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Xeroradiography, Digital Radiography and Computerized Tomography: A Systemic Review

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Abstract: ***Advanced diagnostic technologies are increasingly playing a more vital role in both data collection and assessment capabilities, and the utilization of the information obtained. Diagnostic modalities available to clinicians today expand greatly on the foundation of a comprehensive visual assessment, which has been and will be the cornerstone of the diagnostic process. The diagnostic clinician today is able to obtain a seemingly endless amount of information to assess the patient's oral health, which in turn gives them and the patient's other healthcare providers tremendous knowledge about the patient's overall health and wellness. An excellent example is the advancement of radiographic imaging. In past five decade many advances came in radiology like computed tomography, Magnetic resonance imaging, ultrasonography, Arthrography, nuclear medicine, cone beam computed tomography establish perfect diagnosis that help in treatment planning. In some situations object and superior structures are overlapping to each other, in that case tomography, computed tomography, cone beam computed tomography will help in 3D contraction of the image. Soft tissue diagnosis in radiograph is quite difficult because less density, in such case magnetic resonance imaging and ultrasonography will help to reach a conclusion.***

Keywords: Xeroradiography, Digital Radiography, Computerized Tomography

1. Introduction

1.1 Xeroradiography

Various methods have been introduced for obtaining radiographs among which xeroradiography is a method of imaging which uses the Xeroradiographic copying process to record images produced by diagnostic X-rays. It differs from halide film technique in that it involves neither wet chemical processing nor the use of dark room.[1]

Over the past 40 years, Xerox 125 system became applicable in medical sciences. A prototype Xeroradiographic imaging system specific for intraoral use was later developed[2]. Following these clinical trials showed that xeroradiography is superior for imaging of dental structures necessary for successful periodontal and endodontic therapy[3]. Xeroradiographic radiation of 90% of more than that for silver halide radiograph has been reported, while others found that Xeroradiographic radiation is one third to half of that for halide radiograph.[4]

The imaging method was discovered by an American physicist, Chestor Carlson in 1937.Later, the Xerox company followed the laboratory investigations of the technique and its potential applications in medical sciences.Others like Binnie et al Grant et al and White et al worked on phantoms and cadavers using the Xerox 125system. Xeroradiography may be new in dentistry, but in medicine, it had long been used in the diagnosis of breast diseases, imaging of the larynx and respiratory tract for foreign bodies, Temporo-mandibular joint, skull and para-osseus soft tissues.[5]

Pogorzelska–Stronczak became the first to use xeroradiography ,to produce dental images while Xerox 125 medical system got adapted for extra oral dental use in cephalometry, Sialography and panoramic xeroradiography. Later, a prototype Xeroradiographic imaging system, specific for intraoral use, was acclaimed to be superior over halide based intraoral technique.[4]

Xeroradiography is an electrostatic process which uses an amorphous selenium photoconductor material, vacuum deposited on an aluminium substrate to form a plate .the plate enclosed in tight cassette ,may be linked to films used in halide based intraoral technique[6]

The key functional steps in the process involve the sensitization of the photoconductor plate in the charging station by depositing a uniform positive charge on its surface with a corona emitting device called scorotron. That is the uniform electrostatic charge placed on a layer of selenium is in electrical contact with a grounded conductive backing .In the absence of electromagnetic radiation ,the photoconductor remains non conductive uniform electrostatic charge when radiation is passed through an object which will vary the intensity of radiation, observed by Rawls and Owen. The photoconductor will then conduct its electrostatic charge into its grounded base in proportion to the intensity of the exposure. After charging the cassette is inserted into a thin polyethylene bag to protect the cassette and plate from saliva.

Image Development

The generated latent image is developed through an electro-phoretic development process using liquid toner. The process involves the migration to and subsequent deposition of toner particles suspended in a liquid onto an image reception under the influence of electrostatic field forces. That is by applying negatively charged powder (toner) which is attracted to the residual positive charge pattern on the photoconductor, the latent image is made visible and the image can be transferred to a transparent plastic sheet or to a paper .The toner is thereafter fixed to a receiver sheet onto which a permanent record is made. The plate is then cleaned of toner for reuse.[7]

The Xeroradiographic Plate

The plate is made up of a 9 1/2 by 14 inch sheet of aluminium, a thin layer of vitreous or amorphous selenium photoconductor, an interface layer, and an over cutting on the thin selenium layer

The Aluminium Substrate

The substrate for the selenium photoconductor should present a clean and smooth surface. Surface defects affect the Xeroradiographic plate's sensitivity by giving rise to changes in the electrostatic charge in the photoconductor[29]

The Interface Layer

This is a thin layer of aluminium oxide between the selenium photoconductor and aluminium substrate .The oxide is produced by heat treating the aluminium substrate. As a non conductor, the interface layer prevents charge exchange between the substrate and the photoconductor surface.[4]

The Selenium Coating

The thickness of this layer varies from 150micron meter for powder toner development .Amorphous or vitreous selenium coating, is formed by depositing a vapour form of liquefied selenium in a high vacuum. Because of its ease of use, fabrication and durability, inherent property of electrical conduction when exposed to x-rays and ability to insulate well when shielded from all sources of light, make selenium a Xeroradiographic material of choice. On the other hand, any form of impurity adversely affects its performance .Amorphous form is used in Xeroradiography because crystalline selenium's electrical conductivity is very high which makes it unsuitable in Xeroradiography. However, amorphous selenium undergoes a dark decay of about 5% per minute. A new system of xeroradiography which uses plates with thicker selenium layer (320 micron meter) gives about 50% x-ray absorption[.4]

Selenium Protective Coating

The protective coating is a 0.1micron meter cellulose acetate overcoat .The coat bonds intimately with selenium photoconductor. It helps to prevent degradation of electrostatic lateral image through the prevention of lateral conduction of electrostatic charges. Also it impacts positively on the shelf life of the Xeroradiographic plate[.4]

Advantages

Elimination of accidental film exposure, High resolution, Simultaneous evaluation of multiple tissues, Ease of reviewing, Economic benefit, Reduced exposure to radiation hazards, Wide applications- Generally Xeroradiography have interesting application in the management of neoplasm of laryngo-pharyngeal area, mammary and joint region, as well as aid in cephalometrics analysis.

Disadvantages

Technical difficulties, Fragile selenium coat, Transient image retention, Slower speed, Technical limitations

Uses

Diagnosis of periapical pathology in endodontics , Assessment of bone height in periodontics.

2. Digital Radiography

Since the discovery of x-rays in 1985, film has been the primary medium of capturing, displaying and storing radiographic images. It is a technology that dental practitioners are the most familiar and comfortable with the terms of technique and interpretation. Digital radiography is the latest advancement in dental imaging and is slowly being adopted by the dental profession .Digital or electronic imaging has been available for more than a decade. The first direct digital imaging system, RADIOVISIOGRAPHY (RVG) was invented by DR FRANCES MOUYANS and manufactured by TROPHY RADIOLOGIE in 1984.[6]

Film based and digital imaging principles:

Film based imaging consists of X-ray interaction with electrons in the film emulsion, production of latent image and chemical processing that transforms the latent image into visible one. As such radiographic film provides a medium for recording displaying and storing diagnostic information .Film based images are described as analog images. Analog images are characterized by continuous shades of grey from one area to the next between the extremes of black and white. Each shades of grey has an optical density (darkness) related to the amount of light that can pass through the image at a specific site. Film displays higher resolution than digital receptors with a resolving power of about 161p/mm. However, film is relatively inefficient detector and thus, requires relatively high radiation exposure. The use of rectangular collimation and the highest film speeds are the method that reduces radiation exposure; however the radiation exposure is still 2 to 3 times more than digital radiographic technique. The other disadvantages include chemicals to process the image and are often the source of errors and retakes.[7] The final result is a fixed image that is difficult to manipulate once captured .Digital imaging is the result of X-rays interaction with electrons in electronic sensor pixels (picture elements), conversion of analog data to a digital data, computer processing and display of the visible image on a computer screen. Data acquired by the sensor is communicated to the computer in analog form. Direct digital imaging systems produce dynamic images that permit immediate display, image enhancement storage, retrieval and transmission. Digital sensors are more sensitive than film and require significantly lower radiation exposure. It is a method of capturing a radiographic image using a sensor breaking it into an electronic pieces and presenting and storing an image using a computer. The sensor is used to receive the analog information and through analog to digital converter (ADC) to convert it to a digital image, array of picture elements called pixels, with discrete great values for each one. Special software is used to store and manipulate the digital image in the computer.[7]

Two digital radiography systems rely on the sensor-the direct and the indirect methods. A number of components are required for direct digital image production. These components include an X-ray source an electronic sensor, a digital interface card, a computer with an analog to digital converter (ADC), screen monitor software and a printer. Direct digital sensors are either a charged coupled device (CCD) or a complementary metal oxide semiconductor active pixel sensor (CMOS-APS).The CCD is a solid state detector composed of an array of x-ray on a light or a light sensitive pixels on a pure silicon chip. A pixel or a picture element consists of a small electron well into which the x-ray light energy is deposited upon exposure. The individual CCD pixel size is approximately 40micron with the latest version in the 20 micron range. The rows of pixels are arranged in a matrix of 1604 x 1208 pixels which is increased up to 2048 X 1680 pixels.[8] Charge coupling is a process whereby the number of electrons deposited in each pixel are transferred from one well to the next in a sequential manner to a read-out amplifier for image display on a monitor. There are two types of digital sensor array designs area and linear. Area arrays are used for intraoral radiography while linear arrays are used for extra oral imaging. Area arrays are available in sizes comparable to size zero, size 1and size 2 films, but the sensors are rigid and thicker than radiographic film and have a smaller sensitive area for image capture. The sensor communicates with a computer through an electric cable. Area array CCD has two primary formats: Fibre-optically coupled sensors and direct sensors. Fibre-optically coupled sensors utilize a scintillation screen coupled to a CCD. When x-ray interacts with a screen material, light photons are generated, detected and stored by CCD .Direct sensor CCD arrays capture the image directly. The complementary metal oxide semiconductor active pixel sensor (CMOS-APS) is the latest development in direct digital sensor technology. Externally CMOS sensors appear identical to CCD detectors but they use an active pixel technology and are less expensive to manufacturers

Advantages of Direct Digital Imaging

While digital X-ray sensors have long equalled analog film for diagnostic tasks, they have several advantages over film radiography, including the following[9]:-

Immediate image production with solid state device such as a charged coupled device (CCD) and a complementary metal oxide semiconductor (CMOS), Interactive display on a monitor with the ability to enhance image features and make direct measurements, Integrated storage, providing access to images through practice management software system, Security of available backup and offside anchoring, Perfect image duplicates to accompany referrals to other referrals to other practitioners, Security mechanisms to identify original images and differentiate them from altered images, Ability to tag information such as patient identifier, date of exposure and other relevant details, Interloper ability of the digital imaging and communications in Medicines (DICOM) which enables Clinicians with difficult equipment and software to view and the same image, The actual amount of exposure reduction is dependent on a number of factors including film speed sensor area, collimation and retakes

Disadvantages of Direct Digital Imaging

Rigidity and thickness of the sensor, Decreased resolution, Higher initial system cost, Unknown sensor lifespan transfer, Perfect semiconductor charge transfer, Infection control, Legal issues, Sterilization.

3. Indirect or Scanned Digital Imaging

Technique

As with direct systems, there are advantages and disadvantages to indirect systems. The smaller size and lack of a cord may make intraoral placement of phosphor plates easier than placement of direct sensors. Phosphorplates are somewhat flexible, but the corners cannot be bent (as is sometimes done with film) without damaging the plates. Phosphor plates can potentially be reused hundreds of times, but are susceptible to scratching which will shorten their useful life. Phosphor plates are light sensitive and exposure to ambient light must be minimized during the time period between removal from their protective cover and placement into the scanner. The length of time that plates are exposed to ambient light during this transfer process will determine the level of allowable ambient light at the scanner location. Scanners in which plates are loaded directly into a slot can generally be used in areas of higher ambient light compared to systems in which the plates are loaded ondrums prior to placement in the scanner.

The primary disadvantage of phosphor plate systems involves the time required to scan and erase the plates. Following exposure, plates must be removed from their contaminated barrier pouches, run through the scanner, "erased" with bright light, and repackaged in clean barrier pouches prior to using again. For plate erasure, some scanners incorporate an "erase" cycle within the scanner itself. With other units the plates are moved to a separate plate eraser following the scanning process. It is less expensive to purchase enough phosphor plates to place in every operatory compared to purchasing enough direct sensors for every operatory. The cost for an intraoral phosphor plate is less than twenty-five dollars compared to several thousand dollars for each direct sensor. Most existing panoramic and cephalometric units do not require expensive up grades for use with phosphor plates. Phosphor plates are simply placed in cassettes similar to film, except that no intensifying screens are used. Therefore, the same panoramic or cephalometric unit can be used to expose either conventional film or phosphor plates. Phosphor plate systems require purchase of a scanner.

Imaging area dimensions

The imaging area of direct sensors and phosphor plates can be compared to the imaging area of conventional dental film. Listed here are conventional film sizes for comparison purposes.

Size 0: 22 x 35 mm
Size 1: 24 x 40 mm
Size 2: 31 x 41 mm
Size 3: 27 x 54 mm
Size 4: 57 x 76 mm

The essential components of indirect digital imaging system include a CCD camera and computer. In this method the existing x-ray film is digitalized using a CCD camera. The CCD camera scans the image and then displays it on the computer monitor. This concept is similar in theory to scanning and image such as a photograph to a computer screen

Advantage of Indirect Digital Imaging

Thin sensor compared to direct digital imaging so the patient is more comfortable.

Disadvantage of Indirect Digital Imaging

Indirect digital imaging is inferior to direct digital imaging because the resultant image is similar to a "COPY" of the image versus the original.

4. Computed Tomography

History

The development of computed tomography was a milestone in radiology. Mathematician J.Radon laid the theoretical foundation for its development in 1917 when he demonstrated that the image of an object could be produced from a infinite sets of all of its projections. This foundation was first applied to Radio astronomy, optics and electron neuroscopy. This first clinical computed tomography X-ray unit first developed in 1972 by G.N. Horse field in England[10]

The pursuit of 3-d information has led to exploring the value of CT for the assessment of alveolar bone height. While CT provides exquisite 3D views, its ability to show very small details remains limited , usually not more than 1-2 mm. Although the level of image remains considerable lower than with conventional intraoral imaging, these advancements in CT technology satisfy almost all periodontal imaging needs from a pure technical and possibly diagnostic perspective. Studies have shown that CT assessment of alveolar bone height and intrabony pockets is reasonably accurate and precise[11]

Technique

The technique produces an axial cross sectional image of the head using a narrowly collimated, moving beam of X-rays. A scintillation crystal detected the remnant radiation of this beam, and the resulting analog signal was fed into a computer, digitalized analyzed by a mathematical algorithm and the data reconstructed as an axial tomographic image. The image produced by this technique was like no other x-ray image claimed to be 100 times more sensitive than conventional x-ray systems, it demonstrated differences between various soft tissues never before seen with x-ray imaging techniques. Since1972 computed tomography has many names, each of which referred to at least one aspect of the technique- computerized, axial tomography computerized reconstruction tomography, computed tomography scanning, axial tomography and computerized trans axial tomography. Currently the preferred name is COMPUTED TOMOGRAPHY, abbreviated at CT.[12]

A CT scanner consists of a radiographic tube that emits finely collimated, fan shaped X-ray beam directed to a series of scintillation detectors or ionization chambers. Depending on the scanner mechanical geometry both the radiographic tube and detectors may rotate synchronously about the patient and the x ray tube may move in a circle within the detector ring. CT scanners that employ this type of movement for image acquisition are called INCREMENTAL SCANNERS because the final image set consist of a series of continuous or overlapping axial images.

5. Newer Development

More recently CT scanner has been developed that acquire image data in a SPIRAL OR HELICAL fashion. With these scanners while the gantry containing the x ray tube and detectors revolves around the patient, the table on which the patient is lying continuously advances through the gantry.

This results in the acquisition of continuous spiral of data as the x ray beam moves down the patient. It is reported that compared incremental CT scanner spiral scanners provide multiplanner image construction reduce radiation dose (upto 75%). Regardless of the mechanical geometry, the transmission signal recorded by the detectors represents a composite of the absorption characteristics of all elements of the patient in the path of x ray beam.[13]

The CT image is a digital image reconstructed by computer, which mathematically manipulates the transmission data obtained from multiple projections. For example if one projection is made every one third of a degree, 1080 projections results during the course of a single 360 degree rotation of the scanner about the patient. Data derived from these 1080 projections (1080 projection constitute one scan) contain all the information necessary to construct a single image. The CT image is recorded and displayed as a matrix of individual blocks called VOXELS (volume elements). Each square of image matrix is PIXEL whereas the size of the pixel (about 0.1mm) is determined partly by the computer program used to construct the image, the length of the voxel (about 1- 20 mm) is determined by the width of x ray beam, which in turn is controlled by the pre-patient and post-patient collimators. Voxel length is analogues to the tomographic layer in film topography. For image display, each pixel is arranged a CT number representing dentistry. This number is proportional to the degree to which the material within the voxel has attenuated the X-ray beam. It represents the absorption characteristics or linear alteration coefficient of that particular volume of tissue in the patient CT numbers also known as HOUSEFIELD UNITS, may range from -1000 to +1000, each constitute the different level of optical dentistry. This scale of relative densities is based on air (-1000), water (0) and dense bone (+1000).

Advantages

CT has several advantages over conventional film radiography and film tomography.

CT completely eliminates the superimposition of images of structures outside the area of interest, Because of the inherent high contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished. Conventional radiography requires 10% difference in physical density to distinguish between tissues., Data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images, in the axial, coronal or saggital planes depending on the diagnostic task. This is referred to as MUTIPLANER REFORMATTED IMAGING, CT scan is superior to MRI when evaluating skull fractures, CT scan can provide detailed images of brain nervous system, CT is excellent for individuals involved in head trauma, CT is much cheaper than MRI and equally as fast, Artefacts are less of problem with a CT scan compared to MRI.[14]

Disadvantages

Increased radiation dosage. (This is about same radiation exposure that a normal individual will get in about 2 months., Economically not used for routine dental treatment, CT scan should never be done in a pregnant female because of the exposure of radiation risk to the foetus, The dye used in CT is iodine based and is often a cause of allergy. The dye can also lead to kidney failure in individuals with diabetes, Unlike adults CT scan should not be repeated in children because of the repeated radiation exposure, CT is not very good at identifying pathosis of soft tissue, CT is not good at identifying areas of inflammation or infection of the brain.

Uses

Primarily because of its high contrast resolution and ability to demonstrate small differences in soft tissue density, CT has become useful for the diagnosis of disease in the maxillofacial complex, including the salivary gland and TMJ. However with the advent of magnetic resonance imaging, which has proved superior to CT for depicting soft tissues the use of CT scanning for assessment of internal de-arrangement of the TMJ has decreased significantly. Additionally CT has been shown to be useful for evaluation of patients before placement of endo-osseous oral implants.

Despite the fact the similar information about the maxillary and mandibular anatomy can be obtained with film tomography, CT allows reconstruction of cross section image of the entire maxilla or mandible or both from a single imaging procedure. One of the first applications of 3D CT was the study of patient with suspected intervertebral disc herniation and spinal stenosis. The 3D CT has been applied to craniofacial reconstructive surgery and has been used both for congenital and acquired deformities and for evaluation of intracranial tumours, benign and malignant lesions of the maxillofacial region, cranial spine injuries pelvic fracture, and deformities of hand and feet. The availability of data in three dimension format also has allowed the construction of life sized model that can be used for trial surgeries and the construction of surgical stents for guarding dental implants placement, as well as the creation of accurate implanted prosthesis.

CT technology is been continually advanced. I matron (San Fransisco) has developed a CT scanners capable of acquiring data up to 10 times faster than conventional CT. Its ultrafast CT, which has scan times on the order of 50msec, is able to freeze cardiac and pulp monary motion enhancing the quality without motion artefacts

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