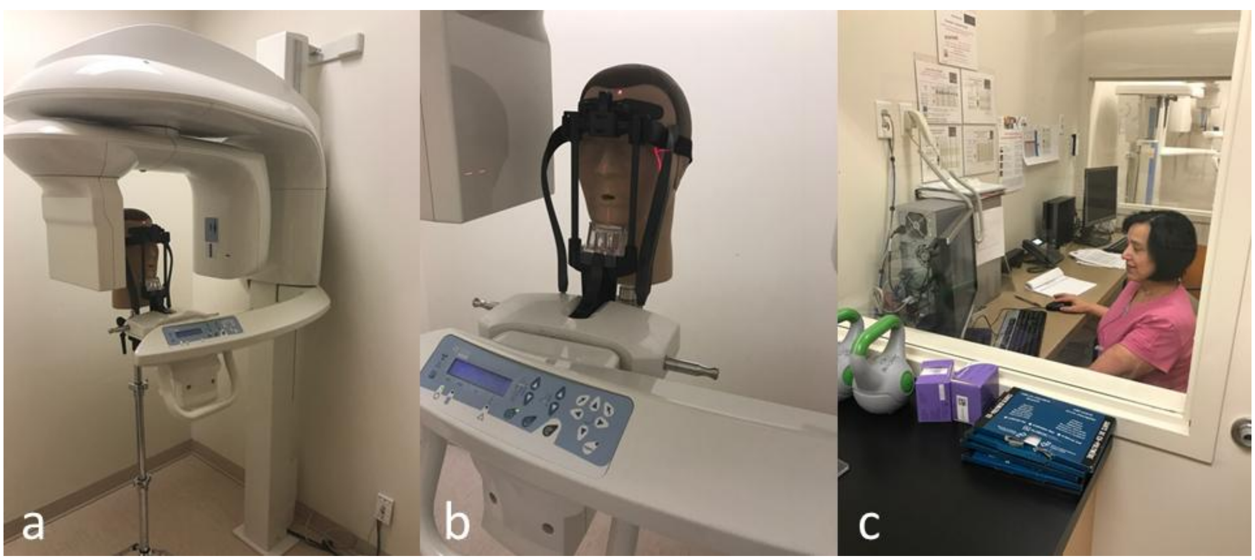

Figure 7: CBCT unit used at UBC dentistry

Carestream 9300 cone-beam computed tomographic (CBCT) unit with anatomical phantom head used for student, staff and faculty training. Note: the human patient will be wearing a full tabard-style lead coat. b. Phantom head positioned as would a patient and as viewed through the Lead-glass window form the control console in c. c. displays the operator as s/he would be when entering the exposure factors onto the monitor prior exposing the patient or reviewing the first images after completion of the exposure. Note. C also displays the kettle-weights which are used to assist those patients whose shoulders otherwise interfere with the free movement of the CBCT gantry. Acknowledgement: Sabina Reitzik, Clinical Instructor, Oral and Maxillofacial Radiology, University of British Columbia.

3.1.1 Title

Audit of CBCT referral for quality assurance at UBC, Faculty of Dentistry.

3.1.2 Aim and objective

Aim: Determine the CBCT prescription pattern and quality assurance at UBC, Dentistry.

Objectives:

1. To determine the sources, reasons and quality of CBCT prescriptions at UBC –Dentistry, Vancouver.

2. To determine the level of compliance with UBC Dentistry's standard operating procedures for Cone-beam computed tomography.

A. For the retrieval and collection of CBCT scans from the 16th January 2012 until the 31st August 2014, the following steps were carried out.

   1. An online referral/prescription system of CBCT was set up in UBC Dentistry in January 2012.

   2. To compile the data, a qualitative questionnaire audit form was produced.

   3. Oral Health Centre's database was reviewed from the 16th January 2012 until the 31st August 2014 for all patients who were investigated by CBCT.

   4. The presence/absence of entries and report were simply rendered by Yes/No in the audit questionnaire form.

B. After filling the audit questionnaire form the consecutive referrals submitted online were reviewed for:

1. The source of the referral. To determine the extent of CBCT use in each specialty at UBC, Faculty of Dentistry.
2. Clinical indication(s) that induced the referral - determine of the most common reasons of referral for CBCT in each specialty.
3. Exposure parameters (FOV selection).
4. Jaw or jaws exposed
5. Age and gender. Age was further subdivided into sub age groups (10-19,20-29,30-39,40-49,50-59,60-69,70-79 and 80+).

3.2 Part 2 – Endodontic cases

Part 1 revealed that after prescription for pre-implant planning the next most important source was from the graduate endodontic program. This was a three-year program that led to the credentialing of the successful student as an endodontist. It was anticipated that the varied reasons of prescription and the lack of *in vivo* studies for the use of CBCT in complex endodontic cases will make it a good and interesting study.

The initial data set (Part 1) from graduate endodontic program had 60 cases. In order to increase the sample size another ethics certificate H15-03507 was granted for this purpose. The study included the samples from 16th January 2012 until the 31st August 2014 and from 1st September 2014 until 20th December 2015. The data was extracted from the *electronic patient record* (EPR;

Romexis software). The data in the patient record was entered by the graduate students during the course of the treatment under the supervision of highly experienced and board-certified endodontists.

3.2.1 Title

Prescriptive pattern and clinical decision using CBCT in endodontics.

3.2.2 Purpose

The main purpose of the study is to determine the use of CBCT in the actual clinical settings in the field of endodontics and how the reasons for CBCT prescription relate to AAOMR/AAE position statement. Although a gold standard, to confirm definitively the diagnosis could not be performed as so few cases investigated by CBCT ultimately required extraction, a gold standard test was possible only when surgical and visual exploration was performed in cases of a vertical root fracture (VRF) as diagnosed by CBCT or upon surgical access in cases of perforation, retrieval of broken instrument or tooth resorption.

3.2.2.1 Aim and objective

Aim: To determine the clinical decision and prescriptive pattern for CBCT in endodontically-involved teeth

Objectives:

1. To determine the additional information revealed in CBCT in endodontically-involved teeth, which includes:

- the % of missed canal
- the % of vertical root fracture
- the % of internal/external resorption
- the % of calcified canal
- the % of periapical lesion

2. To compare the conventional radiographic diagnosis and treatment planning with the CBCT examination.

3. To identify the prescriptive pattern for CBCT as per American Academy of Oral and Maxillofacial Radiology and American Academy of Endodontist (AAOMR/AAE), by correlating the reasons of referral to the position statement.

3.2.2.2 Research question

Can CBCT change the diagnosis and treatment plan previously determined by periapical radiographs in endodontically-involved teeth?

3.2.3 Grouping

The sample was further grouped into 3 groups (Fig.8) and each CBCT was assigned to one of 3 groups; Group 1 (Gp.1): when cases had contradictory signs and symptoms i.e. the signs, symptoms and periapical radiographs were not by themselves adequate to the making a diagnosis; Group 2 (Gp.2): to confirm the diagnosis i.e. sign and symptoms and periapical radiographs were indicating a particular diagnosis but it was not conclusive; and Group 3 (Gp.3): for aid in treatment-planning.

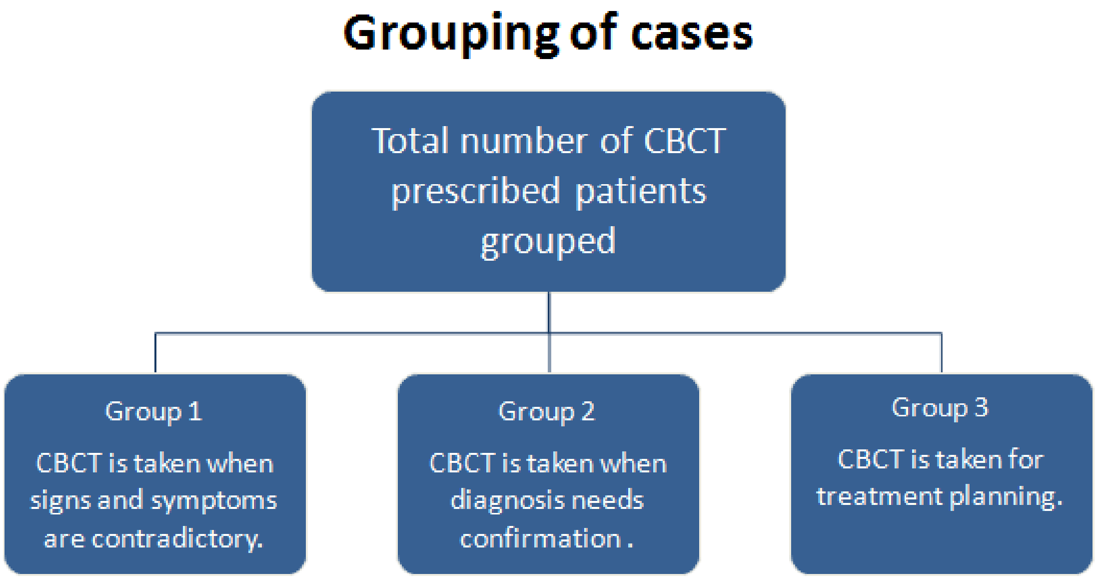

Figure 8: Grouping of cases

3.2.4 Study population

The patient records were taken from the EPR. All the records which were included that at least prescribed one CBCT from Graduate Endodontics Program were retrieved from January 2012 until August 2013 and from 1st September 2014 until 20th December 2015. The ethics certificates H14-02191 and H15-03507 were awarded for this retrospective study. Though there was no inclusion or exclusion criteria set, all the cases prescribed CBCT from graduate endodontic program were considered.

A total of 952 patients were referred to graduate endodontic program. The majority of these cases had been referred, during that period, from undergraduate clinic or from Faculty's own general dentist service to the Graduate Endodontics Program for treatment. Out of these 952 patients 110 patients were included in the study and who had been prescribed CBCTs for various endodontic reasons, during the period of the study.

The need for CBCT examination was made by the graduate endodontic students under the guidance of experienced and credentialed endodontic specialists. These endodontic specialists are also au *fait* in interpreting CBCT images specific to their expertise. The multi-planar interpretations were initially performed by the graduate students and subsequently evaluated by the endodontic faculty. The graduate students had been early in their endodontic program were competency tested in CBCT technique and interpretation.

3.2.4.1 Data collection and sample size

The EPR files of the 110 patients upon whom CBCTs had been made for endodontic reasons between 16th January 2012 and 20th December 2015 were retrospectively reviewed. The referrals had been earlier audited for the quality assurance. An Excel® (Excel 2007, Microsoft) spreadsheet was created to log the data and all the data was anonymized.

Each patient's clinical signs, symptoms and examination details were recorded from the EPR. The examination consisted of percussion, palpation, pulp vitality testing and probing depths of the area of interest. The pulp vitality testing consisted of heat test, cold test and electric pulp test. These examinations or tests were not performed on all the patients rather only specific tests were done depending on the symptoms presented by the patients and their chief complaint.

After completion of the clinical examination periapical radiographs of the area of interest were made. If the clinical findings of these and other tests were insufficient to reach a diagnosis then CBCT was prescribed.

After the descriptive data was logged into the Excel spread sheet it was further reviewed and quantified for:

1. Indications /reasons that induced CBCT prescription. The reasons were further correlated with “AAOMR/AAE updated position statement recommendations 2015” and the groups (Table 3). Any reason which did not fall under the position statement was noted, or if any hiatus was found.

   Not all the recommendations by the position statement were correlated. The recommendation numbers used in this study were recommendations- 2,3,4,6,7,8,9 and 12 (Table 2). The rest of the recommendations were not included as the cases were related to implant planning and trauma related reasons, which are treated by different specialties.

Grouping	
Number given	**Meaning**
1	When signs and symptoms are contradictory
2	When diagnosis needs confirmation
3	CBCT is taken for treatment planning

Table 3: Grouping of cases

2. The clinical features and symptoms were taken from the patient's files as presented by the patients during the course of the treatment (Table 4).

Clinical feature	
Number given	**Characteristic feature**
0	no pain
1	dull pain
2	Pain
3	Swelling
4	swelling and painful
5	pain swelling and pus
6	sinus tract/ pus
7	pain and sinus tract

Table 4: Number given for clinical feature

3. The exposure parameters (FOV selected) were noted.
4. Tooth/teeth involved. Teeth were further subdivided into multi-rooted, single rooted (Table 5) and posterior and anterior teeth. Teeth grouped as posterior were maxillary and mandibular molars and premolars whereas maxillary and mandibular canines and incisors were grouped under anterior (Table 6).

Single / multiple rooted	
Number given	**Meaning**
1	Single rooted
2	Multiple rooted

Table 5: Number given for single or multirooted teeth

Anterior/Posterior Sextant	
Number given	**Meaning**
1	Anterior
2	Posterior

Table 6: Number given for anterior/posterior sextant

5. CBCT interpretation done by the graduate student was reviewed and any additional information revealed was noted.
6. Whether the tooth involved was previously endodontically treated or not was noted (Table 7).

Tooth previously endodontically treated or not treated	
Number given	**Meaning**
0	Not treated
1	Treated

Table 7: Number given for tooth previously treated or not treated

7. Treatment plan made before and after CBCT images were noted, as compared to the periapical radiographs.
8. Age and gender of the patients. The age was further subdivided into 4 subgroups (10-19 years, 20-29 years, 30-50 years and over 50 years).

3.2.5 Periapical radiographic diagnosis and treatment plan

The periapical interpretation done by the endodontic graduate students were reviewed. Each case was grouped under one of the groups (Fig.8) based on radiographic and other clinical findings. There was a direct co-relation between the radiographic diagnosis and the treatment plan made based on periapical radiographic findings. The majority of the cases falling under group 1 and 2 did not have definite treatment plan or no treatment plan was decided by radiographs as more information was required (Fig.28)

3.2.6 CBCT evaluation and treatment plan

The cases were sent for CBCT when periapical radiographic information was insufficient for a diagnosis or if an exact measurement was needed for treatment planning (Gp.3) for example: a) to ascertain the proximity of the apices to the mandibular canal when an apicoectomy is being contemplated on a mandibular molar (Fig.33) or b). to determine the exact location and the size of a lesion associated with root resorption (Fig.27). Any changes wrought by the CBCT on the original diagnosis and the treatment plan were noted by reference to the patient records. Changes in diagnosis occurred with regards to six phenomena, these were the presence or absence of a periapical lesion, missed/extra canal, complex anatomy, a calcified canal, root fracture vertical or horizontal and root resorption. When a diagnosis was considered to have been changed by new information apparent on CBCT it was given the value “1”. If no change occurred it was assigned “0” (Table 9).

Treatment change was based on whether the additional information revealed was significant enough to change the treatment plan which was previously decided by the radiographs. Treatment change was considered “changed”:

- If the treatment given to the patient was decided after viewing CBCT, and no specific treatment plan was made by the radiographs
- If the treatment plan was totally different from what was previously decided by the radiographs.

The treatment change was given the value “1” if the previous treatment plan, as decided by periapical radiographs, was altered or if no definite plan was made by looking at the radiographs together with the other clinical signs and symptoms and examination (Table 8). Otherwise it was assigned “0” (Table 8).

Change in treatment	
Number given	**Meaning**
1	Treatment plan altered post CBCT or no definite treatment made by periapical
0	No change in treatment plan as proposed by periapical

Table 8: Consideration for treatment plan altered or not

Change in diagnosis	
Number given	**Meaning**
1	Additional information identified in CBCT
0	No additional information based on six diagnostic variables.

Table 9: Consideration for diagnosis altered or not

CBCT system Used - The scans were taken by Carestream 9300 (Carestream Dental LLC Atlanta, GA.), software used was carestream software (Diacom), and voxel size used by machine has a 0.9mm focal spot (Fig.7). This unit was serviced by Carestream throughout the entire study.

3.3 Statistical Analysis

Comparison between the findings apparent on the clinical examination and periapical radiographs and those on the CBCTs were determined by the presence/absence of periapical lesions, missed/extra canals, root fracture (vertical or horizontal), complex anatomy, calcified canals and resorption. McNemar test was used to determine whether the observed differences were significant. This test is used on samples with dichotomous trait and with matched pairs of subjects or samples. It is used to determine the significance between the sample frequencies. It is used in nominal data. To see the proportions and the difference between the treatment change, subgroups of teeth, recommendation number and groups of cases Cross tab (Pearson Chi-square test) and Mann Whitney analysis was used to see the significant difference. *Pearson's chi-squared test* (χ^2) is a statistical test applied on categorical data to determine any observed difference between the groups. The statistical analysis was done using IBM SPSS® 2015 software. Significance was defined when $P < 0.05$ and two-tailed.

Chapter 4: Results

4.1 Part 1

Result

The total of 324 patients and 389 CBCT prescriptions audited were identified in the EPR of the Faculty of Dentistry, UBC (Table 10). The origin of most prescriptions for CBCT was the graduate programs in periodontics followed by endodontics, prosthodontics. The prescriptions from the Doctor of Dental Medicine (DMD; dental undergraduate) program were of intermediate in frequency and the least were from the graduate programs in orthodontics and pedodontics.

Program	Scans
Graduate Periodontics	242 (62%)
Graduate Endodontics	60 (15%)
Graduate Prosthodontics	46 (12%)
Graduate Orthodontics	12 (3%)
Graduate Pedodontics	1(<0)
DMD	22 (6%)
Miscellaneous	6 (2%)
Total	389 (100%)

Table 10: CBCTs prescribed by the various programs

The total of 242 cases prescribed by the Graduate Periodontics Program (Table 10), out of which 168 cases were prescribed solely for implant treatment planning (Table 11). Four were for angular bone defects and 2 for impacted canines.

Reasons	Scans
For placement of implants, to assess the bone width and bone quality and to assess the proximity of vital structures (Inferior alveolar canal, maxillary sinus etc.) before implant placement	168 (69%)
Follow up of Maxillary sinus augmentation or Lateral ridge augmentation	62 (26%)
To determine fistula close to implants and to confirm no active pathology at the apex of implants	4 (2%)
To assess the extension of bone destruction especially in angular bone defect	4 (2%)
Failed Implant or Improper Healing	2 (1%)
Canine impaction on the palate and related resorption	2 (1%)

Table 11: Number of CBCTs prescribed as per reasons from the graduate periodontics program

Reasons	Scans
Detect vertical fracture of a tooth or to detect untreated root canal or unsure of canal anatomy	19 (32%)
To evaluate healing process in RC treated tooth or whether an additional apical surgery is needed	14 (23%)
To assess the size and location of periapical lesions	9 (15%)
External root resorption	6 (10%)
To detect calcified canals	3 (5%)
Non-healing sinus tract	3 (5%)
Treatment requiring apicoectomy and retro filling	2 (3%)
Detect fracture of implants/root fracture	2 (3%)
Severe facial abscess (trismus)	1 (2%)
To assess proximity of roots to vital structures	1 (2%)

Table 12: Number of CBCTs prescribed per reasons from the graduate endodontics program

The total of 60 cases prescribed by the Graduate Endodontics Program (Table 12). Almost all were prescribed for endodontic reasons. The total of 46 cases (Table 13) prescribed by the Graduate Prosthodontics Program. 39 cases were prescribed for implant reasons. Six cases were prescribed for endodontic reasons and one for an impacted tooth.

Reason	Scans
Placement of Implants and stents	29 (63%)
Implant supported prosthesis	10 (22%)
Periapical lesion	4 (9%)
Vertical root Fracture	2 (4%)
Impaction	1 (2%)

Table 13: Number of CBCTs prescribed as per reasons from the graduate prosthodontics program

There were a total of 12 cases referred from the Graduate Orthodontics Program (Table 14). From 12 referrals 9 cases were solely referred for impacted canine to know the exact positioning of the canine relative to the incisors. 2 cases were referred for periapical lesion and 1 case was referred for Orthognathic surgery.

Reason	Scans
Impacted teeth esp. canines, to evaluate the status, exact location, length of the root and related resorption before surgical exposure or to evaluate the relative positioning of impacted tooth with the roots of the neighboring teeth	9 (75%)
Periapical lesions	2 (17%)
Orthognathic surgery	1 (8%)

Table 14: Number of CBCTs prescribed as per reasons from the graduate orthodontics program

Of the total of 22 cases prescribed by Doctor of Dental Medicine Program (DMD) (Table 15), 10 were for implants, 10 for periapical lesions, 1 case each to assess the proximity of mandibular canal for an impacted mandibular tooth.

Reasons	Scans
Placement of Implants	10 (45%)
To evaluate the size and location of periapical lesions	10 (45%)
Removal of impacted tooth and to assess the proximity of tooth to vital structures	1 (5%)
Others (broken instrument)	1 (5%)

Table 15: Number of CBCTs prescribed as per from the doctor of dental medicine program

Majority of cases (285) were prescribed for small (5x5) field of view (FOV). Table 16 shows the number of scans as per the FOV selected. The cases are further categorized down to the departmental level, with respect to FOV used.

FOV	Numbers
5x5	285 (73%)
10x5	75 (20%)
8x8	21 (5%)
10x10	8 (2%)
Total	389

Table 16: Total number of CBCTs in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	159 (66%)
10x5	61 (25%)
8x8	16 (7%)
10x10	6 (2%)
Total	242

Table 17: Graduate periodontics in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	60 (100%)
10x5	0
8x8	0
10x10	0
Total	60

Table 18: Graduate endodontics in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	37 (80%)
10x5	4 (9 %)
8x8	4 (9%)
10x10	1 (2%)
Total	46

Table 19: Graduate prosthodontics in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	8 (67%)
10x5	3 (25)
8x8	0
10x10	1 (8%)

Table 20: Graduate orthodontics in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	17 (77%)
10x5	5 (23%)
8x8	0
10x10	0

Table 21: DMD in four Fields-of-Views (FOVs) selected

FOV	Number
5x5	1 (100%)
10x5	0
8x8	0
10x10	0

Table 23: Graduate pedodontics in four Fields-of-Views (FOVs) selected

Reason	Scans
Ectopic Eruption	1

Table 22: Number of scans referred per reason from pedodontics

FOV	NUMBER
5x5	4 (66 %)
10x5	1(17%)
8x8	1 (17%)
10x10	0

Table 24: Miscellaneous in four Fields-of-Views (FOVs) selected

Reasons	Scans
Placement of Implants and stents.	5 (83%)
Periapical lesions	1 (17%)

Table 25: Number of CBCTs prescribed per reason by miscellaneous sources

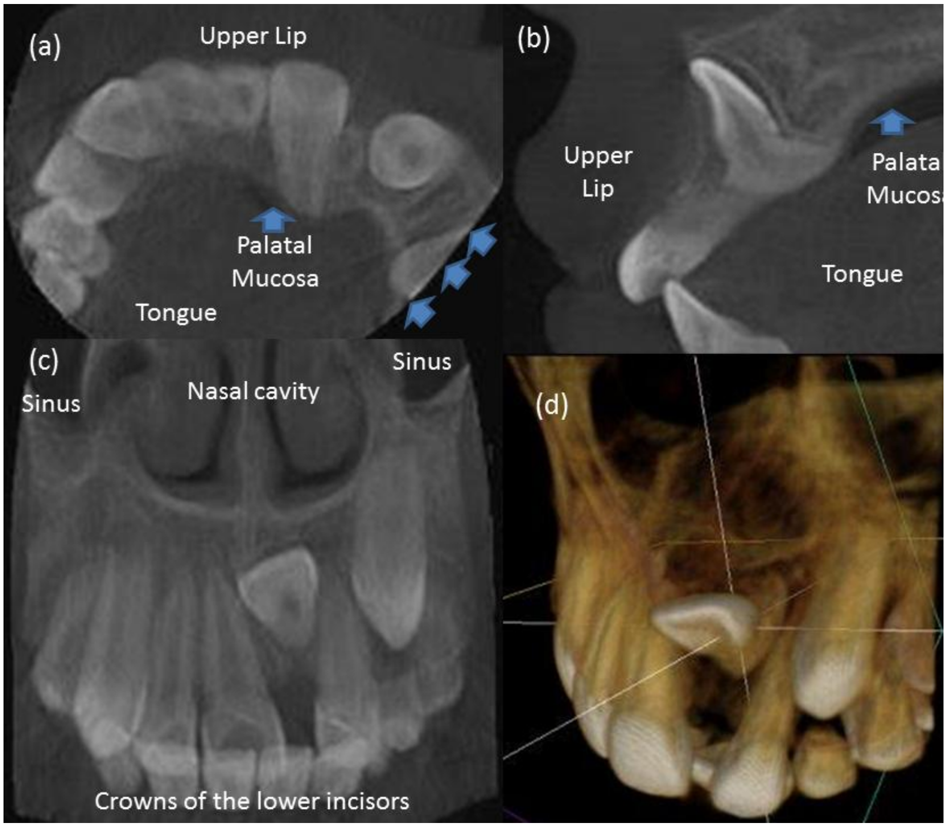

Figure 9: CBCT in orthodontics

Small (5 x 5) field-of-view (FOV) CBCT displaying a dilacerated left central incisor. the cross-sectional or multi-planar reformations in the axial (a), sagittal(b) and coronal (c) planes and the 3-dimensional reformation (d) representing the dataset volume. The 3 *multi-planar reformations* (MPR) are centered on the dilacerated tooth as obvious 'cross-hairs' in (d). The 3 blue arrows in (a) define part of the 5-centimeter diameter and (c) and (d) denote the 5-centimeter height of the 5 x 5 FOC made on a Carestream 9300 CBCT. The dataset has also captured the crowns of the lower incisors. The tongue substantially obdurate the oral cavity (appears as black); The palatal mucosa is thinner; The contour of upper lip is silhouetted by the air surrounding the patient. Note: the erupting left maxillary canine is eroding the root of the preceding deciduous maxillary canine. This resorption is normal and desired.

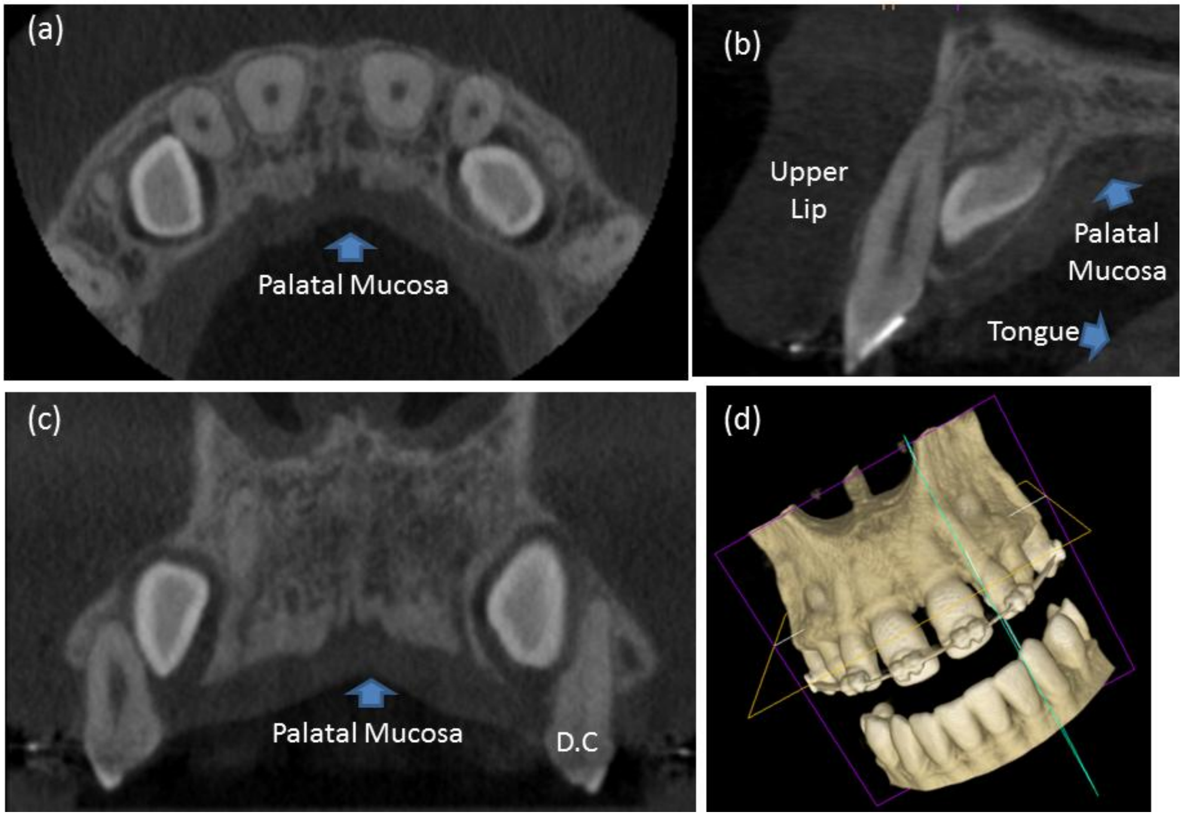

Figure 10: CBCT used for impacted canines

Small (5 x 5) FOV CBCT of impacted maxillary canines prescribed after parallax using conventional intra-oral radiographs was equivocal. Axial (a), sagittal (b) and coronal (c) reformations were made of the dataset represented by the 3-dimensional reformation (d). The position of each plane is clearly displayed in (d). Note. The lower (mandibular) teeth were cropped out in order to compile the above figure. (a) and (b) reveal that the crown of the maxillary canine is in intimate contact with the roots of the erupted permanent lateral incisors, but are not resorbing them at this moment. (c) displays the left maxillary canine resorbing the root of the deciduous canine. This resorption is expected and desirable.

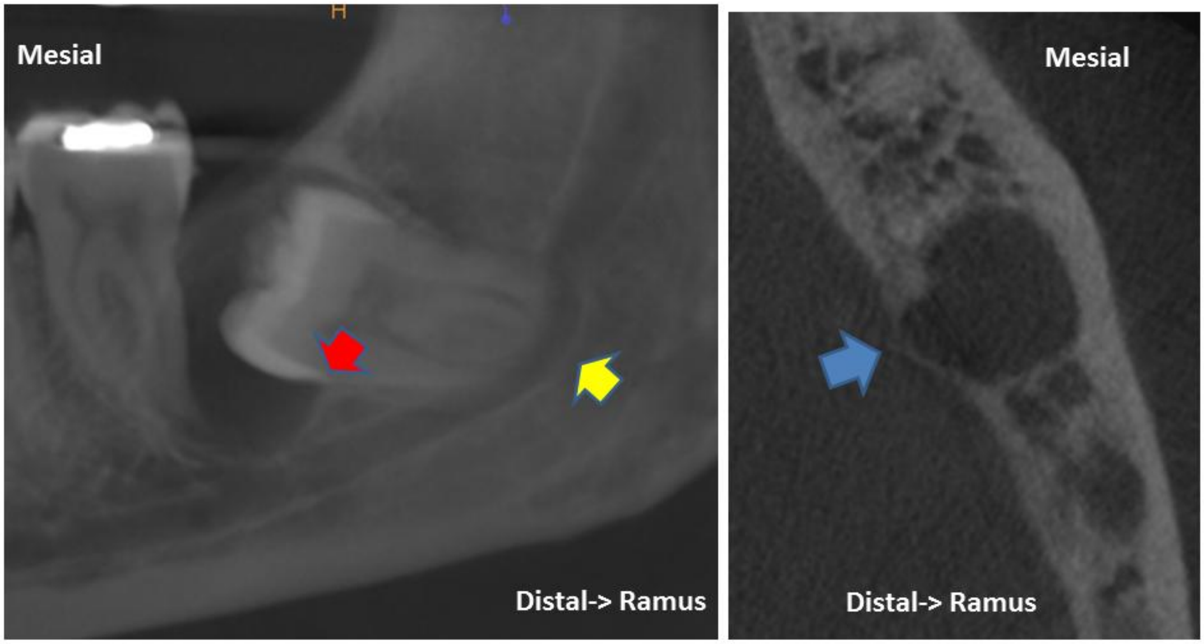

Figure 11: Dentigerous cyst

These are panoramic and axial reconstructions of cone-beam computed tomography of a dentigerous cyst arising from the crown of an unerupted third mandibular molar. The unilocular radiolucency arises from the enamel-dentine junction of the unerupted molar. Although this and the unilocular shape of the lesion on the conventional radiograph is sufficient for diagnosis of a dentigerous cyst, the CBCT was prescribed to ascertain the closeness of its relationship with the mandibular canal which has been displaced down and back and whose diameter has been reduced. These suggest an intimate relationship with the canal, which may result in post-operative paresthesia the patient should have been warned of pre-operatively. The axial reconstruction through the apex of the second molar root displays a round shape and expansion and erosion of the lingual cortex. (Acknowledgement: MacDonald CRAD 2016)

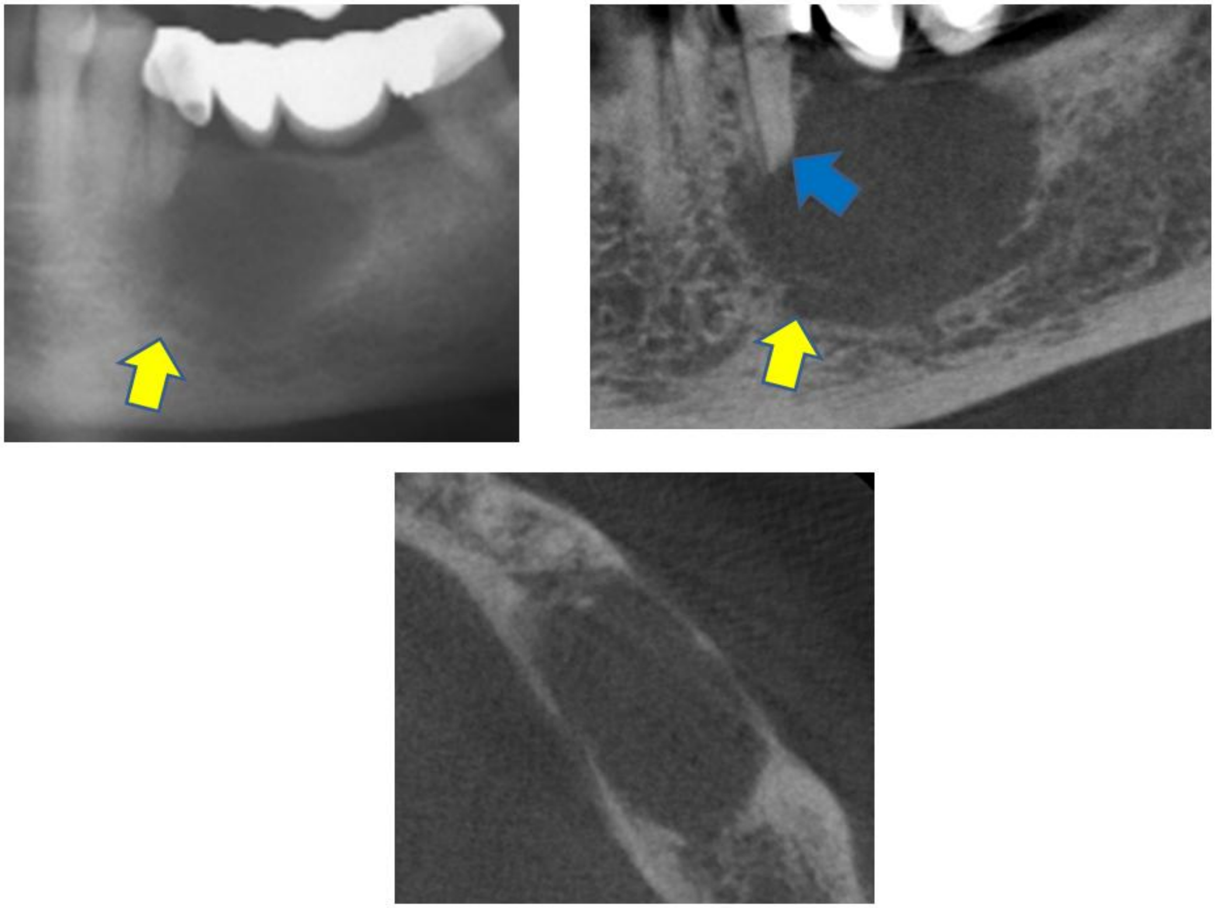

Figure 12: Glandular odontogenic cyst

These are panoramic and axial reconstructions of cone-beam computed tomography of a glandular odontogenic cyst arising in the premolar-first molar area of the mandible. The unilocular radiolucency is associated with root resorption of the second premolar (blue arrows). There is some buccolingual expansion and some extension from the alveolus into the basal process, the mandibular canal appears slight displaced downward (yellow arrows). The superior cortex of the mandibular canal has been eroded with regards to the posterior aspect of the lesion. The margin of the lesion was not particularly well defined. Acknowledgment, MacDonald D, CRAD 2016,

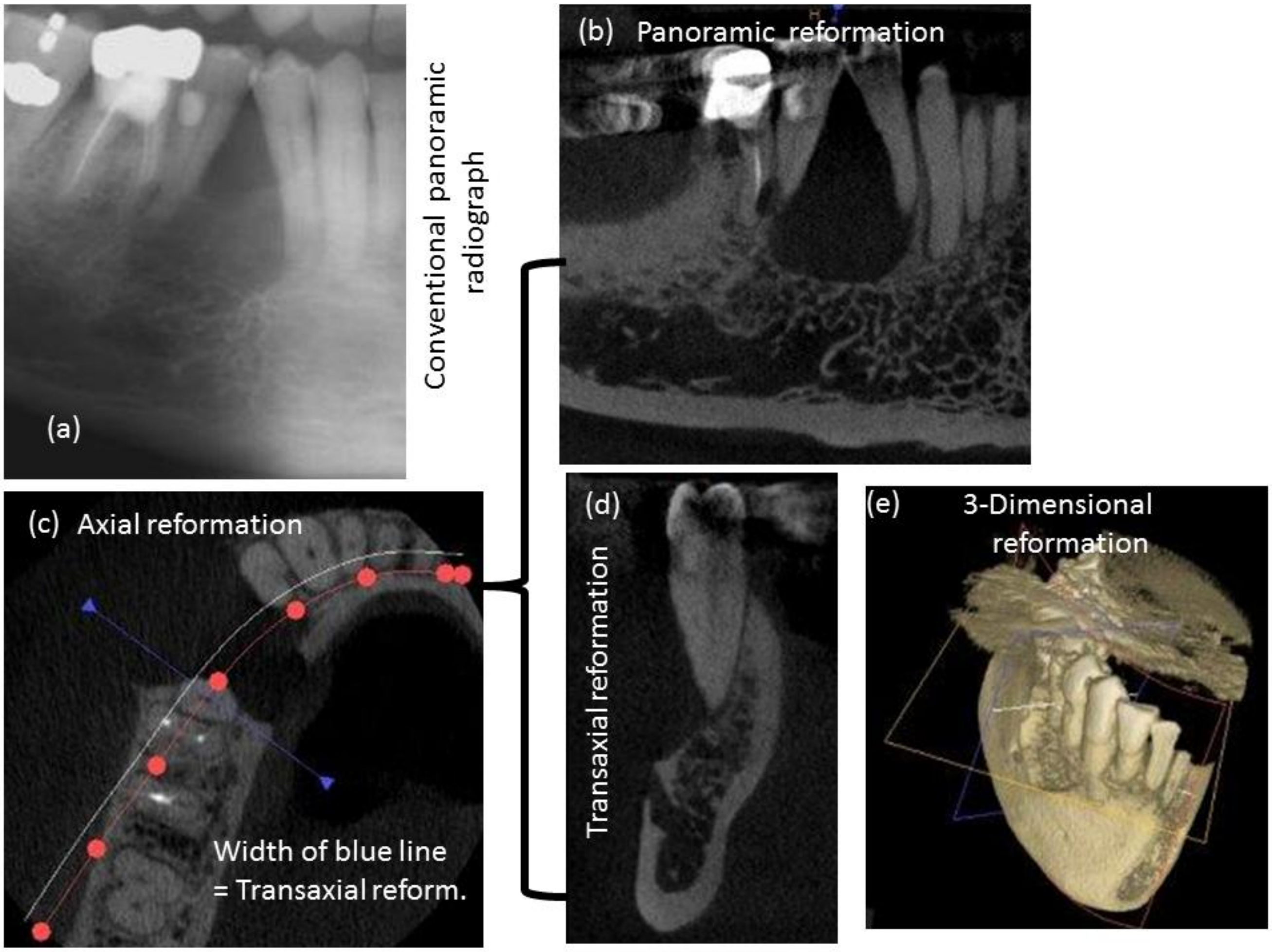

Figure 13: Ameloblastoma

Figure 13 displays (a) and (b) ameloblastoma which mimics radiographically as a periodontal cyst. (c) Axial plane shows both buccal and lingual cortex involvement. (d) The aggressive nature of the lesion can be depicted by resorbed root. (e) The lesion seems to have involved the basal bone.

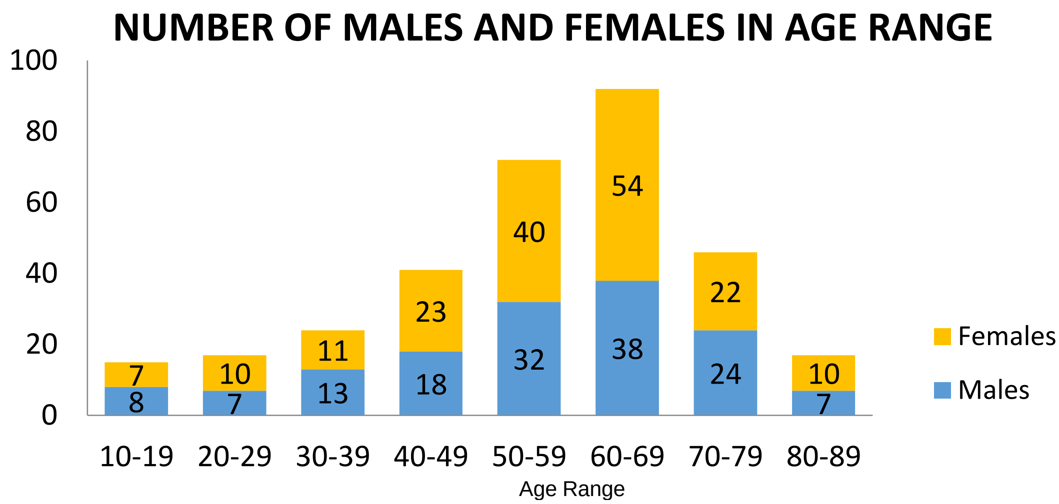

Figure 14: Number of males and females in age range

4.2 Part 2

Out of 952 patients, referred to Graduate Endodontics clinic, only 110 patients were prescribed CBCT. This accounts for approximately 12% of the patients who were examined by CBCT in Graduate Endodontics clinic. There were a total of 128 teeth which were examined in 110 patients. All the patients were subjected to small volume (5x5 FOV). The teeth most frequently sent for CBCT investigation were maxillary first molars; 15.6% were left maxillary molars and 11.7% were right maxillary molars (Fig. 15) The main reason of prescription of maxillary first molars was to confirm presence or absence of a second mesio-buccal (MB2) canal.

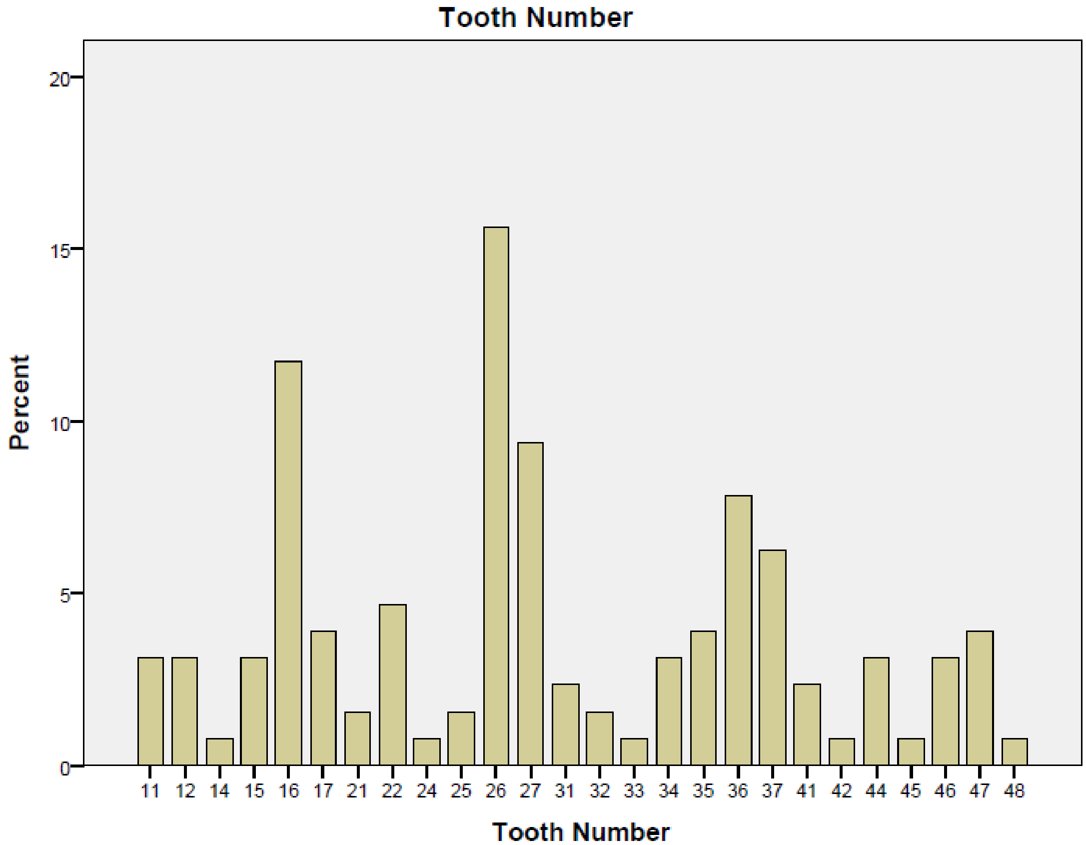

Figure 15: Frequency of type of teeth sent for CBCT examination

4.2.1 Association between position statement and grouping of cases

The in-house indications under grouping of cases (Fig. 16) for CBCT examination were further co-related with AAOMR/AAE position statement which was significant p<0.001 (Table 26). The most frequent reason for CBCT prescription in the whole sample was for treatment planning under Group-3 (61.7%) followed by Group 2 (28.9%) and Group 1(9.3%) (Fig-16).

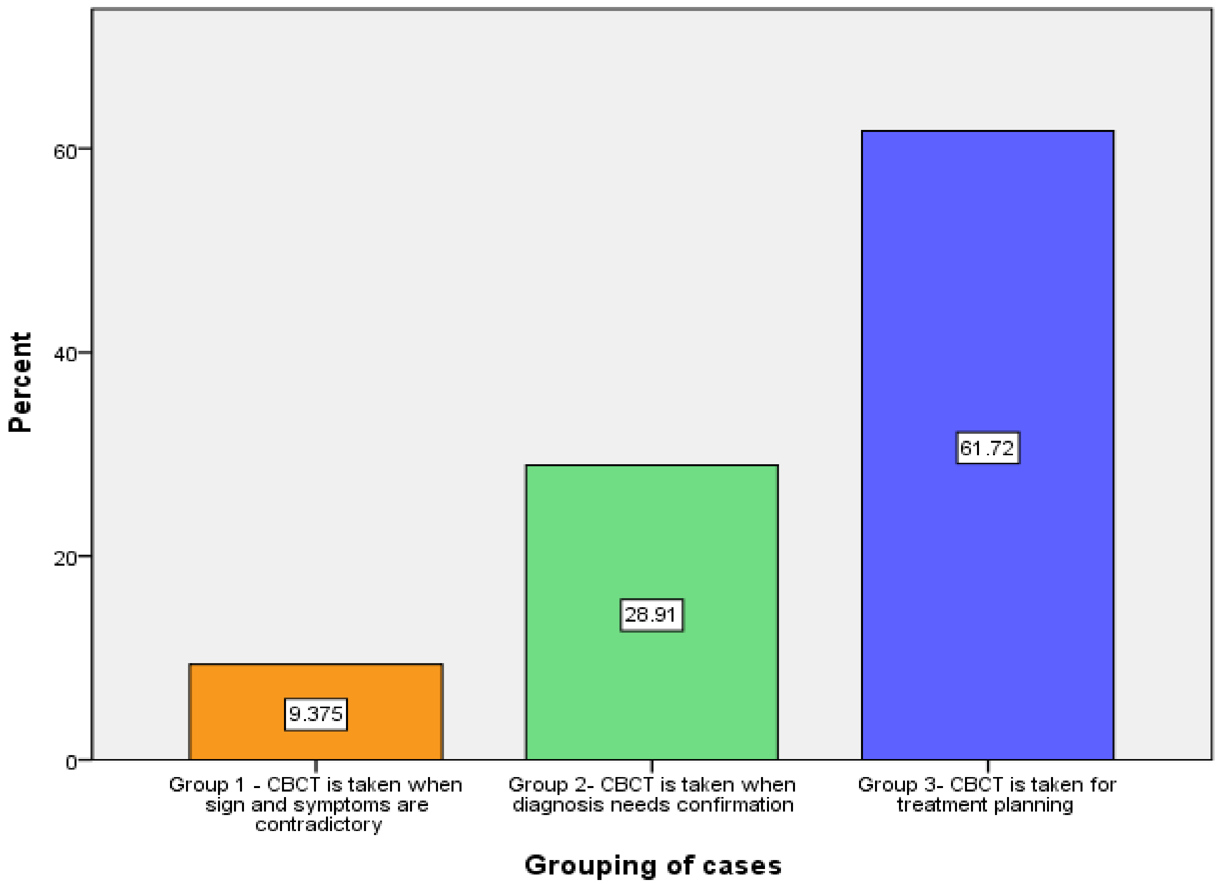

Figure 16: Frequency of grouped cases

Group 1 only had one recommendation under it, R2 (100%), although 14.3% of R2 was also under Group 2. Group 2 and Group 3 had the most varied and most of recommendations under them (Fig. 18). The majority of recommendation under Group 2 were, R3 (35.1%), R6 (29.7%) and R4 (16.2%) for confirmation of diagnosis (Table 26). Group 3 had most number of referrals altogether, with most common being the R7 (46.8%), R12 (20.3%) and R8 (15.2%) (Table 26).

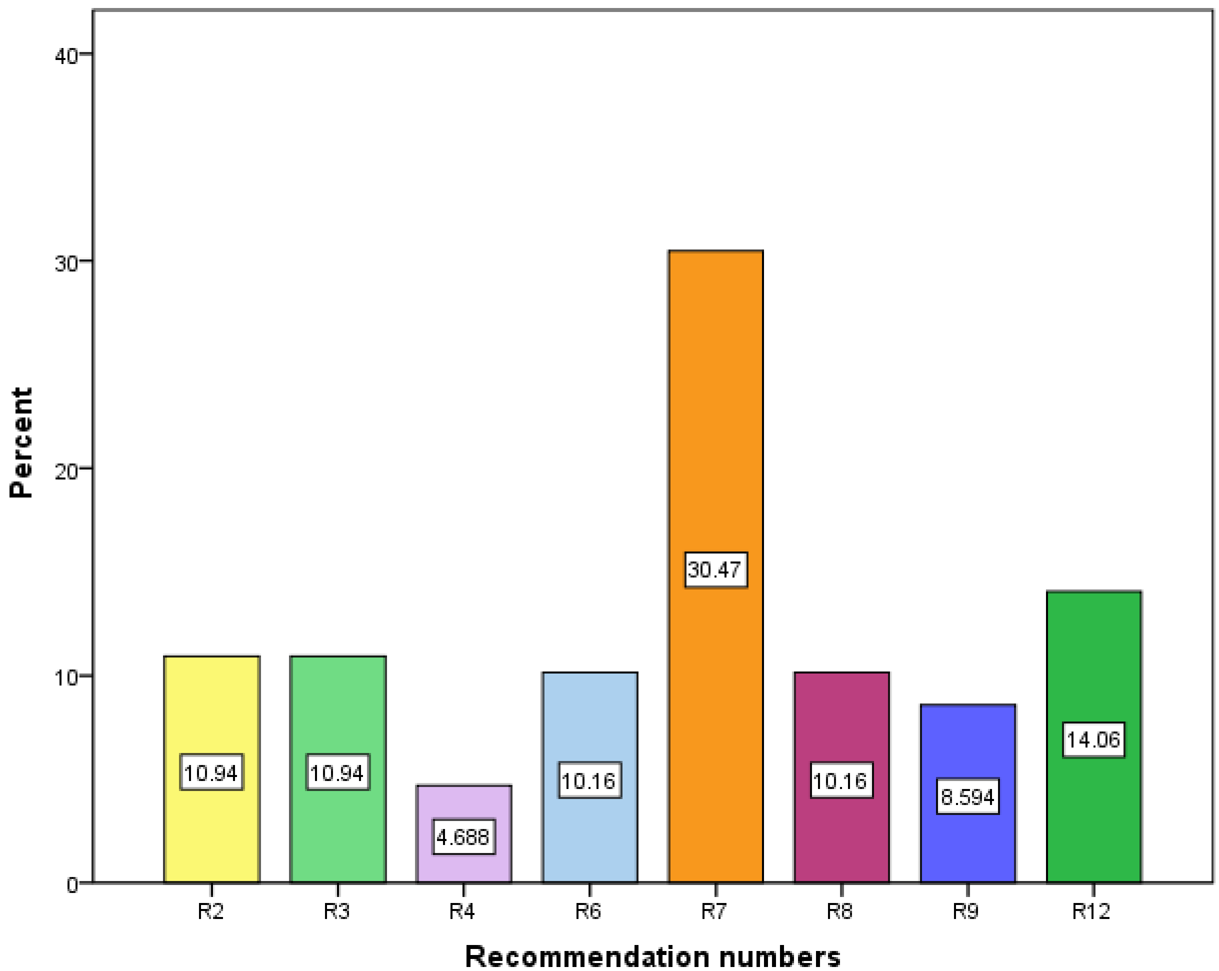

Figure 17: Frequency of AAOMR/AAE recommendation numbers.

It was found that the majority of cases prescribed a CBCT to determine the need for further treatment, such as nonsurgical, surgical or extraction 'R7' (Fig.17), which was under Group 3 (Fig. 18) and this accounted for 30.5 % of teeth. This was followed by treatment planning of resorptive lesions (R 12, 14.1%), for diagnosis in contradictory sign and symptoms (R2, 10.9%), for detection of any extra canals or complex anatomy (R3, 10.9%), detection of VRF (R6, 10.2%) and to access treatment complications associated with separated instruments or overextended obturation material (R8, 10.2%). The need for treatment planning for surgical re-treatment (R9) was solely under Group 3 and identification of calcified canal (R4) was solely under Group 2, as anticipated.

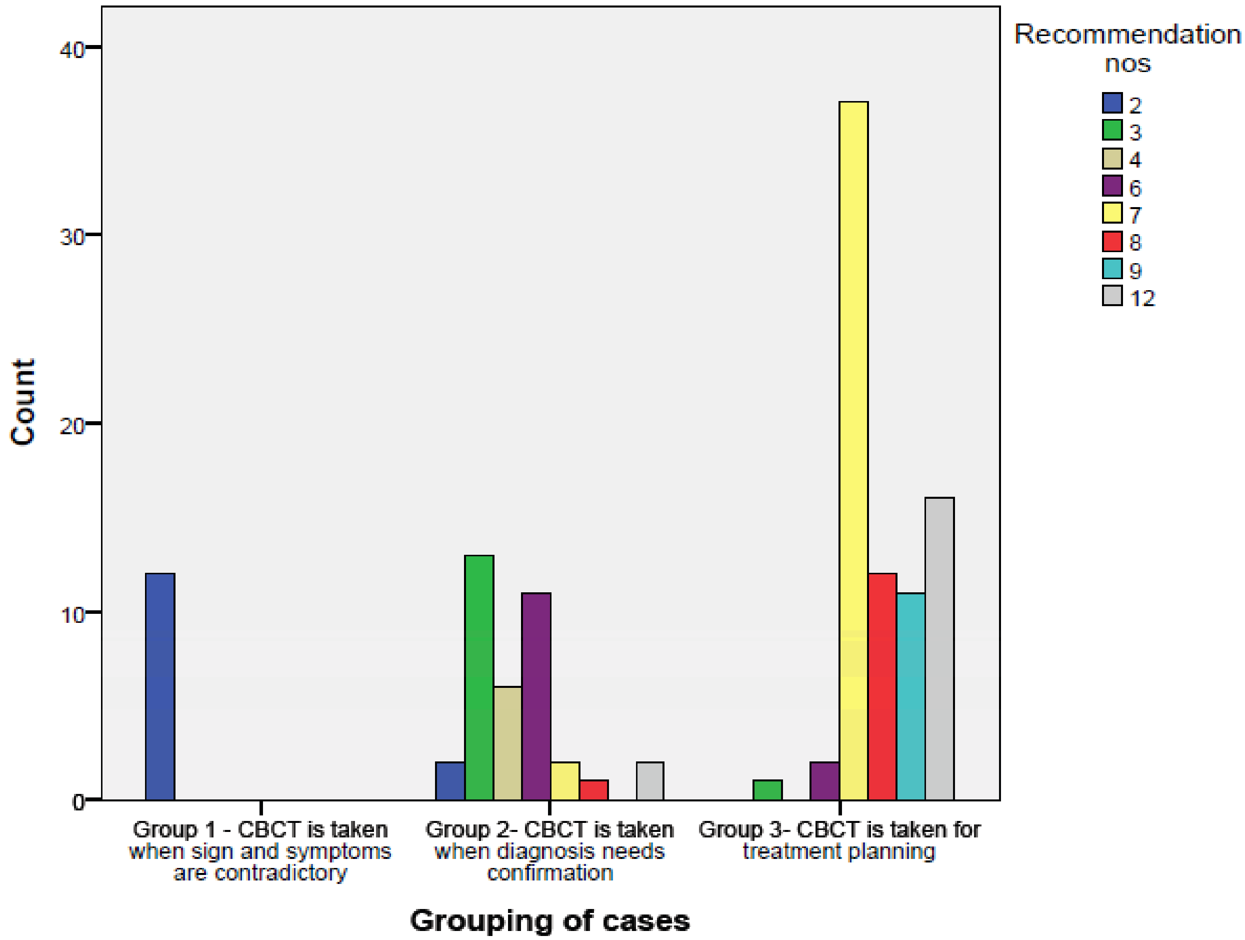

Figure 18: Frequency of recommendation numbers under groups of cases.

Recommendation number	R2	R3	R4	R6	R7	R8	R9	R12	Total number of cases	Significance level
GP - 1	12 (100%)	0	0	0	0	0	0	0	**12**	p < 0.001*
GP - 2	2 (5.4%)	13 (35.1%)	6 (16.2%)	11 (29.7%)	2 (5.4%)	1 (2.7%)	0	2 (5.4%)	**37**	
GP - 3	0	1 (1.3%)	0	2 (2.5%)	37 (46.8%)	12 (15.2%)	11 (13.9%)	16 (20.3%)	**79**	
Total number of cases	**14**	**14**	**6**	**13**	**39**	**13**	**11**	**18**	**128**	

* *Pearson Chi-square test*

Table 26: Association between grouping of cases and AAOMR/AAE position statement 2015 recommendations

4.2.2 Comparison between diagnostic variables

Periapical lesions, extra missed canals, vertical root fracture and complex anatomy were compared between conventional radiographs and CBCT and significant value was obtained ($p = 0.002$, $p < 0.001$, $p = 0.004$, $p = 0.008$) respectively (Table 27) (Fig 19, 20, 21, 22,). Comparison between resorptive lesions and calcified canals between radiographs and CBCT was not significant ($p=0.125$ and $p= 0.289$ respectively) (Table 27). CBCT scan determined more features as compared to 2D ($p<0.001$) (Fig. 23)

Variable	Pre - CBCT identification	Post - CBCT identification	Significance level
Periapical lesions	2	15	p=0.002*
Extra/Missed Canal	1	7	p<0.001*
Vertical Root Fracture	1	10	p=0.004*
Complex Anatomy	1	8	p=0.008*
Resorptive lesions	1	6	p=0.289*
Calcified Canal	2	6	p=0.125*

**Mc Nemar Test*

Table 27: Enhancement of Features in CBCT scan

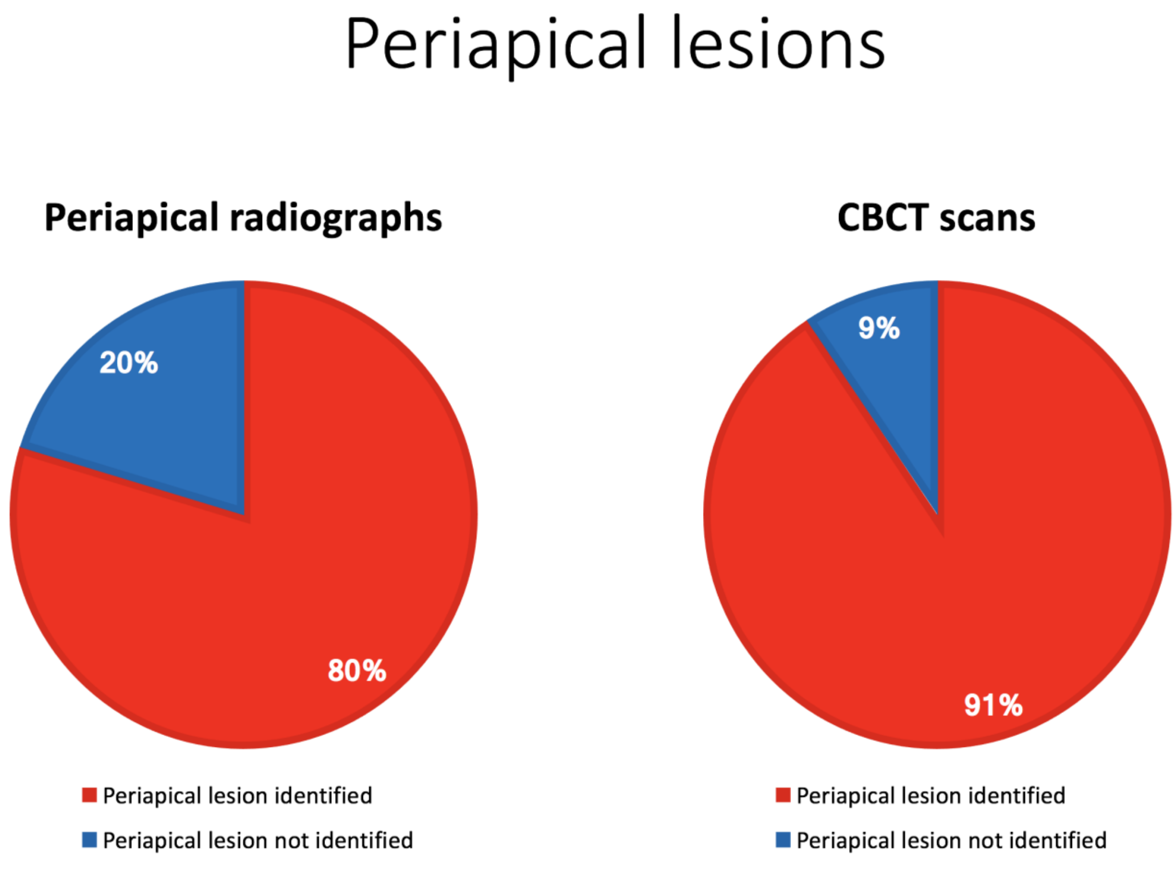

Figure 19: Periapical lesions identified in CBCT scans and radiographs

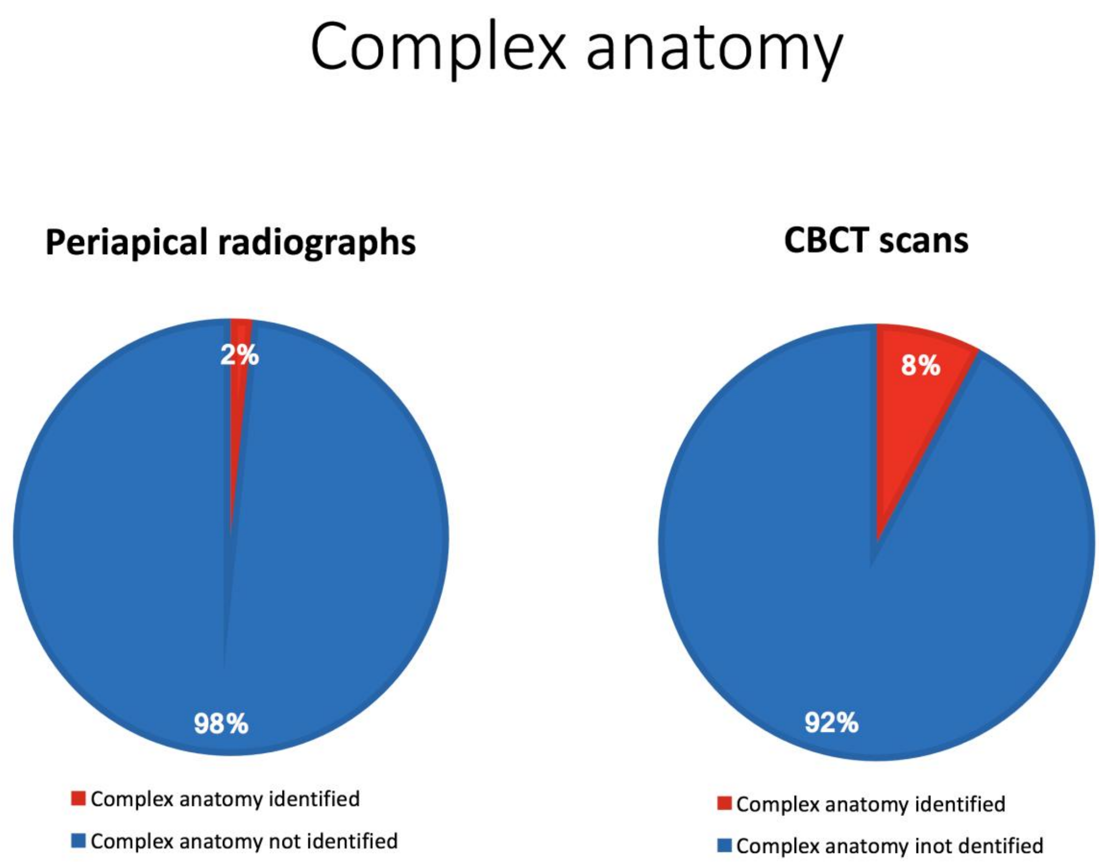

Figure 20: Complex anatomy identified in CBCT scans and radiographs

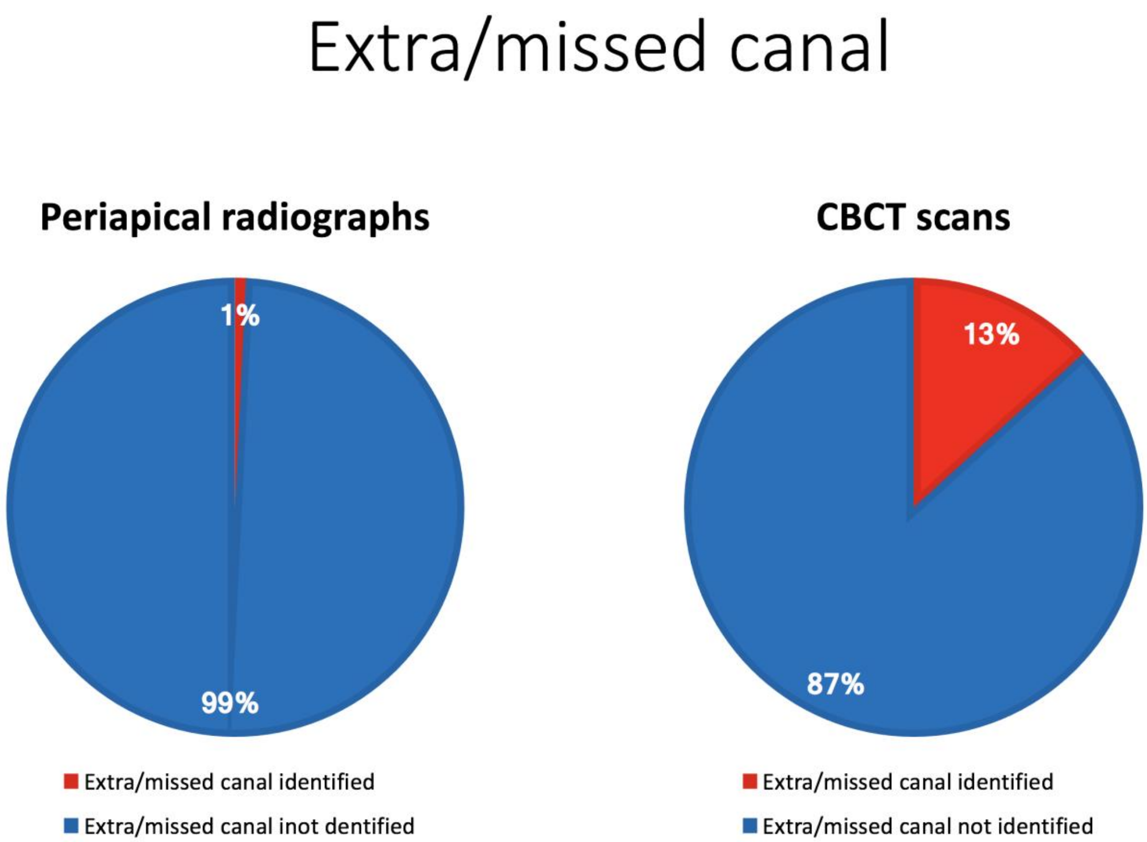

Figure 21: Extra/missed canal identified in CBCT scans and radiographs

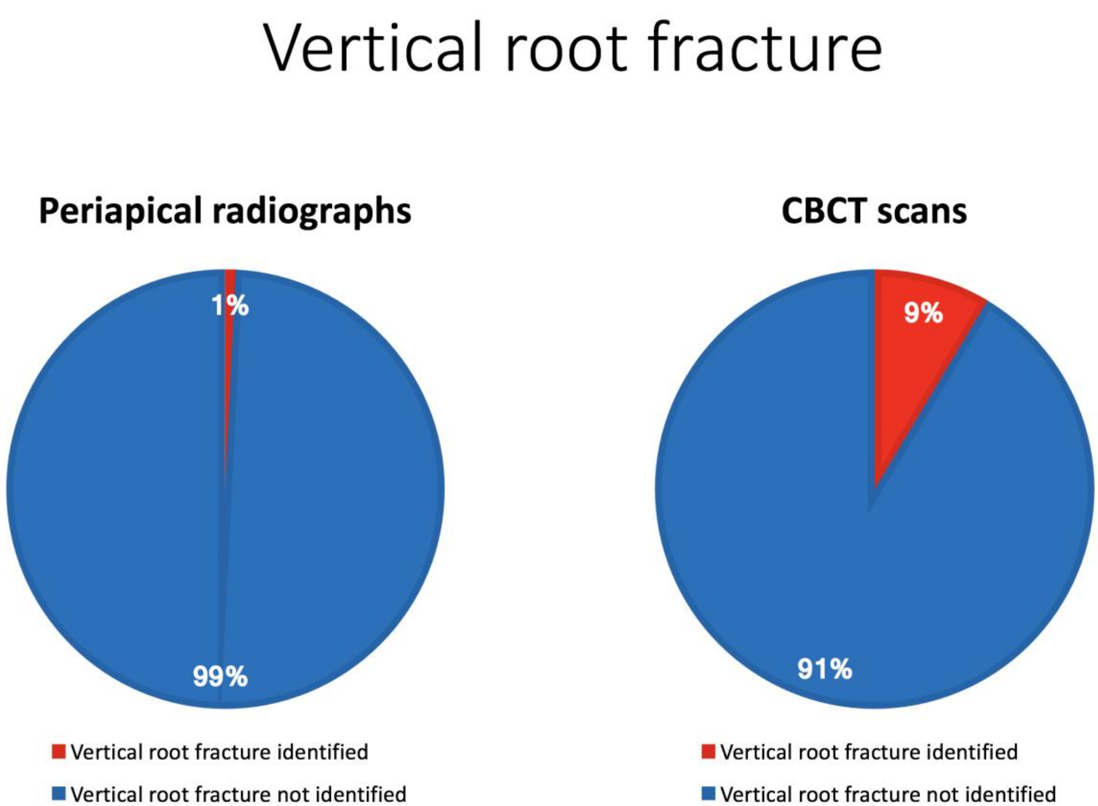

Figure 22: Vertical root fracture identified in CBCT scans and radiographs

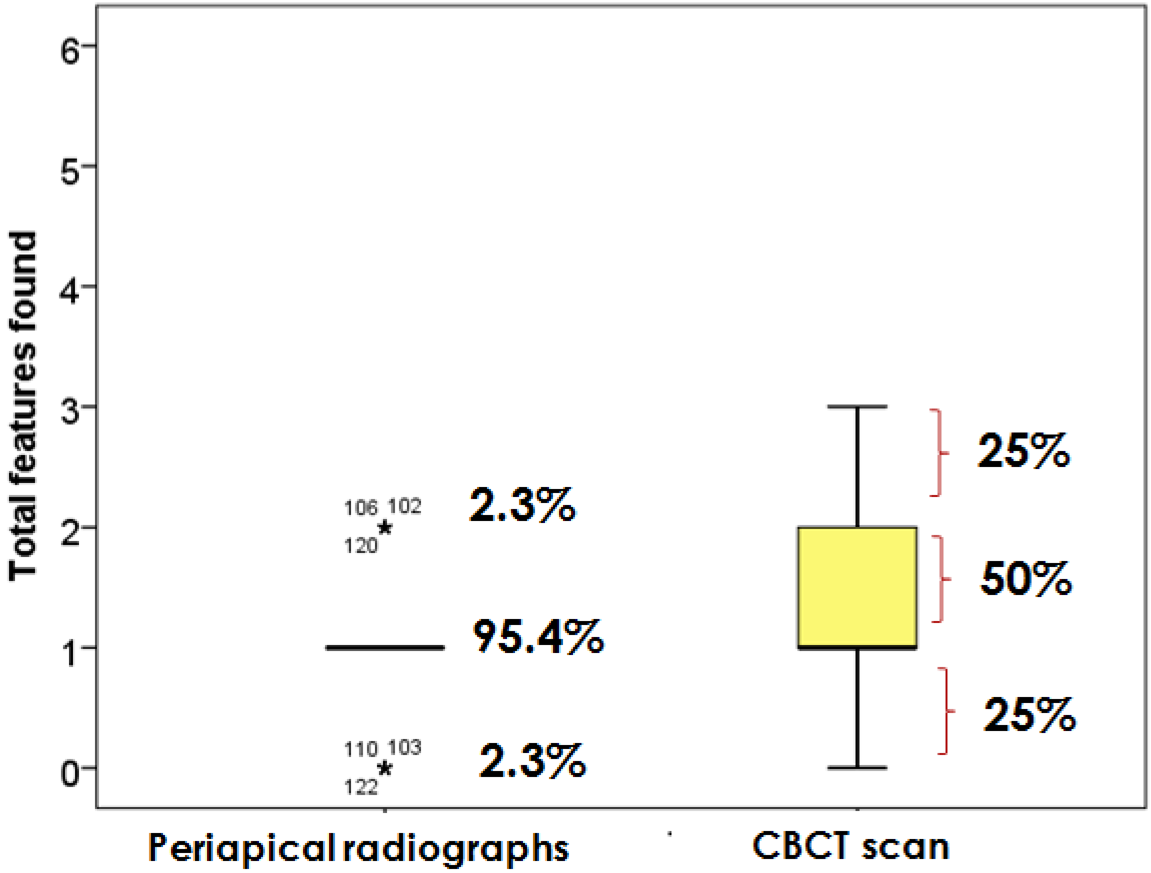

Figure 23: Box plot showing features identified in two different imaging systems

4.2.3 Diagnosis change and association between groups, position statement and tooth type.

The overall pre-and post CBCT diagnosis based on six diagnostic variables or phenomena was significant p=0.001 (Table 28). There were 82 cases where additional information was identified and in 46 cases no additional information was identified. The relationship between the diagnostic change with the groups of cases and the AAOMR/AAE position statement was significant p<0.001(Table 29) and p= 0.001 (Table 32) respectively. There was no significant relationship between the diagnostic change and the type of teeth multi-rooted-single rooted (Table 33) or anterior-posterior teeth (Table 30), even though 55 (67.1%) number of multirooted had additional information identified after CBCT examination (Table 33) and 68 (82.9%) number of posterior teeth had diagnostic change after CBCT investigation (Table 30).

Additional diagnostic information revealed	Number of cases	Significance level
Yes	82 (64%)	p=0.001*
No	46 (36%)	
Total number of cases	128 (100%)	

** Chi-square test*

Table 28: Change in diagnosis

		Grouping of Cases			Total number of cases	Significance level
		Group 1	Group 2	Group 3		
Change in diagnosis	Yes	10 (12.2%)	32 (39%)	40 (48.8%)	82	p<0.001*
	No	2 (4.3%)	5 (10.9%)	39 (84.8%)	46	
Total number of cases		12	37	79	128	

** Pearson Chi-square test*

Table 29: Association between change in diagnosis and grouping of cases

		Sextant		Total number of cases	Significance level
		Anterior	**Posterior**		
Change in diagnosis	**Yes**	14 (17.1%)	68 (82.9%)	82	p = 0.224*
	No	12 (26.1%)	34 (73.9%)	46	
Total number of cases		26	102	128	

** Pearson Chi-square test*

Table 30: Relationship between change in diagnosis and posterior/anterior sextant

		Previously endodontically treated teeth		Total number of cases	Significance level
		Yes	No		
Change in diagnosis	Yes	59 (72%)	23 (28%)	82	p = 0.177*
	No	38 (82.6%)	8 (17.4%)	46	
Total number of cases		97	31	128	

** Pearson Chi-square test*

Table 31: Relationship between change in diagnosis and previously endodontically treated teeth

		AAOMR/AAE position statement recommendation number								Total no. of cases	Significance level
		R2	R3	R4	R6	R7	R8	R9	R12		
Change in diagnosis	Yes	12 (14.6%)	14 (17.1%)	5 (6.1%)	9 (11%)	24 (29.3%)	6 (7.3%)	1 (1.2%)	11 (13.4%)	82	p < 0.001*
	No	2 (4.3%)	0	1 (2.2%)	4 (8.7%)	15 (32.6%)	7 (15.2%)	10 (21.7%)	7 (15.2%)	46	
Total number of cases		14	14	6	13	39	13	11	18	128	

** Pearson Chi-square test*

Table 32: Relationship between AAOMR / AAE position statement recommendation and change in diagnosis

		Single root	Multi-rooted	Total number of cases	Significance level
Diagnosis changed	Yes	27 (32.9%)	55 (67.1%)	82	p = 0.343*
	No	19 (41.3%)	27 (58.7%)	46	
Total number of cases		46	82	128	

** Pearson Chi-square test*

Table 33: Relationship between change in diagnosis according to root type

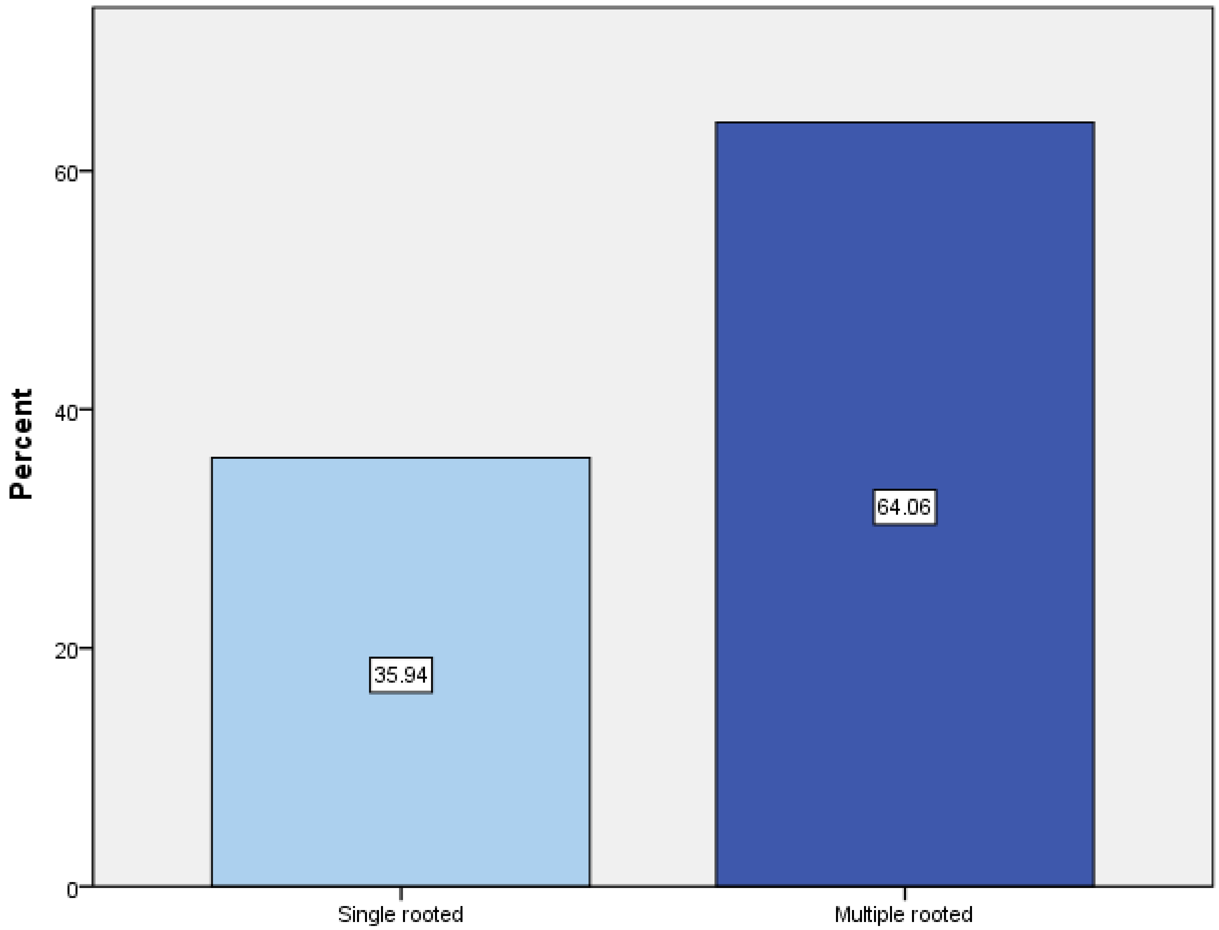

Figure 24: Frequency between single rooted and multi-rooted teeth

4.2.4 Treatment change and association between groups, position statement and tooth type

The altered or definite treatment plan made after CBCT examination was significant p=0.005 (Table 34). There were 80 cases were the treatment plan was altered and in 48 cases there was no alteration of the original treatment plan. The relationship between treatment change was further considered with grouping of cases and position statement, which was significant P=0.002 (Table 35) and P= 0.018 (Table 38) respectively. The majority of teeth prescribed CBCT were multi-rooted teeth 82 (64.1%) and 46 (35.9%) were single rooted (Fig 24). No significant association was seen between treatment change and type of teeth (multi-rooted-single rooted (Table 39) and anterior-posterior teeth (Table 36), even though the majority of treatment change was seen in 53 (66.3%) multirooted teeth and 66 (82.5%) in posterior teeth. In those occasions in which this information could not be gleaned directly from the EPR, the problem cases were reviewed in conjunction with the Graduate Endodontic Program director. There were 25 of which 21 came from the first (earlier) batch and only 4 from the second later) batch. The comparison between in determining the clarity of records as written by the graduate students was significant $p < 0.008$.

Change in treatment	Number of cases	Significance level
Yes	80	p = 0.005*
No	48	
Total number of cases	128	

** Chi-square test*

Table 34: Change in treatment

		Grouping of cases			Total number of cases	Significance Level
		Group 1	Group 2	Group 3		
Change in treatment	Yes	9 (11.3%)	31 (38.7%)	40 (50%)	80	p = 0.002*
	No	3 (6.3%)	6 (12.5%)	39 (81.2%)	48	
Total number of cases		12	37	79	128	

** Pearson Chi-square test*

Table 35: Association between change in treatment and groups of cases

		Sextant		Total number of cases	Significance level
		Anterior	Posterior		
Change in treatment	Yes	14 (17.5%)	66 (82.5%)	80	p = 0.307*
	No	12 (25%)	36 (75%)	48	
Total number of cases		26	102	128	

** Pearson Chi-square test*

Table 36: Relationship between change in treatment and sextant involved

		Previously endodontically treated teeth		Total number of cases	Significance level
		Yes	No		
Change in treatment	Yes	64 (80%)	16 (20%)	80	p = 0.150*
	No	33 (68.8%)	15 (31.3%)	48	
Total number of cases		97	31	128	

**Pearson Chi- square test*

Table 37: Relationship between treatment change and previously endodontically treated teeth

		AAOMR/AAE position statement recommendation number								Total number of cases	Significance level
		R2	R3	R4	R6	R7	R8	R9	R12		
Change in treatment	Yes	11 (13.8%)	13 (16.3%)	2 (2.5%)	11 (13.8%)	23 (28.7%)	7 (8.8%)	4 (5%)	9 (11.3%)	80	p = 0.018*
	No	3 (6.3%)	1 (2.1%)	4 (8.3%)	2 (4.2%)	16 (33.3%)	6 (12.5%)	7 (14.6%)	9 (18.8%)	48	
Total number of cases		14	14	6	13	39	13	11	18	128	

* *Pearson Chi-square test*

Table 38: Relationship between AAOMR / AAE position statement recommendation and change in treatment

		Single root	Multi-rooted	Total number of cases	Significance level
Change in treatment	Yes	27 (33.8%)	53 (66.2%)	80	p = 0.505*
	No	19 (39.6%)	29 (60.4%)	48	
Total number of cases		46	82	128	

* *Pearson Chi-square test*

Table 39: Relationship between Change in treatment and tooth type

4.2.5 Relationship between diagnosis and treatment change

The relationship between the change in diagnosis and treatment was significant p=0.003 (Table 40). There were 82 cases where additional information was identified, out which 59(72%) had significant information to alter the treatment plan. 23(28%) did not have any treatment change despite additional information. 46 cases did not have a change in diagnosis, but out of which 21(45.7%) had more definite plan whereas 25(54.3%) cases had no change in treatment.

		Change in diagnosis		Total number of cases	Significance level
		No	Yes		
Change in treatment	No	25 (52.1%)	23 (47.9%)	48	p = 0.003*
	Yes	21 (26.3%)	59 (73.8%)	80	
Total number of cases		46	82	128	

* *Pearson Chi-square test*

Table 40: Association between additional information revealed and treatment altered

4.2.6 Previously endodontically treated teeth and non-endodontically treated teeth

Out of 128 teeth 97 (75.8%) were previously endodontically treated and 31 (24.2%) teeth had no previous endodontic treatment (Fig 25). In 97 previously endodontically treated teeth, 59 (60.8%) had a change in diagnosis and 64 (66%) had a change in treatment plan, whereas in the 31 non-endodontically-treated teeth, 23 (74.2%) had a change in diagnosis and 16 (51.5%) had a change in treatment plan.

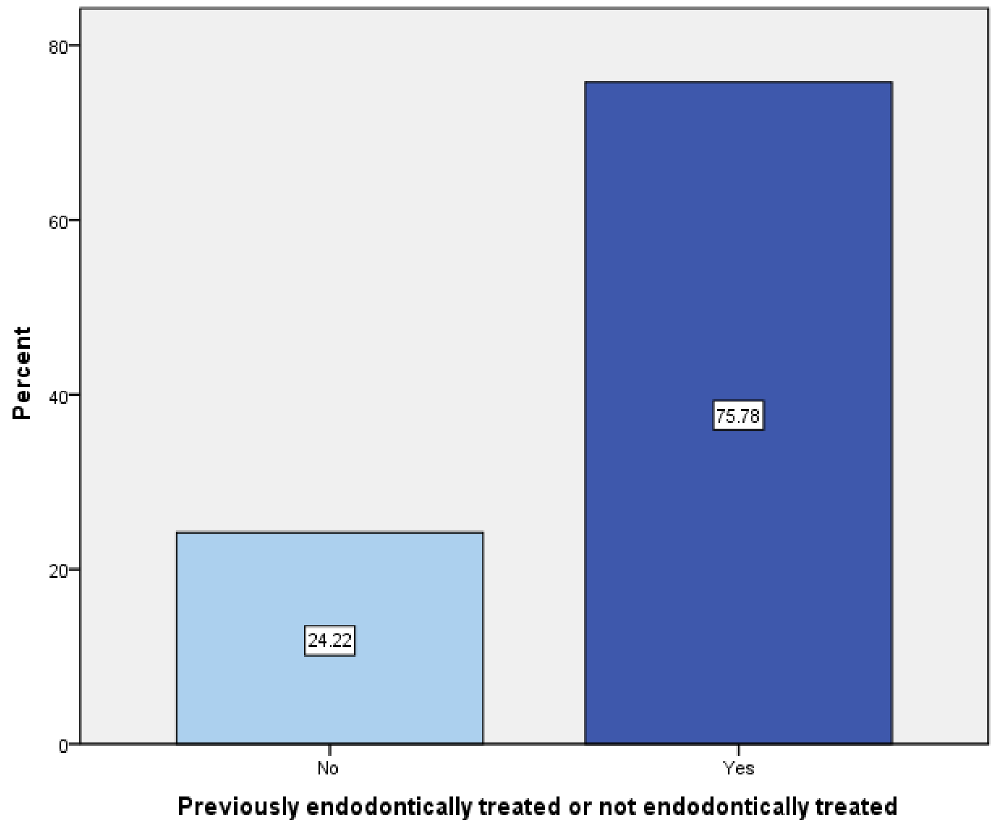

Figure 25 : Frequency between previously treated or not

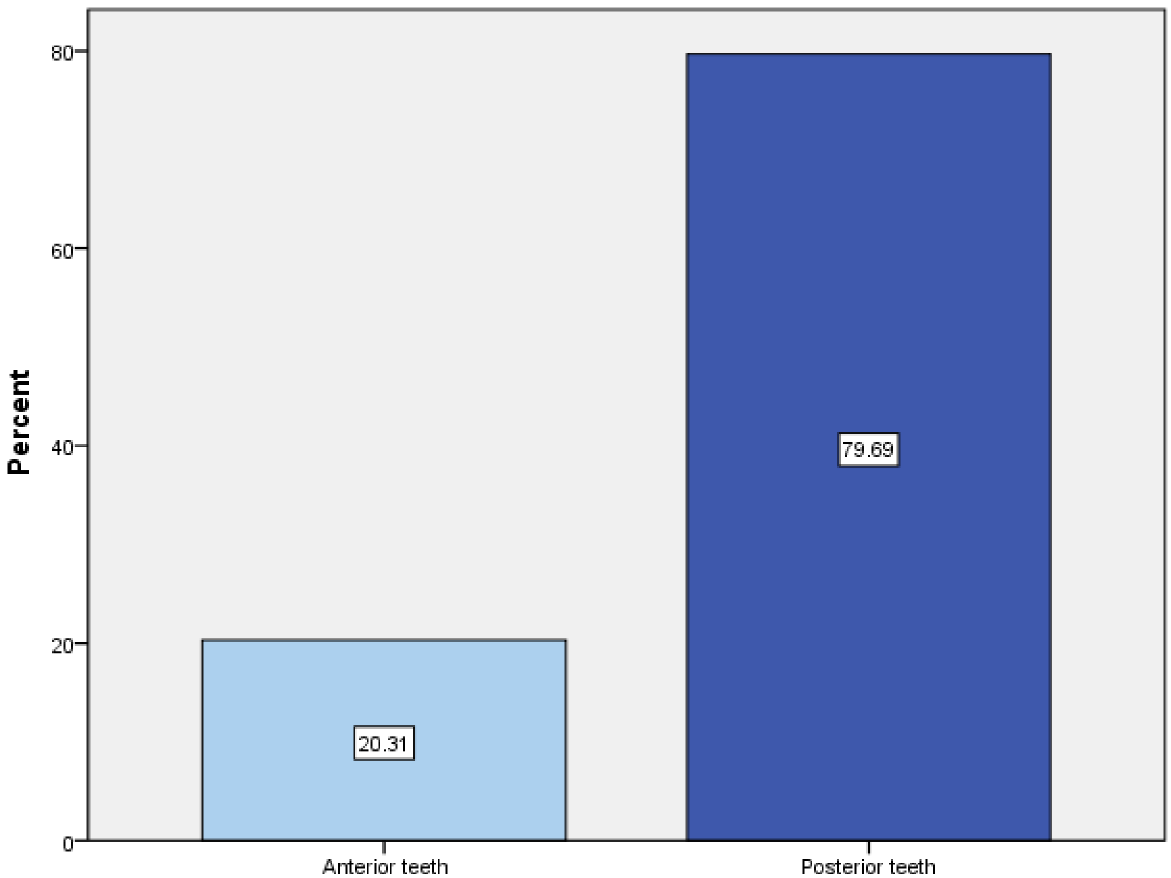

Figure 26: Frequency between anterior and posterior teeth

4.2.7 Age and gender

CBCTs were more frequently prescribed for females (68, 61.81%) than for males (42, 38.18%), this was significant (X^2 = 0.0432). Majority of patients were in the age range of 51 years and above (71), followed by patients in age range of (30-50 years, n= 35), (20-29 years n= 3) and only 1 patient in age range of 10-19 years. Gp.1 tended to have proportionally few retreated patients (X^2 = 0.0813.). Gp.2 was significantly prescribed (X^2 =0.0164) more frequently for females for the posterior sextant and more frequently for males for the anterior sextant.

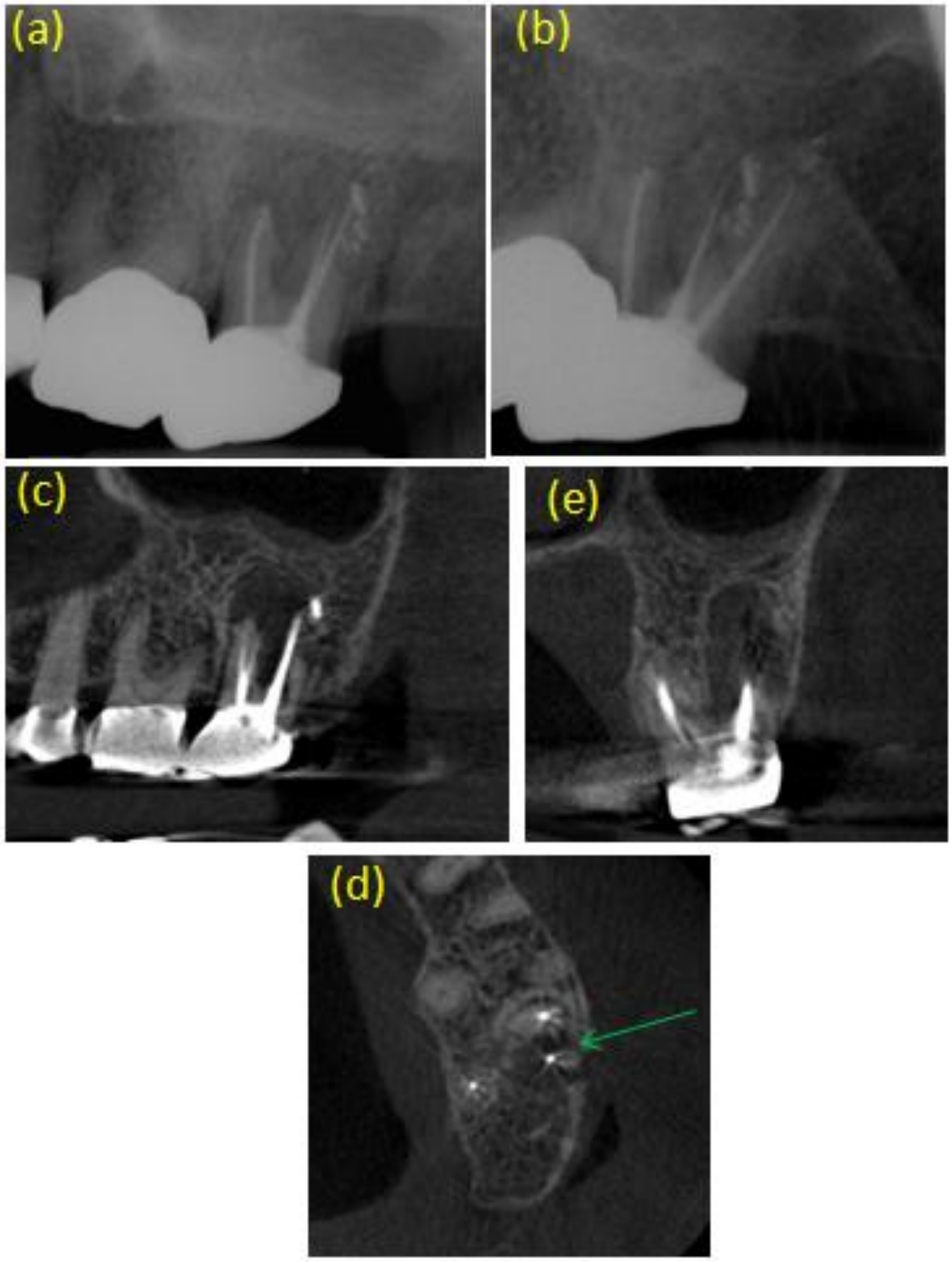

Figure 27: A case on resorptive lesions

The periapical radiographs (a) and (b) shows extrusion of root sealing materials associated with 27. There is a slight radiolucency on mesio-buccal root and furcation. Distal root and palatal seems to show some degree of resorption. The patient complained of swelling and pain in the left cheek. Percussion and bite test were positive. The sagittal view (c) and coronal view (d) shows almost complete resorption of distal root with extruded sealing material. The root has completely resorbed leaving behind the root filling material (gutta-percha). The axial view (e) shows the perforation of buccal cortex (green arrow). Initial non-surgical re-treatment was changed to surgical re-treatment (amputation of remaining distal root.

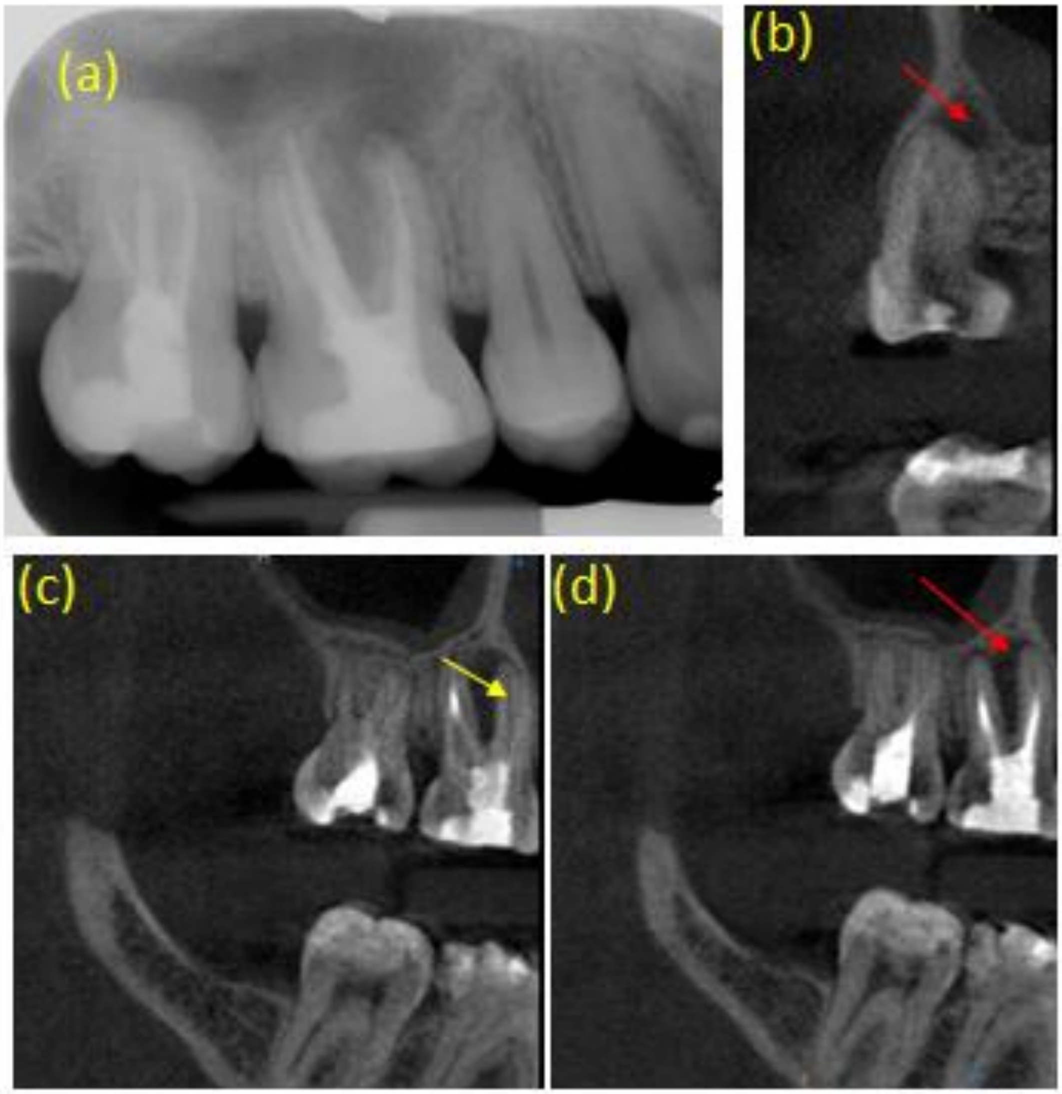

Figure 28: Case on missed canal

(a) Periapical radiograph shows a slight radiolucency associated with mesio-buccal root of 16, with short root fillings. The root filling is not centered in the root, indicating a possibility of missed canal. The patient complained of pain and swelling in the right cheek. On clinical examination 16 was associated with bleeding, 10mm of pocket depth on buccal surface with pain on palpation on the area. Bite test, cold test and percussion were negative. Clinical examinations indicate a possibility of a root fracture. This case was under Group 2 as signs, symptoms and radiographic features were contradictory. Patient was sent for CBCT to confirm root fracture. (d) Sagittal view and (b) coronal view show root fillings with associated radiolucency (red arrow). The radiolucency looks more prominent and distinct in CBCT scan. New periapical radiolucency has also been identified on the palatal root, which was not clearly evident on radiograph. (c) Same tooth on different sagittal plane shows a missed canal (yellow arrow) on mesio-buccal root. A definite treatment plan of non-surgical re-treatment plan was created after CBCT examination. P.S. CBCT shows not only a missed canal in 16 MB root but also a missed canal in 17.

Figure 29: Perforation in a calcified canal

(a) Periapical radiograph and (b) sagittal view show a perforated middle third root canal of 34, associated with a periapical radiolucency. (b) sagittal and (c) Axial view show the calcified root canal in middle third.

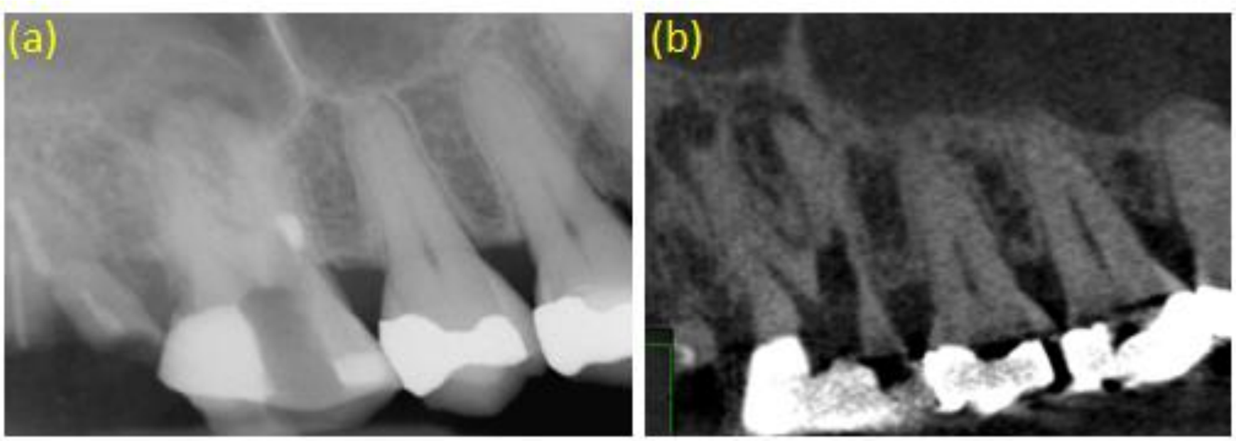

Figure 30: Excessive dentin removal

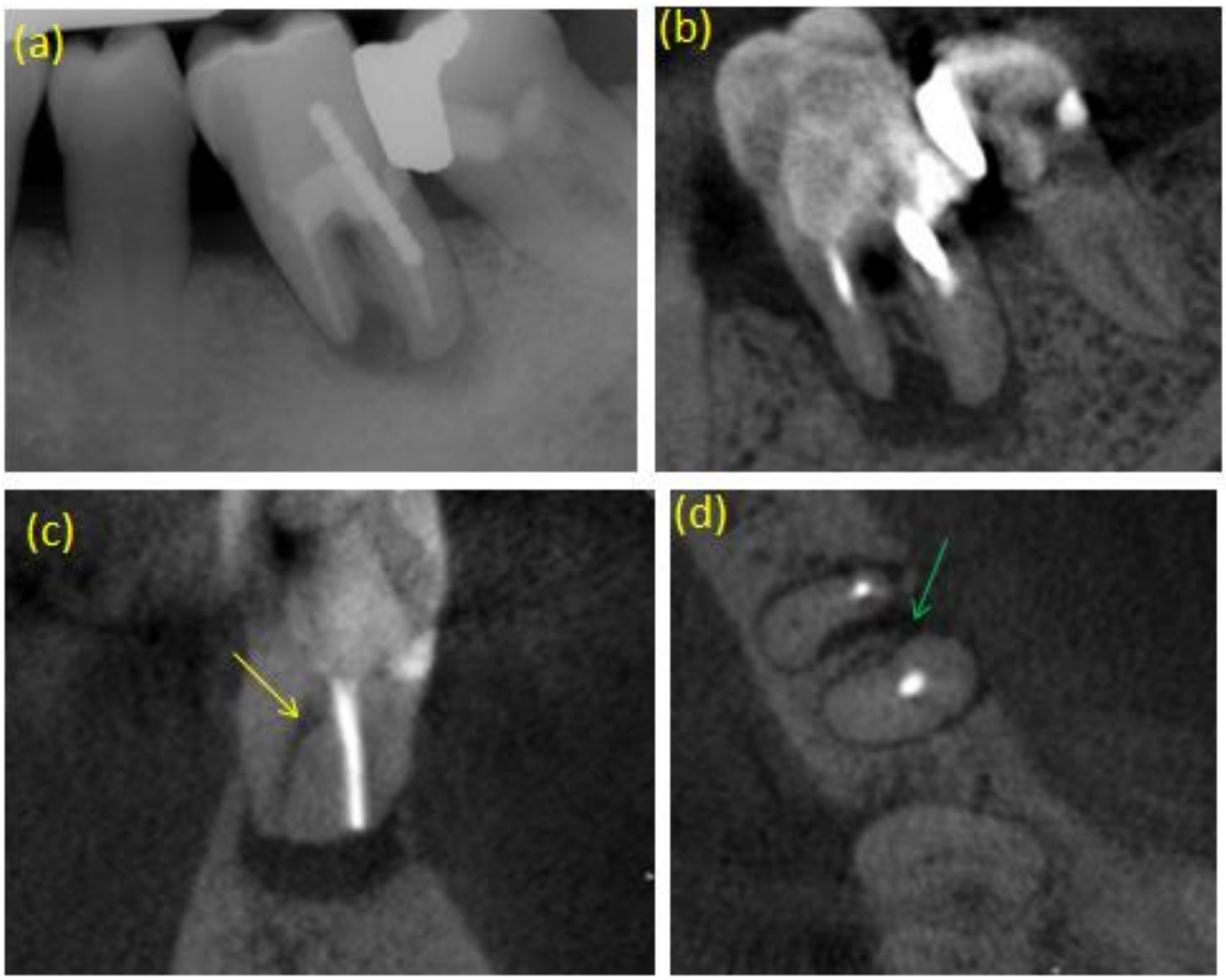

Figure 31: Case on furcation involvement

(a) Periapical radiograph and (b) multi-planar sagittal view shows a periapical radiolucency on previously endodontically treated 37. The periapical radiolucency has involved both the roots. CBCT shows post very close to furcation; significant buccal bone loss' with apical radiolucency (c) coronal view and (d) axial view shows the missed mesial lingual canal (yellow arrow). This identification of extra canal was a new finding. Notice the buccal cortex perforation (green arrow). The treatment plan was changed from extraction to surgical re treatment.

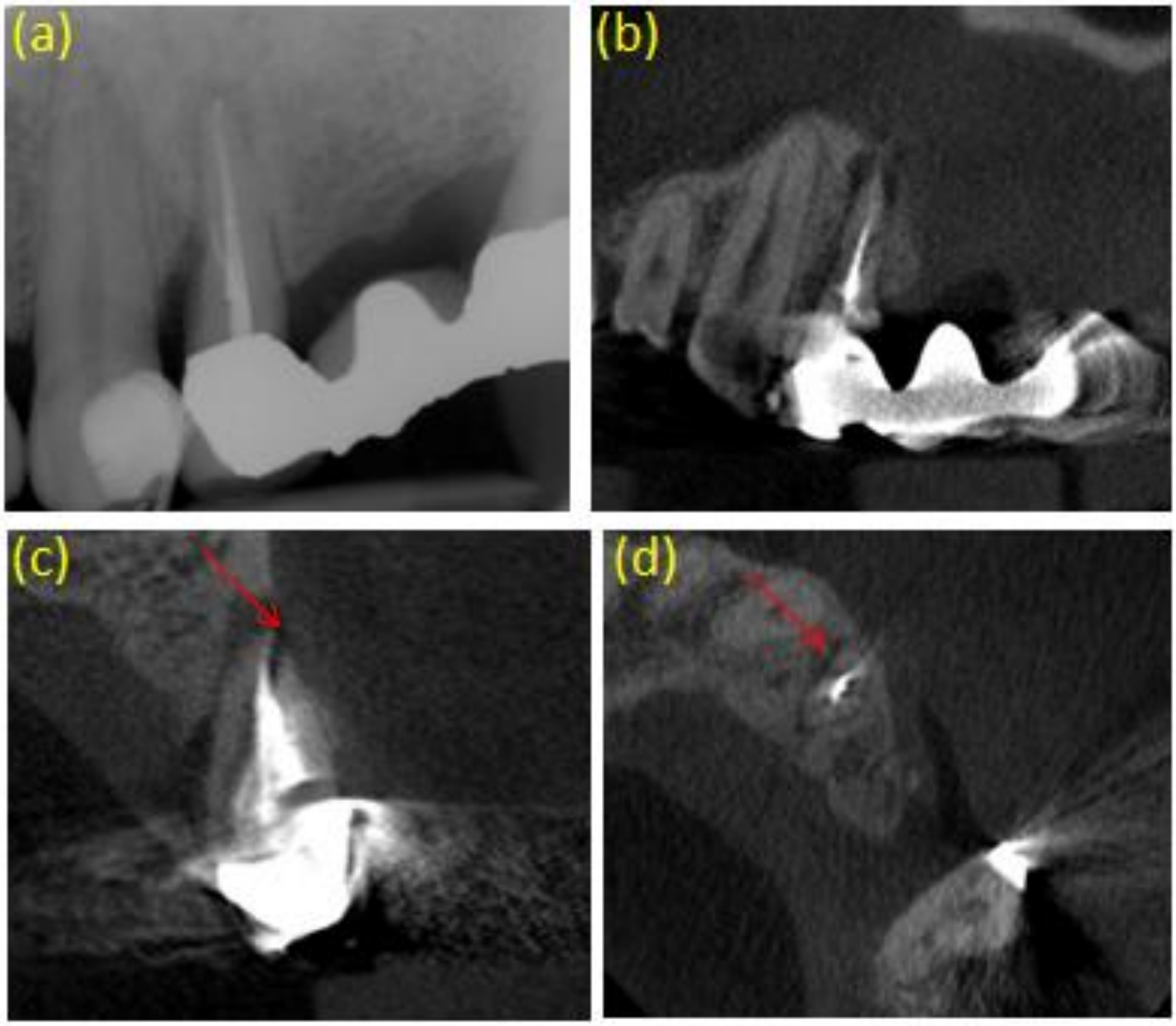

Figure 32: Case on vertical root fracture

The periapical radiograph shows a widened periodontal space on the mesial of 24 and radiolucency at the tip of the root. The patient complained of pain with persistent fistula associated with 24. There was a single site deep probing depth of 7mm on mesial of 24. Palpation, percussion and bite test were negative. (b) sagittal view shows more enhanced radiolucency associated with the root of 24. (c) coronal view and (d) axial view shows presence of VRF (red arrow)

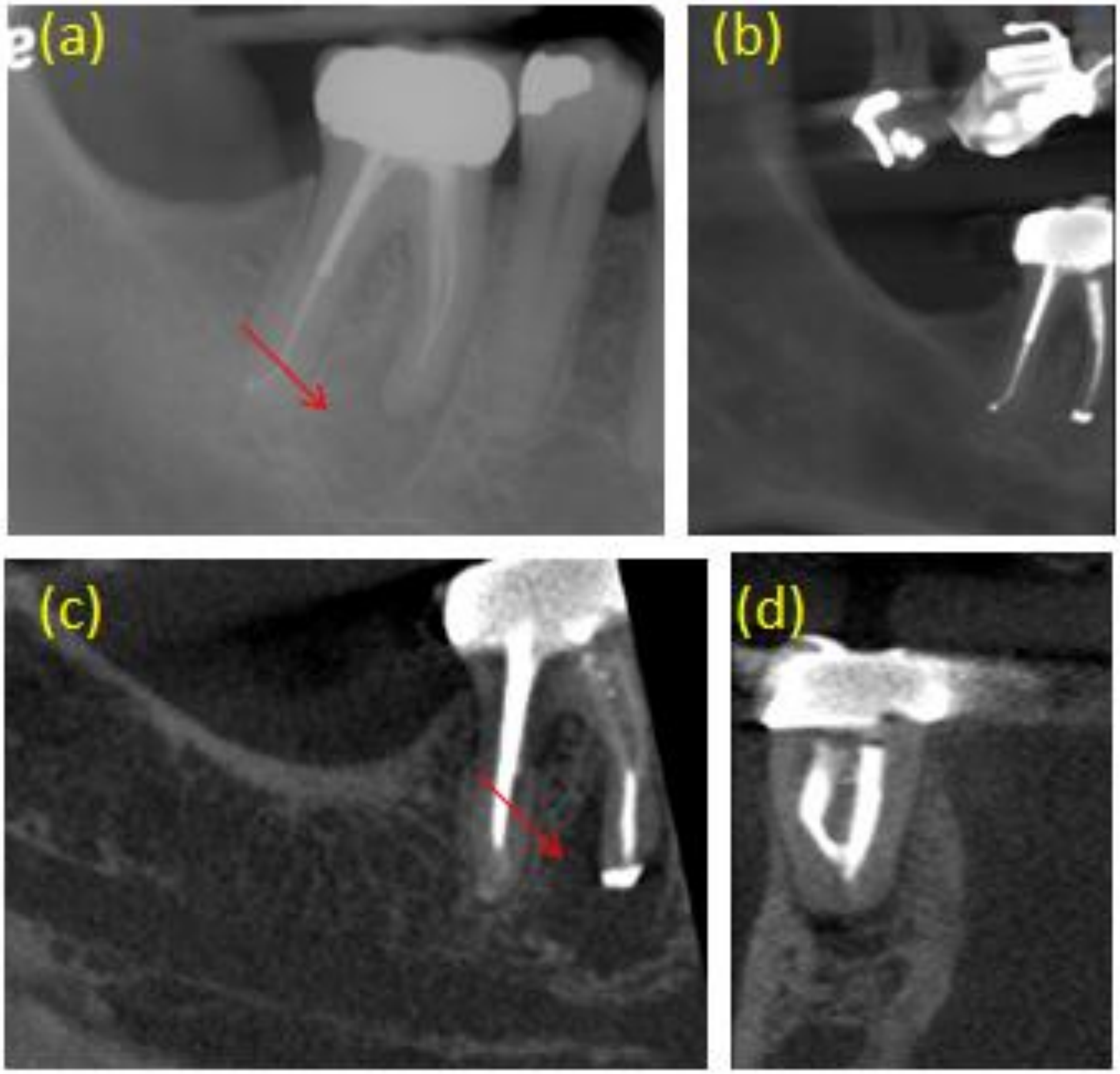

Figure 33 : Case with a broken file

The CBCT was taken for treatment planning of 47 with a broken file. The periapical image (a) and sagittal view (b) shows broken file on mesial root of 47. There is extrusion of root sealing material which is clearly evident on CBCT images. Coronal view (d) shows that the two mesial canals join. The mesial root is also associated with the well define periapical radiolucency (red arrow). The radiolucency is very close to the mandibular canal. The surgical treatment was changed to non-surgical re-treatment due to the vicinity of the root apices with the mandibular canal.

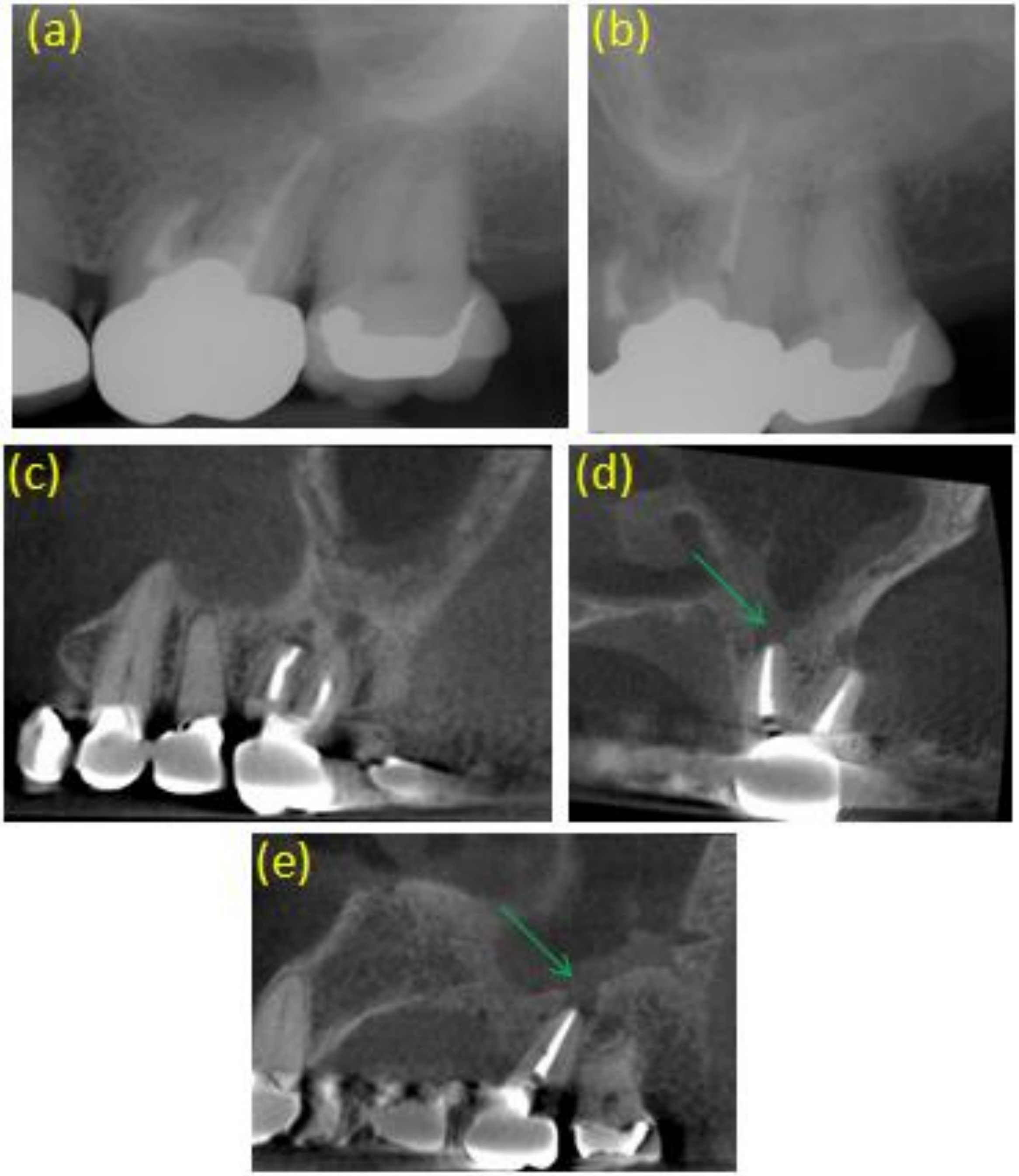

Figure 34: Superimposition of anatomical structures

The patient complained of consistent pain in the area of 26. (a) Periapical radiograph shows a very slight radiolucency in the furcation area. Percussion and bite test were positive. The CBCT examination shows periapical radiolucency (c) sagittal view on the mesial root. Periapical lesion on palatal root and distal root has caused bone loss and even perforated the sinus floor (d) and (e) (green arrow). The lesion in radiograph is superimposed by the anatomical structure (zygomatic process in this case).

Chapter 5: Discussion

5.1 Part 1

Dentistry has experienced the introduction of two innovative technologies which have wrought fundamental changes in the practice of dentistry. These technologies are Osseo-integrated implants and CBCT. The latter's introduction was prompted by the need to obtain cross-sectional imaging of the prospective implantation site. This requirement for cross-sectional imaging was recommended by the AAOMR in 2000 (Tyndall & Brooks, 2000), when the available cross-sectional imaging technologies were medical computed tomography imparting a high radiation dose and dentally-operated tomographic units, such as the COMMCAT and the SCANORA, which imparted much lower doses. The last two produced poorer quality images, which were also subject to magnification. Although CBCT had first been applied experimentally in dentistry in 1988 it did not become commercially available until just before 2000. The first report on its application to pre-implant planning was published in 2003 and from then the number of publications on this topic gradually increased annually in the course of the subsequent decade (MacDonald et al., 2017: Table 1). Even though there is an increase use of CBCT in dentistry, not much emphasis has been placed on the applications of CBCT to dento-alveolar conditions and treatment By reference to this table it can be understood why Tyndall and Rathore commented upon the dearth of CBCT literature pertaining to dento-alveolar lesions and their treatment when they published in 2008 (Tyndall & Rathore, 2008). Indeed a wide range of such lesions have only relatively recently reported (MacDonald, 2016; MacDonald, 2015). Nevertheless in the meanwhile CBCT has continued to impact dentistry across the globe as evidenced by the wide range of countries-of-origin of the CBCT cases featuring in the aforementioned publications (MacDonald, 2016; MacDonald, 2015). This world-wide adoption is substantially due to its facility for multi-planar imaging for a lower purchase cost, easy and cheap installation costs (virtually similar to a standard panoramic radiography unit), smaller footprint, and better spatial resolution than the medical-facility installed multi-detector computed tomography (MDCT). CBCT has almost completely displaced MDCT from the dental theatre, except when neoplasms, large and/or vascular lesions are suspected. As a result, CBCT has become is very popular in North America, particularly in those states and provinces which did not curtail or restrict its early use. Ontario was the most restrictive in Canada and British Columbia (BC)with most permissive. At the time of writing 250 CBCT units have been installed in BC. This wide spread use of CBCT in BC was the main catalyst for the development of the current CBCT-focused OMFR course in both the graduate and DMD programs at UBC's Faculty of Dentistry.

Although CBCT is now used in almost in all dental fields, it is still most commonly used in pre-implant planning as earlier reported by De Vos et al (De Vos et al., 2009). Osseointegrated implants were first developed by the Swede Per-Ingvar Brånemark and his colleagues (Branemark, 1977), transforming the practice of periodontology, which in turn to a substantial degree drove the development of CBCT. Furthermore, CBCT, as already explained, has now become a standard care in implantology for diagnosis and treatment purposes. CBCT allows the clinician to determine with a high degree of accuracy the size and shape of the implant required and its precise spatial placement. These both enhance the quality and life of the implant in addition to reducing peri-surgical complications. Such complications are occasioned by violation of mandibular canal, lingual foramina and thereby the lingual artery, submandibular fossa and maxillary sinus (MacDonald, 2011). (Yilmaz et al., 2016) concluded that “inadequate radiological assessment was the most common cause of” iatrogenic trigeminal nerve injuries related to implant surgery. The same group later declared that “given the elective nature of implant surgery,” iatrogenic trigeminal nerve injury should be fully avoidable (Ucer et al., 2017).

CBCT assists the clinician in determining the dimensions of the proposed implant site and its relationship to adjacent anatomy, thus enabling that clinician to minimize injury to the neurovascular tissues (Fig.11). In addition to those within the mandibular canal, the risk of violating branches of lingual artery during the surgery for placement of implants in the anterior mandible, particularly when it extends to the lingual canals and/or foramina. This has already provoked at least two dozen potentially life-threatening sublingual hemorrhages, which were reported in the literature (MacDonald, 2011). These reported cases are likely to represent only the tip of the ice-berg, since professional approbation and the real risk of litigation is likely to attend their publication. A minority of CBCT were prescribed by the Graduate Periodontics program for non-implant related reasons such as the need for a detailed morphological description of angular bone defects (Table 11). These and CBCTs prescribed for furcation involvement had already been identified by Vandenberge et al (Vandenberghe et al., 2007) as reasons for CBCT prescription. CBCTs have also been used for the post-operative assessment of the implant (Bornstein et al., 2014). CBCTs were prescribed postoperatively in only two cases in this audit (Table 11). They were prescribed when the implant was failing or when healing was not progressing normally. The prescription of such CBCTs is exceptional as most post-operative radiography is performed by conventional periapical radiographs.

The audit found most common reasons (Table 11) for CBCT scans were for implants (65.6%) for implant procedures were for to assess the bone quantity (width and height of the alveolar site of interest) and quality (trabecular density and cortical thickness), post sinus-lift and lateral ridge augmentation follow up. Though these were derived overwhelming from the Graduate Periodontics Program (97.5% of all CBCTs from that program) 84.8% of the CBCTs prescribed by the Graduate Prosthodontics Program were also for pre-implant planning. This is not unexpected as it was the activities of this particular specialty which Brånemark's invention was most affected. Nearly 50% of the CBCTs prescribed for the DMD program were for pre-implant planning and reflected an earlier amendment of the curriculum to introduce both Implants and CBCT into the DMD clinic whenever appropriate cases presented (Table 15). This practice is now being followed by other undergraduate dental programs.

The FOVs chosen in 64.6% of cases were the smallest, namely 5x5, reflecting the single implant that was required for that case (Table 17). This institution's recommendation for the use of a small FOV in those cases in which a single implant is being considered has been recently supported by (Yilmaz et al., 2016) who recommended small FOVs when using CBCT for pre-implant planning in the posterior sextant of the mandible. These cases would have been substantially partially dentulous and the implant was required to support and crown or serve as the abutment of a bridge spanning a one or two tooth gap. This would have been the principle reason for CBCT prescriptions generated by the Graduate Prosthodontics and DMD programs for which the 5x5 FOV CBCT was prescribed in 80.4% and 75% of cases respectively. The larger 10x5 FOV would have indicated the plan to place more than one implant dispersed around the same arch (Table 16). Whereas the 8x8 and 10x10 reflect a need to place implants in both arches.

The larger 10x5 and 10x10 may also have been prescribed with a view to harvesting the vertical ramus for grafting.

The next largest CBCT prescribing program was Graduate Endodontics program which this audit found to have prescribed 15.4% of the CBCTs (Table 12). They were all focused endodontic-related issues arising from a single tooth. Therefore, it is no surprise that the FOVs chosen were the smallest, namely 5x5. The prescription of a CBCT in order to determine the size and location of a periapical lesion was also made by the graduate programs in Prosthodontics and Orthodontics, and the DMD program.

Although a periapical radiolucency of inflammatory origin (PRIO), or possibly dentigerous cysts, would have been high on the differential diagnoses for the graduate prescriber’s other more serious lesions, such as neoplasms would have been higher on the prescriptions arising in the DMD program. This in part reflects the respective patient pools. The main criterion used by those screening patients for the undergraduate clinics, particularly the DMD program is that they should reflect the needs of the general dental public, presenting a range of problems covering more than one specialist area requiring treatment. These patients are treated by the students supervised by general dentists with ready access to specialists, including OMFR, when necessary. One such case considered to be a KCOT was subsequently diagnosed histopathologically as a glandular odontogenic cyst (GOC) (Figure 13), which behaves like a neoplasm in certain cases, with a recurrence rate of 18% (MacDonald, 2016). Another case which presented in the undergraduate clinic was considered to be a possible neoplasm on conventional radiography to be provisionally diagnosed as a solid ameloblastoma (Fig. 12), which histologically confirmed.

The absence of compelling evidence for CBCT cephalometry in preference to conventional cephalometry, persuaded the directors of the Graduate Orthodontics Program to confine the former to cleft-lip and palate and craniofacial anomaly patients. As a result, only one patient identified by the audit fell into this criterion.

Those patients managed in the graduate specialist programs generally present with cases that are too difficult to treat in the DMD program and thus provide a better learning opportunity for a graduate student of an appropriate specialty. Because the majority of specialty patients at the time of this study will have been to a substantial degree triaged by their passage through the DMD program, fewer need to be investigated for serious lesions such as the aforementioned neoplasms. Nevertheless, endodontists serving the community-at-large will encounter the whole gamut of lesions that affect the face and jaws. Recently, a patient was referred to an endodontist who realized that it was not a PRIO and promptly set in train as sequence of events which led to the prompt diagnosis and treatment of a non-hodgins lymphoma arising within the maxillary alveolus (MacDonald et al., 2017). Furthermore, it is not surprising that CBCT is prescribed for investigating of periapical lesions, which in the contemplation of PRIOs in the Graduate Endodontic Program, since it has been shown that CBCT can provide high diagnostic value for periapical pathology (Lofthag-Hansen et al., 2007; Venskutonis et al., 2014). This is important since periapical cysts and granulomas are likely to respond differently to different treatment (MacDonald, 2016). This will be discussed more in part 2.

The CBCT has been very useful in determining the orientation of the unerupted teeth and related resorption of the adjoining tooth. CBCT is indicated more specifically for pre-surgical assessment of impacted maxillary canine and its relation to erupted incisors (MacDonald, 2015) (Fig. 10). CBCT is becoming an important diagnostic tool for impacted teeth especially maxillary canines and for the related resorption of the adjoining teeth (van Vlijmen et al., 2012). The exact positioning and orientation of the impacted canine is important both to the orthodontist and to the surgeon as the position of its apex and crown can vary markedly in 3 planes. Another important feature is resorption of neighboring permanent incisors, particularly the lateral incisor is common (Liu et al., 2008) in spite of the presence of 8 reports, which met Eslami et al's (Eslami et al., 2017) inclusion criteria on the topic of CBCT and impacted maxillary canines, there is still a dearth of strong evidence for a preference of CBCT over conventional radiography for this clinical activity. Nevertheless, (Eslami et al., 2017) concluded that CBCT was more effective than conventional radiography "in evaluating cases that are difficult to diagnose in the initial evaluation with conventional radiology."

A study was done to compare the accuracy of linear distances between landmarks and to compare these readings between CBCT and physical measures, it was found that the data retrieved from CBCT were highly accurate compared with the data taken from physical measurements performed with calipers. This accuracy was achieved with "less than 1% less relative error" (Stratemann et al., 2008).

The small number of cases referred by the orthodontists and just one referral from Pedodontics reflected the concern that the more radiosensitive child patient should only be investigated by the least radiation dose and only when absolutely necessary (Table 23). In a recent study it was found that there is an increase of leukemia and other cancers in children when they were exposed to ionizing radiation for medical purposes, again emphasizing the benefit of radiation over risk (Pearce et al., 2012)

The reasons for CBCT referrals in Endodontics were quite varied and assorted (Table 12). The identification of root canal systems for an Endodontist is very demanding; any missed canal leads to endodontic failure. Martherne et al found that, the endodontist was unsuccessful in identifying, on periapical radiography, the entire root canal systems in 40% of teeth (Matherne et al., 2008). Another challenging area in endodontics is identifying tooth fractures especially the root fractures and cracks. Edlund et al reported that CBCT revealed a positive predictive value of 91%.(Edlund et al., 2011)

The majority of CBCT prescribed patients was female, particularly in the seventh decade (60-69 years) (Fig. 14). The onset of post-menopausal osteoporosis and periodontal bone loss is well reported. Both osteoporosis and periodontitis are characterized by bone loss. Osteoporosis features a generalized loss of bone throughout the skeleton resulting in a reduction in the cancellous microstructure and an enhanced risk of fracture. The bone loss in periodontitis is confined to the dentate alveolus and may result in tooth loss. Wang and McCauley assert that the majority of cross-sectional studies confirm the association between osteoporosis and periodontitis mainly by measurements from conventional radiography rather than clinically (Wang & McCauley, 2016). The multiple risk factors that have been identified and shared by osteoporosis and by periodontitis are age, genetics, hormonal changes and smoking and deficiencies in calcium and Vitamin D. nevertheless, periodontitis has other factors that peculiarly contribute to it. These are oral hygiene, socio-economic status. Regardless, of the underlying cause or causes Friedman and Lamster clearly declare that tooth loss is a predictor or shortened longevity (Friedman & Lamster, 2016). Currently, there is no comparable evidence to counter this be showing that treatment of tooth loss by osseo-integrated implants can enhance longevity. Such a study will have to take into account the patient's ability to pay and therefore socio-economic class. Almost universally the provision of implants and the attendant need for CBCT rests upon the personal resources of the patient as these are generally not covered by government-supported healthcare or by private health insurance policies, certainly in North America.

5.2 Part 2

The main aim of this part of the study was to determine if CBCT detected significant additional information that would change the initial diagnosis and / or change the treatment plan that was initially formulated after reviewing the clinical findings and the conventional radiographs. The clinicians should also keep in mind the differences observed are clinically important or not. In this context, it is the clinician's clinical decision making to see if the CBCT clinically benefits the patient or not. In this study, the comparison between the conventional radiography and CBCT scans proved that CBCT is most useful in detecting new periapical lesions (Table 27, Fig. 19). This study also demonstrated that CBCT assisted in the detection of missed/extra canal (Fig. 21), complex anatomy (Fig.20) and VRF (Fig. 22). With respect to missed/extra canals, there were 14 cases which were sent for identification of missed canal under AAOMR/AAE Recommendation

3, but there were 3 extra cases where missed canal was a new finding (Fig. 28 and Fig. 31) making it a total of 17 cases where extra/missed canal was identified. The significant differences were observed in the EPR between CBCT and periapical radiography with respect to missed canal (Fig. 21), periapical lesion (Fig. 19), complex anatomy (Fig. 20), and VRF (Fig. 22) (Table 27). The comparisons between root resorption and calcified canals apparent on CBCT and on conventional radiographs were not statistically significant in this study (Table 27).

The reason for this was that since the diagnosis of root resorption and calcified canals were mostly achieved by conventional radiographs and particularly in the case of calcified canals, subsequent intra-operative discovery that the canal could not be instrumented. In such cases, CBCT was mainly prescribed to assist treatment planning in those cases as it allowed precise determination of the location and of the extent of these lesions (Fig. 27)

The identification of the exact location and extent of the calcified canals by CBCT directed the endodontist to it without the excess removal of tooth structure that would have otherwise have been necessary (Fig. 30).

The overall change in diagnosis or additional information revealed in our study sample, irrespective of the type of diagnostic variable, by CBCT was significant as compared to the conventional radiographs (Table 28).

The association between the change in diagnosis from the initial diagnosis was dependent on the recommendations by AAOMR/AAE position statement reason, as per our study (Table 32). Change in the initial treatment planning in complicated endodontic cases wrought by the CBCT will have reflected the extra and better information due in large degree to CBCT's multi-planar display in all three plans (axial, coronal and sagittal). This multi-planar display more clearly revealed structure obscured by superimposition in the periapical radiographs which is just a 2D depiction of the 3D region of clinical interest (Fig. 34).

Another reason for the change in treatment planning was attributed to CBCT's revelation of involvement of buccal or lingual cortex (Fig. 31). These changes are erosion and/or displacement of these cortices. The presence of either or both can change the proposed initially-contemplated non-surgical re-treatment to surgery.

The CBCT allowed better display of periapical lesions and determination of their size and their relationship to the roots. In 19 cases the change in treatment from the initially contemplated pre-CBCT non surgical re-treatment was to actual surgical treatment, this surgical re-treatment took the form of apicoectomy or surgical extraction (Fig.31 and 32)

The CBCT was effective in determining the exact vicinity of the root tips to anatomical structure, in such cases CBCT was merely used as a measuring tool (Fig.33). There was only 1.2% of (Recommendation 9) treatment planning cases (Table 32), where additional information was revealed, in rest of the (Recommendation 9) 10 cases, CBCT was not useful in detecting any missed information but was rather helpful in determining accurate dimensions. Recommendation 9 cases were prescribed CBCT for treatment planning. In all these cases apicoectomy was already decided after periapical radiographic interpretation.

The secondary aim of this study was to identify the in-house clinical indications; used to prescribe the CBCT and then co-relate them with the AAOMR/AAE 2015 position statement, our results show that CBCT was most frequently prescribed to assist treatment planning (Gp.3) rather than for diagnosis (Gp.1 or Gp.2) (Fig 16). Gp.3 had the most recommendations under it, almost all the recommendations related to treatment planning (Table 26, Fig 18). Gp.1 accounted for 9.4% of cases with only one recommendation (Recommendation 2) under it, whereas Gp.2 had recommendations for diagnosis purposes, and these reasons which were more precise in nature (Table 26) were all under AAOMR/AAE recommendation (Recommendation 2).

The most common AAOMR/AAE recommendations under treatment planning (Gp.3) was to determine the need for further treatment, namely as to whether it should be non-surgical, surgical and if so, whether apicoectomy or extraction (Recommendation 7- non-healing endodontic cases) (Table 2). Although the AAOMR/AAE recommends (Recommendation 3- complex anatomy or extra canals)(Table 2) pre-operative use of CBCT for identification of extra/missed canals prior to initial treatment, a hiatus was discovered in this recommendation, which was not addressed by another AAOMR/AAE recommendation. Almost all the CBCTs prescribed for identification of missed canals in the present study were already previously endodontically treated and therefore were not under initial treatment procedures. This would suggest that identification of missed/extra canals is not just an issue prior to primary endodontic treatment, but is also pertinent when the already endodontically-treated tooth is being considered for re-treatment or post-operative treatment procedures. This is not a surprise since the need for the recommendation in the first place was that missed canal would be minimized and the success of the primary treatment enhanced. Therefore, the omission with regards to consideration of missed canals in already endodontically-treated teeth, that being evaluated for re-treatment, most likely occurred during the redaction of the AAOMR/AAE recommendations rather than it was never contemplated. The present study is not the first study to observe this phenomenon. Wolcott et al earlier had reported a significant difference in detection of MB2 canals between the initial root canal treatment and the retreatment (Wolcott et al., 2005). This finding is similar to our study, where the majority (13.4%) missed canal in maxillary first molar was detected in already endodontically-treated teeth. This study suggests that the most common failure rate in maxillary first molar can be attributed to missed MB2 canal. Therefore, this AAOMR/AAE recommendation should be amended to reflect the finding of this study, or if this is not possible then an entirely new one addressing the hiatus should be included.

This study confirmed the importance of CBCT in the diagnosis of and in the treatment planning for complicated endodontic cases. Being a multi-planar imaging modality, CBCT does reveal additional diagnostic information that may lie hidden or be otherwise obscured in a 2-D image on a conventional radiograph (Fig. 34). Due to the limitations of periapical radiography some of the important information was not apparent leading to a wrong diagnosis and to ineffective treatment planning. Nevertheless, a CBCT prescription should be based on clear clinical indications. Therefore, the prescriber should have a clear understanding what information a CBCT can reveal and whether it will be significant enough to impact the treatment plan. Although study revealed that only a small proportion of patients (the 110 cases constituted 12% of all patients reviewed in the Graduate Endodontics Program during the study period) were prescribed at least one CBCT examination this sample size is to date the largest. This again signifies that CBCT examination in endodontics is only required in a small proportion of endodontic patients. This need for CBCT may be even lower in an endodontist's office serving the community-at-large. Furthermore, all candidates for CBCT use at UBC are thoroughly scrutinized complying with ALARA; before they can be send for further imaging. This means that existing conventional radiographs are thoroughly reviewed prior to any prescription for CBCT is considered. It appears that the CBCT was more often used for previously endodontically-treated teeth than non-endodontically-treated teeth (Fig. 25). Even though there was a high percentage of a previously endodontically-treated tooth in our sample, the relationship between previously or not previously treated and change in diagnosis (Table 31) and treatment (Table 37) were not significant. Similarly, multi-rooted teeth were more frequently prescribed CBCT than single-rooted teeth, the resultant changes in diagnosis and in treatment between root types were not significant. Therefore, it can be concluded that in this study that a prescription for CBCT was not dependent on the need for CBCT examination. This study also displays that multi-rooted and endodontically-treated teeth are more difficult in diagnosing and treatment planning, owing to the complexity in such cases. Hence, the reason for the high number of CBCT prescriptions. Not all cases were initially treated by the Graduate Endodontics Program. As the majority of these patients were immigrants from other countries and outside North America, the conditions under which their initial endodontic treatment was performed could not be determined.

Another consideration to keep in mind while following up previously endodontically-treated teeth is the late failures or successes. (Molven et al., 2002) case-series of orthograde-treated endodontic patients in their undergraduate clinic revealed late failures and successes in the course of their nearly 3-decade study. Although, ideally, follow-up should be performed, this was not possible in this retrospective study owing to the short follow-up time after the initial endodontic treatment or re-treatment in this relatively-recent established Graduate Endodontics Program.

This study would appear to be unique, the information upon which this study was based were directly derived from the EPR records were taken reflecting the use of CBCT by endodontists in real clinical settings. In those occasions in which this information could not be gleaned directly from the EPR, the problem cases were reviewed in conjunction with the Graduate Endodontic Program director. As most of these cases came early in the program, they do not reflect the tighter record-keeping of the present program.

As per the imaging hierchial model of diagnostic efficacy (Fryback & Thornbury, 1991) (Fig.35) the use of CBCT lacks the evidence of its diagnostic efficacy. The majority of research on CBCT in endodontics is based on technical efficacy and diagnostic accuracy (Rosen et al., 2015). Our study reflects the therapeutic efficacy as per the Fryback & Thornbury imaging model (Fig. 35).

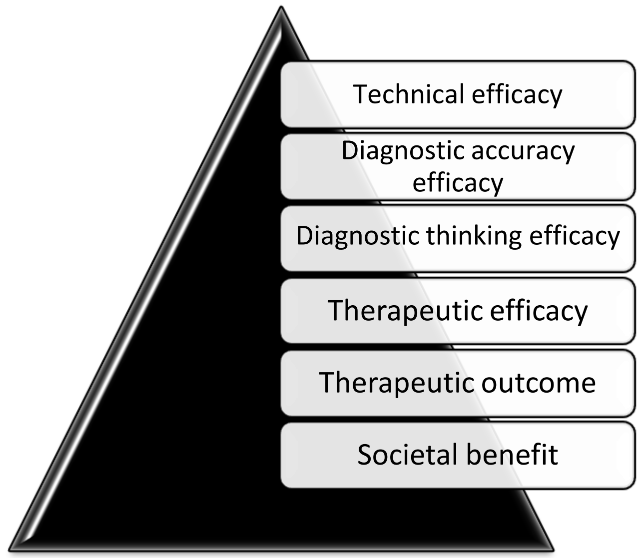

Figure 35: Fryback and Thornbury imaging model

To date there appear to be very few published reports which have considered the change CBCT has wrought on the initial diagnosis and/or the treatment planning of endodontically-involved teeth (Ee et al., 2014; Mota de Almeida et al., 2014) (Table 41). The reasons for CBCT prescription in this study addressed all AAOMFR/AAE recommendations indicating that it mirrored the real life-clinic situation. The review of the clinicians' notes and where necessary the intervention of the program director endeavored to reveal some of the endodontist's thought processes that led to the prescriptions. One of the strengths of this study was that patients presented with real clinical problems and a genuine history. Unlike the aforementioned studies the present study also had hitherto the largest sample size derived from an endodontic clinic in addition to covering the whole gamut of reasons of referral (Table 41).

Study	Retrospective	Consecutive Case series	Sample size (patients)	CBCT unit	Spatial resolution
Cheung et al (2013)	Yes	No - selected	60	I CAT	0.3 mm Voxel size
Almeida et al (2014)	Yes	Yes	57	3D Accuitomo 170	0.08 mm and 0.125 mm Voxel size
Ee et al (2014)	Yes	No - selected	28	Kodak 9000 3D	Not mentioned
Present study	Yes	Yes	110*	Carestream 9300	0.9 mm Voxel size

Table 41: Comparison between similar studies and our study

5.2.1 Limitations of the study

This study is based upon a consecutive case series of endodontic patients prescribed at least one CBCT for endodontic reasons

According to the dental epidemiologists Bulman and Osborn, it is the patient not the tooth or root which is the basic unit, because it is independent. Counting more than one tooth in the same patient is not independent because they are subject to similar conditions. Unfortunately, using the patient as the basic unit, is not always achievable when actual patients are involved. In the present study 2 separate CBCT were prescribed for 18 patients. Each supplemental CBCT was for a different tooth than the first CBCT and often for different clinical reasons or indications. Although this latter point means that more than one CBCT prescribed in the same patient for different teeth and different indications are to some degree dependent of each other, it makes little difference in a clinical study based on a consecutive case series diagnosed and treated in a similar clinical environment. In order to be meaningful such a case series needs to be as comprehensive and as complete as possible, thus, in this study, requiring the inclusion of all CBCTs.

The comprehensiveness of the consecutive case series is further and perhaps uniquely enhanced by the fee structure Graduate Endodontic Program has used since its inception in 2009. This fee structure was formally decided between the Graduate Endodontic Program director and the Clinic Director. All patients admitted for complex/advanced endodontics pay a set fee that covers completely the cost of a CBCT if so required. This fee is a fraction of the full cost of a CBCT. This means that the financially-challenged patient will not be deprived the appropriate means of diagnosis that would enable the endodontist to inform optimally the patient with regards to the diagnosis, treatment options and prognosis. Therefore, any patient who presented with a case of complex/advanced endodontics and were otherwise admissible to the Graduate Endodontics Program and who required a CBCT was prescribed one. Once prescribed a CBCT was invariably performed unless at the time of exposure it the patient was found to have a major contraindication such as severe Parkinsonism or some other neurological condition that made the patient remaining still during the 20 second exposure impossible. No prescribed cases were cancelled.

This study is wholly based upon the entries into the electronic patient record.

There was no inter-examiner panel created in our study. This was not perceived to be necessary as the clinicians' electronically-entered notes in the institution's EPR were reviewed. These notes reflect the input of endodontically-credentialed faculty in every case. Whenever their meaning was uncertain the case was discussed with the program director. Interestingly such cases generally only affected the earlier cases reflecting the value and success of continuous quality assurance processes both of this new program and the faculty as a whole, which only became wholly 'filmless-and-paperless' within the last decade. The assessment of such processes was not an aim of this study, although the researchers were aware of their progressive and continuous nature. It was considered important that the researchers endeavored to view the notes through the eyes of the endodontists who produced them rather than import a non-endodontic bias. The risk of this bias would have been further enhanced if the images were also reviewed at the time of the review of the notes. The images were reviewed only after the review of the notes a particular case had been completed. The images were not subject to independent analysis in this study, which focused retrospectively upon the decisions made by the endodontists in response to these images. Nevertheless, these images were reviewed to produce visual aids (viz figures) to accompany this study.

Although the clinical experience of an endodontist will impact every clinical decision, such decisions would be consistent with a generally-accepted endodontic practice that can be expected of a credentialed-endodontist. The specialty as with other specialties in dentistry and medicine published recommendations periodically to give guidance to their memberships. These recommendations are not directives. Furthermore, the recent AAOMR/AAE recommendations were issued with the caveat that they will lose effect 5 years after publication. This reinforces the point that these recommendations are based on best-evidence available at that time and therefore are not 'written in stone.'

Electronic patient record

A completely filmless-and-paperless patient record has a number of advantages over a traditional analogue and paper operation. The entries are made on the appropriate part of the standardized record and are therefore more likely to appear in the most appropriate part of the record when it is retrospectively reviewed. Furthermore, the record will not suffer from illegible hand-writing, lost pages and images, namely radiographs and clinical photographs, which are long-standing disadvantages of the original analog system it replaced, In addition the EPR at UBC Dentistry has a number of quality control tools built into it to compel appropriate conduct such as offering clinical indications when prescribing imaging and reporting them. These were set out in the original 'hierarchy for authorization compiled by Dr MacDonald in February 2004 (updated on 3rd September 2004). Once written the entry was authorized by endodontically-credentialed faculty. An example of the on-line prescription form for CBCT is displayed in Appendix C. It is called a 'referral form' as it occurs within the specialist-referral section of the EPR. The difference between a referral and a prescription was made earlier.

King et al recently wrote "Significant improvements in endodontic record keeping can be achieved through the provision of education, departmental guidelines, consent leaflets and endodontic record keeping forms" (King et al., 2017). The Graduate Endodontic Program in addition to every other program in the UBC Dentistry have benefited from a EPR which included these and much more than a mere click on the keyboard.

The Clinical Environment of the Graduate Endodontic Program at UBC Dentistry.

Dental expertise plays an important role in endodontic-treatment outcomes (Balasundaram et al., 2012). The use of operating microscopes has immensely enhanced the quality of non-surgical endodontic-treatment by locating more canals, hence enhancing the prognosis.

But the main challenge in a study centered on a dental school endodontic program patient base, is that it may not reflect endodontic practice sited in the community-at-large. The teeth of interest in the majority of the former patients had already been endodontically treated elsewhere, mainly outside North American. Therefore, information as to what were the original conditions prior to the initial treatment and the conditions under which it was taken could not be ascertained. Nevertheless, previous radiographs and treatment notes performed in North American dental practices are not always available in spite of its importance being long emphasized in dental education.

The gold standard for vertical root fractures was a surgical investigation of the affected root. With the advent of CBCT this gold standard may be less frequently applied today than in the past. CBCT has already substantially replaced the need for biopsy for many simple bone cysts and lingual bone defects both of which are the most frequent causes of radiolucencies in the jaws which are not of inflammatory origin (MacDonald, 2016). Furthermore, CBCT displayed better the early mineralization occurring within osseous dysplastic lesions. These lesions in their early stages present as radiolucencies especially on periapical radiolucencies and have been frequently wrong diagnosed and needlessly endodontically treated. Osseous dysplasia is a major consideration in the Lower Mainland of British Columbia, where large communities of residents of East Asian origin reside. Both florid and focal osseous dysplasia present in middle-to-old aged females in these communities. Furthermore, the largely European-derived communities of Kelowna are more susceptible to, periapical osseous dysplasia, a variant of osseous dysplasia previous called periapical osseous dysplasia (MacDonald, 2015).

The success rate of endodontic-treatment depends on many factors. One of the most important factors is the pre-operative diagnosis and the type of endodontic treatment given (Molven et al., 2002). The failure rate for re-treatment of endodontic-treated teeth is higher than for those after primary endodontic treatment (Sjögren et al., 1990). The success rate outcome of healing in endodontically-treated teeth varies from 60%-85% as demonstrated in periapical radiographs (Ng et al., 2007). The studies determining the initial healing outcome concluded that CBCT was more sensitive in visualizing a periapical lesion when a CBCT is taken to assess the initial rate of healing (Davies et al., 2015). Whereas, a more recent 5-year follow-up study (Fernández et al., 2013) found a success rate of 94.3% and 92.3% in analog and digital radiographs, respectively. A minimum of at least 4 year is regarded necessary for treatment outcome (Weiger et al., 1998). There are periapical changes occurring in endodontically-treated teeth even after nearly 3 decades years of treatment (Molven et al., 2002). However, the studies concluded that the initial healing outcome appear low in endodontically-treated teeth, when evaluated by CBCT (Fernández et al., 2013; Patel et al., 2012), suggesting that CBCT is more sensitive in detecting periapical lesions than conventional radiographs. Indeed, Petersson et al’s systematic review suggested that CBCT can overestimate the endodontic failures (Petersson et al., 2012). Therefore, the findings made from a CBCT dataset should be considered with a degree of circumspection rather than a rush to retreat. The radiological finding of a feature that may indicate failure may not necessarily mean that the endodontic treatment has failed, particularly if the patient is symptom-free and the endodontically-treated tooth is functioning normally. This recalled Molven et al's study which not only reported late failures of treatment that was deemed earlier to have succeeded, but the late healing of symptom free cases that had for over at least 2 decades were otherwise determined radiologically to have failed.

So more long-term follow-up studies are required to assess the healing outcome. The main reason for endodontic treatment failure is the presence of microorganisms in the root canal systems (Cohen, 2016). There are many prognostic factors which are associated with the outcome of the endodontic treatment. A study by Fernandez et al in their study found the four prognostic factors (root canal curvature, disinfection of gutta-percha, presence of missed canals, and the quality of definitive coronal restoration) were significantly associated with the poor outcome to the non-surgical endodontic treatment (Fernández et al., 2013).

A point that most previous studies have not considered is what is actually happening in the periapical radiolucency associated with a clinically determined non-vital tooth. Periapical radiolucency associated with a non-vital tooth is referred as *periapical radiolucency of inflammatory origin* (PRIO) (MacDonald, 2016). PRIOs represent the three histological diagnoses of granuloma, radicular cyst and abscess, which differ also both in clinical presentation and in outcomes of treatment (MacDonald, 2016). After successful treatment, either by root-treatment (endodontics) or extraction, the PRIOs generally regress, unless they are already cystic in which they may persist as 'residual cysts' (MacDonald, 2016) After root-treatment most PRIOs resolve within a year, but some may persist for decades before resolving. Those that resolved early may have been granulomas, whereas those that resolved much later may have been radicular cysts (MacDonald 2016).

5.2.2 Future studies

This study exhaustively reviewed retrospectively the endodontic patient's EPR to determine the endodontist's own response to both the direct clinical information s/he was able to extract by the history taking and the clinical examination of the patient and from the review of the conventional radiographs s/he prescribed. This study then reviewed the endodontist's determination that a CBCT was now necessary and then assigned the indications to one of the AAOMR/AAE recommendations and the effect the CBCT had on the initial diagnosis and treatment plan. It would now be pertinent to move onto an in-depth and independent review of the conventional radiographs and CBCT datasets, blind to the EPR records. The perceived main outcome of this will be formative in that it will refine the teaching of oral and maxillofacial radiology to the DMD students in their Endodontic rotation and to the graduate students in the Graduate Endodontic Program. The topics for further study are: -

1. The conventional radiographs and CBCT dataset be retrospectively reviewed to determine whether adequate clinical information was already present to support the definitive treatment prior to the CBCT prescriptions.

2. Review of the multi-planar and ‘curved’ reconstructions of CBCT datasets to determine which one displayed the problem best. The multi-planar reconstruction is the native or default reconstruction for most CBCT units. It is the tradition reconstruction used in medicine. The ‘curved’ reconstruction was initially created to allow medical CT units to be used to allow planning for dental osseous integrated implants. The software was marketed extensively as ‘Dentoscan.’ Unlike the former it requires the clinician simply to denote a dental arch from which panoramic and trans-axial reconstructions are automatically generated. Perhaps because of the addition of the albeit simple steps have deterred endodontists from selecting it.
3. What role does 3-D reconstruction have in endodontic treatment planning? Hitherto there is only an *in vitro* study which indicates that this may have some clinical merit (Maret et al., 2014).
4. The series of patients should be followed-up in about 5 years from now to determine the outcomes of treatment (Weiger et al., 1998)

Chapter 6: Conclusion

6.1 Part 1

1. This study shows that at UBC, majority of the patients require small FOVs thus complying with ALARA.

2. Apart from pre-implant assessment and graft procedures the next most frequent referrals were related to endodontics. Almost all the cases referred from endodontics were pre-treated complicated cases such as missed canals, root resorption, and calcified canals

3. The third most important referrals were from graduate orthodontics for ectopic or impacted maxillary canine. They were only prescribed after an inconclusive parallax, reflecting the awareness of the referring clinicians of the ‘Image Gently’ campaign.

4. A greater proportion of patients referred for implants were female within the sixth and seventh decades.

5. The jaw for which, CBCT was most frequently prescribed and exposed was the maxilla. Most of the patients were prescribed CBCTs by Periodontologists for implant purposes.

6.2 Part 2

The main conclusions of this study are:

1. The performance of this study is unique in a number of important ways: This retrospective study was based upon a review of cases prescribed a CBCT for complex/complicated endodontics.

   a. Each patient's clinical details were entered on a highly-structured EPR by endodontists. Although the primary recorder was mainly a graduate student in the Graduate Endodontic Program, each entry was approved by endodontically-credentialed faculty. The wholly filmless-and-paperless EPR, though owned by an international company, at UBC Dentistry was substantially developed at UBC's faculty of Dentistry for its own clinical and teaching requirements. Subsequent updates remained broadly consistent with these requirements.

   b. Each patient for whom a CBCT was prescribed had appropriate clinical indications for the prescription.

   c. The Graduate Endodontic Program fee for patients requiring complex/complicated endodontics included the cost of a CBCT for those patients who required it. Therefore, no patients admitted to this cohort were denied a CBCT simply on an ability to pay. This was important as many patients were financially challenged.

   d. All CBCT prescriptions were related to the most recent AAOMR/AAE recommendations. The latter served not only as a framework for this part of the study, but in turn was tested against a consecutive case series of cases for completeness of coverage.

One important hiatus was detected in the AAOMR/AAE recommendations. See Point 3 below.

2. All 128 prescriptions on 110 patients were AAOMR/AAE-guidelines compliant. The majority of CBCT prescriptions were to confirm suspected disease or to aid treatment-planning.

3. The AAOMR/AAE recommendations should amend Recommendation 3 to include missed canals in not only of teeth considered for initial treatment but also those already endodontically-treated teeth for re-treatment. If this is found not to be possible then a separate recommendation addressing this point should be made.

4. CBCT revealed more cases of periapical lesions, missed canal, complex anatomy and vertical root fracture, by virtue of its multi-planar imaging it is useful in identifying the additional information, which might be missed in conventional radiography.

5. If judged effectively, the treatment plan is dependent on the additional information gathered from CBCT examination, and a more definitive treatment plan can be formulated which can also increase the prognosis of the tooth. But studies are needed to determine the treatment outcome of such cases over a period of follow-up.

6. The majority of CBCT-prescribed teeth were already endodontically treated indicating the complexity in diagnosing and treating such cases. The presence of gutta-percha or other root fillings decreases the diagnostic accuracy in conventional radiography by obscuring features such as missed canals by superimposition. In such cases CBCT has proved useful even although

it is turn has limitations, such as metal artifact. Nevertheless, these limitations are comparatively low with respect to the advantages and the information revealed.

7. CBCT was more useful in diagnosing the periapical status of the tooth, particularly in the already endodontically-treated tooth resulting in more appropriate treatment and thereby an improved prognosis.

8. CBCT can be used effectively in surgical-treatment planning of complicated cases. It gives an accurate position of the root apices to important anatomical structures like maxillary antrum and mandibular canal. It also determines the exact location and size of resorptive lesions.

9. The prescriptions for CBCT were not confined to a particular jaw or region of the arch. The study showed that the more accurate and definitive treatment plan is dependent on the additional information revealed by the CBCT (Fig. 31), the figure explains how VRF was initially diagnosed by signs and symptoms, but CBCT examination revealed a missed canal, which was then treated accordingly, thus increasing the prognosis as compared to VRF.

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Appendices

Appendix A : Abstract for IADR 2017 (0648)

Description

Presentation Blocks: 03-23-2017 - Thursday - 11:00 AM - 12:15 PM

Title: Prescriptive Pattern Using CBCT in Endodontics

Authors:

Meeta Bhatt **(Presenter)**, University of British Columbia

David MacDonald, University of British Columbia

Jeffrey Coil, University of British Columbia

Babak Chehroudi, University of British Columbia

Andrea Esteves, University of British Columbia

Abstract:

Objectives: To identify the reason for CBCT prescription in an educational institution. To determine if the prescriptive patterns for CBCT of patients attending a single center Graduate/Residency in Endodontics were compliant with the recommendations of the American-Academy-of-Oral-and-Maxillofacial-Radiology and the American-Academy-of-Endodontics (AAOMR/AAE) position statement.

Methods: A total of 110 patients who had a small (5-centimeter-by-5-centimeter) field-of-view CBCT (Carestream-9300) were included in this retrospective study. They were considered according to gender, jaw, sextant and whether teeth investigated were for re-treatment. Each AAOMR/AAE recommendation was assigned to one of 3 groups; Gp.1, rule out disease; Gp.2, confirm suspected disease, Gp.3, aid treatment planning. Contingency table and Fisher-exact-test (FET) were used on data collected.

Results: Sixty six cases were in the maxilla of which 47 were molars, 44 cases were in the mandible of which 26 were molars; this was not significant (FET = 0.219). Females were significantly (FET=0.0432) referred more for CBCT than males. Those teeth requiring retreatment compared to those considered for first treatment was 54 to 12 for the maxilla and 34 to 10 for mandible; this was not significant (FET = 0.630). Gp.1, Gp.2, and Gp.3 accounted for 19, 42 and 49 CBCTs respectively. Gp.1 tended to have proportionally few retreated patients (X^2=0.0813.). Gp.2 was significantly prescribed (FET=0.0164) more frequently for females for the posterior sextant and more frequently for males for the anterior sextant.

Conclusions: Although all 110 prescriptions were AAOMR/AAE recommendations compliant a hiatus in the guidelines was detected. The majority of prescriptions were to confirm suspected disease or to aid treatment planning. The perceived complexity of the root canal anatomy and whether the tooth was considered for re-treatment or first treatment did not appear to confine the use of CBCT to a particular jaw or region of the arch.

Appendix B : CBCT audit checklist

CBCT QUALITY ASSURANCE REPORT AUDIT CHECKLIST

CHART # ___________________________

VOLUME #: _____ DATE OF SCAN: _______________________FOV: __________

- **Online Referral (and attached to EOHR): Y N**
  - **Approved by: ___________________________________**
- **EOHR Indicate / Request: Y N**
  - **Approved by: ___________________________________**
- **2D Screenshot Imported to EOHR: Y N**
- **INTERPRETATIONS in EOHR (linked to 2D Image): Y N**
  - **Reference entire 3D volume being interpreted Y N**
  - **Specific interpretation related to indication Y N**
  - **Approved by: ___________________________________**

Appendix C : Referral form used at UBC dentistry

Referral Form

The Referral Form is for creating a new referral. If this is not what you want to do, click here to go back.

INSTRUCTIONS FOR USE

When the need for a referral has been identified by a student or faculty member, the student will access the referral form via the shortcut on the desktop of OHC computers.

Once all details of the referral form have been completed, the student will ask the supervising faculty member to review the form and authorize the referral.

DATE OF REFERRAL: September-28-17

REFERRAL TO:

○ DHDP	○ DMD	○ Faculty Practise	○ Grad Endo	○ Grad Ortho
○ Grad Pediatrics	○ Grad Perio	○ Grad Prosth	○ OHC-Oral Surgery	○ Oral Medicine
○ Pharmacists Clinic	○ Staff RDH	○ Cone Beam CT	○ DMD Implant	- --

- -- - -- - -- - -- - --

REFERRAL FOR:

(Enter Chart Number)

REQUEST FROM:

(Enter Provider ID)

REFERRAL DETAILS:

CHIEF CONCERN:

SUMMARY OF SIGNIFICANT MEDICAL HISTORY:

AREA/CONDITION OF CONCERN:

REFERRAL TREATMENT CONSIDERED AND SUMMARY:
(using SOAP/FIFE principles, include a brief summary of investigations to date, how this treatment fits within a comprehensive plan and any information that you may have already provided to the patient about the procedure)