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Cone Beam Computed Tomography in Endodontics: An Overview.

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Review Article

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ABSTRACT

The interpretation of an image for the dento-maxillofacial region is complicated due to the complex anatomy and the varying radio density of the tissues. The classic 2 dimensional radiographic technique do provide an excellent representation of the tissues, but are limited in differentiating superimposing structures. This drawback has been be overcome by Cone Beam Computed Tomography (CBCT). CBCT is a medical imaging technique consisting of X-ray based computed tomography where the X-rays are divergent forming a cone. It has the ability to eliminate superimposition of structures that normally overlap in the commonly used two-dimensional radiography. CBCT produces a high contrast image with good resolution in a short period of time. In endodontics, this particularly relates to early diagnosis of periradicular disease with greater precision of lesion size, extent and nature of position. CBCT also provides a lower dose of radiation and a higher image quality when compared to medical tomography. It can provide clear distinction of the delicate structures such as the dentin, enamel, pulp cavity and the alveolar cortical. CBCT system configurations are also available that provide small field of view images at low dose with sufficient spatial resolution. These characteristics make it highly relevant for applications in endodontic diagnosis, treatment guidance and post treatment evaluation. This article provides a literature overview of CBCT as an imaging adjunct in the field of dental science, more specifically in endodontics.

History of Imaging

The X-rays discovered in 1895 has been an invaluable aid in the practice of dentistry. Though clinicians still depend greatly on dental radiography for obtaining diagnostic information, including the field of endodontics and in relation to the diagnosis of periradicular disease, the major shortcoming of classic dental radiography is the two dimensional reproduction of a three dimensional entity.

However this shortcoming was overcome in 1972 by the invention of Computed Tomography (CT) by Sir Godfrey N Hounsfield. However CT had a high radiation exposure and high cost. These drawbacks were overcome with the introduction of 3D Cone Beam CT (**CBCT**) which was first used for angiographic applications in 1982 and then adapted to the maxillofacial region and is acquiring popularity so much so that it is now called the Dental CT [1,2].

The first CBCT was introduced and approved by the food and drug administration for the dental use in United States in March 8, 2001 and was named as NewTom DVT 9000. Three more CBCT was introduced by FDA followed by 3D Accuitomo in March 6th 2003, I CAT which was introduced in October

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2nd 2003 and CB mercury on October 20th 2003, and many more CBCT imaging systems were introduced later on.

Role of Imaging in Endodontics

Radiography is very essential for the successful diagnosis of odontogenic and non-odontogenic pathoses, treatment of the pulp chamber and canals of the root of a compromised tooth via intracoronal access, biomechanical instrumentation, final canal obturation, and assessment of healing. Imaging serves its purpose at various stages in endodontics [3].

Preoperative Assessment

Imaging achieves visualization of dental and alveolar hard tissue morphology and pathologic alterations to assist proper diagnosis. It provides information like the morphology of the tooth which includes location and number of canals, pulp chamber size and degree of calcification, root structure, direction and curvature, fractures, iatrogenic defects, and the extent of dental caries. The effects of periradicular and periapical disease can also be determined, including the characteristics of periapical osteolysis and the degree of root resorption. Larger lesions which is only determined by imaging, may necessitate adjunctive surgical procedures in addition to the conventional intracanal therapy. The diagnostic radiographs help predict the potential for complications, permit root fracture detection, and additionally demonstrate periapical lesions.

Intraoperative

During therapy two intraoral periapical images can be obtained. The first is a “working” radiograph achieved by placement of a metallic file(s) into the root canal(s) to a length that equates to that of the root as radiological and anatomic root apexes are very rarely coincident. This helps to ensure that mechanical debridement of the intracanal contents extends to the apical terminus of the canal and that obturation is dense, homogeneous, and contained within the root canal system. In addition, as a precursor to final obturation, a “final” or pre-condensation radiograph is made to assure the proper fitting of the master cone.

Postoperative

A “postoperative” radiograph immediately after root canal obturation is obtained to assess the sealing condensation and also the containment of the root canal filling material within the root canal system. In cases where in the periradicular healing is incomplete, this acts as a baseline for assessment of healing in the medium. Imaging is very important in evaluating the results of the previous therapy and delayed healing, evaluating potential obstacles to the retreatment, as well as aid surgical considerations.

Limitations of Conventional 2D Imaging

Intraoral radiography is based on the transmission, attenuation, and recording of X-rays on an analog film, and requires optimized geometric configuration of the X-ray generator, sensor and tooth to provide an accurate projection of the tooth. The image produced is a two-dimensional (2D) representation of a three-dimensional (3D) object[1] and hence doesn’t closely resemble the original object.

If any component of the imaging chain process is compromised, the resulting image may demonstrate geometric errors and may not be useful. Various 3D object characteristics such as complex dental anatomy and surrounding structures can make interpretation of 2D “shadows” difficult and can potentially contribute to non-healing of endodontic cases.

The Success in endodontics is assessed with the healing of the periapical bone adjacent to obturated canals. Goldman et al [4]. showed that in evaluating the healing of periapical lesions using 2D based periapical radiographs there was only 47% agreement between six examiners. Additionally Goldman et al [5]. also reported that when those very same examiners evaluated the same films at two different points in time, they only had 19%–80% agreement between the two evaluations.

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Cone Beam Computed Tomography

The traditional medical CT uses a fan shaped beam and makes multiple passes around the patient, whereas a CBCT uses a cone shaped beam of radiation to acquire a volume in a single 360 degree rotation around the patient. The building blocks of CBCT are voxels, the voxels are isotropic meaning equal sided, which enable objects within the volume to be measured accurately. The data in the CBCT is captured as a volume representing the patient's anatomy. The axial, coronal and sagittal sections can be viewed simultaneously which are valuable because they are not seen in traditional 2D radiography [6].

Cone beam computed tomography is established using a rotating gantry in which a detector and an x-ray source are fixed.

A narrow cone shaped beam of ionizing radiation is directed through the middle of the region of interest onto the area of x ray detector which is in the opposite side of the patient capturing a volume of the patient ,the x-ray source and detector rotates around the fixed fulcrum within the region of interest between 180-360 degree.

Cone beam CT allows producing a desired image in a single rotation without the movement of the scanner or the patient.

Types of CBCT equipment's

Items of CBCT equipment have their own characteristics and differ with respect to sensor type, Field Of View – FOV, resolution and the software used. These differences make certain versions of the equipment more relevant for specialities like endodontics where a high resolution image is necessary. Based on FOV CBCT based equipment can classified into 3 types. They are

- Small Volume Equipment
- Large Volume Equipment, and
- Large Volume and Small Volume Equipment [7].

Small Volume Equipment: The small volume tomographs have FOV up to 8x8 cm. Their main advantage is to evaluate areas of interest only in high resolution, without exposing the patient unnecessarily to radiation in areas of no interest. Occasionally, when a major field of image is required, then two or more volumes can be acquired to complement the exam. The small volume is an appropriate choice in cases where high resolution is essential, such as in endodontics, implants of some elements, re-absorptions and ATM and pathologies.

Large Volume Equipment: Large volume tomographs acquire image volume of over 8x8 cm, generally from 12x12 cm upto 18x22cm. Here the radiation dose is higher and the image quality is lower when compared with the small volume equipment. These can generate multilayer reconstructions with 2 dimensional and 3 dimensional visions, like lateral, frontal and axial teleradiographs, as well as panoramic radiographs with virtually no distortions observed. These aspects help in special requirement cases, where in a big area has to be analyzed, like extensive pathologies, multiple implants, orthodontics and traumatology.

Large Volume and Small Volume Equipment: New generations of tomographs are being developed with the idea of uniting the best features of large and small volume. The radiation dose of a cone beam exam depends on the brand and the model of the deployed equipment, configurations of k-voltage (KV), milli-amperage (MA), exposure time and the range of volume of exam.

Additional CBCT imaging systems classification can be based on the orientation of the patient during image acquistation.

Patient Orientation: Depending on the CBCT system used, maxillofacial CBCT can be performed with the patient in three possible positions: (1) sitting, (2) standing, and (3) supine. Equipment that requires the patient to be in supine position has a larger physical footprint and may not be accessible for patients with physical disabilities. The Standing units may not be able to be adjusted to a height to accommodate patients who are wheelchair bound. Seated units are the most comfortable among the three; however drawback being; fixed seats may not allow ready scanning of physically disabled or wheelchair bound patients. The scan times are often similar to or greater than those used with panoramic imaging, therefore more important than patient orientation is the head restraint mechanism used [3].

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Radiation dose considerations

There are various factors that affect the radiation dose produced by CBCT imaging systems which include the various image parameters used (kvp, mAs), continuous versus pulsed beam; amount, type and shape of the beam filtration and the limitations on the size of the field of view [3].

It is shown that smaller the field of view for a given system lower is the radiation dose applied [8, 9]. The reports published have shown that effective dose of radiations is substantially reduced (up to 98%) when compared to conventional CT [1]. Additionally it is seen that several images of the teeth can be obtained with approximately the same radiation dose as two periapical radiographs and they can provide a dose saving over various traditional images in complex cases [10].

Currently the CBCT imaging system with the highest resolution and the smallest field of view (the KODAK 9000 3D) involves patient radiation exposure varying from as little as 0.4 to 2.7 digital panoramic equivalents depending on the exact part of the mouth studied.

Advantages of CBCT

- Very Compact equipment
- Higher resolution resulting in sharper images and better diagnosis.
- Produces a 3D rendition of a 2D image and provides geometrically accurate images [11]
- Increased specificity for caries, periodontal and periapical lesions when compared to conventional CT and periapical radiographs [11].
- Small FOV – hence possible to have images of only the area of interest.
- Fewer metal devices
- Less exposure time and lower radiation dose when compared to medical CT.
- Patient comfort increases when compared to traditional intra oral radiographs as there is no placement of intra oral film or sensors [11]. Also for most equipment the patient is in a sitting position, and in not lying down as with medical CT further increasing the comfort and acceptance by the patients.
- Good soft tissue rendition when compared to the traditional 2D imaging [11].

Limitations of CBCT

- Despite the provision of the third dimension, the spatial resolution of CBCT images (0.4 mm to 0.076 mm or equivalent to 1.25 to 6.5 line pairs per mm^{-1}[$lp.mm^{-1}$]) is inferior compared to conventional film-based (approx. 20 $lp.mm^{-1}$) or digital (ranging from 8–20 $lp.mm^{-1}$) intraoral radiography. However, the ability of this technology to demonstrate geometrically accurate images in all three dimensions and the elimination of anatomic noise facilitates the assessment of a number of features which is important in endodontic diagnosis, treatment, and long-term management.
- Limited contrast resolution still remains as a barrier to the extension CBCT technologies into diagnostic imaging in which detection of small changes in soft tissue attenuation is a absolute requirement.
- Increased radiation exposure compared to conventional intraoral radiographs
- Increased chances of beam scatter and hardening of high density materials which in turn causes various artefacts.
- Cost of CBCT is high, hence affordability to the common population.
- Dentist must be computer savvy [11].

Application in of CBCT in endodontics

The use of cone beam computed tomography plays a major role in diagnosis and treatment planning and most of these applications are focused on pre operative assessment which include diagnosis of canal morphology [12-14],assessment of external and internal root resorption [14,15,16,17] to identify root fractures, pre surgical assessment of anatomic structures [12,13,14]

Various reports have shown that CBCT is more accurate than conventional periapical radiographs in measurement of length of the root canal fillings and diagnosing the presence of resorptive lesions, bone defects, root fractures, and perforations

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One indication cited in the joint position statement of AAE and AAOMR for the use of CBCT in endodontics was "intra –or post operative assessment of endodontic treatment complications such as over –extended root canal obturation material, separated instrument, calcified canals, identification and location of perforation.

Intra operative use of CBCT helps in avoiding various iatrogenic mishaps which highly affects the outcome of endodontic treatment [18].

Ball et al studied a case of calcified canal in palatal root of upper maxillary first molar which could not be identified in the conventional periapical radiograph, where in a CBCT scan revealed a 5mm of calcification from the radiographic apex in the palatal root.[18]

Ball et al prescribed a CBCT scan for a mandibular second molar when an iatrogenic root perforation had occurred and analysis of scan revealed the relationship of the perforation with respect to crestal bone and exact location of the canal was also identified. When compared to periapical radiographs [18].

Simon et al studied that CBCT can differentiate between periapical granuloma and radicular cyst in 13 out of 15 cases [11].

Jaffery et al studied a comparison between digital peri apical and cone beam computed tomography to locate the number of canals in the mesiobuccal root of the maxillary molars and to compare these micro computed tomography which was also used to determine canal configuration and it showed that for maxillary molars micro CT canal counts were significantly different from digital periapical radiograph count but not different from CBCT counts [19].

Lofthag Hansen et al studied a comparsion with intra oral periapical radiograph with CBCT for diagnosing periapical disease in 36 patients and it showed that CBCT provided additional informations which was not found in periapical radiograph [20].

Starropoulos and wenzel studied the efficiency between the CBCT and intraoral digital and conventional radiograph in periapical defects in pig jaw ,analysis from CBCT showed a higher sensitivity and diagnostic accuracy compared to intra oral digital and conventional radiographs [21].

Cotton et al concluded that CBCT technology helps with diagnosing canal morphology assessing root and alveolar fractures ,analyzing resorption lesions,identifying disease of non endodontic origin and assessment of root end surgery with higher accuracy and higher resolution and with reduced scan time and reduced radiation dose [22].

Primary periapical disease can also be detected faster with greater precision and sensitivity when compared to periapical or panoramic radiographs [23].

Anatomic information relating to the size, shape and position of the roots and their relationship with the maxillary sinus can be obtained from maxillary posterior CBCT scan [24].

CONCLUSION

Conventional intra-oral radiography provides clinicians with an accessible, cost effective, high-resolution imaging modality that continues to be of considerable value in endodontic therapy. There are however some specific situations, both pre- and postoperatively, where the understanding of spatial relationships afforded by CBCT helps to facilitate diagnosis and influence the treatment. The usefulness of CBCT imaging can no longer be disputed—CBCT is a useful task specific imaging modality and an important piece of technology for comprehensive endodontic evaluation.

CBCT is a valuable aid in the field of endodontics and has been established to be superior to conventional intra oral radiographs and panoramic radiographs. However selected criteria for CBCT should be followed based on the diagnostic information obtained from the scan because of the increased risk of radiation exposure. Therefore professional judgment in minimizing the radiation dose to the patient is deemed essential for optimal diagnosis and comprehensive treatment guidance.

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