CONE BEAM COMPUTED TOMOGRAPHY

CONTENTS:

INTRODUCTION

- Two-dimensional imaging modalities have been used in dentistry since the first intraoral radiograph was taken in 1896.
- Significant progress in dental imaging techniques has since been made, including Panoramic imaging and Tomography, which enable reduced radiation and faster processing times.
- However, the imaging geometry has not changed with these commonly used intraoral and panoramic technologies.
- **Cone-beam computed tomography (CBCT)** is a new medical imaging technique that generates 3-D images at a lower cost and absorbed dose compared with conventional computed tomography (CT).
- Initially developed for angiography in 1982 and subsequently applied to maxillofacial imaging.
- This imaging technique is based on a **Cone-shaped X-ray beam** centered on a 2-D detector that performs one rotation around the object, producing a series of 2-D images.
- These **images are reconstructed in 3-D** using a modification of the original cone-beam algorithm developed by **Feld Kamp *et al.* in 1984.**
- Images of the craniofacial region are often collected with a **higher resolution than those collected with a conventional CT.**
- In addition, the new systems are more practical, as they come in **smaller sizes**
- It is only since the late 1990s that it has become possible to produce clinical systems that are both inexpensive and small enough to be used in the dental office.

Four technologic factors have converged to make this possible:

1) The development of compact high quality flat-panel detector arrays
2) Reductions in the cost of computers capable of image reconstruction,
3) Development of inexpensive x-ray tubes capable of continuous exposure and,
4) Limited volume scanning (e.g., head and neck), eliminating the need for sub second gantry rotation speeds.

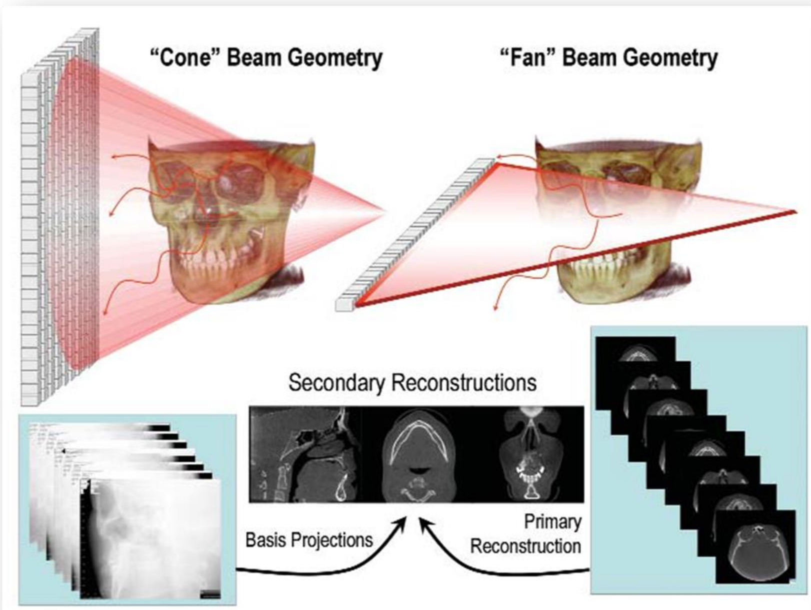
OTHER NAMES

- Dental volumetric tomography, Cone-beam volumetric tomography, Dental computed tomography, and Cone-beam imaging.

BASIC PRINCIPLE OF CBCT

All CT scanners consist of an x-ray source and detector mounted on a rotating gantry. During rotation of the gantry, the receptor detects x rays attenuated by the patient. These recordings constitute "raw data " that is reconstructed by a computer algorithm to generate cross sectional images whose component picture element (pixel) values correspond to linear attenuation coefficients.

CT can be divided into two categories on the basis of acquisition x-ray beam geometry, namely, fan beam and cone beam.



Cone-beam scanners use a two-dimensional digital array providing an area detector rather than a linear detector as CT does. This is combined with a three-dimensional (3D) x-ray beam with circular collimation so that the resultant beam is in the shape of a cone, hence the name " cone beam. " Because the exposure incorporates the entire region of interest (ROI), only one rotational scan of the gantry is necessary to acquire enough data for image reconstruction. Conebeam geometry has inherent quickness in volumetric data acquisition and therefore the potential for significant cost savings compared with CT. CBCT produces an entire volumetric dataset from which the voxels are extracted. Voxel dimensions are dependent on the pixel size on the area detector. Therefore CBCT units in general provide voxel resolutions that are isotropic—equal in all three dimensions.

IMAGE ACQUISITION

The cone-beam technique involves a rotational scan exceeding 180 degrees of an x-ray source and a reciprocating area detector moving synchronously around the patient ' s head. During the rotation, many exposures are made at fixed intervals, providing single projection images known as basis images. These are similar to lateral cephalometric radiographic images, each slightly offset from one another. The complete series of basis images is referred to as the projection data. Software programs incorporating sophisticated algorithms including back-filtered projection are applied to these projection data to generate a 3D volumetric data set that can be used to provide primary reconstruction images in three orthogonal planes (axial, sagittal, and coronal).

There are four components to CBCT image acquisition:

- X-ray generation
- Image detection system
- Image reconstruction
- Image display

X-RAY GENERATION

PATIENT POSITIONING - CBCT can be performed with the patient in three possible positions: sitting, standing, and supine.

X-RAY GENERATOR

- During the scan rotation, each projection image is made by sequential single-image capture of the remnant x-ray beam by the detector.
- **Pulse the x-ray beam** to coincide with the detector sampling.
- This means that actual exposure time is markedly less than scanning time.
- This technique reduces patient radiation dose considerably.
- CBCT exposure factors - adjusted on the basis of patient size.
- Selection of either - **Tube current (milliamperes [mA]),**
  - **Tube voltage (kilovolts peak [kVp]), or both.**
- On some CBCT units both kVp and mA are automatically modulated in near real time by a feedback mechanism detecting the intensity of the transmitted beam, a process known generically as **Automatic Exposure Control** .

- On others, exposure settings are automatically determined by the **initial scout exposure.**

SCAN VOLUME

- The dimensions of the field of view (scan volume) able to be covered are primarily dependent on the Detector size and shape, Beam projection geometry, and Ability to Collimate the beam.

SCAN FACTORS

FRAME RATE - The speed with which individual images are acquired. Measured in frames, projected images, per second.

- Higher frame rates- Increase the signal-to-noise ratio, producing images with less noise. Reduces metallic artifact.

SCAN ARC - 360 degrees to acquire projection data.

SCAN TIME - as short as possible to reduce motion artifact resulting from subject movement.

Increasing the detector frame rate, reducing the number of projections, or reducing the scan arc.

IMAGE DETECTION

- Current CBCT units can be divided into two groups on the basis of detector type:
- **Image intensifier tube/charge-coupled device combination or Fat-panel imager.**

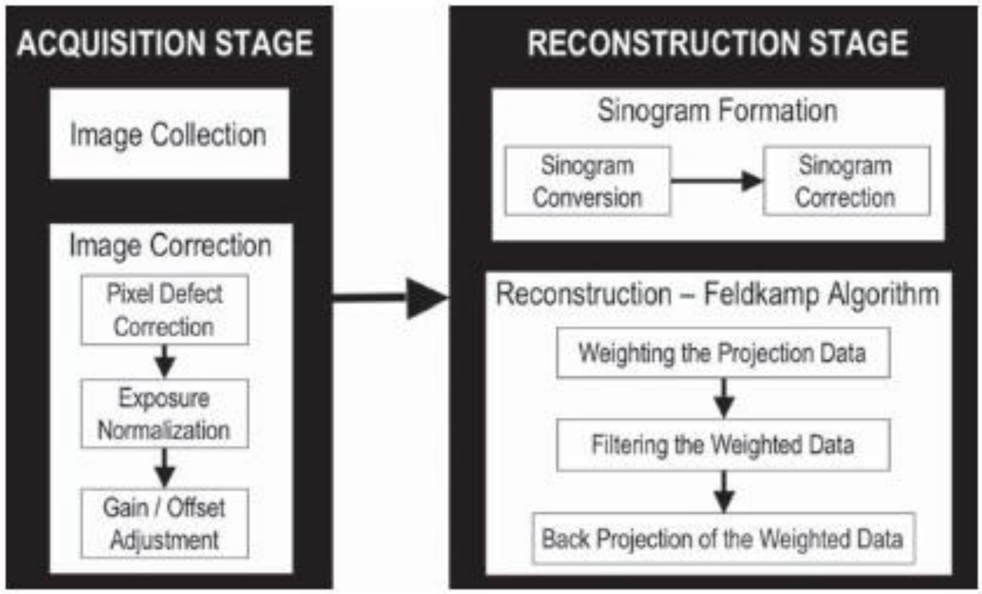
Voxel Size

- Depends on x-ray tube focal spot size, x-ray geometric configuration, and the matrix and pixel size of the solid state detector.

Grayscale

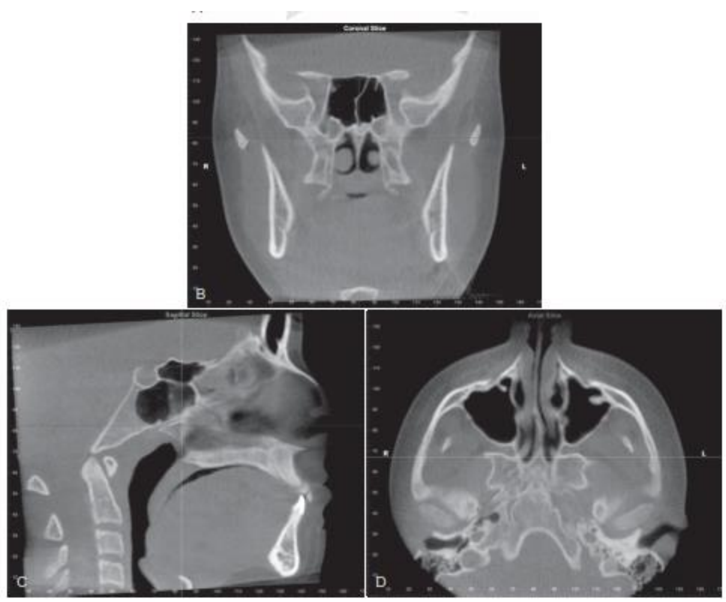
- The ability of CBCT to display differences in attenuation is related to the ability of the detector to detect subtle contrast differences.
- This parameter is called the **" BIT DEPTH"** of the system and **determines the number of shades of gray available to display the attenuation.**
- **12-bit detector** (2^{12}) is used to define the scale, 4096 shades are available to display contrast.

RECONSTRUCTION



DISPLAY

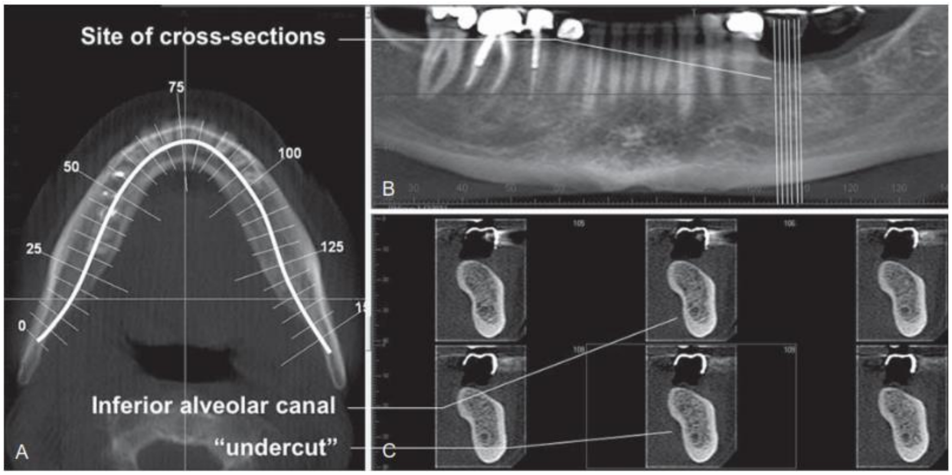
- Displayed as secondary reconstructed images in three orthogonal planes (axial, sagittal, and coronal).



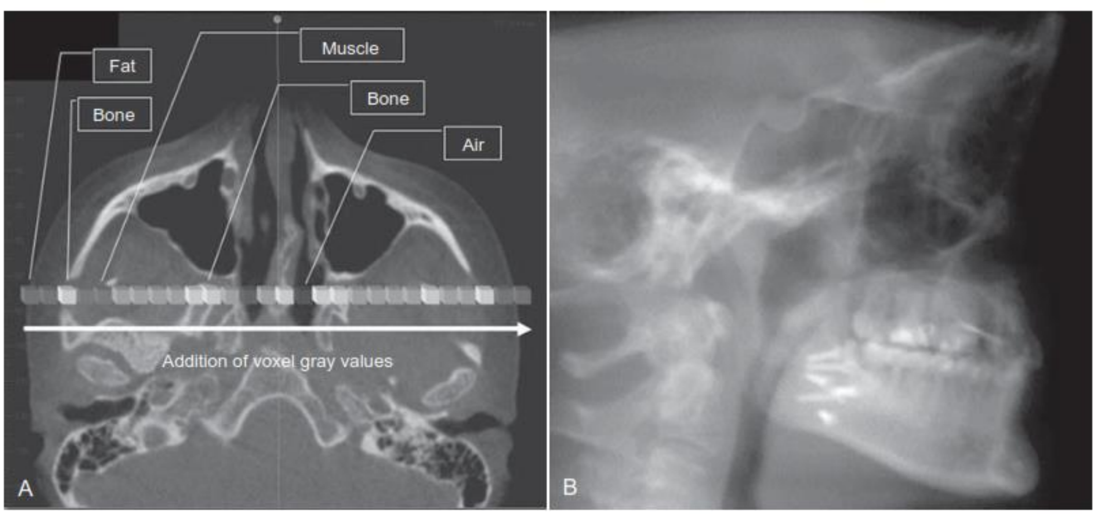
MULTIPLANAR REFORMATION

- Because of the isotropic nature of the volumetric dataset, data sets can be sectioned nonorthogonally. Most software provides for various nonaxial two-dimensional images, referred to as multiplanar reformation (MPR). Such MPR modes include oblique, curved planar reformation and, serial transplanar reformation.

- Because of the large number of component orthogonal images in each plane and the difficulty in relating adjacent structures, two methods have been developed to visualize adjacent voxels.



- Most simply, any multiplanar image can be " thickened" by increasing the number of adjacent voxels included in the display. This creates an image slab that represents a specific volume of the patient, referred to as a RAY SUM . Full-thickness perpendicular ray sum images can be used to generate simulated projections such as lateral cephalometric images . Unlike conventional radiographs, these ray sum images are without magnification and parallax distortion. However, this technique uses the entire volumetric data set and interpretation suffers from the problems of " anatomic noise " — the superimposition of multiple structures.



THREE-DIMENSIONAL VOLUME RENDERING

- Volume rendering refers to techniques that allow the visualization of 3D data by integration of large volumes of adjacent voxels and selective display. Two specific techniques are available.

- Indirect volume rendering is a complex process requiring selection of the intensity or density of the grayscale level of the voxels to be displayed within an entire data set (called “ segmentation ”). This is technically demanding and computationally difficult, requiring specific software; however, it provides a volumetric surface reconstruction with depth.

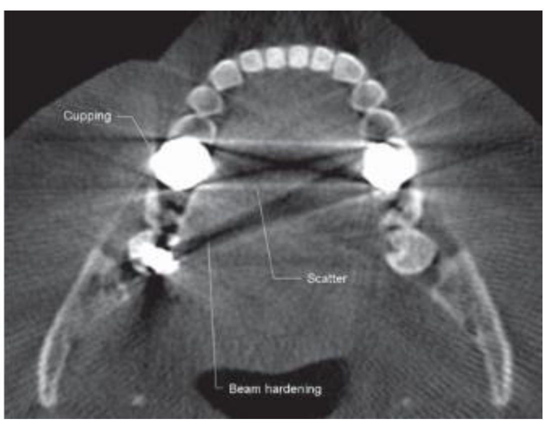
- Direct volume rendering is a much simpler process. The most common technique is maximum intensity projection (MIP). MIP visualizations are achieved by evaluating each voxel value along an imaginary projection ray from the observer’s eyes within a particular volume of interest and then representing only the highest value as the display value. Voxel intensities that are below an arbitrary threshold are eliminated.

IMAGE ARTIFACTS

An image artifact may be defined as a visualized structure in the reconstructed data that is not present in the object under investigation.

ACQUISITION ARTIFACTS

Artifacts can arise from limitations in the physical processes involved in the acquisition of CBCT data. As an x-ray beam passes through an object, lower energy photons are absorbed in preference to higher energy photons. This phenomenon, called beam hardening, results in two types of artifact: (1) distortion of metallic structures as a result of differential absorption, known as a cupping artifact, and (2) streaks and dark bands that can appear between two dense objects. In clinical practice it is advised to reduce the field size, modify patient position, or separate the dental arches to avoid scanning regions susceptible to beam hardening (e.g., metallic restorations, dental implants).



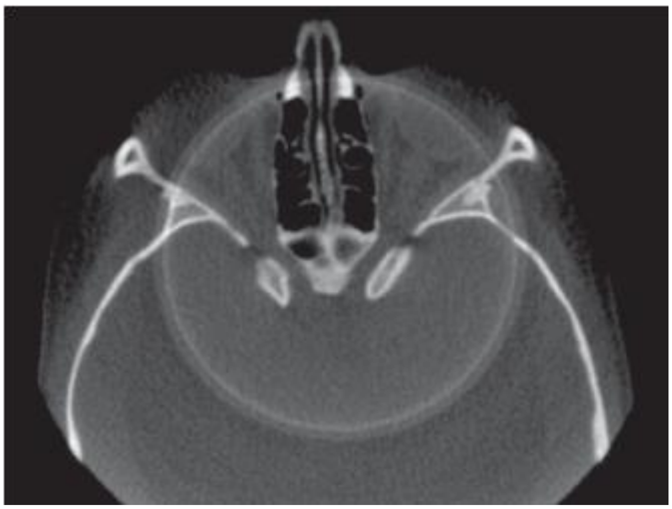
PATIENT-RELATED ARTIFACTS

- Patient motion can cause misregistration of data, which appear as unsharpness in the reconstructed image.

- This can be minimized by restraining the head and using as short a scan time as possible.
- It is also important to remove metallic objects such as jewelry before scanning because of the beam-hardening artifacts described previously.

SCANNER-RELATED ARTIFACTS

Typically scanner-related artifacts present as circular or ring streaks resulting from imperfections in scanner detection or poor calibration. Either of these problems will result in a consistently and repetitive reading at each angular position of the detector, resulting in a circular artifact.



CONE BEAM – RELATED ARTIFACTS

The beam projection geometry of CBCT and image reconstruction method produce three types of cone-beam – related artifacts:

PARTIAL VOLUME AVERAGING

- Occurs when the selected voxel size of the scan is larger than the size of the object being imaged.
- For instance, a voxel 1 mm on a side may contain both bone and adjacent soft tissue.
- In this case, the displayed pixel is not representative of either bone or soft tissue but rather becomes a weighted average of the different brightness values.
- Partial volume averaging artifacts occur in regions where surfaces are **rapidly changing in the z direction, for example, in the temporal bone.**

UNDERSAMPLING

- Occur when too few basis projections are provided for image reconstruction.
- A reduced data sample leads to misregistration, sharp edges, and noisier images as a result of aliasing, which appear as fine striations in the image .
- Because increasing the number of basis projections is proportional to patient exposure, the importance of this artifact should be considered in relation to the diagnostic information.

CONE BEAM EFFECT

- 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, structures at the top or bottom of the image field will only be exposed when the x-ray source is on the opposite side of the patient.
- This results in image distortion, streaking artifacts, and greater peripheral noise.
- This effect is minimized by manufacturers incorporating various forms of cone-beam reconstruction.
- Clinically it can be reduced by positioning the region of interest in the horizontal plane of the x-ray beam.

STRENGTHS OF CBCT

- **Size and Cost**
- **High-Speed Scanning-** less than 30 seconds.
- **Submillimeter Resolution-** 0.4 mm to as low as 0.125 mm (bone trabeculae, Periodontal ligament, root formation)
- **Low Patient Radiation Dose- Pulsed beam, FOV**
  52 to 1025 microsieverts (μ Sv).
- **Interactive Analysis-** CBCT data reconstruction and viewing – personal computer.
  Specific applications- implant placement or orthodontic analysis.
  Cursor-driven measurement algorithms provides the practitioner with an interactive capability for real-time dimensional assessment, annotation, and measurements.

LIMITATIONS OF CBCT

- Increased noise from scatter radiation and concomitant loss of contrast resolution
- Low soft tissue contrast
- Limited detector size causes limited field of view and limited scanned volume
- Streak artifacts from metal restorations.
- Image degradation from patient movement.
- Cost.
- Training.
- Can not be used for estimation of Hounsfield units (HU)
- Typical doses of various dental radiological procedures.

APPLICATIONS

IMPLANT PLANNING

- DICOM data can be imported into third-party software applications that provide many useful tools that can be used to assess and plan both the surgical and prosthetic components of implant therapy.
- In addition, the data set may then be used to construct a surgical implant guidance stent to facilitate the precise placement of implants.

ORTHODONTICS & THREE-DIMENSIONAL CEPHALOMETRY

LOCALIZATION OF THE INFERIOR ALVEOLAR CANAL

TEMPOROMANDIBULAR JOINT

- CBCT provides Multiplanar and potentially 3D images of the condyle and surrounding structures.
- Imaging can depict the features of degenerative joint disease, developmental anomalies of the condyle, ankylosis, and rheumatoid arthritic disease.
- Imaging protocols- reformatted panoramic and axial reference images, corrected parasagittal and paracoronal transerial slices, and for those cases in which asymmetry or surgery is contemplated, 3D reconstructions.

PERIODONTICS

- As accurate as direct measurements using a periodontal probe.

ENDODONTICS

- **Visualization of canals**

CONDITIONS OF THE MAXILLOFACIAL COMPLEX

- CBCT can assist in the assessment of
- Impacted canines and supernumerary teeth,
- Fractured or split teeth,
- Periapical lesions, and Periodontal disease
- Benign calcifications (e.g., tonsilloliths, lymph nodes, salivary gland stones, phleboliths)
- Extent and degree of involvement of osteomyelitis.
- Location, size, shape, extent, and full involvement of jaw conditions.
- Although CBCT does not provide suitable soft tissue contrast to distinguish the contents of paranasal opacifi cations, the morphologic characteristics and extent of these lesions are particularly well seen (e.g., mucous extravasation cyst).
- **Dentigerous cyst**
- **Salivary calculi**
- **Cleft palate**

RAPID PROTOTYPING

- Rapid prototyping (RP) is broad term used to describe a group of related processes and techniques that are used to fabricate physical scale models directly from 3D computer-assisted design data.
- In maxillofacial imaging - create a life-size, dimensionally accurate model of an anatomic structure.
- These models are also referred to as biomodels .
- **Used for presurgical planning** of a number of complex maxillofacial surgical cases, including **craniofacial reconstruction for correction of deformity caused by trauma, tumor resection, distraction osteogenesis, and, more widely, dental implants .**

- The models provide the practitioner with a higher level of confidence before he or she performs a surgical procedure and may reduce surgical and anesthetic time.

CONCLUSION

CBCT imaging systems have been recently been introduced for imaging hard tissues of the maxillofacial region. CBCT is capable of providing accurate, sub millimeter resolution images at shorter scan times, lower dose, and lower costs compared with medical fan-beam CT. Increasing availability of this technology provides the practitioner with an imaging modality capable of providing a 3D representation that is extending maxillofacial imaging from diagnosis to image guidance of operative and surgical procedures.