Essential guidelines for using cone beam computed tomography (CBCT) in implant dentistry. Part 1: Technical considerations

Johan Hartshorne[1]

Summary

The development of inexpensive x-ray tubes, high-quality detector systems and powerful personal computers has paved the way for commercially available and affordable 3D CBCT imaging systems for the dental practice. The purpose of Part 1 of this series is to provide clinicians with an overview of the technical considerations relating to: (i) the basic elements of CBCT hardware, (ii) types and characteristics of different CBCT units, (iii) the fundamental principles of the CBCT imaging workflow chain, (iv) the benefits and limitations of incorporating a CBCT unit into your practice, and (v) to provide some guidelines and recommendations on what factors must be considered when purchasing a CBCT unit. These technical considerations will enhance the practitioners understanding of the fundamental principles required for safe and effective use of this technology. CBCT technology is increasingly being introduced into the dental practice setting due to its invaluable diagnostic and communication capabilities, high quality and accurate images, easy to use, and very suitable for the dental office setting.

Introduction

Intra-oral and extra-oral two-dimensional (2D) radiographic imaging procedure (periapical, lateral cephalometric, and panoramic), traditionally used for pre-operative dental implant diagnostics and treatment planning, suffer from the same inherent limitations common to all planar 2D projections namely, magnification, distortion, superimposition, and misrepresentation of structures.[1] Although numerous efforts have been made towards developing three-dimensional (3D) radiographic imaging (e.g., stereoscopy, tuned aperture computed tomography (TACT), and multi-detector computed tomography (MDCT), the use of these advanced CT imaging techniques have been unavailable or limited for most dental practitioners because of cost, physical complexity and size, and high radiation dose considerations.1 The development of inexpensive xray tubes, high-quality detector systems and powerful personal computers have paved the way for commercially available and affordable 3D CBCT imaging systems, small enough to be used in dental practice.[2]

Since CBCT's introduction for the maxillofacial region by Italian co-inventors Attilio Tacconi and Piero Mozzo in 1998, CBCT imaging has become an important and established diagnostic tool for the clinical assessment and treatment planning of patients needing dental implants.[3-5] The value of CBCT imaging as a diagnostic tool has also

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Figure 1: Basic elements of CBCT imaging hardware – X-ray source on the left, Image detector or sensor on the right, and the gantry or rotating platform that connects the x-ray source and the detector.

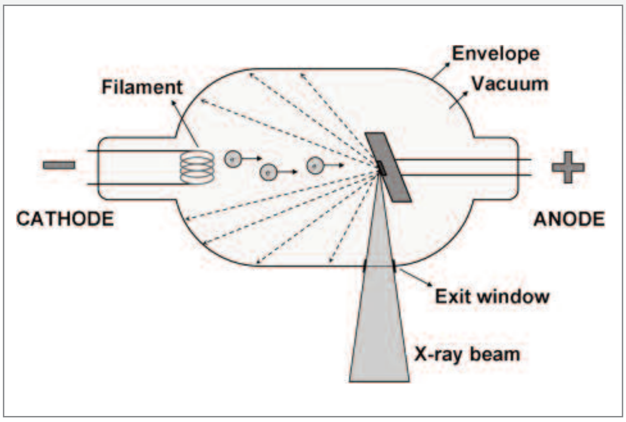

Figure 2: Basic elements of a CBCT X-ray source.

been reported for various other fields of dentistry such as oral-maxillofacial surgery, dental traumatology, endodontics, temporo-mandibular joint, periodontology, orthodontics and forensic odontology.[1,6]

The widespread use of CBCT scanners however, has resulted in several concerns for clinicians regarding: (i) indications, justification and optimization of CBCT exposures; (ii) training to optimize safe and effective use of CBCT in the clinical setting; and (iii) quality assurance of CBCT scanners. It is therefore important for clinicians to have a full understanding of the technical principles of dental CBCT imaging in order to purchase the correct machine, and using it correctly and effectively to reap the full benefit of this technology, whilst minimizing radiation-related patient risk.[7]

Purpose

The purpose of Part 1 of this series is to provide clinicians with an overview of the technical considerations relating to: (i) The basic elements of CBCT hardware; (ii) Types and characteristics of different CBCT units; (iii) The fundamental principles of the CBCT imaging workflow chain; (iv) The benefits and limitations of incorporating a CBCT unit into your practice; and (v) To provide some guidelines and recommendations on what factors must be considered when purchasing a CBCT unit.

What are the nuts and bolts of CBCT imaging hardware?

CBCT Imaging hardware consists of three basic elements: (i) an x-ray source (x-ray generator), (ii) an image detector (sensor), and (iii) a gantry (C-arm or rotating platform) that connects the x-ray source and the detector. (Fig. 1)

(i) X-ray source

An X-ray beam is generated in a tube containing an electrical circuit with two oppositely charged electrodes (i.e. a cathode and anode) separated by a vacuum (Fig. 2). The cathode is composed of a filament that gets heated when an electric current is applied, inducing the release of electrons through an effect known as thermionic emission. Because of the high voltage between the cathode and anode, these released electrons will be accelerated towards the anode, colliding with it at high speeds at a location called the focal spot. Ideally, this focal spot is point sized, but typical focal spots in CBCT are 0.5-mm wide; the size of the focal spot is one of the determinants of image sharpness.[8] The energy generated through this collision are mainly lost as heat, but a small part is converted into X-rays through an effect known as Bremsstrahlung. X-rays are emitted in all directions, but absorption within the anode and the tube housing results in a beam emerging from the tube perpendicular to the electron beam. The anode surface is slightly tilted in order to maximize the outgoing X-ray beam through the exit window of the tube.[8] A lead-alloy collimator is used to block X-rays that are not passing through the scanned volume or region of interest (ROI), thus reducing patient exposure. Most CBCT systems have multiple pre-defined field-of-view (FOV) sizes, so a collimator will have several pre-defined openings according to the FOV sizes.[8] Thus collimation of the x-ray beam by adjustment of the FOV limits the radiation to the ROI only. Furthermore, collimation defines the width and height of the primary x-ray beam and therefore the size of the reconstructed FOV.

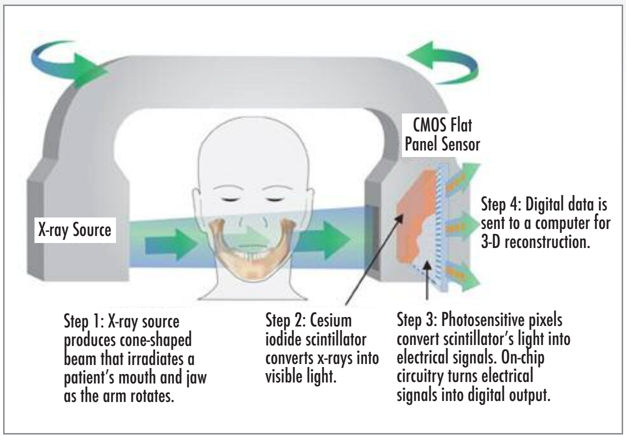

Figure 3: Conversion of in-coming X-ray photons to an electrical signal by the image detector.

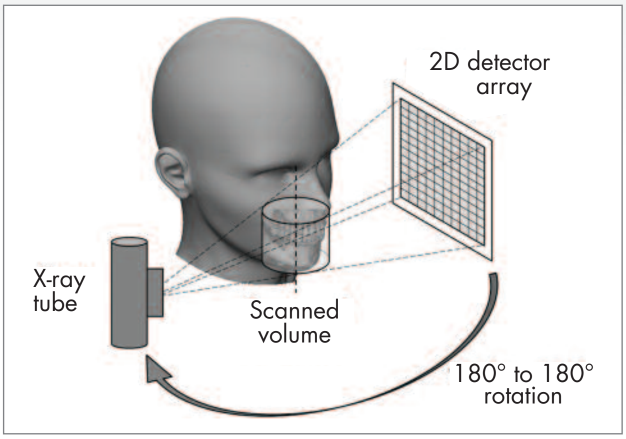

Figure 4: The x-ray source and reciprocating image detector synchronously moves 180° to 360° around the patients head.

The cone-shaped X-ray beam has two primary characteristics: quality and quantity. X-ray beam quality refers to the overall energy of the photons in the x-ray beam. Factors that affect (increase or decrease) X-ray beam quality are peak kilo voltage (kVp), filtration and the type of waveform used. X-ray beam quantity on the other hand refers to the number of photons in the x-ray beam. When the number of photons increases, beam intensity increases, thus affecting X-ray beam quantity. X-ray beam quantity is affected by change in tube anode current (mAs), kVp, filtration and changes in distance from the tube. Beam hardening refers to the process in which the quality (energy) of an x-ray beam is increased by removing lower energy photons with appropriate filtration. Exposure can be controlled either automatic or manual adjustment of kVp or mAs.

(ii) Image Detector

X-ray detectors convert the incoming X-ray photons to an electrical signal and are therefore a crucial component of the imaging chain (Fig. 3). There are basically two types image detectors (also referred to as 'sensors') used in contemporary CBCT units. A scanner will have either a charge-coupled device with a fiber-optic image intensifier detector (IID), or an amorphous silicon flat-panel detector (FPD). During the initial introduction of CBCT, most units were constructed with the large, bulky image-intensifier detectors. Currently, most CBCT scanners have nearly all transitioned to the smaller, flat panel linear array detectors.[9] Besides being less bulky and having a smaller footprint, the flat panels have minimal distortion of the image dimensions at the periphery of an image display; have a higher dose efficiency, a wider dynamic range and can be produced with either a smaller or larger FOV[8] hence, these units are considered to generate better data volume sets.

(iii) Gantry

Most dental CBCT systems have a fixed C-shaped rotating platform or gantry with the X-ray source and the image detecto r mounted on opposite sides of the C-arm or gantry. (Fig. 4) During a CBCT scan, the C-arm or gantry performs a partial (180°) or full rotation (360°) around the patients' head in which the x-ray source and the reciprocating area detector synchronously move around the patient's head. (Fig. 4) Some CBCT devices offer the opportunity to select a partial rotation (180°) with a reduction of radiation dose to the patient[8] The patients' head is stabilized during the rotation process with a head restraint device, while capturing multiple 2-D images at different intervals, also known as "basis" images of the FOV. These series of basis images are referred to as the projection data or data volume.[8] The head restraint mechanism (Fig. 5) is used to minimize movement and to limit motion artifacts during the 3-D scanning process.[1]

Types of CBCT machines

There are several different dental CBCT machines that vary in their design, footprint, detector configurations and protocol selection features.

CBCT machines can be categorized according to: (i) orientation of the patient during image acquisition (i.e. sitting, standing or supine) (Fig. 6); or (ii) the scan volume, also referred to as the FOV irradiated.[1] (Fig.7)

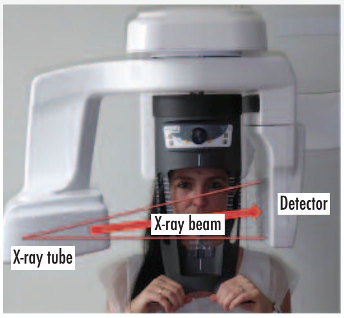

Figure 5: Head restraint mechanism to minimize movement and limit motion artefacts during the 3-D scanning process.

Figure 6: Different types of CBCT units categoprized according to orientation of the patient during image aquisition: Left: Seated patient position; Middle: Standing patient position; Right: Supine patient position.

a. CBCT machines based on patient orientation during image acquisition

There are three different types of CBCT gantries that can scan patients in three different positions (Fig. 6): (i) seated patient position (i.e. 3D Accuitomo® , J. Morita, Kyoto, Japan; Promax 3D, Planmeca, Qy, Helsinki, Finland; Kavo 3D Kavo dental GmbH Bismarckring, Germany); Galileos, Dentsply Sirona, Bensheim, Germany; (ii) standing patient position (i.e, Carestream CS9300, Kodak Dental Systems, Carestream Health, Rochester NY, USA.; WhiteFox®; Acteon Group, Mérignac, France); and (iii) supine patient position (i.e. NewTom 3G, Quantitative Radiology, Verona, Italy) Each have there own advantages and disadvantages. Scanners allowing for standing patient positioning, are usually more accommodating for wheelchairs (Fig. 8), and occupy no more space than a panoramic radiography device. However, some standing units may not be able to be adjusted to a height to accommodate wheelchair-bound patients. Seated units on the other hand are the more comfortable. However, fixed seats may not allow scanning of physically disabled or wheelchair-bound patients. Additionally, scanners with a built-in chair or table occupy a larger space. CBCT-scanners that require the patient to lie supine physically occupy a larger surface area or physical footprint and may not be accessible for patients with physical disabilities.

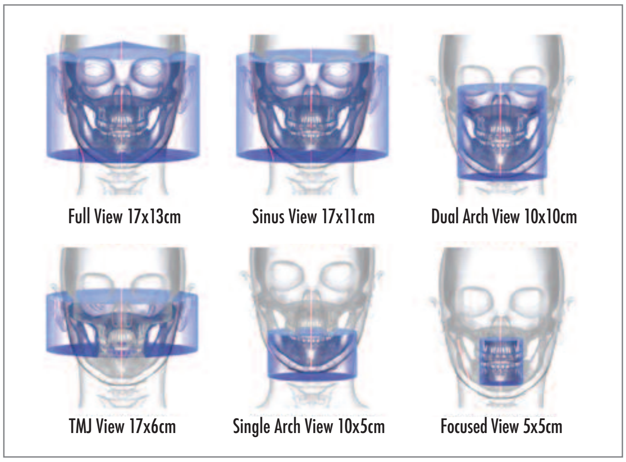

Figure 7: CBCT units can also be categorized according to scan volume or field of view (FOV) irradiated.

b. CBCT systems based on scan volume or FOV

CBCT machines can also be categorized according to the available FOV or selected scan volume height as follows (Fig. 7):

- Localized region: approximately 5 cm or less (e.g., dentoalveolar, temporo-mandibular joint)
- Single arch: 5 cm to 10 cm (e.g., maxilla or mandible)
- Interarch: 7 cm to 10 cm (e.g., mandible and superiorly to include the inferior concha)
- Maxillofacial: 10 cm to 15 cm (e.g., mandible and extending to Nasion)
- Craniofacial: greater than 15 cm (e.g., from the lower border of the mandible to the vertex of the head)

The FOV is an important parameter that defines a CBCT imaging protocol. It represents collimation of the beam size to a predetermined area. Adjusting the FOV determines the size of anatomic coverage, image resolution and patient radiation dose. In general, clinicians should select the smallest FOV that provides adequate anatomic coverage and adequate image resolution.[10] For most units, a smaller FOV is acquired using a smaller voxel size, and thus, has higher spatial resolution. Additionally, the reduced scatter radiation with a smaller FOV also contributes to improved image quality. Typically, the radiation dose decreases with

Figure 8: Scanners allowing for standing patients are usually more accommodating for wheelchairs.

a smaller FOV size.[11] FOV limits depend on the detector size and shape, beam projection geometry and the ability to collimate or not. It is desirable to limit the FOV to the smallest volume that can accommodate the region of interest.

How does the image workflow of a 3-D CBCT scanner work?

CBCT image production workflow consists of four stages: (1) acquisition, (2) detection, (3) reconstruction, and (4) display of the image.[1] (Fig. 9)

1. Acquiring the scan

Depending on the type of cone beam imaging system used, the subject may be positioned in a standing, sitting or supine position, with the head or area of interest placed at the center of the CBCT system. Upon situating the patient in place, the patient's head is stabilized with a restraint mechanism and chin rest, to minimize movement during the scanning process. The frame rate, speed of rotation, FOV and completeness of the trajectory arc are set manually or automatically to get the image desired by the dental practitioner.

The x-ray source produces a cone-shaped beam of ionizing radiation that passes through the center of the ROI in the patients' head to the x-ray detector on the other side. A single partial (180°) or full rotational (360°) scan from the X-ray source takes place while the reciprocating detector moves synchronously with the scan around a fixed fulcrum within the region of interest (ROI).[1]

This fulcrum acts as the centre of the final acquired volume imaged. During the scan rotation each projection image is made by sequential image capture of the attenuated x-ray beam by the detector.[1] Whilst rotating, the x-ray source emits radiation in a continuous or pulsed mode allowing 2-D projection radiographs or "basis images".[1] In a single rotation, the detector can generate between 150 to 600 high-resolution 2-D basis images.[8] The series of basis images are referred to as the projection data. Typical rotation times range between 10 and 40 s, although faster and slower scan protocols exist.

Technically, the easiest method of exposing the patient is to use a continuous beam of radiation during the scan rotation and allow the x-ray detector to sequentially sample or capture single images of the attenuated x-ray beam in its trajectory. However, continuous radiation emission does not contribute to the formation of the image and results in greater radiation exposure to the patient.[9] In most contemporary units the x-ray beam exposure is pulsed to coincide with the detector sampling. Pulsed x-ray beam exposure at intervals allows that there is time between basis-image acquisition for

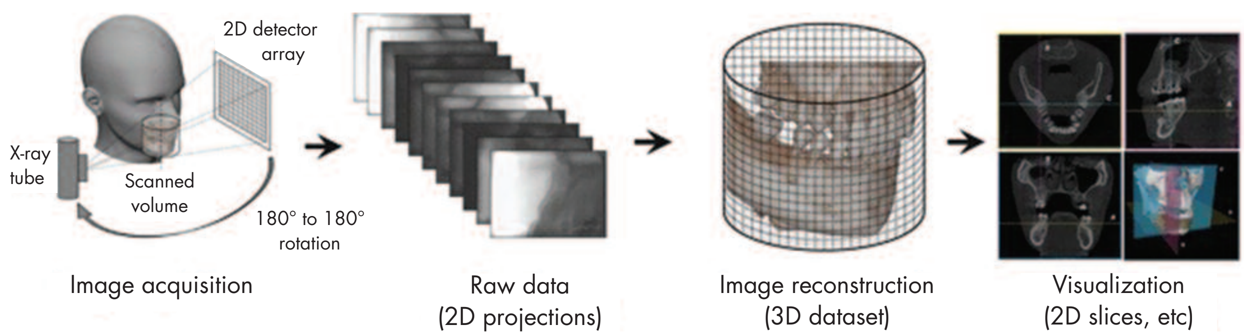

Figure 9: Image workflow stages of a 3D CBCT scanner.

the signal to be transmitted from the detector area to the data-storage area and the detector to rotate to the next site or angle of exposure. Hence, the x-ray tube does not generate x-rays for the entire rotational cycle, and which means that actual radiation exposure time is markedly less than scanning time.[9] The total scan time is equivalent to exposure time where the x-ray tube allows only continuous exposure. In comparison, CBCT scanners using pulsed exposure the exposure time is markedly less than the scan time. Thus, pulsed X-ray beam generation is preferable as it results in less radiation dosage to the patient. Pulsed x-ray beam exposure is a major reason for considerable variation in reported cone-beam unit dosimetry.[1]

Depending on the mAs, a 180° rotation protocol can lead to a slight or more pronounced increase in noise than in a 360° protocol. A partial rotation (180°) and reduced sampling associated with shorter scan time tends to decrease overall image quality due to the amount of noise associated with reduced mAs.[8] More projection data from a 360° rotation protocol provides more information to reconstruct the image; allow for greater spatial and contrast resolution; increase the signal-to-noise ratio, producing ''smoother'' images; and reduce metallic artifacts. However, more projection data usually necessitate a longer scan time, a higher patient dose, and longer primary reconstruction time. In accordance with the ''as low as reasonably achievable'' (ALARA) principle, the number of basis images should be minimized to produce an image of diagnostic quality.[1]

2. Detecting the image

During scan rotation, a divergent pyramidal or cone-shaped source of ionizing radiation is directed through the middle of the ROI (fulcrum) and the transmitted attenuated radiation is projected onto the detector on the opposite side (Fig. 4). The X-ray source emits x-ray photons. The scintillator in the detector absorbs the x-ray photons and converts them into light. The photodiode array in the amorphous silicon panel absorbs the light and converts it into an electronic charge.[8] Each photodiode represents a pixel or 2-D picture element. (Fig.10) The electronic charge at each pixel is read out by low-noise electronics to provide digital data. This data is then transmitted to and collected at a dedicated computer.

The pixel size of the detector is the principle determinant of the voxel size (3-D picture element) (Fig.10). Detectors with small pixel size capture fewer x-ray photons per voxel; and result in more noise. In CBCT, pixel size can vary from .12 mm to .4 mm. The lower pixel-size image takes more exposure time (20 to 40 seconds) and more radiation. It is very susceptible to movement distortion. Thus, even though small pixel-size images lend more definition to smaller object areas, the risk of movement distortion makes it impractical for most applications. Therefore, imaging subtle pathology such as caries, root fractures, or periodontal bone loss is not practical due to movement-related distortion.

3. Reconstructing the image

In a single rotation, the detector can generate anywhere between 150 to 600 high-resolution 2-D basis images.[2] The basis images, each with more than one million pixels with 12 to 16 bits of data assigned to each pixel, is transferred to a processing computer (work station) for reconstruction using software programs incorporating sophisticated algorithms (FDK algorithm) including back filtered projection to construct a 3D image, also known as a volumetric data set.[2] The most widespread form of 3-D filtered back projection used in CBCT uses the Feldkamp–Davis–Kress (FDK) algorithm.[8] Reconstruction time is usually less than 3 minutes for standard resolution scans.[1] Reconstruction time is usually dependent on the quality of the software and computer hardware. Once the basis images are reconstructed they can be recombined into a single digital 3-D image or volumetric data set for visualization by the clinician.

The voxel is the smallest individual volume element in the 3-D environment and determines the spatial resolution of the image (Fig. 10). They are cubic in nature and equal in all dimensions (isotropic). When viewed as a digital image, the pixel size controls the resolution. The smaller pixel size yields a higher resolution image, and conversely, the larger the pixel size, the lower the resolution or quality of the image. More projection data provide more information to reconstruct the image; allow for greater spatial and contrast resolution;

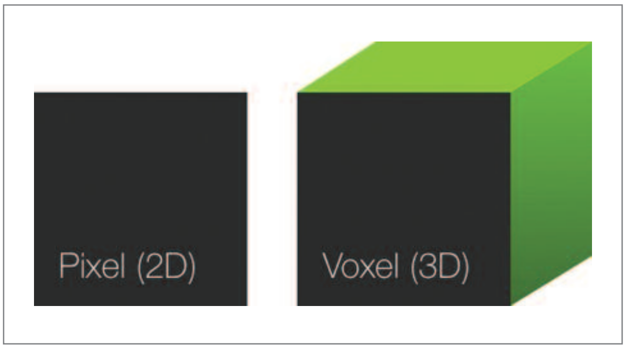

Figure 10: Pixel is the basic 2D basis image picture element, whilst a voxel is 3D picture element and thus represents the smallest individual volume element of a 3D scan.

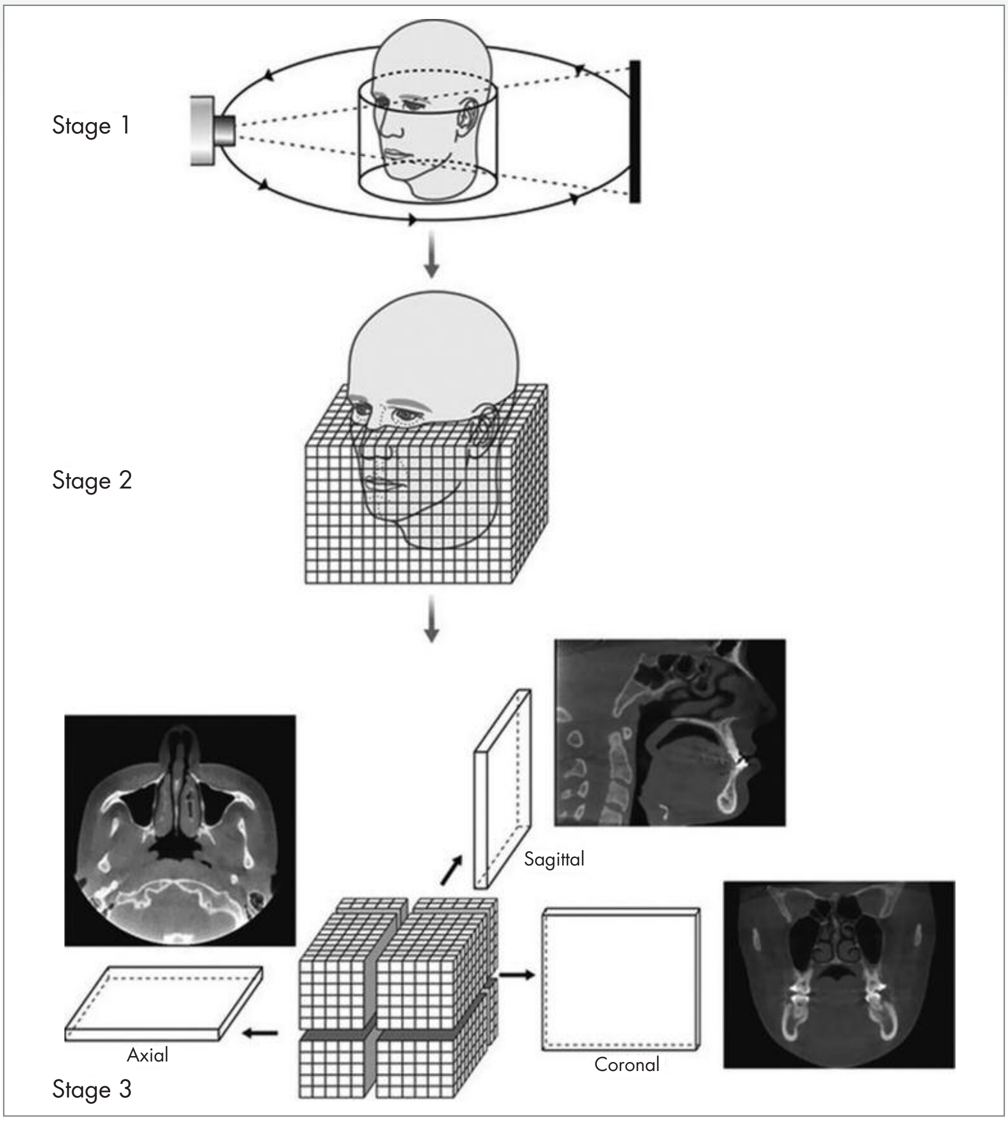

Figure 11: The 3D volumetric data set is a compilation of all available voxels presented to the clinician (Stage 2) and presented to the clinician in real time on screen as secondary reconstructed 2-D cross sectional images in three orthogonal planes (axial, sagittal and coronal) (Stage 3).

increase the signal-to-noise ratio, producing "smoother" images; and reduce metallic artifacts. However, more projection data usually necessitate a longer scan time, a higher patient dose, and longer primary reconstruction time. In accordance with the "as low as reasonably achievable" (ALARA) principle, the number of basis images should be minimized to produce an image of diagnostic quality.[1]

4. Displaying and manipulating the image

CBCT technology provides a complete digital model at the end of the process. The software also provides the dental clinician with a relatively large choice of display formats, allowing for 2-D, 3-D and panoramic views of the mouth and head, along with other viewing options to help focus in on areas of interest.

The default presentation of the 3-D volumetric data set is a compilation of all available voxels and presented to the clinician in real time on screen as secondary reconstructed 2-D cross-sectional images in three orthogonal planes (axial, sagittal and coronal) for visualization and manipulation. (Fig.

11) Axial planes are a series of slices from top to bottom in the volume. Sagittal planes are a series of 2D slices from left to right, and coronal planes are a series of 2-D slices from anterior to posterior (front to back). Each panel of the display software presents one of a series of contiguous images in that plane. Each image is inter-relational such that the location of each image in the sequence can be identified in the other two planes.

CBCT data should be considered as a volume to be explored from which selected images are extracted. Technically, four stages are recommended to provide an efficient and consistent systematic approach to optimize CBCT image display before interpretation namely: (a) reorientation; (b) optimization; (c) viewing; and (d) formatting the data.

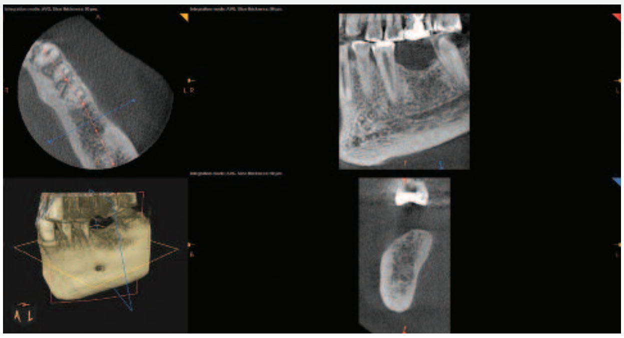

Figure 12: The volumetric data can be re-orientated so that the region of interest are realigned symmetrically in three orthogonal planes: Axial or horizontal plane (top to bottom views) (upper left); Sagittal (right to left or mesial to distal) (upper right); Coronal or frontal plane (front to back) (buccal to lingual) (lower right); and 3D rendering is lower left) for real time visual and dimensional assessment.

a. Reorientation of the data

One of the advantages of CBCT is that the resultant volumetric data set can be reoriented in all three planes using PC-based software. Initial adjustment of the volumetric data set should include reorientation, such that the patient's anatomic features are realigned symmetrically according to three orthogonal reference planes, namely: axial or horizontal plane (top to botom cross sections), coronal or frontal plane (front to back crosss section), and sagittal plane (right to left or buccal to lingual cross sections). (Fig. 12) This stage is particularly important for aligning subsequent cross-sectional, transaxial images perpendicular to the structure of interest, such as to visualize single tooth pathology, or to measure the maximal height and width of the residual alveolar ridge in an edentulous segment for implant site assessment.

Data can be reoriented so that the patients' anatomic features are realigned. Cursor-driven measurement algorithms provide the clinician with an interactive capability for real-time dimensional assessment and pre-implant treatment planning in all three planes. On screen measurements provide dimensions free from distortion and magnification. Basic image enhancement includes magnification.

b. Optimize the data

Great variability can exist in the overall density and contrast of orthogonal images between CBCT units and within the

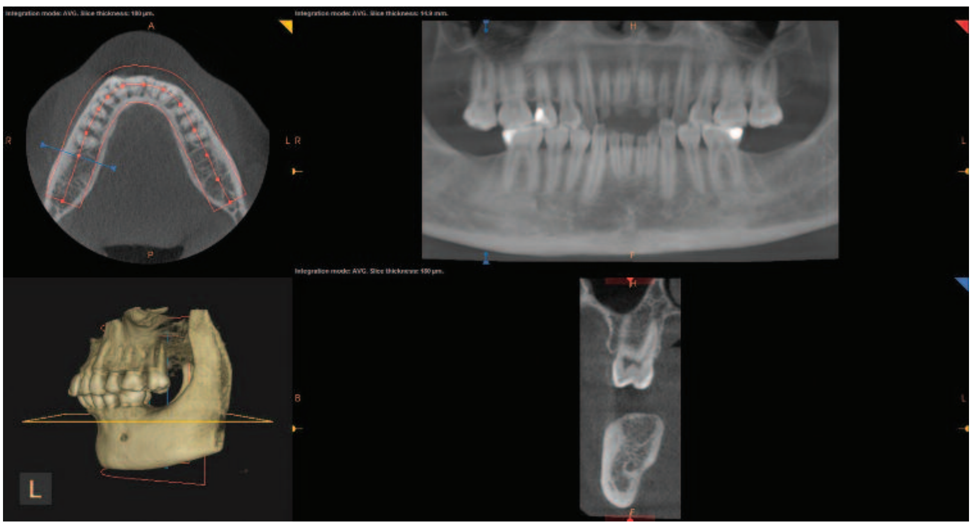

Figure 13: Ray sum image (upper right) and Volume rendering image (Lower left).

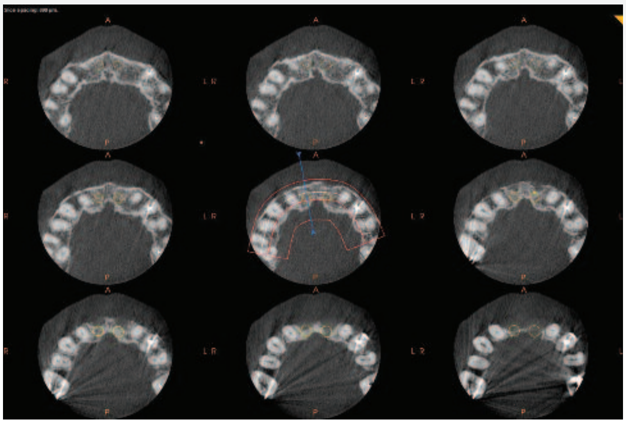

Figure 14: Example of Serial trans-axial images.

same unit depending on patient images and scan parameters selected. Therefore, to optimize image presentation and to facilitate diagnosis, it is often necessary to adjust contrast (window) and brightness (level) parameters to favor bony structures. Although CBCT proprietary software may provide for window and level presets, it is advisable that these parameters be optimized for each scan. After these parameters are set, further enhancements can be performed by the application of sharpening, filtering, and edge algorithms. The use of these functions must be weighed against the visual effects of increased noise in the image. After these adjustments, secondary algorithms (e.g., annotation, measurement, magnification) can be applied with confidence.

c. Viewing the data

Because there are numerous component orthogonal images in each plane, it is impractical to display all slices on one display format. Therefore, it is necessary to review each series dynamically by scrolling through the consecutive orthogonal image "stack." This is referred to as a "cine" or "paging" mode. This review process will be described in greater detail in Part 2 of this series.

CBCT software programs allow scrolling through the stack of images. A cursor represented by 2 crossing lines indicates the precise localization in virtual space. The data set can also be rotated, panned, or zoomed to allow visualization of the region of interest; at any angle, scale, or position, a rendered image can be created. It is recommended that scrolling be performed cranio-caudally (i.e., from head to toe) and then in reverse, slowing down in areas of greater complexity (e.g. inferior alveolar nerve, maxillary sinus). This scrolling process should be performed at least in the coronal and axial planes. Viewing orthogonal projections at this stage is recommended as an overall survey for disease and to establish the presence of any asymmetry.

d. Formatting the data

CBCT software provides three basic non-orthogonal display formatting options for 3D volumetric data: (i) multiplanar reformatted images (linear oblique, curved oblique (ii) ray sum images (Fig. 13); or (iii) volume rendering (indirect or direct) (Fig.13), or serial trans-axial (Fig. 14);. Each image display option should be selected on visualizing specific anatomic features or functional characteristics of the volumetric data set. These images can be used to highlight specific anatomic regions and diagnostic tasks. Overall, selection should be based on applying thin sections to show detail and thicker sections to demonstrate relationships.

Protocols incorporating field of view (FOV) scan exposure parameters and display modes should be applied selectively to highlight anatomic features or functional characteristics within a specific diagnostic task.

Most volumetric data sets can be sectioned non-orthogonally to provide multiple or a series non-axial 2D images, referred to as multi-planar reformation.

Personal computer based (original equipment manufacturer), or third party, software facilitates dynamic interaction with the clinician to provide task specific display modes useful in dentistry (Figure 2). Strategies that are useful in OMF imaging include:

The non-orthogonal display mode options available for CBCT volumetric data are: (i) multiplanar reformatted images (linear oblique, curved oblique, or serial trans axial); (ii) ray sum images; or (iii) volume rendering (indirect or direct). These images can be used to highlight specific anatomic regions and diagnostic tasks

(i) Multiplanar Reformatting (MPR)

Because of the isotropic nature of image acquisition, the volumetric data set can be sectioned non-orthogonally to provide nonaxial two-dimensional planar images referred to as multiplanar reformatting (MPR). In a multiplanar reformation (MPR) window, axial, coronal and saggital orthogonal planar views are related through intersection lines or crosshairs, allowing for straightforward orientation and navigation.[8] Multiplanar reformation. A, C and S indicate intersection lines corresponding with axial, coronal and sagittal planes, respectively. MPR modes can be viewed in three basic formats namely, linear oblique, curved planar, and serial trans axial reformations.[2]

• The linear oblique technique creates non-axial 2D images by transecting a set or "stack" of axial images. Several anatomic structures are not particularly well visualized and represented as displayed in orthogonal planes, and oblique reformatting can be useful in these instances. Oblique images are most often used to transect and evaluate specific structures such as the mandibular condyle, TMJ and impacted third molars.[2]

- The curved oblique technique for planar reformation creates non-axial 2D images by aligning the long axis of the imaging plane with a specific anatomic structure. This mode is useful in displaying the dental arch, providing familiar panorama-like thin-slice images (Fig. 12 & 13). Images are undistorted so that measurements and angulations made from them have minimal error.[2] Panoramic MPR reconstructions are useful for jaw evaluation. Such reconstructions must be thick enough to include the entire mandible to avoid missing disease.
- Serial trans-axial technique produces a series of stacked sequential cross-sectional images orthogonal to the oblique or curved planar reformation. Images are usually thin slices (e.g., 1 mm thick) of known separation or interval (e.g., 1 mm apart). Resultant images are useful in the assessment of specific morphologic features such as alveolar bone height and width for implant site assessment, the inferior alveolar canal in relation to impacted mandibular molars, condylar surface and shape in the symptomatic TMJ or evaluation of pathological conditions affecting the jaws.[2] Cross-sectional images are optimal for examining teeth and alveolar bone. (Fig. 14)

(ii) The Ray Sum technique is used to produces images of increased sliced thickness. The slice thickness of orthogonal or MPR images 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. (Fig. 13) The thickness of the slab is usually variable and determined by the thickness of the structure to be imaged. Full-thickness perpendicular ray sum images can be used to generate simulated projections, such as a panoramic X-ray or lateral cephalometric images. This mode can be used to generate simulated panoramic images by increasing the slice thickness of curved planar reformatted images along the dental arch to 25–30 mm, comparable to the in-focus image layer of panoramic radiographs. (Fig. 13) In contrast to conventional radiographs, these ray sum images are without magnification and parallax distortion. However, this technique uses the entire volumetric data set, and interpretation is negatively affected by "anatomic noise"—the superimposition of multiple structures—also

Figure 15: CBCT used to communicate valuable information to the patient.

inherent in conventional projection radiography. Unlike conventional radiographs, these ray sum images are without magnification and are undistorted.[3]

(iii) Volumetric rendering techniques also referred to as 3D renderings (Fig. 12, 13), allow the visualization of 3D data by selective display of voxels This can be achieved by direct volume rendering (DVR) providing a volumetric surface reconstruction with depth, or indirect volume rendering (IVR), most commonly as a maximum intensity projection (MIP). MIP is used to demonstrate high intensity structures by providing a "pseudo" 3D reconstruction.

For simplicity, some viewer software has set pre-defined threshold values for different anatomical structures. From different threshold values result in different forms of 3D surface rendering, thus one needs to keep in mind that 3D rendering is for visualization purposes only, not for diagnosis and analysis.[8] A variety of 3D image qualities with varying render times can be provided by the visualization software.[8]

e. Exporting data

CBCT produces two data products: (i) the volumetric image data from the scan, and (ii) the image report generated by the operator. All these images are saved in the DICOM (Digital Imaging and Communication in Medicine) format. CBCT data can be exported in the non proprietary DICOM file format standard and imported into task specific third party diagnostic and planning software to facilitate virtual implant placement and/or create diagnostic and surgical implant guidance stents; and assist in the computer-aided design and manufacture of implant prosthetics.

Benefits of implementing CBCT into your practice

Invaluable diagnostic and communication tool

CBCT provides superior diagnostic and patient communication capabilities.

The patients are amazed by the technology, and it gives them a far greater understanding of any dental problems they may be having. Seeing things in three dimensions greatly increases patients' understanding of the problem and its location. Large monitors in front of the patient chair allow patient's to sit with the clinician and co-diagnose their problems and do their virtual treatment planning. This is very exciting, for both the patient and the clinician. (Fig. 15)

Images are superior to conventional 2D imaging

The potential benefits of using CBCT in dentistry for assessment and diagnosis of pathologies and pre-surgical planning is undisputed. Experience has shown that CBCT imaging is superior to conventional 2D images in demonstrating the location and extent of pathology, the quantity and quality of bone, and the spatial relationships of an object relative to critical anatomical structures.[12] It provides clear images of highly contrasted structures and is extremely useful for analysing bone.

No image distortion and high accuracy

CBCT volumetric data is isotropic, which means all three dimensions of the image voxels are the same. This makes it possible to reorient the images to fit the patient's anatomic features and perform real-time measure-ments without any distortion.[12]

High Image resolution and quality

Image voxels sizes (a 3D cuboid unit of images) can be generated ranging from 0.4mm to as small as 0.125 mm in dimension, which contributes to its superior image resolution and quality. The resolution obtained with CBCT often exceeds the highest grade multi-slice CT.[12]

X-ray beam limitation and reduced radiation dose

Reducing the size of the irradiated area by collimation of the primary x-ray beam to the area of interest (FOV) minimizes the radiation dose. Most Cone Beam CT units can be adjusted to scan small regions of interest for specific diagnostic tasks. Others are capable of scanning the entire craniofacial complex when necessary. The smaller the FOV, the greater the resolution and lesser radiation dose exposure for the patient.[12]

Compact size and design, less expensive and easier to use than conventional CT

Compared to conventional CT equipment, the compact size and cost of CBCT makes it ideal and suitable for the dental office setting. Another advantage is that CBCT software for use in planning implants is usually much easier to use and far more useful than is software available with CT.[12,13]

Easy reorientation

Because the CBCT volu-metric data set is isotropic the entire volumetric data set can be reoriented in all three reference planes (axial, coronal, sagittal) using the PC-based soft-ware so that the patient's anatomic features are realigned. Aligning reference planes perpendicular to the structure of interest, facilitates visualization of single tooth pathology, vital anatomical structures and allows accurate measure-ment of the residual alveolar ridge in an edentulous segment for pre-implant site assessment.[12]

Reformatting and display ability

Reconstruction of CBCT data is performed natively by a personal computer. This provides the clinician with the opportunity to use chair-side image display, real-time analysis and MPR modes that are task specific. Moreover, a CBCT image can be reconstructed in many formats with which the oral care provider is already familiar. For instance, a CBCT image can be reformatted to panoramic, cephalometric, or bilateral multiplanar projections of the temporomandibular joint. These images, in turn, can be annotated, assessed, and measured for diagnostic and treatment planning purposes. In addition, cursor-driven measurement algorithms allow the clinician to do real-time dimensional assessment.[12]

Rapid scan time

Because CBCT acquires all basis images in a single rotation, scan time is rapid (10–70 seconds). Although faster scanning time usually means fewer basis images from which to reconstruct the volumetric data set, motion artifacts due to subject movement are reduced.

Lower radiation dose than CT

Risks have also been noted in the radiation dose needed with CBCT although it is generally believed that the radiation dose of CBCT is significantly lower than a conventional CT.[14] The effective dose of radiation required for conventional fan beam CT (average range 36.9–50.3 microsievert [μSv]), is significantly reduced by up to 98% compared with the effective radiation dose for CBCT (average range for mandible 1,320–3,324 μSv; average range for maxilla 1,031–1,420 μSv).

Improved clinical outcomes and reduced risk of complication

The diagnostic and treatment planning capabilities of CBCT contributes towards improved clinical outcomes, lesser risks and complications for the patient and thus increased patient satisfaction.

Medico-legal reassurance

CBCT is increasing being seen as the standard of care in many fields of dentistry. Using a CBCT correctly where indicated will prevent and eliminate risks and complications and will therefore play an essential role in preventing medico-legal litigation.

Positive return on investment

Reimbursement drives adoption in new technologies. Investing in this technology provides increased opportunities for superior diagnostics, whilst increasing the standard of care in all fields of dentistry.

Limitations of CBCT

Requires expertise en specialized monitoring equipment

Referral to an Oral Maxillofacial Radiologist may be indicated for need of expertise and because a proper monitor, ambiente lighting, and equipment settings may be available only in a specialist radiologist envirenment.[12]

CBCT is more expensive

CBCT is more expensive than classic 2D radiologic assessments. However, the counterarguments is that 2D radiologic assessments does not have the diagnostic and treatment planning capabilities and benefits that CBCT has.

Increased radiation dose risk

Currently available CBCT units from different manufacturers vary in dose by as much as 10-fold for an equivalent FOV examination.[15] As most devices exhibited effective doses in the 50-200 μSv range, it can be stated that CBCT imaging results in higher patient doses than standard radiographic methods used in dental practice for dental therapy but significantly lower than a conventional MDCT.[14,15] The effective radiation dose for a CBCT is 2-4 times greater than for a cephalometric X-ray; 3-6 times greater than a panoramic X-ray and 8-14 times greater than a peri-apical x-ray.

The effective radiation dose of CBCT can be affected to an order of magnitude by the factors: patient size, FOV, region of interest, and resolution. A careful selection of all these parameters is needed to optimize diagnostic information and to reduce the patient's radiation exposure.[16]

In general, imaging parameters (i.e. kV, mAs, and FOV size) has an effect on the effective radiation dose as well as image quality parameters (spatial resolution, contrast, noise and artefacts).[8] In terms of optimization of exposure, the most straightforward imaging parameter are FOV size, as larger FOVs increase radiation dose to the patient. Significant dose reduction can be achieved by reducing the FOV to the actual region of interest.[15] In addition; larger FOVs increase the relative amount of scattered radiation reaching the detector, leading to an increase in noise and artefacts. Therefore, FOVs should always be kept as small as possible, covering only the ROI.[8,10]

Requires training and has a learning curve

It requires new competencies from the clinician and the value of information obtained is interpretation sensitive. This requires training and new knowledge from the clinician.

Poor soft tissue contrast

One major disadvantage of CBCT is that it can only demonstrate limited contrast resolution. If the objective of the examination were hard tissue only, then CBCT would not be a problem. However, CBCT is not sufficient for soft tissue evaluation as it provides limited resolution to deeper (inner) soft tissues and MRI and CT are better for soft tissue imaging.[12]

Imaging artifacts

Artefacts are any dis-tortions or errors in the image that is unrelated to the subject being studied, Such image artefacts can be inherently related to the image acquisition and reconstruction process of the CBCT machine, or patient related (i.e. metal artefacts, or motion artefacts).[12] Metal artefacts, are the result of high X-ray absorption by high-density objects. These artifacts contribute to image quality degradation and can lead to inaccurate or false diagnosis.

It is important to note that a CBCT user has little influence on metal artefacts, as increasing exposure settings (e.g. mA and number of projections) do not improve the appearance of metal artefacts substantially enough to justify the increased radiation dose.[8] Depending on the amount of motion during image acquisition, slight blurring or severe artefacts may occur. Due to the relatively long scan times in CBCT, motion is an important issue. Any movement artefacts affect the whole dataset and thus the whole image.

Motion artefacts however, can be controlled by the CBCT user by using a head restraint device with long scan times and selecting a protocol with a short scan time for patients at risk for excessive motion.

Bone density and grayscale

CBCT is commonly used for the assessment of bone quality primarily for pre-implant treatment planning. Traditionally bone quality has been based on bone density, estimated throiugh the use of Hounsfield units derived from multidetector CT (MDCT) data sets. However, due to crucial differences between MDCT and CBCT, which complicate the use of quantitative gray scale values (GV) for assessment of bone density with CBCT[17] Experimental and clinical research suggest that the qualitative use of GV in CBCT to assess bone density should be avoided at this stage.[17] Current scientific literature suggests a paradigm shift of bone quality assessment from a density-based analysis to structural evaluation.[17]

Considerations and guidelines for purchasing CBCT imaging equipment

The number of CBCT devices available on the market has increased substantially and new models are being developed and released on a continuous basis. Currently there are more than 50 types of cone beam computed tomography models available, including multimodal types for additional panoramic and/or cephalometric imaging, and cheaper primary panoramic machines with a small field-of-view three-dimension button.[18] These devices exhibit a wide variability in terms of capabilities, and crucial exposure parameters.[19] Additionally, 3D radiographic technology is continuously evolving and improving. Each dentist has to identify what he wants out of the device and then pitch his purchase towards the strong points of the popular and/or available brands that will meet his specific needs. A good place to start is to consult with other users, and suppliers of CBCT devices.

Decision-making when purchasing a CBCT machine is primarily based on four parameters: needs and benefits, hardware capabilities, software capabilities and cost considerations.

Needs and benefits

Critical questions that a potential buyer must ask is: Why do I need a CBCT device, and what benefits do I expect my patients will get from having a CBCT machine?

CBCT machines are generally used for diagnostics and treatment planning in dental implantology, endodontics, oral and maxillofacial surgery (wisdom teeth, TMJ, trauma, orthognatic surgery), and orthodontics (cephalometric skeletal tracing, naso-pharyngeal airway analysis). CBCT machines can also be integrated with CAD/CAM and/or digital printer devices for fabrication of surgical guides, prosthodontics and orthodontic appliances.

Potential purchasers also need to understand that acquisition of this technology has a learning curve on how to use the device and that learning how to interpret and read images requires time, effort and experience. Therefore, make certain the manufacturer has a technical support service and get more than one opinion before buying.[20] Needless to say, and important guideline is to get a machine that is very easy to use.

Patients appreciate the convenience of having a CBCT machine in your office, and that it will improve the diagnosis the outcome of their treatment and reduce treatment complications.

Hardware capabilities

What type of machine should I get and what features should it have?

CBCT machines can be categorized according to: (i) design of the device or orientation of the patient during image acquisition (i.e. sitting, standing or supine); or (ii) the scan volume, also referred to as the FOV irradiated.[1] The advantages and disadvantages of the different orientations are already described elsewhere in this article. First decision is to make sure that there is sufficient space available to accommodate the footprint of a sitting, standing or supine CBCT machine in the practice.

A basic CBCT machine should have the capability to allow for a small FOV for a single tooth clinical situation (i.e. 5 x 5 FOV), a full upper or lower jaw (i.e. 5 x 10 FOV), or to view the upper and lower jaw simultaneously (i.e. 10 x 10 FOV)

Additionally, most dentists require that a CBCT machine should at least have the capability to take Panorex X-rays as well (also referred to as multimodal capability). If you are doing orthodontic treatment your CBCT device should preferably also have a 2D cephalometric X-ray capability. Oral and Maxillofacial surgeons require an extended field of view (full skeletal 3D view) to manage trauma, orthognathic and TMJ cases.

Software capabilities

Three important guidelines that CBCT has to comply with are: (i) the software must have all the required tools and easy to use; (ii) there should be a bridge to, and be compatible with the office management software; and (iii) it must be compatibility with optical scanners.

Features or software capabilities (characteristics) that should be looked for or considered when purchasing a CBCT machine are the following: (i) automatically converts DICOM files; (ii) Imports STL files; (iii) nerve mapping; (iv) implant site measurement tools; (v) virtual implant library; (vi) implant abutment library; (vii) prosthetic planning; (viii) cephalometric tracing; (ix) airway space analysis; (x) surgical guide fabrication; (xi) radiology reporting capability.[21] Various software packages are available for the interpretation of Digital Imaging and Communications in Medicine (DICOM) files generated from CBCT scans.

Cost and return on investment

Is the return on investment worth the purchase price? The current cost of a cone beam device is high, typically around R750,000 to R1,500000. Purchasing a CBCT machine that has a multimodal functionality (i.e. can also take peri-apical, bitewings, panorex or cephalometric x-rays) helps to pay for the machine.

Thus when observing the high financial outlay for a cone beam device, prudent practitioners should determine how often they would use the device in their practices. Typical current fees for cone beam imaging in the South Africa range from R1200 to R4600. It is easy to multiply the number of images anticipated in a typical month of practice by the individual image fees to see if the return on investment is worth the expense. The various fee levels and frequency of use will make this analysis different for each practice. A word of caution related to any high-cost technology - when practitioners have such devices, there is a tendency to overuse them for financial reasons, which is unethical practice.

Besides costs of a CBCT unit, having inadequate space for a machine and having to learn and maintain additional software and hardware – probably the major reason that is emerging as a barrier for acquiring a CBCT unit, relates to skills and competencies required for interpretation of images.[22]

Conclusion

The development of inexpensive x-ray tubes, high-quality detector systems and powerful personal computers have paved the way for commercially available and affordable 3-D CBCT imaging systems for the dental practice.

Over the past decade, CBCT has revolutionized dento-maxillofacial radiology by providing 3D imaging for the dental setting, overcoming the major limitations of traditional 2D intra-oral, panoramic and cephalometric radiographs.

Despite the lack of universal standards of care for dentistry, 3D CBCT imaging capabilities for diagnostics, pre-surgical planning, and improving treatment outcome in dental implantology, is now rapidly moving towards being the standard of care. As with any emerging technology, dental professionals need adequate theoretical and practical training to use CBCT effectively and safely.

Finally, dentists have an ethical duty to preserve the health of their patients and to prevent or limit risks, and always seek the best treatment in such a way that the benefits will always exceed the risks. The quest begins with the radiographic assessment that requires the least amount of radiation dose to treat the patient appropriately.

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