Applications of Cone Beam Computed Tomography Scans in Dental Medicine and Potential Medicolegal Issues

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KEYWORDS

• CBCT • Cone beam • Panoramic • Plan film • Maxillofacial • FOV • Radiography

KEY POINTS

- A cone beam computed tomography (CBCT) scan produces images in orthogonal and non-orthogonal with great spatial resolution.
- When a dental health care practitioner (DHP) orders a CBCT scan, they should consider if it is truly indicated, as CBCT scans carry up to four times the dosage of radiation compared to panoramic radiographs.
- Any diagnostic imaging obtained of a patient should include a formal interpretive report commenting on the findings within the imaging.
- Ordering of limited field of view (FOV) CBCT scans and failing to report on abnormal findings present outside of the region of interest (ROI) is a potential medicolegal issue.

BACKGROUND

Cone beam computed tomographic (CBCT) imaging was initially developed for medical applications in angiography in the early 1980's. The first CBCT machines were introduced in Europe in 1996 and made their way to the United States in 2001.[1] There are three main components to CBCT imaging: image production, visualization, and interpretation. A CBCT scan is performed using a rotating platform carrying an x-ray source and detector. The collimator in the x-ray tube helps to generate a cone-

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shaped beam. The source of radiation is directed through the region of interest (ROI), and the residual attenuated radiation beam is projected onto an area x-ray detector on the opposite side.[2] During the rotation, multiple planar projection images (ranging from 150 to 599 unique radiographic views) are captured sequentially. The complete series of these images is referred to as the projection data.[1]

Using sophisticated algorithms, imaging software reconstructs the projection data, producing a digital volume of anatomic data that can be visualized three dimensionally in voxel resolution. A voxel is the smallest subunit of a digital volume. CBCT voxels are generally isotropic (the X, Y, and Z dimensions are all equal) and range in size from approximately 0.07 mm to 0.40 mm per side.[1,3] The projection data in these three orthogonal planes is limited by the dimensions of the scan volume, also known as the field of view (FOV). CBCT units are classified according to the maximum FOV incorporated from the scan. Large FOV scans provide images of the entire craniofacial skeleton. A medium FOV scan provides images of the maxilla or mandible. A focused or limited FOV scan provides high-resolution images of limited regions.[4]

Cone-beam imaging has numerous features compared to multidetector computed tomography (MDCT) that makes it suitable for dental applications. These include: size & cost, speed of image acquisition, image resolution, and radiation dose. A CBCT machine has a smaller physical footprint and costs approximately one-fourth to one-fifth as much as an MDCT machine.[5] Additionally, with more recent advances in solid-state detector achievable frame rates and computer processing speeds, most CBCT scanning can be performed in less than 30 seconds.[4,6] According to the 2007 recommendations from the International Commission on Radiological Protection, the effective dose for various CBCT machines ranges from 25 to 1025 uSv. These values are roughly equivalent to 1 to 42 digital panoramic radiographs (approximately 24 uSv) or 3 to 123 days' equivalent per capita natural background radiation (approximately 3000 uSv in the United States) (**Table 1**).[7]

CONE BEAM CENTRAL TOMOGRAPHY AND DENTAL IMPLANT PLANNING

Today, roughly every fourth article published on CBCT is related to the use of CBCT scans in implant dentistry, with two out of three on the presurgical use of CBCT scans, primarily for presurgical planning and transfer to implant placement.[8] Radiographic assessment of the 3D implant position, angulation, and restorative space is essential

Table 1
Range of radiation doses

	Range of Dose of Radiation
CBCT	11–674 μSv (median value 61 μSv) for small and medium FOV scans (volumes <10 cm) 30–1073 μSv (median value 87 μSv) for large FOV scans (volumes > 10 cm)
Panoramic Radiograph	9–26 μSv
Intraoral full mouth radiographic series	34.9 μSv (PSP plates/F-speed film, rectangular collimation) 170.7 μSv (PSP plates/F-speed film, round collimation) 388 μSv (D-speed film, round collimation)
MDCT	290–1410 μSv
Average Background Radiation in USA	8 μSv per day

Adapted from Tamimi D, Hatcher D. Specialty Imaging Temporomandibular Joint 1st Edition. Elsevier 2016, Philadelphia, PA.

during presurgical diagnostics and treatment planning of implant sites within the residual alveolar bone.[9] CBCT scans provide cross-sectional images of the alveolar bone height, width, and angulation and accurately depict vital structures, such as the inferior alveolar dental nerve canal or the maxillary sinus (**Figure 1**).[10]

When a CBCT scan is performed on patients with preexisting metallic dental materials (ie, amalgam restorations, porcelain fused to metal (PFM) crowns, dental implants), these materials can create artifacts in the scan due to the beam hardening phenomena. This phenomenon occurs when an x-ray beam composed of polychromatic energies passes through an object, leaving only high-energy photons to contribute to the beam and thus the mean beam energy is increased or “hardened.”[11] This can result in a streaking artifact, which manifests as multiple dark streaking bands positioned between two dense objects. The presence of these artifacts decreases the overall image quality and if severe enough can render the scan useless.[12]

Implant planning software, utilizing CBCT imaging, allows greater sophistication in analysis and planning, providing interactive methods of translating prosthetic planning to the surgical site. In implant planning, software can be used to select and direct the placement of implant bodies either directly by the use of CBCT image-guided navigation or indirectly via the construction of 3-D printed surgical guides fabricated to the patient’s specific measurements obtained on CBCT imaging.[13] Currently, there is no literature to support placing implants via computer-guided surgery being superior to conventional methods. Implants placed utilizing computer-guided surgery with a follow-up period of at least 12 months demonstrate a mean survival rate of 97.3% (n = 1941), which is comparable to implants placed following conventional procedures.[14]

When planning dental implants in an edentulous patient, CBCT scans can assist with virtual implant placement and fabrication of surgical guides. In the edentulous patient, a new denture can be fabricated and used as a radiographic stent. The patient then has a CBCT scan performed with the radiographic stent in place. When obtaining this scan, it is paramount that the intaglio surface of this denture fits perfectly to the mucosa with no “air” pockets. If cross-sections of the CBCT scan show space

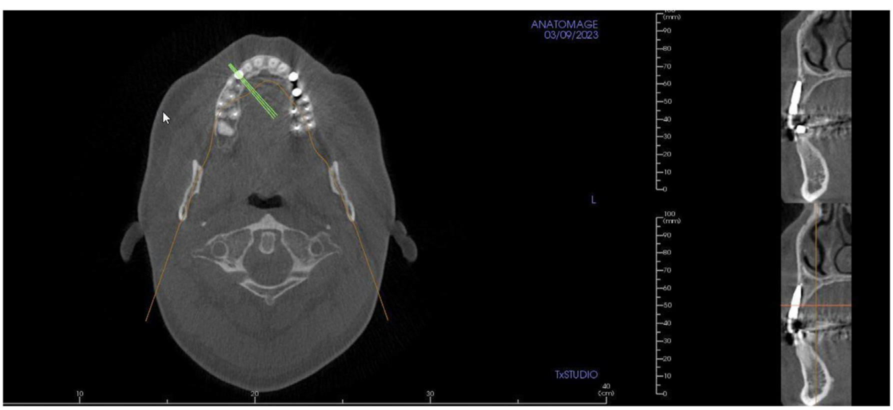

Fig. 1. The left image is a CBCT axial cut of the maxilla, the green lines indicate the location of the axial view in relation to the sagittal view. The images in the right-hand column are the sagittal views in the locations of the green lines from the right-hand image. In this view, the relationship to vital structures, such as the nasal floor, and the apex of the implant can be appreciated. As well as the angle of the implant’s inclination.

between the mucosa and the stent, then the surgical guide stent fabricated using this scan will not fit, and the implant placement will be inaccurate.[15,16]

Proponents for the use of CBCT scans in dental implantology argue that the benefits of planning implants for the edentulous patient assisted by CBCT scan and static surgical guide include: complete knowledge of the bone morphology before surgery, use of a flapless surgical technique which shortens the surgical time and reduces postoperative pain and swelling, and laboratory preparation of the denture based on the transfer of the CBCT plan to a working model.[15,16,17] However, this all falls under the pretense that the CBCT scan was obtained accurately and that the provider ordering the scan is capable of interpreting any errors before moving forward with any stent fabrication.

CONE BEAM CENTRAL TOMOGRAPHY AND VIRTUAL SURGICAL PLANNING

Today the use of CBCT imaging for presurgical orthognathic treatment has begun to overtake conventional model surgery in popularity amongst providers performing these procedures. From a presurgical imaging standpoint, the increased adoption of CBCT can partly be attributed to a CBCT machine's ability to obtain high-resolution images in under 30 seconds, allowing for a two-dimensional (2D) cephalometric analysis to be visualized in the three-dimensional (3D) realm.[4,18] As computer software technology has continued to advance, the software environments which allow virtual surgical planning (VSP) have been shown to be less time-consuming and in some ways more accurate than conventional model surgery.[17,19] The key feature that makes systems interoperable is the use of image files that are conformant with the Digital Imaging and Communications in Medicine (DICOM) standard file format.[19] When using VSP for orthognathic surgery, DICOM data from CBCT scans can be used to construct physical stereolithographic models or to generate virtual 3-D models (**Figure 3**).[20] These reconstructions can then be used as aids intraoperatively to adapt custom cutting guides and analyze the spatial relationship of neighboring structures[21] (**Figure 2**).

A reason VSP and subsequently CBCT has become so widely adopted, is its high level of recorded accuracy. A study performed by De Riu and colleagues, measuring the accuracy of bimaxillary orthognathic surgery between computer-assisted model surgery and conventional model surgery at the immediate postoperative time point, found angular measurements were more accurate with computer-assisted surgery

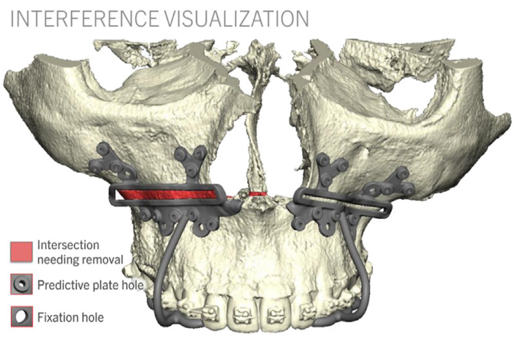

Fig. 2. 3-D rendering created from a preoperative CBCT scan highlighting anticipated bony interferences and placement of custom cutting guides for a planned LeFort 1 osteotomy advancement.

than with conventional presurgical planning with 1.19° difference between planned and actual movements.[22]

Despite the recorded increase in accuracy of virtual surgical planning over conventional model surgery, there are still areas in which error can be introduced. One crucial step in virtual surgical planning that can introduce significant error is the acquisition of the CBCT scan. In maxilla-first virtual surgical planning, the CBCT scan, is in essence, the facebow transfer for the model surgery. Therefore, the CBCT scan must be obtained in centric relation for maxilla-first virtual surgical planning. If the patient is not in centric relation with their condyle in the fossa, then the intermediate splint will be inaccurate and place the maxilla off from the pre-planned position.[23]

Another major limitation to the use of CBCT when performing VSP is CBCT technology currently lacks the ability to capture the teeth and their occlusal surfaces with high accuracy. In order to produce accurate CAD/CAM splints for intraoperative use, it is necessary to replace inaccurate occlusal surfaces from CBCT scans with high-resolution scans of the maxillary and mandibular arches utilizing digital intraoral scanners.[24]

CONE BEAM CENTRAL TOMOGRAPHY AND ENDODONTICS

Success in endodontics is assessed in healing of the periapical bone adjacent to obturated canals. Goldman and colleagues showed that in evaluating healing of periapical lesions using 2-D periapical radiographs there was only 47% agreement between six examiners.[25,26] Goldman and colleagues also reported that when those same examiners evaluated the same films at two different times, they only had 19%–80% agreement between the two evaluations.[27] The limitations associated with traditional 2-D intraoral radiography, has led to a greater adoption of CBCT imaging in endodontics.

Bernardes and colleagues retrospectively compared conventional periapical radiographs and CBCT images for 20 patients with suspected root fractures. They found that CBCT was able to detect fractures in 18 (90%) of patients whereas conventional periapicals could only detect fractures 6 to 8 of the cases (30% to 40%) and indicated that CBCT was an excellent supplement to conventional radiography in the diagnosis of root fractures[28] (see **Figure 3**). Stavropoulos and Wenzel compared CBCT to digital- and film-based intraoral periapical radiography for the detection of periapical bone defects on 10 frozen pig mandibles by four calibrated examiners. They reported

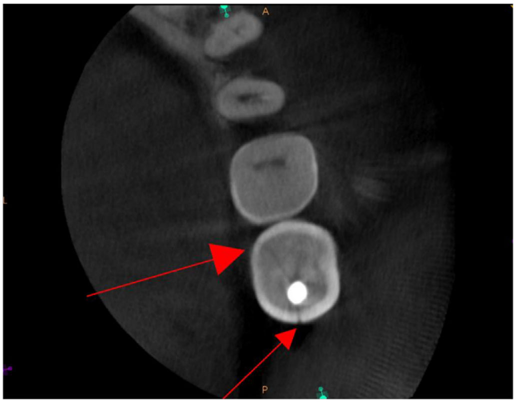

Fig. 3. Axial cut of a CBCT scan highlighting a vertical crown root fracture of a mandibular second molar.

that CBCT provides greater diagnostic accuracy (61%) compared with digital (39%) and (44%) conventional radiographs.[29]

Despite the advantages of CBCT imaging in endodontics, conventional intraoral radiography provides clinicians with an accessible, cost effective, high-resolution imaging modality that continues to be of value in endodontic therapy. There are, however, specific situations, both pre- and postoperatively, where the understanding of spatial relationships afforded by CBCT imaging facilitates diagnosis and influences treatment. CBCT imaging is a useful task-specific imaging modality and should be limited to the assessment and treatment of complex endodontic conditions.[25]

CONE BEAM CENTRAL TOMOGRAPHY AND PATHOLOGY

CBCT can be used as a noninvasive diagnostic technique in maxillofacial pathosis (see **Fig. 3**). Simon and colleagues compared the diagnosis of large periapical lesions (granulomas vs cysts) using CBCT and biopsy. These authors examined 17 lesions with a size equal to or greater than 1 cm × 1 cm, making a preoperative diagnosis based on the density of the lesions measured by CBCT. There was concordance between the preoperative diagnosis based on CBCT and the histologic study in 13 of 17 cases. In four of the 17 lesions, the preoperative diagnosis by CBCT was of a cyst whereas the histologic result was of chronic periapical granuloma.[30] These results suggest that CBCT could be a rapid diagnostic method without invasive surgery and/or prolonged periods of observation to see if a nonsurgical therapy is effective (**Fig. 4**).

The occasional discovery of occult pathologies upon commissioning of maxillofacial imaging is a widespread and well-known occurrence, a study conducted by Bondemark and colleagues in 2006 showed revealed that the panoramic imaging of 8.7% of 496 orthodontic patients displayed radiographic lesions other than those for which the image was commissioned.[31,32] However, CBCT scans with their increased resolution and field of view, have multiplied the range of pathologies that can be incidentally detected. The potential for incidentally encountering an unexpected pathology with a CBCT scan is triple that compared to a panoramic radiograph.[33]

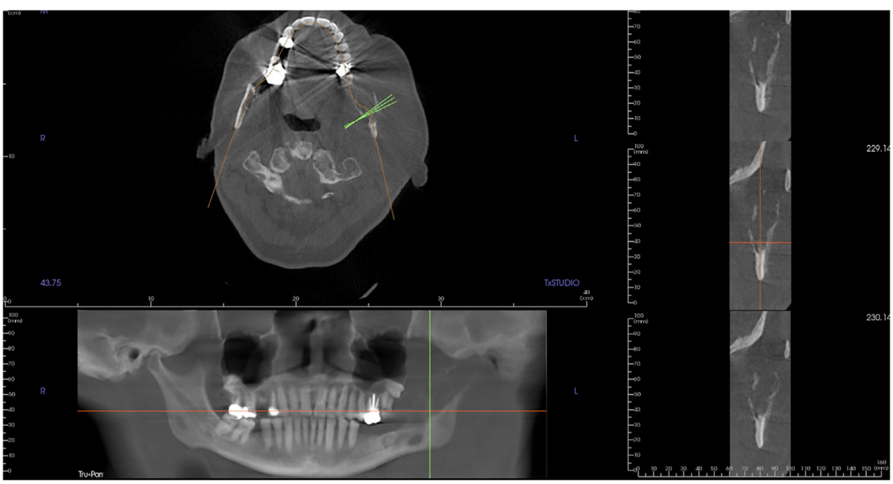

Fig. 4. CBCT of an odontogenic keratocyst. The CBCT is capable of illustrating the extent of lytic bone destruction. Additionally, the coronal views provide the visualization of the buccal and lingual expansion of the mandibular bone.

Interpretation and Reporting of a Cone Beam Central Tomography Image

The essential elements of a cone-beam computed tomographic radiologic report include: patient information, scan information, radiologic findings, and radiologic impression. The most important and often most overlooked components of the radiologic report for a CBCT scan are the radiologic findings and impression. The radiologic findings should include reference to intraoral findings such as: missing teeth, preexisting restorations, presence of implants, root canal-treated teeth, periapical lesions, alveolar bone status, and edentulous regions. As well as making reference to extraoral findings/structures such as: the temporomandibular joint (TMJ), paranasal sinuses, nasopharyngeal airway, soft tissues of the neck, and intracranial calcifications.[34,35] The radiologic impression component of the report should include a differential diagnosis related to the rationale for the imaging examination or clinically significant incidental findings, a comparison to previous imaging studies (if available), and any recommendations for additional clinical or diagnostic studies to clarify, confirm, or exclude a diagnosis.[36]

DISCUSSION

According to the National Council of Radiation Protection and Measurement, the average annual radiation dose per person in the United States is 6.2 mSv, half of which comes from natural background sources, such as cosmic radiation, naturally occurring radiation in the ground and human body, and the radioactive gasses radon and thoron, which are produced by the radioactive decay of naturally occurring elements such as uranium and thorium.[2,37] Another 48% of the average annual radiation dose a person in the United States is exposed to, comes from medical treatment and diagnostic tests. Of that 48%, half, or 24% of the total dose, comes from CT imaging of one form or another.[37]

Currently, there are multiple different medical device companies manufacturing CBCT machines for medical use. The exposure profile of a CBCT scan varies from machine to machine and is also influenced by the FOV of the scan. A full FOV CBCT scan requires seven times the effective dosage of radiation compared to panoramic imaging.[38] When compared to a medical grade CT scan of the maxilla and mandible, a full FOV CBCT scan of the maxilla and mandible has a fraction of the effective dose of radiation (1800–2100 mSv vs 34–89 mSv respectively).[39,40,41] Which according to the Environmental Protection Agency's Federal Guidance Report, would account for only 2% to 5% of the effective dosage of medical grade CT.[10,42]

The US Food and Drug Administration (FDA) classifies CBCT machines as CT machines.[43] The regulatory standards and practices for CBCT machines vary state to state. In states within the US where a CBCT machine is considered a medical device, a dental technician or assistant may not be qualified to perform a CBCT scan under state law. In these regions, performing a CBCT scan may be restricted to a certified medical radiology technician, radiologist, or a specifically trained individual.[34,44] The importance of a properly trained individual operating a CBCT machine and performing scans is highlighted by the risk of fatal malignancy related to CBCT radiation exposure. In adults, the risk can range from 1 in 100,000. In children, the risk of fatal malignancy related to CBCT radiation exposure can be doubled.[41]

Conventional medical radiology requires an over-read by a medical radiologist and a formal written report. Accredited health care centers are required to use the report as a manifestation of quality and a tool to facilitate peer review of images. Historically, these practices have not been followed by the field of dental medicine, because most dental images are considered diagnostic tools.[38] There is one standard of care for any procedure in dental medicine and the dental health care practitioner (DHP) must meet said standard. Although over-reads are generally not required, the DHP ordering the CBCT study must be capable of reading and interpreting the entire FOV captured by the study, including structures outside the region of interest.[34,45] Dental health care practitioners ordering CBCT scans, should be able to read and interpret any conventional radiograph, including a CBCT scan, and identify and report any identifiable pathology. Whether it is with a conventional panoramic image or CBCT scan, failure to diagnose an identifiable pathology could be a potential medicolegal issue.[46]

As a matter of law, a DHP owes a duty to a patient to use the ordinary skills, means, and methods that are recognized as necessary and which are customarily followed in the particular type of case according to the standard of those who are qualified by training and experience to perform similar services in the community.[47] This standard of care is judged on a local level for generalists or general practitioners, whereas specialists are held to a national standard of care.[48] For one to prevail in a medical malpractice action, a plaintiff must identify the standard of care owed by the DHP, produce evidence that the DHP breached the duty to render medical care in accordance with the requisite standard of care, and establish that the breach proximately caused the injury alleged.[49]

A DHP must perform proper diagnostic imaging for preoperative planning. The issue is whether a DHP can rely solely on periapical and/or panoramic radiographs in their preoperative planning diagnostic imaging, or whether MDCT or CBCT are considered the standard of care.[50] When a DHP does elect to order a CBCT scan, they are responsible for the identification of all pathology within the FOV. Some authors have suggested a solution being the decrease of the FOV to include only those structures within the usual and customary dental view. A potential problem could arise if the FOV is reduced to exclude unfamiliar structures and therefore the ability to diagnose potential conditions. The better course is to include within the FOV all anatomic structures relevant to the treatment planning of the patient. Prudence may dictate that the DHP defer reading of the CBCT to a practitioner with the requisite special knowledge to comprehensively interpret the diagnostic modality. It is the authors' counsel that the DHP strongly consider deferring to an Oral and Maxillofacial Radiologist or to use the services of a CBCT "Over-read" service. These "over-read" services can provide the DHP with a written radiologic analysis and assessment and represent a method of reducing potential exposure for failure to diagnose disease/lesion and/or anatomic abnormalities.

The use of CBCT scans in dental medicine today is becoming an increasingly valuable imaging modality. Today's CBCT scanners are capable of rapidly obtaining high-resolution, three-dimensional imaging of the maxillofacial region. Although CBCT scanners are capable of these measures, because of the increased cost and radiation exposure to the patient, CBCT scans should not be considered the blanket "gold standard" for all maxillofacial imaging in dental medicine. It is the authors' belief that less invasive imaging modalities be performed first in the assessment and diagnosis of patients, reserving CBCT scans as an adjuvant task-specific imaging modality when indicated.

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