Clinical Considerations for Cone Beam Imaging in Dentistry

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Introduction
The introduction of Cone Beam Computerized Tomography (CBCT) to dentistry has created an unprecedented revolution in oral and maxillofacial imaging, eclipsing the introduction of panoramic radiography in the 1960’s. Beginning with the commercial introduction of CBCT in Europe in 1999, the adoption of this technology in dentistry has expanded globally both in terms of its manufacturing centers (units are now made in Japan, France, the United States, Finland and Korea) and clinical applications in dentistry. More than a dozen CBCT systems are currently commercially available, all providing useful diagnostic images. The purpose of this guide is to outline the concepts of CBCT technology, introduce practitioners to technical considerations in obtaining and viewing the image, and provide clinical guidance on the appropriate use of this modality in dental practice.

Principles of CBCT Imaging
The mechanics of CBCT imaging comprise two phases (Figure 1):

1) Acquisition phase. A pyramidal or cone shaped x-ray beam is directed towards an area x-ray detector on the opposite side of the patient’s head and multiple exposures are made during a single full or partial synchronous rotation. The resultant series of two-dimensional (2D) projections or basis images form a set referred to as the projection data.

2) Reconstruction phase. Software programs are applied to projection data to generate a three-dimensional (3D) volumetric data set composed of cuboidal volume elements (voxels). The default presentation of the data set is usually as a series of contiguous images in three right angle planes (axial, sagittal and coronal).
CBCT Technique vs. Panoramic Radiology Technique

Procedural similarities exist between CBCT and panoramic radiography (Table 1). However, there are also a number of important distinctions between the two techniques, the most important being the greater number of technique parameters available for CBCT imaging.

1) Technical parameters. Two parameters need to be adjusted when performing a CBCT scan; the tube current and the tube voltage. These two factors control the quantity and the quality of the x-ray photons generated by the tube head. They have a direct influence on the quality of the image and the dose of radiation received by the patient. Adjustment of these parameters, if possible, can provide significant dose reduction without compromising the image quality.2,3

In contrast with panoramic radiography, CBCT units also allow additional modifications of scan parameters that may influence image quality and affect patient dose. These include:

A. Field of View (FOV). The tissue volume of the patient’s head exposed during imaging is referred to as the FOV. An adjustable FOV, particularly in large units, is desirable as x-ray exposure should be limited to cover only the region of interest. This provides marked reduction in patient radiation exposure compared to panoramic radiology. 4

B. Projection data. The total number of basis images comprising the projection data of a single scan may be fixed or variable. This is usually reflected in the selection of scan time. While increasing scan time provides more basis images, and produces “smoother”, less grainy images, this is usually accomplished at a higher patient radiation dose.

C. Spatial resolution. While nominal resolution for CBCT units is equipment specific (range: 0.076mm to 0.4mm), the resolution of some CBCT units can be varied at the reconstruction phase using a process of pixel binning (the gathering and combining of information from adjacent regions). This can substantially reduce file size and therefore reconstruction time. Resultant images have reduced resolution but improved image contrast. Higher resolution settings may not be clinically important as patient motion may be the limiting factor in CBCT resolution.5

D. Scan arc. Many CBCT imaging systems employ a complete circular (3600) trajectory, however some use a limited, or even a variable, scan arc. A limited or variable arc reduces the scan time and is mechanically easier to perform, however data must be extrapolated to provide a full volumetric dataset. The effect, if any, on diagnostic image quality or radiation dose is currently unreported.

Scan parameter choice should be based on the requirements of the imaging task – a concept referred to as task specific imaging. For example a secondary TMJ scan to determine the degree of translation of the condyle with jaw opening should be performed at the lowest resolution, shortest scan time and reduced FOV. This provides optimal imaging with a nominal radiation dose.

2) Patient Positioning. The patient’s head must be firmly stabilized, whether they are standing, lying or seated, during the entire scan when obtaining a CBCT image. This reduces the potential for motion during the scan, a significant source of reduced image quality.5 Stabilization 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.

3) Patient Protection. The patient should be draped in a lead torso apron to reduce exposure to scatter radiation during the obtainment of both CBCT and panoramic imaging.

### TABLE 1. Comparison of Imaging Procedures: Panoramic Radiography vs. CBCT.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Similarities</th>
<th>Differences for CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set technique factors</td>
<td>Made before exposure; controls image quality and patient radiation dose</td>
<td>CBCT offers more choices than panoramic radiography, which usually has only kVp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scan factors for CBCT should be adjusted to be task specific.</td>
</tr>
<tr>
<td>Prepare patient</td>
<td>Patient standing or seated, head stabilized, position critical to resultant image.</td>
<td>Patient may also be supine and no bite block used for CBCT.</td>
</tr>
<tr>
<td>Protect patient</td>
<td>Lead torso shield</td>
<td>Lead torso shield; thyroid shield is desirable if possible.</td>
</tr>
<tr>
<td>Expose</td>
<td>Patient informed to keep still</td>
<td>Scan time varies from 5s to greater than 30s; motion artifacts are more likely to occur; frequent image calibration necessary.</td>
</tr>
<tr>
<td>View image</td>
<td>Image viewed immediately</td>
<td>Image must be reconstructed before viewing (30s – 20 min), secondary orthogonal images must be reformatted; data is interactive (contrast, brightness, image mode); resultant data can be re-oriented to compensate for head position.</td>
</tr>
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</table>

CBCT and panoramic radiography (Table 1).
images. Use of a thyroid collar should 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.  

4) Exposure Adjustment. Because CBCT exposes the head in one rotational scan, acquisition time is comparable to that of panoramic radiography. However CBCT imaging also incorporates correction and further computational processes on the original projection images. The time for data set reconstruction can be much longer than the scan time and may range from 30 seconds up to several minutes. Image correction necessitates routine calibration of the digital detector, referred to as image calibration, to prevent untoward artifacts affecting image quality.

5) Image Viewing. Unlike panoramic radiography, CBCT units provide a sequential “stacked” set of coronal, sagittal and axial orthogonal images. These images are not inherently easy to interpret. Viewing CBCT images, unlike panoramic images, is performed as an interactive process – windowing and leveling, changing the brightness and contrast, reorienting, rotating or reslicing the volume in all directions may be used by the operator to adapt the final image to his/her diagnostic objectives.

Relative Radiation Exposure

The type and model of CBCT device as well as the scan parameters used (particularly FOV) markedly influence the radiation dose to the patient. CBCT provides an equivalent dose of 3 to 44 times that of a single panoramic radiograph, or between 8 to 131 days of background radiation. While smaller FOV units should reduce radiation exposure, some actually produce far greater patient exposure because they have tube heads producing continuous radiation exposure.

Imaging Techniques

Personal computer based OEM (original equipment manufacturer), or third party, software facilitates dynamic interaction with the clinician to provide task specific display modes useful in dentistry (Figure 2). Strategies that are useful in OMF 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 provides 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, at right angles 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) 3D Volume Rendering. These techniques allow the visualization of 3D 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). MIP is used to demonstrate high intensity structures by providing a “pseudo” 3D reconstruction.

Appropriate Use Of CBCT Imaging

Evidence-based clinical efficacy studies and consensus-derived specific patient selection criteria are currently not available for CBCT use. Generally accepted guidelines state that CBCT should be used as an adjunctive diagnostic tool to existing dental imaging techniques for specific clinical applications, not as a screening procedure for oral pathology, dental caries
detection and/or assessment of periodontal destruction. Parameters should be adjusted to deliver the minimum exposure to the patient and to provide the image quality necessary for adequate diagnostic information.

CBCT imaging provides excellent detail of osseous structures, however cone beam projection geometry and limitations in detector sensitivity provide images with reduced contrast resolution and higher "noise" (more grain) compared to medical computed tomography. Image quality can be further compromised by image artifacts due to acquisition (beam hardening producing scatter streaks and dark bands) (Figure 3), 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.8

The American Academy of Oral and Maxillofacial Radiology7 recently published their executive committee opinion statement on performing and interpreting diagnostic CBCT in dentistry <http://www.aaomr.org/carter_2008_Oral_Surgery.pdf?PHPSESSID=20c5ccfe9f28707a7558a934ad100817>. This document provides guidance on the appropriate use and prescription of CBCT, details the responsibilities of practitioners and licensed operators in performing the examination, outlines the appropriate documentation and radiation safety considerations and provides recommendations for quality control and patient education.

Specific Clinical Applications

CBCT has been applied to adjunctive diagnosis in all areas of dentistry including:

1) Implant Sites. The most common use for CBCT imaging is for the assessment of potential implant sites by providing cross-sectional images of the alveolar bone and accurately depicting important anatomic features (the mandibular canal in the mandible or maxillary sinus in the maxilla).

2) Orthodontics. Large FOV imaging of facial asymmetry craniofacial syndromes9 and maxilla/mandibular disparities can be demonstrated using 2- or 3-D formats allowing precise measurements of the skull and facial bones.10 Small regions can also be imaged to determine the exact position of impacted11 and/or supernumerary teeth and their relationships to adjacent roots or other anatomical structures.

3) TMJ. CBCT facilitates the visualization of bone morphology, joint space and dynamic function as compared to conventional imaging12, a critical key to providing appropriate treatment in patients with signs and symptoms of TMJ pathology.

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**FIGURE 3: CBCT ARTIFACTS**

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

**FIGURE 4: CBCT FOR IMPACTED TOOTH ASSESSMENT**

Reformatted panoramic image (upper) provides a reference and undistorted conventional image demonstrating relative angulation of multiple impacted teeth. Serial cross-sectional images (lower) show bucco-lingual orientation and relationship of maxillary canine to existing teeth.
4) Oral Pathology. CBCT demonstrates the location, size, shape, extent and full involvement of pathology of the jaws. Various dental conditions including additional teeth (supernumeraries), impacted canines (Figure 4) and third molars are clearly identified.

5) Extragnathic Conditions. Diagnostically important soft tissue such as the pharyngeal airway space and sinus conditions can also be visualized on CBCT images.

CBCT data can be exported in the non proprietary Digital Imaging and Communications in Medicine (DICOM) file format standard and imported into task specific third party diagnostic and planning software to: assist in orthodontic assessment and analysis; facilitate virtual implant placement and/or create diagnostic and surgical implant guidance stents; and assist in the computer-aided design and manufacture of implant prosthetics.

| TABLE 2. Technique Variables Involved In CBCT Imaging |
|---------------------------------|--------------------------------------------------|
| **Factor**                      | **Variables**                                    |
| Exposure Setting                | Variable (Ma, kVp) or fixed                      |
|                                 | Generator Type (constant or pulsed)              |
| Scan Parameter                  | Field of View (variable or fixed)                |
|                                 | Number of Projection Images (fixed or variable)  |
|                                 | Resolution (fixed or variable)                   |
|                                 | Completeness of Trajectory (full, partial or limited) |

**Conclusion**

Use of CBCT imaging by both general and specialist practitioner will undoubtedly increase. This technology provides the clinician with an imaging modality with increased precision, acceptable patient dose, and the capability of visualizing the third dimension. CBCT also extends dental imaging from diagnosis to image guidance for operative and surgical procedures. Practitioners using CBCT should be aware that guidance documents by relevant organizations will be periodically updated to ensure optimize image quality and minimize patient radiation exposure.

**References**

1. Which of the following image types form the projection 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 full head cone beam imaging procedure (in units of panoramic exposure)?
   a. 1-3 x panoramic  
   b. 3-5x panoramic  
   c. 3-44x panoramic  
   d. 10-80x panoramic

3. How can radiation exposure to the patient be minimized during a cone beam imaging procedure?
   a. Use of a lead apron  
   b. Use of a thyroid collar  
   c. Reducing the area to be irradiated to a region of interest (ROI)  
   d. All of the above

4. Which of the following statements regarding cone beam imaging is incorrect?
   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 and technical imaging parameters for CBCT are similar to panoramic radiography.  
   d. Currently there are more than a dozen FDA approved cone beam units for sale in the United States.

5. 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. Reformatting of the data for display.  
   c. Reorientation of the entire dataset, allowing realignment of the patient’s anatomic features.  
   d. All of the above

6. 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. Exposure and technical parameters for CBCT imaging should be adjusted according to the reason for imaging.  
   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.

7. What is the non-proprietary file format for export of CBCT images?
   a. DICOM  
   b. JPEG  
   c. TIFF  
   d. PDF

8. 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

9. For which of the following diagnostic imaging tasks is conventional intraoral radiography superior to cone beam imaging?
   a. Interproximal dental caries detection  
   b. Determination of the extent of maxillofacial pathology  
   c. Determination of alveolar bone height  
   d. Both a. and c.

10. 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.
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