Special Article
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Introduction to Cone Beam Computed Tomography for the dental practitioner

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Abstract

Cone Beam Computed Tomography (Cone beam CT) is a rapidly expanding technology with an ever-increasing number of applications. Its many advantages have resulted in the rapid adoption by the dental profession worldwide. Every day, new innovations are reported in the literature as investigations in different dental specialties discover applications of the technology. As part of this evolutionary process, manufacturers are planning new models with a variety of innovative features. At the present time a number of new manufacturers are planning to introduce Cone Beam CT machines in the very near future while current manufacturers continue to compete among themselves in the development of newer models. This dynamic process will certainly be of great benefit to the dentist who is the consumer of these devices but, more importantly, it is the patient who will ultimately benefit by this worldwide improvement in the standard of care in the various fields of dentistry.

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Key words: *Cone Beam Computed Tomography; Cone Beam CT systems; dentistry*

Introduction

Evolution of Computed Tomography Imaging

For nearly three quarters of a century after Roentgen's discovery of x-rays, radiographic images were produced by passing a beam of x-rays through the patient's body and recording the transmitted x-rays on a photographic film. The resulting image was a two-dimensional representation of the attenuation of the x-ray beam along its path through the body and was a composite effect of the thickness, density, and atomic number of the tissues encountered along the way. In the nineteen seventies the introduction of high-speed digital computers opened the door to a whole new world of x-ray imaging. Computed tomography (CT) led the way in this development, which has given rise in the years to come to a wide variety of digital radiographic techniques. With all this development, CT has continued to evolve technically and to find new clinical applications.

First generation

The first CT scanner, introduced by Hounsfield in 1973, utilized an x-ray source and a sodium iodide scintillation detector moving on parallel linear tracks. After executing a linear scan, during which the transmitted beam was recorded electronically, the scanning assembly was rotated one degree and another linear pass was made. This process was continued every degree for 180 degrees, a process that required about five minutes for the early scanners. The attenuation data acquired in this laborious manner were then processed by a digital computer in order to "reconstruct" a two dimensional map of the linear attenuation coefficients within a slice of the body. Scanners performing in this manner made up the "first generation" of CT equipment.

Second generation

A second generation of CT scanners was made possible when the single scintillation detector was replaced by a number of detectors (thirty or so was typical) arranged along an arc intercepting the wider beam. Linear scans were still performed before rotating to the next angular position but fewer scans were required because data from several beams were simultaneously acquired. This considerably reduced the time required for scanning.

Third generation

In third generation, a much larger number (hundreds) of detectors were utilized and the beam was now a much wider "fan" beam intercepting the entire width of the body. This made it possible to dispense altogether with the linear scanning movement. This purely rotational movement could be performed in a matter of seconds, providing all the information required to reconstruct a slice.

Fourth and fifth generation

A fourth and fifth generation of CT scanners were developed using different variations of the "fan beam geometry" used in the third generation. In both of these generations, the x-ray source is the only moving part, the x-ray detectors being mounted in fixed positions along a circle. Only a few of the detectors are intercepted at any moment of time by the x-ray beam that rotates around the patient. In fourth generation scanners, the x-ray tubehead physically moves around the patient along a circular path just as third generation machines. In fifth generation scanners, an electron beam scans a circular anode surrounding the patient, producing, in effect, a moving x-ray source.

Axial mode scanning

The first five generations of CT can be used to reconstruct a volume by the repetitive imaging of slices. Between slices, the table is moved a small amount in the direction of the patient's long axis (the "z" axis) and the rotational scan is repeated again and again. This has been referred to as axial-mode scanning. The result is a three-dimensional volumetric representation of the body. Modern medical CT scanners use either scintillation detectors (sodium iodide has been replaced by bismuth germinate or calcium fluoride because of the shorter fluorescence decay times of these materials) or high pressure xenon-filled ionization chamber detectors.

Helical scanning

By combining third or fourth generation rotational fan-beam scanning with a continuous movement of the table in the z-axis a helical-mode scan (sixth generation) can be performed. From the point of view of the patient, the tube takes a helical or corkscrew path around him while all the time data is being recorded. Data is interpolated between data sets straddling the slice being reconstructed. In earlier helical scanners, interpolation was performed between data sets separated by a full 360 degree rotation. More modern scanners interpolate between data separated by 180 degrees, the assumption being that divergence is almost negligible. Because data is acquired continuously it is possible to reconstruct slices at arbitrary z-positions. An important parameter in helical scanning is pitch, defined as the distance traveled by the table during one rotation of the tube divided by the tube collimation in the z-direction. If the pitch is 1, the data will be like a ribbon wrapped around a cylinder without gaps or overlaps. If it is smaller than 1 the data will overlap; if it is greater than 1 it will be more stretched out. Typically, one rotation takes place every second and the table moves 1 to 15 mm. The collimation in the z-dimension ranges between 1 to 10 mm and the pitch is between 1 and 2.

Multi-row scanning

Helical scanning with a single row of detectors made it possible to reduce the scan time considerably as compared to older machines. The desire for even faster scan times led to the replacement of the single row of detectors by arrays of 4, 8, 16, 32, or 64 parallel rows. Machines operating on this principle have been called seventh generation or multi-row scanners. These devices can operate either in the axial or helical mode and can acquire multiple slices during a single rotation. Needless to say, the interpolation schemes utilized in these scanners are much more complicated than single row scanners and there is more variation in the parameters that effect image quality.

Cone beam scanning

As the number of rows of detectors increases, the collimation must be adjusted so that the x-ray beam becomes a wide pyramidal cone beam instead of the thin transverse fan used in single row systems. If there are enough rows it becomes possible to dispense altogether with movement in the z-dimension. We have then arrived at a pure cone beam system capable of reconstructing a three-dimensional volume from a set of two dimensional images acquired during a single rotation. For the reconstruction process special cone beam reconstruction algorithms are utilized. The development of such algorithms is the subject of a great deal of current research.

Cone Beam CT in Dentistry

CT Scanners employing cone beam geometry are becoming popular tools in modern dental practice.

Cone beam CT scanners used in dentistry use either a scintillator detector combined with an image intensifier or an amorphous silicon plate to record the projection data. Some machines reconstruct the entire maxillofacial area while others are used for imaging a much smaller region of interest, although usually with finer resolution. Some scanners are limited to one of these approaches while others offer a choice between full-volume or regional options. Some machines position the patient in a supine position like that used in conventional CT units while others accommodate a seated patient as used in many dental panoramic machines. Unlike conventional CT scanners, which must provide contrast resolution sufficient to visualize differences in soft tissues, scanners used in dentistry are mostly used to distinguish bone from soft tissue. As a result, noise is not as important in dental CT scanners and it is possible to get by with much fewer x-ray photons. This means that much lower-powered x-ray generators can be used (dental x-ray machines similar to those used in panoramic radiography are not uncommon) and that the radiation dose to the patient required for such scanners is much lower than that used in medical CT. Because cone beam reconstruction algorithms make it possible to reconstruct an entire volumetric region, this region can be reformatted to show anatomical detail in any imaginable plane. Views not usually seen with traditional modes of dental radiography can be achieved and accurate measurements can be performed free from the usual problems of magnification and distortion.

Cone Beam CT Systems Availability

Aperio, Verono Italy (NewTom 9000 and NewTom 3G)

This machine is the only CBCT device configured like conventional medical CT machines. There are two models: the older 9000 acquiring only one volume size with 8 bit images and the current 3G system offering the choice of 3 volume sizes with 12 bit images (Fig. 1).

Fig. 1 The Aperio NewTom 9000 Cone Beam CT machine

Asahi Roentgen Inc. Co. Ltd. Kyoto, Japan (PSR 9000N)

This equipment is currently available in Japan and offers the widest variety of exposure techniques. Some of these include panoramic CT, block or volume CT, dental CT and conventional panoramic imaging (Fig. 2).

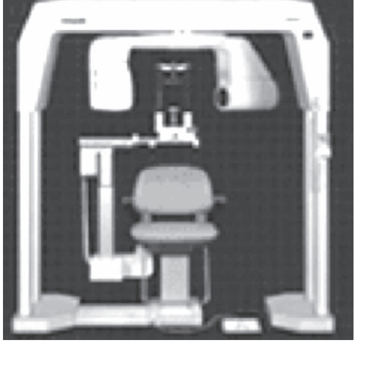


Fig. 2 The Asahi Roentgen PSR9000N machine

Hitachi Medico Technology Corp. Tokyo, Japan (CB MercuRay)

This is the largest of the CBCT machines and offers a variety of combinations of volume sizes. It was the first machine equipped with a 12 bit charge coupled device (CCD) receptor (Fig. 3).

Fig. 3 The Hitachi MercuRay machine

Imaging Sciences International. Hatfield Pennsylvania (i-CAT)

This machine is the least expensive of the larger volume devices. It is the first to utilize an amorphous silicon flat-panel detector. The system has a 12 bit depth capability. It is capable of taking a conventional panoramic radiograph (Fig. 4).

Fig. 4 The ISI I-CAT machine

Fig. 5 The J. Morita 3DX Accuitomo machine

Morita, Kyoto Japan (3DX Accuitomo)

This machine has the smallest and most limited volume size (3 cm height and a diameter of 4 cm) with the best resolution of all CBCT machines[1,2] (Fig. 5).

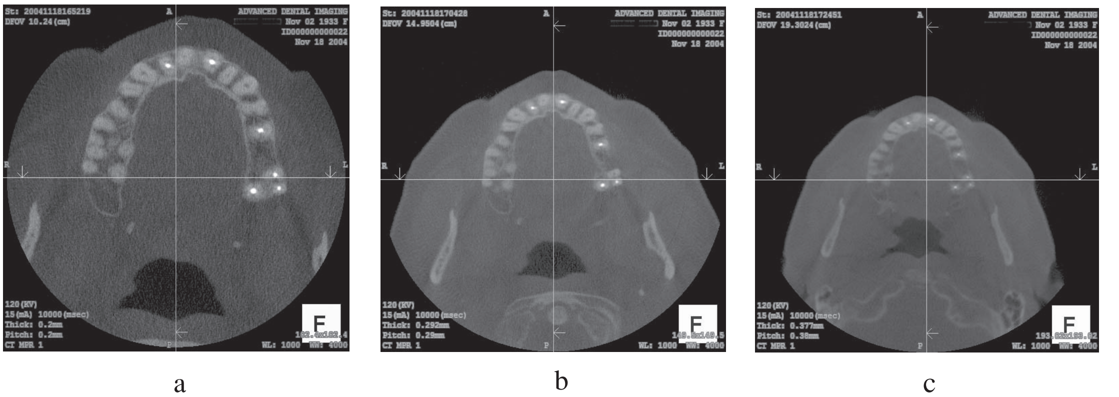
Comparative Features

Scan time

A short scan time is significant in CBCT as even minimal patient movement causes significant degradation of the image quality and detail. This is due to the complex algorithm needed to reconstruct the volume. This is also true of medical CT. Scan times vary as follows: Newtom 3G 30 sec,[3] 3DX Accuitomo 17 or 9 sec,[4] i-Cat 40 sec,[5] MercuRay 9 sec[6] and PSR 9000N 20 sec.[7]

Image size

Image size is important in CBCT depending upon the needs of the practitioner. For example, the MercuRay is capable of scanning the whole head in a 12x12x12 cubic inch volume. This means that cephalometric analyses and other diagnostic studies requiring this image size can be done. Smaller volumes of 5^3, 6^3 and 9^3 cubic inches associated with other machines may be used for studies limited to the teeth, jaws and immediate surrounding structures (Fig. 6). Some examples include TMJ,[8-10] implant[7] and impacted teeth for diagnosis and treatment planning.[11-13]



a b c

Fig. 6 The same patient scanned with three different fields of view (a: 6” FOV, b: 9” FOV, c: 12” FOV)

Spatial resolution

In simple terms, spatial resolution defines the sharpness and detail of imaged structures. It is closely related to the number of pixels contained in one image. In effect, the smaller the pixel size the greater the number of pixels that can be fit into a defined area. This, in turn, results in finer details. The pixel size of CBCT machines varies from 0.125 - 0.4 mm[3] while in medical CT, the smallest pixel size is 0.3 mm.[4]

Bit depth

In simple terms, “bit depth” defines the number of shades of gray in the image. A greater variety of structural details can be distinguished as a result. CBCT machines can acquire images at a bit depth ranging from 8-12 (256-4096 shades of gray). Though the computer screen (monitor) is limited to 256 gray levels, the software is capable of instantly processing the image to the gray level range (wide or narrow) as needed by the operator. This means the practitioner can selectively study soft tissue versus hard tissue details.[3]

Patient position

In most CBCT machines, patients are imaged in the sitting position. However, the NewTom machine is the only CBCT machine configured like a medical CT where the patient is examined in the supine position. This may aid in preventing patient movement. Further, studies such as those relating to airway patency may be more diagnostic when the patient is imaged in the supine position.[3,14]

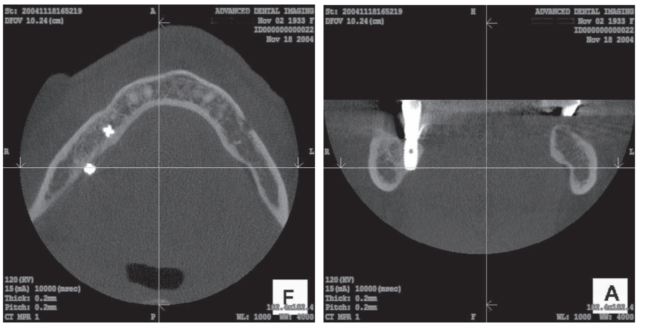
Patient radiation exposure

In CBCT imaging, there is a significant reduction of patient dose as compared to medical CT. Doses range from 50 μSv[15] (Newtom 3G) to 1000 μSv (MercuRay) using the largest volumes.[16] Because of its small volume, the 3DX accuitomo delivers the smallest dose at 7.4 μSv per volume.[17] These doses are 10-30 times less than those used in medical CT acquisitions for the same volumes. With some models of CBCT, the dose is equivalent to as little as those of panoramic radiographs.[15]

Clinical Applications of Cone Beam CT

Anatomical relationships

Cone beam CT is a volumetric technique. Anatomical structures are displayed in their correct relationships with each other free of magnification effects or distortions. Treatment planning requiring accurate assessments of anatomic interrelationships can be done for the first time in dental practice.[2] This CBCT characteristic can be used to enhance the outcomes of treatments such as implant placement (Fig. 7), impacted tooth removal, space analysis relations of pathology to surrounding structures.[18]



a b

Fig. 7 Implant placed in the sublingual fossa (a: Axial view, b: Coronal view)

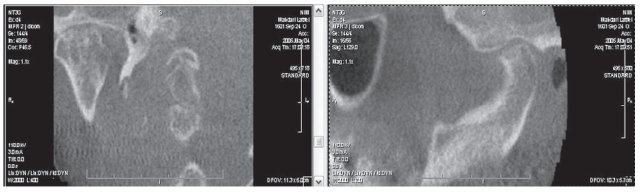
3-D Rendering

In CBCT, all three dimensions are viewed simultaneously. Thus, the height, width, and depth of structures are studied simultaneously[6] and any of these dimensions can be measured on a one to one basis.[18] This gives the practitioner a perspective previously available only in medical imaging systems. 3-D models of structures can be viewed on the monitor and built using 3-D printers such as stereolithography. Such models can be used for surgical treatment planning,[11] orthodontic records[19] and surgical guides for implant placement.

Adjacent regions of special interest

With CBCT, the bony structures of the TMJ are revealed in excellent detail (Fig. 8). Technical difficulties associated with plain film and tomography are overcome.[9,10] The maxillary sinus and nasal fossa are easily studied with respect to the presence of disease of odontogenic and non-odontogentic origin to ultimately enhance the outcome of dental treatments

(Fig. 9). Soft tissue calcifications in the region of the jaws can be more accurately studied. Thus, conditions such as salivary stones, calcified lymph nodes, calcified scar, tonsilloliths, blood vessel wall calcifications, phleboliths and soft tissue osteomas can be localized and studied in detail.



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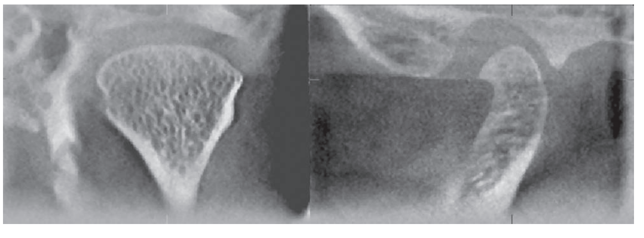

b

Fig. 8 TMJ examinations with CBCT
(a: NewTom 3G, b: Morita Accuitomo)

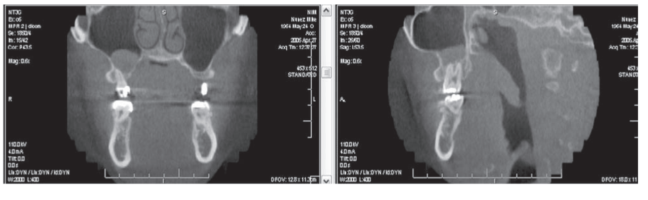

Fig. 9 Mucosistis in the maxillary sinus

References

1. Terakado M, Hashimoto K, Arai Y, Honda M, Sekiwa T, Sato H. Diagnostic imaging with newly developed ortho cubic super-high resolution computed tomography (Ortho-CT). Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;89:509-18.
2. Mengel R, Candir M, Shiratori K, Flores-de-Jacoby L. Digital volume tomography in the diagnosis of periodontal defects: an in vitro study on native pig and human mandibles. J Periodontol. 2005;76:665-73.
3. Danforth RA, Dus I, Mah J. 3-D Volume imaging for dentistry: a new dimension. J Calif Dent Assoc.2003; 31:817-23.
4. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;95: 371-7.
5. Sukovic P, Brooks SL, Clinthorne N. Initial performance mesurments of the first clinical prototype of Dento-CAT TM- a Cone Beam CT scanner for dentomaxillofacial imaging. International Congress. 2003; Series 1256:1221-3.
6. Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRaye): system configuration and phycical properties. Dentomaxillofac Radiol. 2004;33:51-9.
7. Hamada Y, Kondoh T, Noguchi K, Iino M, Isono H, Ishii H, et al. Application of limited cone beam computed tomography to clinical assessment of alveolar bone grafting: a preliminary report. Cleft Palate Craniofac J. 2005;42:128-37.
8. Honda K, Arai Y, Kashima M, Takano Y, Sawada K, Ejima K, et al. 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;33:391-5.
9. Honda K, Larheim TA, Johannessen S, Arai Y, Shinoda K, Westesson PL. Ortho cubic super-high resolution computed tomography: a new radiographic technique with application to the temporomandibular joint. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2001; 91:239-43.

10. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radio graphic examination of the temporomandibular joint using cone beam computed tomography. Dentomaxillofac Radiol. 2004;33:196-201.
11. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. Dentomaxillofac Radiol. 2002; 31:126-30.
12. Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. J Calif Dent Assoc. 2003;31:825-33.
13. Danforth RA, Peck J, Hall P. Cone beam volume tomography: an imaging option for diagnosis of complex mandibular third molar anatomical relationships. J Calif Dent Assoc. 2003;31:847-52.
14. Bianchi SD, Lojacono A. 2D and # 3D images generated by Cone Beam Computed Tomography for dentomaxillofacial investigations. Computer Assisted Radiology and Surgery;1998 June 24-27; Tokyo, Japan.
15. 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;32:229-34.
16. Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton WB. Dosimetry of 3 CBCT units for oral and maxillofacial radiology. 15th International Congress of Dentomaxillofacial Radiology; 2005 May 28-June 2; Cape Town, South Africa.
17. Arai Y, Honda K, Iwai K, Shinoda K. Practical model "3DX" of limited cone-beam X-ray CT for dental use. International congress. 2001; series 1230:713-8.
18. Marmulla R, Wortche R, Muhling J, Hassfeld S. Geometric accuracy of the NewTom 9000 Cone Beam CT. Dentomaxillofac Radiol. 2005;34:28-31.
19. 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.

บทแนะนำโคนบีมคอมพิวท์โทโมกราฟฟีแก่ทันตแพทย์

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บทคัดย่อ

โคนบีมคอมพิวท์โทโมกราฟฟี (โคนบีมซีที) เป็นเทคโนโลยีที่ถูกนำมาประยุกต์ใช้มากขึ้น ด้วยข้อดีหลายประการของเทคโนโลยีนี้ทำให้ถูกนำมาใช้ทางทันตกรรมอย่างรวดเร็วและแพร่หลายทั่วโลก ทุกวันจะมีรายงานถึงการนำโคนบีมซีทีไปประยุกต์ใช้โดยผู้เชี่ยวชาญทางทันตกรรมสาขาต่างๆ หนึ่งในขบวนการพัฒนา คือ การที่ผู้ผลิตกำลังวางแผนผลิตเครื่องรูปแบบใหม่ที่มีรูปลักษณ์ใหม่และหลากหลาย โดยที่ผู้ผลิตใหม่กำลังวางแผนที่จะผลิตเครื่องโคนบีมซีทีเข้าสู่วงการ ขณะที่ผู้ผลิตเก่ายังคงแข่งขันกันในการพัฒนาเครื่องรูปแบบใหม่ การพัฒนาเหล่านี้จะเป็นประโยชน์อย่างยิ่งต่อทันตแพทย์ผู้ใช้เครื่องมือนี้ และที่สำคัญยิ่งกว่า คือ ผู้ป่วยจะเป็นผู้ได้รับประโยชน์สูงสุดจากผลของการพัฒนาเพื่อให้ได้รับการรักษาที่ได้มาตรฐานทางทันตกรรมในสาขาต่างๆ

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คำสำคัญ: *โคนบีมคอมพิวท์โทโมกราฟฟี; ทันตกรรม; ระบบของโคนบีมซีที*
