Heal Talk

Cone Beam Volumetric Tomography- An overview

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Abstract

Radiographic examination is essential in diagnosis and treatment planning in dentistry. The interpretation of an image can be confounded by the anatomy of both the teeth and surrounding structures. The ability to assess an area of interest in 3-Dimension is beneficial for both novice and experienced clinicians.

Cone Beam Volumetric Tomography also known as cone beam computed tomography, captures a cylindrical volume of data in one acquisition. The volume acquired by a CBVT is composed of voxels. A voxel is a 3-D pixel. As the data are captured in a volume, all the voxels are isotropic, which enables objects within the volume to be accurately measured in different directions. CBVT offers distinct advantages over conventional CT. These advantages include increased accuracy, higher resolution, scan-time reduction, and dose reduction.

CBVT allows the clinician to view the tooth and pulpal structures in thin slices in all three anatomic planes: axial, sagittal, and coronal. This capability alone allows visualization of periapical pathology and root morphology previously impossible.

This presentation will be containing its use for assessment of implants, for third molar extraction and orthodontic analysis. Along with its use in endodontics for Apical morphology and suspected lesions of endodontic origin, Root canal system morphology, Presurgical visualization, Suspected root fractures and trauma, Internal and external root resorption.

Keywords: CBVT (Cone Beam , Volumetric Tomography, 3D imaging , Maladies

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Introduction

Imaging is an important diagnostic adjunct to the clinical assessment of the dental patient. Intraoral and extraoral procedures, used individually or in combination, suffer from the inherent limitations of all planar two-dimensional (2D) projections: magnification, distortion, superimposition, and misrepresentation of structures. The introduction of cone-beam volumetric tomography (CBVT) heralds a true paradigm shift from a 2D to a 3D approach to data acquisition and image reconstruction.[1]

Fig. 1 Cone-Beam 3D volumetric imaging

Cone-Beam 3D volumetric imaging was invented by Willi Kalender in the 1980s.

Cone beam technology was first introduced in the European market in 1998 and into the US market in 2001.[2]

Imaging is accomplished by using a rotating gantry to which an x-ray source and detector are fixed. A divergent pyramidal- or cone-shaped source of ionizing radiation is directed through the middle of the area of interest ontoan area x-ray detector on the opposite side. The x-ray source and detector rotate around a rotation fulcrum fixed within the center of the region of interest.

During the rotation, multiple, sequential planar projection images of the field of view (FOV) are acquired in a complete, or sometimes partial, arc.[1]

This procedure varies from a traditional medical CT, which uses a fan-shaped x-ray beam in a helical progression to acquire individual image slices of the FOV and then stacks the slices to obtain a 3D representation. Each slice requires a separate scan and separate 2D reconstruction. Because CBVT exposure incorporates the entire FOV, only one rotational sequence of the gantry is necessary to acquire enough data for image reconstruction.

Just as a digital picture is subdivided into pixels, the volume acquired by a CBVT is composed of voxels. Essentially, a voxel is a 3-D pixel. Because the data are captured in a volume as opposed to slices, all the voxels are isotropic, which enables objects within the volume to be accurately measured in different directions.[3] The axial height of a medical CT voxel, however, is determined by the slice thickness or pitch Fig 2 (1–2mm thick) and results in an anisotropic voxel.[4]

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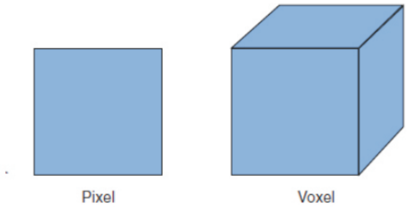
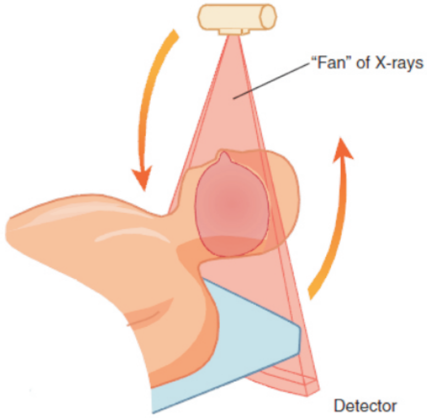


In other words, unlike the CBVT voxel, a medical CT voxel is not a perfect cube, and measurements made in multiple planes are not accurate. In addition to increased accuracy and higher resolution, CBVT offers significant scan-time reduction, radiation dose reduction, and reduced cost for the patient(4-6). With the help of viewer software7, the clinician is able to scroll through the entire volume and simultaneously view axial, coronal, and sagittal 2-D sections that range from 0.125–2.0 mm thick. The axial and proximal (sagittal in the anterior, coronal in the posterior)

views are of particular value, because they are generally not seen with conventional periapical radiography. The ability to reduce or eliminate superimposition of the surrounding structures makes CBVT superior to conventional periapical radiography8. In addition to the 2-D slices, Fig : 3 3-D reconstruction enables further assessment of the area of interest.

Fig 3 3-D reconstruction enables further assessment of the area of interest.



CBVT technology allows the dental practitioner to virtually immediately, evaluate patients for a wide variety of maladies.

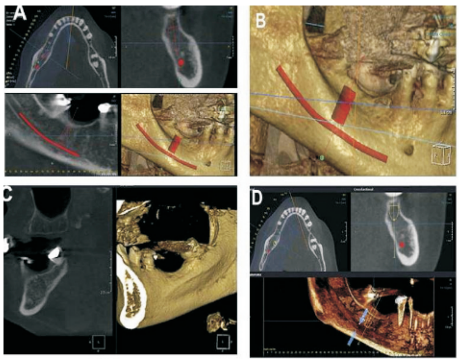
- Ranging from dental and jaw trauma and infections.
- Edentulism (quantitative and qualitative osseous evaluation for dental implants).
- Temporomandibular joint osseous pathology.
- Impacted and supernumerary teeth.
- Developmental and congenital jaw deformities.
- Dental endodontic lesions.
- Oral and maxillofacial pathology.[9]

Implant Site Assessment[10]

Greatest impact of CBVT has been on planning of dental implant placements. It provides cross sectional images of the alveolar bone height, width, and angulation and accurately depicts vital structures such as the inferior alveolar dental nerve canal in the mandible or Sinus in the maxilla.

Fig 4.(A) Typical implant planning image set shows a "generic" implant fixture orientation in relation to the inferior alveolar nerve. (B) A close-up image of the case above isolating the 3D color volume and proposed implant placement visualization. (C) A 3D colorized view to show the submandibular fossa in relation to the implant site. (D) A colorized "slab" rendering allows the clinician to actually see the canal and the desired position of the intended implant fixture.

Precise measurements can now be made



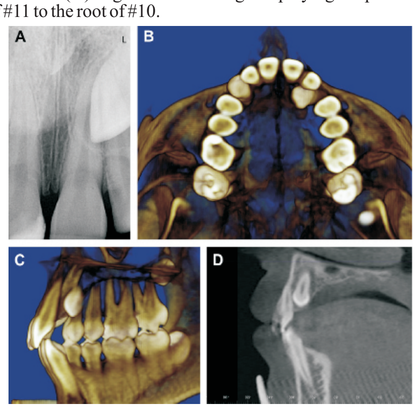
Orthodontic Analysis[11]

Orthodontists have routinely treated patients' malocclusions by applying forces in all three planes of space. The movement of alveolar bone may be accomplished in two directions: in a transverse direction or in a sagittal direction. For years, the three-dimensional (3D) movements have been diagnosed and treatment planned based on two dimensional (2D) imaging. Hence with the application of cone-beam volumetric tomography in various orthodontic tasks the unanswered questuions from 2D imaging can be avoided.

Impacted canines

Possibly the most recognized need for CBVT imaging in orthodontics is that of impactedcanine evaluation. The ratio of palatal to labial impactions has been shown to be as high as 9:1. Studies have been carried out relating the position of the impacted canine to the success of uncovery and orthodontic traction. CBVT imaging is precise in determining not only the labial/lingual relationship but also a more exact angulation of the impacted canine. These 3D images are beneficial in determining the proximity of adjacent incisor and premolar roots, which can be invaluable in determining the ease of uncovering and bonding and the vector of force that should be used to move the tooth into the arch with a lesser chance of adjacent root resorption.

Fig 5.(A) Periapical radiograph displaying an impacted tooth #11. (B) CBCT axial image showing the palatal position of tooth #11. (C) CBCT image of the relationship between teeth # 9 and #11. (D) Sagittal CBCT image displaying the proximity of #11 to the root of #10.



One should note that the four views in fig 5 are all static images made from a 3D CBCT scan. Using software like Dolphin 3D, the doctor can rotate the 3D skull, allowing for cuts at various angles to aid in visualization. The plane of view can be moved through the entire skull in all three axes of space. Some clinicians are now suggesting that tissue and bony uncover of the significantly palatally displaced and impacted canines without orthodontic traction would allow these teeth to drift into the oral cavity spontaneously; they then may be bonded some months later by the orthodontist[12]. Theenhanced knowledge of canine position supplied by the CBCT scans will aid the orthodontist as he or she determines whether to simply uncover the palatally impacted canine or apply immediate traction.

Other impacted teeth

Various other teeth become impacted less often than canines but still pose a significant orthodontic challenge. Maxillary central incisors can be impacted and displaced subsequent to the presence of a mesiodens. Fig. 6 shows a CBCT image of an impacted tooth # 9 subsequent to such a mesiodens.

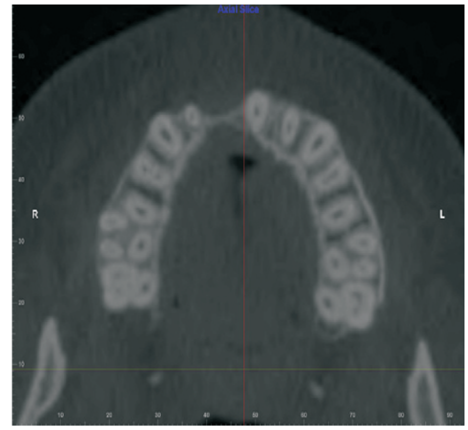
Never before have we been able to determine such an exact position of these displaced and impacted central incisors. The position of these teeth and the root and crown morphology can be evaluated. This knowledge can help determine the desirability of retaining and placing traction on these impacted teeth. Many times, the orthodontist is the first to recognize the presence of supernumerary teeth or odontomas in the young patient. Two-dimensional radiographs, especially panoramic ones, can make definitive diagnosis of an early-forming supernumerary tooth difficult. The CBCT image allows a more exacting view to help determine the presence and position of these unwanted surprises.

Fig 6. CBCT image showing a mesiodens (arrow) that has deviated the maxillary left central incisor to a horizontal position.

Cleft Lip & Palate

Estimates of the size (dimensions) of the osseous defects and the spatial relationship of the defect to other important anatomic structures are difficult to obtain in 2D images. CBCT can provide the cleft's exact anatomic relationships and bone thickness around the existing teeth in proximity to the cleft or clefts. This information is invaluable for the grafting procedures planned and for possible tooth movement in the existing dentition.

Fig.7 Axial CBVT image of a patient who has a unilateral cleft and missing central incisor.



Orthodontic Temporary Anchorage Device Placement

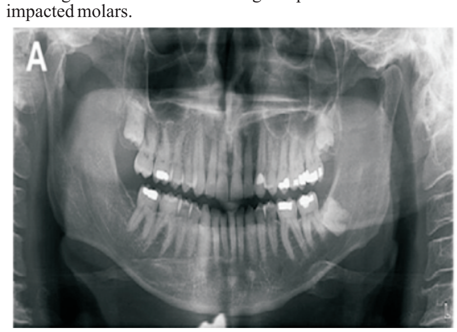
The temporary anchorage device (TAD) has gained popularity of late for use in orthodontic treatment. The knowledge of the root positioning can greatly enhance the opportunity for proper placement and success of TADs. CBVT images allow more successful placement and better treatment planning of where these TADs should be placed so that proper force vectors can be used during orthodontic treatment. CBVT data can be used to construct placement guides for positioning mini-implants between the roots of adjacent teeth in anatomically difficult sites.

Localization of Inferior Alveolar Canal

The relationship of the inferior alveolar canal to the roots of mandibular third molar is important.

This nerve damage may lead to permanent loss of sensation to one side of the lower lip. Thus accurate assessment of the position of canal to the impacted third molar may reduce injuries to this nerve. But, Not every impacted third molar is located close to anatomic entities that could cause problems like the inferior alveolar nerve (IAN) or the maxillary antra. If an oral and maxillofacial surgeon can obtain the initial information on a panoramic image, film, or digital image, and if the teeth to be removed are in locations that do not approximate the sinuses or IANs, then the clinical treatment decision is simple, the panoramic image provides the necessary data by itself, and CBVT may not be required.[10]

The Fig 8 shows excellent digital panoramic reveals 3 impacted molars.



If only the upper molars were impacted, a CBVT volume may not be necessary. However, the lower left third molar does appear to be in close proximity to the IAN, so a CBVT should be ordered.

Fig 9. This pseudopanoramic volume has the nerve colorized and shows the developing apex of third molar touching the IAN.

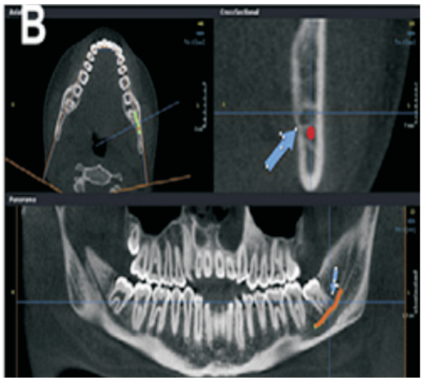
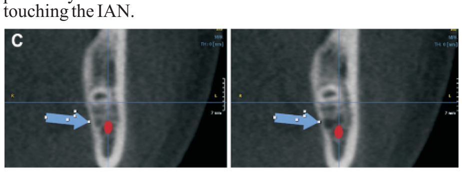


Fig 10. These cross-sectional images of tooth #17 show the proximity of the IAN to additional root areas of the tooth touching the IAN.



Hence, CBVT will replace conventional panoramic images as the standard of car only for difficult third molar extraction cases.

Endodontic Applications

CBVT for endodontic purposes appears to be the most promising use of CBVT, in many instances instead of 2D images. Applications would include apical lesions, root fractures, canal identification, and characterization of internal and external root resorption.

The complexities and variations of the root canal system present a continuous challenge to endodontic diagnosis, treatment, and prognosis. The maxillary second molar usually presents with 3 roots: 1 palatal, 1 mesiobuccal, and 1 distobuccal, each with a single canal.[13,14]

It has shown to exhibit variations in canal number and configurations13 and the commonest variation is the presence of a second mesiobuccal canal. Studies concerning root canal morphology of the maxillary second molar reported an equal incidence of 1 or 2 canals in the mesiobuccal root.

A case report describes a new variant of a maxillary second molar with 5 roots each with its own separate canal. This unusual morphology was diagnosed with an operating microscope and confirmed with the help of cone beam volumetric tomography.[15]

Fig 11. The involved tooth was focused and the morphology was obtained in transverse, axial, and sagittal sections of 0.5-mm thickness. The images revealed that the right maxillary second molar had 2 palatal roots, 2 separate mesiobuccal roots, and 1 distobuccal root each with its own separate canal.

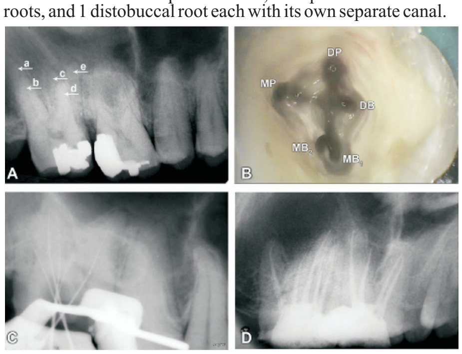
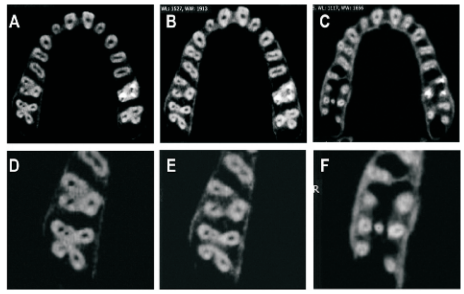


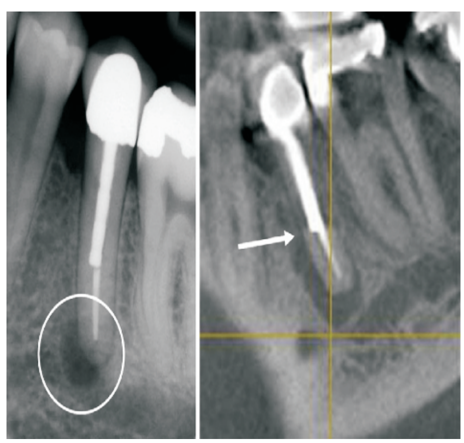
Fig 12. A-C, CBCT images showing axial sections of maxillary arch. D-F, Enlarged axial section CBCT image of #2 showing 5 roots and 5 canals.



Periapical Lesion Diagnosis

Current 2D technologies are film and digital based. Stavropoulos and Wenzel[17] remarked that the two have few, if any, differences. The investigators do point out that digital enhancements may result in limited improvement in detection. The classic study by Bender and Seltzer [18,19] demonstrated the limitations of intraoral radiography for the detection of periapical lesions. Their study revealed that in order for a lesion to be visible radiographically, the cortical plate of bone must be engaged. Many subsequent studies since that time have underscored the difficulty of detecting periapical lesions.[16]

Fig. 13 The standard 2D periapical radiograph did not reveal the true extent of the apical lesion (circle). The pattern of the lesion suggests a root fracture (arrow). In this case, the treatment of the tooth was changed from re-treating the root canal to extracting the tooth.



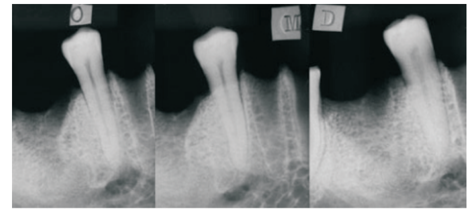
Root Resorption

Root resorption is the loss of dentine or cementum as a result of osteoclastic cell action. IRR occurs exclusively as a result of pulpal inflammation. Until recently, the diagnosis of internal and external resorptive defects has been limited to the information obtained from conventional radiographic techniques. CBVT provides additional relevant information on the location and nature of root resorptive defects when compared with that provided by conventional radiographs.

Identification of Simulated External Root Resorption.

Fig 14 shows Periapical radiographs, in three horizontal projections (orthoradial,mesioradial and distoradial)[20]

Fig 14. Simulated external root resorption: these were created with a size 014 spherical bur in a slow handpiece and were approximately 2 mm in diameter. Half of the active tip of the bur was used in random regions of the buccal or lingual surfaces, so that they overlapped the root canal, with the aim of making differential diagnosis difficult.[20]



Hence, Cone-beam tomography provided more accuracy in the detection of external root resorptions.

Internal Root Resorption

Fig 15 Representative cone-beam computed tomography images of external root resorption on the buccal side: (a) coronal, (b) axial and (c) sagittal views of the same tooth.

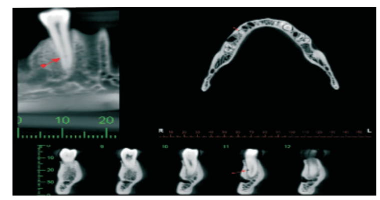


Fig 16 a)Clinical view showing preoperative status of crowned tooth 12. (b) Preoperative radiograph of the tooth demonstrating periradicular radiolucency and internal root resorption.

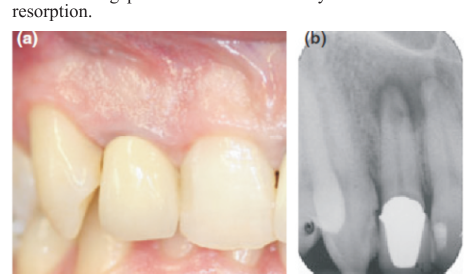
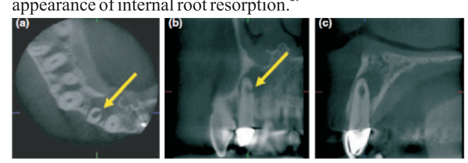
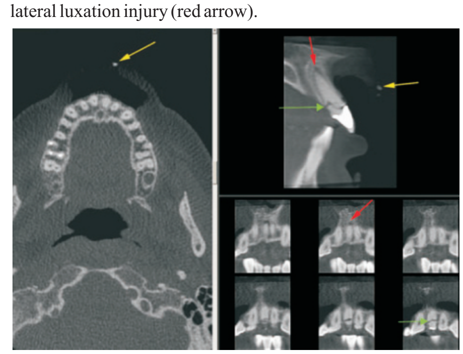


Fig. 17. Selected cone beam volumetric tomography images of tooth 12; (a) axial slice demonstrating palatal perforation (yellow arrow), (b) coronal slice shows location and size of perforating resorptive defect (yellow arrow) as well as the extent of the periradicular lesion, (c) further slice does not disclose perforation but clearly demonstrates 'classical' appearance of internal root resorption.[21]



CBCT may also prove useful in the diagnosis of dento-alveolar trauma, because the exact nature and severity of alveolar and luxation injuries can be assessed from just one scan.[22]

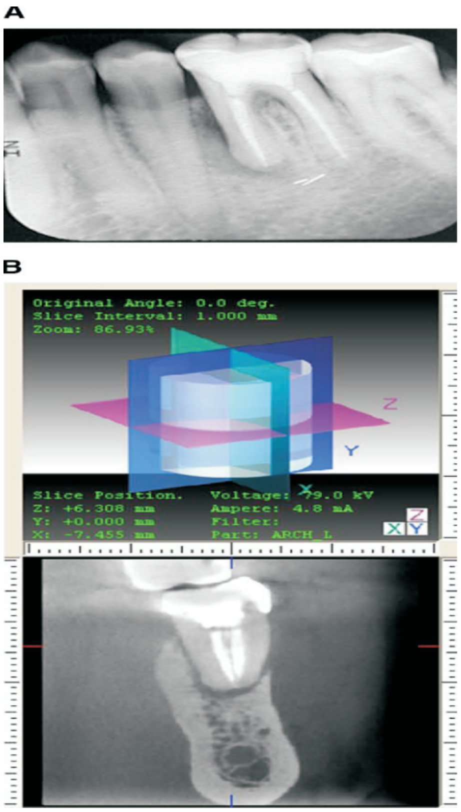
Fig. 18. A single CBVT scan used in the management of a Luxation Injury. The axial (left) and sagittal (top right) views reveal the presence and exact location of the fractured portion of the crown fragment (yellow arrow) in the upper lip, the scan also reveals an oblique fracture of tooth 21 (green arrow) and widened labial apical-third periodontal space as a result of a lateral luxation injury (red arrow).



Root Fracture Diagnosis

The diagnosis of some root fractures on conventional radiographs may be complicated, because of the lack of specific clinical signs and symptoms. limitation of intraoral radiographs is the absence of radiographic signs when the x-ray beam is not parallel to the plane of the fracture.[24] The superimposition of other structures further limits the sensitivity of radiographs for the detection of longitudinal fractures.[23]

Fig 19. Images obtained by 3D volumetric tomography (arrow indicates the fracture) was confirmed by checking against the symptomatology. (Images A and b)



Periodontal Applications

In his 2004 summary of periodontal imaging methods in Periodontology, Mol states, "Relatively few technologies have emerged to address the critical needs in periodontal diagnosis" [25]

In a review on CBVT for periodontology, Kasaj and Willershausen[26] conclude that the low dosage and superior image quality in comparison with conventional CT are promising for periodontal applications:

- Like intrabony defects
- Dehiscence and fenestration defects
- Periodontal cysts
- Diagnosis of furcation-involved molars.

Fig 20. Three images depicting a complete periodontal furcation involvement of a second molar. The figure on the left visualizes a furcation involvement delineated by the circle. The center and right images demonstrate the extent of the lesion (arrows) from facial-lingual and axial views.[16]

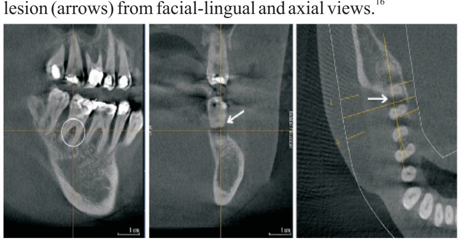
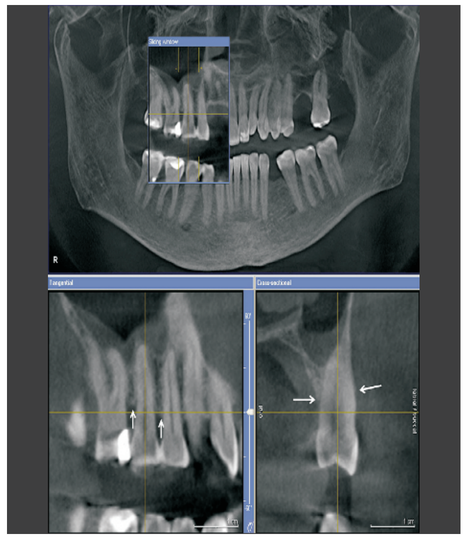


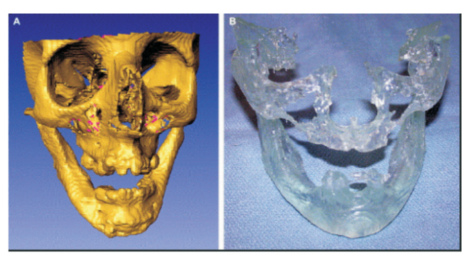
Fig 21. Three-dimensional depiction of periodontal bone loss around a maxillary second premolar tooth. The arrows indicate the extent of bone loss on the facial, palatal, mesial, and distal aspects of the tooth.



Rapid Prototyping

It's a broad term used to describe a group of related processes and techniques used to fabricate physical scale models directly from 3D computer assisted design data. Its purpose in maxillofacial imaging is to create life- size, dimensionally accurate model of an anatomic structure. These are also known as biomodels.[27]

Fig. 22. A. 3D volumetric reconstruction from CBVT data B. Rapid prototype constructed model of patient with right sided chemically induced osteonecrosis. Modeling was performed before surgical resection and reconstruction to provide addition of bone in right mandibular premolar area.



The major disadvantage of CBVT is a limitation in image quality related to noise and contrast resolution because of the detection of large amounts of scattered radiation.[1]

Conclusion

The development and rapid commercialization of CBVT technology dedicated for use in the maxillofacial region will undoubtedly increase general and specialist practitioner access to this imaging modality. CBVT is capable of providing accurate, submillimeter-resolution images in formats allowing 3D visualization of the complexity of the maxillofacial region. All current generations of CBVT systems provide useful diagnostic images. Future enhancements will most likely be directed toward reducing scan time; providing multimodal imaging (conventional panoramic and cephalometric, in addition to CBVT images); improving image fidelity, including soft tissue contrast; and incorporating task-specific protocols to minimize patient dose (eg, high-resolution, small FOV for dentoalveolar imaging or medium-resolution, large FOV for dentofacial orthopedic imaging). The increasing availability of this technology provides the practitioner with a modality that is extending maxillofacial imaging from diagnosis to image guidance of operative and surgical procedures.

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