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CBCT in Clinical Practice

Tarunjeet Pabla BDS, DMD, MS, Dip. ABOMR
Tufts University School of Dentistry, Tarunjeet.Pabla@tufts.edu

Hugo C. Campos DDS, DMD, MDS, Dip. ABOMR
Tufts University School of Dentistry, Hugo.Campos@tufts.edu

Aruna Ramesh BDS, DMD, MS, Dip. ABOMR
Tufts University School of Dentistry, Aruna.ramesh@tufts.edu

CBCT in Clinical Practice: Guidance for Best Practice

By Tarunjeet Pabla, BDS, DMD, MS, Dip. ABOMR,
Hugo C. Campos, DDS, DMD, MDS, Dip. ABOMR, and Aruna Ramesh, BDS, DMD, MS, Dip. ABOMR

The introduction of 3D imaging to dentistry brought a paradigm shift in dental radiography. 3D imaging was introduced in U.S. dental practices in the form of Cone Beam Computed Tomography (CBCT) in 2001.

Since its introduction, remarkable progress has been made in applying CBCT imaging to dentistry. Clinicians rapidly realize the advantages of CBCT imaging in all areas of clinical practice. However, to take advantage of this modality, a clear understanding of the technology must be understood with its risks/benefits to patients, responsibilities, and future advances. This article aims to help clinicians gain knowledge for the successful inclusion of CBCT imaging in clinical practice.

CBCT IMAGING CONSIDERATIONS

Acquisition

CBCT image is obtained in two stages: *image acquisition* and *image reconstruction.* The CBCT unit consists of a conventional X-ray source connected to a flat panel detector with a c-shaped arm that rotates horizontally around the patient. The patient may be standing or sitting, depending on the type of machine. A cone or pyramid-shaped X-ray beam is emitted during the scan, generating hundreds of 2D X-ray projections (called raw or basis data) *acquired* by the detector. A computer algorithm then *reconstructs* this raw data into 3D images. (Fig. 1)

Technical parameters

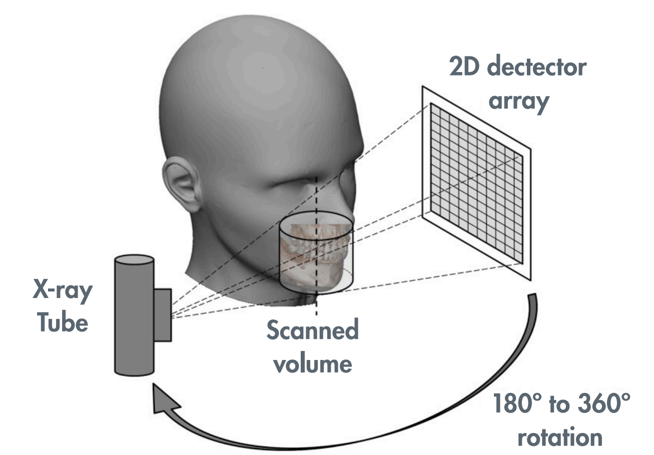
A. Field of View (FOV). CBCT image capture can be sorted into four broad categories based on vertical and horizontal FOV,[1] as demonstrated in Figures 2-6 (see Pages 39 and 40).

- Large (maxillofacial): Covers most of the craniofacial skeleton, usually greater than 15 cm in any dimension.
- Dentoalveolar (both jaws): Usually 8 cm or more in diameter and height.
- Single jaw/dual TMJ. Can cover single jaw (excluding ramus for mandible) or both TMJs.

Abstract

As Cone Beam Computed Tomography (CBCT) technology becomes integral to general dental practices, understanding of key aspects of this imaging modality is critical to establishing best practices. In this article we have summarized various technical, clinical, and quality control aspects related to CBCT imaging. This article describes factors that affect image quality, options for viewing and transfer of CBCT images, guidelines for equipment maintenance, as well as guidance for prescription and interpretation. Understanding these aspects will help clinicians in planning the CBCT workflow within the practice that ties protocols for selection, prescription, interpretation, documentation, and quality assurance prior to use of this imaging technology, and ensures the success of integrating CBCT imaging in their practice.

Figure 1 — CBCT image acquisition. (Pauwels et al. 2015, under the British Institute of Radiology's License to Publish.)



Figures 2 and 3

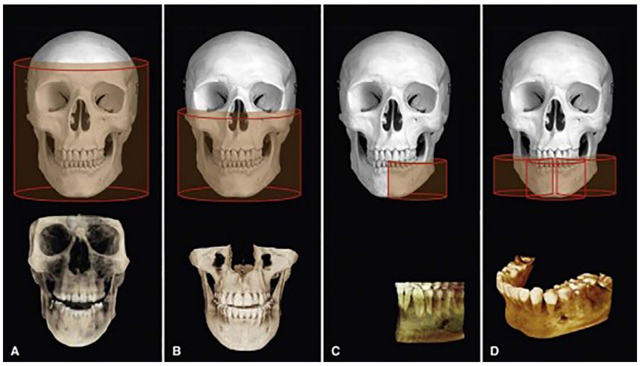


Fig. 2: Different fields of view in CBCT. A) large; B) dentoalveolar; C and D) small or sectional.[3] (Yavuz et al. The possible usability of three-dimensional cone beam computed dental tomography in dental research, Journal of Physics 2017.)

Fig. 3: CBCT panoramic reconstruction: Large FOV for evaluation of orthodontic treatment.

■ Small (localized). As small as 3 cm in any dimension, covering 2-4 teeth and surrounding alveolus or single TMJ.

In general, the larger the FOV, the higher the radiation dose. Large FOV units can be collimated to a specific region of interest. However, with small FOV units multiple scans will need to be captured to expand the area of interest, increasing the radiation dose. Regardless of the FOV capacity of the unit, it is vital to restrict FOV to the region of interest in order to reduce the radiation dose and adhere to ALARA/ALADA (as low as reasonably/diagnostically achievable) radiation protection guidelines.[4]

B. Voxel size. Voxel is the basic unit of the 3D image. In CBCT, the image of a scanned object is reconstructed as a matrix of isotropic (each side has the same measure-

(Continued on Page 40)

Figure 4 — CBCT panoramic reconstruction: Dentoalveolar FOV for evaluation of edentulous sites of the maxilla and mandible for implant treatment planning and assessment of TMJ regions.

Figure 5 — CBCT panoramic reconstruction: Sectional FOV for evaluation of impacted and inverted tooth #9.

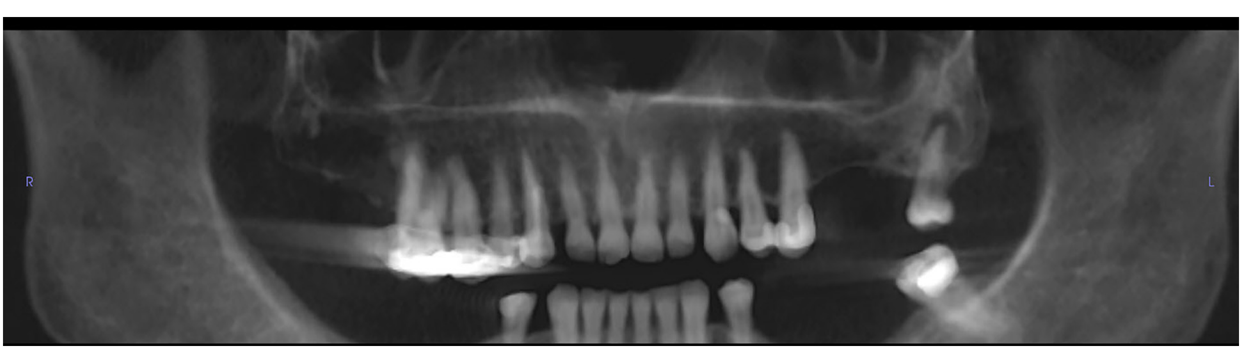
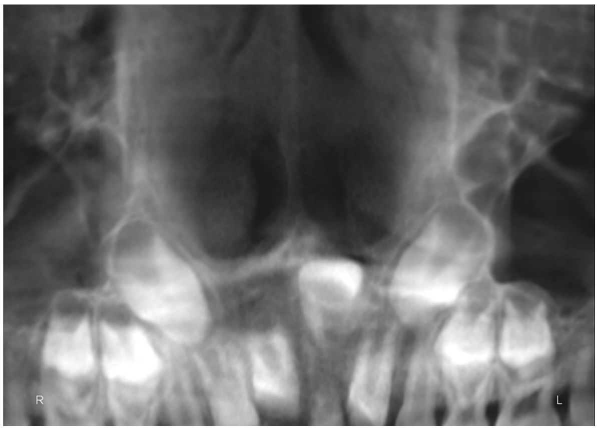


Figure 6 — CBCT panoramic reconstruction: Sectional FOV for evaluation of impacted and inverted tooth #9.



ment) voxels. Each voxel contains one single shade of gray depending on the region evaluated. In CBCT, voxel size varies from 0.041 mm to 0.6 mm. The size of the FOV determines the size of the voxel. For a large FOV, the size of the voxel is greater, resulting in a scan with lower resolution. Similarly, small and sectional FOV images have smaller voxel size, resulting in a scan that offers more detail and resolution. Larger voxel size is recommended in scans for evaluation of patients who require orthognathic surgery, middle voxel size is recommended for evaluation of implant treatment planning, and small voxel size is recommended for evaluation of possible fracture or pathology[5] (Fig. 7, Fig. 8).

C. Spatial resolution and contrast resolution. *Spatial resolution* or sharpness of an image is the ability to distinguish closely located structures. Voxel size is one of the factors contributing to spatial resolution in CBCT images. Small voxel size in CBCT scans provides high resolution to facilitate diagnostic tasks in dentistry, including periapical pathology, root resorption, frac-

Figures 7 and 8

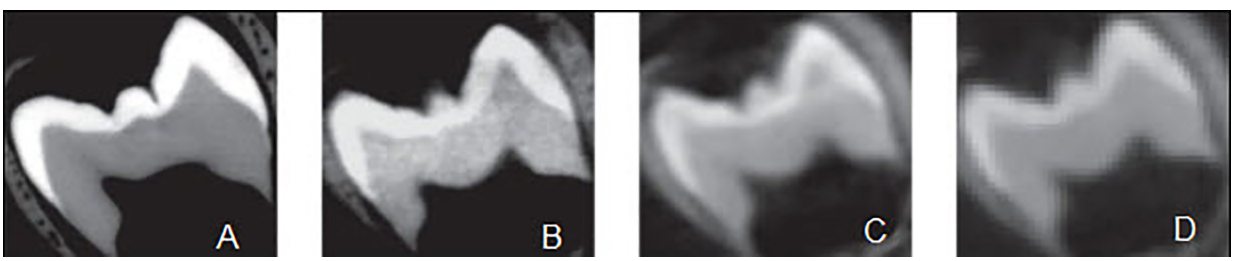


Fig. 7: Different resolution of CBCT scans due to voxel size. Same tooth is shown with different voxel size. **A:** 0.041 mm, **B:** 0.076 mm, **C:** 0.2 mm and **D:** 0.3 mm (Maret et al., Effect of voxel size on the accuracy of 3D reconstructions with cone beam CT. *Dentomaxillofacial Radiology.* 2012 Dec;41(8):649-55.

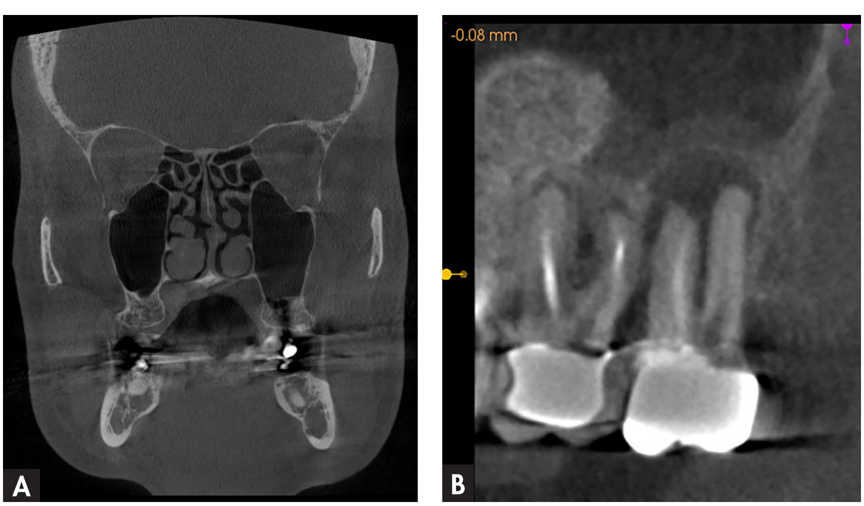


Fig. 8: Different types of resolution in CBCT. **A:** CBCT coronal view with large FOV for evaluation of implant treatment planning. **B:** CBCT sagittal view with small FOV for evaluation of pathology periapical to teeth #14 and #15.

tures, etc. Keep in mind that spatial resolution in CBCT scans is approximately one order of magnitude lower than that of intra-oral radiographs.[6] In other words, intra-oral 2D images with good contrast are better suited for detecting caries and small periodontal defects.

Contrast resolution in X-ray imaging describes the ability to distinguish between objects with different radiodensities. Due to several technical factors, the CBCT images have lower contrast resolution when compared to Multidetector Computed Radiography (MDCT) (Fig. 9, Fig. 10). Due to low contrast resolution, it is difficult to distinguish the margins of lesions located in the soft tissues in a CBCT scan. However, changes in soft tissues like expansion and asymmetry can be noted in CBCT images[1] (Fig. 9, Fig. 10).

Image viewing and transfer

The data acquired from the scan is reconstructed into 3D images, using manufacturers' proprietary algorithms. It is important to note that all CBCT units come with a standard viewing software. This basic software provides simple features like zoom, simple measurements, and enhancements to density and contrast in the displayed images. Third-party software is needed to provide enhanced features like color rendering, volume reformatting, mandibular nerve location, airway mapping, and implant planning. Several independent/third-party dental 3D viewing software programs are available as open-source, prepaid, or pay-as-you-go service options.

DICOM (Digital Imaging and Communications in Medicine) format images are standard for handling, storing, printing, and transmitting information in medical imaging, including CBCT.[2] DICOM format is recommended for exporting the CBCT data set. CBCT data when exported in DICOM format can be opened in any of the third-party software for visualization of images, implant treatment planning programs, and making surgical guides. Essentially, if a clinician wants to export CBCT images to a specialist/lab or wishes to receive CBCT images taken outside their practice, the use of DICOM format is recommended.

Artifacts

Motion artifact. A relatively common artifact in CBCT is related to patient motion during imaging. Due to relatively long scan times (15-20 seconds), patient movement can introduce mild to severe blurring in the images. While minor movements like swallowing and regular breathing do not lead to considerable image degradation, excessive movement can lead to severe distortion requiring retakes[7] (Fig. 11, see Page 43).

Beam hardening artifacts. Beam hardening artifacts

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Figures 9 and 10

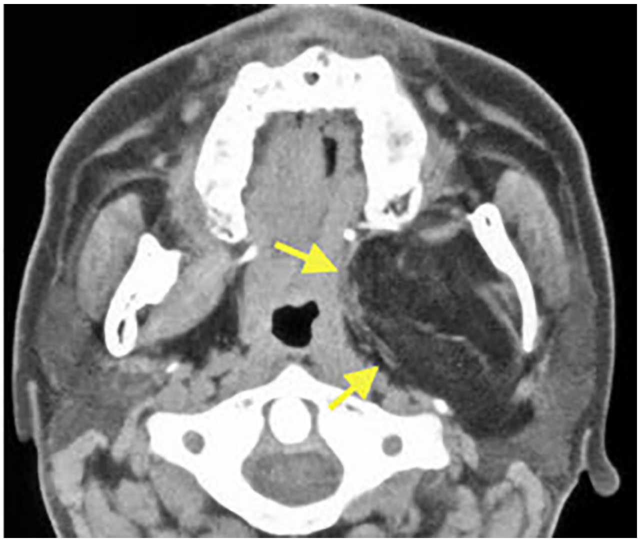

Fig. 9: MDCT axial view, soft tissue window for evaluation of lipoma. Note the high contrast resolution of MDCT.

Fig. 10: CBCT axial view for evaluation of possible pathology at the apical region of tooth #15. Note the low contrast resolution compared to the image in Fig. 9.

are common in CBCT images. Metallic objects are the leading cause of these artifacts, seen as *streaks* or *dark bands*.

A) Streaking artifact: Metallic restorations can result in bright and dark streaks adjacent to the metal. The presence of these streaking artifacts can negatively affect the diagnostic quality of the scan (Fig. 12). Therefore, all metal objects should be removed before scanning, if possible.

B) Dark bands: This type of artifact presents as a dark band adjacent to endosseous dental implants and endodontic silver points. An area of undersampling is created adjacent to implants, thereby reducing visualization of the implant-to-bone interface (Fig. 13, Fig. 14). 2D periapical radiography and clinical examination are recommended methods for post-operative follow-up of dental implants.

Machine calibration and service. CBCT machines vary in their protocols for calibration. Some CBCT machines require daily calibration and others require less frequent calibration. The machine manual should be consulted for the calibration frequency. If recommended calibration is not performed, scans may need to be repeated due to artifacts (Fig. 15, Fig. 16, see Page 44).

The ADA Council on Scientific Affairs recommends that a performance evaluation of CBCT units be completed at least annually. It further states that facilities using CBCT systems should consult a health physicist (or other qualified expert) to perform equipment performance and compliance evaluations initially at installation, and then follow a schedule in compliance with local, state and federal requirements.[4]

Radiation dose, risks and protection

Several dosimetry studies indicate a wide range in patient doses for maxillofacial CBCT resulting from CBCT device configuration, FOV selected, and acquisition parameters like the number of basis image selection.

Radiation doses to the patient from diagnostic imaging are generally reported as effective dose, which is a measure of stochastic risks. Stochastic effects occur from very low doses of radiation, including radiographic imaging. The stochastic effects may damage DNA that could result in the risk of cancer and genetic (heritable) effects.

It is not easy for patients to comprehend risks when mentioned in units of radiation doses. Conveying the relative magnitude of dose in terms of equivalent days or months of natural background radiation helps the patient understand the risk in perspective. Table 1 shows typical effective doses from standard dental radiographic procedures.

While the risk of radiation exposure from CBCT imaging is small, it warrants consideration. Best practice recommends that radiographic prescriptions follow a risk/benefit analysis by comparing the risk of radiation resulting from capture of the image against the diagnostic benefit of imaging, leading to better treatment outcomes for the patient.

Table 1 — Effective dose estimates for common dental radiographic examinations and CBCT imaging.[4]

Radiographic Procedure	Effective dose in microsieverts (μSv)	Equivalent background exposure
Digital panoramic radiograph	3.0- 24.3	2.5 days
Digital cephalometric radiograph	5.1- 5.6	0.6 days
Full mouth radiographs using rectangular collimation (CCD sensor)	20	2.5 days
Full mouth radiographs using round collimation (CCD sensor)	100	12 days
Dentoalveolar CBCT (small and medium FOV)	50-100	6-12 days
Maxillofacial CBCT (large FOV)	120	15 days

2D vs. 3D imaging and decision-making

Before taking a CBCT scan the clinician must take into consideration the following:

■ Is a CBCT scan needed to answer the clinical question?

■ Are there alternate exams that use less or no radiation exposure?

■ Can duplicate radiographic examinations be avoided by reviewing the patient's medical imaging history?

The American Dental Association Council on Scientific Affairs has published general guidelines on the use of CBCT in clinical dentistry.[4] Some of the recommendations by the council are as follows:

■ CBCT imaging should be used only after a review of the patient's health and imaging history and the completion of a thorough clinical examination.

■ CBCT should be considered as an adjunct to standard intraoral imaging modalities.

■ The ALARA/ALADA principle ("As low as reasonably/diagnostically achievable") should be employed. The clinician should limit the radiation dose for CBCT scans by optimizing image quality and using the smallest FOV necessary for imaging a specific anatomical area of interest. The lowest combination of tube output and scan time is consistent with adequate image noise content and motion artifact.

■ Protective thyroid collars and lead aprons should be used when they will not interfere with the examination.

■ A CBCT examination should be prescribed by a dentist who has appropriate training and education in CBCT imaging, including understanding the significance of CBCT selection and imaging findings.

■ Dentists must abide by applicable federal and state regulations in the provision of dental imaging

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Figures 11–14

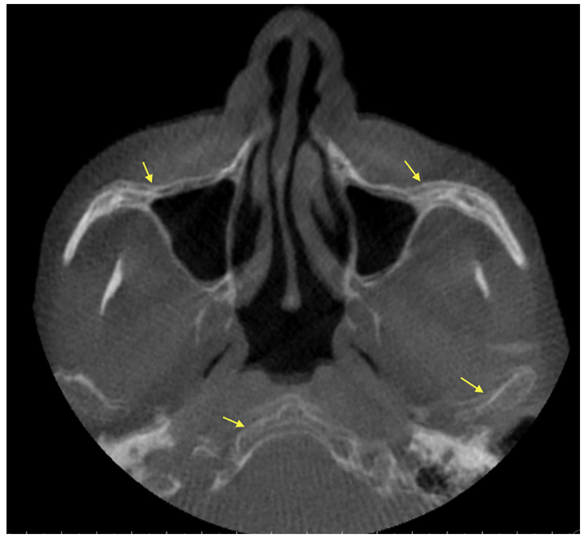


Fig. 11: CBCT axial view — effect of motion during CBCT scan. Note the double images in the region of the Zygomatic process of the maxilla, condyles, and cervical vertebrae.

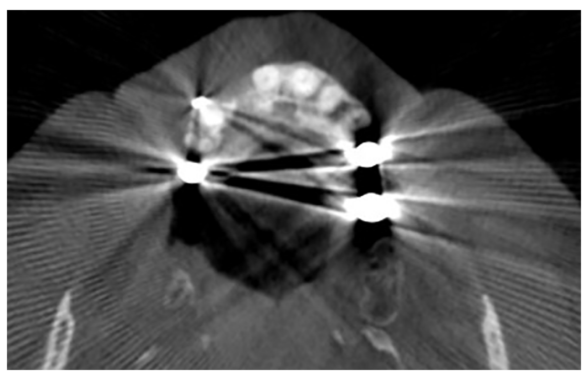


Fig. 12: CBCT axial view — multiple streaking artifacts due to dental implants.

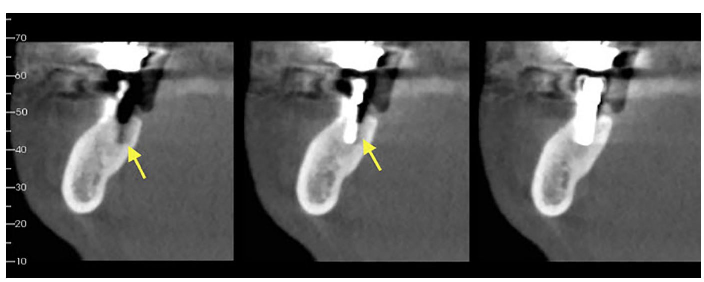


Fig. 13: Cross-section views of mandible — dark band adjacent to dental implant (yellow arrows).

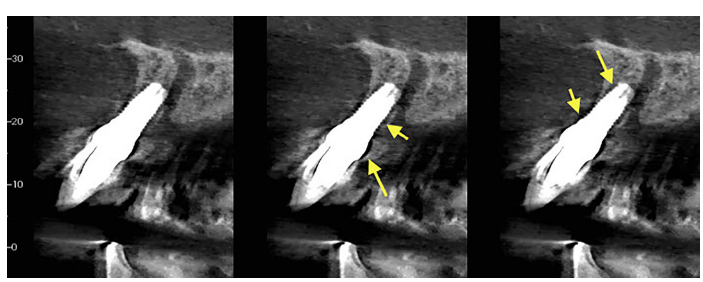


Fig. 14: Cross-section views of maxilla — dark band adjacent to dental implant (yellow arrows).

modalities. Dentists should contact state and local radiation control programs to verify any additional requirements for the operation of CBCT, including applicable requirements for licensure or accreditation.

■ Facilities using CBCT should establish a quality control program.

Interpreting CBCT images

Given the complex and large volume of data presented by a CBCT scan, interpretation of these images is a dilemma for the practitioners who take these scans in their practice. Not reading the scan or missing an essential finding in the scan can become a source of liability for the practitioner. Just like other dental X-ray images, dentists are responsible for the CBCT images that they obtain.

Legally, this does not mean that they have to read them personally; this means they are responsible for the scans to be read by a competent individual. They can a) read the scans themselves; b) refer to a medical radiologist/oral and maxillofacial radiologist; or c) send the scan to a center that offers CBCT reading service.[8]

Several courses are available for dentists who wish to improve their CBCT interpretive skills. We recommend the courses taught by oral and maxillofacial radiologists. One such course is "Basic CBCT Level 1 Course: An Introduction to Cone Beam Computer Radiography." This course is offered a few times a year by AAOMR and approved by ADA CERP. Its information can be found on the American Academy of Oral and Maxillofacial Radiology website at aaomr.org under the section Information for Dental Professionals/Continuing Education for Dentists.

The ADA Council on Scientific Affairs recommends that "Regardless of the primary purpose for the selection of CBCT, the complete image data set must be interpreted by an appropriately qualified health care provider (such as a dentist or a physician). The prescribing clinician should receive a thorough radiological report. If the prescriber also interprets the CBCT images, they should enter the findings into the patient record and communicate them appropriately to the patient or, if the patient is a minor, to their parent or legal guardian."[4]

In summary, the dentist who obtains a CBCT scan is responsible for reading the "whole" scan, not just the region for which the scan was taken. This standard of care for CBCT images is the same as for any other dental image. We do not read only part of a panoramic radiograph or part of full mouth survey.

Figures 15 and 16

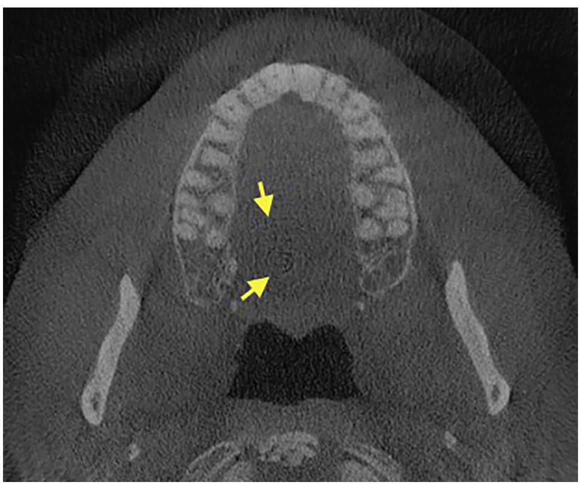


Fig. 15: CBCT axial view — concentric rings in the CBCT scan due to lack of recommended calibration of CBCT unit.

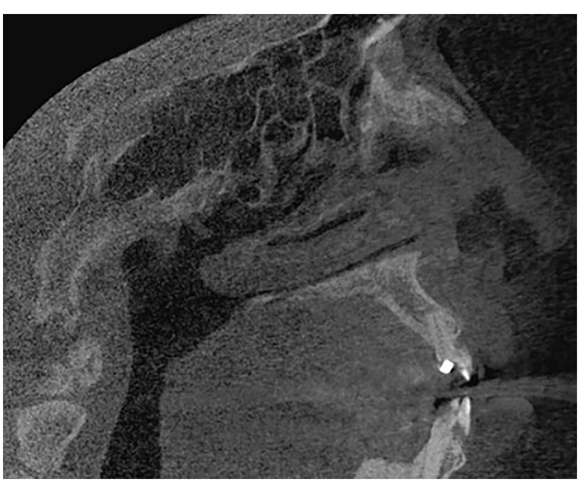


Fig. 16: CBCT sagittal view — note the poor quality of the scan due to lack of recommended calibration of the CBCT unit.

Liability and risks

According to Friedland and Miles,[8] the risk of liability for the dentist cannot be mitigated by having the patients sign a waiver. Waivers of liability have no legal standing. Most jurisdictions have held that physicians and hospitals cannot require patients to waive their rights to recover damages for negligence.[8]

Letting the patient choose to have a CBCT scan read will not limit the clinician's responsibility. Friedland and Miles[8] state that the choices offered to patients to allow them to make informed decisions are limited by the bounds of the accepted standard of care. If a clinician lacks the skills to interpret a CBCT image, not having a

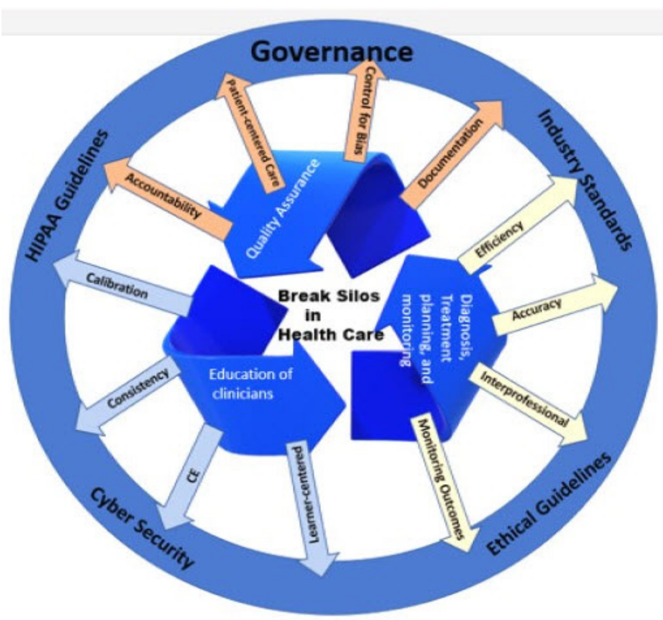
CT scan read by a trained colleague may be considered below the standard of care.

Return on investment

Any technology that the dentist brings to their practice has to be put under the lens of return on investment (ROI), and CBCT is no different. Improving the ability to provide appropriate care to the patients is a good ROI. Should every practice consider purchasing a CBCT unit? CBCT machines can serve as a great adjunct to a multispecialty/surgical group practice and general practitioners providing these services. Practitioners primarily focused on caries and periodontal disease management will find acquiring a CBCT machine may be an expensive investment that may not deliver a significant return. Referral to a CBCT center for complex cases may be a better option for these practitioners.

The CBCT machine is an adjunct to intra-oral and panoramic imaging, not a replacement. Acquiring a CBCT machine brings additional expense and the need for managing and storing vast amounts of data, as well as interpretation of images and in some cases transferal of images to labs and for referrals. The time and staff commitment needed for these tasks can slow down the daily workflow. The potential increased liability and cost for malpractice insurance coverage must also be evaluated when acquiring a CBCT machine.

Fig. 17 — AI Wheel: application and governance



Artificial intelligence/machine learning

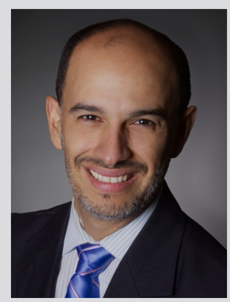
Artificial intelligence (AI)/machine Learning (ML) applications focusing on visual perception and pattern recognition matching the level of a clinical diagnostician are evolving rapidly. There have been many reports on the efficiency and accuracy of AI systems in detecting various dental abnormalities, highlighting the potential of AI systems to evolve into an economically viable adjunct to oral and maxillofacial radiologists.[9-16] Applications of AI in diagnostic imaging include diagnostics, treatment planning, measurement of treatment outcomes, quality assessment, claims processing, and population studies, and medical and dental education, to name a few. The impact of AI in clinical, education, and

(Continued on Page 67)

About the Authors

Pabla

Tarunjeet Pabla, BDS, MS, DMD, is assistant professor in the Division of Oral and Maxillofacial Radiology at Tufts University School of Dentistry. She has participated in the research, teaching, and practice of oral maxillofacial radiology since 2002. She is a Diplomate of the American Board of Oral and Maxillofacial Radiology. She maintains private practice in oral and maxillofacial radiology.



Campos

Hugo Campos, DDS, DMD, MDS, is associate professor and division head of oral and maxillofacial radiology at Tufts University School of Dental Medicine. He has served as a full-time faculty of the Division of Oral and Maxillofacial Radiology at Tufts since 2014. He is a Board-certified oral and maxillofacial radiologist.

Ramesh

Aruna Ramesh, BDS, MS, DMD, is a professor and associate dean for academic affairs at Tufts University School of Dental Medicine. She has been a full-time faculty member at Tufts since 2001. She is a Diplomate of the American Board of Oral and Maxillofacial Radiology. She currently serves as a commissioner with the National Commission on Recognition of Dental Specialties and Certifying Boards. She was a pioneer in establishing a solo private practice in oral and maxillofacial radiology in the New England region.