the Journal of Contemporary Dental Practice
at www.thejcdp.com
Volume 3 Number 4 November 15, 2002
Fall Issue

Digital Radiography: An Overview

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Abstract

Since the discovery of X-rays in 1895, film has been the primary medium for capturing, displaying, and storing radiographic images. It is a technology that dental practitioners are the most familiar and comfortable with in terms of technique and interpretation. Digital radiography is the latest advancement in dental imaging and is slowly being adopted by the dental profession. Digital imaging incorporates computer technology in the capture, display, enhancement, and storage of direct radiographic images. Digital imaging offers some distinct advantages over film, but like any emerging technology, it presents new and different challenges for the practitioner to overcome.

This article presents an overview of digital imaging including basic terminology and comparisons with film-based imaging. The principles of direct and indirect digital imaging modalities, intraoral and extraoral applications, image processing, and diagnostic efficacy will be discussed. In addition, the article will provide a list of questions dentists should consider prior to purchasing digital imaging systems for their practice.

Keywords: Radiography, digital imaging, electronic imaging, image processing, radiographic image enhancement

Citation: Parks ET, Williamson GF. Digital Radiography: An Overview. J Contemp Dent Pract 2002 November;(3)4:023-039.

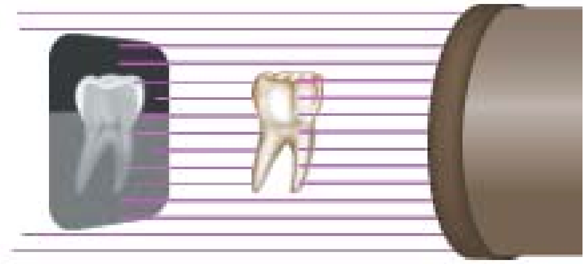
Introduction

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 Mouyens and manufactured by Trophy Radiologie (Vincennes, France) in 1984 and described in the U. S. dental literature in 1989.[1] Since then, the market has expanded and many digital imaging systems are available from a variety of dental X-ray machine manufacturers. It is estimated that 10-20% of dental practitioners use digital imaging technology in their dental practice.[2] It is anticipated these numbers will steadily increase over the next five to ten years as dentistry continues to move from film-based to digital imaging.

The purpose of this article is to discuss the principles of digital imaging including: direct and indirect digital imaging modalities, intraoral and extraoral imaging applications, diagnostic efficacy, image processing techniques, as well as a variety of factors dentists should consider when purchasing digital imaging systems. A variety of different terms are used to describe aspects of digital imaging and vary somewhat from film-based imaging. Definitions are listed in Table 1.

Film-based and Digital Imaging Principles

Film-based imaging consists of X-ray interaction with electrons in the film emulsion, production of a latent image, and chemical processing that transforms the latent image into a visible one.



As such, radiographic film provides a medium for recording, displaying, and storing diagnostic information.[3] Film-based images are described as analog images. Analog images are characterized by continuous shades of gray from one area to the next between the extremes of black and white. Each shade of gray has an optical density (darkness) related to the amount of light that can pass through the image at a specific site.[4] Film displays higher resolution (Table 2) than digital receptors with a resolving power of about 16 lp/mm.[5] However, film is a relatively inefficient radiation detector and, thus, requires relatively high radiation exposure.[3] The use of rectangular collimation and the highest speed film are methods that reduce radiation exposure, but these techniques are not practiced commonly in private dental offices.[6] Chemicals are needed to process the image and are often the source of errors and retakes. The final result is a fixed image that is difficult to manipulate once captured.[3]

Digital imaging is the result of X-ray interaction with electrons in electronic sensor pixels (picture elements), conversion of analog data to 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. Computers operate on the binary number system in which two digits (0 and 1) are used to represent data. These two characters are called bits (binary digit), and they form words eight or more bits in length called bytes. The total number of possible bytes for 8-bit language is $2^8 = 256$. The analog-to-digital converter transforms analog data into numerical data based on the binary number system. The voltage of the output signal is measured and assigned a number from 0 (black) to 255 (white) according to the intensity of the voltage. These numerical assignments translate into 256 shades of gray. The human eye is able to detect

Table 1: Terminology

Film-Based Imaging	Digital Imaging
Density – The overall degree of darkening of an exposed film	**Brightness** - Digital equivalent to density or overall degree of image darkening.
Latitude – Measure of the range of exposures that will produce usefully distinguishable 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 represented.
Film Speed – Amount of radiation needed to produce a standard density; refers to the sensitivity of the film to radiation. The faster the film, the less radiation required.	**Linearity** – Linear or direct relationship between exposure and image density (See Fig.1); contrast is not affected but density can be altered after image acquisition
Contrast – The difference in densities between various areas on a radiograph; high contrast images have few shades of gray between black and white while low contrast will demonstrate more shades of gray.	**Contrast Resolution** – The ability to differentiate small differences in density as displayed on an image.
Resolution - Ability to distinguish between small objects that are close together; measured in line pairs per millimeter.	**Spatial Frequency** – Measure of resolution expressed in line pairs per millimeter. **Modulation Transfer Function** - Measure of image fidelity as a function of spatial frequency; how close the image is to the actual object.
Radiographic Mottle (Noise) – Appearance of uneven density of an exposed film or graininess	**Background Electronic Noise** – Small electrical current that conveys no information but serves to obscure the electronic signal
Sharpness – Ability of a radiograph to define an edge or display density boundaries.	**Signal to Noise Ratio** – Ratio between the fraction of the output signal (voltage or current or charge) that is directly related to the diagnostic information (signal) and the fraction of output that does not contain diagnostic information (noise).

Table 2: Intraoral Receptor Comparison

Feature	Film	CCD	PSP
Radiation dose	Higher	Lower*	
Generation of Visible Image	Chemical	Computer	Laser scanner, computer
Image viewing	Delayed; viewbox transillumination	Real time on computer monitor	Delayed; computer monitor
Resolution**	16 – 20 lp/mm	8-10 lp/mm	6-8 lp/mm
Construction	Thin, flexible	Thick, rigid, wire	Thin, flexible
Lifespan	Single use	Reusable ¯ 10,000 exposures?	Reusable after erasure Not known
Infection control	Film barrier and/or drop-out technique	Barrier cover	
Common errors	Film placement Horizontal overlap	Horizontal placement Vertical angulation	Comparable to film
Image enhancement	Fixed unchangeable image	Multiple operations – contrast, density, magnification, positive/negative, measurement	
Storage	Patient record	Variety of archiving methods - server, Zip, CD	

* The actual dose reduction is dependent on factors such as film speed, collimation, exposure factors, and retakes.
** The unaided eye can resolve to approximately 10lp/mm.

approximately 32 gray levels.[7] Some digital systems sample the raw data at a resolution of more than 256 gray values such as 10 bit or 12 bit values.[8] The large number of gray values is reduced to 256 shades of gray with the advantage of controlling under or overexposed images.[8]

Direct digital imaging systems produce a dynamic image that permits immediate display, image enhancement, storage, retrieval, and transmission.[3] Digital sensors are more sensitive than film and require significantly lower radiation exposure. Dynamic range or latitude is the range of exposures that will produce images within the useful density range.[9] This corresponds to the straight line portion of the Hurter and Driffield (H & D) curve or the characteristic curve. (Figure 1) This curve demonstrates the relationship between exposure (number of X-rays) and optical density

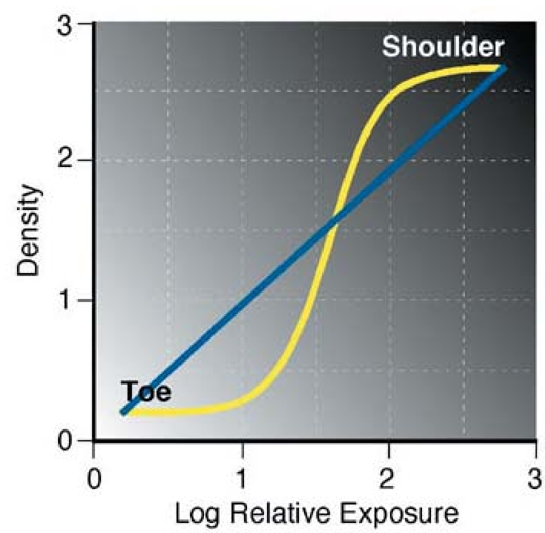


Figure 1

(darkness) of an image receptor. The scale of useful densities ranges from 0.6 (low density – light) to 3.0 (high density – dark).[10] Beyond these parameters, the image is not diagnostic. Typically, the H & D curve for film has a stretched letter S appearance with the top curve known as the shoulder and the bottom curve the toe. Exposure changes in the shoulder (high exposure) and toe (low exposure) have little affect on density, but small changes in the straight-line portion between them significantly affect density. The more vertical the straight-line portion of the curve is, the smaller the range and the narrower the film latitude. In comparison, the dynamic range of charged-coupled devices (CCDs) is linear with no shoulder or toe and is much wider than film.[5]

Direct Digital Imaging

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), a screen monitor, software, and a printer. (Figure 2) Typically, systems are PC based with a 486 or higher processor, 640 KB internal memory equipped with an SVGA graphics card, and a high-resolution monitor (1024 X 768 pixels).[11] Direct digital sensors are either a charge-coupled device (CCD) or complementary metal oxide semiconductor active pixel sensor (CMOS-APS).

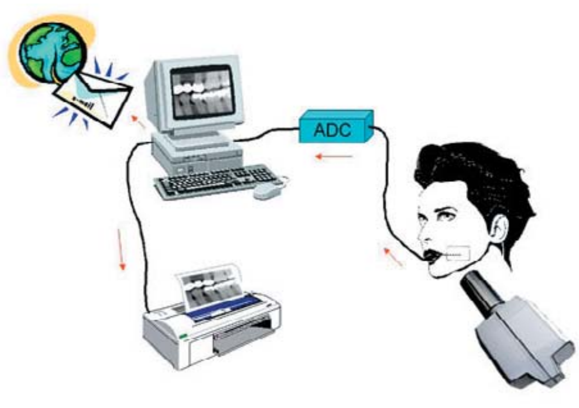


Figure 2

The CCD is a solid-state detector composed of an array of X-ray or light sensitive pixels on a pure silicon chip. A pixel or picture element consists of a small electron well into which the X-ray or light energy is deposited upon exposure. The individual CCD pixel size is approximately 40µ with the latest versions in the 20µ range.[8] The rows of pixels are arranged in a matrix of 512 x 512 pixels. 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 the monitor.[11] There are two types of digital sensor array designs: area and linear.[5] Area arrays are used for intraoral radiography, while linear arrays are used in extraoral imaging. Area arrays are available in sizes comparable to size 0, size 1, and size 2 film, but the sensors are rigid and thicker than radiographic film and have a smaller sensitive area for image capture. The sensor communicates with the computer through an electrical cable. Area array CCDs have two primary formats: fiberoptically coupled sensors and direct sensors.[5] Fiberoptically coupled sensors utilize a scintillation screen coupled to a CCD. When X-rays interact with the screen material, light photons are generated, detected, and stored by CCD. Direct sensor CCD arrays (Figure 3) capture the image directly.

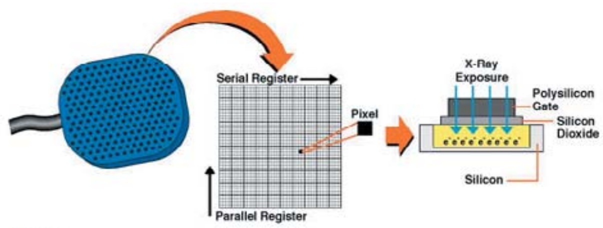
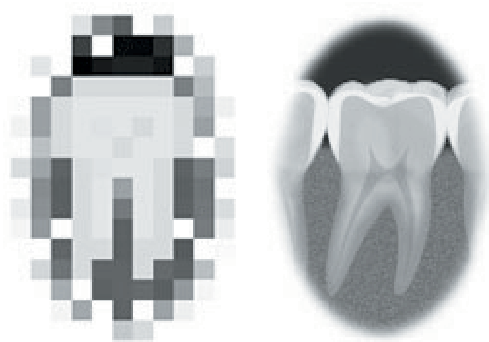


Figure 3

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 manufacture. The APS technology reduces by a factor of 100 the system power required to process the image compared with the CCD.[12] In addition, the APS system eliminates the need for charge transfer and may improve the reliability and lifespan of the sensor.[13] In summary, CMOS sensors have several advantages including design integration, low power requirements, manufacturability, and low cost.[11] However, CMOS sensors have more fixed pattern noise and a smaller active area for image acquisition.[11]

Advantages and Disadvantages

CCDs have distinct advantages over film in terms of exposure reduction, elimination of processing chemicals, instant or real time image production and display, image enhancement, patient education utility, and convenient storage.[12] The actual amount of exposure reduction is dependent on a number of factors including film speed, sensor area, collimation, and retakes. The primary disadvantages include the rigidity and thickness of the sensor, decreased resolution, higher initial system cost, unknown sensor lifespan, and perfect semiconductor charge transfer.[12] Infection control presents another challenge for clinicians using direct digital imaging. CCD sensors cannot be sterilized. Care needs to be taken to properly prepare, cover, and ensure the barrier is not damaged during patient imaging procedures. Direct saliva contact with the receptor and electrical cable must be avoided to prevent cross-contamination.



With regard to intraoral radiography, CCDs are not as forgiving of differences in technique[14] and patient discomfort may result in a greater number of retakes.[15] Versteeg et al. demonstrated substantial horizontal placement errors, especially in molar areas, and vertical angulation errors in the anterior regions in which the incisal edges were cut off and not viewable.[15] In this clinical study, three experienced radiography technicians each took periapical film and CCD images of 50 teeth. Twenty-eight percent of the CCD images were unacceptable and required retakes compared to 6% for film. Sommers et al. found a greater number of technique errors and unsatisfactory images occurred in CCD imaging when compared to film.[16] Twenty-seven student subjects exposed an average of 10 retakes using CCD receptors per ideal full mouth manikin series versus 3 retakes using film. The most common errors in periapical CCD imaging were vertical angulation and cone cutting, while the most common errors in periapical film-based imaging were placement and horizontal angulation. No difference in error type and number was found between systems for bitewing projections. In addition, it was concluded that the ease of retaking CCD images might increase the frequency of retakes when compared to film. In 2001, Wenzel and Moystad surveyed Norwegian dental practitioners regarding digital imaging for intraoral radiography.[17] Those using solid state sensors complained about sensor thickness and positioning difficulties and had more retakes compared to film. Overall, the majority of dentists reported that digital image quality (CCD and PSP) was the same or better than film with reduced exposure and examination time. However, practitioners reported that technical problems and repairs were common. Berkhout et al. surveyed Dutch dental practitioners who used digital imaging systems and obtained similar results. With regard to solid state sensors, practitioners found preparation and placement of the sensor significantly more difficult than for film. However, practitioners reported that processing, viewing, archiving, and system maintenance were easier than for film-based systems.

Diagnostic Utility of Digital Imaging

A number of studies have investigated the efficacy of digital imaging vs. film-based imaging in a variety of diagnostic tasks: caries, periodontal disease, and periapical lesion detection. Generally, the findings are consistent and demonstrate that film and digital imaging modalities are not significantly different in their ability to record dental disease states.[12,14,19-24] The following discussion presents a sampling of investigations that have been conducted in an effort to determine the utility of digital imaging in typical dental diagnostic tasks.

In 1998, Wenzel reviewed the evidence on the diagnostic efficacy of digital imaging systems for caries detection and concluded that digital imaging systems appear to be as accurate as film for caries diagnosis in general.[19] In 1998, Tyndall et al. investigated the accuracy of proximal caries detection comparing enhanced and unenhanced Siemans Sidexis CCD-based digital images with Ektaspeed Plus (Eastman Kodak, Rochester, NY) films.[20] Sixty carious and noncarious teeth were selected to provide 120 proximal surfaces for evaluation. The teeth were imaged and evaluated by six trained observers. The observers were instructed to score the presence or absence of a carious lesion on a 5-point scale and were permitted to optimize the digital image brightness and contrast as a third modality. It was concluded that unenhanced digital images were equivalent to film for the detection of proximal caries. However, observer enhanced Sidexis images exhibited a statistically significant lower diagnostic accuracy than the unenhanced digital and film images. The ability to enhance the images did not improve caries detection. Again in 2000, Wenzel reviewed digital imaging for dental caries and reiterated that current intraoral digital receptors seem to provide a diagnostic outcome as accurate as film.[21] To date, most studies have evaluated diagnostic performance in the laboratory setting, but few clinical studies have been conducted to determine whether the clinical efficacy approximates laboratory findings.

A number of studies have been conducted to explore the diagnostic efficacy of digital imaging with regard to periodontal lesions. Nair et al. investigated the accuracy of alveolar crestal bone detection utilizing Ektaspeed Plus film, Sidexis direct digital images, and brightness-enhanced digital images.[22] More than 100 proximal and furcal areas in both the anterior and posterior maxilla and mandible per three tissue-equivalent human skull phantoms were imaged. A panel of three experts assessed the presence or absence of crestal bone on all images. No significant differences were found in the diagnostic efficacy for periodontal lesion detection among the three modalities. In 2001, Wolf et al. conducted a study to determine the reproducibility and validity of linear measurements of interproximal bone loss in intrabony defects on digitized radiographs.[23] Fifty patients with moderate to advanced untreated periodontal disease had standardized bitewing radiographs taken of teeth with intrabony defects following initial periodontal treatment. All radiographs were digitized using a flat bed scanner and six different versions of each image were created; one unenhanced and five with selected enhancements. Trained examiners measured distances from the CEJ to alveolar crest and CEJ to bony defect on the various digitized versions. The results of the investigation determined that selected digital manipulations failed to produce statistically significant more reproducible or valid measurements of interproximal bone loss within intrabony defects when compared to digitized but unchanged images.

Several recent studies have been conducted to evaluate the efficacy of film and digital sensors in the detection of periapical lesions. Paurazas et al. conducted a study of the detection of periapical lesions using Ektaspeed Plus film, CCD, and CMOS-APS imaging systems.[12] Periapical lesions were made in the cortical and trabecular bone of 10 dried human mandibles using sizes 2, 4, 6, and 8 round burs and subsequently imaged. Seven observers were asked to indicate their certainty of the presence or absence of a lesion using a 5-point scale. No significant difference in diagnostic performance was found between the three modalities in the detection of periapical bony lesions. Regardless of the type of imaging system, lesions in cortical bone were detected more accurately than lesions in trabecular bone. But when cortical bone was involved, lesion identification approached a high level of accuracy. In 2001, Wallace et al. investigated the diagnostic efficacy of film and digital sensors in the detection of simulated periapical lesions.[14] Lesions were created using sizes 1, 2, 4, and 6 burs in the periapical regions of 24 human mandibular sections invested in acrylic and imaged using Ektaspeed Plus film, CCD, and PSP systems. A panel of four calibrated observers determined the presence or absence of a lesion using a 5-point confidence rating scale. The results demonstrated that film displayed the highest sensitivity and specificity followed by PSP and CCD images when observers were able to adjust digital image contrast and brightness enhancements.

Indirect or Scanned Digital Imaging

Direct digital imaging indicates the original image is captured in a digital format, i.e., the image is made up of discrete packets of information called pixels (picture elements). On the other hand, indirect digital imaging implies the image is captured in an analog or continuous format and then converted into a digital format. As with any data conversion, this analog to digital conversion (ADC) results in the loss and alteration of information. Figure 4 demonstrates the most common data alteration that occurs in an analog to digital conversion. Instead of capturing the border that traverses a particular pixel, the pixel value is averaged. This is called partial volume averaging. Consequently, many edges are lost or distorted in an analog to digital conversion. The original indirect digital imaging technique was to optically scan a conventional film image (analog) and generate a digital image. Obviously, this technique required an optical scanner capable of processing transparent images as well as the appropriate software to produce the digital image. As imaging systems became more sophisticated, other techniques for capturing the digital image from an analog original were developed. Many intraoral videocameras (IOVC) allow the clinician to capture an analog conventional radiograph with a push of the foot pedal. The image is grabbed as a frame of a video image. One of the shortcomings

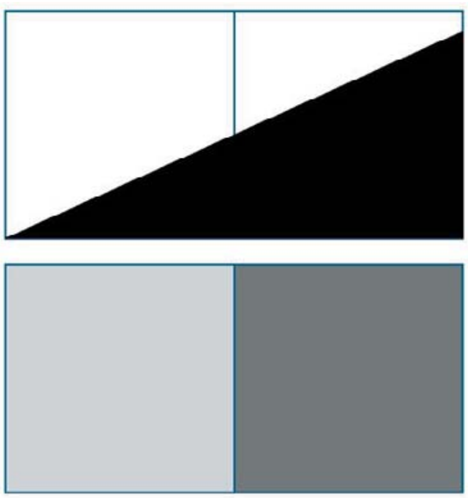


Figure 4

of this technique is that a gray scale image is captured in a color image format. Many of these images appear blue and the file size may be three times the size of the same image captured in a gray scale format.

Indirect Photostimuable Phosphor Plates

Imaging using a photostimulable phosphor (PSP) can also be described as an indirect digital imaging technique. The image is captured on a phosphor plate as analog information and is converted into a digital format when the plate is processed. (Figure 5) Photostimulable phosphor radiographic systems were first introduced in 1981 by the Fuji Corporation (Tokyo, Japan).[24] The PSP consists of a polyester base coated with a crystalline halide emulsion that converts X-radiation into stored energy. The crystalline emulsion is made up of a europium-activated barium fluorohalide compound ($BaFBrEu^{2+}$).[25,26] The energy stored in these crystals is released as blue fluorescent light when the PSP is scanned with a helium-neon laser beam. The emitted light is captured and intensified by a photomultiplier tube and then converted into digital data. Not all of the energy stored in the PSP is released during scanning and consequently, the imaging plates must be treated to remove any residual energy. PSP technology is used for intraoral as well as extraoral imaging.[27] Several PSP systems are currently available.

Numerous studies have evaluated the diagnostic utility of the PSP systems.[28,29,30] Most studies report comparable utility when evaluating conventional film images with PSP images. Svanaes and associates reported no difference in proximal caries detection between PSP and Ektaspeed film.[28] Cederberg and associates found that PSP images performed better than conventional Ektaspeed film images for the determination of endodontic working lengths.[29] PSP images appear to have a limiting resolution of approximately 6 lp/mm (line pairs per millimeter). This resolution is significantly less than can be achieved with conventional film (~20 lp/mm) but not much different from what can be perceived with the naked eye (8-10 lp/mm).

Figure 5

A major advantage of the PSP image receptor is that it is cordless. This significantly impacts the ease of receptor placement. The receptor is approximately the same size as conventional film and is somewhat flexible. However, the impact of this flexibility on receptor longevity has not been determined. Additionally, it should be kept in mind that numerous image receptors are needed in a busy practice (e.g., 20 receptors for a full mouth series of radiographs). These sensors must also be kept in an infection control barrier because the imaging plate cannot be sterilized. Finally, the receptors must be erased by exposure to white light before reuse.

Extraoral Imaging

Extraoral digital imaging can be accomplished utilizing direct or indirect digital imaging systems. There are several panoramic systems available that use either linear array CCD or PSP plate sensors. The cost of the sensor, the time needed to capture the image data, and file size are all considerations that must be evaluated when considering a digital panoramic system. In either case, the method is similar to conventional panoramic radiography, but the receptor, processing, display, and storage differ from film-based imaging. Both film-based and digital formats produce comparable images with spatial resolution of 4 lp/mm.[31]

Plain head films can also be captured using PSP technology. CCD or CMOS based plain film systems are also being developed. The PSP image receptor for extraoral imaging will be the same size as conventional film. The cost would be prohibitive to produce an area array the size of a panoramic film using either CCD or CMOS sensors. Consequently, the trade-off is determining the smallest size of array that can capture an extraoral image without taking too much time to off load the captured signal. The design for a CCD or CMOS area array for panoramic imaging is less complex because only a small part of the image is captured at any given time. The extraoral plain film images create a huge design problem because conventional plain film images are captured with a single exposure. Consequently, the image receptor needs to be the size of conventional film to maintain a similar patient exposure. Another option is to shape the beam so it can move at the same time the image sensor moves. Then the rate-limiting step is the ability of the sensor to off load data. Once a digital image has been captured, it must be saved. Extraoral images can be quite large. For example, an 8 by 10 inch head image with a resolution of 10 lp/mm would produce a file in excess of 20 million bytes—roughly 20 floppy disks. Obviously, this amount of data would overwhelm the storage capacity of most computers in a very short time. Consequently, the file size must be decreased or compressed. Images can be compressed in two ways: lossless and lossy compression. Lossless compression means just that, no information is lost in the compression of the file. Unfortunately, lossless compression algorithms (e.g., LZW) can only produce about a 2:1 compression ratio, which would decrease the file size by one-half. Lossy compression algorithms result in lost data but can produce much higher compression rations. Two of the more common lossy compression algorithms are JPEG and Wavelet compressions. Wavelet compressions can produce a 300:1 compression ratio but also generate an image with no diagnostic utility. Research is ongoing to determine the maximum compression ratio that can still produce an image with acceptable diagnostic utility. Currently, 10:1 or 15:1 compression ratios are considered acceptable for most medical imaging. Either JPEG or Wavelet compression algorithms can produce acceptable images at either the 10:1 or 15:1 compression ratios.

Image Enhancement

Regardless of the method by which an image is captured, once it has been digitized, several computerized enhancements can be performed on the image. Density and contrast can both be altered. The ability to alter density allows the clinician the chance to “salvage” an image that is either too dark or too light. There is a limit to the ability to salvage poor images. You cannot save an image in which all of the pixels have been saturated (too dark) or where the noise (useless information) in the system overwhelms the signal (useful information). Density can be manipulated by simply adding (or subtracting) the same value to each pixel. Image contrast can also be manipulated by altering the gradient of the gray levels in the image. Again, there is a limit to how much contrast can be altered. Manipulating the image contrast cannot salvage an image in which the subject contrast is inadequate. Other image enhancements include inversion of the gray scale (flip-flop of black and white in the image), magnification, and pseudocolor enhancement. While pseudocolor enhancement is attractive, the diagnostic utility of this feature has not been demonstrated. When a clinician looks at a radiographic image, he or she knows what the relationship of the different gray levels means. The addition of color without an understandable gradient provides no new information. Obviously, if a digital system could identify carious lesions as red, this enhancement would be of great value. Several software packages are in the development stage to perform such a task but are not currently available.

Digital Subtraction Radiography

For years dentistry has dealt with the problem of no quantitative measures to determine the success of a particular treatment. When evaluating bone height, changes can be masked by disparities in projection geometry. Digital subtraction radiography is a technique that allows us to determine quantitative changes in radiographs. The premise is quite simple. A radiographic image is generated before a particular treatment is performed. At some time after the treatment, another image is generated. The two images are digitized and compared on a pixel-by-pixel basis. The resultant image shows only the changes that have occurred and "subtracts" those components of the image that are unchanged. (Figure 6) The magnitude of the changes can then be measured by evaluating the histogram (graphic depiction of the distribution of gray levels) of the resultant image. If the exact projection geometry and receptor placement are not recreated, the changes in the subtracted image will demonstrate the effects of misregistration rather than the effects of a therapeutic intervention. Direct digital imaging has been a great help in the quest to take the technique of digital subtraction radiography out of the laboratory setting and actually use it clinically.[32] The greatest advantage offered by direct digital imaging (and PSP) is the image file sizes are always the same. You cannot perform a digital subtraction unless you have the same number of pixels in both images. Now that consistent file sizes can be achieved, the attention is being directed towards methods for recreating image receptor placement and projection geometry so dentistry can start to provide quantitative data about treatment outcomes.

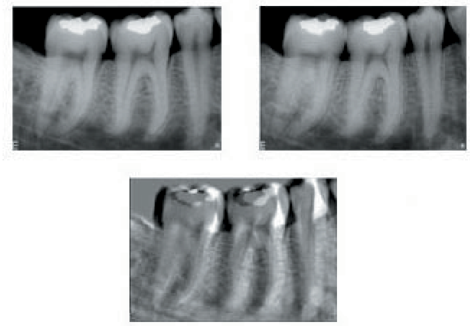


Figure 6

Image Output

Once an image is captured, it must be converted into a form that can be evaluated. Viewing the image on a computer screen allows the clinician to use the information captured in the image but does not allow the image to be shared with other clinicians. A digital image can be sent to a distant site as long as that site is equipped with the appropriate software to convert the digital information into a visible image. This can be accomplished by either both sites having the same software or by producing an image that can be read by many different image processing software packages. The ability to send an image to a distant site is called teleradiography. The size of the image and the speed of the image transfer are major considerations when considering the hardware requirements of sending radiographic images to distant sites. There is also some concern regarding licensure when an image is transmitted to a different state for consultation. These issues are currently being addressed. Another alternative is producing a printed copy of the image. Numerous printers are available as are types of paper on which to print the image. The major considerations for choosing a printer are cost, output resolution, paper requirements, and gray scale. The impact of cost is obvious. Output resolution is measured in dots per inch or dpi. A 600 dpi printer should be able to accurately display an image with a resolution of approximately 12 lp/mm. Some printers require special paper for the output of radiographic images. The cost of the required paper is a consideration when determining the cost/benefit ratio of the use of a radiographic digital imaging system. Finally, the printer must be able to generate an image with 2^8 or 256 shades of gray. A half-tone printer would provide a 1-bit image rather than an 8-bit image.

DICOM Standard

Medical imaging has dealt with many of the issues that confront digital dental imaging. Medical radiologists found that many of their imaging systems could not communicate with each other. Most manufacturers had their own proprietary software and file types that were not compatible with those of other manufacturers. This led to the development of the DICOM Standard.[33] DICOM stands for Digital Imaging and Communications in Medicine. The current version is 3.0. The DICOM 3.0 standard addresses the need for standardized formats so digital information can be transferred to remote sites as well as local workstations. Dentistry is beginning to recognize the DICOM 3.0 standard, but there is still no uniform implementation of the standard.[34] When one is evaluating a digital system, it is important to determine if the system is DICOM compliant. By being compliant, the system utilizes common file formats that are universally recognized. This is of particular importance when one is contemplating digital image submission to insurance companies or determining if all of the office software is compatible (e.g., dental record, voice activated charting).

Checklist

There is a wide array of digital radiographic imaging products on the market. The busy clinician can easily go into information overload when evaluating these products for potential use in their practice. The following list of questions should help the clinician decide what role digital radiographic imaging will have in his/her dental practice. Although the list is not all inclusive, it will provide a good starting point for the clinician to prepare and ask the right questions when evaluating a digital radiographic imaging product.

Before you take the plunge, you need to ask yourself these questions:

1. What are your expectations of digital radiography?
2. What types of procedures are most commonly performed in your office?
3. How many of those procedures are amenable to the use of digital radiography?
4. How many operatories are equipped with tubeheads?
5. How modern are your tubeheads?
6. Do you anticipate sending images electronically?
7. What is the status of your office electronic infrastructure (i.e., wiring, modem, DSL, hard drive space)?
8. Is your office paperless? Do you want it to be?
9. What other electronic components are present?
10. Is your staff willing to learn new techniques?
11. Do you have time in your schedule to allow for a learning curve?
12. Can you handle a system crash as a part of your normal day?
13. When, where, and how will the system be serviced and upgraded?
14. What services and costs are involved in warranty contracts?

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