Third Edition

Quality Resource Guide

Clinical Considerations for Cone Beam Imaging in Dentistry

Author Acknowledgements

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Educational Objectives

Following this unit of instruction, the learner should be able to:

1. Understand the principles of CBCT imaging.
2. Describe the technical factors involved in performing a CBCT examination.
3. Explain the concept of task specific imaging to reduce patient radiation dose and optimize image quality.
4. Appreciate the relative patient radiation dose provided by CBCT imaging.
5. Understand that consensus general and selected discipline-specific use guidelines are now published that support the use of CBCT imaging as a supplemental diagnostic imaging modality with specific clinical applications.

MetLife designates this activity for **1.0 continuing education credits** for the review of this Quality Resource Guide and successful completion of the post test.

The following commentary highlights fundamental and commonly accepted practices on the subject matter. The information is intended as a general overview and is for educational purposes only. This information does not constitute legal advice, which can only be provided by an attorney.

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Introduction

Maxillofacial cone beam computed tomography (CBCT) is the most significant advance in dental radiographic imaging in the 21st century. There are many manufacturers, each producing a variety of models. CBCT provides the clinician with a cost effective, readily available and easy to use radiographic volumetric imaging modality with applications in diagnosis, treatment planning, surgical simulation and, most recently, fabrication of devices for image guidance of operative and surgical procedures. CBCT should be considered an adjunctive diagnostic modality after consideration of the patient's history and a thorough clinical examination. While recent technique modification may reduce radiation exposure to the patient, CBCT imaging usually produces substantially higher exposures than other dental radiographic procedures. The clinical use of CBCT imaging should therefore be "task specific" with image quality and radiation exposure being dependent on judicious choice of various parameters including within scanning and image visualization protocols. CBCT images display far more detailed information of the maxillofacial region than other dental radiographic images and necessitates a thorough knowledge of the 3-D anatomy and an appreciation of normal variability.

The purpose of this article is to outline the current concepts of CBCT technology, introduce practitioners to the role of both scanning and image visualization choices in image quality and patient dose and provide guidance on the appropriate clinical use of this modality in dental practice.

Principles of CBCT imaging

There are three phases in CBCT imaging **(Figure 1)** (Scarfe *et al.*, 2018):

1) Acquisition. A rotating platform supports the synchronous single full or partial rotation of an x-ray source and a reciprocating area x-ray sensor around a fixed axis of rotation centered within the patient's head. A divergent pyramidal (originally "cone-shaped") beam of ionizing radiation is directed through the middle of the region of interest (ROI) onto the area sensor with the field of view (FOV) being determined by the physical collimation applied. During the rotation, between 150 to over 600 individual single, sequential planar projection images are acquired. This series of two-dimensional (2-D) projection or basis images form a set referred to as the projection data.

2) Reconstruction. Software algorithms process the projection data to correct for magnification, distortion, and density variances and then generate a three dimensional (3-D), usually cylindrical volumetric data set composed of cuboidal volume elements (voxels).

3) Reformatting. Perpendicular sectioning of the volumetric dataset to provide contiguous images in three orthogonal planes (axial, coronal and sagittal) planes is referred to as secondary reconstruction.

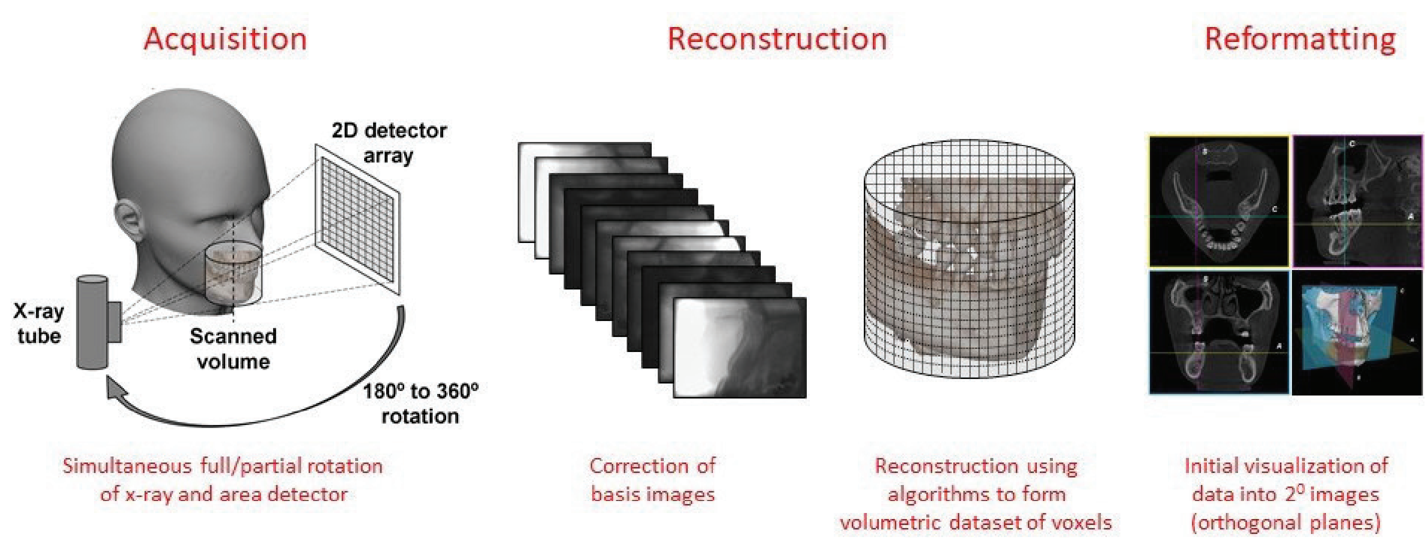
CBCT technique

CBCT and panoramic imaging share some procedural similarities however, there are several important differences between them, the most important being the greater number of technique options available for CBCT imaging **(Table 1)**.

Set technique factors. There are two factors to consider when performing CBCT imaging to optimize image quality and minimize patient exposure: **(Figure 2)**.

1) Scanning Protocol: These comprise exposure and acquisition setting selections to provide optimal imaging with least amount of dose (As low as diagnostically achievable [ALADA]).

Figure 1

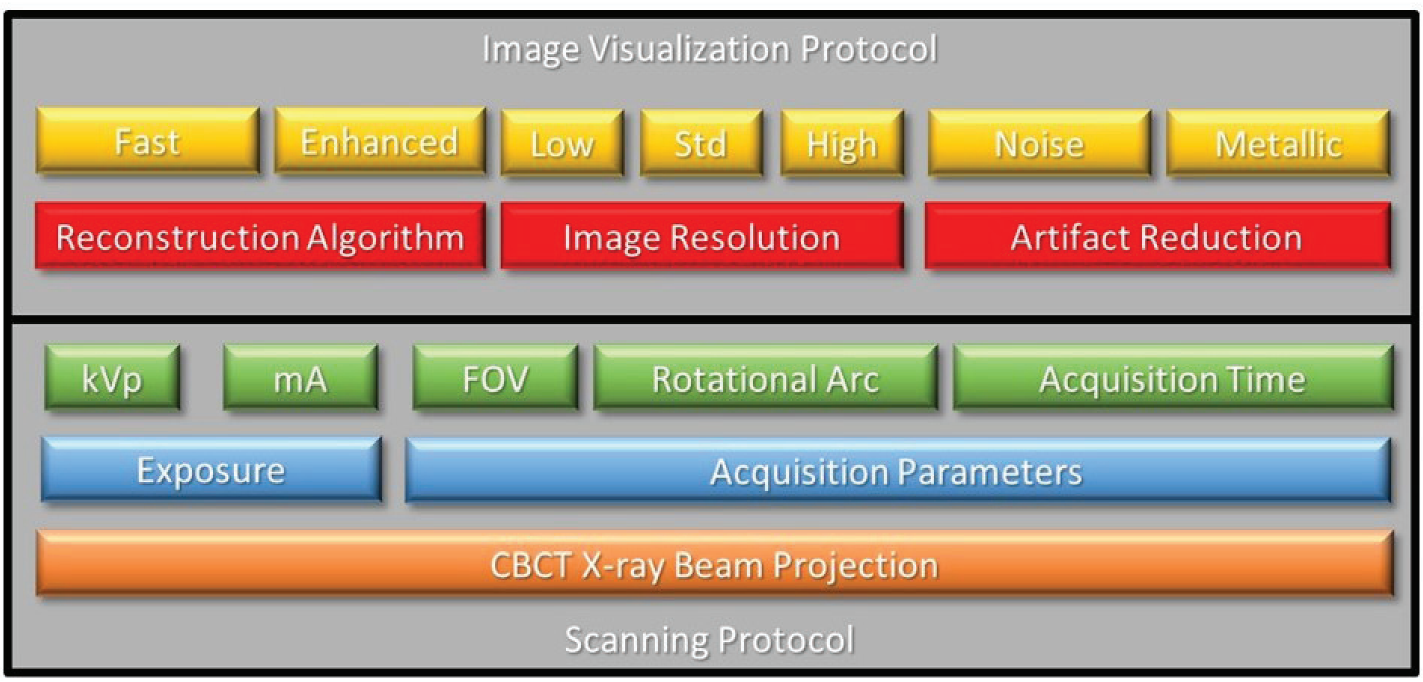


The three phases of CBCT acquisition. Multiple basis projections of the patient from the synchronous full/partial circular rotational exposure of a pyramidal x-ray beam projection on to an area detector are corrected to form the projection data from which a volumetric dataset is reconstructed and subsequently reformatted to produce orthogonal planar images.

Table 1 - Comparison of imaging procedures: Panoramic radiography vs. CBCT

Stage	Similarities	Differences
Set technique factors	Made before exposure; kVp and mA settings determine image quality and patient radiation dose.	CBCT image quality depends on selection of both scanning (*e.g.* FOV, arc trajectory, acquisition time) and image visualization (*e.g.* image resolution, artifact reduction) protocols which are patient and indication specific.
Prepare patient	Patient standing or seated, head stabilized, often with bite block.	Patient head position less critical in CBCT imaging.
Protect patient	Lead torso shield.	Thyroid shield is desirable, especially for maxillary scans.
Expose	Patient informed to keep still, with tongue completely flat against the roof of the mouth.	Scan time for CBCT is usually longer; head motion affects entire image in CBCT and more likely to occur; metallic objects create artifacts throughout image in CBCT.
View image	Single image viewed on monitor.	CBCT image reconstruction may take up to 2 to 3 mins; orthogonal images must be reformatted; volumetric data can be re-oriented to compensate for head position; CBCT image interpretation is dynamic (contrast, brightness, image mode).

Figure 2



CBCT Technique Factors. Scanning protocols allow the operator to adjust both exposure and acquisition parameters to balance image quality with patient radiation dose and should be task specific. Visualization protocols can be applied, often after acquisition, to optimize image quality and include choice of reconstruction and artifact reduction algorithms, and image resolution.

Exposure settings such as kilovoltage (kV) and/or milliamperage (mA) may be "fixed" for certain patient types (adult vs. child) or manually adjusted. Selection should be based on the relative size of the patient and in compliance with manufacturer's recommendations. These choices affect both image quality and patient radiation dose (Scarfe *et al.*, 2018). The primary acquisition settings include:

a) *Field of view.* The volume of tissue of the patient's head irradiated during exposure is referred to as the field of view (FOV). These dimensions are most often fixed for different regions (*e.g.* one jaw, both jaws, dental quadrant) or may be customized. The FOV should be correspond to the region of interest (ROI). This provides marked reduction in patient radiation exposure ranging from 25% to 66% depending on the machine, degree of collimation and location. (Ludlow and Ivanovic, 2008 da Silva Moura *et al.*, 2019)

b) *Acquisition time.* The total number of basis images comprising the projection data of a single scan is usually fixed but may be variable on some units. This is determined by adjustment of the acquisition or scan time. While increasing scan time provides more basis images to produce less noisy images, this is achieved at a proportionately higher patient dose.

c) *Arc Trajectory.* Most CBCT systems are now multimodal, based on the panoramic platform, and use a fixed limited arc of rotation of less than 3600. This reduces scan time and minimizes the opportunity for patient motion during the scan, however data must be extrapolated to provide a full volumetric dataset. Machines that use a complete circular (3600) rotation may offer a limited arc trajectory scan that, for some tasks (*e.g.* periapical bone loss), produce images at lower radiation exposure with comparable diagnostic accuracy (Lennon *et al.*, 2011; da Silva Moura *et al.*, 2019)

2) Image Visualization Protocol: Several units now offer post-acquisition options to apply to the volumetric dataset prior to display, improving image quality. All techniques can be applied without increasing patient radiation exposure.

a) *Reconstruction algorithm.* The Feldkamp, Davis and Kress (FDK) algorithm is the most widely used for 3-D reconstruction. It has a relatively fast processing time. Iterative reconstruction (IR) algorithms are now provided as an option in some units. These provide enhanced processing to images with reduced noise and artifacts, greater contrast and spatial resolution but have longer processing time. They are particularly useful in units with limited trajectory arcs.

b) *Spatial Resolution.* The acquired voxel dimensions of a CBCT unit reflect the pixel size and matrix dimensions of the image sensor. For larger scans, addition of the data in adjacent pixels is often performed to reduce file size and improve contrast resolution using a process of pixel binning. Some CBCT units provide options where spatial resolution can be improved by post-processing. Resolution settings should be selected based on the diagnostic task with implant and orthodontic applications using a low resolution (0.25 to 0.4mm voxel size), TMJ assessments and tooth impactions using a standard resolution (0.125 to 0.25mm voxel size) and endodontic diagnosis using a high resolution (< 0.125 mm voxel size).

c) *Artifact Reduction.* Two algorithms can be applied to the volumetric dataset prior to interpretation that may potentially improve image quality – noise and metallic artifact reduction. Both should be used with caution as they may add considerable time to the reconstruction phase and introduce other undesirable effects into the image.

Selection of scanning and image visualization protocols should be based on the requirements of the imaging task – a concept referred to as task specific imaging. For example, a TMJ scan to determine the degree of translation of the condyle with jaw opening should be performed at the standard resolution, shortest scan time and reduced FOV. This provides optimal imaging at a nominal dose.

Prepare patient. Whether the patient is standing, lying or seated, the jaws must be firmly stabilized during the entire scan. This reduces the potential for motion during the scan, a significant source of reduced image quality. (Bontempi et al., 2008) This can be accomplished using equipment such as chin rests and/or head holders and providing adequate instructions to the patient prior to exposure to remain still during the procedure and to keep the teeth closed either together or on a bite block.

Protect patient. The patient should be draped in a lead torso apron to reduce scatter radiation. Use of a thyroid collar should also be considered when it does not interfere with the area to be imaged as this substantially reduces patient radiation by shielding exposure to the hyoid, esophagus and cervical spine. (Qu *et al.*, 2012)

Exposure. CBCT scan time is often comparable to that of panoramic radiography. However, unlike panoramic imaging, CBCT also incorporates correction of the collected images. The digital detector may require periodic correction, referred to as detector calibration, to prevent untoward artifacts affecting image quality.

View the image. To assist in interpretation of the 3-D imaging volume, image display should be software-assisted, dynamic and performed as an interactive process – the value of the voxels must be adjusted (brightness, contrast), the volumetric dataset reoriented and the data reformatted for display using task specific protocol formatting.

Relative Radiation Exposure

Patient radiation dose is markedly influenced by the type and model of CBCT device, patient size (child vs. adult), region of interest (mandible vs. maxilla), exposure settings (kV, mA,) scan parameters (size of FOV, number of basis images, rotational arc, voxel size and resolution) and use of protective shielding. CBCT effective dose range from 11–252 μSv for small FOV, 28–652 μSv for medium FOV, and 52–1,073 μSv for large FOV comparable to approximately 1 to 70 times that of a single digital panoramic image (da Silva Moura *et al.*, 2019). Exposure to ionizing radiation is of particular concern for younger patients who are more radiosensitive than adults and have a mortality risk three to five times higher than that of adults for the same exposure (National Research Council of the National Academies , 2006).

Reformatting Techniques

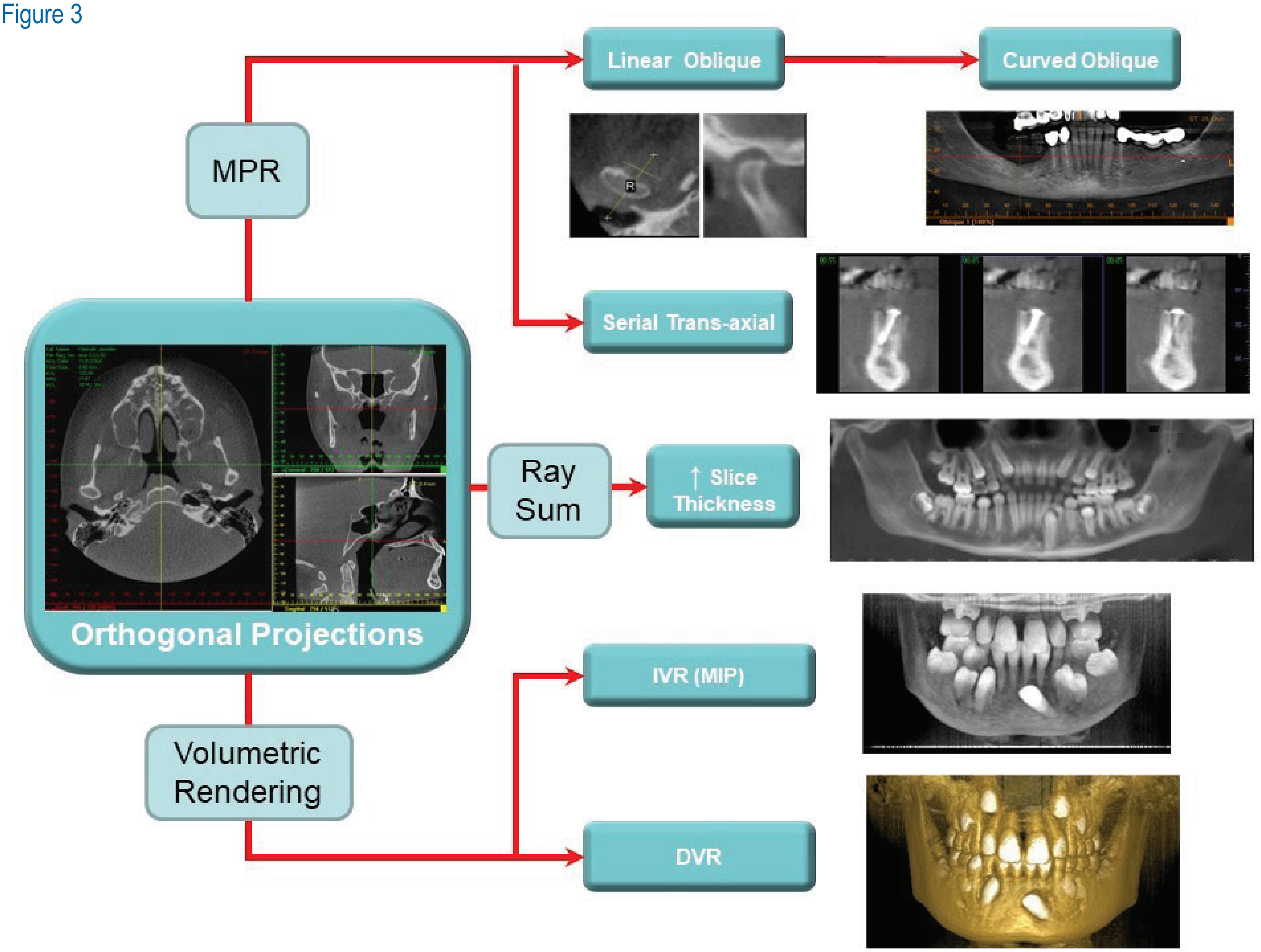
Personal computer based proprietary or third-party software facilitates dynamic interaction of the clinician with the volumetric data to provide task specific display modes useful in Dentistry (**Figure 3**) (Scarfe *et al.*, 2018). Strategies that are useful in oral and maxillofacial imaging include:

1) Multi-planar reformation (MPR).
This technique creates non-axial 2D images by transecting a set or "stack" of axial images. Linear or curved oblique MPR provide useful sectioning with respect to specific maxillofacial anatomy such as the TMJ or dental arch. Subsequent serial trans-axial cross-sectional imaging provides sequential, multiple, thin-slice images, orthogonal to the MPR.

2) Increasing slice thickness.
The addition of the grayscale values of adjacent voxels of orthogonal or MPR sections is known as "ray sum" and enables the production of simulated but undistorted projection images such as lateral cephalometric and panoramic images.

3) Volume rendering.
This refers to techniques which allow the visualization of 3-D data by selective display of voxels. This can be achieved by direct volume rendering (DVR) providing a volumetric surface reconstruction with depth or indirect volume rendering (IVR), most commonly as a maximum intensity projection (MIP).

Figure 3



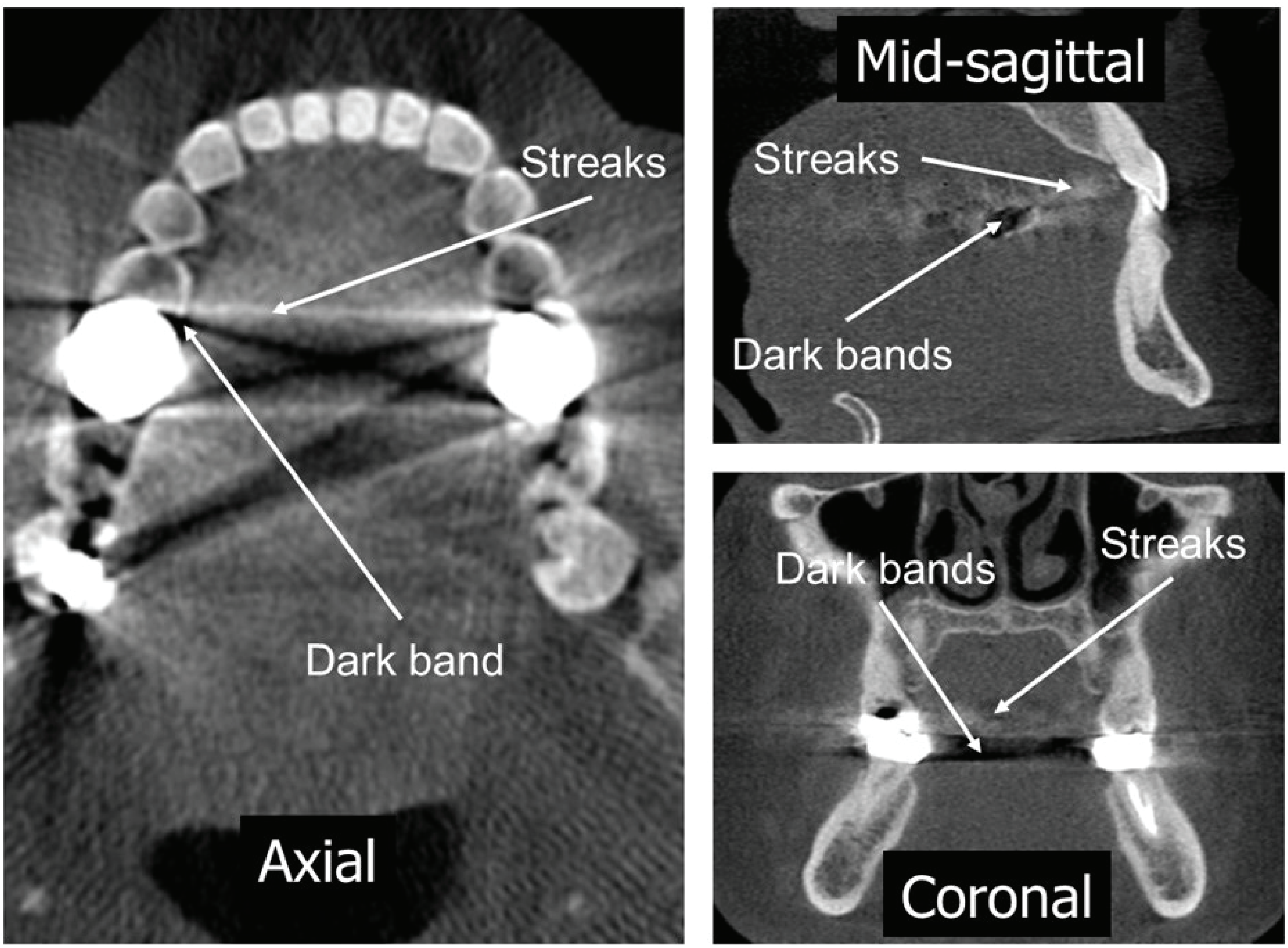
CBCT Reformatting. Display modes can be divided into 3 categories: a) Multiplanar reformatted (MPR) consisting of linear, curved oblique and serial trans-axial images, b) Ray sum comprising images of increased section thickness and, c) Volumetric images consisting of indirect volume rendering (IVR), the most common of which being maximum intensity projection (MIP) and direct volume rendering (DVR).

Clinical Use of CBCT Imaging

Numerous consensus-derived statements providing guidelines on the clinical use of CBCT are available. General use guidelines (Carter *et al.*, 2008; American Dental Association Council on Scientific Affairs, 2012) provide general statements on performing and interpreting diagnostic CBCT. These documents provide guidance on the appropriate use and prescription of CBCT, detail the responsibilities of practitioners and licensed operators in performing the scan, outline the appropriate documentation and radiation safety considerations and provide recommendations for quality control and patient education. In addition, specific use guidelines are available for endodontics (Special Committee to Revise the Joint AAE/AAOMR Position Statement, 2015), orthodontics (American Academy of Oral and Maxillofacial Radiology, 2013), periodontics (Mandelaris *et al.*, 2017) and implant dentistry (Tyndall, *et al.*, 2012; Jacobs *et al.*, 2018). CBCT should be used as an adjunctive diagnostic tool to current dental imaging techniques for specific clinical applications, not as a screening procedure. Technical factors should be adjusted to provide the minimum exposure that provides the image quality necessary for adequate diagnostic information.

CBCT imaging provides excellent detail of osseous structures, however images have reduced contrast resolution and more noise ("grainier) as compared to conventional computed tomography. Image quality may be compromised by image artifacts due to acquisition (beam hardening producing scatter streaks and dark bands), **(Figure 4)** patient related artifacts (patient motion leading to unsharpness), the scanner itself (ring artifacts) or the cone beam technique (distorted periphery). Contrast, resolution and artifacts currently make CBCT imaging unsuitable for dental caries diagnosis (Haiter-Neto *et al.*,

Figure 4



CBCT artifacts. The presence of metallic restorations in the mouth creates streak and dark band effects which present horizontally on axial (left), coronal (lower right) and sagittal (upper right) orthogonal images.

2008) or alveolar bone assessment (Mandelaris *et al.,* 2017), particularly when restorations are present in the dentition.

Specific Clinical Applications

CBCT has application in all areas of dentistry including:

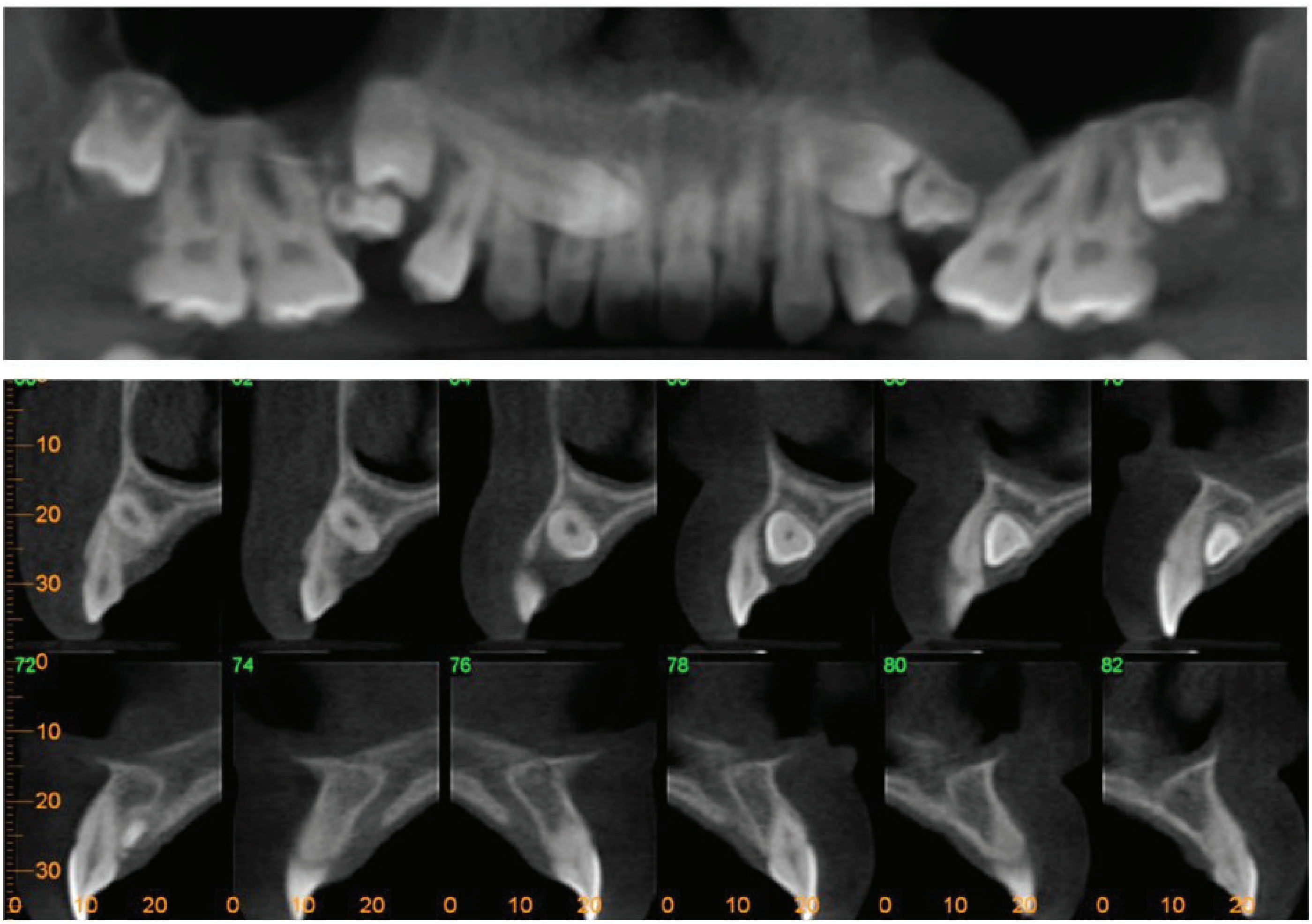
- **Implant site assessment**
  Cross-sectional images at potential implant sites provide accurate evaluation of alveolar bone volume and depict important anatomic features (the inferior alveolar canal in the mandible or the maxillary sinus in the maxilla).

- **Orthodontics**
  Large FOV imaging of facial asymmetry, craniofacial syndromes (Korbmacher *et al.*, 2007) and maxilla/mandibular disparities can demonstrate and allow assessment of the complicated relationships of the skull and facial bones (Kau *et al.*, 2005). Small FOV images are more commonly used to determine the exact position of impacted (**Figure 5**) (Liu *et al.*, 2007) and/or supernumerary teeth and their relationships to adjacent roots or other anatomical structures.

- **TMJ disorders**
  Facilitates the visualization of bone morphology, joint space and dynamic function as compared to conventional imaging, critical keys to providing appropriate treatment in patients with TMJ signs and symptoms.

- **Pathology**
  Demonstrates the location, size, shape, extent, and full involvement of pathology of the jaws. The relationship of the roots of third molars to the inferior alveolar canal are clearly identified.

Figure 5



CBCT for impacted tooth assessment. Reformatted panoramic image (upper) provides a reference and undistorted conventional image demonstrating relative angulation of multiple impacted teeth whereas serial cross-sectional images (lower) show bucco-lingual orientation and relationship of maxillary canine to existing teeth.

- **Extragnathic conditions**
  Diagnostically important soft tissue such as the pharyngeal airway space and sinus conditions can also be visualized.

The DICOM (Digital Imaging and Communications in Medicine) file format standard allows importation of CBCT data into task specific third party diagnostic and planning software; to assist in orthodontic assessment and analysis (Dolphin 3D, Dolphin Imaging, Chatsworth, CA, USA); to facilitate virtual implant placement and/or create diagnostic and surgical implant guidance stents (Simplant; Materialise, Leuven, Belgium); and even assist in the computer aided design and manufacture of implant prosthetics (NobelGuide / DTX studio software; Nobel Biocare Services AG, Zurich, Switzerland).

Conclusion

Maxillofacial CBCT imaging provides accurate, sub-millimeter resolution images of diagnostic quality enabling volumetric visualization of the osseous structures of the maxillofacial region. Consistent image quality depends on practitioner adherence to best practices (**Table 2**). Increasingly CBCT applications are being extended from diagnosis to image guidance of operative and surgical procedures. CBCT imaging provides additional information about the condition and relationship of maxillofacial structure which has implications for increased practitioner responsibility both in the performing, viewing and interpreting volumetric datasets. Practitioners using CBCT should be aware of general and discipline-specific guidelines to ensure optimize image quality and minimize patient radiation exposure.

Table 2 - Best practices in CBCT imaging

- Use CBCT to supplement conventional imaging and clinical examination
- Use lead apron / thyroid collar (if possible)
- Collimate the FOV to the ROI
- Ensure patient head stabilization during exposure
- Use indication oriented and patient specific exposure and acquisition parameters to acquire images
- Apply image visualization protocols to optimize image quality
- Use appropriate display formats

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POST-TEST

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We suggest reviewing the questions and then circling your answers on this page prior to completing the online exam.

(1.0 CE Credit Contact Hour) Please circle the correct answer. 70% equals passing grade.

1. Which of the following two-dimensional image types provide the fundamental data for image reconstruction in cone beam imaging?

a. basis
b. axial
c. coronal
d. sagittal

2. What is the range of radiation exposures a patient could receive for a cone beam imaging procedure (in units of digital panoramic exposure)?

a. 1-3x panoramic
b. 1-5x panoramic
c. 1-15x panoramic
d. 1-70x panoramic

3. Which of the following is not an indication for use of CBCT?

a. Impacted mandibular third molars adjacent the mandibular canal.
b. As a screening imaging modality to replace panoramic imaging to investigate occult pathology.
c. Investigation of TMJ articulation of patients with clinical signs and symptoms of a temporomandibular disorder.
d. Alveolar bone assessment in edentulous area for potential endosseous implant placement.

4. What is the highest spatial resolution currently available using cone beam imaging?

a. Less than 0.1mm
b. Between 0.1mm and 0.15mm
c. Between 0.15mm and 0.25mm
d. Between 0.25 and 0.35mm

5. Which of the following statements regarding cone beam imaging is <u>incorrect</u>?

a. Image spatial resolution is potentially limited by patient motion.
b. The procedural stages for performing cone beam imaging are similar to panoramic radiography.
c. Exposure parameters for CBCT are similar to panoramic radiography.
d. Acquisition parameters for CBCT are similar to panoramic radiography.

6. Which of the following must be performed to adequately view CBCT images?

a. Adjustment of the value of the voxels (*e.g.* brightness, contrast)
b. Reorientation of the entire dataset.
c. Reformatting of the volumetric data for display.
d. All of the above

7. Which of the following statements correctly describe *task specific imaging*?

a. Fees for CBCT imaging should be determined based on the reason for the scan.
b. Adjustment of exposure and acquisition parameters for CBCT imaging should be adjusted according to the reason for imaging (indication-oriented).
c. CBCT imaging reimbursement is based on the difficulty of the scan.
d. CBCT imaging should be performed without changes in exposure and technical parameters, irrespective of task, to ensure uniformity.

8. What is the non-proprietary file format for the export of CBCT images?

a. DICOM
b. JPEG
c. TIFF
d. PDF

9. Which of the following techniques provide the practitioner with visualization of the entire cone beam dataset?

a. Volumetric reconstruction
b. Multi-planar reformatting (MPR).
c. Maximum intensity projection (MIP)
d. Orthogonal projections

10. Which of the following currently make CBCT imaging unsuitable for dental caries diagnosis?

a. Limited contrast resolution
b. Limited spatial resolution
c. Artifacts
d. All of the above

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