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REVIEW ARTICLE

CAPTURE THE BEAUTY – LOOKING IN TO THE WORLD OF CONE BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

Cone-beam computed tomography (CBCT) or Cone-Beam Volumetric Tomography (CBVT) is a diagnostic imaging technology that is changing the way dental practitioners view the oral and maxillofacial complex as well as teeth and the surrounding tissues. CBCT has been specifically designed to produce undistorted three dimensional images similar to computed tomography (CT), but at a lower equipment cost, simpler image acquisition and lower patient radiation dose.

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INTRODUCTION

Radiographic examination is essential in diagnosis and treatment planning in dentistry. The amount of information gained from conventional film and digitally-captured periapical radiographs is limited by the fact that the three-dimensional anatomy of the area being radiographed is compressed into a two-dimensional image. As a result of superimposition, periapical radiographs reveal limited aspects of the three-dimensional anatomy. The high radiation dose, cost, availability, poor resolution and difficulty in interpretation have resulted in limited use of CT imaging in dentistry. These problems may be overcome using small volume cone-beam computed tomography (CBCT) imaging techniques. (Manoj Kumar *et al*., 2011) Cone-beam computed tomography (CBCT) is a new medical imaging technique that generates 3-D images at a lower cost and absorbed dose compared with conventional computed tomography (Dr Mohammed A. Alshehri 6th edition).

Historical background

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. 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 during the "Festival della Scienza" in Genova, Italy on October 25, 2013. (Hatcher, 2010) An early volumetric CT predecessor of CBCT, the dynamic spatial reconstructor, was developed in the late 1970s by the Biodynamics Research Unit at the Mayo Clinic (Rochester, MN, USA) (Jessica *et al*., 2014) In the late 1990s, Japanese and Italian groups working independently of each other, developed a new tomographic scann er known as CBCT or CBVT specifically for dental use. In 2000, Food and Dmg Administration (FDA) approved the first unit of CBCT for Dentistry use in United States of America. Clinical application of CBCT allows better and high accuracy of the obtained image, enabling the generation of images only of the interested area, without superposition of structures, bi and tridimensional visualizations, and images without distortions (Jefferson José de Carvalho Marion *et al*., 2013).

Principle of CBCT (Fig. 1)

This imaging technique is based on the principle of tomosynthesis. (Freny R Karjodkar, 2011) and the shape of the x ray beam is cone-shaped centred on a 2-D detector that performs one rotation around the object, producing a series of 2-D images. These images are re-constructed in 3-D using a

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modification of the original cone-beam algorithm developed by Feldkamp *et al*. in 1984. (Dr Mohammed A. Alshehri 6th edition) The image replicate the patients anatomy into single 3D volume that consists of volume elements- voxels. Each voxel is small in size (0.1-0.4mm for each face) and hence the image has reasonably high resolution. The field of view (FOV) can be customized to include a portion of or the entire maxillofacial region. The CBCT software permits reformatting and viewing the image data from multiple approaches i.e., in straight or curved planes. (Freny R Karjodkar, 2011)

Types of CT Scanners (Rajasekaran Cone, 2014)

Computed tomography can be divided into 2 categories based on acquisition x- ray beam geometry; namely: fan beam and cone beam. (Rajasekaran Cone, 2014) In fan-beam scanners, an x-ray source and solid-state detector are mounted on a rotating gantry. Data are acquired using a narrow fan- shaped x-ray beam transmitted through the patient. The patient is imaged slice-by slice, usually in the axial plane, and interpretation of the images is achieved by stacking the slices to obtain multiple2D representations. The linear array of detector elements used in conventional helical fan-beam CT scanners is actuallya multi-detector array. This configuration allows multidetector CT (MDCT) scanners to acquire up to 64 slices simultaneously, considerably reducing the scanning time compared with single-slice systems and allowing generation of 3D images at substantially lower doses of radiation than single detector fan-beam CT array (Rajasekaran Cone, 2014). A cone beam scanner, on the other hand, uses a cone-shaped beam and a reciprocating detector, which rotates around the patient 360 degrees and acquires projected data. Using sophisticated computer software along with a back-filtered projection, a 3D image is produced that can be viewed in axial, coronal, and sagittal planes (Shawn Adibi *et al*., 2012) Cone-Beam CT Technology CBCT scanners are based on volumetric tomography, using a 2D extended digital array providing an area detector. This is combined with a 3D x-ray beam. At certain degree intervals, single projection images, known as “basis” images, are acquired. This series of basis projection images is referred to as the projection data. Beginning with the NewTom QR DVT 9000 (Quantitative Radiology s.r.l., Verona, Italy) introduced in April 2001, other systems include CB MercuRay (Hitachi Medical Corp., Kashiwa-shi, Chiba-ken, Japan), 3D Accuitomo – XYZ Slice View Tomograph (J. Morita Mfg Corp., Kyoto, Japan) and i-CAT(Xoran Technologies, Ann Arbor, Mich., and Imaging Sciences International, Hatfield, PA).These units can be categorized according to their x-ray detection system. Most CBCT units for maxillofacial applications use an image intensifier tube (IIT) - chargecoupled device. Recently a system employing a flatpanel imager (FPI) was released (i-CAT). The FPI consists of acesium iodide scintillator applied to a thin film transistor made of amorphous silicon. Images produced with an IIT generally result in more noise than images from an FPI and also need to be preprocessed to reduce geometric distortionsinherent in the detector configuration. (Rajasekaran Cone, 2014) (Fig.2)

European Academy of DentoMaxilloFacial Radiology has developed the following basic principles on the use of CBCT in dentistry (Dr Mohammed A. Alshehri 6th edition)

1. CBCT examinations must not be carried out unless a history and clinical examination have been performed.
2. CBCT examinations must be justified for each patient to demonstrate that the benefits outweigh the risks.
3. CBCT examinations should potentially add new information to aid the patient’s management.
4. CBCT should not be repeated on a patient ‘routinely’ without a new risk/benefit assessment having been performed.
5. When accepting referrals from other dentists for CBCT examinations, the referring dentist must supply sufficient clinical information (results of a history and examination) to allow the CBCT practitioner to perform the justification process.
6. CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiography.
7. CBCT images must undergo a thorough clinical evaluation (radiological report) of the entire image dataset.
8. Where it is likely that evaluation of soft tissues will be required as part of the patient’s radiological assessment, the appropriate imaging should be conventional medical CT or MR, rather than CBCT.
9. CBCT equipment should offer a choice of volume sizes, and examinations must use the smallest that is compatible with the clinical situation, if this provides a lower radiation dose to the patient.
10. Where CBCT equipment offers a choice of resolution, the resolution compatible with an adequate diagnosis and the lowest achievable dose should be used.
11. A quality assurance programme must be established and implemented for each CBCT facility, including equipment, techniques and quality-control procedures.
12. Aids to accurate positioning (light-beam markers) must always be used.
13. All new installations of CBCT equipment should undergo a critical examination and detailed acceptance tests before use to ensure that radiation protection for staff, members of the public and patient are optimal.
14. CBCT equipment should undergo regular routine tests to ensure that radiation protection, for both practice/facility users and patients, has not significantly deteriorated.
15. For staff protection from CBCT equipment, the guidelines detailed in Section 6 of the European Commission document Radiation protection 136: European guidelines on radiation protection in dental radiology should be followed.
16. All those involved with CBCT must have received adequate theoretical and practical training for the purpose of radiological practices and relevant competence in radiation protection.
17. Continuing education and training after qualification are required, particularly when new CBCT equipment or techniques are adopted.
18. Dentists responsible for CBCT facilities, who have not previously received ‘adequate theoretical and practical training’, should undergo a period of additional theoretical and practical training that has been validated by an academic institution (university/ equivalent). Where national specialist qualifications in dento-maxillofacial radiology exist, the design and delivery of CBCT training programmes should involve a DMF radiologist.
19. For dentoalveolar CBCT images of the teeth, their supporting structures, the mandible and the maxilla up

to the floor of the nose (for example, 8 cm x 8 cm or smaller fields of view), clinical evaluation (radiological report) should be done by a specially trained DMF radiologist or, where this is impracticable, an adequately trained general dental practitioner.

20. For non dentoalveolar small fields of view (for example, temporal bone) and all craniofacial CBCT images (fields of view extending beyond the teeth, their supporting structures, the mandible, including the TMJ, and the maxilla up to the floor of the nose), clinical evaluation (radiological report) should be done by a specially trained DMF radiologist or by a clinical radiologist (medical radiologist) (Dr Mohammed A. Alshehri 6th edition).

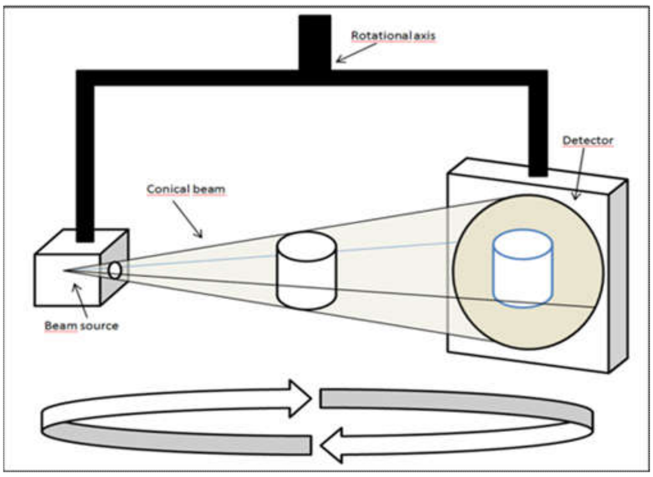

Fig. 1. Principle of CBCT

Fig. 2. CBCT Machine

Applications in dentistry

Grondahl (2007) reported that in Sweden in 2007 the relative frequency in the use of CBCT between different oral specialties was (Manoj Kumar *et al*., 2011):

Implantology (Manoj Kumar *et al*., 2011)

With increased demand for replacing missing teeth with dental implants, accurate measurements are needed to avoid damage to vital structures. This was achievable with conventional CT. However, with CBCT giving more accurate measurements at lower dosages, it is the preferred option in implant dentistry today. With new software that constructs surgical guides, damage is also reduced further. Heiland *et al.* describe a technique in which CBCT was used inter-operatively in two cases to navigate the implant insertion following microsurgical bone transfer. (Manoj Kumar *et al*., 2011) To assess the quantity and quality of bone in edentulous ridges. To assess the relation of planned implants to neighboring structures. To assess the success of implant osseointegration. Before ridge augmentation in anodontia. Before bone reconstruction and sinus lifting. During planning and in designing a surgical guidance template (Manoj Kumar *et al*., 2011).

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 and the assessment of bone grafts. It is also helpful in analysing and assessing paranasal sinuses and obstructive sleep apnea (Manoj Kumar *et al*., 2011). It is the best option for intra-operative navigation during procedures, including gun- shot wounds. CBCT is largely used in orthognathic surgery planning when facial orthomorphic surgery is indicated that requires de- tailed 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. (Manoj Kumar *et al*., 2011) In trauma cases, CBCT is able to show a larger number of fracture lines and fractures when compared with conventional images, depicting precisely the position and orientation of displaced fragments in a reasonably short time interval (Manoj Kumar *et al*., 2011). In orbital fractures CBCT can assess high-contrast structures, such as lateral and median walls or search for foreign bodies (Manoj Kumar *et al*., 2011).

Temporomandibular joint disorder

One of the major advantages of CBCT is its ability to define the true position of the condyle in the fossa, which often reveals possible dislocation of the disk in the joint, and the extent of translation of the condyle in the fossa. With its accuracy, measurements of the roof of the glenoid fossa can be done easily. Another advantage is their ability to visualise soft tissue around the TMJ, which may reduce the need for magnetic resonance imaging in these cases. (Manoj Kumar *et al*., 2011) CBCT also helps in the diagnosis of osteoarthritis and ankylosis. Condylar fractures can also be appreciated clearly by means of CBCT.

Orthodontics

CBCT helps in planning of orthognathic surgery. In obstructive sleep apnea it is useful in evaluation of air space. CBCT also beneficialin the evaluation of Cleft palate, positions of teeth, planning operations, orthodontic treatment, localization of eventual bone, control of intervention and Cephalometric analysis. (Manoj Kumar *et al*., 2011) Today, CBCT is already the tool of choice in the assessment of facial growth, age, airway function and disturbances in tooth eruption. (Manoj Kumar *et al*., 2011) With the advent of cone beam computed tomography (CBCT), it is now possible to quantitatively evaluate the effects of rapid maxillary expansion (RME) on the entire maxillary complex in growing patients

(4). CBCT is useful for ensuring a safe insertion and to assess the bone density before, during and after treatment.

Endodontics

CBCT helps in the 3 dimesional canal assessment of molars. CBCT also helps in evaluation of Cysts, granulomas, periapical lesions, endodontic surgery, fractured instruments in canal.unobturated, lateral or supernumerary root canals. CBCT is superior to periapical radiographs in detecting tooth fractures, whether they are buccolingual or mesiodistal. In cases with inflammatory root resorption, lesions are detected much easier in early stages with CBCT compared to conventional 2-D X-ray. In other cases, such as external root resorption, cervical and internal resorption, not only the presence of resorption was detected, but also the extent of it. It is also a reliable tool for pre- surgical assessment of the proximity of the tooth to adjacent vital structures, size and extent of lesions, as well as the anatomy and morphology of roots with very accurate measurements. (Manoj Kumar *et al*., 2011) CBCT scans provide clearer images of the mandibular canal when compared to digital panoramic radiographs, since CBCT images are free of overlap and other problems inherent to panoramic radiographs. Therefore, CBCT should be indicated for surgical planning, to minimize the risk of misinterpretation of the panoramic radiograph. [(6)] Sensitivity of CBCT scans in the teeth with gutta-percha and without prefabricated posts was a little higher than in the teeth without gutta-percha and prefabricated posts. In the study conducted by Melo *et al*, the sensitivity of CBCT in the teeth with gutta-percha having a voxel size of 0.2 mm was higher than in those without gutta-percha (Ehsan Moudi *et al*., 2014).

Periodontics

CBCT can be used in accurate analysis of bone loss as well as bone healing after periodontal treatment or regenerative therapy. Periodontal complications arising from root fractures, which can be visualized with CBCT when a two-dimensional image fails to give any information. (Manoj Kumar *et al*., 2011) Furthermore, it also aids in assessing furcation involvements. CBCT can be used to detect buccal and lingual defects. Additionally, owing to the high accuracy of CBCT measurements, intra-bony defects can accurately be measured and dehiscence, fenestration defects and periodontal cysts assessed. CBCT has also proved its superiority in evaluating the outcome of regenerative periodontal therapy (Manoj Kumar *et al*., 2011).

Forensic dentistry

Many dental age estimation methods, which are a key element in forensic science, are described in the literature. CBCT was established as a noninvasive method to estimate the age of a person based on the pulp–tooth ratio (Manoj Kumar *et al*., 2011).

Advantages

Hashimoto *et al*. have conducted series studies to compare the image performance between CBCT and medical multidetector helical CT for dental use they concluded that, in terms of image quality, reproducibility, and validity, the CBCT produced superior images to the helical CT, with approximately 400-fold less radiation exposure in the dental radiology field. (Shawn Adibi *et al*., 2012) One study reported that the average radiation effective dose of CBCT is within 36.9 and 50.3 microsievert, which is up to a 98 % reduction compared to fan-beam CT systems. In addition, Ludlow and Ivanovic conducted comprehensive evaluations of the effective doses of various CBCT units based on the 1990 and 2007 recommendations of the International Commission on Radiological Protection (ICRP). They found that calculated doses were much higher when using the new guidelines, which resulted in 68-1073 µSv for large field of view (FOV), 69-560 µSv for medium FOV, and 189-652 µSv for small FOV. This study also confirmed that a similar-FOV medical CT produced a higher dose than CBCT (Shawn Adibi *et al*., 2012). Based on the 2007 ICRP report, the effective dose from panoramic radiography was approximately 13 µSv, from cephalometric radiography is 1-3 µSv, and from periapical radiography is 1-8 µSv. These researchers found that i-CAT CBCT delivered a higher dose to the patient than a typical panoramic radiography by a factor of 5-16. Overall, the radiation dose from a CBCT is lower than that from a conventional CT, but is significantly higher than traditional dental radiography technique (Shawn Adibi *et al*., 2012). Accuracy- The size of the voxels regulates the resolution of the image. This produces sub millimetre resolutions ranging from 0.4mm to as low as 0.125mm. (Freny R Karjodkar, 2011) CBCT volumetric data is isotropic, which means all three dimensions of the image voxels are the same. This makes it possible to reorient the images to fit the patient's anatomic features and perform real-time measurements. (Shawn Adibi *et al*., 2012) Rapid scan time- CBCT acquires all basis images in a single rotation, hence the scan time is less (10-70 seconds) and subsequently motion artifacts due to subject movement are reduced. (Freny R Karjodkar, 2011) CBCT units provide choices for field of view (FOV), which allows irradiation of particular area of interest to dentists, while limiting irradiation of other tissues. This function contributes to excellent resolution and minimal radiation risk for patients (Shawn Adibi *et al*., 2012).

Disadvantages

One major disadvantage of CBCT is that it can only demonstrate limited contrast resolution, mainly due to relatively high scatter radiation during image acquisition and inherent flat panel detector related artifacts. If the objective of the examination is hard tissue only, using a CBCT would not be a problem however, CBCT is not sufficient for soft tissue evaluation (Shawn Adibi *et al*., 2012). Risks have also been noted in the radiation dose needed with CBCT (Shawn Adibi *et al*., 2012). The effective radiation dose of CBCT can be affected to an order of magnitude by the factors of patient size, FOV, region of interest, and resolution. According to 2009 ICRP reports, the risk of adult patient fatal malignancy related to CBCT is between 1/100,000 and 1/350,000, and when using the technology for children, the risk could be twice as much. Cone beam technology centered on an image intensifier may create distortion of the periphery of the images. Prolonged time required for image manipulation and interpretation (Freny R Karjodkar, 2011) Streaking and motion artifacts are largely limited with current CBCT units; however, they are not completely avoided (Shawn Adibi *et al*., 2012).

Conclusion

The development and rapid commercialization of CBCT technology dedicated to imaging the maxillofacial region will increase dental practitioner access to 3D radiographic assessments in clinical dental practice. CBCT is important in the diagnostic process and plays an integral role in treatment planning and outcome assessment. CBCT has increased accuracy, higher resolution, reduced scan time, a reduction in radiation dose and reduced cost for the patient. CBCT eliminates superimposition of surrounding structures, providing additional clinically relevant information.

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