
Cone-Beam Computed Tomography in Dentistry

A Review

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Abstract:

The introduction of CBCT is dedicated to imaging the maxillofacial region heralds, a true paradigm shift from 2D to 3D approach to data acquisition and image reconstruction, expanding the role of imaging from diagnosis to image guidance for operative and surgical procedures with the help of third-party applications software. CBCT is capable of providing resolution in images of high diagnostic quality, with short scanning times and radiation dosages up to 15 times lower than those of conventional CT scans. This article provides an review of cone beam computed tomography in relevance to clinical practice and research in dentistry.

Introduction:

Radiographic imaging is very important in the diagnostic assessment of the dental patient.¹ Although combinations of plain x-ray transmission projections and panoramic radiography can be adequate in a number of clinical situations, use of multiple projections, effect of soft tissue edema on image contrast, lack of soft tissue imaging, variability in exposure and technique problems related to film coverage, and geometric distortion are always needed to addressed.² In the 1960s, tomography and rotational panoramic radiography were commercialized. While both techniques reduced the untoward effects of the superimposition of highly contrasting structures inherent in conventional radiographs, they each have their own limitations.³ Godfrey Hounsfield in 1970, first, applied the mathematical principle of CT clinically and in 1972, he introduced it to imaging world.⁴ CT provides three-dimensional imaging and has been used to overcome the inherent problems with conventional two dimensional radiographic techniques. Although offering spectacularly high speed imaging of both hard and soft tissues, X-ray dose is high, the equipment exceptionally expensive and generally only found in hospital settings.⁵ CBCT is a recent technology, which was developed as an alternative to conventional CT. It provides more rapid acquisition of a data set of the entire FOV and is comparatively inexpensive and small enough to be used in the dental office.⁶ Most dental practitioners are familiar with the thin-slice images produced in the axial

plane by conventional helical fan-beam CT. CBCT scanners use back-projection reconstructed tomography to acquire data of the area of interest through a single or partial rotation of the conical X ray beam and reciprocal image receptor.⁷

Thus a principle difference between CT and CBCT is the method by which data are gathered while CT acquires image data using rows of detectors, CBCT exposes the whole section of the patient over one detector. The CBCT volumetric data set is usually reconstructed in orthogonal orientations to allow viewing of the images in the axial, sagittal and coronal planes.⁸ CBCT allows to create images not only in the axial plane but also 2-dimensional (2D) images in the coronal, sagittal and even oblique or curved image planes by a process referred to as multiplanar reformation. In addition, CBCT data are amenable to reformation in a volume, rather than a slice, providing 3-dimensional(3D) information. This article provides an review of cone beam computed tomography in relevance to clinical practice and research in dentistry.

Cone-Beam CT Technology:

The cone-beam technique involves a single 360° scan in which the x-ray source and a reciprocating area detector synchronously move around the patient's head, which is stabilized with a head holder. At certain degree of intervals, single projection images, known as "basis" images, are acquired. They are similar to lateral cephalometric radiographic

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images, each slightly offset from one another. This series of basis projection images is referred to as the projection data.⁹

Software applications incorporating sophisticated algorithms including back-filtered projection are applied to these image data to generate a 3D volumetric data set, which can be used to provide primary reconstruction images in 3 orthogonal planes (axial, sagittal and coronal).

Reconstruction of CBCT data is performed natively by a personal computer. In addition, software can be made available to the user. This provides the clinician with the opportunity to use chair-side image display, real-time analysis and MPR modes that are task specific.

Instrumentarium VT (PaloDEx Group), ProMax 3D (Planmeca), Galileos (Sirona), and PreXion3D (PreXion). NewTom QR DVT 9000 (Quantitative Radiology s.r.l., Verona, Italy); CB MercuRay (Hitachi Medical Corp); 3D Accuitomo – XYZ Slice View Tomograph (J. Morita Mfg Corp.) and I-CAT (Xoran Technologies, and Imaging Sciences International,) are some of the dental CBCT machines marketed.

Except I- CAT all other machines have image intensifier tube charge couple device x-ray detection system. I- cat has a flat panel image detection system. Flat panel image detection system produce less noise on the images when compared to the intensifier charge couple device.⁹

The volumetric data set comprises a 3D block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray absorption. The size of these voxels determines the resolution of the image. CBCT units provide voxel resolutions that are isotropic equal in all 3 dimensions. This produces sub-millimetre resolution.

Published reports indicate that the effective dose of radiation (average range 36.9–50.3 microsievert [μSv])^{10–14} is significantly reduced by up to 98% compared with “conventional” fan-beam CT systems (average range for mandible 1,320–3,324 μSv ; average range for maxilla 1,031–1,420 μSv).^{10,11,15–17} It reduces the effective patient dose to approximately that of a film-based periapical survey of the dentition (13–100 μSv)^{18–20} or 4–15 times that of a single panoramic radiograph (2.9–11 μSv).^{14,17–20}

Limitations of Cone-Beam Ct Imaging²¹

1. Because the CBCT x-ray beam is heterochromatic and has lower mean kilovolt (peak) energy compared with conventional CT, thus, X-ray beam artifacts are more pronounced on CBCT images.
2. Cone beam–related artifacts are of three types:
 Partial volume averaging: It occurs when the selected voxel resolution of the scan is greater than the spatial or contrast resolution of the object to be imaged.
 Undersampling: Undersampling can occur when too few basis projections are provided for the reconstruction.
 Cone-beam effect: The cone-beam effect is a potential source of artifacts, especially in the peripheral portions of the scan volume. Because of the divergence of the x-ray beam as it rotates around the patient in a horizontal plane, projection data are collected by each detector pixel.
3. The scatter-to-primary ratios are about 0.01 for single-ray CT and 0.05 to 0.15 for fan-beam and spiral CT, and may be as large as 0.4 to 2.0 in CBCT. Image noise is the major problem with CBCT.
4. CBCT provides poor soft tissue contrast. Three factors limit the contrast resolution of CBCT. Although scattered radiation contributes to increase image noise, it is also a significant factor in reducing the contrast of the cone-beam system.

Clinical Dental Practice and Cbct:

The greatest advantage of CBCT is the ability it provides to interact with the data and generate images replicating those used in clinical practice.

CBCT is most commonly used in the assessment of bony and dental pathologic conditions including fracture, structural maxillofacial deformity and fracture recognition, preoperative assessment of impacted teeth, TMJ imaging and in the analysis of available bone for implant placement. In orthodontics, CBCT imaging is now being directed towards 3D cephalometry.

The Value of Cbct Imaging in Implant Planning^{21–23}

Implantologists have appreciated the value of 3- dimensional imaging. Conventional CT scans are used to assess the osseous dimensions, bone density, and alveolar height, especially when multiple implants are planned.

Locating landmarks and anatomy such as the inferior alveolar canal, maxillary sinus, and mental foramen occurs more accurately with a CT scan. The use of the third dimension has improved the clinical success of implants and their associated prostheses, and led to more accurate and aesthetic outcomes. With CBCT technology both the cost and effective radiation dose can be reduced. CBCT has been in use in implant therapy and may be employed in orthodontics for the clinical assessment of bone graft quality following alveolar surgery in patients with cleft lip and palate. The images produced provide more precise evaluation of the alveolus. This technology can help the clinician determine if the patient should be restored or if teeth should be moved orthodontically into the repaired alveolus. Anatomic structures such as the inferior alveolar nerve, maxillary sinus, mental foramen, and adjacent roots are easily visible using CBCT. The CBCT image also allows for precise measurement of distance, area, and volume. Using these features, clinicians can feel confident in the treatment planning for sinus lifts, ridge augmentations, extractions, and implant placements.

Before implant placement and during treatment planning, the implant clinician must be able to measure the height and width of the alveolar process to ensure adequate bone and to select appropriately sized implants. In addition, the clinician must know the precise location of the mandibular canal (injury to the neurovascular bundle within the canal can result in facial paresthesia) and the maxillary sinuses (perforation of the sinuses creates the possibility of antral infections and increases the likelihood of implant failure). Multiple views of the proposed implant site should be taken, which often require the use of different imaging procedures. Various radiographic modalities are available to the clinician, including intraoral films (i.e., periapical and occlusal radiographs), panoramic radiographs, cephalometric radiographs, plain (conventional) tomography, computed tomography (CT), cone beam CT, digital subtraction radiography, and magnetic resonance imaging.

Cross-sectional imaging techniques can be an invaluable tool during preoperative planning for complicated endosseous dental implantation procedures. Conventional linear tomography and CT have traditionally been

used in presurgical imaging, though the former has overlain ghosting artifacts and the latter has relatively high radiation exposure and cost.

The Value of Cbct Imaging in Orthodontics²⁴⁻²⁹

Possibly the most recognized need for CBCT imaging in orthodontics is for impacted canine evaluation. CBCT imaging is precise in determining not only the labial/lingual relationship but also a more exact angulation of the impacted canine. These 3D images are beneficial in determining the proximity of adjacent incisor and premolar roots, which can be invaluable in determining the ease of uncovering and bonding and the vector of force that should be used to move the tooth into the arch with a lesser chance of adjacent root resorption. Root resorption involved in orthodontic treatment can be readily viewed on periapical radiographs. However, resorption that occurs on the facial or lingual side of the tooth is difficult to ascertain and quantify with this 2D view. CBCT scanning allows for better viewing of resorption on either of these surfaces. CBCT images allow more accurate and dependable views of the interradicular relationships than panoramic radiographs. These images allow not only more successful placement but also better treatment planning of where these TADs should be placed so that proper force vectors can be used during orthodontic treatment. CBCT data can be used to construct placement guides for positioning mini-implants between the roots of adjacent teeth in anatomically difficult sites. Facial asymmetry and temporomandibular joint disorders can be precisely diagnosed with CBCT.

The Value Of Cbct Imaging In Endodontics³⁰⁻³²

Case studies appeared in the endodontic literature in which patients underwent CBCT imaging for the purposes of diagnosis and presurgical treatment planning. Recent reports have successfully shown the use of CBCT to locate missed canals, detect the extent of dentoalveolar fractures, identify resorption patterns, and compare cystic with granulomatous periapical lesions. Through show a case in which the missed canal was suggested by periapical radiographs but confirmed with CBCT. Similarly in through, the additional diagnostic information attained from CBCT confirmed the diagnosis and

extent of the root fracture, which initially was observed in the periapical radiographs. Notably, the extent of the lingual fracture as well as any alveolar complications could be visualized by CBCT.

Conclusions:

Cone-beam imaging is one of the most exciting developments in dental and maxillofacial

radiology and, owing to its versatility, will almost certainly become an increasingly popular form of imaging available in dental practice. As a result, more manufacturers will develop units with the result that purchase costs will almost certainly reduce. Some manufacturers are already producing hybrid units combining dental panoramic tomography with a limited cone-beam facility incorporated.

References:

1. American Dental Association and U.S. Department of Health and Human Services. The selection of patients for dental radiographic examinations, Chicago: American Dental Association, 2004.
2. White SC, Heslop EW, Hollender LG, Mosier KM, Ruprecht A, Shrout MK; American Academy of Oral and Maxillofacial Radiology, ad hoc Committee on Parameters of Care. Parameters of radiologic care: an official report of the American Academy of Oral and Maxillofacial Radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001; 91(5):498–511.
3. Hu H, He HD, Foley WD, Fox SH. Four multidetector-row helical CT: image quality and volume coverage speed. *Radiology* 2000; 215(1):55–62.
4. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *Eur Radiol* 1998; 8(9):1558–64.
5. Baba R, Konno Y, Ueda K, Ikeda S. Comparison of flat-panel detector and image-intensifier detector for cone-beam CT. *Comput Med Imaging Graph* 2002; 26(3):153–8.
6. Baba R, Ueda K, Okabe M. Using a flat-panel detector in high resolution cone beam CT for dental imaging. *Dentomaxillofac Radiol* 2004; 33(5):285–90.
7. Sukovic P, Brooks S, Perez L, Clinthorne NH. DentoCAT – a novel design of a cone beam CT scanner for dentomaxillofacial imaging: introduction and preliminary results. In: Lemke HU, Vannier MW, Inamura K, Farman AG, Doi K, editors. *Computer assisted radiology and surgery*. Amsterdam: Elsevier Science; 2001. p. 659–64.
8. Sukovic P. Cone beam computed tomography in craniofacial imaging. *Orthod Craniofac Res* 2003; 6(Suppl 1):31–6.
9. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. *Dentomaxillofac Radiol* 2002; 31(2):126–30.
10. Cohnen M, Kemper J, Mobes O, Pawelzik J, Modder U. Radiation dose in dental radiology. *Eur Radiol* 2002; 12(3):634–7.
11. Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. *Dentomaxillofac Radiol* 2004; 33(2):83–6.
12. Heiland M, Schulze D, Rother U, Schmelzle R. Postoperative imaging of zygomaticomaxillary complex fractures using digital volume tomography. *J Oral Maxillofac Surg* 2004; 62(11):1387–91.
13. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003; 96(4):508–13.
14. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofac Radiol* 2003; 32(4):229–34.
15. Scaf G, Lurie AG, Mosier KM, Kantor ML, Ramsby GR, Freedman ML. Dosimetry and cost of imaging osseointegrated implants with film-based and computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997; 83(1):41–8.
16. Dula K, Mini R, van der Stelt PF, Lambrecht JT, Schneeberger P, Buser D. Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible. *Eur J Oral Sci* 1996; 104(5-6):503–10.

17. Ngan DC, Kharbanda OP, Geenty JP, Darendeliler MA. Comparison of radiation levels from computed tomography and conventional dental radiographs. *Aust Orthod J* 2003; 19(2):67–75.
18. White SC. 1992 assessment of radiation risk from dental radiography. *Dentomaxillofac Radiol* 1992; 21(3):118–26.
19. Danforth RA, Clark DE. Effective dose from radiation absorbed during a panoramic examination with a new generation machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; 89(2):236–43.
20. Gibbs SJ. Effective dose equivalent and effective dose: comparison for common projections in oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; 90(4):538–45.
21. Sato S, Arai Y, Shinoda K, Ito K. Clinical application of a new cone-beam computerized tomography system to assess multiple two-dimensional images for the preoperative treatment planning of maxillary implants: case reports. *Quintessence Int* 2004; 35(7):525–8.
22. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. *Int J Oral Maxillofac Implants* 2004; 19(2):228–31.
23. Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. *J Calif Dent Assoc* 2003; 31(11):825–33.
24. Honda K, Matumoto K, Kashima M, Takano Y, Kawashima S, Arai Y. Single air contrast arthrography for temporomandibular joint disorder using limited cone beam computed tomography for dental use. *Dentomaxillofac Radiol* 2004; 33(4):271–3.
25. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. *Dentomaxillofac Radiol* 2004; 33(4):196–201.
26. Honda K, Arai Y, Kashima M, Takano Y, Sawada K, Ejima K, and other. Evaluation of the usefulness of the limited cone-beam CT (3DX) in the assessment of the thickness of the roof of the glenoid fossa of the temporomandibular joint. *Dentomaxillofac Radiol* 2004; 33(6):391–5.
27. Aboudara CA, Hatcher D, Nielsen IL, Miller A. A three-dimensional evaluation of the upper airway in adolescents. *Orthod Craniofac Res* 2003; 6(Suppl 1):173–5.
28. Baumrind S, Carlson S, Beers A, Curry S, Norris K, Boyd RL. Using three-dimensional imaging to assess treatment outcomes in orthodontics: a progress report from the University of the Pacific. *Orthod Craniofac Res* 2003; 6(Suppl 1):132–42.
29. Maki K, Inou N, Takanishi A, Miller AJ. Computer-assisted simulations in orthodontic diagnosis and the application of a new cone beam X-ray computed tomography. *Orthod Craniofac Res* 2003; 6(Suppl 1):95–101.
30. Miller ME. MedPAC recommendations on imaging services. March 17, 2005 Available from: URL: http://www.medpac.gov/publications/congressional_testimony/031705_Testimony_Imaging-Hou.pdf (accessed December 2005).
31. Cohenca N, Simon JH, Mathur A, et al. Clinical indications for digital imaging in dento-alveolar trauma. Part 2: root resorption. *Dent Traumatol*. 2007; 23(2):105–113.
32. Cotton TP, Geisler TM, Holden DT, et al. Endodontic applications of cone-beam volumetric tomography. *J Endod*. 2007; 33(9):1121–1133.