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CBCT: A dentist perspective

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Abstract

Two-dimensional imaging modalities have been used in the field of dentistry since the first intraoral radiograph was taken in 1896. They have been providing with evidences for dentistry and medicine for many years and there is a little doubt that 2D images will continue to contribute to the process of diagnostic for years to come. For most dental practitioners, the use of advanced imaging has been limited because of cost, availability and radiation dose considerations; however, the introduction of CBCT for the maxillofacial region provides opportunities for dental practitioners to request multiplanar imaging. The goal of this article is to review the possible clinical implications of the CBCT in dentistry.

Key words: CBCT, 2-D imaging, 3-D imaging.

Introduction

Dentistry has witnessed tremendous advances in all its branches over the past 3 decades. With these advancements, the need for more precise tools, especially imaging methods, has become mandatory. Changes from an analogue to a digital system has not only made the process simpler and faster, but also made image storage, manipulation and retrieval easier. Broadly imaging techniques have been categorized as I/O, E/O, Analogue and Digital, Ionizing and Non-ionizing, and 3-D imaging. CBCT is a new medical imaging technique that generates 3-D images at a lower cost and absorbed dose compared with conventional CT. An overview of the recent digital imaging modality CBCT and its application in various disciplines of dentistry is presented here.

History

Cone beam technology was first introduced in the European market in 1996 by QR s.r.l. (NewTom 9000) and into the US market in 2001.[1]

During the "Festival della Scienza" in Genova, Italy, on October 25, 2013, the original members of the research group: Attilio Tacconi, Piero Mozzo, Daniele Godi and Giordano Ronca received an award for the cone-beam CT invention, a revolutionary invention that changed the world's dental radiology panorama.

Principles of CBCT

CBCT has become increasingly important in treatment planning and diagnosis of implant dentistry and interventional radiology (IR), among other things. Perhaps due to the increased access to such technology, CBCT scanners are now finding many uses in dentistry, such as in the fields of oral surgery, endodontics and orthodontics whereas Integrated CBCT has become an important tool for patient positioning and verification in image-guided radiation therapy (IGRT). [1]

Cone beam computed tomography (or CBCT, also referred to as C-arm CT, cone beam volume CT, or flat panel CT) is a medical imaging technique consisting of X-ray computed tomography where the X-rays are divergent, forming a cone.[2]
This imaging technique is based on a cone-shaped X-ray beam centered on a 2-D detector that performs one rotation around the object in order to produce a series of 2-D images. These images are then re-constructed in 3-D using a modification of the original cone-beam algorithm developed by Feldkamp *et al.* in 1984. Images of the craniofacial region are often collected with a higher resolution than those collected with a conventional CT. In addition, the new systems are more practical, as they come in smaller sizes.[1]

Since the late 1990s it had become possible to produce clinical systems that are both inexpensive and small enough to be used in the dental office. Four technological factors have converged to make this possible: (1) the development of compact high-quality flat-panel detector arrays, (2) reductions in the cost of computers capable of image reconstruction, (3) development of inexpensive x-ray tubes capable of continuous exposure and, (4) limited-volume scanning (e.g. head and neck), eliminating the need for sub-second gantry rotation speeds.[3]

Types of CT scanners

Computed tomography can be divided into two categories based on the acquisition of x-ray beam geometry: namely fan beam and cone beam.
In ***fan beam CT*** *scanners*, an x-ray source and solid-state detector are mounted on the rotating gantry. Patients are imaged slice-by-slice using the fan shaped x-ray beam in axial plane and an interpretation is achieved by stacking the slices. The Multi-detector CT scanner allows the acquisition of up to 64 image slices simultaneously, reducing the scanning time.
Cone beam CT *scanners* utilises a 360-degree scan in which the x-ray source and reciprocating area detector synchronically moves around the patient's head. At certain degree intervals, single projection images, known, as "basis" images are required. A series of these images are called as Projection data. Software programs are incorporated to these image data to generate a 3-D volumetric data set, which can be used to provide primary reconstruction images in 3 orthogonal planes.[2]

All of the CBCT scanners currently on the market use the same technology, with only slight differences. The major difference, however, is in the detector used, either an amorphous silicon flat-panel detector or a combination of an image intensifier and a charge-coupled device (CCD) camera. Both these technologies have been proven to be accurate and reliable and able to provide sufficient resolution for the needs of dental medicine. [4]

Within every scientific field, the introduction of new technology raises several fundamental questions, including identifying the practical applications of the new technology and determining whether it is truly superior to existing modalities.

Applications in Dentistry

Oral and maxillofacial surgery

CBCT enables the analysis of jaw pathology, the assessment of impacted teeth, supernumerary teeth and their relation to vital structures, changes in the cortical and trabecular bone related to bisphosphonate-associated osteonecrosis of the jaws. CBCT images are used for pre and post-surgical assessment of bone grafts recipient sites. It is also helpful in analysing and assessing paranasal sinuses and obstructive sleep apnea. [5]
Dentists are employing this technique to evaluate maxillofacial trauma. CBCT allows accurate measurement of surface distances, so this advantage has made CBCT the technique of choice for investigating and managing mid-facial and orbital fractures, post-fracture assessment, interoperative visualization of maxillary bones, and intraoperative navigation during procedures involving gunshot wounds.[4-5]

CBCT is also largely used in orthognathic surgery planning when facial orthomorphic surgery is indicated that requires detailed visualisation of the interocclusal relationship in order to augment the 3-D virtual skull model with a detailed dental surface. With the aid of advanced software, CBCT facilitates the visualisation of soft tissue to allow for control of post-treatment aesthetics, for example in cleft palate cases to evaluate lip and palate bony depressions.

Craniofacial surgery
Volumetric analysis promises to offer better prediction in terms of the morphology of the defect, as well as the volume of graft material necessary for repair. Questions abound regarding the stability of the arch after grafting, the quality of the bone graft over time, and the effect on overall facial growth; CBCT provides a means to investigate these issues in depth.[4]

Implant Imaging

With increased demand for replacing the missing teeth with dental implants, accurate measurements are needed to avoid damage to vital structures.
CBCT is the preferred option for implant dentistry, providing greater accuracy in measuring compared to 2-D imaging, while utilizing lower doses of radiation. New software has reduced the possibility of malpositioned fixtures and damaged anatomical structures.[6]
CBCT has reduced implant failures by providing information about bone density, the shape of the alveolus, and the height and width of the proposed implant site for each patient.
CBCT's effectiveness in quantifying and assessing the shape of the alveolus has led to improved case selection. By knowing in advance the complications that can occur during a

specific proposed treatment, the treatment plan can be designed to address the complications or to plan an alternate treatment.

TMJ Disorders

Diagnosis and treatment of TMJ disorders is quite challenging. MRI is usually considered to be the gold standard for intra-articular components of TMJ, while the evaluation of bony components is left to conventional panoramic radiography.

The imaging capabilities offered by current CBCT machines have been shown to provide a complete radiographic evaluation of the bony components of the TMJ. The resulting images are of high diagnostic quality. Given the significantly reduced radiation dose and cost compared with conventional CT, CBCT may soon become the investigational tool of choice for evaluating bony changes of the TMJ.[7]

Endodontics

It is in the area of endodontic applications where related literature has proved to be most fruitful to date. Endodontic applications include the diagnosis of periapical lesions due to pulpal inflammation, visualization of canals, elucidation of internal and external resorption, and detection of root fractures.

CBCT technology provides the clinician with an unparalleled visualization of the often-complex relationships and boundaries between teeth and their associated pathology and anatomic features within the alveolus and jaws, such as the maxillary sinus and mandibular canal and foramen.[8]

In general, the use of CBCT in endodontics should be limited to the assessment and treatment of complex endodontic conditions such as:

- Pre-surgical case planning to determine the exact location of root apex/apices and to evaluate the proximity of adjacent anatomical structures.
- Diagnosis of pathosis of non-endodontic origin in order to determine the extent of the lesion and its effect on surrounding structures.
- Identification of root canal system anomalies and determination of root curvature.
- Diagnosis of dental periapical pathosis in patients who are present with contradictory or non-specific clinical signs and symptoms.
- Intra or post-operative assessment of endodontic treatment complications, such as over-extended root canal obturation material, separated endodontic instruments, calcified canal identification and localization of perforations.
- Diagnosis and management of dentoalveolar trauma, especially root fractures, luxation and/or displacement of teeth, and alveolar fractures.
- Localization and differentiation of external from internal root resorption and the determination of appropriate treatment and prognosis.

Orthodontics

Orthodontists can use CBCT images in orthodontic assessment and cephalometric analysis. Today, CBCT is already the tool of choice in the assessment of facial growth, age, airway function and disturbances in tooth eruption.

Periodontics

CBCT can be used in assessing a detailed morphologic description of the bone because it has proved to be accurate with only minimal error margins. CBCT can be used to detect buccal and lingual defects, which was previously not possible with conventional 2-D radiographs.

Additionally, owing to the high accuracy of CBCT measurements, intra-bony defects can accurately be measured as well as assessment of dehiscence, fenestration defects and periodontal cysts. CBCT has also proved its superiority in evaluating the outcome of regenerative periodontal therapy.[1] CBCT can also be used to assess furcation involvement of periodontal defects and allow clinicians to evaluate post-surgical results of regenerative periodontal therapy.[6]

Forensic dentistry

Many dental age estimation methods, which are a key element in forensic science, have been described in the literature. CBCT was established as a non-invasive method to estimate the age of a person based on the pulp–tooth ratio.

Limitations of CBCT:

A significant issue that can affect the image quality and diagnostic accuracy of CBCT images is the scatter and beam hardening artifacts caused by high density adjacent structures, such as enamel, and radiopaque materials such as metal posts, restorations and root filling materials.[8]

CBCT has a low contrast resolution and a limited ability to visualize internal soft tissues. Due to the lack of consistency between manufacturers, CBCT cannot generate accurate HU (Hounsefield Units) measurements and is therefore unreliable for quantifying bone density.[4]

In addition, interpreting these images requires extensive anatomical knowledge of areas that have traditionally been in the realm of dentistry and neuroradiology.[4]

Advantages

CBCT is well suited for the imaging of the craniofacial area. It provides clear images of highly contrasted structures and is extremely useful for evaluating bone structure. The use of CBCT technology in clinical practice provides a number of potential advantages for maxillofacial imaging compared with conventional CT: [2]

- X-ray beam limitation: Reducing the size of the irradiated area by collimation of the primary x-ray beam to the area of interest minimizes the radiation dose. Most Cone Beam CT units can be adjusted to scan small regions for specific diagnostic tasks. Others are capable of scanning the entire craniofacial complex when necessary.[2]

- Image accuracy: The volumetric data set comprises a 3-D block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray absorption. The size of these voxels determines the resolution of the image. In conventional CT, the voxels are anisotropic rectangular cubes where the longest dimension of the voxel is the axial slice thickness and is determined by slice pitch, a function of gantry motion. Although CT voxel surfaces can be as small as 0.625 mm square, their depth is usually in the order of 1–2 mm. All CBCT units provide voxel resolutions that are isotropic equal in all 3 dimensions. This produces sub-millimetre resolution (often exceeding the highest grade multi-slice CT) ranging from 0.4 mm to as low as 0.125 mm (Accuitomo).
- Rapid scan time: Because CBCT acquires all basis images in a single rotation, scan time is rapid (10–70 seconds) and comparable with that of medical spiral MDCT systems. Although faster scanning time usually means fewer basis images from which to reconstruct the volumetric data set, motion artifacts due to subject movement are reduced.
- **Dose reduction:** Published reports indicate that the effective dose of radiation (average range 36.9–50.3 microsievert [µSv]) is significantly reduced by up to 98% compared with “conventional” fan-beam CT systems (average range for mandible 1,320–3,324 µSv; average range for maxilla 1,031–1,420 µSv). This reduces the effective patient dose to approximately that of a film-based periapical survey of the dentition (13–100 µSv).
- **Display modes unique to maxillofacial imaging:** Access and interaction with medical CT data are not possible as workstations are required. Although such data can be “converted” and imported into proprietary programs for use on personal computers (e.g., Sim/Plant, Materialise, Leuven, Belgium), this process is expensive and requires an intermediary stage that can extend the diagnostic phase. Whereas, reconstruction of CBCT data is performed natively by a personal computer. In addition, software can be made available to the user, not just the radiologist, either via direct purchase or innovative “per use” licence from various vendors (e.g., Imaging Sciences International). This provides the clinician with the opportunity to use chair-side image display, real-time analysis and MPR modes that are task specific. Because the CBCT volumetric data set is isotropic, the entire volume can be reoriented so that the patient’s anatomic features are realigned.

- **Reduced image artifact:** With manufacturers' artifact suppression algorithms and increasing number of projections, our clinical experience has shown that Cone Beam CT images can result in a low level of metal artifact, particularly in secondary reconstructions designed for viewing the teeth and jaws.

Advantages of CBCT
Reduces Scan Time
Beam Limitation
Image Accuracy
Multiplanar Reformation
Interactive display mode
Reduced Artifacts
Dose reduction

Conclusion

Conventional intraoral radiography provides clinicians with cost-effective, high-resolution imaging that continues to be the front-line method for dental imaging. However, it is clear that there are many specific situations where the 3-D images produced by CBCT facilitate diagnosis and influence treatment. The usefulness of the CBCT cannot be disputed. It is a valuable task-specific imaging modality, producing minimal radiation exposure to the patient while providing maximal information to the clinician. By the end of the twentieth century and the beginning of the twenty-first, it has become apparent that CBCT imaging may indeed be the next major advancement in dentoalveolar imaging, providing true 3-D imaging at a lower cost than conventional CT, with radiation risks similar to current methods of intraoral imaging, including panoramic and full-mouth radio-graphic examination.

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