Review

Cone beam imaging: is this the ultimate imaging modality?

Key words: application, beam hardening, caries, CBCT, computed tomography, cone beam, CT, image quality, implant, interpretation, limitations, multislice, periapical, periodontal, radiation dose, requirements, resolution, responsibilities, scatter, signal, soft tissue

Abstract: This review article provides an overview of cone beam (CB) imaging technology and its role in orofacial imaging, including comparison with two-dimensional (2D) radiography and multislice computed tomography (MCT). The radiation dose levels of CB systems are discussed, with reference to those delivered by MCT and common dental 2D views. The large variation in dose levels delivered by CB systems and the importance of using ultra low-dose CB units are emphasized. Low-dose MCT protocols can be used. CB and MCT image quality are compared. CB is an essential technique that all dental and orofacial clinicians must be familiar with. Where ultra low-dose systems and protocols are used, CB imaging should be considered in day-to-day clinical practice. However, CB imaging is not the technique of choice in many clinical scenarios. Rather than replacing other modalities, CB imaging complements intraoral 2D radiography, panoramic radiography, MCT and other techniques including magnetic resonance imaging, ultrasound and nuclear medicine. MCT is a much more powerful and flexible modality and presently remains the technique of choice over CB imaging in many clinical scenarios. All radiologic examinations, including CB and MCT, should be comprehensively evaluated in entirety. The responsibilities and the radiological skill levels of clinicians involved in imaging as well as the associated ethical and medico-legal implications require consideration.

Radiation dose levels

In 2007, the ICRP released new tissue weight recommendations for calculating effective doses [ICRP 2007]. The key implication to orofacial imaging is the inclusion of salivary glands (0.01), which was not [ICRP 1990 recommendations] specifically identified previously. This has resulted in the overall increase in calculated effective doses delivered during orofacial imaging, notably the panoramic radiograph. It may remain necessary to refer to the 1990 ICRP recommendations for ease of comparison with earlier studies.

The reported effective doses delivered by orofacial CB units range widely; from 6–806 mSv [1990 tissue weights] and 27–1073 mSv [2007 tissue weights] (Ludlow et al. 2003, 2006, 2008; Schulze et al. 2004; Kumar et al. 2007; Ludlow & Ivanovic 2008; Scarfe & Farman 2008; White 2008; Okano et al. 2009; Roberts et al. 2009; Suomalainen et al. 2009). Compared with MCT, there is relatively limited control over CB protocols and the wide range of CB doses delivered is largely unit specific. Also of note is that some small field of view (FOV) units deliver larger doses than some larger FOV units. The difficulty in making a detailed comparison of the various units and published studies is recognized (De Vos et al. 2009). This is due to a variety of factors, including variation in device properties, FOVs, detectors, frame rates and the image quality required.

MCT examinations of the jaws have been reported to deliver effective doses between 180–2100 μSv (1990) and 474–1410 μSv (2007), with significant variation in scanning protocols [Ngan
et al. 2003; Loubele et al. 2005, 2008, 2009; Ludlow & Ivanovic 2008; Suomalainen et al. 2009). While there are some equipment differences, the MCT doses delivered for jaw examinations are very much dependent on the imaging protocols. It has been shown that appropriate protocols can be used to significantly reduce radiation dose levels with no significant compromise in image quality (Loubele et al. 2005). This author’s experience supports these findings and also that various low-dose MCT protocols can be sufficient to produce diagnostic images for many purposes in dentistry.

Reported effective dose levels associated with panoramic radiographs also vary significantly, with a range of 4.7–54 μSv [ICRP 1990] (Ludlow et al. 2003; Ngan et al. 2003; Kobayashi et al. 2004; Gijbels et al. 2005; Gavala et al. 2009). A full-mouth 2D intraoral series has been reported to deliver effective dose levels between 34.9 and 388 μSv [ICRP 2007] (Ludlow et al. 2008; Aarup et al. 2009).

When comparing the radiation dose levels delivered by these modalities, the key points are:

- CB radiation doses range widely, largely depending on the unit used,
- some CB units deliver higher radiation dose levels than MCT scans of the jaws, when appropriate low-dose MCT protocols are used,
- some CB units are able to deliver lower dose levels than low-dose MCT scans for the same volume,
- small FOV CB units do not necessarily deliver doses that are lower than some larger FOV CB units,
- some CB units are capable of delivering doses comparable to or even lower than the panoramic radiograph (some units) and some intraoral 2D series (number of projections, technique and detector dependent),
- comparing available data are difficult and this technology continues to evolve quickly.

Image quality

CB units produce images with a voxel resolution range of 0.076–0.4 mm (Scarfe & Farman 2008; White 2008). However, the benefit of higher resolution of CB compared with MCT can be significantly reduced by other factors (Draenert et al. 2007; Sanders et al. 2007; Watanabe et al. 2009).

For a similar volume, MCT scans are faster than CB units, therefore reducing potential motion-related image degradation.

Patients are supine during MCT scans while most of the presently used CB units image patients in the standing or sitting position, potentially contributing to motion artefact.

In CB imaging, a much larger cone-shaped volume is irradiated during each planar basis projection and large area detectors are used. This leads to a much larger amount of Compton scatter, which significantly increases image noise and degradation compared with MCT images. In addition, the lower energy photons of CB units result in a much lower signal-to-noise ratio.
compared with MCT. This results in relative difficulty in examining the structures of interest in CB images, as they do not "stand out" as much from the increased "background noise", compared with MCT. The appearance of less variation between denser and less dense structures, a "flatter" image, is typical of CB images. This needs to be considered when interpreting CB images.

As a result of the low signal nature of CB imaging, beam hardening can be a significant disadvantage compared with MCT (Draenert et al. 2007; Sanders et al. 2007). This is related to the polychromatic nature of X-ray beams, with the initial attenuation of low-energy photons and the resultant increased mean energy of the beam. This leads to the appearance of shadows and bands associated with dense structures. Beam hardening increases with patient head size and denser structures, especially when these structures are in close proximity. In contrast, beam hardening associated with dense non-metallic objects is rarely of significance in MCT scans of the head and neck region.

Metal artefact (extreme attenuation) from restorations is more significant with MCT than CB but the limitations of CB described, including beam hardening [Draenert et al. 2007; Sanders et al. 2007] tend to result in an overall similar weakness in both techniques in relation to metallic objects.

The examples shown in Figs 1–6 demonstrate some of the differences between CB and MCT images.

The soft tissue contrast resolution of images produced by current CB units used in dentistry is poor [Watanabe et al. 2009]. MCT scans produce much better soft tissue contrast resolution [Watanabe et al. 2009], allowing an evaluation of various soft tissue structures, soft tissue lesions and soft tissue changes related to bony lesions. This important diagnostic value can be further enhanced with the use of IV contrast. This advantage of MCT can be of significant diagnostic value (Figs 7–9). It should be noted that many soft tissue lesions are best examined with magnetic resonance imaging (MRI).

The various limitations in CB image quality described vary between different makes of CB units.

Measurements made on images from MCT and CB data have been shown to be similar and sufficiently accurate to plan many common dento-orofacial procedures [Klinge et al. 1989; Hanazawa et al. 2004; Kobayashi et al. 2004; Loubele et al. 2005; Marmulla et al. 2005; Suomalainen et al. 2008; Kamburoglu et al. 2009; Nickenig et al. 2009]. MCT and CB images have been shown to be more accurate in identify-

![Fig. 3. Cross-sectional (para-axial) cone beam images of two palatally positioned implants, not appreciated in two-dimensional plain film imaging. While the relationship of the implant to the residual ridge is appreciated, note is made of the associated artefact (white and black arrows), which contributes to difficulty in evaluating the immediately adjacent peri-implant bone. The artefacts are worse when there are two or more adjacent implants.](image)

![Fig. 4. Coronal and sagittal multislice computed tomography (MCT) (reduced dose) and cone beam (CB) images of the same case, demonstrating a periapical inflammatory lesion of the distal molar (black arrows) with reactive mucosal thickening at the maxillary antral base. The significant reactive sclerosis of the adjacent bone is also evident. Note the "flatter" CB images with less contrast between the root, adjacent bone and mucosal thickening compared with the MCT image. There is artefact related to beam hardening of the CB image not seen in the MCT image (vertical white arrows). Metallic streak artefact is seen in the MCT image (horizontal white arrow). Note the combined metal artefact and beam hardening in the CB image (right angle arrow). The reduced image quality of this case compared with those in Fig. 1 is largely related to the large amount of restorative therapy and head size.](image)
ing important structures (e.g. mandibular canal) and allow for more accurate measurement compared with panoramic and intraoral 2D radiography (Klinge et al. 1989; Lindh et al. 1992; Ylikontiola et al. 2002; Howe 2009; Kamburoglu et al. 2009).

Application

The potential application of CB technology is wide and the advantages of being able to evaluate structures in three dimensional (3D) and high resolution appears obvious. CB technology appears to have a role in almost all areas of dentistry, ranging from pain diagnosis, endodontics, periodontics, implant planning, ectopic and impacted teeth, orthodontics to orofacial surgery including image guided surgery, to name a few.

It is beyond the scope of this article to discuss all the potential specific applications in detail. However, note is made of the inability of CB in evaluating caries when metallic or even radiodense restorations are present. In the absence of restorations, studies evaluating the role of CB in caries diagnosis appear promising but require maturation, especially in vivo studies (van Datselaar et al. 2004; Akdeniz et al. 2006; Kalathinagal et al. 2007; Tsuchida et al. 2007; Haiter-Neto et al. 2008). Also of note is that, overall, the available literature suggests that CB and MCT are superior to periapical 2D images in periapical disease diagnosis and endodontics (Velvart et al. 2001; Huuomen et al. 2006; Simon et al. 2006; Draenert et al. 2007; Lothtag-Hansen et al. 2007; Mora et al. 2007; Nair & Nair 2007; Patel et al. 2007; Stavropoulos & Wenzel 2007; Low et al. 2008) as well as in the evaluation of periodontal bone loss (Fuhrmann et al. 1995; Fuhrmann et al. 1997; Misch et al. 2006; Mol & Balasundaram 2008; Vandenbergh et al. 2008).

With regard to imaging for implant planning, both MCT and CB have been shown to be sufficiently accurate, being more accurate and more reliable for morphologic evaluation than common dental views (Klinge et al. 1989; Lindh et al. 1992, 1997; Kobayashi et al. 2004; Hanazawa et al. 2004; Marmulla et al. 2005; de Morais et al. 2007; Nickenig & Eitner 2007; Loubele et al. 2008; Suomalainen et al. 2008; Kamburoglu et al. 2009). The differences between CB and MCT discussed earlier should be considered.

Overall, there is varying clinical and scientific evidence supporting the benefits of using CB technology. Further clinically based studies are required to confirm the benefits of CB imaging, especially the advantages of CB over plain 2D radiography and how CB compares with MCT. However, it is recognized that carrying out these investigations with rigorous methodologies is not simple, requiring considerable time. As a result of the pace of evolution of imaging technology, including CB and MCT, these studies are quite frequently not “up to date” when finally published. With this in mind, the low dose of CB
imaging becomes a key factor. For many clinical scenarios, the advantages of CB imaging seem obvious if high-resolution CB 3D images for a specific diagnostic purpose can be acquired while delivering doses similar to or less than an equivalent plain 2D radiographic examination. However, this is only achievable with ultra low-dose CB units. Also, the use of optimal protocols to produce diagnostic images remains critical. Associated costs, accessibility and other related factors should also be considered.

MCT presently remains a more powerful and flexible imaging modality than CB in orofacial diagnosis. At this stage, it appears prudent to continue evaluating complex cases and more serious/significant pathoses with MCT rather than with CB. The advantages of MCT, including better signal-to-noise ratio and being able to evaluate the soft tissues, can be critical in the diagnosis and management of orofacial disease, including dentoalveolar inflammatory disease.

Both CB and MCT units are able to export data in the DICOM file format standard. This allows both MCT and CB data to be viewed with a range of third party software used for diagnostic and treatment planning purposes, including creation of 3D models and various applications related to image-guided surgery.

**Interpretation**

The clinician obtaining the CB images is responsible for interpreting the volume data [Carter et al. 2008; Scarfe & Farman 2008; Suomalainen et al. 2008]. The following points identify some of the key requirements and responsibilities involved in radiologic interpretation of a CB study of which the practitioner should be aware:

- Appropriateness of CB imaging for a particular application.
  - Strengths and limitations of CB imaging
  - Effect of protocols on image quality
  - Other modalities, which may be more suitable, e.g. MCT, MRI, ultrasound and nuclear medicine
- The entire data set must be evaluated.
  - To varying extents, most CB scans include the paranasal sinuses, pharyngeal air spaces, skull base, cervical spine and upper neck
  - The practitioner is responsible for the entire volume of information, not just for the primary focus of the study (Carter et al. 2008), e.g. implant planning
- Knowledge of radiologic anatomy.
  - As depicted in multiplanar, volume and other images reformatted from the volume data. This differs from plain 2D radiographs
  - Awareness of anatomic variants
- Knowledge of pathology, which may affect all the structures included in the scan. Appreciation of the clinical significance of the various disorders.
The ability to perform morphologic analyses and plan surgical procedures is different to the skill set required to evaluate the data set for disease. The algorithm used in evaluating volumetric data is different to that used to interpret plain 2D radiographs.

Understanding and an ability to identify radiologic features, which suggest the presence of disease.

Many abnormalities do not present as obvious opacities or lucencies.

Ability to identify the key radiologic characteristics of a lesion.

Knowledge to interpret the radiologic characteristics identified.

Requires a thorough knowledge of the radiologic characteristics of diseases affecting the orofacial structures.

Below are some examples of conditions, which were identified during radiologic interpretation of CB data. (Figs 10–17).

The responsibilities and the radiological skill levels of clinicians involved in CB imaging as well as the associated ethical and medico-legal implications require consideration (Carter et al. 2008; Scarfe & Farman 2008). If the practitioner is not able to comprehensively interpret CB datasets in entirety or does not have suitable training, it appears prudent that arrangements should be made for appropriately skilled radiologists to perform this. Radiological reports should be provided for CB scans (Carter et al. 2008).

**Fig. 10.** Cone beam coronal images of two different cases. Features of the superior and inferior borders of the right maxillary antral base lesion of Case A is compatible with a mucous retention cyst, while those of Case B are compatible with a radicular cyst.

**Fig. 11.** Coronal cone beam image demonstrating paranasal sinus inflammatory disease, including air-fluid meniscus within the left maxillary sinus and opacification of the ostio-meatal complexes.

**Fig. 12.** Cone beam sagittal image demonstrating cortical erosions of an infiltrative lesion such as lymphoma. The patient presented to the dentist with facial swelling and discomfort and was concerned about dentoalveolar infection.

**Fig. 13.** Axial cone beam image demonstrating left pharyngeal prominence suggesting a primary malignant lesion or metastatic disease. This was proven to be lymph node metastatic spread of a lateral tongue squamous cell carcinoma.


Fig. 14. Coronal cone beam images demonstrating radiologic features of right sphenoidal sinus chronic inflammatory disease.

Fig. 15. Cone beam coronal image demonstrating parotid calcifications consistent with chronic sialadenitis related to Sjogrens syndrome.

Fig. 16. Axial cone beam image demonstrating two right Vidian canals, a normal variant.

Fig. 17. Cone beam axial image demonstrating left mandibular condylar osteoradionecrosis, which can present with aggressive appearances radiologically. A history of radiotherapy was obtained.

Summary
CB technology is certainly very much an integral part of the imaging techniques for orofacial diagnosis. The many advantages over plain film are obvious although further clinically based studies remain necessary. With this in mind, the use of ultra low-dose CB units capable of delivering dose levels similar or only slightly higher than those delivered during an equivalent plain 2D radiographic examination is important.

CB technology is a much more powerful and flexible modality and presently remains the technique of choice over CB imaging in several instances, especially complex cases and in the evaluation of more serious disease. Low-dose MCT protocols can be used.

CB imaging is an essential technique, which all dental and orofacial clinicians must be familiar with. CB imaging (using ultra low-dose units) should be considered in day-to-day clinical practice to the same extent as intraoral 2D or panoramic radiographs. However, rather than replacing other modalities, CB imaging complements plain 2D radiography, panoramic radiography, MCT and other techniques including MRI, ultrasound and nuclear medicine. CB imaging is not the technique of choice in several clinical scenarios.

All radiologic examinations, including CB and MCT, should be comprehensively evaluated in entirety. The responsibilities and the radiological skill levels of clinicians involved in imaging as well as the associated ethical and medicolegal implications require consideration.

References


