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RESEARCH ARTICLE

COMPUTED TOMOGRAPHY – A REVOLUTION IN RADIOLOGY

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ABSTRACT

Imaging is an important diagnostic adjunct to the clinical assessment of the dental patients. Since the discovery of x-ray, dental radiology has played a vital role in diagnosis of diseases. With the expanding array of imaging modalities, dental radiology has played revolutionary role in determining diagnosis, treatment plan and prognostic value. Present day intraoral and extraoral procedures, used individually or in combination, suffer from the same inherent limitations of all planar two-dimensional projections: magnification, distortions, superimpositions, and misrepresentation of structures. Numerous efforts have been made toward three dimensional (3D) radiographic imaging. During the last decades, an exciting new array of digital imaging modalities, has provided astounding new images that continually contribute to the accuracy of diagnostic tasks of the maxillofacial region. Among which computed tomography is one of them. This article reviews about the evolution, history, principles and advances of CT.

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INTRODUCTION

Sir. Wilhelm Conrad Roentgen first discovered X-Rays on 8th November 1895, which eventually led to a series of radiographic techniques in the field of radiology. X-Rays played a vital role in the diagnosis of various diseases from 1895 onwards. Computed Tomography (CT) was a significant development in the history of imaging since the discovery of x-rays (Ambrose, 1973). Computed tomography (x-ray CT) is a technology that uses computer-processed x-rays to produce tomographic images (virtual 'slices') of specific areas of the scanned object, allowing the user to see what is inside it without cutting it open (Cormack, 1973). CT was developed for clinical use in 1972 and 1973 by Godfrey Hounsfield. The information presented in a CT image is different from that in a conventional radiographic image. The most conspicuous difference is that CT shows cross-sectional views of patient anatomy. Sir Godfrey was awarded a Nobel Prize in 1979 for this major achievement (Willi A Kalender, 2006). CT is thus synonymous with Computerized Transverse Axial Tomography (CTAT), Computer-Assisted Tomography or Computerized Axial Tomography (CAT), Computerized Tomography (CT), Reconstructive Tomography (RT), and Computerized Transaxial Transmission reconstructive Tomography (CTT) (Hounsfield, 1973). In conventional radiography a 2-dimensional image of a 3-D object is projected on to a film by a beam of X-Ray traveling through the object. This results in super imposition of those structures lying in different planes at right angles to the central ray of the X-ray beam. Because of the complex nature of the anatomy of the maxillofacial regions, it is difficult at times to study and interpret the extent of lesion on a plain film. Computed tomograph was developed to overcome this problem (Cormack, 1973) Soon CT had revolutionized the diagnosis of diseases and the demand for CT scanners rose rapidly throughout the world. The success of the brain scanner led to the development of a scanner designed to examine the whole body. Clinical studies indicated that body CT made an important contribution to diagnose and to plan the treatment. The value of the CT in the medical field and its various clinical disciplines has been well documented (Kopp, 2000)

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The history of computed tomography

The history of the CT scanner, as a viable imaging modality can be traced back to a period of 1970 to 1973 and it revolutionized imaging of the human body. From its inception CT's ability to provide direct information about the existence and nature of pathology was quickly appreciated and made other imaging techniques obsolete.

The introduction of panaromic radiography in the 1960’s and its widespread adoption throughout the 1970’s and 1980’s heralded major progress in dental radiology, providing clinicians with a single comprehensive image of jaws and maxillofacial structures (Andre Gahleitner *et al*., 2003). In 1967 the first CT scanner was developed by Sir. Godfrey N. Hounsfield, an engineer at EMI. Since then, CT technology rapidly underwent four developmental generations. The first generation of CT scanners used a single detector element to capture a beam of X-rays, corresponding to the integral of linear attenuation coefficients along a single line. Hounsfield's unit belonged to this generation, as did the first commercial CT scanners introduced in 1972 (Goldman, 2005). In 1975 a second generation of CT systems was introduced. These systems, also known as "hybrid" machines, used more than one detector and used small fan-beam, as opposed to pencil-beam, scanning. Like the first generation of CT scanners, these scanners also used a translate-rotate design, and were for the most part head-only scanners (Mc Cabe, 2005)

In 1976 third generation CT scanners appeared. These scanners use a large, arc-shaped detector that acquires an entire projection without the need for translation. This rotate-only design, frequently referred to as "fan-beam", utilizes the power of the X-ray tube much more efficiently than the previous generations (White, 1983). In 1976 fourth generation scanners followed third generation scanners, replacing the arc-shaped detector with an entire circle of detectors. In this design the X-ray tube rotates around the patient, while the detector stays stationary (Herman, 1983) In 1978 one of the earliest 3D volumetric scanner was the Dynamic Spatial Reconstructor (DSR) installed in the medical sciences building on the mayo clinic Rochester campus**.**

The technique of dental CT, also called Dentascan, was developed by Schwarz *et al*. in 1987, when these investigators first used curved multiplanar reconstructions of the jaw(Lloyd, 1988). By late 1998, all major CT manufacturers launched multiple row detector CT (MDCT) scanners capable of at least four slices per x-ray tube rotation.(1) In year **1999**, PET/CT developed, developed by Dr David Townsend and Dr Ron Nutt (Pittsburgh, USA). In early 2002, 8- and 16-slice scanners were introduced.

Generations of CT

The original 1971 prototype took parallel readings through angles, each apart, with each scan taking a little over five minutes. The images from these scans took hours to be processed by algebraic reconstruction techniques on a large computer.

First generation

CT scanners used a pencil-thin beam of radiation. The images were acquired by a "translate-rotate" method in which the x-ray source and the detector in a fixed relative position move across the patient followed by a rotation of the x-ray source/detector combination (gantry) by 1° for 180°. The thickness of the slice, typically 1 to 10mm, is generally defined by pre-patient collimation using motor driven adjustable wedges external to the X-ray tube (Goldman, 2005)

Second generation: The x-ray source changed from the pencil-thin beam to a fan shaped beam. The "translate-rotate" method was still used but there was a significant decrease in scanning time. Nevertheless, these scanners required slower scan speeds to obtain adequate x-ray flux at the detectors when scanning thicker patients or body parts (White).

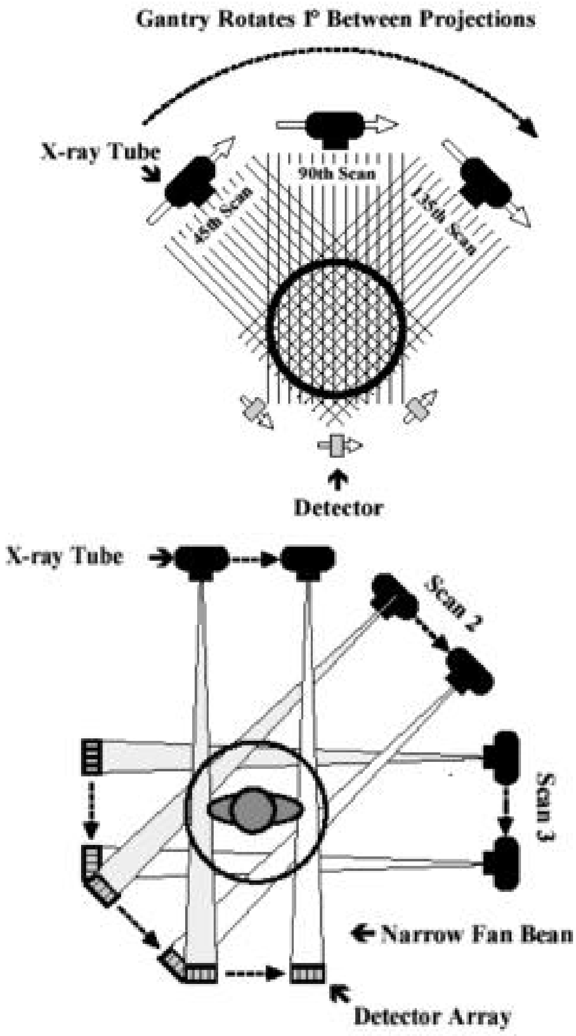


Figure 1. 1st generation x-ray tube and 2nd generation x-ray tube

Third generation become a Rotate-Rotate geometry. A typical machine employs a large fan beam such that the patient is completely encompassed by the fan, the detector elements are aligned along the arc of a circle centered on the focus of the X-ray tube (Ariji *et al*., 1991) The X-ray tube and detector array rotate as one through 360 degrees, different projections are obtained during rotation by pulsing the x-ray source, and bow-tie shaped filters are chosen to suit the body or head shape by some manufacturers to control excessive variations in signal strength (Ambrose, 1973)

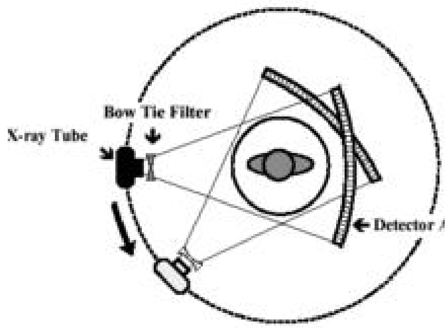


Figure 2: 3rd generation x-ray tube

Fourth generation of CT scanner uses **Rotate-Fixed Ring** geometry where a ring of fixed detectors completely surrounds the patient. The X-ray tube rotates inside the detector ring through a full 360 degrees with a wide fan beam producing a single image. Due to the elimination of translate-rotate motion the scan time is reduced comparable with third generation scanner, initially, to 10 seconds per slice but the radiographic geometry is poor (Ariji, 1991). Further, they were more sensitive to artifacts because the non-fixed relationship to the x-ray source made it impossible to reject scattered radiation(Ambrose, 1973).

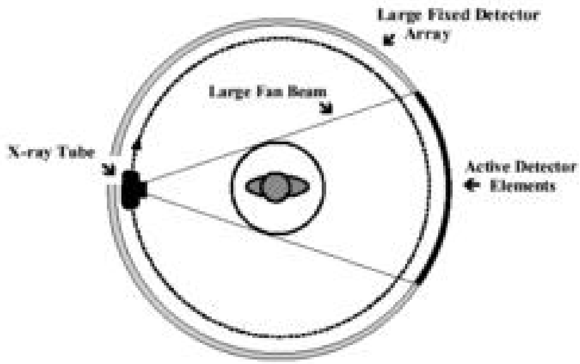


Figure 3. 4th generation x-ray tube

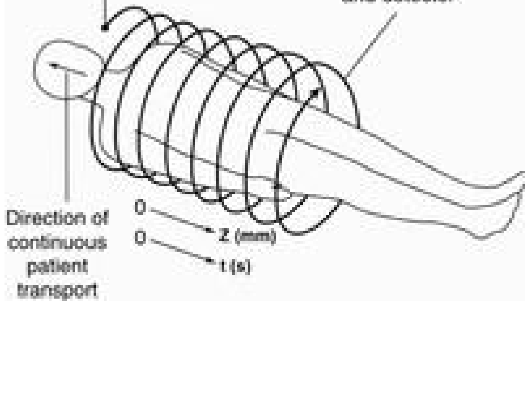
Fifth generation CT

Electron beam tomography is a specific form of computed axial tomography (CAT or CT). This different design was explicitly developed to better image heart structures which never stop moving, performing a complex complete cycle of movement with each heart beat. The X-Ray tube is much larger than the imaging circle and the electron beam current within the vacuum tube is swept electronically, in a circular (partial circle actually) path and focused on a stationary tungsten anode target ring (Goldman *et al*., 2005).

SIXTH GENERATION CT

Helical / Spiral CT scanner

Spiral scanning is a take-off from regular Computed Tomography. The procedure is only possible with the advent of continuous rotation scanning, fast data acquisition systems and lots of memory space (Ariji *et al*., 1991) This allows a continuous stream of intensity data with its associated gantry position data to be correlated with table position data.. The computer will examine each data acquisition, scale its intensity data and apply the data to each slice in which the measurement holds voxel intensity data (Yonetsu *et al*., 1998)



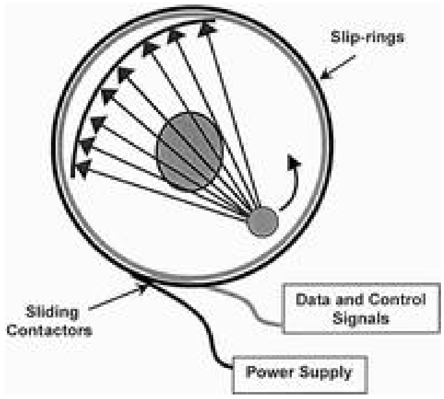


Figure 4. Spiral CT and its mechanism

SEVENTH GENERATION CT

Strategies to achieve a better longitudinal resolution and faster scans include the simultaneous acquisition of multiple slices at a time, thus termed Multi-Detector Row CT or Multi-Slice CT (MSCT). Multiple detector array collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data Opening up the collimator in a single array scanner increases slice thickness, reducing spatial resolution in the slice thickness dimension (Goldman, 2007) Sixteen-slice scanners have been widely available for years, while 64-slice MDCT scanners became available in 2004 and represent significant improvements in image quality and scan time (White).

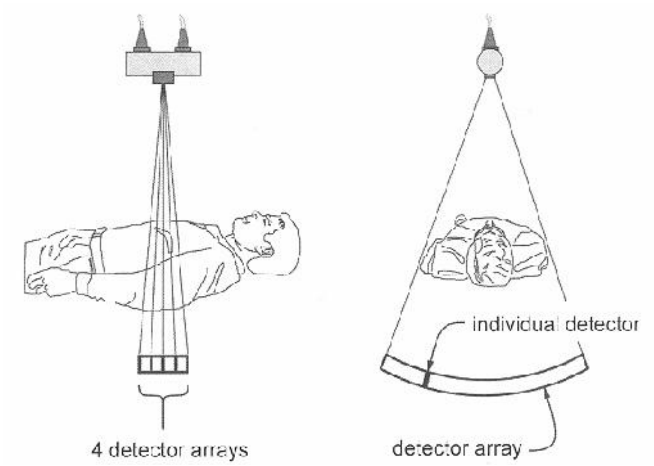


Figure 5. Multiple detector array computed tomography

EQUIPMENT OF CT

Computed tomography (CT) is the science that creates two-dimensional cross sectional images from three-dimensional body structures. Each component of a CT system plays a major role in the accurate formation of each CT image it produces (O'Connor, 2011)

Gantry

The imaging system primarily includes the gantry and patient table or couch. The gantry is a moveable frame that contains the x-ray tube including collimators and filters, detectors, data acquisition system (DAS), rotational components including slip ring systems and all associated electronics such as gantry angulation motors and positioning laser light (O'Connor,, 2011). The opening through which a patient passes is referred to as the gantry aperture. Gantry aperture diameters generally range from 50-85 cm (Erbel *et al*., 2000).

The diameter of the gantry aperture is different for the diameter of the scanning circle or scan field of view (Amber *et al*., 2007). Lasers or high intensity lights are included within or mounted on the gantry. The lasers or high intensity lights serve as anatomical positioning guides that reference the center of the axial, coronal, and sagittal planes (Klingenbeck-Regn, 2002). The gantry consists of two parts, a stationary one and a rotating one. The functional components of a gantry:

a.Scan Control: it is a term applied to a group of electronics that in general, interfaces the gantry to the host computer system. Via this interface, information is exchanged between gantry components and the host (O'Connor, 2011).

b.Gantry Rotation: In order to reconstruct a CT Image, a number of "intensity profiles" (also known as readings or projections) must be gathered from different views around an object. This information is then typically used to assure that rotation speed is within the specified tolerance, position the X-ray tube to a pre-defined angular displacement for a Topogram study, and provide angular position information to the Image Processor (Klingenbeck-Regn, 2002).

c.Collimation: The primary function of a collimation system is to limit the amount of X-rays impinging upon the patient, to that which contributes to the "attenuation profile." The resultant opening actually determines the slice thickness of the scan. Most CT units on the market today, have a range of slices available; the smallest slice of any use is about I mm and the largest is about 12 mm (White).

d.X-ray source: The important variables that determine how effective an X-ray source will be for a particular task are the size of the focal spot, the spectrum of X-ray energies generated, and the X-ray intensity. The energy spectrum defines the penetrative ability of the X-rays, as well as their expected relative attenuation as they pass through materials of different density. Medical CT systems tend to have X-ray spot sizes that range from 0.5 mm to 2 mm.(Erbel *et al*., 2000)

Detectors

In conventional radiography we utilize a film-screen system as the primary image receptor to collect the attenuated information. The image receptors that are utilized in CT are referred to as detectors (Crawford, 1990) The two types of detectors utilized in CT systems are scintillation or solid state and xenon gas detectors. Scintillation detectors utilize a crystal that fluoresces when struck by an x-ray photon which produces light energy (Goldman, 2005). The most frequently used scintillation crystals are made of Bismuth Germinate (Bi4Ge3012) and Cadmium Tungstate (CdWO4). The second type of detector utilized for CT imaging system is a gas detector.(16) The gas detector is usually constructed utilizing a chamber made of a ceramic material with long thin ionization plates usually made of Tungsten submersed in Xenon gas. The ionization of ions produces an electrical current (Goldman, 2007)

BASIC PHYSICAL PRINCIPLES

The internal structure of an object can be reconstructed from multiple projections of the object. With CT, an image of a body slice is obtained by taking a very large number of narrow X-ray beam projections at multiple angles through that slice. Assuming the intensity of the X-ray beam as it enters the body is constant, then measurement of the intensity of the emerging beam will reflect the magnitude of the absorption of X-rays by the body (Kalender *et al*., 1990). CT is essentially a tomographic technique giving images of slices of the patient's anatomy. In the CT scanner the slice location is determined by moving the patient in or out of the gantry housing. At a given slice location the gantry rotates around the patient with the transmitted radiation that passes through the patient measured by an array of many hundreds of detectors. From these measurements the computer makes calculations to fill in each square in a matrix 512 X 512 in size (Kalender, 1995)

Pixels and voxels

Each square in this matrix is called a pixel or picture element. After the necessary calculations each pixel is assigned a digital value. This represents the X-ray absorption coefficient of all the tissue present within 1 voxel in the patient. A voxel is defined as the volume of tissue bounded by the dimensions of a pixel and the width of the X-ray beam. For example, in head scanning the machine is targeted so that the head fills the entire matrix (Herman, 1983)

Hounsfield units (Hu)

The digital value ascribed to each pixel is called the Hounsfield value which lies on a scale where pure water has a value 0 and air has a value of -1000. Bone has a value of the order of + 1000. The values for different tissue types are measurable and reproducible (Crawford *et al*., 1990) Present scanners have a measurement range of -1000 HU to +3095 HU. Because they are recorded digitally they can be displayed, manipulated, interrogated and stored, thus giving an enormous range of diagnostic possibilities. Most machines have a region of interest (ROI) capability which allows a small box on the machine monitor to be moved to an area of interest. The average Hounsfield value of all the pixels contained within that box is then displayed on the monitor (Brink *et al*., 1992).

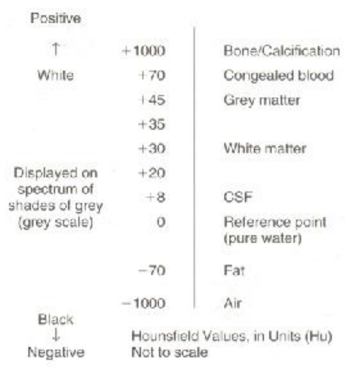


Figure 6. Hounsfield units

Windowing and grey scale

The average human eye can only differentiate some 30 shades of grey, despite the fact that most modern scan computers work with many more than this. The technique of windowing is an electronic manipulation of the data to enable these shades of grey to be used to represent a limited range, or window, of Hounsfield values (Kopp, 2000). The window width (WW) is the range of CT numbers for the gray scale, while the midpoint or center of the gray scale is the window level (WL).

By changing the WW and WL, the radiologist can enhance the visualization of structures in which he is most interested. Narrowing the window or compressing the grey scale thus increases contrast for the purposes of visual perception, without changing absolute values or disturbing relative radiographic tissue densities.

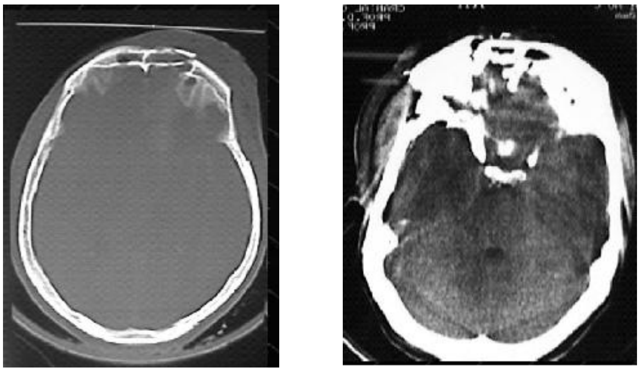


Figure 7. Narrow window width and Wider window width Conversely, widening the window will increase the range of Hounsfield numbers displayed in a single shade of grey (Schaller *et al*., 1999)

Generation of the Topogram or scout image

Topogram - sometimes referred to as a scout view, is used to determine the region of interest when planning to perform a series of Tomograms. The net result of this procedure is to locate the exact starting and ending points of scanning thus eliminating unnecessary dose to the patient. A scout image is generated by energizing the X-ray beam and passing the relevant part of the patient in one movement through the gantry. This continuous exposure as the patient moves through the beam generates a topogram which resembles a plain X-ray. (Sara Lofthag-Hansen *et al*., 2007) From this scout image the position, number and angulation of the subsequent slices are chosen.

ARTIFACTS

Motion artifacts

The most common of these artifacts are those caused by motion, both voluntary and involuntary. Any movement during scanning will produce star-like streaks on the CT image. These streaks may appear tangential to the skull or diagonally across the skull for nodding and rotating movements respectively (Andre Gahleitner *et al*., 2003)

Metallic artifacts

Metallic material on or in the patient generally will produce streak artifacts. The X-ray absorption coefficient of metal is much higher than any other structure found in the human body. In head scans this is encountered with surgical clips, gunshot debris, dental amalgam or other extraneous objects (Goldman, 2005).

Equipment-related artifacts

A whole range of technical malfunctions are possible in a CT scanner most of which result in complete failure of image production. They are caused by unstable mechanics, detector drift (different detector responses), geometry of the system, changes in photon flux from time to time, insufficient transmission readings, and beam hardening (Crawford, 1990)

Streak artifact

Streaks are often seen around materials that block most X-rays, such as metal or bone. Numerous factors contribute to these streaks: under sampling, photon starvation, motion, beam hardening, and Compton scatter. This type of artifact commonly occurs in the posterior fossa of the brain, or if there are metal implants.

Partial volume effect

This appears as "blurring" of edges. It is due to the scanner being unable to differentiate between a small amount of high-density material (e.g., bone) and a larger amount of lower density (e.g., cartilage). This can be partially overcome by scanning using thinner slices, or an isotropic acquisition on a modern scanner (Yonetsu *et al*., 1998)

Ring artifact

Probably the most common mechanical artifact, the image of one or many "rings" appears within an image. This is usually due to a detector fault, or miscalibration of an individual detector element (Ambrose, 1973)

Noise

This appears as grain on the image and is caused by a low signal to noise ratio. This occurs more commonly when a thin slice thickness is used. It can also occur when the power supplied to the X-ray tube is insufficient to penetrate the anatomy (Amber *et al*., 2007)

Beam hardening

This can give a "cupped appearance". It occurs when there is more attenuation along a path passing through the center of an object, than a path that grazes the edge. This is easily corrected by filtration and software (Crawford, 1990)

Ct Interpretations

Anatomic structures are delineated by their differences in X-ray absorption. They may be displayed in the scan in two ways. Dense lesions with average absorption values greater than the surrounding tissue appear as white areas on the display where as low density lesions with average absorption values lower than the surrounding tissue appear as dark areas. Lesions exhibiting the same average absorption value as the surrounding tissue are not normally easily distinguished. For such lesions contrast enhancement may be utilized by the intravenous injection of various conventional radiographic contrast media (Tao Ouyang, 2010).

RECENT ADVANCES IN CT

Contrast enhanced computerised tomography

The CT images can be enhanced by the use of IV contrast media, the contrast enhanced computerised tomography or CECT effectively delineates extent of vascular lesions, tumor masses and approximation to vital structures (White).

CE imaging describes the acquisition of a baseline image(s) without contrast enhancement followed by a series of images acquired over time after an intravenous bolus of conventional CA. The presence of CA within cerebral blood vessels and tissues affects measured X-ray attenuation on CT in a linear fashion and the calculated signal intensity on MRI in a non-linear manner (White).

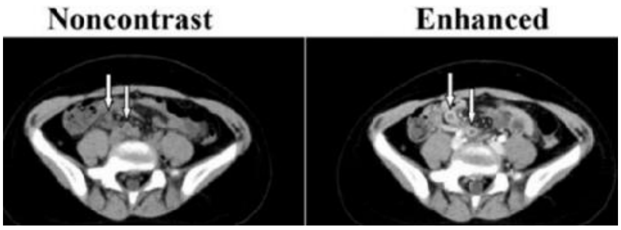


Figure 8. CECT imaging

Cone beam computerised tomography (cbct)

Cone-beam imaging, sometimes referred to as digital volume tomography, is one of the most exciting developments in dental and maxillofacial radiology and, owing to its versatility, will almost certainly become an increasingly popular form of imaging available in dental practice. CBCT allows the creation in "real time" of images not only in the axial plane but also 2-dimensional images in the coronal, sagittal and even oblique or curved image planes — a process referred to as multiplanar reformation (MPR). CBCT has a broad range of applications in the field of dentistry like treatment planning of orthognathic surgery, assessment of bone height for implants, detection of course of inferior alveolar nerve, etc. The scanner in CBCT uses a cone shaped x-ray beam rather than a conventional linear fan beam to provide accurate imaging (Herman, 1983) .

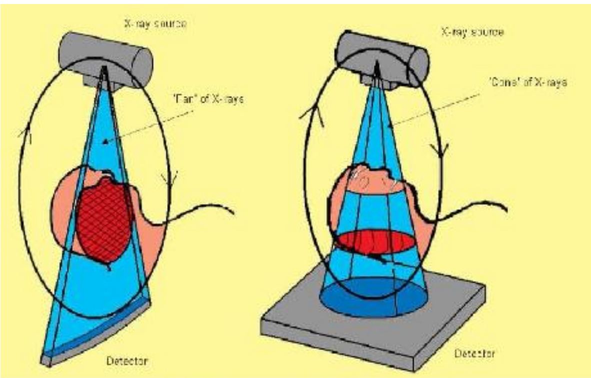


Figure 8. Showing cone beam of x-rays

The most common indication for cone-beam imaging in dentistry are assessment of the jaws for placement of dental implants, examination of teeth and facial structures for orthodontic treatment planning, evaluation of the temporomandibular joints (TMJs) for osseous degenerative changes, evaluation of the proximity of the lower wisdom teeth to the mandibular nerve before extraction, assessment of teeth for root fracture or periapical disease, and evaluation of bone for signs of infections, cysts, or tumors (Yonetsu *et al*., 1998)

Positron emisson tomography

Positron emission tomography, also called PET imaging or a PET scan, is a type of nuclear medicine imaging.

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases, including many types of cancers, heart disease, gastrointestinal, endocrine, neurological disorders and other abnormalities within the body. Because nuclear medicine procedures are able to pinpoint molecular activity within the body, they offer the potential to identify disease in immediate response to therapeutic interventions (Andreas, 2008). Nuclear medicine imaging procedures are noninvasive and, with the exception of intravenous injections, are usually painless medical tests that help physicians diagnose and evaluate medical conditions. These imaging scans use radioactive materials called radiopharmaceuticals or radiotracers. the radiotracer is either injected into the body, swallowed or inhaled as a gas and eventually accumulates in the organ or area of the body being examined. Radioactive emissions from the radiotracer are detected by a special camera or imaging device that produces pictures and provides molecular information (Miyazaki Chihoko, 1999)

P*Et al*lows assessment of changes in the tissues before there would be detected by other diagnostic images. The principle of PET relies on positron emitting radio nucleotide generated in cyclotrons. FDG {Fluoro-2 Deoxy glucose} is the most widely used radioactive substance in PET (Miyazaki Chihoko, 1999)

Single positron Emission Computed tomography (SPECT)

SPECT is a tomographic scintigraphic technique in which a computer-generated image of local radioactive tracer distribution in tissues is produced through the detection of single-photon emissions from radionuclides introduced into the body (Clinical Applications of SPECT/CT, 2008)

Main indications for ct in the head and neck

- Investigation of intracranial disease including cysts, tumors, haemorrhage and infarcts.
- Investigation of suspected intracranial and spinal cord damage following trauma to the head and neck.
- Assessment of fractures of maxillofacial region.
- Tumour staging — assessment of the site, size and extent of tumors, lymph node metastasis, both benign and malignant, affecting the maxillofacial region.
- Investigation of sialolithiasis, tumors and tumor-like discrete swellings both intrinsic and extrinsic to the salivary glands, osteomyelitis of bones, TMJ evaluation, cyst, inflammatory disease, oroantral fistulas and surgical procedures (Lloyd, 1988)

Conclusion

As health care professions have crossed more than a century of the discovery of x-radiation, one is reminded of the paramount position radiography has attained in the battle against disease. Imagining a world in which a health care provider is asked to diagnose, treat and manage disease without x-rays is impossible. CT is now regarded by many as the linchpin of modern diagnostic imaging. During recent years the application of CT has widened, image quality has improved and scanning techniques have become more sophisticated. Furthermore, a wealth of experience has been gained which has helped to define the advantages and limitations of CT compared with those of other techniques.

Our knowledge and understanding of CT is, therefore, ever changing and it is important for radiologists practicing CT to keep abreast of current concepts and new approaches in this challenging area of radiology.

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