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The use of cone beam computed tomography in endodontics

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ABSTRACT
Since the adequacy of radiography for dental use, it has been the most widely used imaging test in endodontics. Useful in all stages of treatment, this imaging test allows us to evaluate the tooth and important adjacent anatomical structures. Because it is a two-dimensional examination of three-dimensional structures, it has considerable limitations, such as distortions, noise, and artifact projections. Cone Beam Computed Tomography has the advantage of being a high-resolution three-dimensional examination and allows the evaluation of structures in various planes without overlapping or distortions.

Keywords: Endodontics, Cone Beam Computed Tomography, Volumetric Tomography, Periapical Radiography.

1 INTRODUCTION

1.1 HISTORY OF CBCT IN ENDODONTICS

In 1899 Kells revolutionized dentistry and especially endodontics, after in an experiment he was able to detect a conductive wire inside a canal through a radiogram, allowing the endodontic working length to be established. (LANGLAND, LANGLAIS, 1995). Since then, radiography has been a fundamental tool in endodontics. (SCARFE et al. 2009). Even today, this type of imaging remains the main imaging base in this specialty.). However, in recent decades, modern medical imaging techniques have also been used in several areas of dentistry. (DURACK, PATEL, 2012).

Since the first efforts by pioneers trying to apply conventional computed tomography and microtomography in endodontics, the introduction of Cone Beam Computed Tomography (CBCT) in

1996 resulted in the first three-dimensional imaging tool for endodontic purposes. (FARMAN, LEVATO, SCARFE, 2007) After the approval in 2000 by the Food and Drugs Administration (FDA), dentists were able to use the advantages of 3D CBCT in relation to conventional radiography, which can be considered a revolution in dentoalveolar imaging, with a radiation dose similar to conventional intraoral imaging methods, including whole-mouth and panoramic radiographs. (TYNDALL, RATHORE, 2008, LUDLOW et al., 2006)

The use of Cone Beam Computed Tomography in dentistry has increased exponentially since its introduction. CT scanners have become smaller and cheaper. CT units allow you to adjust scan settings, such as Field of View (FOV) adjustment, Voxel size (resolution), and scan time. In the software, it is possible to work with the scanned images in multi-planes, allowing the dentist to evaluate areas of interest for dentoalveolar alterations, root fractures, tumors, prosthetic evaluation, orthodontic-orthognathic planning and implant planning. (ABRAMOVITCH K, RICE D, 2014).

1.2 STUDIES ON THE USE OF CBCT IN ENDODONTICS

The X-ray examination is useful in all phases of endodontics, from the diagnosis of odontogenic and non-dental pathologies, to the treatment of the Root Canal System (SCR) in infected teeth, during chemical mechanical preparation, filling and preservation of the tooth. (SCARFE et al., 2009). Periapical radiographs during endodontic procedures are the most commonly used imaging methods. They provide useful information on the presence and location of periradicular lesions, canal anatomy, and proximity to important adjacent structures. Even with all these uses, radiographs have limitations, such as the overlapping of structures (because it is a two-dimensional examination) and results in the compression of three-dimensional structures, geometric distortions (elongation and shortening) and anatomical noise. (PATEL et al., 2009).

When a 3D scan is required, CBCT is considered the gold standard. (FARMAN, 2006). Although it originates from conventional medical CT, it differs in many aspects that make it even more suitable for dental use. (DURACK, PATEL, 2012). In the late 1990s, two independent groups of Italians and Japanese developed a new tomographic scanner known as the volumetric digital tomograph, specifically for dental and maxillofacial use. Offering a lower dose of radiation, this three-dimensional examination has been implemented in oral and maxillofacial surgeries, implant dentistry, endodontics, orthodontics, periodontics, and temporomandibular dysfunction. (PATEL et al., 2007).

CBCT has a conical X-ray beam that captures a cylindrical or spherical volume of data, described as a field of view. A volume of 3D data is acquired in a single shot of the scan, using a direct and simple connection of the radiation emitter and the sensor that rotates 180º-360º around the patient's head. (PATEL et al., 2007). During the examination, hundreds of planar projections are obtained from the field of view (FOV). In this way, this exam presents accuracy and immediate 3D images. Only one rotating sensor sequence is required to acquire sufficient data for image reconstruction, since the exposure encompasses the entire FOV. (FARMAN, 2007). Each image projection consists of up to 512^2 pixels. The 3D reconstructed data will include 512^3 pixels, or voxels. (DURACK, PATEL, 2012). You can increase the number of pixels per image projection from 512^2 to 1024^2, which also increases the resolution. However, this generates a two- or three-fold increase in radiation. (SCARFE, FARMAN, 2008). CBCT uses simpler and cheaper hardware than conventional CT scanners. (COTTON et al., 2007). This has resulted in an increase in use in dental practice. (ARNHEITER, SCARFE, FARMAN, 2006). In this way, it is an exam that allows to significantly change the diagnosis and management of endodontic problems, since the dentist can easily work in the software to evaluate the areas of interest in any plan. (PATEL, 2009).

Cone beam CT scans are typically classified by volume and field of view (FOV) dimensions. This will be chosen appropriately based on the patient's pathology and region of interest to be examined. According to the availability or height of the volume to be scanned, the size of these can be classified into: Small field (< 5cm), Single arch (FOV 5-7cm), Interarch (7-10cm), Maxillofacial (10-15cm) and Craniofacial (> 15cm). (SCARFE et al., 2009). In general, the smaller the scanned volume, the higher the resolution. Ideally, in endodontics, the resolution should not exceed the mean width of the periodontal ligament (200 μm), considering that the most recent signs of periapical alterations are discontinuity of the lamina dura and splurge of the periodontal ligament. (TYNDALL, RATHORE, 2008). However, more modern CT scanners with 76 μm voxels have higher resolution and allow a better diagnosis of cracks, fractures and root canal localization, and generate a lower radiation dose. (DURACK, PATEL, 2012).

Considering the radiation emitted by cone beam CT scanners, the exposure is converted to an effective dose that is measured in Sieverts (Sv), for a meaningful comparison of radioactive risk. The Sv is a large unit, so in maxillofacial CT milliSieverts (MSv)[10-3] or microSieverts μSv[10-6] are used. The effective radiation dose for specific regions is measured and adjusted for the volume of tissues in the FOV. (SCARFE et al., 2009). For the posterior jaws, the scans generate 9.8 μSv, while for the posterior mandibulars, 38.3 μSv, and in the anterior region it generates 4. μSv. (OSER et al., 2017).

Cone beam tomography overcomes the limitations of conventional radiography by producing three-dimensional images that allow a better evaluation of the anatomy and spatial relationship of pathology and anatomical structures. (PATEL, KANAGASINGAM, MANNOCCI, 2010). The clinician can choose and view volumetric data in all orthogonal and non-orthogonal planes, so anatomical noise is easily eliminated. (SCARFE, FARMAN, 2008). The voxels of this examination, unlike conventional CT scans, are isotropic (they have the same physical properties in all directions), ensuring that the images produced are accurate, in any plane and free of distortions. (SCARFE, FARMAN, SUKOVIC, 2006).

In general, the main advantages of CBCT over conventional CBCT are the lower radiation dose and superior image quality over hard tissues. Since the X-ray beam is pulsatile, the patient is exposed to radiation for a short period of time (2 to 5 seconds) compared to the examination time of the panoramic X-ray, which is useful since the probability of the patient moving the head becomes lower. In addition, this type of examination is much cheaper than conventional CT. (PATEL, 2009). Perhaps the most advantageous feature of CBCT is that images can be reconstructed three-dimensionally in 3 orthogonal planes (axial, sagittal, and coronal). (SCARFE et al., 2009).

Regarding the limitations of CBCT, its spatial resolution and contrast resolution are lower than those of conventional analog or digital intraoral radiographs. (FARMAN, FARMAN, 2005). Radiographic artifacts are another problem. When the x-ray beam collides with a very high-density object, such as enamel or metal restorations, low-energy photons from the beam are absorbed by the structure. This produces two types of artifacts that can impair diagnostic imaging: distortion of metal structures, called rarefaction artifacts, and the presence of dark stripes and bands between two dense structures. (SCARFE, FARMAN, 2008).

Despite the few limitations of CBCT, it is extremely useful in endodontics, in more complex cases or cases in which conventional radiographic examination is limited, being extremely useful in the detection of apical periodontitis, planning for surgical endodontics, evaluation for endodontic retreatment in complex cases, evaluation of dento-alveolar trauma, diagnosis of different types of root resorption, evaluation of the anatomy and morphology of the canal, diagnosis of vertical root fractures, among others (SCARFE, FARMAN, SUKOVIC, 2006) and a more current use, is the planning of guided access for coronary opening and localization of atresial or partially calcified canals. After the cone beam tomographic examination, the images are examined, the canal is located, and an access direction to it is established. This information is sent to another software that plans a surgical access guide, which is made by a 3D printer. With the positioning of this guide in the mouth, a special milling cutter is used for the coronary opening and location of the root canal, allowing the endodontic treatment itself to be performed. (KRASTL et al., 2016).

In a study conducted by MICHETTI et al., (2010), to evaluate the accuracy of CBCT, in which the examinations of extracted teeth were reconstituted in 2 dimensions, it was concluded that this examination was very reliable and accurate when compared to the analysis under an optical microscope of the histological sections of the same teeth.

In a study conducted by USTUN et al.,(2016), 73 single-rooted teeth underwent a CBCT examination and subsequently underwent root canal treatment. The images of the examination were evaluated and the teeth in question were measured by means of tomography. During the endodontic procedure, odontometry was performed by two different electronic apical locators (Propex Pixi –

Dentstply and Raypex 6-VDW) and it was concluded that the measurements obtained by the CT scans were as accurate as those performed by the locators.

4 The definitive diagnosis of vertical root fractures in endodontically treated teeth is challenging. According to TAMSE et al. (1999), the clinical symptoms and radiographic signs are not completely pathognomonic, although PITTS, NATKIN, (1983), consider the double paths and fistulas in pouches on the opposite side of the root to be very characteristic of this type of complication. The prognosis of vertical root fractures is poor. In a study in which endodontically treated teeth were preserved for 5 years, root fracture was the adverse event in 32.1% and the treatment of choice was the extraction of the element. (CHEN, CHUEH, 2008).

BASSAM et al. (2009) conducted a study with the main objective of evaluating the accuracy of CBCT compared to digital periapical radiographs in the detection of vertical fractures in teeth with filled and unfilled roots. The second objective was to evaluate the influence of gutta percha on the detection of fractures through these examinations and periapical radiographs. According to the results, the tomographic scans were more accurate than the periapical ones in detecting vertical root fractures, but the presence of filling material inside the canal generated artifacts, impairing their diagnosis.

The proximity of the roots of the maxillary posterior teeth to the floor of the maxillary sinus may be associated with the development of chronic sinusitis. (MEHRA, MURAD, 2004). In a study conducted by LIMA et al.,(2017), 83 patients were selected and submitted to clinical examination to evaluate tooth mobility and pulp condition. In addition, a CT scan was performed to evaluate the presence of periapical lesion and bone loss and to measure the distance from the root apex to the cortical maxillary sinus. The results associated chronic sinusitis with patients with periodontal disease and/or endodontic infection near the maxillary sinus, demonstrating the usefulness of CBCT to aid in the diagnosis of chronic sinusitis of odontogenic origin.

External cervical resorption (CER) is difficult to diagnose and plan treatment even for specialists. Although its exact etiology remains unknown, it is believed to be associated with orthodontics, trauma, occlusal dysfunction, periodontal treatment, and endogenous whitening. (PATEL, KANAGASINGAM, PITT, 2009). This pathological change usually occurs asymptomatically and in 3 stages: initial, active resorption, and reparative stage. (MAVRIDOU et al., 2016). In a study conducted by GOODELL, MINES, KERSTEN, (2017), 30 teeth with WHtR were evaluated. All resorption teeth were diagnosed by CBCT scan, and 29 of the cases were detected by panoramic radiography. This only undiagnosed case was due to the lesion being located on the lingual surface of the tooth, overlapping the bone tissue. The authors concluded that both imaging studies were effective in diagnosing resorptive pathologies, however, because they presented more details, tomography allowed a better treatment plan, as it accurately showed the extent and location of the resorptions.

Radiographic examinations are essential in all stages of endodontic treatment. Along with the absence of signs and symptoms, success is also assessed by comparing baseline and follow-up radiographs. The evaluation of the appearance of periapical tissues on radiography is influenced by the overlapping of anatomical structures and the variable nature of the density and texture of the bone trabeculate. (GELFAND, SUNDERMAN, GOLDMAN, 1983). In a study in which 200 teeth were evaluated and submitted to cone beam tomography, periapical radiography and endodontically tested (through cold sensitivity tests and electrical tests), it was noted that the periodontal ligament (PL) was thicker in CBCT than in periapical radiography, because this is a more sensitive examination. The results also showed that on CT scanning, most of the vital teeth showed some degree of LP spacing. (POPE, SATHORN, PETERS, 2013).

One of the difficulties in identifying fractured instruments in filled canals using CBCT compared to periapical radiography is the production of artifacts in image reconstruction, due to the absorption of radiation due to the structural density of the metals. (NEVES et al., 2014). In a study conducted by ROSEN et al.,(2016) in which 60 teeth were divided into 2 groups (30 with fractured instruments and 30 without them), it was concluded that periapical radiography is more effective in detecting fractured instruments in the apical third of filled teeth than CBCT, as it does not generate artifacts.

One of the factors that influence the success of endodontic treatment is the anatomical knowledge of the root canal system. (BAISDEN, KULILD, WELLER, 1992). Due to the difficulty of conventional radiography methods to evaluate root canals, computed tomography has been very useful. In a study conducted by CAPUTO et al., (2016), in which 342 mandibular first molars were evaluated tomographically in order to analyze their anatomy. The results showed that 0.3% of the molars had 2 canals, 75.1% had 3 canals, 23.7% of the sample had 4 canals and 0.9% of the molars had 5 canals. It was concluded that this imaging test was very effective for the study of the morphology of the root canals.

The use of CBCT in endodontics has increased significantly and is now suggested by both the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology as the test of choice for the treatment of complex morphological root canals, calcified root canals, apecectomy, resorptions, trauma, and non-surgical retreatments. (AMERICAN ASSOCIATION OF ENDODONTISTS, 2015).

Surgical endodontic treatment should be considered when other, more conservative treatments have not been successful. Endodontic surgery evolved into microsurgery. (KIM, KRATCHMAN, 2006). Before the surgical procedure, it is essential that the surgeon is familiar with the anatomical structures as well as their dimensions, thickness of the buccal and lingual bone, dimensions and inclinations of the roots and especially location of nerves and sinuses. Radiographic examination is commonly used for surgical planning. CBCT is one of the diagnostic tools that can help to obtain accurate measurements of the surgical field, as it does not present distortions when compared to conventional radiographs. (SIMONTON, AZEVEDO, SCHINDLER, 2009). In a study conducted by LAVANASI et al. (2016), 155 cone beam CT scans were used to evaluate the measurements of 505 teeth and their adjacent areas. Through these examinations, it was possible to accurately measure the buccal and lingual bone width and the distance between the apices and the floor of the maxillary sinus. It was possible to conclude that this three-dimensional examination is a superior complementary tool in surgical endodontic planning than conventional radiographs.

Endodontic treatment failures result from incomplete debridement and filling because of the variable anatomical composition of the SCR, including apical branches and morphological variations. (SONG et al., 2011). In a study conducted by SOUSA et al., to evaluate the presence of lateral canals before and after endodontic treatment using CBCT, it was concluded that CBCT was not an effective and accurate test for the detection of lateral canals.

Many endodontic treatments fail in maxillary molars due to the forgetting of the second MV canal. (SHAH et al., 2014). The MV2 canal hole may be present in up to 95% of maxillary molars, but it is not always found. (KULILD, PETERS, 1990). Additional tools such as CBCT may be required to locate these channels. In a study conducted by STUDEBAKER et al., (2017), information, radiographs, and CT scans of 886 maxillary molars were evaluated. In 74.1% of the cases, MV2 was located during access. In 14.2% of cases, MV2 was located with the aid of drills and ultrasonic tips. In 11.7% of cases, these canals were located only with the aid of three-dimensional examination. The results showed that the CT scan was useful for the detection of these channels in many of the cases and that the MV2 channel occurred in 55.8% of the cases.

The central and lateral mandibular incisors usually have only 1 canal. VERTUCCI (1974) described the complex system of canals and identified 8 different configurations. He found that 70 percent of the central incisors and 75 percent of the mandibular lateral incisors had only one canal and one foramen. In a study conducted by SHEMESH et al., (2017), a total of 1472 central and 1508 lateral were evaluated by CBCT. The results showed that the incidence of more than 1 canal in the central and mandibular lateral incisors was approximately 40%. Once again, CBCT proved useful for diagnosing pulp morphology and for identifying extra canals and roots.

The success of endodontic treatment is variable. 60-100% of cases demonstrate cure during preservation. (NG et al., 2007). Therefore, when this preservation is performed through CBCT, a lower initial cure percentage is demonstrated, as this is a more sensitive examination when compared to conventional radiographs. (PATEL et al., 2012) In a study conducted by DAVIES et al., (2015), single periapical radiographs, periapical radiographs using the Clark technique, and CT scans of 100 teeth indicated for endodontic treatment were evaluated. The number of periapical lesions and roots identified through CT scans was significantly higher than in periapical radiographic scans, demonstrating the superiority of three-dimensional scans in this aspect over two-dimensional scans.

1.3 IMPORTANT CONSIDERATIONS ABOUT CBCT IN ENDODONTICS

This chapter reports the beginning of the use of imaging exams in dentistry. Radiography, developed from 1893 onwards, continues to be the most widely used imaging test in endodontics. (LANGLAND, LANGLAIS, 1995). Because it is a two-dimensional test, it has many limitations. With the introduction of CBCT in 1996, many of these limitations in relation to conventional radiographs were overcome through a three-dimensional, high-resolution examination that allows the dentist to evaluate, through a software, the images obtained from the teeth and important adjacent structures, in multi-planes, without distortions and without anatomical noises. allowing the diagnosis of periradicular pathologies, localization and planning of guided access in calcified canals, detection of root fractures, planning for complex endodontic treatments. (SCARFE, FARMAN, SUKOVIC, 2006; KRASTL, 2016).

CBCT also has its limitations and disadvantages, such as availability, cost, exposure to ionizing radiation, and projection of artifacts onto the image (when in the presence of high-density objects). (SCARFE, FARMAN, 2008).

In the studies evaluated, cone beam computed tomography was useful for almost all purposes. MICHETTI et al. (2010) confirmed the accuracy of tomographic images compared to histological sections of teeth visualized under a microscope.

USTUN et al., (2016) demonstrated the same efficacy of CBCT in performing odontometry compared to apical locators.

BASSAM et al., (2009) concluded that CBCT was more effective in detecting vertical root fractures compared to conventional radiographs.

LIMA et al.,(2017) stated that CBCT is an effective test for the association of chronic sinusitis with odontogenic infections in teeth close to the maxillary sinus.

In several studies, it has been possible to prove the efficacy of CBCT for the evaluation of dental morphology and important adjacent structures. (POPE, SATHORN, PETERS, 2013); (CAPUTO et al., 2016); (LAVANASI et al., 2016); (STUDEBAKER et al., 2017); (SHEMESH et al., 2017); (DAVIES et al., 2015)

In a study conducted by GOODELL, MINES, KERSTEN, (2017), both CBCT and panoramic radiography were effective for the diagnosis of WHtR.

However, in a study conducted by ROSEN et al.,(2016), it was concluded that CBCT is not an effective test for the detection of fractured instruments in the cervical third of filled teeth, due to the characteristic of projecting artifacts.

In view of all the uses of CBCT, it has been shown to be extremely effective, even in more complex treatments. However, the higher effective dose of ionizing radiation compared to conventional two-dimensional radiographs is not justified in all cases.

2 FINAL THOUGHTS

Endodontics presents difficulties even for the most experienced specialists. Cone Beam Computed Tomography has proven to be an excellent complementary tool in many situations in aiding diagnosis and planning of more complex endodontic treatments. In developed countries, it is already widely used as a first choice in many cases. CBCT was not developed to replace conventional radiographic methods, but to complement them.

REFERENCES

Langland OE, Langlais RP. Early pioneers of oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995;80(5):496-511

Scarfe WC, Levin MD, Gane D, Farman AG. Use of cone beam computed tomography in endodontics. Int J Dent. 2009;2009:634567.

Durack C, Patel S. Cone beam computed tomography in endodontics. Braz Dent J. 2012;23(3):179-91.

Farman AG, Levato CM, Scarfe WC. 3D X-ray: an update. Inside Dentistry. 2007;3(6):70-4.

Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. Dent Clin North Am. 2008;52(4):825-41, vii.

Abramovitch k, Rice D. Basic Principles of Cone Beam Computed Tomog raphy. Dent Clin N Am 58 (2014) 463–484

Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol. 2006;35(4):219-26.

Patel S, Dawood A, Whaites E, Pitt Ford T. New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. Int Endod J. 2009;42(6):447-62.

Patel S, Dawood A, Ford TP, Whaites E. The potential applications of cone beam computed tomography in the management of endodontic problems. Int Endod J. 2007;40(10):818-30.

Farman A, Levato C, Scarfe W. A primer on cone beam computed tomography. Inside Dentistry. 2007;3:90-2.

Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler WG. Endodontic applications of cone-beam volumetric tomography. J Endod. 2007;33(9):1121-32.

Arnheiter C, Scarfe WC, Farman AG. Trends in maxillofacial cone-beam computed tomography usage. Oral Radiology. 2006;22(2):80-5.

Patel S. New dimensions in endodontic imaging: Part 2. Cone beam computed tomography. Int Endod J. 2009;42(6):463-75.

Oser DG, Henson BR, Shiang EY, Finkelman MD, Amato RB. Incidental Findings in Small Field of View Cone-beam Computed Tomography Scans. J Endod. 2017 Jun;43(6):901-904. doi: 10.1016/j.joen.2017.01.033. Epub 2017 Mar 28.

Patel S, Kanagasingam S, Mannocci F. Cone beam computed tomography (CBCT) in endodontics. Dent Update. 2010;37(6):373-9

Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008;52(4):707-30, v.

Scarfe WC, Farman AG, Sukovic P. Clinical applications of conebeam computed tomography in dental practice. J Can Dent Assoc. 2006;72(1):75-80.

Farman AG, Farman TT. A comparison of 18 different x-ray detectors currently used in dentistry. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;99(4):485-9.

Scarfe WC, Farman AG, Sukovic P. Clinical applications of conebeam computed tomography in dental practice. J Can Dent Assoc. 2006;72(1):75-80.

Michetti J, Maret D, Mallet JP, Diemer F. Validation of cone beam computed tomography as a tool to explore root canal anatomy. J Endod. 2010 Jul;36(7):1187-90. doi: 10.1016/j.joen.2010.03.029. Epub 2010 May 13.

Krastl G, Zehnder MS, Connert T, Weiger R, Kuhl S. Guided Endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. Dental Traumatology 2016; 32: 240–246; doi: 10.1111/edt.12235.

Üstün Y, Aslan T, Şekerci AE, Sağsen B. Evaluation of the Realiability of Cone-beam Computed Tomography Scanning and Eletronic Apex Locator Measurements in Working Length Determination of Teeth with Large Periapical Lesions. J Endod. 2016 Sep;42(9):1334-7. doi: 10.1016/j.joen.2016.06.010. Epub 2016 Jul 30.

Tamse A, Fuss Z, Lustig J, Ganor Y, Kaffe I. Radiographic features of vertically fractured, endodontically treated maxillary premolars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999 Sep;88(3):348-52.

Pitts DL, Natkin E. Diagnosis and treatment of vertical root fractures. J Endod. 1983 Aug;9(8):338-46.

Chen SC, Chueh LH, Hsiao CK, Wu HP, Chiang CP. First untoward events and reasons for tooth extraction after nonsurgical endodontic treatment in Taiwan. J Endod. 2008 Jun;34(6):671-4. doi: 10.1016/j.joen.2008.03.016. Epub 2008 Apr 25.

Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. J Endod. 2009 May;35(5):719-22. doi: 10.1016/j.joen.2009.01.022.

Patel S[1], Kanagasingam S, Pitt Ford T. External cervical resorption: a review. J Endod. 2009 May;35(5):616-25. doi: 10.1016/j.joen.2009.01.015.

Mavridou AM, Hauben E, Wevers M, Schepers E, Bergmans L, Lambrechts P. Understanding External Cervical Resorption in Vital Teeth. J Endod. 2016 Dec;42(12):1737-1751. doi: 10.1016/j.joen.2016.06.007. Epub 2016 Oct 21.

Gelfand M, Sunderman EJ, Goldman M. Reliability of radiographical interpretations. J Endod. 1983 Feb;9(2):71-5.

Neves FS, Freitas DQ, Campos PS, Ekestubbe A, Lofthag-Hansen S. Evaluation of cone-beam computed tomography in the diagnosis of vertical root fractures: the influence of imaging modes and root canal materials. J Endod. 2014 Oct;40(10):1530-6. doi: 10.1016/j.joen.2014.06.012. Epub 2014 Aug 12.

Baisden MK, Kulild JC, Weller RN. Root canal configuration of the mandibular first premolar. J Endod. 1992 Oct;18(10):505-8.

Caputo BV, Noro Filho GA, de Andrade Salgado DM, Moura-Netto C, Giovani EM, Costa C. Evaluation of the Root Canal Morphology of Molars by Using Cone-beam Computed Tomography in a Brazilian Population: Part I. J Endod. 2016 Nov;42(11):1604-1607. doi: 10.1016/j.joen.2016.07.026. Epub 2016 Sep 10.

American Association of Endodontists, American Academy of oral and Maxillofacial Radiology, AAE and AAOMR Joint Position Statement use of cone beam computed tomography in endodontics 2015 update. J endod 2015;41:1393-6.

Kim S[1], Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod. 2006 Jul;32(7):601-23. Epub 2006 May 6.

Simonton JD, Azevedo B, Schindler WG, Hargreaves KM. Age- and gender-related differences in the position of the inferior alveolar nerve by using cone beam computed tomography. J Endod. 2009 Jul;35(7):944-9. doi: 10.1016/j.joen.2009.04.032.

Lavasani SA, Tyler C, Roach SH, McClanahan SB, Ahmad M, Bowles WR. Cone-beam Computed Tomography: Anatomic Analysis of Maxillary Posterior Teeth-Impact on Endodontic Microsurgery. J Endod. 2016 Jun;42(6):890-5. doi: 10.1016/j.joen.2016.03.002. Epub 2016 Apr 27.

Song M[1], Kim HC, Lee W, Kim E. Analysis of the cause of failure in nonsurgical endodontic treatment by microscopic inspection during endodontic microsurgery. J Endod. 2011 Nov;37(11):1516-9. doi: 10.1016/j.joen.2011.06.032. Epub 2011 Aug 19.

Sousa TO, Hassan B, Mirmohammadi H, Shemesh H, Haiter-Neto F. Feasibility of Cone-beam Computed Tomography in Detecting Lateral Canals before and after Root Canal Treatment: An Ex Vivo Study. J Endod. 2017 Jun;43(6):1014-1017. doi: 10.1016/j.joen.2017.01.025.

Shah M[1], Patel P, Desai P, Patel JR. Anatomical aberrations in root canals of maxillary first and second molar teeth: an endodontic challenge. BMJ Case Rep. 2014 Jan 20;2014. pii: bcr2013201310. doi: 10.1136/bcr-2013-201310.

Kulild JC, Peters DD. Incidence and configuration of canal systems in the mesiobuccal root of maxillary first and second molars. J Endod. 1990 Jul;16(7):311-7.

Studebaker B, Hollender L, Mancl L, Johnson JD, Paranjpe A. The Incidence of Second Mesiobuccal Canals Located in Maxillary Molars with the Aid of Cone-beam Computed Tomography. J Endod. 2017 Nov 15. pii: S0099-2399(17)31005-1. doi: 10.1016/j.joen.2017.08.026.

Vertucci FJ. Root canal anatomy of the mandibular anterior teeth. J Am Dent Assoc. 1974 Aug;89(2):369-71.

Shemesh A, Kavalerchik E, Levin A, Ben Itzhak J, Levinson O, Lvovsky A, Solomonov M. Root Canal Morphology Evaluation of Central and Lateral Mandibular Incisors Using Cone-beam Computed Tomography in an Israeli Population. J Endod. 2018 Jan;44(1):51-55. doi: 10.1016/j.joen.2017.08.012. Epub 2017 Oct 21.

Ng YL[1], Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature - part 1. Effects of study characteristics on probability of success. Int Endod J. 2007 Dec;40(12):921-39. Epub 2007 Oct 10.

Patel S, Wilson R, Dawood A, Foschi F, Mannocci F. The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography - part 2: a 1-year post-treatment follow-up. Int Endod J. 2012 Aug;45(8):711-23. doi: 10.1111/j.1365-2591.2012.02076.x.

Davies A, Mannocci F, Mitchell P, Andiappan M, Patel S. The detection of periapical pathoses in root filled teeth using single and parallax periapical radiographs versus cone beam computed tomography - a clinical study. Int Endod J. 2015 Jun;48(6):582-92. doi: 10.1111/iej.12352. Epub 2014 Sep 13.