Review Article

Dental computed tomography, cone-beam computed tomography - A review

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ABSTRACT

Radiographs are valuable diagnostic tools, for clinical examination in the diagnosis of dental diseases. Two-dimensional (2-D) periapical radiographs and panoramic radiographs are routinely used in dental practice. However, there are certain limitations of 2-D radiographs, which can be overcome by three-dimensional, imaging techniques such as cone-beam computed tomography (CBCT) and CT. The purpose of this article is to analyze the recent advances made in digital dental imaging (CT and CBCT). Correct use of newer radiographic techniques can help early detection and appropriate and timely treatment for various dental and oral pathologies. Recent advances in imaging technologies have revolutionized dental diagnostics and treatment planning. Correct use of appropriate imaging technology and their correct interpretation, following the as low as reasonably achievable principles and cost-effectiveness, newer radiographic techniques can help to detect pathologies in very early stages, which ultimately help to reduce morbidity and mortality and improve the quality of life of the patients.

KEY WORDS: Advances, Computed tomography, Cone-beam computed tomography, Digital technology, Imaging

INTRODUCTION

Dentistry has experienced tremendous advances in all its branches over the past three decades. With these advances, the need for more precise diagnostic tools, especially imaging methods, have now become mandatory. From the simple intraoral periapical X-rays, advanced imaging techniques such as computed tomography (CT) and cone-beam CT (CBCT) have also found a place in modern dentistry.[1] Two-dimensional (2-D) conventional radiographs provide excellent images for most of the dental radiographic needs. Their primary use is to supplement the clinical examination by providing insight into the internal structure of teeth and supporting bone to reveal caries, periodontal and periapical diseases, and other osseous pathologies. A significant constraint of conventional radiography is the superimposition of overlying structures, which objects the object of interest. Eventually, it results in collapsing three-dimensional (3-D) structural information onto 2-D images, which leads to loss of spatial information in the third dimension.

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The film-based radiography requires the presence and maintenance of darkroom, chemical handling, and of course it is associated with processing errors. All these disadvantages can be overcome with the advent of digital radiography. This enormous revolution is the result of both technologic innovation in image acquisition processes and the development of networked computing systems for image retrieval and transmission.[1]

CT

The first commercial CT scanner was developed in 1972 by Sir Godfrey N. Hounsfield, who was an engineer at EMI, Great Britain. Since then, the introduction of clinical X-ray CT has transformed medical imaging and is described as the greatest advancement in radiology, since when the discovery of X-rays was introduced. CT uses a narrow fan-shaped X-ray beam and multiple exposures around an object to reveal the internal structures that help the clinician to view morphologic features and pathology in three-

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dimensions.[2] It also determines the mesiodistal as well as the buccolingual extent of the pathology.

CT scanner consists of a radiographic tube which is attached to a series of scintillation detectors or ionization chambers. The patient is now advanced in the circular aperture in the center of the gantry. The tube head and reciprocal detectors within the gantry either rotate simultaneously around the patient, or the detectors might form a continuous ring around the patient, and the X-ray tube moves in a circle within the detector ring.

There are four generations in CTs. The Hounsfield's unit belongs to the first generation of CT scanners which is been used as a single detector element to capture a beam of X-rays. The second generation of CT systems was introduced in 1975, which used more than one detector and used small fan-beam, as opposed to pencil-beam scanning in the first generation. The first and second generations of CT scanners used a translate-rotate design, and these were used to scan only the head.

Third generation CT scanners were introduced in 1976 which uses a large, arc-shaped detector that acquires an entire projection without the need for translation. Third generation scanners are been used most extensively today. Fourth generation scanners then replaced the arc-shaped detector with an entire circle of detectors. In this design, the X-ray tube rotates around the patient, whereas the detector stays stationary. As the fourth generation scanners were more expensive and suffered from higher levels of scatter, these are not been used today.

The incremental scanning approach was subjected to errors relating to patient movement and limited Z-axis (vertical) image resolution resulting in loss of fracture conspicuity. The development of the power slip ring facilitated to the development of spiral (or helical or volumetric) CT in the late 1980s. In spiral CT, the patient is to be moved continuously through the rotating gantry, and image data are acquired as a "spiral" or "helix" form rather than in the form of a series of slices.[3] Compared with incremental CT scanners, spiral scanners provide improved multiplanar image reconstructions, which actually reduced the exposure time (12 s vs. 5 min), and reduced radiation dose up to 75%.[4]

Current CT scanners are called multi-slice CT scanners that have a linear array of multiple detectors (up to 64 rows) which simultaneously obtain tomographic data at different slice locations. It provides various advantages including significant reduction in scan time, reduced artifacts, and sub-millimeter resolution (up to 0.4 mm isotropic voxel).[4] However, these scanners are extremely expensive and beneficial for CT angiography and cardiac imaging, which might have limited application in maxillofacial diagnosis.

CT was the first technology to allow visualization of both hard and soft tissues of the facial bones by image processing enhancement and the ability to acquire multiple, non-superimposed cross-sectional images which were accurate too. CT scans were widely used in medicine since 1973, but it became available for dental application only in 1987. CT provides high contrast resolution and allows differentiation of tissues with <1% physical density difference compared to 10% and is required to be distinguished with conventional radiography.[4]

CT images have less noise (i.e., they are less grainy), that results from superior collimation of the exit beam in CT machines. CT software programs highlight pathologic lesions from normal anatomic structures using color-enhancement features. CT images have the ability to show slices of a given tissue, with each slice thickness of 1-2 mm and location chosen by the operator.[2]

Trope *et al.*[5] in 1989 used CT scans to differentiate radicular cysts from granulomas based on the marked difference in the density between the content of the cyst cavity and granulomatous tissue.

CT is considered to be the gold standard imaging technique to assess injuries of the maxillofacial skeleton region. It is an excellent tool for detecting complex facial fractures, such as those involving the frontal sinus, naso-ethmoidal region,[6] and the orbits.[7] CT helps in defining the displacements of fractures before surgical reduction and fixation. It helps to diagnose undisplaced fractures of the mandible and the condyle, which are not apparent on panoramic radiographs. Markowitz *et al.*[8] found coronal CT to be the most accurate method in the diagnosis of mandibular fractures, followed by mandibular series and panoramic radiography. CT offers superb visualization of impacted teeth and its relation to nearby anatomic structures which guides the surgeon during surgical removal of impacted teeth.

Aggarwal *et al.*[9] used CT scans and ultrasound with power Doppler flowmetry in the diagnosis of large periapical lesions. They concluded that both, the CT scans and ultrasound with power Doppler flowmetry can provide an additional but more accurate diagnosis of periapical lesions with validity equivalent to histopathological diagnosis.[9]

CT scan is also an excellent aid in detecting vertical root fracture or split teeth which cannot be detected on periapical radiographs since CT is not sensitive to beam orientation, unlike conventional radiograph.[10]

CT helps to identify multiple extra root canals which when missed can lead to endodontic treatment failure.

Chronic apical periodontitis can be seen with the CT scan in early and established stages. It is seen as an enlargement of the periodontal space, which is seen as a small osteolytic reaction around the root tips.[11] Velvart *et al.*,[12] in 2001, compared CT scans and periapical radiographs of 50 mandibular posterior teeth scheduled for periapical surgery.

They found that CT detected the presence of an apical lesion and the location of the inferior alveolar nerve in all cases, compared with 78% and 39%, respectively, with periapical radiographs. Robinson *et al.*[13] evaluated mandibular first premolars on 120 routine dental CT images for variations in root/root canal morphology. They found that CT images identified a greater number of morphologic variations than did a panoramic radiograph.[13]

CT has been used as a research tool to compare the volume of root canals before and after instrumentation with different rotary nickel-titanium systems[14] and for volumetric analysis of root filling using various obturation systems.[15]

3-D images from spiral CT helped in evaluating the close relationship between maxillary sinus disease and adjacent periodontal defects and their treatment[16] Rigolone *et al.*[17] obtained anatomic information using low dose CT to plan peri-radicular surgery through the vestibular approach. CT scan also detects resorption of adjacent roots.

CT scan can precisely distinguish between intrinsic and extrinsic salivary tumors and is used for staging these tumors.[18] It is excellent for planning for implant placement for ear prosthesis in patients with hemifacial microsomia.[19]

3-D CT angiography can determine the actual extent of the vascular malformation and helps in pre-interventional planning noninvasively.[20]

TUMORS IN CT

CT remains the optimal imaging modality for diagnosing tumors in the mesentery. Although primary neoplasms arising from the mesenchymal tissues of the mesentery are rare, the small bowel mesentery is a major avenue for the dissemination of tumor within the peritoneal cavity. Tumors spread to the mesentery by four major routes: (a) Direct extension, commonly seen with carcinoid tumor of the small intestine as well as intraabdominal cancers such as pancreatic and colon cancer; (b) lymphatic dissemination of lymphoma and some epithelial malignancies; (c) hematogenic spread resulting in embolic metastases to the small intestinal wall, usually seen in melanoma and breast cancer; and (d) seeding through the peritoneum from ovarian and gastrointestinal malignancies as well as some lymphomas. Although percutaneous imaging-guided or surgical biopsy is often necessary to guide management, analysis of CT features along with the clinical history may be useful in differentiating mesenteric tumors from infectious, inflammatory, or vascular processes affecting the mesentery.[14]

TUNED APERTURE CT (TACT)

TACT is a relatively simple, faster method for reconstructing tomographic images, which was developed by Webber *et al.*[21] It is based on the concept of tomosynthesis and optical-aperture theory.[22,23] TACT uses 2-D periapical radiographs acquired from different projection angles as base images and permits retrospective generation of longitudinal tomographic slices (TACT-S) lining up in the Z-axis of the area of interest.

It produces true 3-D data from any number of arbitrarily oriented 2-D projections. TACT has shown to be a promising, effective alternative to other conventional modalities for a number of clinical applications. The overall radiation dose of TACT is not >1–2 times that of a conventional periapical X-ray film. The resolution is stated to be similar with 2-D radiographs. Artifacts associated with CT, such as starburst patterns were seen with metallic restorations, do not exist with TACT. Major advantage of TACT over CT is the considerably lower effective radiation dose to which patients are exposed.

In 1998, Nair *et al.*[24] reported TACT to be more effective imaging modality than film or individual digital images for the detection of recurrent caries. Webber *et al.*[25] in 1999 also found TACT to be diagnostically more informative. Nance *et al.* reported that with TACT 36% of extra canal second mesiobuccal canals were detected in maxillary molars and 80% of third (mesiolingual) canals in mandibular molars.[26] TACT has proved to be effective in the determination of root fractures, especially vertical fractures.

Nair *et al.*[27] found that TACT was a more effective and accurate imaging modality for non- destructive quantification of osseous changes within the healing bony defects. It was found to be better than planar images for the detectability of trauma-induced radicular fractures and mandibular fractures *in vitro* studies.[28] Liang *et al.*[29] reported that TACT provides an alternative to conventional tomography for pre-surgical implant imaging. However, TACT is still at the trial stage for dental applications but appears to be a promising imaging modality for the future.

Micro-CT is another alternative CT technique that has been used in dental imaging. However, the use of micro-CT remains a research tool limited to animal and *in vitro* studies on small samples. Due to the high radiation dose required, micro-CT cannot be employed for human imaging.

CBCT

This imaging technique is based on a cone-shaped X-ray beam centered on a 2-D detector. It performs one rotation around the object and produces a series of 2-D images which are reconstructed in 3-D using a modification of the original CB algorithm developed by Aboudara *et al.*[30] in 1984. Radiation dose of one CBCT scan may be as little as 3–20% that of a conventional CT scan, depending on the equipment used and the area scanned.[4]

CBCT does not require an additional mechanism to move the patient during the acquisition. CB technology significantly increases the X-ray utilization and requires far less electrical energy than fan-beam technology. X-ray tubes of cone-beam scanning are much less expensive than that for conventional CT. Images have isotropic voxels that can be as small as 0.125 mm. Subjective image quality is high, even compared to helical CT, for the highest resolution modalities. CBCT provides a high spatial resolution of bone and teeth which allows accurate understanding of the relationship of the adjacent structures.

CBCT has found varied application in all fields of dentistry. High resolution of CBCT helps in detecting a variety of cysts, tumors, infections, developmental anomalies, and traumatic injuries involving the maxillofacial structures. It has been used extensively for evaluating dental and osseous disease in the jaws and temporomandibular joints (TMJs) and treatment planning for dental implants.

CBCT is categorized into large, medium, and limited volume units based on the size of their field of view (FOV). The size of the FOV depicts the scan volume of CBCT machines. It depends on various factors such as the size and shape of the detector, beam projection geometry, and the ability to collimate the beam. Collimation of the beam limits the X-radiation exposure to the region of interest and ensures the most favorable FOV to be selected, based on disease presentation. Smaller scan volumes produce higher resolution images and lower the effective radiation dose to the patient. Size of the field irradiated is the principal limitation of large FOV CB imaging.[31]

Large FOV units encompass those CBVTs with a FOV from 15 to 23 cm. These units are mainly useful in the assessment of maxillofacial trauma, orthodontic diagnosis and treatment planning, TMJ analysis, and pathologies of the jaws. Medium FOV range from 10 to 15 cm and is useful for mandibulomaxillary imaging and pre-implant planning and pathological conditions. Small FOV units (limited FOVs) of <10 cm with some as small as 4 cm × 4 cm in size are suitable for dentoalveolar imaging and are most advantageous for endodontic applications.[32]

DIFFERENCES BETWEEN CT AND CBCT

A CBCT scanner uses a CB radiating from an X-ray source in the shape of a cone covering large volume with one single rotation about the patient. The X-ray images are reconstructed by use of algorithms to come up with 3D high-resolution images. An example of a CBCT scanner is i-CAT.

On the other hand, a conventional CT scanner uses a fan beam in which transmitted radiation is in the form of a helix/spiral. The images are interpolated into image detectors arranged around the patient in an arc where only single slice images per scan can be produced. In a single breath hold, considerable regions of the body can be imaged. It is also possible to obtain 3D images from conventional CT scans.

A traditional CT scanner utilizes a high-output anode X-ray tube that rotates whereas a CBCT scanner utilizes a medical fluoroscopy tube that is low-power.

There is also a huge difference between the two scanners, the CT and CBCT, based on the amount of radiation exposure patients are subjected to. A CBCT has quicker motion compared to the spiral motion of a traditional CT scanner. It is, therefore, possible to conduct a CT scan using a CBCT scanner with lower doses of radiation. An example can be found in panoramic radiography. A typical CT scan will require separate maxilla and mandible scans which expose the patient to 200–300 times the required radiation for this radiography. If both jaws are scanned, the exposure doubles. A CBCT scans both the maxilla and mandible at the same time hence reducing exposure.

The required scanning posture is also different for the two scanners. In conventional CT scanners, the patient must lie down which is not the case for all CBCT scanners. Using the same example of panoramic radiography, in a traditional CT scan, a patient's jaw must be directly parallel to the X-ray beam direction. Any slight deviation causes an error. In a CBCT scan, however, orientation does not affect the final image as the entire field information is captured at a go. This upholds accuracy.[23]

DISCUSSION

Applications of CBCT in Dentistry

Oral and maxillofacial surgery

CBCT is majorly used in oral and maxillofacial surgery for surgical evaluation and planning for surgery for impacted teeth, cysts and tumors, orthognathic and implant surgeries and diagnosis of fractures, and inflammatory conditions of the jaws and the sinuses.

CBCT is largely used the diagnostic technique in the assessment of mid-face[33] and orbital fractures.[34] It allows easy detection of non-displaced, inter-articular fractures of the condylar head.[35] Artifacts from metal objects are lower on CBCT images;[36] hence, it provides better information in cases involving gun-shot wounds.[37] However, in cases of trauma to the cervical vertebrae, use of CBCT is contra-indicated, as the patient is unable to be in an upright position which is required for CBCT imaging.

Detailed visualization of the inter-occlusal relationship of 3-D virtual skull model makes CBCT a valuable tool in orthognathic surgery planning. It allows for morphological analysis and spatial relationship of the neighboring structures during follow-ups to evaluate growth, development, and function. It provides pre-surgical information when planning for sinus floor augmentation in preparation for implant placement.[38]

CBCT has been used for measuring the thickness of the glenoid fossa.[39] It often reveals the possible dislocation of the disk in the joint by defining the true position of the condyle and the extent of translation of the condyle in the fossa.[40] It has also been used for an image-guided puncture technique of the TMJ which is a treatment modality for TMJ disk adhesion.[41] CBCT provides a dose and cost-effective alternative to helical CT for the diagnostic evaluation of osseous abnormalities of the TMJ.

Endodontics

CBCT has been extensively used in endodontics. Numerous studies have reported its usefulness in the diagnosis of periapical lesions.[42-45] Estrela *et al.*[46] proposed a CBCT-based periapical index (PAI), termed as CBCT-PAI to measure and monitor periapical lesion size pre- and post-endodontic treatment.

a. A CBCT scan gives a 3-D view of the area of interest. In this case, the periapical lesion is being evaluated;
b. The image gives values in Hounsfield unit of cementum and alveolar.

CBCT enables in the differential diagnosis of cyst from granulomas by measuring the density from the contrasted images of the periapical lesion[47,48] Lofthag-Hansen *et al.*[49] found that CBCT detected 62% more periapical lesions on individual roots when compared with periapical X-ray examinations. Vertical root fractures are better evaluated with CBCT images compared to periapical radiographs. CBCT can determine fractures in buccolingual or mesiodistal directions.[50,51]

Patel *et al.*[52] in their review of literature found CBCT to be efficacious in endodontic surgery planning and identification of root canals not seen on 2-D images. Alshehri *et al.*[53] in their review article on CBCT reported it to be useful in cases such as inflammatory external and internal resorption. CBCT not only detects the presence of resorption but also determines its extent. They also found CBCT useful in determining root morphology; to measure the number of roots, canals, and accessory canals and to establish their working lengths, angulations and in the location of the separated instrument in the canal.[53]

CBCT is an exciting and clinically useful tool in studying root canal morphology.[54] 3-D imaging using CT has been used in endodontics over the past decade.[55]

For most endodontic applications, limited volume CBCT is preferred over large volume CBCT for the following reasons:

1. Increased spatial resolution to improve the accuracy of endodontic-specific tasks such as the visualization of accessory canals, root fractures, apical deltas, and calcifications and
2. Decreased radiation exposure to the patient.

Implantology

CBCT has been used for pre-operative and post-operative dental implant assessment. Preoperatively, it can accurately determine the quantity and quality of bone available for placement of the implant.[56,57] It also provides more detailed and accurate information of the adjoining vital tissues so that these could be protected during the placement of the dental implant. Heiland *et al.*[58] described a technique in which CBCT was used intraoperatively in two cases to navigate the implant insertion following the microsurgical bone transfer.

Orthodontics

CBCT images have been used in orthodontic assessment and cephalometric analysis.[59] CBCT helps to determine root angulations, although variations are seen from the true anatomy.[60] CBCT is valuable tool to assess the facial growth, age, airway function, and disturbances in tooth eruption.[61] CBCT can provide enhanced visualization of roots, making it a valuable tool for assessing pre- and post-orthodontic root resorption.

CBCT evaluates the success of alveolar bone grafts in patients with cleft lip and palate by determining the buccopalatal width and allowing the visualization of the 3-D morphology of the bone bridge.[62] Kim *et al.*[63] used CBCT to construct placement guides for mini-implants between the roots of adjacent teeth in anatomically difficult sites.

Periodontics

CBCT has proved to be a practical clinical tool to detect intra-bony and furcation defects, dehiscence, fenestration, and periodontal cysts.[64] It provides a detailed morphologic description of the bone with minimal error margins. CBCT has also been used to evaluate the outcome of regenerative periodontal therapy.[65]

Limitations of CBCT

Despite a growing trend of CBCT in dentistry, it has some disadvantages like artifacts. Artifacts are discrepancies between the reconstructed visual image and the actual content of the subject which degrade the quality of CBCT images, making them diagnostically unusable. In addition, structures that do not exist in the subject may appear within images. Such structures can occur due to patient motion, the image capture, and reconstruction process.

Some of the artifacts are X-ray beam artifacts such as beam hardening and cupping artifacts. Basically there are three types of artifacts, X-ray beam artifact, patient related and scanner related. X-ray beam artifacts are beam hardening and cupping artifacts. Patient related artifacts are metal jewelry artifacts, movement artifacts. Scanner related artifacts such are ring artifacts and software errors. Image noise such as scatter, extinction artifacts, exponential edge gradient effect, aliasing artifacts, stair-step artifacts, and zebra artifacts is some of the common artifacts that occur.[66] Image quality and diagnostic accuracy of CBCT are affected by the scatter and beam hardening artifacts caused by high-density structures such as enamel and radiopaque materials.[67] Scatter radiation reduces the contrast and limits the imaging of soft tissues. Hence, CBCT is principally indicated for imaging hard tissues.[68]

Due to distortion of Hounsfield Units, CBCT cannot be used for estimation of bone density. Scan times for CBCT are lengthy at 15–20 s and require the patient to stay completely still.

CONCLUSION

Recent advances in imaging technologies have revolutionized dental diagnostics and treatment planning. Correct use of appropriate imaging technology and their correct interpretation, following the as low as reasonably achievable principles and cost-effectiveness, newer radiographic techniques can help to detect pathologies in very early stages, which ultimately help to reduce morbidity and mortality and improve the quality of life of the patients.

Thus, CT and CBCT are recent and still advancing technologies which are very essential and significant in the field of dentistry, and still they require some advancement to improve and reduce the limitations which are mentioned above in the article.

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