Application of cone beam computerized tomography in prosthodontics.

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Abstract
Cone beam computed tomography (CBCT, also known as C-arm computed tomography [CT], cone beam volume CT, or flat panel CT) is a type of X-ray computed tomography in which the X-rays are divergent and form a cone. Hard tissues of the maxillofacial region can be imaged using CBCT systems. With short scanning times (10–70s) and radiation doses reportedly up to 15–100 times lower than conventional CT scans, CBCT can produce images with sub-millimeter resolution and high diagnostic quality. As this technology becomes more widely available, dental clinicians will have access to an imaging modality that can provide a three-dimensional representation of the maxillofacial skeleton with minimal distortion. CBCT is a unique imaging option for a prosthodontist's various treatment needs. It can be useful in a variety of situations in prosthodontics, including imaging of the temporomandibular joint for accurate movement simulation and denture therapy. CBCT could play an important role in reduction of pressing routine of the clinician. Therefore, the aim of this article is to specify the applications of CBCT in the field of prosthodontics along with the advantages of CBCT.

Keywords: Cone beam computed tomography, prosthodontics, x-ray, implant dentistry.

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Introduction

Although nothing can replace an extensive history and physical examination when evaluating patients, non-invasive technology for imaging areas not visible to the naked eye has become an increasingly important part of the diagnostic process. In recent years, dental imaging has advanced at a rapid rate. In the maxillofacial region, static projectional images were used for diagnosis, but we are now moving toward digital, three-dimensional (3D), and interactive imaging applications. A recent computerised tomography (CT) technology known as "cone-beam computed tomography" or "digital volume tomography" is attributed with much of this movement. Dentists can now see in all the angles of areas of concerns. The dental profession has quickly embraced this technology. Many in the field consider it to be "what was missing." In a variety of ways, 3D imaging has improved diagnostic efficiency and dentistry practise; from routine evaluation to complex analysis of unusual pathology and congenital deformities, today's technology makes dentistry better, easier, and more accurate. Simultaneously, a plethora of applications that use 3D data for a variety of tasks have been developed, including implant planning, surgical navigation, orthodontic applications, and more. All of this are for the benefit of patients.[1] Cone-beam CT (CBCT) can eliminate the projection inaccuracies of two-dimensional (2D) cephalograms and provide accurate assessment of craniofacial structures in three dimensions with exposure sequences that are shorter than those for standard panoramic radiography and only a few times the dose of one such image. The recorded volume can be used to simulate a variety of plain and tomographic projections.[2]

Background

Intraoral radiography was developed just weeks after Roentgen discovered X-rays in 1895. Soon after, extraoral imaging, including cephalometric radiography, was performed.[3] Broadbent introduced cephalometry in dentistry in 1930, 36 years after Roentgen's discovery of X-ray in 1895. Broadbent (1931) used a combination of lateral and anteroposterior radiographs to record the 3D nature of the head.[4,5] Dr. Numata of Japan proposed and experimented with the panoramic radiograph in the 1930s, and the father of panoramic radiography, Dr. Yrjo Veli Paatero of Finland, refined the panoramic technique in the mid-1940s.[6] Orthodontists began to rely on the lateral cephalometric radiograph as a diagnostic aid in the 1940s and 1950s, and diagnostic ability was limited to 2D. Panoramic radiography, which was introduced in the 1960s and became widely used in the 1970s and 1980s, marked a major progress in dental radiology, providing clinicians with a single comprehensive image of the jaws and maxillofacial structures. Even so, 2D views have their limitations: geometric, rotational, and head positioning errors mean that the anatomy is not accurately represented; some elements can be obscured; and calibrating the views is a challenge.[7] Sir Godfrey Hounsfield, who later shared the Nobel Prize in Medicine with Allan Cormack, the developer of the mathematical algorithms for data reconstruction, invented computerised tomography in 1967, and since then, there have been five generations of such systems.[8]

Types of computed tomography scanners

Computed tomography can be divided into two categories based on the acquisition of X-ray beam geometry, namely, fan beam, and cone beam.

1) Fan Beam Computed Tomography Technology

An Xray source and solid-state detector are mounted on a rotating gantry in fan beam scanners (fig. 1a). A narrow fan-shaped Xray beam is transmitted through the patient to collect data. Slice by slice, usually in the axial plane, the patient is imaged, and the images are interpreted by stacking the slices to obtain multiple 2D representations. In traditional helical fan beam CT scanners, the linear array of detector elements is actually a multidetector array. This configuration allows multidetector CT scanners to acquire up to 64 slices at the same time, significantly reducing scanning time when compared to single-slice systems and allowing the generation of 3D images with significantly lower radiation doses than single detector fan beam CT arrays.[8]

2) Cone Beam Computed Tomography Technology

Volumetric tomography is used in cone beam computed tomography scanners, which use a 2D extended digital array as an area detector. This is combined with a three-dimensional X-ray beam (fig. 1b). A single 360° scan is used in the cone beam technique, in which the Xray source and a reciprocating area detector move synchronously around the patient's head, stabilised by a head holder. Single projection images, also known as "basis" images, are acquired at specific degree intervals. These look like lateral cephalometric radiographic images, but they're slightly offset from one another. The projection data refers to this set of basis projection images. These image data are processed using software programmes that use sophisticated algorithms like back filtered projection to create a 3D volumetric data set that can be used to generate primary reconstruction images in three orthogonal planes (axial, sagittal and coronal).
Although the CBCT principle has been in use for nearly two decades, it has only recently become commercially available due to the development of low-cost Xray tubes, high-quality detector systems including such flat panel detectors (FPDs),

and powerful personal computers. From the first quantitative radiology (QR) DVT 9000 (QR s.r.l., Verona, Italy)[9] introduced in April 2001 to NewTom's latest VGi (or 5G) or other systems such as Galileos/Orthophos XG3D (Sirona Dental company, Germany), CS9000 (Kodak Dental Systems, Carestream Health, Rochester, NY, USA), iCAT (Xoran Technologies, Ann Arbor (Planmeca, Finland). The X-ray detection systems used by these units can be classified. An image intensifier tube is used in most CBCT units for maxillofacial applications (IIT). i-CAT has released a system that uses a flat panel imager (FPI).[10,11] A cesium iodide scintillator is applied to a thin film transistor made of amorphous silicon in the FPI–charge coupled device, now known as FPD. Images created with an IIT have more noise than images created with an FPD, and they must also be preprocessed to remove geometric distortions caused by the detector configuration.[12,13] As a result, FPD receptors are used in the majority of currently available CBCT machinery.

Advantages of cone beam computed tomography

The craniofacial region is well-suited to cone beam computed tomography imaging. It produces clear images of highly contrasted structures, making it ideal for evaluating bone.[13,14] Although there are some limitations to using this technology for soft tissue imaging at the moment, efforts are being made to develop techniques and software algorithms to improve the signal-to-noise ratio and increase contrast. The use of CBCT technology in clinical practice provides a number of potential advantages for maxillofacial imaging compared with conventional CT, which include:

1) X-ray beam limitation

The radiation dose is reduced by collimating the primary Xray beam to the area of interest, which reduces the size of the irradiated area. Most CBCT scanners can be configured to scan small areas for specific diagnostic purposes. Others have the ability to scan the entire craniofacial complex if needed (fig. 2).

2) Image accuracy

The volumetric data set is made up of a 3D block of smaller cuboid structures called voxels, each of which represents a different level of Xray absorption. The image's resolution is determined by the size of these voxels. Voxels in traditional CT are anisotropic, rectangular cubes with the longest dimension being the axial slice thickness, which is determined by slice thickness. Pitch is a gantry motion function. CT voxel surfaces can be as small as 0.625 mm2, but their depth is usually around 1–2 mm. All CBCT units provide isotropic, or equal, voxel resolutions in all three dimensions. This produces sub-millimeter resolution (often exceeding the highest grade multi-slice CT) ranging from 0.4 mm to as low as 0.125 mm (Accuitomo; i-Cat; ProMax).

3) Rapid scan time

Because CBCT acquires all basis images in a single rotation, scan times are comparable to those of medical spiral CT systems (10–70 seconds). Despite the fact that a faster scanning time usually means fewer basis images from which to reconstruct the volumetric data set, motion artefacts caused by subject movement are reduced.[15]

4) Dose reduction

According to published reports, the effective dose of radiation- average range of 36.9-50.3 millisievert (usv)[16-20] is significantly reduced by upto 98% when compared to “conventional” fan beam CT systems (average range for mandible is 1320–3324 usv; average range for maxilla is 1031–1420 usv), the effective dose of radiation is reduced by up to 98 percent (average range for mandible is 1320–3324 usv; average range for maxilla is 1031–1420 usv). The effective patient dose is reduced to about the same as a film-based periapical dentition survey (13–100 usv) or 4–15 times that of a single panoramic radiograph (2.9–11 usv).

5) *Display modes unique to maxillofacial imaging*

Because workstations are required, access to and interaction with medical CT data is not possible. Though this data can be "converted" and imported into proprietary programmes for use on personal computers (e.g., SimPlant, Materialise, Leuven, Belgium), the process is costly and necessitates an intermediate step that can prolong the diagnostic phase. A personal computer performs CBCT data reconstruction natively. Furthermore, software can be purchased directly or through innovative “per use” licenses from various vendors and made available to the user, not just the radiologist (e.g. Imaging Sciences International). This allows the clinician to use task-specific image display, real-time analysis, and MPR modes while sitting in the chair. The entire volume can be reoriented to realign the patient's anatomic features because the CBCT volumetric data set is isotropic. Furthermore, cursor driven measurement algorithms enable the clinician to perform dimensional assessment in real time (fig.3). Because of this, the software can incorporate nerve tracking with specific nerve sizes (mandibular canal, incisive canal).[15]

6) *Reduced image artifact*

Clinical experience has shown that CBCT images can result in a low level of metal artefacts, e.g., with the manufacturer's artefact suppression algorithms and increasing number of projections. Sirona's Metal Artifact Reduction Software (MARS), which is especially useful in secondary reconstructions for viewing the teeth and jaws.16

Applications of CBCT in Prosthodontics[15,21]

-Implant prosthodontics
-Temporomandibular joint (TMJ) imaging
-Maxillofacial prosthodontics
-Craniofacial and airway analysis
-Comprehensive treatment planning in over denture patients.

1) Implant prosthodontics

Dr. P. Branemark discovered osseointegration, which led to the development of endosseous dental implants. The success of dental implant restorations is based in part on accurate diagnostic information about the oral region's bony structures. Depending on the case and the practitioner's experience, this information is usually obtained through imaging, which can range from simple 2D views, such as panoramic radiographs, to more complex views in multiple planes.[4,15,22] CBCT can be used to plan implant placement by assessing the presence of pathology, anatomic features, osseous morphology, and the amount of bone available. CBCT allows for easy viewing of anatomic structures such as the inferior alveolar nerve, maxillary sinus, mental foramen, and adjacent roots. Furthermore, these specific CBCT images allow for precise distance, area, and volume measurements.[23] It has been suggested that it could be used in pre-surgical imaging, surgical-intraoperative evaluation, and post-surgical evaluation (for assessment of osseointegration). In addition, the availability of newer software for creating surgical guides has reduced the risk of structural damage even more. A radiopaque marker can be used to locate the final tooth position in the “prosthetically driven implant” technique. When arranged on CBCT, this information can be used to create a surgical guide for precise implant placement, ensuring that the final prosthesis fits correctly with the implant alignment.[15,23,24] CBCT has a variety of applications in areas where there is insufficient bone to support dental implants. Prior to surgery, this will aid in estimating the volume and type of graft material required. It aids in obtaining important information about sinus membrane thickening and perforations, as well as the patency of the osteomeatal complex and surgical access into the sinus. As a result, a prosthodontist has a lot of information about every detail needed to perform and improve the success rate of implants in the region of maxillary sinus.[25]

a) Assessment of ridge morphology[26]

On a two-dimensional imaging system, the buccolingual ridge pattern is difficult to assess, but the CBCT system shows the alveolar ridge morphology. Ridge patterns such as irregular ridges, narrow crestal ridge form, and knife-shaped ridges appear in the images. Cortical bone loss and associated concavities are visible. 3D images more accurately depicted true osseous topography, making them a useful diagnostic tool.

b) *Assessment of quality of bone*[26]

The term "bone quality" is frequently used in implant success and failure reports. Skeletal sizes, bone architectures, the three-dimensional orientation of the trabeculae, and bone matrix properties all contribute to bone quality. As a result, it is a fundamental patient-based factor in determining success. Bone quality is of four types:

Type 1: Homogeneous cortical bone;

Type 2: Thick cortical bone with marrow cavity;

Type 3: Thin cortical bone with dense trabecular bone of good strength; and

Type 4: Very thin cortical bone with low density trabecular bone of poor strength.

Even with all the available options in CBCT, there are other imaging modalities for better assessment of the quality of bone.

2) Temporomandibular joint imaging

The ability of CBCT to define the true position of the condyle in the fossa, which often reveals the possibility of disc dislocation in the joint and the extent of translation of the condyle in the fossa, is one of its major advantages. CBCT allows for easy measurement of the roof of the glenoid fossa and visualisation of the three-dimensional relationship between the condylar head and the glenoid fossa due to its accuracy. Soft tissue calcifications around the TMJ are easily visible, reducing the need for an MRI in such cases. Due to these advantages, CBCT has become the imaging device of choice in cases of pain and dysfunction, trauma and fibro-osseous ankylosis, as well as in the detection of condylar cortical/sub-cortical erosion, and cysts.[26-28]

3) Maxillofacial prosthodontics

Cone beam computed tomography, like standard computed tomography, plays an important role in craniofacial defect reconstruction. With the help of DICOM data software, CBCT can create three-dimensional augmented virtual models of the patient's face, bony structures, and dentition in treatment planning. This digital compatibility (DICOM) is a globally accepted data transfer protocol developed to prevent malpractice with minimal distortion and a actual primary image. With this, the viewer can select any workstation to aid in a better understanding of the work. The shape of the graft can be virtually planned and positioned in the defect prior to surgery, creating a virtual reconstruction of the defect. Also, if necessary, the implant can be placed on the graft as needed. Finding the source of the obstruction in the airway is always a challenge. Several methods, including nasopharyngoscopy, cephalometry, nasal airway resistance, and polysomnography, have been used to determine the location of the airway for many years. The use of lateral and frontal radiographs to evaluate the pharyngeal airway has also proven to be useful. CBCT can also be used to create a three-dimensional representation of the airway and surrounding structures for accurate volumetric analysis. The analysis of the anatomy of complex airways (fig. 4) using CBCT scans has been found to be accurate, which is supported by previous research. CBCT-based volumetric measurement of airways is found to be accurate and error-free. As a result, three-dimensional imaging is a very effective method for examining encroachments and monitoring diffuse or focal airway narrowing.[29-31]

4. Comprehensive treatment planning in overdenture patients

The concept of retaining teeth/roots was described 150 years ago for denture rehabilitation. Clinicians discovered in the 1950s that when teeth were extracted, there was continuous resorption of alveolar bone, which left complete dentures with very little support, making them difficult to wear (fig.5).

Previous longitudinal studies revealed that in edentulous patients who had been wearing complete dentures for a long time, bone resorption was severe, progressive, and cumulative. The rate of resorption was highest in the first 6 months after tooth extraction, but there were variations due to biological and mechanical factors. The rate of resorption in the mandible, on the other hand, was found to be 4 times that of the maxilla. The reason was based on previous research that found that after 25 years of denture wear, the average vertical height loss in the mandible was 9-10 mm, compared to 2.5–3 mm in the maxilla. CBCT can be utilised along with various third party softwares in the meticulous planning of overdentures and improving its prognosis.[32-34]

Clinical value proposition

A clinical value proposition is a subjective assessment of the benefit-to-cost, risk-to-benefit, and time-to-benefit ratios. Desired diagnostic information, risks and costs to the patient, and time efficiency are all variables that define a clinical value proposition. The implant planning and placement process begins with the establishment of clinical objectives, which sets in motion a series of steps aimed at achieving those objectives. When all of the important information is taken into account, the best implant placement plans are created. CBCT provides anatomical accuracy, unlike traditional 2-D imaging methods. Clinicians can use virtual modelling to gather and combine input from a multidisciplinary team in order to create a single optimal treatment plan. Using a virtual environment for planning could be the most efficient and cost-effective method. The radiation dose is reduced by limiting the CBCT scanning field of view to only the areas of interest. The potential for a successful outcome is enhanced by careful planning to avoid nerve injury, penetrations of jaw boundaries, and implant proximity to adjacent teeth, as well as to facilitate implant alignment with the prosthetic elements.

Conclusion

CBCT imaging is a well-established radiographic modality in treatment planning for dental implants that is growing in popularity and use around the world. This is due in part to new knowledge of anatomic landmarks and structures that are highly susceptible during implant placement, such as neurovascular structures. Another reason for the rising popularity of CBCT scanning is the growing popularity of computer-guided surgery, which relies on digital planning based on high-quality CBCT images and may also include the superimposition of intraoral and extra-oral face scans to create a 3D virtual dental patient. The efficacy of diagnostic capability is much higher with lower radiation dose, which helped propel this technology into the spotlight, transforming a prosthodontist's pressing work schedule into one that is relaxed, easier, and more precise.

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FIGURES

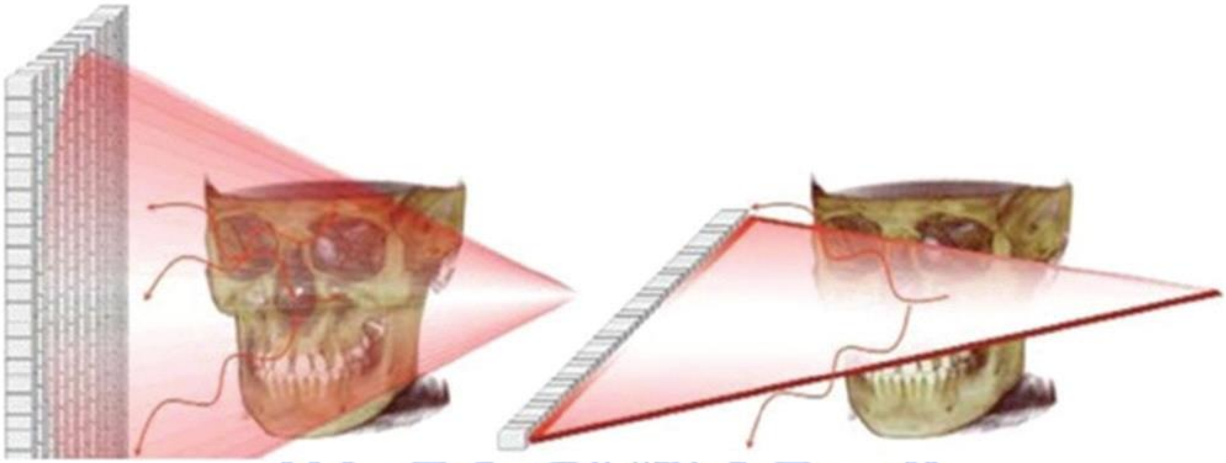

Fig.1 X-ray beam projection scheme comparing single detector array, a) fan-beam computed tomography and b) cone beam (Image Courtesy: Scarfe WC, Farman AG (2007) cone beam computed tomography: A paradigm shift for clinical dentistry. Australasian Dental Practice July/August; page number 102)

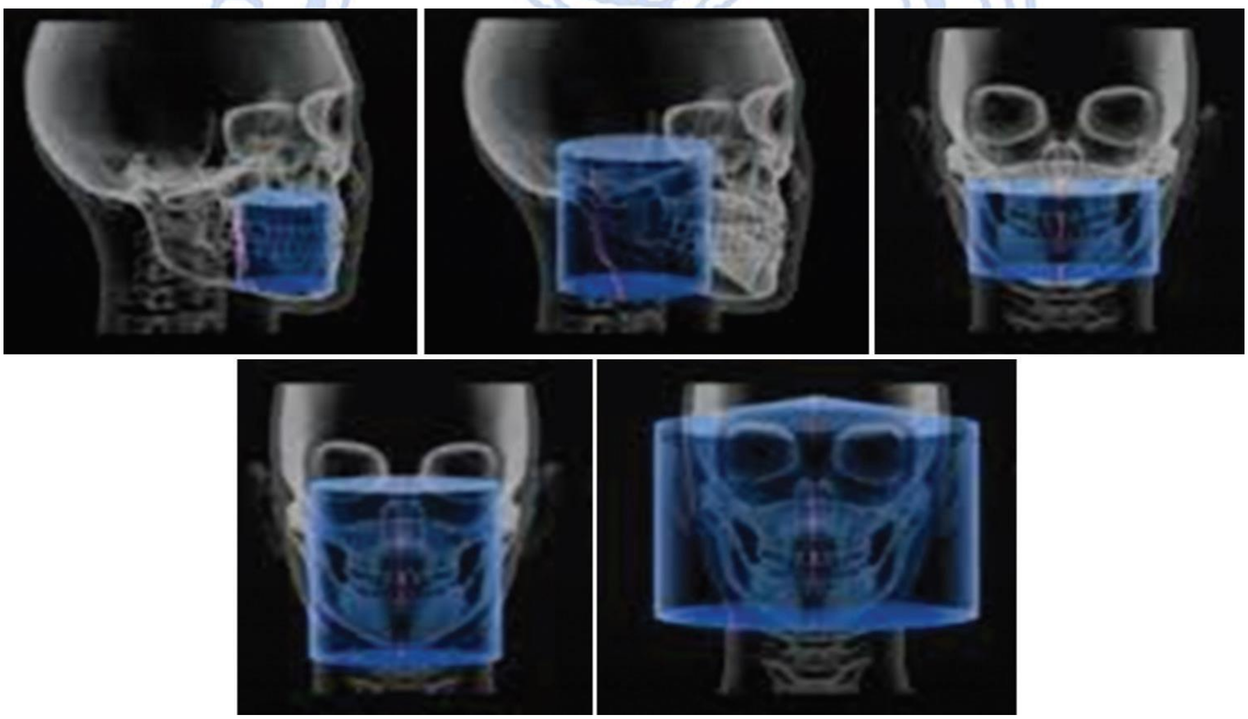

Fig. 2 Volume sizes – 5 × 5" (a), 8 × 8" (b), 8 × 10" (c), 15 × 12" (d), 15 × 15" (e) used in cone beam computed tomography imaging

Fig. 3 Representative standard cone beam computed tomography monitor display of Galaxis software (Sirona) showing panoramic image (a), three-dimensional image (b), tangential (c), cross-sectional (d) and axial (e)

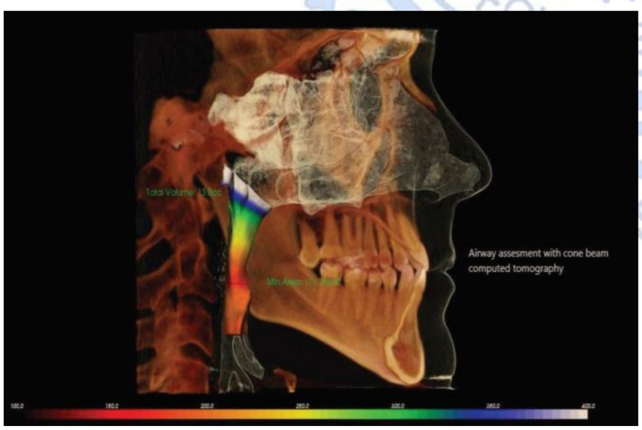

Fig. 4 Airway analysis using cbct

Fig.5 CBCT in Planning of Overdentures