Cone-Beam Computed Tomography (CBCT) Applications in Dentistry

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Conflict of Interest Disclosure Statement
- Dr. Casian reports no conflicts of interest associated with this course. She has no relevant financial relationships to disclose.
- Dr. Liang reports no conflicts of interest associated with this course. She has no relevant financial relationships to disclose.

Introduction
This course will review Cone-Beam Computed Tomography (CBCT) and its applications in clinical dentistry. The technology and how it differs from other types of dental imaging, keys for optimal imaging based on the desired outcomes, radiation dose to patients, interpretation, and medico-legal considerations will be discussed.

Course Contents

Overview

Cone-Beam Computed Tomography (CBCT) is an imaging modality that has shown a tremendous upward trend since its introduction in the late 1990s. The technology, keys for optimal imaging based on desired outcomes and exposure factors, and information on image analysis will be discussed.

Learning Objectives

Upon completion of this course, the dental professional should be able to:
- Describe CBCT technology and how it differs from other intraoral or extraoral dental imaging.
- Describe dental scenarios as to when a CBCT scan might be an imaging modality of choice.
- Discuss the options in CBCT scan acquisition to limit radiation exposure to the patient.
- List steps to systematically review and interpret a CBCT scan.
- Discuss the ethical and medico-legal considerations of CBCT.

Introduction

Cone-beam computed tomography (CBCT), also referred to as cone-beam volumetric tomography (CBVT) or cone-beam volumetric imaging (CBVI), was introduced in Europe in the late 1990s and approved by the FDA for use in the United States in 2001.[1] Because of the increasing applications of CBCT in dental practice over the past two decades, clinicians should seek to understand the basic concepts of this technology in order to provide appropriate treatment options for their patients.[2]

The main advantage of CBCT technology is the ability to view and analyze in three dimensions (3D) the patient's osseous oral and maxillofacial structures, overcoming the magnification and superimposition of structures found with 2D imaging modalities like panoramic imaging.[3,4] It is important to realize that with current CBCT technology only the bone and calcified structures are visualized along with airway spaces; soft tissue structures including muscles, glands, vasculature, and soft tissue tumors cannot be completely identified or assessed in a CBCT image. CBCT imaging provides high quality, accurate 3D representation of the osseous elements of the maxillofacial region.

When the patient is exposed to ionizing radiation, the beam passes through different tissues of varying densities. Structures with the highest density will be metallic materials, followed by enamel and bone. High density objects attenuate the x-ray beam, resulting in a reduction in the number of x-ray photons which strike the detector or sensor. Air absorbs very little of the x-ray beam. The difference in densities is registered by the x-ray detector, and the computer applies a formula/algorithm for each attenuation. The result is a numeric matrix of an assigned value to each location, displayed on the computer monitor as an image of varying shades of gray. High density structures display as white/light in the image, while low density structures that absorb very little of the x-ray beam, such as air, display as black/dark.[4,5]

How much ionizing radiation is the patient receiving during the CBCT acquisition? A CBCT study emits more ionizing radiation than an intraoral series or panoramic imaging but approximately 10 times less than a medical MDCT. The amount of ionizing radiation will be different according to each manufacturer or CBCT unit. Some CBCT machines emit continuous radiation exposure, which means

that during the entire acquisition process the unit is continually emitting ionizing radiation. Other CBCT units utilize pulsated radiation or intermittent radiation with less total radiation emitted.[6]

Radiation dose produced by CBCT is dependent on various machine parameters, such as field of view (FOV), peak kilovoltage (kVp), milliamperage (mA), and a continuous or intermittent beam, number of basis images, scan time and the degree of rotation.[5] These are factors that will influence the amount of radiation absorbed by the patient. Some of these factors are specific to each machine and some are clinician dependent, especially the field of view selected. A leaded apron should be utilized for patient protection as long as it is not positioned between the x-ray source and the area of interest and may be required depending upon state laws.

CBCT is a type of imaging that offers many advantages over conventional or multidetector computed tomography (MDCT) used in medicine.[4,5] In CBCT imaging the x-ray beam is cone- or pyramidal-shaped, as compared to the narrow fan-shaped x-ray beam in MDCT imaging.[1,4,7] The CBCT unit typically makes a single rotation of 180 or 360 degrees around the patient's head to acquire the two dimensional (2D) images, called "basis images;"[7] the MDCT x-ray source must make many rotations around the patient to acquire the volume of images.[1,5,8] A CBCT study has higher spatial resolution, shorter scan time, lower cost,

and lower radiation dose when compared with MDCT study, except poor soft tissue contrast.

All imaging modalities should follow the ALARA rule — As Low As Reasonable Achievable.[4,9] This principle is the basis for radiologic safety. Not all patients require a CBCT scan or 3D imaging.[10] Radiation exposure is only warranted if the proposed study will provide beneficial clinical information. A clear objective needs to be established prior to scanning a patient and should not be used on a routine basis or for screening purposes on all individuals.[9-11]

Principles of CBCT

CBCT units can be categorized according to patient positioning, field of view, clinical functionality, and detector type. Clinicians should consider all these characteristics prior to purchasing a unit. The first CBCT unit was similar in design to MDCT, with the patient in a supine (reclined) position during the scan. Most CBCT units have the patient seated or standing; this type of unit requires less space in the dental office and may be more accessible for wheelchair users.[1,2]

Field of view (FOV) is another way to categorize these units. FOV refers to the anatomical area that will be included in the data volume, or the area of the patient that will be irradiated.[7,9] Depending upon the type of machine/detector, and the geometry of the x-ray beam, the FOV could be classified as small or limited, medium and large (Figure 1).[1,4,5]
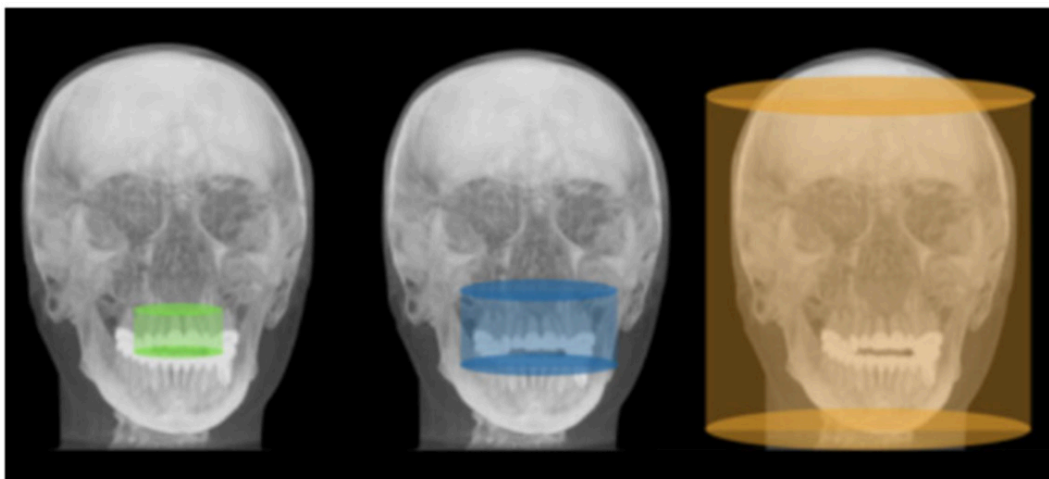

Figure 1. Examples of small, medium, and large field of view (FOV).

The units that scan small or limited areas, cover approximately 5 teeth (5 cm diameter) and surrounding anatomical structures, resulting in less volume for interpretation. Small FOV scans are normally used for endodontic purposes due to the capability of high spatial resolution and ability to visualize changes to the periodontal ligament spaces (PDL) or lamina dura, root fractures, periapical lesions, relationship of an impacted tooth with the surrounding anatomical structures, and root canal morphology. One capability of the small field of view units is the ability to create a larger volume of the complete arch rather than just a few teeth through the stitching process.[5] In this process, multiple adjacent limited field of view scans are united during the reconstruction phase to recreate one dental arch. The main disadvantage of the stitching technique is that the patient is exposed to multiple CBCT scans.[1]

Medium field of view is normally referred to those scans that image one arch or both dental arches, approximately 6-11 cm in height. When evaluation of the extent of a lesion or status of the temporomandibular joints is desired, a medium FOV is suggested. When both dental arches are scanned, a pseudopanoramic rendering can be derived from the data set. Medium field of view is also indicated in implant planning cases.

The large field of view is recommended for specific cases with skeletal anomaly/asymmetry and where orthodontic/orthognathic surgery is planned. The scanned area may range from 11 to 24 cm in height and covers most of the craniofacial skeleton. For comprehensive surgical planning, oral surgeons and orthodontists require a scan that extends from the inferior border of the mandible to the supraorbital ridges or vertex of the skull. The main disadvantage of the large FOV is the larger radiation exposure. With the large field of view the osseous structures of the temporomandibular joints and facial asymmetry can be evaluated. There are some manufacturers that offer the clinician the ability of acquiring different types of FOV according to their own needs. Each patient will present a unique situation, but it is important to always request the smallest possible FOV to avoid unnecessary radiation exposure to the patient.[9]

There are also "hybrid systems" that have the capability of acquiring a panoramic projection image, posteroanterior or lateral cephalometric image, and limited FOV 3D images (CBCT).

Another way to categorize the CBCT units is according to the type of detector: CCD/image intensifier (II) or flat panel detector.[5] The size of the detector dictates the FOV capabilities of each unit. This is directly related to the price of the unit; the larger the detector the more expensive the unit will be. The CCD/II are bulkier and require greater floor space in the dental office, compared to the flat panel detector that is smaller, and requires less space.[1]

Image Acquisition and Reconstruction

There are two phases in CBCT imaging: the acquisition phase and the reconstruction phase. During the acquisition phase, the patient is positioned into the machine with the head stabilized to avoid movement during the acquisition of the data volume. After patient positioning, a scout view will be acquired to verify that the area of interest is within the FOV. This step is highly recommended for small FOV scans to verify that the desired area is included, to avoid additional scans and exposing the patient to more radiation.

Once the clinician has assessed the scout image and approved it, the scan begins with rotation around the patient's head, either 180 or 360 degrees, and the cone-shaped x-ray beam is directed through the center of the area of interest. The beam and the receptor rotate simultaneously around the patient's head during the acquisition. During this rotation, basis images are acquired in intervals as the radiation passes through the patient and is captured by the receptor. A wide range of several hundreds of 2D images is collected in the detector within a few seconds.[4,5] These 2D images are called basis images. The exact number of basis images will be determined by the degree of rotation and the time of acquisition. A faster scan will acquire fewer images, whereas a longer scan will acquire more basis images and thus more information will be provided and a better quality image will be created.

There are two types of image reconstruction depending on the type of detector used. The resulting 3D reconstruction can be spherical (Figure 2) or cylindrical (Figure 3) in appearance.[1,5] The main clinical difference is the peripheral distortion experienced by the spherical reconstruction with a CCD/II detector; if a measurement is made in the center of the
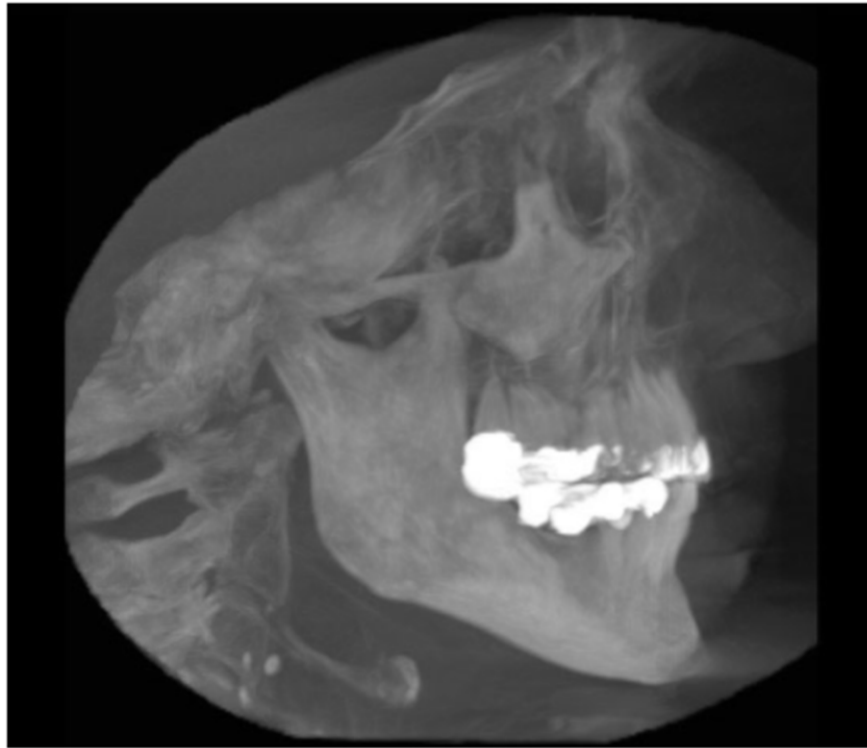

Figure 2. Maximum intensity projection (MIP) using CCD/II detector.
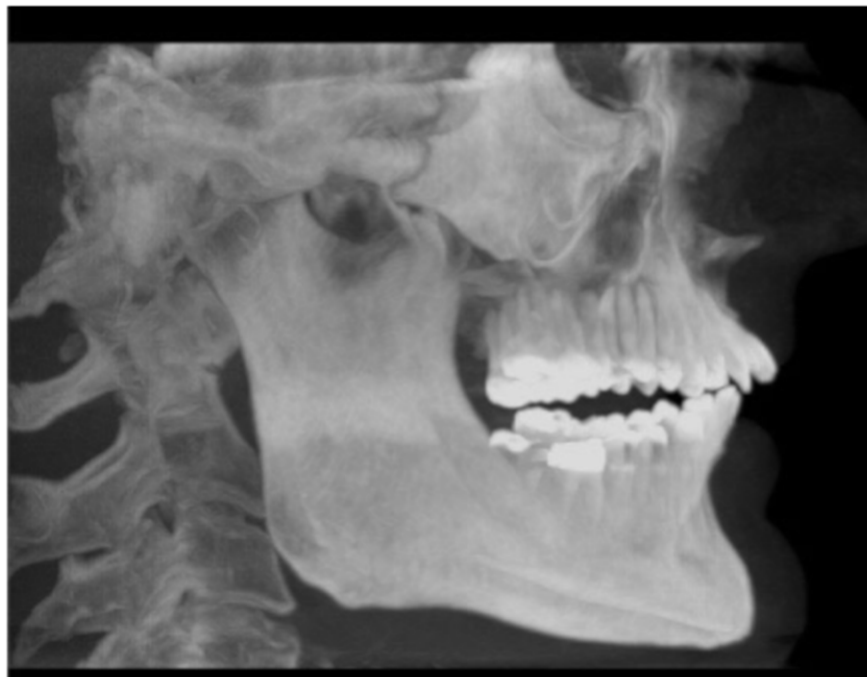

Figure 3. Maximum intensity projection (MIP) using flat panel detector.

volume, the measurement will be an accurate representation compared to a measurement made near the edges of the volume. The flat panel detector does not experience this type of distortion; thus, accuracy in the measurement will be found in the center of the volume as well as the edges of the volume.[1]

During the *reconstruction phase*, the set of several hundreds of basis images will be sent to dedicated software that will then create a 3D volume reconstruction of the data volume (Figure 4) and multiplanar (MPR) reformatted images in axial, coronal, and sagittal orientation (Figure 5). The coronal images look at the patient from behind in a series of images starting at the back of the head and moving towards the face (anteroposterior view). The sagittal plane will allow evaluation of the patient's structures from side-to-side in a series of images starting at one ear and moving to the other. The axial plane evaluates the patient
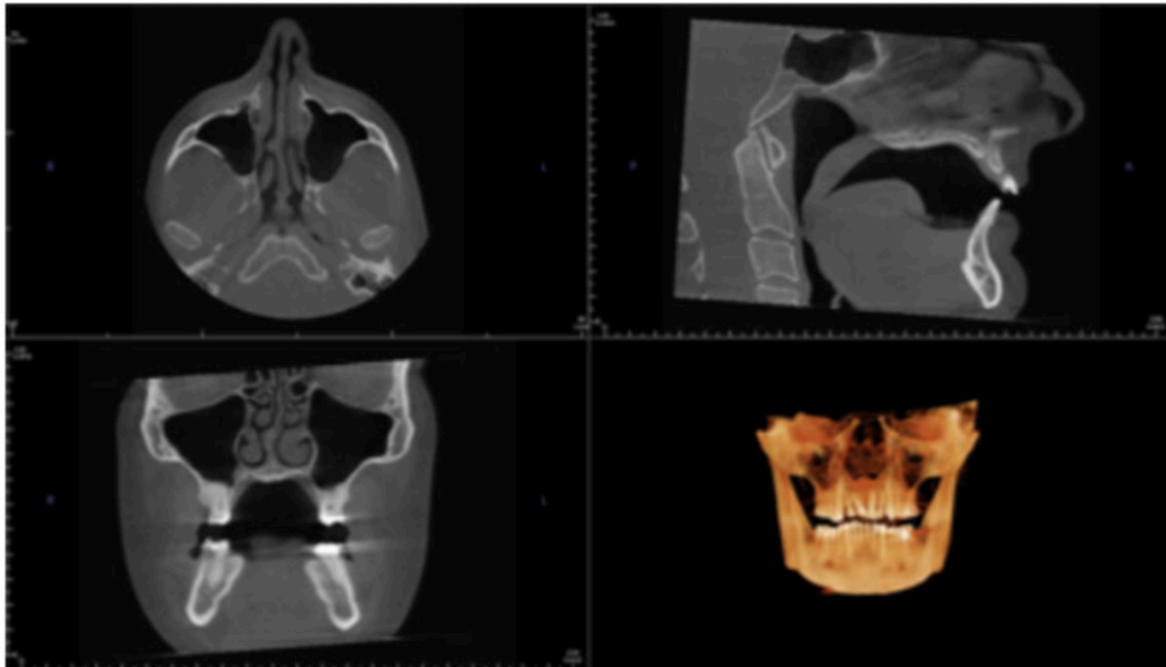

Figure 4. Multiplanar (MPR) reformatted images in axial, coronal, and sagittal orientation with 3D image.
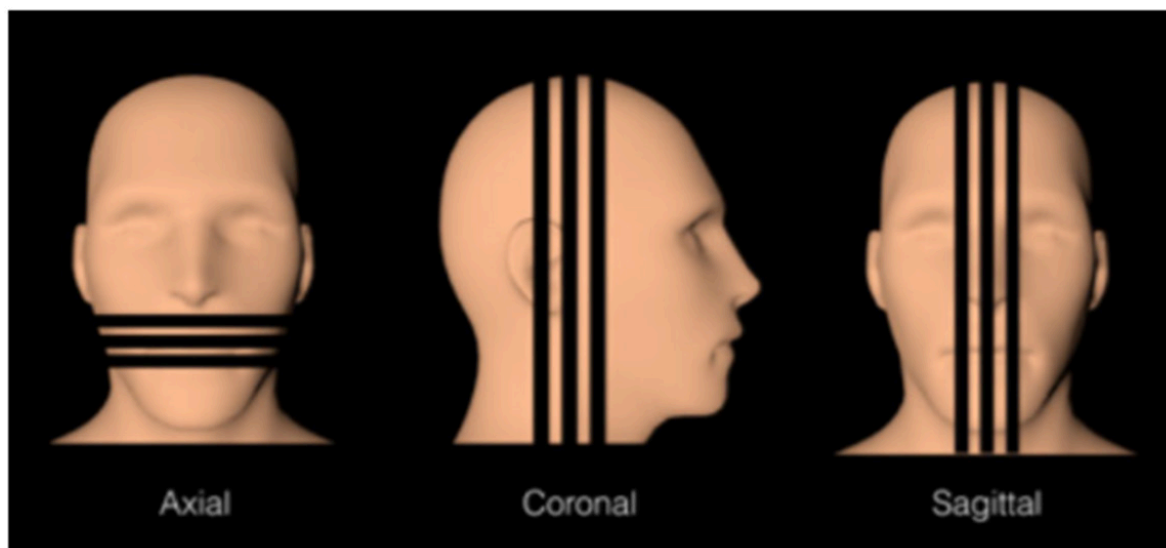

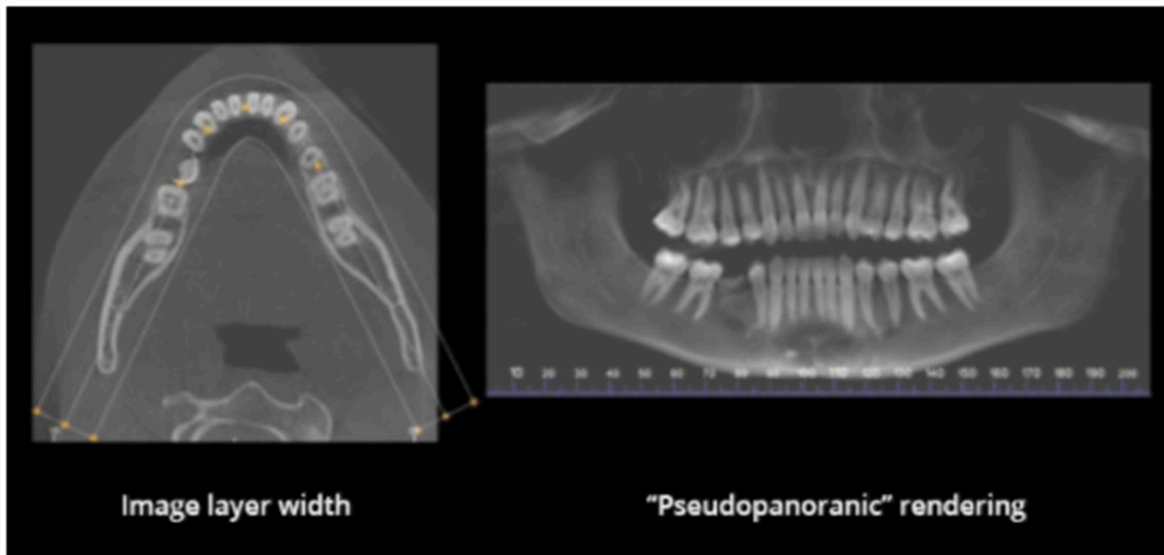**Figure 5.** Reformatting in axial, coronal, and sagittal orientation

Figure 6. Axial image and pseudopanoramic rendering.

from below in a series of images starting at the chin and moving to the top of the head (axial view).[2]

These secondary images are derived from the primary or basis images and are those that the dentist may feel most comfortable using because of the similarity to other imaging in dentistry: panoramic reconstruction, lateral cephalometric, and posteroanterior (PA) cephalometric. Perhaps the most useful secondary image in pathology and in implant planning is the cross-sectional image because it is a perpendicular view of the arch, allowing the clinician to evaluate the thickness of the alveolar crest.[12] The panoramic reformatted image is often utilized among clinicians; however, attention must be made to choose a width where anatomical structures, pathoses or other structures will be shown in the image (Figure 6). The principle is similar to a panoramic projection image formation; the clinician creates a focal trough or image layer that will represent the anatomic structures shown. If the image layer selected is not of sufficient width, anatomical structures outside the selected width will not be visualized.

Voxel
A voxel is the smallest 3D element of the volume,[2] and is typically represented as a cube or a box, with height, width and depth. Just as 2D images are made of several pixels (represented as squares, with height and

width) and the smaller the pixel the better the quality of the picture, the same concept applies to a 3D data volume. Each three-dimensional voxel represents specific x-ray absorption. The voxel size on CBCT images is isotropic, which means that all the sides are the same dimension with uniform resolution in all directions. In contrast, an MDCT voxel is in general nonisotropic meaning that one side of the voxel is different in dimension (Figure 7). This is considered an advantage of the CBCT because if a certain structure needs to be measured, the measurement will be exact in all the three orthogonal planes. There are different voxel sizes depending on the capabilities of each unit. The small field of view units may use a small voxel size of 0.076 mm, which enables visualization of very small changes to structures. Other voxel sizes available for CBCT units are variable, such as 0.2 mm, 0.3 mm, and 0.4 mm. It is important to note that the larger the voxel size, the less resolution the image will have and less capability to differentiate between small structures (Figure 8). The voxel size is dependent of the imaging objective and the size of the unit detector.

Voxel size needs to be smaller than the desired anatomical structure for adequate representation. For example, the first sign of periapical inflammatory lesion is discontinuity of the lamina dura; thus, if visualization changes to the periapical area (lamina dura
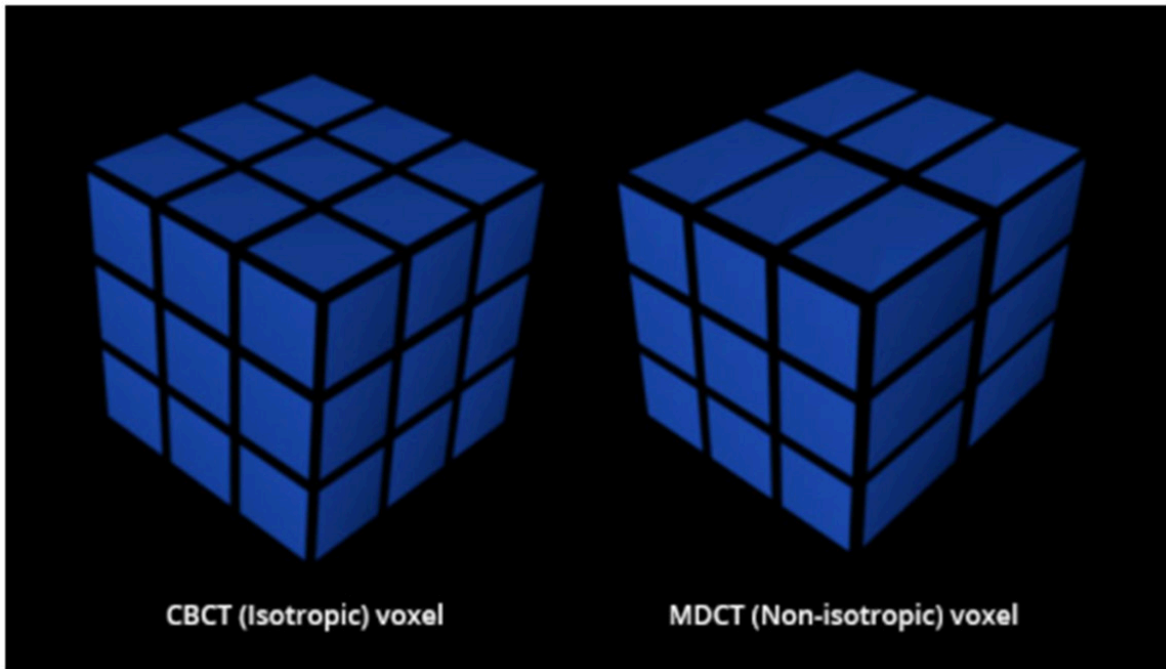
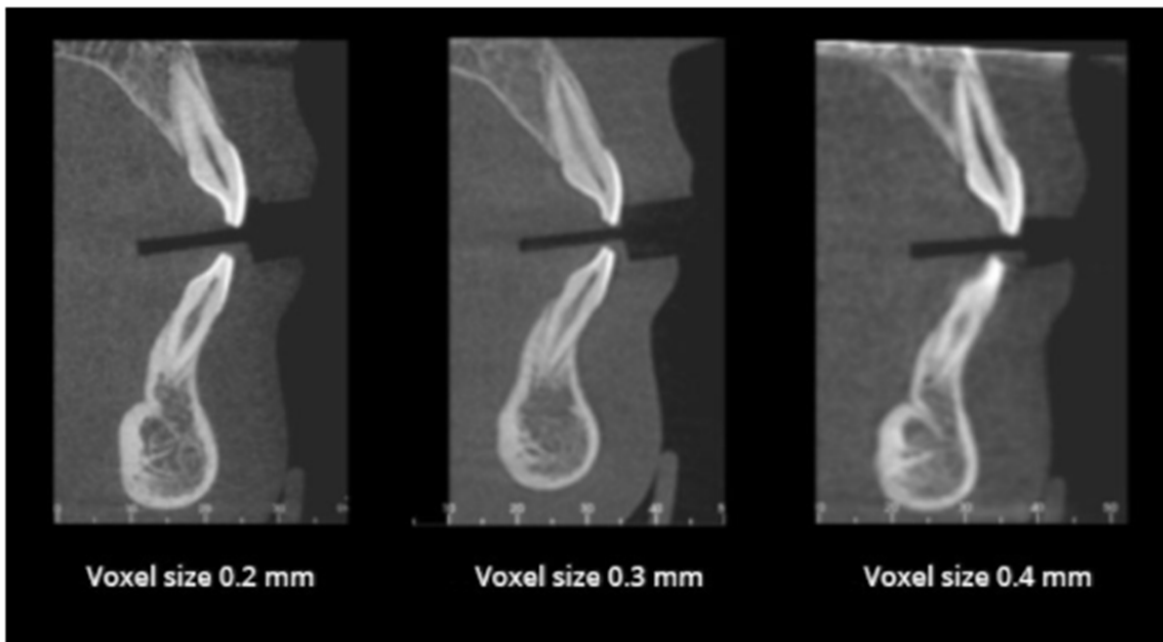**Figure 7.** Illustration of CBCT and MDCT voxel size.

Figure 8. Voxel size affects details of the objects imaged.

and PDL space) is desired, a CBCT less than 0.2 mm needs to be acquired. Structures smaller than the voxel size will not be visualized in the scan (example, small cracks in the enamel). As previously mentioned, soft tissue structures including mucosa, gingiva, cartilage, nerves and blood vessels cannot be evaluated in a CBCT study.

Spatial Resolution
There are different parameters that have direct influence on the resolution of an image. Voxel size is one of the most important parameters; however, field of view, scan time, number of basis images and type of detector also influence the resolution and quality of the scan.

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The longer the acquisition time, the more basis images are available. If a small voxel size is chosen the result will produce high spatial resolution but the amount of radiation exposure to the patient will be increased. These parameters change according to each patient situation. If a pediatric patient or an elderly patient has difficulty remaining still, a faster scan time might be the more appropriate way to evaluate a certain condition, resulting in decreased image resolution. As a general rule, the smaller the voxel size the higher the resolution.

Image Interpretation

There are two ways of reading the CBCT data set. The first is utilizing DICOM files (Digital Imaging and Communications in Medicine), which is both a communication protocol and a file format standard for handling, storing and transmitting information in medical imaging.4 The format ensures all the patient data and information stay together, as well as provides for transfer of the information between DICOM-supported devices from multiple manufacturers. The DICOM files are the 150-600 axial images that form the volume when they are merged together. Most implant companies offer their own DICOM file reading software, with different capabilities such as treatment planning or 3D printing of surgical guides. If the clinician does not have viewing software to allow uploading of the DICOM data, or the case does not require a 3D printed guide, the clinician can utilize a simple viewer to assess the images. The viewer will allow the clinician to evaluate the MPR images, make linear measurements and recreate a panoramic reformatted image. Other options typically found are zoom, magnification, brightness/contrast, rotation, and mandibular canal tracing.

The first step before analyzing the scan is to virtually reorient the patient data set until the arch is in a suitable position and the head is not tilted. The occlusal plane should be leveled with the horizontal plane. In the axial view, the midline should be coincidental with the patient's midline. This will help to evaluate symmetry of structures and avoid misinterpreting the images.

Once the patient reorientation is done, the MPR images can be read. It is very important to systematically read the entire comprehensive data volume. Key ideas to remember are to assess for symmetry and continuity of osseous borders. If the clinician does not feel comfortable assessing for abnormalities or pathoses in the skull base or cervical vertebrae, should they be within the field of view of the CBCT scan, consultation or scan interpretation by an oral and maxillofacial radiologist is paramount. The coronal MPR images are helpful to analyze anatomic structures with an anteroposterior orientation such as paranasal sinuses, nasal cavity, and some structures of the skull base (i.e., foramen rotundum). The axial images are helpful to analyze anatomical structures in a vertical path, with the sagittal images analyzing structures latero-medially.

The panoramic reformatted image is a useful tool because all teeth can be assessed in one image without superimposition and magnification that limits a 2D panoramic projection. The CBCT image is reconstructed based on a focal layer or trough, similar to a panoramic projection. The clinician can select the width and the extent of a focal trough in CBCT reformatting. However, an inappropriate choice of an image layer may lead to misdiagnosis. For example, an impacted maxillary canine may not be shown in the panoramic reformatted image if the selected curved image slice is not wide enough to include it. Some clinicians describe this reformat "pseudopanoramic."

The most important feature of the panoramic rendering is that according to the path of its curved image slice, the cross-sectional image will be displayed. The cross-sectional image is a perpendicular image through the mandibular or maxillary arch. This image will assist in evaluating the height and width of the alveolar ridge for potential implant site measurements, or the buccolingual extension of a pathosis and its relationship with the cortical bone.[12]

Image Artifacts

An artifact is described as any image distortion that is not related to the patient's anatomical structures.[13] There are several types of artifacts that may interfere with the image

quality. It is important that the clinician knows how to differentiate these artifacts to avoid misinterpretation.

The most common artifacts are beam hardening artifacts. Metallic restorations or objects, orthodontic appliances, and endodontic materials are the main cause of beam hardening in CBCT data volumes. Due to the high density of these materials, it creates an area of undersampling where information cannot be recorded. Beam hardening artifacts reduce the image quality in the axial plane; it presents as white streaks and black bands. (Figure 9).[1] To limit artifacts, reduction of the FOV may avoid inclusion of metallic restorations. Placing cotton rolls between the arches during the acquisition may also be appropriate to decrease the beam hardening artifact from opposing arch restorations. CBCT manufacturing companies continue to develop computer metal artifact reduction algorithms to reduce the number of artifacts visualized in a CBCT data volume.

Another artifact related to technique is called "aliasing." It is created when too few basis images are acquired due to a fast scan technique; therefore, a reduced data set leads to a noisier image and it appears as small lines throughout the scan.

Patient-related artifacts are typically due to motion during the acquisition of the data volume, such as pronounced respiration, eye motion, or tremors. Movement artifact ranges from blurring to double contours of bony outlines (Figure 10). Evaluation and consideration on how much the movement artifact prevents the visualization of the region of interest should be made prior to rescanning. Head straps and chin cups are utilized to avoid motion artifact during the acquisition phase. In addition, by using as short a scan time as possible can minimize motion artifact and also reduce radiation dose associated with CBCT imaging.

"Ring" artifact may appear consistently in studies acquired in a machine in which the detector is not properly calibrated. It is visualized in the axial plane as a black or white circular artifact normally located in the center or at the edges of the data volume.[13] Periodic realignment/calibration of CBCT unit is needed based on manufacture's recommendation.

Applications of CBCT in Clinical Dentistry

CBCT technology is being widely used in all fields of dentistry, including orthodontics, endodontics, oral surgery/pathology, periodontics, and implant treatment planning. Depending upon the characteristics of the CBCT machine, such
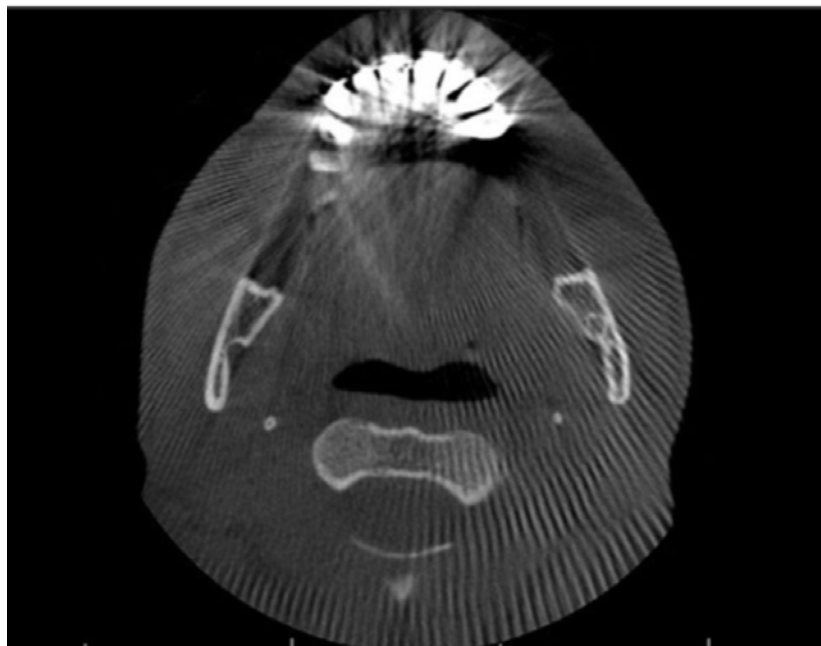

Figure 9. Beam hardening artifacts with white streaks and black bands.

Figure 10. Patient motion artifacts with double contour of bony outlines.

as size of detector and voxel size, different applications may be selected.

Before acquiring a CBCT on a patient, it is very important that the clinician review the medical history, clinical information and previous radiographic images to assess the need for the CBCT images. There must be a risk-benefit balance between any radiation exposures versus the information that may be gained by the study.[11] Is the patient going to benefit from the CBCT study? Would the additional information potentially change the diagnosis and/or the treatment planning? A good principle would be to acquire a CBCT study only when, in conjunction with the clinical examination, the benefit to the patient will be higher than the risk to the patient.

Implant Dentistry

A proper implant position that allows an ideal final restoration is always desired by clinicians regardless if it is a single crown, an implant-supported fixed dental prosthesis, implant-retained overdenture, or implant-supported fixed removable hybrid prosthesis. In order to achieve a successful result, a thorough analysis of the anatomy of the residual ridge

and evaluation of bone density is required. Typically, two-dimensional radiographic images — periapical and panoramic — have been used for the visualization of the edentulous area. Despite the high spatial resolution of the 2D images, the main disadvantage is that the buccolingual width of the alveolar bone and cortical plates cannot be accurately assessed which may lead to implant positioning errors and a compromised final outcome.[3] CBCT technology provides accurate assessment of dimensions and contours of the residual ridge in a buccolingual dimension (Figure 11).

CBCT in implant planning utilizes multiplanar and 3D images to aid in determining the exact height, width and alveolar ridge anatomy of the alveolar bone, as well as the relationship of the edentulous sites with adjacent anatomical structures. These important structures include the mandibular canal, mental foramen, and the maxillary sinus and nasal fossa. Guided implant placement surgery can be performed with the aid of the CBCT data sets. With the 3D capability of the CBCT the clinician can determine if pre-prosthetic surgery such as bone grafting or sinus lift is needed prior to implant placement.
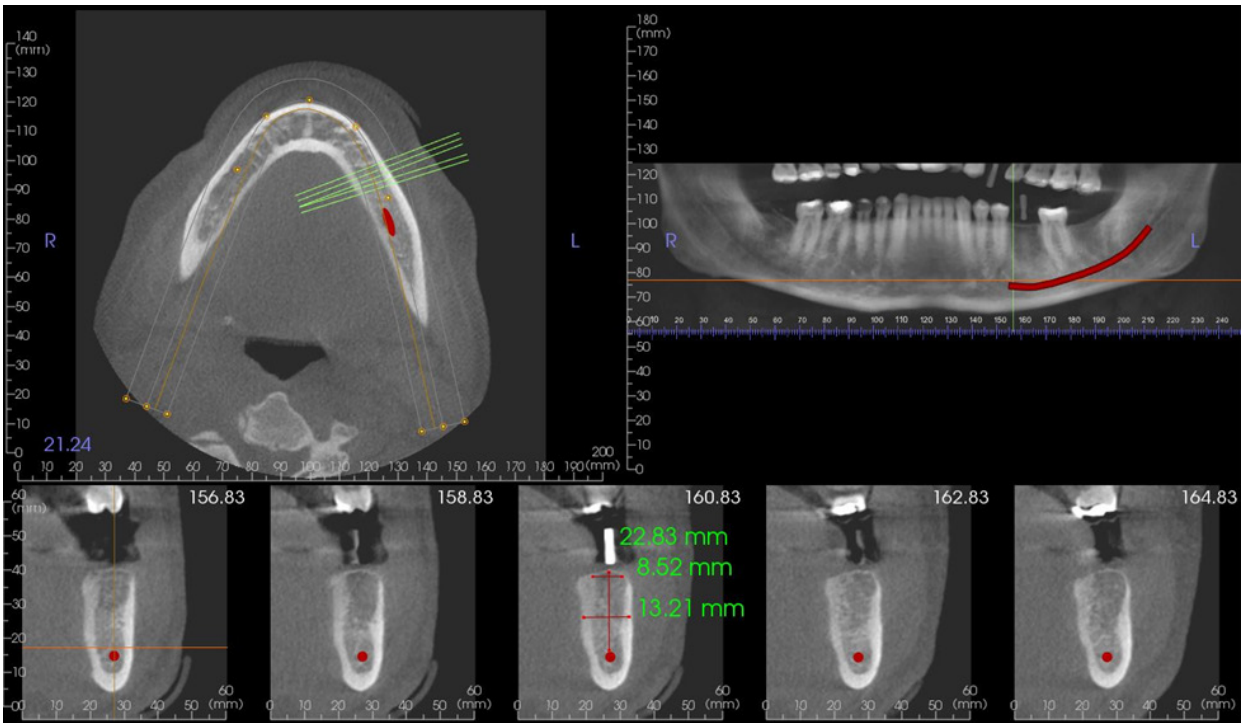
Figure 11. CBCT images for potential implant site assessment.

It is suggested that a well-fitting radiographic guide be used during the acquisition of the data volume.[10] The radiographic guide is an appliance with radiopaque markers for the localization of ideal implant sites.[3] The appliance is seated in the patient's mouth prior to the scan. Various materials may be utilized for the fabrication of guides and for the markers; an ideal guide is non-flexible to avoid distorting the location of the marker during acquisition. With the use of barium/acrylic, foil or composite, not only the site and angle of the implant can be assessed, but also prosthetic information such as the shape of the final crown and the restorative margin can be visualized for better positioning of the desired implant. With the information gained, the clinician can determine the best surgical approach for each specific situation.

After the CBCT acquisition is complete, the data volume may be exported in a file format that is compatible with third-party software to create virtual 3D models for implant planning or to fabricate surgical guides; each CBCT file set created for the patient might be several hundred MB. The clinician can also select the shape, length, and platform size of the implant from various software programs.[3]

In 2012, the American Academy of Oral and Maxillofacial Radiology published a position statement on selection criteria for the use of radiology in dental implantology with emphasis on CBCT. It stated that the panoramic image should be used for initial implant evaluation along with periapical radiographs; CBCT imaging should not be used exclusively for an initial evaluation. However, in implant planning, cross-sectional images are important images for treatment planning in many cases and thus a CBCT scan may be appropriate imaging to acquire.[12]

To follow up previous implant surgery, a 2D image such as a periapical image is the most convenient imaging modality, especially if the implant is asymptomatic. However, if the implant is symptomatic and the 2D image suggests bone loss adjacent to an implant requiring further evaluation and treatment, a CBCT scan may be advised, although the beam hardening artifact generated by the implant may reduce the ability of the scan to detect fine details.[12]
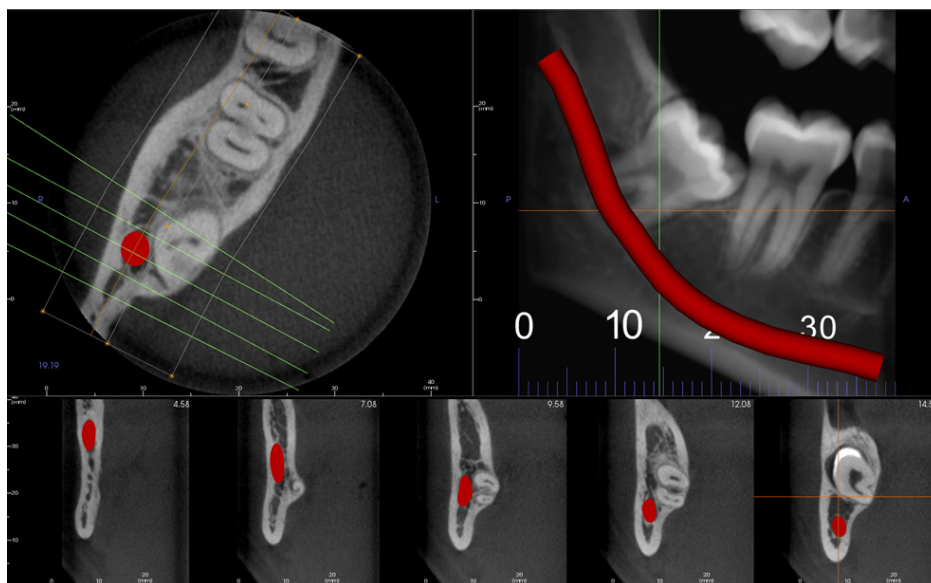
Figure 12. Anatomic relationship between impacted third molar and the mandibular canal.

Pre-surgical Evaluation

Clinicians shall identify potential harm to anatomical structures and should be able to determine the need for a pre-surgical evaluation.

Visualization and mapping of the mandibular canal is one of the advantages of a CBCT study of the mandibular arch. For most patients, a well-defined, corticated radiolucent track will be visualized in cross-sectional images. It typically will be located adjacent to the lingual cortex, originating at the mandibular foramen and extending anteriorly to the mental foramen. The distance from the alveolar crest to the visualized superior border of the mandibular canal can be determined with accuracy using a diagnostic CBCT image. Changes in the path of the mandibular canal and variants of normal may be assessed as well.

In the anterior mandible, it is essential to evaluate the area and identify the anatomical structures of the mandibular incisive canal, the lingual foramen and mental foramen to avoid hemorrhage and neurovascular damage.

In the posterior mandible the submandibular fossa extension is an area to be assessed prior to implant placement. The submandibular fossa is located below the mylohyoid ridge in the area of the mandibular molars. If a pronounced concavity is present, it may not be realized clinically or in a panoramic radiograph, with the potential for implant placement through the lingual cortical plate and high risk of hemorrhage that may be life threatening.

In the anterior maxilla, the incisive foramen is located posterior to central incisors and its diameter may vary. Size, exact localization and topography of such foramen are important because impinging on this anatomical structure can cause neurovascular damage.

In the posterior maxilla, one of the important structures are the maxillary sinuses. When planning for a sinus lift, a CBCT of the area may be requested for evaluation of both sinus health and anatomy. The middle superior alveolar canal will be visualized as a small round radiolucent structure running antero-posteriorly within the lateral wall of the maxillary sinus at the premolar area and should be identified prior to flap procedures in that area. Another anatomical structure in the posterior maxilla is the greater palatine foramen, located distal to the second molar area; its localization is extremely important for flap design. It is important to mention that

in CBCT imaging, the location of the greater palatine foramen (osseous opening) will be visualized but the neurovascular bundle (soft tissue) will not be seen. After a sinus lift surgery, a CBCT study can provide information regarding the post-surgical outline of bone grafting as well as how well adapted the bone graft is.

When a block bone graft is planned, information gained from a CBCT scan will assist in donor site evaluation. Autologous bone graft is harvested from the patient's symphysis or mandibular ramus. In the ascending ramus the distance from the mandibular canal to the buccal cortex should be accurately measured to avoid bleeding or neurological problems. Evaluation for the presence of bifid canals, not uncommon in the ascending ramus, should be determined. If the graft will be harvested from the symphysis, it is important to evaluate the anatomy of the area to avoid damaging apices of teeth or neurovascular bundles like the mandibular incisive canal.

One common treatment consideration for the use of CBCT is the assessment of the unerupted mandibular third molars. The cross-sectional images are extremely helpful in detecting the relationship and proximity of the mandibular canal to the roots of the third molar (Figure 12).

Paranasal Sinuses
The four paranasal sinuses of the head – ethmoid, sphenoid, frontal, maxillary – are visualized radiographically as radiolucent (black) areas. The presence of gray levels (varying opacities) within a sinus on a CBCT image may suggest some type of pathoses. Of all of the paranasal sinuses, the maxillary sinuses are the largest and the most important for the dental clinician due to their proximity to the maxillary alveolus.[2,14]

The inner walls of the paranasal sinuses are covered with a thin layer of mucosa, normally less than 1 mm thick and typically not seen radiographically.[2] There are several
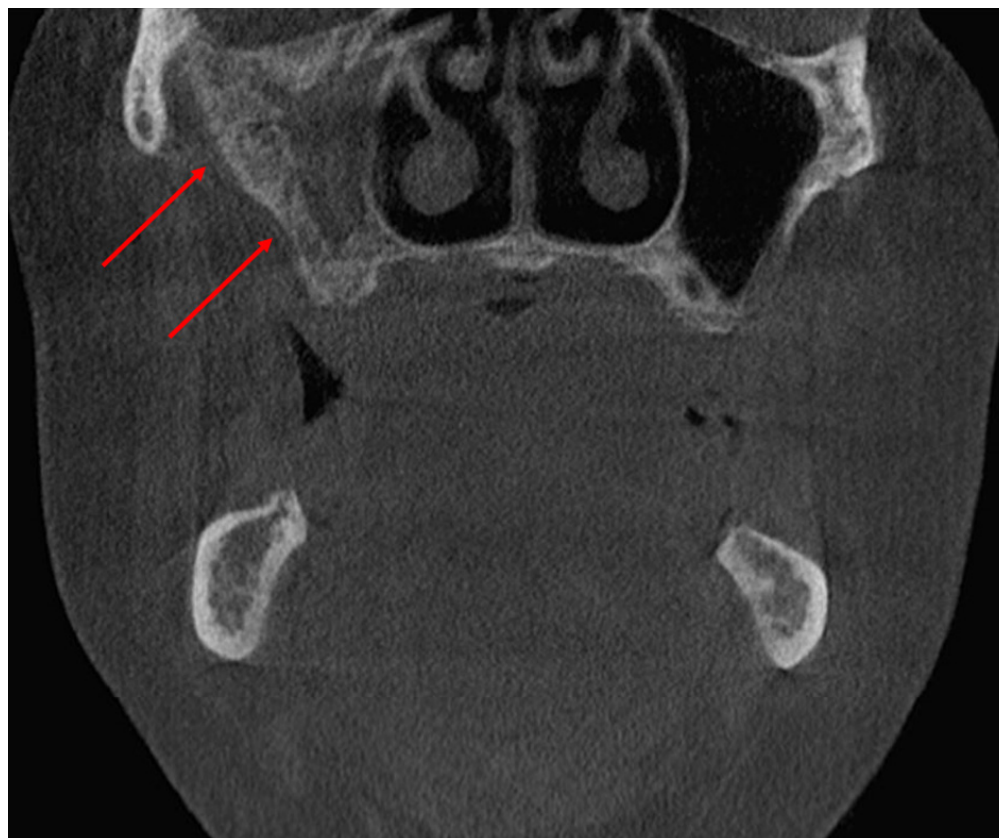

Figure 13. Mucosal thickening with sclerotic and thickened walls of right maxillary sinus.

reasons that can lead to mucosal thickening, varying from allergies, foreign bodies, or even odontogenic processes in proximity to the floor of the maxillary sinus. If such an inflammatory process crosses the floor of the sinus, it can create localized reactional mucosal thickening, which might be mucositis. However, if fluid level is present or sinus walls are thickened (Figure 13), based on the clinical presentation and duration, acute or chronic sinusitis are diagnosed. If maxillary sinuses are included in the field of view of the scan, the clinician must evaluate the health of the sinuses along with the patency of the maxillary ostium (the sinus-draining foramen).[2,14] The cause of sinusitis should be identified and treated before a surgical procedure such as a sinus lift is performed in the area.

A dome-shaped lesion arising from the floor of the sinus, without mucosal thickening of the rest of the sinus, is characteristic of a retention pseudocyst.[2] This common pathologic finding is generally asymptomatic and does not require treatment unless it enlarges to the point where it blocks the ostium.

Sinus lift procedures and foreign body removal are two important indications for requesting a CBCT scan. An antral septum may divide the sinus in two cavities; if not evaluated before surgery, it could cause major complications during the procedure. Visualization and analysis of the size and shape of an antral septum is of clinical importance when a sinus lift is desired in that area.[15] Three-dimensional localization of a foreign body within the maxillary sinus by CBCT will assist in determining the best surgical approach for its removal.[16]

Orthodontics

CBCT has been used in orthodontics due to the capacity of imaging a large field of view that includes all the landmarks for cephalometric analysis. For analysis of skeletal jaw relationships, the three-dimensional image needs to include the skull base, facial bones, and facial soft tissues. By exporting the DICOM files into specialized software programs, orthodontists are able to perform cephalometric analysis and treatment planning. A CBCT study will be helpful in an orthodontic case with proposed orthognathic surgery.[17]

Another application of CBCT in the field of orthodontics is to find the exact location of any impacted teeth, along with the relationship of adjacent anatomical structures. This information can assist the clinician in determining the best approach for each case. If root resorption of teeth is present due to impacted teeth, the extent of the resorption may be evaluated through CBCT imaging (Figure 14). The main advantage of CBCT over other dental imaging is the cross-sectional view without superimposition, where the buccolingual position of the roots can be assessed. Despite the benefits and advantages of CBCT studies, it should not be routinely used for all orthodontic patients.[17,18]

Endodontics

The preferred CBCT unit is one that allows acquiring a small FOV with a small voxel size; the result will be a radiographic study with high resolution that will allow evaluation of dental pathoses and relationships with adjacent anatomical structures.[19] The American Academy of Oral and Maxillofacial Radiology, in conjunction with the American Association
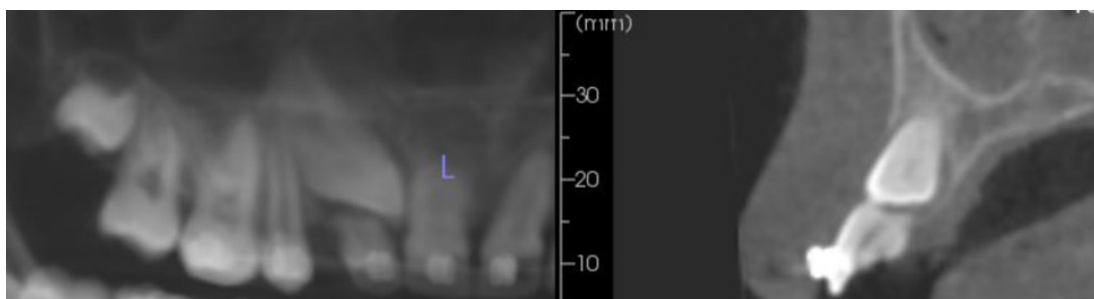

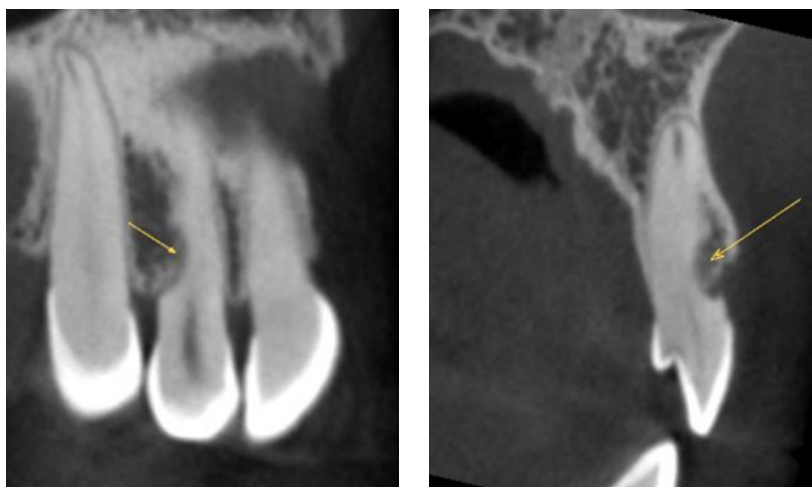**Figure 14.** Impacted tooth #6 with apical root resorption on tooth #7

Figure 15. External root resorption on distal facial aspects of root #7.

of Endodontists, published a position paper in 2015 on the use of CBCT in endodontics. The joint position paper states that intraoral radiographs should be considered the initial imaging modality of choice in the evaluation of the endodontic patient.[20] A CBCT should not be made in routine diagnosis or for screening purposes in the absence of endodontic signs.

Uses of a limited FOV CBCT in endodontics include evaluation of complex pulpal morphology or accessory canals, limited dento-alveolar or root fractures, or presence of resorptive defects (Figure 15). Post-treatment indications include evaluation of endodontic treatment complications, such as overextended canal obturations, separated instruments, or perforations. Pre-surgical uses include the localization of root apices and proximity to anatomical structures prior to an apical surgery.[20]

A CBCT may be beneficial to the clinician for diagnosis in patients with contradictory or non-specific clinical signs and symptoms associated with untreated or previous endodontically treated teeth following evaluation of inconclusive intraoral radiographic findings.

Airway Analyses
The airway space includes the nasal cavity, nasopharynx, velopharynx, oropharynx and hypopharynx. Large FOV CBCT studies, such as those acquired to assess the craniofacial

skeleton for orthodontics and orthognathic surgery, will typically include the airway spaces. In MDCT units where the patient is in a supine (lying with face up) position, gravitational forces on the tongue and soft palate will result in narrowing of the airway space.[21] With most CBCT units the patient is in a seating position that does not replicate the sleeping position. The visualized airway is not only influenced by the position of the soft tissue of the neck, it is also influenced by the position of the tongue during acquisition, which can cause the airway to appear narrower.[22] CBCT can help identify patients with a high predisposition for obstructive sleep apnea (OSA), although the final diagnosis is typically made through a medical sleep study (polysomnography).

CBCT studies provide only a static image of the airway space and can be helpful in the detection of anatomical or pathological changes. The airway space should be evaluated systematically for patency and symmetry, with the capability to measure airway dimensions or provide 3D modeling. Although CBCT imaging provides excellent visualization of static airway morphology, it does not provide any direct information on airflow or airway resistance.

Hyperplasia of the nasal turbinates is the most common form of nasal obstruction and can be caused either by infection or chronic inflammation. Other causes of nasal obstruction are nasal septum deviation, nasal
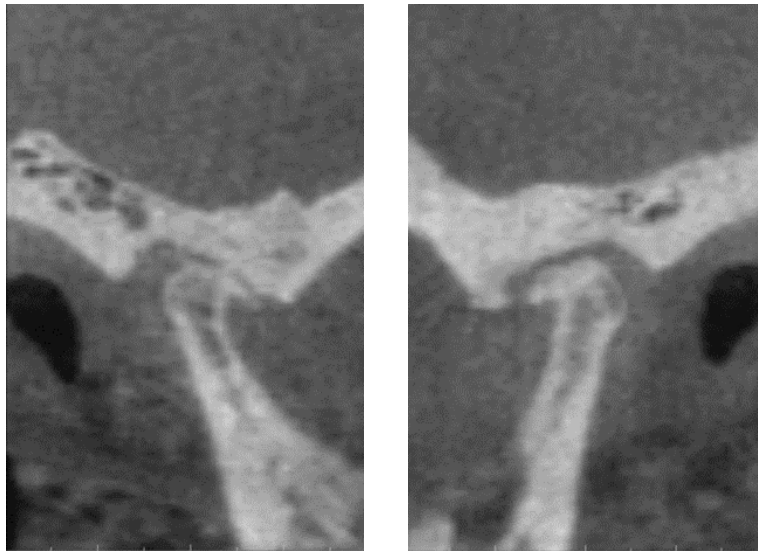
Figure 16. Osteophyte formation on both condyles with sclerotic changes in glenoid fossae.

polyps, benign tumors (such as osteoma), and malignant tumors (such as squamous cell carcinoma). Neoplasms in the nasopharynx and oropharynx can cause narrowing and/or asymmetry of the airway space. The most common pathological conditions that can affect the airway in children are enlarged pharyngeal and palatine tonsils.[2]

An airway analysis may be performed prior to orthognathic surgery. Volumetric measurements can be taken for the patient with surgical treatment options considered according to the severity in the position of the jaws.

Temporomandibular Joints (TMJs)
A CBCT scan will not demonstrate the position or integrity of the disk, as the disk is not a calcified structure. A CBCT scan that visualizes the TMJs may be evaluated for osseous changes to the mandibular condyle or glenoid fossa of the temporal bone (Figure 16). These osseous changes may result from trauma/fracture, degenerative changes or neoplastic processes.[23,24] If demonstration of the soft tissue components of the joint is requested by the clinician, another type of imaging such as magnetic resonance (MR) is recommended. The musculature of the TM joints cannot be assessed by CBCT; the use of a CBCT scan for diagnosis and treatment of myofascial pain

disorder or disk displacement is not indicated and thus will not be useful to the clinician.

If osseous evaluation of the TM joints is requested, it is important to choose a scan height to adequately image the entire joint space.[23] A drawback of the units using an image intensifier as the detector is that the TM joint spaces are often incompletely imaged or will be visualized at the edge of the spherical scan and prone to distortion.

Conclusion
Although CBCT is a great tool that provides 3D images, it does not replace standard dental radiographic images and should be utilized as a complementary tool for specific cases, and not for routine cases. CBCT studies with small field of view and small voxel size will provide improved spatial resolution, especially for endodontic purposes.

The advantages of CBCT over panoramic radiographs are 3D analysis, no superimposition or distortion, and the ability to create cross-sectional images. The disadvantages over panoramic imaging are increased radiation dose, acquisition artifacts, and cost.

The advantages of the CBCT over MDCT are faster scan time with less potential for movement artifact, less cost, and less radiation

exposure to the patient. A major disadvantage is poor soft tissue contrast, which prevents soft tissue assessment.

National Council on Radiation Protection and Measurements (NCRP) has recently published Report No.177 in 2019 - Radiation Protection in Dentistry and Oral & Maxillofacial Imaging. Because CBCT units are markedly more sophisticated than any of the other dental imaging devices, appropriate education and proper training for practitioners and operators are critical in the safe and effective use of this modality. On its recommendation 62, it says "Every person who operates cone-beam computed tomography (CBCT) equipment, supervises the use of CBCT equipment, or tests and evaluates the functions of CBCT equipment shall have ongoing continuing education in the safe and effective use of that equipment."

There are several steps the clinician must check and analyze for each patient and clinical situation:

Region of interest and field of view: Which teeth or anatomical structures are to be visualized? Are the TMJ areas to be included in the scan? Is visualization of both dental arches required, or only one arch? Is partial visualization of the maxillary sinuses enough?

Radiographic Guide: Is a radiographic marker showing the exact location of the desired implant site indicated? Will guided surgery be required? Is the radiographic guide well-adapted? In cases where the scan will be acquired at a separate location and a radiographic guide will be used, the referring clinician must pre-fit and assess the guide prior to the scan appointment. Also, the clinician should explain to the patient the correct position of the radiographic guide to avoid malposition.

Voxel size: Which voxel size would be the best for this specific situation?

Other: Should the patient's teeth be in maximum intercuspal occlusion while acquiring the scan or with teeth apart? Should cotton rolls be placed between teeth to separate the arches or should a bite registration be used?

If an oral and maxillofacial radiologist is to write a report on the scan, it is important to provide enough clinical information (age, gender, significant past medical history, duration of the pain or swelling) to assist in formulating an accurate differential diagnosis and treatment options.

It is the dentist's responsibility to critically assess the need for a CBCT study on a case-by-case basis, and to provide an interpretation of the entire data volume. This applies whether the clinician ordered or acquired the CBCT scan, and whether for use within that dental clinic or for use by a referral client.

Course Test Preview

To receive Continuing Education credit for this course, you must complete the online test. Please go to: *www.dentalcare.com/en-us/professional-education/ce-courses/ce531/start-test*

1. **An advantage of CBCT over conventional dental imaging is _____.**
    A. ability to visualize in 3 dimensions
    B. decreased patient exposure
    C. decreased cost to patient
    D. ability to see soft tissue

2. **The following are advantages of CBCT over a medical MDCT EXCEPT one. Which one is the exception?**
    A. less radiation exposure to patient
    B. faster scan
    C. less cost for the scan
    D. soft tissue differentiation

3. **CBCT machines may be classified based upon the _____.**
    A. shape of the x-ray beam
    B. field of view
    C. exposure time
    D. kilovoltage

4. **Modifying which factor would decrease radiation exposure to the patient during a CBCT scan?**
    A. Decreasing the field of view
    B. Increasing the region of interest
    C. Increasing the scan time
    D. Decreasing the voxel size

5. **Voxel size in CBCT image acquisition _____.**
    A. may be modified by post-processing
    B. is pre-selected by patient size
    C. is the same as for a medical MSCT
    D. is isotrophic in nature

6. **Selection of an increased voxel size for a CBCT scan _____.**
    A. affects measurement accuracy
    B. affects structural relationships
    C. decreases image resolution
    D. increases image detail

7. **The interpretation of the CBCT image volume should be _____.**
    A. systematic, treatment-directed
    B. systematic, comprehensive
    C. focused, limited
    D. focused, symptom-directed

8. **Which view is considered a reformatted image useful in implant planning?**
    A. Axial
    B. Coronal
    C. Sagittal
    D. Cross-sectional

9. **"Beam hardening" artifacts in CBCT images can occur as a result of _____.**
   A. patient movement during the acquisition
   B. superimposition of structures
   C. dense, radiopaque materials within the area scanned
   D. too low of exposure setting

10. **A CBCT scan may need to be reacquired if _____.**
    A. the patient's head was tipped resulting in distortion
    B. double contours of bone are seen on the images
    C. the patient continued to breath during the scan acquisition
    D. the voxel size was too small

11. **A CBCT scan would be potentially helpful for which assessment?**
    A. Locating an accessory canal during endodontic treatment
    B. Determining a crack in enamel for a patient with pain on biting
    C. Noting disk displacement in the TMJ area
    D. Finding caries beneath a dental restoration or cast crown

12. **What type of findings can be visualized in a CBCT image?**
    A. Mucous plug in salivary duct
    B. Hematoma at an injection site
    C. Asymmetry or interruption of airway space
    D. Salivary gland outlines within the soft tissue

13. **In a scan of the temporomandibular joints, which could be potentially confirmed or denied on a CBCT scan?**
    A. Disk displacement
    B. Edema following trauma
    C. Condylar neck fracture
    D. Soft tissue tumor

14. **According to NCRP Report No. 177, in the safe and effective use of CBCT unit, proper training and continue education on CBCT shall be needed for the following individuals EXCEPT one. Which one is the exception?**
    A. practitioner
    B. operator
    C. experts who evaluate the unit
    D. front desk people

15. **What is the dentist's interpretive responsibility for a large FOV CBCT scan?**
    A. Teeth and alveolar bone
    B. Maxilla and mandible
    C. Dental arches and maxillary sinuses
    D. All areas imaged within the scan

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Additional Resources
- Basic Principles for Use of Dental Cone Beam CT. The SEDENTEXCT-EADMFR Collaboration. Accessed October 23, 2017.
- NCRP Report No. 177: Radiation Protection in Dentistry and Oral & Maxillofacial Imaging. Licensed copy of Texas A&M College of Dentistry.

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