REVIEW ARTICLE

Digital Imaging

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ABSTRACT

With the rapid developments in the field of computers and technology, newer methods of image acquisition and processing are available, which have been made very easy to perform. These systems utilize electronic media to record the image and advanced computer software to process the acquired image and also to modify it according to our needs. In digital imaging, the tonal value of each pixel is represented in a binary code. The binary digits for each pixel are called "bits," which are read by the computer to determine the analog display of the image. The number of pixels-per-inch (ppi) is a good indicator of the resolution, which is the ability to distinguish the spatial detail of the digital image. The bit-depth and the pixel measurement of the pictures relate to the colours which are viewable in the image, and determine the size of the image file on a computer. Images with only two pixel shades – black and white – are binary. Gray-scale images are typically displayed in an 8-bit mode, which is 256 shades of gray.

The aim of this article is to enlighten this latest imaging technology with its advantages and disadvantages and its multiple applications in dentistry.

KEY MESSAGE

Continuing research efforts are required to address the technical and diagnostic performance of new technologies with respect to the specific clinical needs.

Key Words: Direct digital imaging, Photostimulable phosphor radiography, Charged couple device

INTRODUCTION

The advent of digital imaging has revolutionized radiology. The term 'digital radiography' refers to the method of capturing a radiographical image by using a sensor, breaking it into electronic pieces and presenting and storing the image by using a computer. This system is not limited to intraoral images; panoramic and cephalometric images may also be obtained [1]. With the rapid development in the field of computers and technology, newer methods of image acquisition and processing are available. These systems utilize electronic media to record the image and advanced computer software to process the acquired image and also to modify it according to our needs [2]. The diagnostic efficacy of intraoral radiography [3] with its limitations of clinical use, are often poorly understood or simply ignored. The aim of this article is to review the digital techniques with their advantages and disadvantages over the conventional imaging modality with reference to oral radiology.

DISCUSSION

Continuing research efforts are required to address the technical and diagnostic performance of new technologies with respect to specific clinical needs. Because detector technology only addresses one aspect of the diagnostic imaging chain, solutions might not be found merely on the basis of developments at this level. Studies are needed, that can help to improve our understanding of the complex relationships among x-ray attenuation, detector characteristics, and observer performance, and their effect on diagnostic performance and clinical outcomes. Although the currently available digital sensors are by no means ideal detectors, the increased spatial resolution and improved contrast characteristics of these sensors may already represent a level of receptor performance. The loss of oral hard tissues is a well-known public health problem for which better diagnostic methods are needed. X-ray films are poorly suited for absorptiometric measurements because their response is nonlinear and not very reproducible [4].

A study by White S C [5] (1992) says that continuing efforts to reduce the patients' dose are desirable; however, it has been demonstrated that the dose and the associated risks for patients who are subjected to intraoral radiography are very small [5]. This is especially true when an E-speed film and a rectangular collimation are used; moreover, the use of ionizing radiation for diagnostic purposes is based on cost-benefit considerations. As a result, the benefit of dose reduction should be considered in the context of physical characteristics and clinical diagnostic performance. A large number of studies have addressed the physical characteristics of intraoral films and digital systems [6-10]. An even greater number of investigators have studied the performance of emerging digital systems for various diagnostic tasks [11-14].

The rate at which new technologies are entering the marketplace and the limited amount of knowledge regarding the relationship between the physical characteristics and clinical outcomes, sustain a high demand for diagnostic efficacy testing. This would facilitate the clinical extension of scientific outcomes and the provision of data to drive the development of new technologies on the basis of diagnostic needs [15].

Diagnostic accuracy with intraoral radiography still leaves much to be desired, and detector technology only addresses one aspect of the diagnostic imaging chain. Further advancement requires a better understanding of the various components of the diagnostic imaging chain and their interactions with each other.

Various advantages of the digital systems are as follows. Chemical processing of the film is not required, the acquired images can be modified to obtain the desirable density and contrast and the exposure lattitude is higher in digital imaging as compared to films. Images can be obtained without the loss of their quality and can be retrieved as and when required. They can also be transmitted via electronic media [2]. The other advantages are; superior grey scale resolution [1], easy reproducibility, reduced exposure to radiation, increased speed of image viewing, lower equipment and film cost, increased efficiency, the enhancement of the diagnostic images and its strong efficiency as a patient education tool.

The various disadvantages [2] of the technique which were noted, are as follows. The expenditure involved in initially setting up a digital imaging system is quite high, the image receptors are vulnerable to the effects of rough handling, once damaged, they are expensive to replace and the image receptors are bulky and rigid and tolerate the rigid sensor in the mouth as compared to the film. The resolution of the images which are acquired with a digital system is inferior to the conventional film based images. At a time, not more than two to three teeth can be studied with digital image receptors. As for infection control [1], the sensor has to be covered adequately in a disposable plastic wrapper. There can also be legal issues, because the original digital image can be manipulated.

Three methods to obtain a digital image

1. **Direct digital imaging (DDI):** Here, a sensor [1] is placed in the patient's mouth and is exposed to radiation. The sensor captures the radiographical image and then transmits the image to a computer monitor, and within seconds, the image appears on the computer screen.
   The recent introduction of direct digital radiographical devices for oral use is a potential breakthrough for oral hard tissue measurement. Like films, photostimulable phosphor radiography (PPR) systems have good imaging characteristics and acceptable resolution [16]. Unlike films, the phosphor plates have a reproducible, linear response over many orders of magnitude [17-19] and are therefore well suited for quantitative measurement.
2. **Indirect digital image:** In this method, an existing x-ray film is digitized by using a CCD camera [1] which scans the image and the digitizer or converts the image and then displays it on the computer monitor.
3. **Storage phosphor imaging:** This is a wireless digital radiography system [1]. A reusable imaging plate which is coated with phosphor is used. These plates are flexible and fit into the mouth. The storage phosphor imaging records diagnostic data on the plates following the exposure to the x-ray source and uses a high speed scanner to convert the information to electronic files which can be displayed to electronic files, which can be displayed on the computer screen.

Analog versus Digital

A digital image [1] consists of a number of collections of individual pixels which are organized in a matrix of rows and columns. Each pixel has a row and a column coordinate that uniquely identifies its location in the matrix. The electrons that make up the electronic detector can be visualized as being divided into an arrangement of blocks or picture elements known as 'pixels'. A pixel is a small box or "well" into which the electrons produced by the x-ray exposure are deposited. A pixel is the digital equivalent of a silver crystal which is used in conventional radiography. As opposed to the film emulsion that contains a random arrangement of silver crystals, a pixel is structured in an ordered arrangement. The X-ray photons that come into contact with the electronic device, cause electrons to be released from the silicon and produce a corresponding electronic charge. Consequently, each pixel arrangement or electron potential well contains an electronic charge which is proportional to the number of electrons that react within the well. Furthermore, each electronic well corresponds to a specific area on the linked computer screen. When x-rays activate the electrons and produce such electronic charges, an electronic latent image is then transmitted and stored in the computer, which can be converted into a visible image on screen or can be printed on paper. The formation of a digital image requires several steps, beginning with the analog processes. At each pixel of an electronic detector, the absorption of x-rays generates a small voltage. At each pixel, the voltage can fluctuate between a minimum and maximum value and is therefore called as an Analog signal.

The production of a digital image requires a process called 'analog to digital conversion' (ADC). This consists of 2 steps

Sampling: That is a small range of voltage values which are grouped together as a single value

Quantization: In which every sampled signal, is assigned a value. The values are stored in the computer and represent the image. This is done by the computer by organizing the pixels in their proper locations and giving them shades of gray that corresponds to the number that was assigned during the quantization step [1].

The different types of sensors or digital detectors:

1. **Charged couple device (CCD):** This is a solid state detector [1] that contains a thin wafer of silicon chip with an electronic circuit embedded in it. The silicon chip is sensitive to x-rays or light. The silicon matrix and its associated readout and amplifying electronics are enclosed with a plastic housing to protect them from the oral environment.
2. **Complementary metal oxide semiconductors (CMOS):** These are silicon based semiconductors [1] where the pixel is isolated from its neighboring pixels and is directly connected to the transistor. This technology is believed to give 25% more resolution and the chip is less expensive and offers greater durability than the CCD.
3. **Charge injection device (CID):** This is another sensor technology. Structurally, it is very much like the CCD, but in this case, no computer is required to process the images.
4. **Photostimulable phosphor plates (PSP):** These absorb and store energy from x-rays and then release this energy as light when stimulated by other lights of radiographic imaging is Europium doped, barium fluorohalide.
5. **Flat panel Detectors (FPD):** These provide a relatively large matrix area with pixel sizes less than 100 microns. This allows the direct digital imaging of larger areas of the body, including the head.

The digital image display can be done by two ways:

1. Cathode ray tubes which are used in conventional computer monitors.
2. Thin Film Transistor (TFT) is used in laptops and in flat panel computer displays [1].

Digital Substraction radiography

This is used for the diagnosis of subtle changes in the bone [1]. Eg; it can be used to assess the bone levels before and after periodontal therapy, for the study of the periapical region and to study the superior surface of the condyle. The basic advantages include an improved overall contrast the structures are more closely visualized in the processed image, the trabecular fine marrow spaces are excellently visualized and low density as well as high density structures are equally enhanced and better visualized. The diagnostic problem in a radiographical examination lies primarily in the identification of the image features which are caused by a pathological process and are buried in a background of normal anatomical structures. During interpretation, the desired part has to be separated from the irrelevant distribution of other structures. The other structures which do not contain diagnostic information of interest have been termed as "noise". Here, the reference radiograph is digitized and converted into its positive image by the computer. The subsequent radiograph is then displayed on the same server and is aligned to the reference image and then digitized. Substraction of the gray levels between the two images is then performed. Any change that has occurred between the original radiograph and the subsequent radiograph shows up as light or dark areas. Loss of bone is seen as dark areas and gain of bone as the light areas [1]. To compensate for variations in the film response, oral hard tissue measurements with films are sometimes made with the aid of an intraoral step wedge. Correct placement of the wedge is however a problem, because it is difficult to match the cheek thickness and the scattered radiation intensity without superimposing the step wedge image on the teeth, bone, film-positioning device, or on the occlusal registration material [20], [21]. Subtraction radiography with films [22], [23] is improved by contrast and exposure corrections. The process is tedious and is of questionable validity for the detection of generalized bone loss (osteopaenia). The loss of a substantial amount of bone [24], [25] would violate a fundamental assumption by changing the histogram and would therefore reduce the apparent bone loss or gain if a histogram-based correction is used [15], [26]. No one has yet shown as to how to distinguish among the changes in the histogram which are due to changes in bone mass, film, exposure and processing. Indeed, an unambiguous distinction may not be possible from the image histograms alone. If contrast corrections and the use of intraoral stepwedges are fraught with difficulties, then a better and a more reproducible method for measuring x-ray attenuation is needed. [Table/Fig 1]

Film based imaging	Digital imaging
Density: The overall degree of darkness	**Brightness:** Digital equivalent to density or overall degree of image darkening
Latitude: Measure of range of exposure that will produced distinguished densities on a film	**Dynamic range:** The numerical range of each pixel; in visual terms it refers to the number of shades of gray that can be presented.
Film speed: sensitivity of the film to radiation.	**Linearity:** Linear or direct relationship between exposure and image density; contstrast is not affected
Contrast: differences in the densities between various areas on radiograph	**Contrast resolution:** The ability to differentiate small differences in density as displayed on an image.
Resolution: ability to distinguish between small objects which are close together	**Spatial frequency:** Measure of resolution expression in line pairs per millimeter.
Radiographic mottle/noise: Appearance of uneven density of an exposed film or graininess	**Modulation Transfer Function:** Measure of image fidelity as a function of spatial frequency; how close the image is to the actual object
Sharpness: Ability of the radiograph to define edge or display density borders	**Background electronic noise:** Small electrical current that conveys no information but serves to obscure the electronic signal.
	Signal to noise ratio: Ratio between the fraction of the output signal that is directly related to the diagnostic information and the fraction of output that does not contain diagnostic information (noise)

[Table/Fig 1]: Terminologies used for Film-based imaging and Digital imaging

(Courtesy: Freny R.Karjodkar, editor, Textbook of dental and maxillofacial Radiology. Jaypee brothers, Medical publishers)

Diagnosis

One of the most challenging areas of research [27] is the development of tools and procedures that can automate the detection, classification and the quantification of radiographical signs of the disease. The rationale for the use of such methods is to achieve early and accurate disease detection by using reproducible and objective criteria. The development of image analysis operations is very complex and requires a thorough understanding of anatomy, pathology and radiographical image formation. Caries detection, the classification of periodontal disease and the detection and quantification of periapical bone lesions. The success of many of these applications is highly dependent on specific imaging parameters. Very few of these provide reliable results when used clinically. This underscores the complexity of the radiographical image interpretation process.

Image store

The use of digital [27] imaging in dentistry requires an image archiving and management system which is very different from that which is used for conventional radiography. The storage of diagnostic images on magnetic or optical media raises a number of new issues that must be considered. The file size of the dental digital radiographs varies considerably, ranging from approximately 200kilobytes for intraoral images to as much as 6 megabytes for extraoral images. The storage and the retrieval of these images in an average sized dental practice is not a trivial issue. [Table/Fig 2]

Fortunately, the development of new storage media and the continuing decrease in the price of a unit of storage has alleviated the capacity issue in dental radiography. The hard drive capacities of modern computers already exceed the storage needs of most dental practices. The simplicity with which a digital image can be modified though image processing, poses a potential risk with respect to ensuing the integrity of the diagnostic information. Once they are in a digital format, critical image data can be deleted or modified. [Table/Fig 3]

Image Receptors For Extraoral Radiography

Most of these OPG machines have direct digital acquisition [27] panoramic machines. The receptor on such a machine is an array that transmits an electronic signal to the controlling computer, which displays the image on the view screen as it is being acquired. The software of the unit makes internal adjustments to the acquired data to render an interpretable image on the screen. The PSP plate is processed in the same manner as an intraoral PSP, and a similar image characteristic adjustment is automatically performed by the software package. Both these digital modalities allow the user to perform post-processing modifications on the image. DICOM- digital imaging and ccommunication in medicine allows rapid communication worldwide. DICOM is the international standard language for the electronic communication of digital images, be they radiographs, photographshistopathological slides, or any other type of "Picture images."

Clinical Consideration

Some fundmental differences from films in the clinical handling of digital receptors should be noted. Because digital receptors are intended to be reusable, they must be handled with greater care than their film counterparts. Indeed, in certain situations, films may be intentionally damaged through bending to accommodate the patient anatomy. This is never the case with digital receptors. Because of the inability of the digital detectors to be bent to accommodate patient anatomy, imaging strategies must be used for some patients.

The advantages of digital imaging [28] are that, it has a superior gray scale resolution, easy reproducibility, reduced exposure to radiation, an increased speed of image viewing, lower equipment and film cost, increased efficiency and the enhancement of the diagnostic images. It also gives an excellent quality image with no loss of quality. Loss of quality is commonly associated with conventional chemical processing. Image processing and enlargement and reconstruction for specific diagnostic purposes are possible with the help of computers. The detection of defects and the 3-dimensional visualization of the dental structures, based on radiographical data, is a possible effective patient education tool. The disadvantages include; the initial set up is costly and the sensor size is thicker than that of the intraoral films. For infection control, the sensor has to be covered adequately in a disposable plastic wrapper. There can be legal issues, because the original images can be manipulated.

CONCLUSION

A basic understanding of computers and the mastery of common computing skills is essential for viewing digital images. Beyond this, learning the pecularities will take time and may not be intuitive. Digital images avoid environmental pollutants which are encountered with film processing, but the initial financial outlay for digital imaging hardware make these systems more expensive than films. The mishandling of the digital system components can catastrophically shorten any projected life expectancy.

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