Cone-Beam Computed Tomography: Third Eye for Dental Surgeons

1Ravindra B Govindwar, 2Pravin B Sundarkar, 3Neeraj G Alladwar, 4Vinod Agrawal, 5Anshul Khandelwal

1Professor and Head, Department of Orthodontics, Guardian College of Dental Sciences, Kalyan, Maharashtra, India
2Professor, Department of Prosthodontia, Triveni Dental College, Bilaspur, Chhattisgarh, India
3Professor, Department of Orthodontics, SDKS Dental College, Nagpur, Maharashtra, India
4Professor and Head, Department of Conservative Dentistry, Triveni Institute of Dental Sciences, Bilaspur, Chhattisgarh, India
5Postgraduate Student, Department of Oral Medicine and Radiology, CDCRI, Rajnandgaon, Chhattisgarh, India

Correspondence: Ravindra B Govindwar, Professor and Head, Department of Orthodontics, 16 Dream Residency Pioneer Cooperative Housing Society, Gawande Layout Near Chhatrapati Square, Nagpur-440015, Maharashtra, India
e-mail: dentalignnagpur@yahoo.com

ABSTRACT

Cone-beam computed tomography is a relatively new three-dimensional imaging technology, which has been specifically developed for imaging of the teeth and jaws. This article gives an overview of the subject and discusses some of the implications for dental practitioners. An understanding of the underlying principles will allow the users of this technology to tailor the imaging protocol to the patient’s individual needs to achieve appropriate imaging at the lowest radiation dose.

Keywords: Computed tomography, Gantry, Artifacts, Cuboids, Voxels, Digital volume tomography.

INTRODUCTION

Ever since the ‘dental X-ray pioneers’ took the first radiographs of teeth in early 1896, radiology has become an integral component in the assessment of the dental patient. For most dental practitioners, the use of more advanced imaging modalities, as found in general hospital radiology departments, have been limited as a result of accessibility, cost and radiation dose considerations. Although combinations of plain X-ray transmission projections and panoramic radiography can be adequate in a number of clinical situations, radiographic assessment may sometimes be facilitated by multiplanar images including computed tomographs.1

The introduction of cone-beam computed tomography (CBCT) technology in dentistry is rapidly changing the diagnostic landscape, allowing dentists to now diagnose in three dimensions. The advent of digital 2D X-rays was also a significant technological advance and is used by the majority of dentists in practice today.

Now, 3D CBCT technology has put dental diagnostics on ‘steroids’. Some dentists are hesitant to embrace cone-beam computed tomography, but this is rapidly changing. The hesitancy may just be a fear of its hefty, but necessary price tag, or merely a fear of the unknown.

New technology is often intimidating, because of the need to learn new skills. However, we hope to help, educate our medical and dental colleagues in order to further expand the use of this technology.

Although cone-beam technology has been around for almost two decades, it is only recently that production costs, including relatively inexpensive but powerful, personal computers, has enabled units to be produced that are affordable for a dental clinic.2

As most dentists and dental specialists have learned in recent years, dentistry is not entirely about filling cavities. In the last five years the dental field has been experiencing a profound ‘Sea Change’.

Conventional vs Cone-beam CT

Conventional CT uses a fan-shaped X-ray beam rotating in a helical fashion around the patient, with the data being acquired by solid state detectors located around the gantry. In most modern scanners, the detectors are arranged in parallel arrays, allowing up to 64 slices to be obtained simultaneously with each rotation. This considerably reduces the scanning time compared to the older single slice acquisition formats. The images obtained are typically ‘axial’ cross sections through the region of interest, but with associated computer algorithms these can be reformatted to be viewed in coronal and sagittal planes, as well as three-dimensionally.

Conversely, cone-beam scanners are based on a cone-shaped beam of X-rays rotating around the object of interest giving a volume of data, using a two-dimensional extended digital array as an area detector (Fig. 1). The technique involves a single 360° scan in which the X-ray source and reciprocating area detector synchronously move around the patient’s head, which is stabilized with a head holder. At certain degree intervals, single projection images, known as ‘basis’ images, are acquired. These are similar to lateral cephalometric radiographic images.
each slightly offset from one another. This series of basis projection images is referred to as the projection data. Software programs incorporating sophisticated algorithms, including back-filtered projection, are applied to these image data to generate a 3D volumetric dataset, and can be used to provide primary reconstruction images in three orthogonal planes (axial, sagittal and coronal), as well as three-dimensionally. 

Application of CBCT Imaging to Clinical Dental Practice

Unlike conventional CT scanners, which are large and expensive to purchase and maintain, CBCT is suited for use in clinical dental practice where cost and dose considerations are important, space is often at a premium and scanning requirements are limited to the head.

It has the potential to transform practically all aspects of dental imaging. The 3D nature of the data obtained allows easy visualization of structures in the complex maxillofacial environment.

All CBCT units initially provide correlated axial, coronal and sagittal perpendicular MPR images (Fig. 2). Basic enhancements include zoom or magnification and visual adjustments to narrow the range of displayed greyscales (window) and contrast level within this window, the capability to add annotation and cursor-driven measurement.

Perhaps the greatest practical advantage of CBCT in maxillofacial imaging is the ability it provides to interact with the data and generate images replicating those commonly used in clinical practice. All proprietary software is capable of various real-time advanced image display techniques, easily derived from the volumetric data set.

The potential scope of clinical applications for cone-beam imaging is vast and currently has been shown to be particularly useful in the following dental and maxillofacial areas:
1. Investigation of jaw pathology including cysts, tumors and fibro-osseous lesions.
2. Investigation of the paranasal sinuses.
3. Investigation of the bony components of the TMJ.
4. With this technology, implants (Fig. 3) and crowns can be placed with more ease and accuracy.
5. In orthodontics, CBCT imaging is useful in the assessment of impacted canines as well as growth and development. 
6. Impacted, hidden or missing teeth can be precisely located, in particular, their relationship to the inferior dental canal.
7. Endodontics—‘Hopeless teeth’ can be saved by discovering untreated nerve canals.
8. Evaluation of facial trauma (Fig. 4)
9. This power of perception can also help to identify bone and gum disease.

In addition, sleep disorders can be diagnosed that prior to CBCT, could only be assessed with a full cranial hospital.
CT scan. Ultimately, 3D CBCT will become the ‘Nirvana’ of the future.

**Why CBCT?**

The radiation dose from a scan is much lower than what is used in hospital settings. Viewing a patient’s anatomy in 3D gives dentists real ‘Superhero Powers’ of perception, and diagnosis that would not be possible using standard two-dimensional digital images.

Cone-beam imaging is well matched for the craniofacial area, in particular for evaluating bone and dental hard tissue. As these units have been custom designed for this region, unlike conventional CT, the software has been specifically produced to simplify obtaining the most useful views using preset parameters. In addition, most have been developed to work with other propriety maxillofacial imaging software, such as SimPlant (Materialize, Leuven, Belgium) and Nobel Biocare (Sweden) for implant planning. Also, compared to conventional CT, there are a number of significant advantages.

a. **Dose reduction:** When performing numerous 2D X-rays patients are exposed to radiation doses higher than that emitted from a single CBCT scan, which may only require one scan for the entirety of the treatment. Published data for cone-beam CT indicate an effective radiation dose between 0.035 and 0.10 mSv,\(^6\) which is up to 98% reduction compared to conventional CT (effective dose for CT of mandible and maxilla being 0.4 mSv–Newcastle University Trust Hospitals data*) and equivalent to approximately a full mouth series of periapicals or 3–10 standard dental panoramic tomograms.

   Typical doses from various dental radiological procedures:
   - Intraoral (F speed, rectangular collimator) 0.001 mSv
   - Intraoral (E speed, rectangular collimator) 0.004 mSv
   - Full mouth set (F speed, round collimator) 0.080 mSv
   - Lateral ceph (F speed, rare earth screen) 0.002 mSv
   - CBCT both jaws 0.068 mSv
   - Hospital CT scan both jaws 0.6 mSv.

   (*Dose calculated by Julie Willis, Medical Physics Department, Newcastle upon Tyne Hospitals using a program produced by imaging performance of CT scanners ‘www.impactscan.org/ctdosimetry.htm’

b. **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 scanners can be adjusted to scan specific small regions or to include the entire craniofacial complex, depending on the required task.

c. **Rapid scan times:** Because all the basis images are acquired in a single rotation, scan time is quick, varying between 10 and 40 seconds. Fast scan times also result in fewer artefacts, such as those due to patient movement. These scan times are comparable to conventional dental panoramic imaging and those of modern helical CT units.

d. **Image accuracy:** The volumetric dataset comprises a 3D block of smaller cuboid units, 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, i.e. 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\(^2\), their depth is usually in the order of 1-2 mm. All cone-beam units provide voxel resolutions that are isotropic, i.e. equal in all three dimensions. This produces submillimeter resolutions (often exceeding the highest grade multislice CT) ranging from 0.4 mm to as low as 0.125 mm.\(^2\)

e. **Minimizes discomfort:** The use of CBCT makes taking diagnostic dental impressions an unnecessary, cumbersome task of the past. This minimizes the patient’s in-office work-up time, discomfort of dental impressions and the overall time it takes to formulate an accurate treatment plan.

   Two-dimensional X-rays including procedures, such as bite wings and panoramic images, must be performed multiple times on a patient to obtain ‘complete’ views of the mouth, while CBCT could have not only obtained all the views available to the 2D machine, but could have also shown hidden anatomical problems in the third-dimension.

f. In conventional CT of the oral region, the presence of metallic dental restorations causes a problem due to streak artefact, which can significantly degrade the image. Cone-beam imaging also produces streak artefact but to a much lesser extent and consequently provides superior quality images of oral structures.

**Limitations of Cone-beam Imaging**

Cone-beam imaging is not in itself a panacea in radiological terms. In fact, its exact role in head and neck imaging has yet to be critically evaluated. The quest to accumulate an evidence-based approach is meeting a number of obstacles. For example, who should collate the evidence and make recommendations for best practice.

- Research into cone-beam imaging has to meet the challenge of rapid changes in both hardware and software technology, which can render publications outdated before they even get to press.

- The equipment itself is changing in order to meet the clinical requirements reported to manufacturers, who in turn have markets to consider. However, it should not be forgotten that there are intrinsic limitations in the technique which mean, in some circumstances, other forms of dental imaging would be more appropriate. Caries and teeth adjacent to amalgam and other dense prosthetic restorations are not well imaged by cone-beam technology owing to beam hardening and streak artefact. Some units combat this anomaly better than others. Even gutta-percha may give rise to streak artefact and appear as dense as amalgam might on conventional CT. This should be borne in mind when assessing a potential site for implants adjacent to root-filled teeth.

- If the clinical question is about lamina dura configuration or bony detail, then the periapical image may provide the
answer with a fraction of the radiation dose, both lamina dura and bony detail being superior on periapical radiographs compared to cone-beam. 

1. In order to acquire an undistorted image with cone-beam imaging, it is essential that the patient’s head is kept still during the gantry rotation. Obviously, quicker scan times help facilitate this and most machines come with a head positioning and stabilizing device but, as with dental panoramic tomography, patient movement can limit the technique for very young children, those unable to stay still or with movement disorders.

2. Interestingly, to those not used to working with 3D volumes, radiological interpretation can be difficult when using a smaller field of view, as it is easy to become disoriented when scrolling through the images, as points of reference, such as normal dental landmarks, or anomalous anatomy, can make orientation difficult.

3. Cone-beam technology based on an image intensifier may allow the periphery of the image to be distorted.

4. To date, cone-beam technology gives little in the way of soft tissue detail and, although newer algorithms have been developed to improve this aspect, it in no way compares to those capable of conventional CT. This, obviously, precludes the technique in the assessment of head.

DISCUSSION

Cone-beam imaging, sometimes referred to as digital volume tomography, is one of the most exciting developments in dental and maxillofacial radiology and, owing to its versatility, will almost certainly become an increasingly popular form of imaging available in dental practice. As a result, more manufacturers will doubtless develop units with the result that purchase costs will almost certainly reduce. Some manufacturers are already producing hybrid units combining dental panoramic tomography with a limited cone-beam facility incorporated (Kodak 9000 3D C). However, although cone-beam imaging allows images to be displayed in a variety of formats, the interpretation of volumetric datasets, particularly when it involves large areas, means more than simply the generation of 3D images. Interpretation demands an understanding of the spatial relations of bony anatomical elements and a comprehensive pathological knowledge of the various maxillofacial structures involved. Obviously, this information can extend beyond purely the dentoalveolar complex. There is mounting concern among oral and maxillofacial radiologists, based on issues of quality and patient safety, that interpretation of extended field of view diagnostic imaging studies using cone-beam should not be performed by dentists with inadequate training and experience.

The obvious potential for missed occult pathology with these units does, if nothing else, increase the risk of litigation. A recent study using CBCT showed 24.6% had incidental findings. In addition, the radiological report can give added value, often with that ‘extra insight’ into matters dental where an incidental radiological finding could make a major difference to treatment planning. The problem is exacerbated by the fact that cone-beam imaging uses ionizing radiation doses exceeding any other existing form of dental imaging. The basic tenets of ALARA and maximizing the benefit/risk ratio to the patient still apply when selecting cases for imaging. With increasing potential use of cone-beam imaging for a variety of clinical situations, guidelines need to be developed indicating best practice. Dental graduates will require training in the interpretation and limitations of cone-beam CT. With regard to obtaining specialist radiological reports and opinions, tele-dentistry, whereby images can be electronically sent to imaging centers of excellence, would allow ease of access to specialist advice, and any dental practitioner contemplating purchasing a cone-beam CT unit should consider such a liaison. Image files can be quite large and protocols would need to be agreed as to what data are sent.

CONCLUSION

The development and rapid commercialization of CBCT technology dedicated to imaging the maxillofacial region will undoubtedly increase dental practitioner access to 3D radiographic assessments in clinical dental practice. CBCT imaging provides clinicians with submillimeter spatial resolution images of high diagnostic quality with relatively short scanning times (10-70 seconds) and a reported radiation dose equivalent to that needed for 4 to 15 panoramic radiographs. However, CBCT should only be used after careful consideration, where conventional two-dimensional imaging techniques are not sufficient or where access to the technological processes such as guided surgery will improve patient management. When selecting the best CBCT examination for an individual, it is important to minimize X-ray dose while striving for an image that enables appropriate diagnosis and management. This requires an understanding of the concepts behind CBCT and related technologies, making appropriate training essential for every member of the dental team.

REFERENCES