Digital Radiography in Dentistry:
Moving from Film-based to Digital Imaging

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Continuing Education Units: 4 hours


Disclaimer: Participants must always be aware of the hazards of using limited knowledge in integrating new techniques or procedures into their practice. Only sound evidence-based dentistry should be used in patient therapy.

This continuing education course will provide a foundation for understanding digital imaging technology, necessary equipment, digital imaging receptors, technique, acquisition, enhancement, transfer and storage. Comparisons with film-based imaging as well as the diagnostic utility of digital images will be discussed.

Conflict of Interest Disclosure Statement
• The author reports no conflicts of interest associated with this work.

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Overview

For more than a century, radiographs have been made using radiographic film. However, traditional film is being replaced by digital imaging in both private practice dental offices and academic institutions for educating dental professionals. Digital imaging reduces radiation exposure to the patient and offers quick, convenient image acquisition, viewing and storage and eliminates darkroom processing that leads to many film-based errors.

Technology supporting digital dental radiology began in France in 1984. An article describing direct digital imaging technology was first published in U. S. dental literature in 1989. Since then, digital imaging technology has evolved with improvements in sensor design, computer software, hardware packages and technical support. The following course will provide a foundation for understanding digital imaging technology, necessary equipment, digital imaging receptors, technique, acquisition, enhancement, transfer and storage. Comparisons with film-based imaging as well as the diagnostic utility of digital images will be discussed.

Learning Objectives

Upon completion of this course, the dental professional should be able to:

• List the basic components of a digital imaging system.
• Outline the advantages and disadvantages of digital imaging as compared to film-based imaging.
• Explain the difference between analog and digital data.
• Differentiate between direct and indirect digital imaging.
• Compare and contrast digital imaging receptors.
• Discuss the basic infection control requirements for intraoral digital receptors.
• Describe the procedure used to acquire and store a digital image.
• Discuss the digital applications for extraoral digital imaging.
• Describe the enhancement features available with digital imaging systems.
• List common errors that occur in digital imaging.
• Discuss the importance of Digital Imaging and Communications in Medicine Standard (DICOM) in digital imaging.

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Glossary

**absorption** – Transfer of some or all of x-ray photon energy to material or matter; dependent on the energy of the x-ray beam and composition of the absorber.

**ALARA** – Safety principle that states that radiation exposure should be kept to a minimum or as low as reasonably achievable.

**algorithm** – Computer-adapted mathematical calculation applied to raw data during image reconstruction.

**analog data** – Data characterized by a continuous grayscale from black to white.

**analog to digital converter (ADC)** – Device that converts the analog output signal into numeric data based on the binary number system of 0 and 1; 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.

**area array** – Matrix or layout of pixels in columns and rows; format for intraoral direct digital receptors.

**back up** – Copying files from the hard drive to another medium, such as compact disks, to store files and use in the event that data is lost.

**binary number system** – Computer language in which two digits, 0 and 1, are used to represent information.

**bit** – Binary digit, smallest unit of information that a computer is able to recognize and represent in the form of 0 or 1.

**brightness** – Digital equivalent to density or overall degree of image darkening.

**bytes** – Group of eight bits that represents one character or digit; the number of possible bytes in computer language is $2^8$ or 256.

**bus** – Path the computer uses to transfer data.

**cephalometric radiography** – Extraoral images of the skull accomplished by use of a head positioning device or cephalostat, typically 8” x 10” projections; the lateral head plate is a common view used in orthodontic evaluation.

**charge coupled device (CCD)** – Solid-state, silicon chip detector that converts light or x-ray photons to electrons.

**collimation** – Device used to restrict the size and shape of the x-ray beam.

**complimentary metal oxide sensor (CMOS)** – Solid-state detector similar to the CCD with built-in control functions, smaller pixel size and lower power requirements.

**complimentary metal oxide sensor active pixel sensor (CMOS-APS)** – CMOS detector with active amplifying transistors integrated in each pixel to decrease noise and improve signal output.

**contrast** – The difference in densities between various areas on a radiographic image; high contrast images have few shades of gray between black and white while low contrast images will demonstrate more grays.

**contrast resolution** – The ability to differentiate small changes in density as displayed on an image.

**data compression** – Method of storing data in a way that requires less space or memory.

**density** – Overall degree of blackness or image darkening of an exposed film; comparable to brightness in digital imaging.

**DICOM (Digital Imaging and Communications in Medicine)** – Standard with detailed specifications that describes a method of formatting and exchanging digital images and related information; standard applies to the operation of the interface used to transfer data in and out of an imaging device.

**digital image** – A video image in pixel format that can be stored in the computer memory for processing.

**digitization** – Conversion of an incoming analog signal into a digital or numeric value for storage and processing.
**direct sensor** — Receives radiation directly like film and deposits the energy in the electron wells or picture elements.

**distance and position rule** — Radiation safety rule in which the operator stands 6’ from source of x-rays and positioned between 90° - 135° angle to the primary beam to minimize occupational exposure.

**dpi (dots per inch)** — Method of measuring the density output of scanners and printers; the greater the dpi, the better the resolution of the printed image.

**dynamic range** — The numerical range of each pixel; in visual terms it refers to the number of shades of gray that can be represented.

**edge** — Borders between regions of an object.

**electron well** — Individual pixel into which x-ray or light energy is deposited during x-ray exposure of CCD or CMOS detectors.

**fiber optics** — Thin transparent fibers of glass or plastic material that transmit light throughout their length by internal reflection.

**filtering** — Analog or digital image processing used to enhance or modify an image.

**focal spot** — Anode tungsten target where x-rays are generated; focal spot size should be as small as possible in the range of .5 to 1.5 mm²; the size has an influence on image quality in terms of sharpness and geometric distortion.

**gigabyte (GB)** — Unit of computer storage equivalent to a billion bytes.

**gray level** — Measure of image brightness or intensity in a range between black and white.

**hard drive** — Hardware that contains the hard disk or storage disk inside the computer.

**hardware** — The physical parts or components of the computer system.

**histogram** — Graphic representation of the frequency of each gray value that appears in the image.

**histogram equalization** — Modification of the histogram to evenly distribute a narrow range of gray levels across the entire available range.

**image processing** — An operation used to improve, correct, analyze or alter an image.

**image enhancement** — Image processing operations that alter the visual appearance of the image; typical enhancement tools include density, contrast, colorization, and various filters.

**image matrix** — The layout of cells in rows and columns with each cell corresponding to a specific location and representing the brightness or intensity in that location.

**indirect sensor** — Receptor that receives x-rays upon exposure and stores the energy until released via a scanning process.

**intensity** — The relative brightness of part of an image.

**kilovoltage (kV)** — Potential difference between the anode and cathode in an x-ray tube; it controls the quality or penetrating power of the x-ray beam.

**latitude** — Measure of the range of exposures that will produce usefully distinguishable densities on a film.

**linearity** — Linear or direct relationship between exposure and image density; contrast is not affected but density can be altered after image acquisition.

**linear array** — A solid-state detector that consists of a single row of pixels; used in direct digital extraoral imaging.

**line pair** — A bar and its interspace of equal length; used to quantify the resolution of an image.

**lossy** — Storage method in which some data is lost but the compressed file is still capable of producing a diagnostically acceptable image.

**lossless** — Storage method in which no information is lost in the compression of a file.
memory – High speed, large capacity storage in the computer where data and images are stored and retrieved.

network – Method of connecting several computers so that they interact with each other and information can be accessed and displayed at any workstation in the network.

noise – Unwanted or irrelevant information that interferes or undermines diagnostic information.

operating system (OS) – Computer system that links the computer with the user.

output – Processing of transferring information from primary memory to storage or the user.

photon – Electromagnetic radiation in the form of x-rays and gamma rays that interact with matter like a particle or small bundle of energy rather than a wave.

photostimulable phosphor plate (PSP) – Polyester base coated with a crystalline halide emulsion; the plate converts x-ray energy into stored energy that is released when scanned with a helium-neon laser beam.

photostimulation – Emission of visible light after excitation by a laser light beam.

photomultiplier tube – Electron tube that converts visible light into an electrical signal.

pixel – Picture element; individual cell of the image matrix in which the value of cell determines brightness.

primary barrier – Protective barrier adequate to absorb the primary or useful beam.

RAM (random access memory) – Temporary memory of the computer in which programs and information are stored.

receptor – Any device or medium that transforms x-ray energy into latent images that can be made visible by processing.

resolution – Measures how well a radiographic image reveals small objects that are close together; measured in line pairs per millimeter.

sharpening – Computer operation that enhances edges.

sharpness – Ability of a radiographic image to define an edge or display density boundaries.

software – Computer programs that tell the hardware what to do and how to store data.

spatial frequency – Measure of resolution expressed in line pairs per millimeter.

spatial resolution – Measure of the extent that the displayed image appears identical to the original analog image; determined by the number and size of the pixels used to compose the displayed image.

storage phosphor – Another term or name for photostimulable phosphor plate receptors.

subtraction – Computer processing technique that subtracts information from pre- and post-radiographic images by removing all unnecessary structures and enhancing areas of interest or change.

teleradiography – The process of remote transmission and viewing of digital images.

template – A pattern or format used to create a document or file that is similar but may have some small differences.

USB (universal serial bus) – Hardware bus standard that permits the user to plug a peripheral into a USB port and have it automatically configured for use.

workstation – Desktop computer system often connected to larger computer systems to allow users to transfer and share information.

x-rays – A form of electromagnetic radiation with wavelengths shorter than visible light with abilities to penetrate, ionize and produce a latent image.

Equipment Requirements
Digital imaging utilizes computer technology and digital receptors for the acquisition, viewing, enhancement, storage and transfer of radiographic images. Essential components include an x-ray machine capable of producing...
small increments of radiation, a computer and monitor with appropriate hardware, software, and printing capabilities, an analog-to-digital converter and a digital sensor.

In some instances, older x-ray equipment may need to be replaced in order to achieve the lower exposure settings used for digital radiography. X-ray units recommended for use in digital radiography should have the following characteristics: the smallest focal spot possible, an accurate timer capable of producing very short exposures, direct current with 70 kV setting or below and 5 mA or less and rectangular collimation. Technical specifications vary among manufacturers but typical minimum requirements include an Intel® Core™ i3/i5 processor with Microsoft® Windows® operating system (8 Pro, 7, XP Pro, Vista), 2 GB RAM and 250 GB of hard disk drive, minimum CRT with .28 dot pitch @ 800 x 600 or flatscreen LCD with 400:1 contrast ratio @ 1024 x 768, USB 2.0 port and Intel® chipset and database server (MSDE SQL Server 2000 or SQL Server Express). Daily back-up of digital data is recommended. Other peripherals may be needed or desired depending on the digital system selected, network set-up, and accessories that the clinician may want to supplement the imaging capabilities.

The optimal application of digital technology in the dental practice setting is to have a networked office system that is paperless and integrates all aspects of the patient record, including medical and dental history information, digital radiography, intraoral camera and cosmetic dentistry imaging, with patient education and entertainment resources, as well as billing capabilities.

When new technology such as digital radiography is implemented in the office, it is important that all members of the office staff are committed to the change, receive training, and have an opportunity to prepare and practice before utilizing the technology on patients. This will make the transition smoother, allow clinicians to gain confidence and competence with the new technology and be able to present it in a positive and enthusiastic manner to patients.

Advantages and Disadvantages
Digital radiography is a very attractive alternative to film-based imaging. One of the most commonly cited positive features is radiation dose reduction. Intraoral imaging dose reduction is dependent on the particular film speed used, number of images taken, beam collimation and the number of retakes. Intraoral digital image receptors provide equal or greater dose reduction compared to F speed film. Greater dose reduction can be achieved when retakes were eliminated and the number of additional images is limited. There is no significant dose reduction in extraoral digital imaging when digital systems are compared to high-speed film and rare-earth screen combinations.

Other obvious benefits include the elimination of the darkroom, processing chemistry and the errors associated with improper darkroom maintenance, chemical handling, solution replenishment and replacement. Several studies have indicated that improper processing is the most significant contributor to retakes in film-based imaging. Additional advantages include the ability to view the image more quickly, enhance the captured image as well as the ease of storage, retrieval, duplication and transmission. Digital receptors are reusable but may require replacement if mishandled or damaged. Adoption of digital technology presents the office in a positive light and infers that the dentist and supportive dental health professionals are up-to-date with current trends in dentistry.

The major disadvantages of digital radiography include the cost of the systems and their set up, susceptibility of some receptors and/or components to damage, high receptor replacement costs and other issues related to a relatively new industry such as system obsolescence or manufacturers going out of business. Manufacturers of digital imaging systems continue to address these concerns and have made progress in these areas. Spatial resolution has also been cited as a disadvantage of digital imaging when compared to film. Theoretically, the spatial resolution of digital imaging systems ranges between six and twenty-six line pairs per millimeter (lp/mm) compared to more than 20 lp/mm for film. However, the actual resolution is typically lower due to noise and other aspects in signal transfer and image production. PSP systems have lower spatial resolution than solid-state digital detectors and...
the more recent CMOS detectors appear to have higher spatial resolution than CCD detectors. In addition, there are certain features of intraoral sensors that make them less desirable than film in terms of infection control and placement inside the mouth. These particular aspects will be addressed in the next section.

**Intraoral Digital Radiography**

Digital imaging is very similar to film-based imaging in that it requires x-ray interaction with a receptor, latent image processing and subsequent viewing of the image. In digital imaging, the receptors are highly sensitive sensors that require considerably less radiation exposure than film. The data acquired by the receptor is analog data in the form of a continuous gray scale and must be converted to digital data to be useful. The ADC or analog-to-digital converter transforms analog information into numerical information based on the binary number system. Computers operate on the binary number system in which two digits (0 and 1) are used to represent data or information. These two characters are called bits (binary digit) and they form words eight or more bits in length termed bytes. The total number of possible bytes for 8-bit language is $2^8 = 256$. 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. Some digital systems sample the raw data at a resolution of more than 256 gray values such as 10 bit or 12 bit values but are reduced to 256 shades of gray. Once the computer processes the data, the image appears on the monitor for interpretation, enhancement and subsequent storage.

**Intraoral Digital Receptors**

Digital radiography receptors include “direct” and “indirect” receptors. Direct receptors communicate with the computer through an electronic cable, although a wireless sensor system is available that transfers data through a radiofrequency transmitter. Indirect receptors require a scanning step.

**Direct Receptors**

The charge-coupled device (CCD), complimentary metal oxide semiconductor (CMOS), and the complimentary metal oxide semiconductor active pixel sensor (CMOS-APS) are all direct receptors. These receptors are rigid, solid-state detectors made of silicon that are arranged in an array of x-ray or light sensitive pixels (Figure 1).

All three of these sensors use similar technology with differences in power requirements, internal components, charge transfer and manufacturability. Each pixel is approximately 40μ to 20μ in size and is configured into rows arranged in a matrix of 512 x 512 pixels. The pixel size varies depending on the digital receptor, and the size of the pixel has an influence on the image resolution. For example, a 40μ-50μ pixel size results in an image resolution of approximately 10 to 11 lp/mm. Solid-state sensors used for intraoral imaging are area arrays with two basic formats, direct and fiberoptically coupled. Direct sensors capture the image directly like film while fiberoptically coupled sensors utilize a scintillation screen coupled to a CCD. When x-rays strike the screen material light photons are produced, detected and stored by the CCD. Direct sensors communicate with the computer via an electrical cable, although wireless sensors recently have been introduced for direct digital intraoral imaging. Direct sensors are available in sizes comparable to 0, 1, and 2 film but are thicker and more rigid in their construction. The active image area is smaller than film so the area of coverage is somewhat diminished. Direct detectors can be reused for each successive projection and the acquired image can be viewed almost instantaneously after exposure.

**Indirect Receptors**

Photostimulable phosphor plates (PSP), also known as storage phosphor plates (SPP), uses...
indirect receptors. PSP/SPP are flexible, wireless receptors that are similar in size and thickness to film (Figure 2).

Phosphor plates are available in the same sizes as intraoral film including 0, 1, 2, 3 and 4. An individual plate must be used for each projection in the survey, just like film. The phosphor plates consist of a polyester base that is coated with a crystalline halide emulsion of a europium-activated barium fluorohalide compound.\(^{19}\) When x-rays interact with the phosphor, a latent image is formed and stored until the energy is released during a scanning process (Figure 3).

The plates must be carefully transferred and inserted into a scanning device in which a helium-neon laser beam is applied to release the energy in the form of light. The intensity of the emitted light is proportional to the amount of x-ray energy absorbed by the phosphor plate. The light is captured and intensified by a photomultiplier tube, which converts the light into an electronic signal. The analog-to-digital converter digitizes the data and displays the image on the computer monitor. Before the plates can be reused, the remnant energy must be removed or erased by exposure to intense light. This can be accomplished by exposing the plates to viewbox light, use of commercially produced devices, or by utilizing erasure features built into newer scanner models.

There are a number of phosphor plate systems available for digital imaging. Like direct sensors, the primary advantage is exposure reduction. In addition, PSP receptors have wider dynamic range, a larger active area, are thin and wireless and can be used like film. As previously mentioned, the spatial resolution is lower than direct sensors and film,\(^{8,20}\) a processing step is required like film and, thus, image display is delayed. The time delay varies from seconds to minutes depending on the system and the type and number of projections taken. The plates require careful infection control and gentle plate handling to avoid image artifacts. A study conducted by Bedard et al.\(^{21}\) investigated the durability of phosphor plates and the degradation of image quality due to emulsion scratches. They found that plate placement on the scanner drum had a significant impact on the number of scratches produced as did increased usage per plate.\(^{21}\) Therefore, the plates need to be checked for wear on an ongoing basis and may need to be replaced after 50 uses.\(^{21}\) However, Ergun et al.\(^{22}\) determined that phosphor plates could be used confidently up to 200 times. Another study investigated the effects of different storage conditions and varying time intervals between exposure and scanning of the plates.\(^{23}\) Martins et al.\(^{23}\) found that with one PSP system certain storage conditions and time delay in processing the plates resulted in loss of image density, which could have an impact on image interpretation. This impact was demonstrated in a study by Sogur et al.\(^{24}\) in which plate scanning delays had a significant effect on pixel intensity degradation and the ability to detect occlusal caries.
Film-based images can be scanned to digitize radiographic information. Scanned radiographs are another form of indirect digital imaging. Since the scanning process produces a second version of the original image, some information is lost in translation. This technique requires an optical scanner that is capable of scanning at 600 dpi, able to process transparent images and has the appropriate software to produce the digital image.16,20 This method allows digitization of film-based radiographic images so that they can be stored and incorporated into the digital patient record when the dental office makes the transition from conventional to digital radiography. The radiographic images are then available for comparison to newly acquired images and all information is organized and stored in one source for retrieval.

**Intraoral Technique**
As with film-based imaging, the paralleling technique is the preferred method for acquiring intraoral digital images. Most digital imaging system manufacturers provide receptor instruments that accommodate their sensor size, allow placement inside the patient’s mouth and conform to the principles of paralleling technique (Figure 4). Also, tab techniques may be used for bitewing radiography (Figure 5).

**Infection Control**
Typically, the receptor instruments can tolerate sterilization methods such as steam autoclaving before reuse. Digital receptors cannot be sterilized so the clinician must adhere to careful disinfection and barrier coverage techniques to avoid direct and cross-contamination of the receptor. The standard spray-wipe-spray or immersion disinfection technique is not appropriate for sensor preparation. Wiping rigid digital sensors with a mild disinfectant agent before barrier placement is thought to be an acceptable disinfection practice.26 When in doubt, refer to the manufacturer’s instructions regarding recommendations for sensor preparation and protection prior to use. (Figure 6A and Figure 6B).

PSP plates should be inserted into a barrier envelope and sealed before placement in the mouth. After removal, the barrier should be cleaned with disinfectant hand soap and water and then dried.26 Following glove removal and hand washing, the barrier should be opened carefully.

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Figure 4. Receptor holders designed for digital sensors.

Figure 5. The tab technique can be used for either direct sensors, as demonstrated here, or indirect sensors for bitewing radiography. *Before actual exposure, the tab must be correctly centered over the sensor.*

Figure 6a. Digital sensor in plastic sheath.
Figure 6b. Sterile paralleling instruments are recommended for intraoral radiography. Disinfected sensors are placed into the instrument with an infection control barrier placed over the sensor and attached wire. Instruments: Dentsply Rinn LLC, Elgin, Illinois; Sensors: Sirona Dental Systems, Charlotte, North Carolina

Table 1. Steps in Intraoral Digital Technique

<table>
<thead>
<tr>
<th>Steps:</th>
<th>Procedure</th>
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<tbody>
<tr>
<td>Step 1</td>
<td>Create a patient file and template for images.</td>
</tr>
<tr>
<td>Step 2</td>
<td>Prepare and cover receptor, then place in holder instrument.</td>
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<tr>
<td>Step 3</td>
<td>Pre-set the exposure time.</td>
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<tr>
<td>Step 4</td>
<td>Place radiation shield on patient and explain procedure.</td>
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<tr>
<td>Step 5</td>
<td>Place covered receptor in mouth in the proper position.</td>
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<tr>
<td>Step 6</td>
<td>Align vertical &amp; horizontal angle and center x-ray beam.</td>
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<tr>
<td>Step 7</td>
<td>Prepare software for exposure, move behind barrier and trigger exposure.</td>
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<tr>
<td>Step 8</td>
<td>Remove receptor; view direct image on monitor or scan plate.</td>
</tr>
<tr>
<td>Step 9</td>
<td>Evaluate result; retake, enhance and/or save as needed.</td>
</tr>
<tr>
<td>Step 10</td>
<td>Or acquire additional images as needed, repeat steps 8 and 9 as appropriate.</td>
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and the plate dropped out with the sensitive side down into the transfer carrier. The clinician should be observant during the radiographic procedures to ensure that the barrier does not become torn during instrumentation. Table 1 presents the basic steps involved in intraoral digital imaging.

An example of a patient file is depicted in Figure 7. The act of saving the image is similar to saving any file on a computer system.

Common Errors
As with any imaging technique, errors can be produced when the clinician fails to place the receptor properly or align the x-ray beam in the correct vertical and horizontal angulation or center the x-ray beam over the receptor. Therefore, it is possible to produce image foreshortening, elongation, overlapping, cone cuts and inadequate coverage of the crowns or apices of the teeth (Figure 8). Ultimately, the technical quality of digital images as with film-based imaging is dependent on the skill of the clinician.

Several studies have identified some difficulties associated with the placement of rigid receptors. Versteeg et al. found a significant increase in horizontal placement errors, especially in molar regions, and vertical angulation errors in the anterior segments that cut off the incisal edges of the teeth. Other studies have documented similar findings in horizontal placement and vertical angulation errors as well as cone cuts and difficulties with vertical bitewing placement resulting in missed structures and patient discomfort. Storage of phosphor plates present other image problems. Although the plates are flexible and thinner like film, they are susceptible to the production of image artifacts by abrading the emulsion during handling and erasure.
and cephalometric machines are available that utilizes either linear array CCD or CMOS detectors or PSP plate sensors. With CCD or CMOS extraoral imaging, conventional film is replaced by a long, vertical, rigid digital receptor a few pixels wide. With PSP receptors, the plate is configured in the same dimensions as panoramic or cephalometric film and can be placed directly into the cassette with the intensifying screens removed. As with intraoral direct digital imaging, a patient file must be created, the appropriate template or projection selected, patient positioned, exposure made and image viewed on the monitor (Figure 9).

With PSP plate receptors, the plate needs to be scanned before the image can be viewed. The technique for preparing and positioning the patient is similar to conventional panoramic and cephalometric radiography. In addition, errors can be produced when the patient is improperly prepared and the head alignment does not conform to technique requirements. The quality of the resulting image is ultimately the responsibility of the clinician and proper application of extraoral imaging techniques.

**Extraoral Digital Radiography**

As with intraoral digital radiography, extraoral digital images can be acquired using direct or indirect digital imaging systems. Digital panoramic and cephalometric images can be obtained using extraoral devices that utilize either linear array CCD or CMOS detectors or PSP plate sensors. With CCD or CMOS extraoral imaging, conventional film is replaced by a long, vertical, rigid digital receptor a few pixels wide. With PSP receptors, the plate is configured in the same dimensions as panoramic or cephalometric film and can be placed directly into the cassette with the intensifying screens removed. As with intraoral direct digital imaging, a patient file must be created, the appropriate template or projection selected, patient positioned, exposure made and image viewed on the monitor (Figure 9).

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**Figure 7.** One of the steps in digital imaging is to create a patient file in the computer software to acquire and archive radiographic images. In this example, a bitewing template was selected, and then the images were captured and displayed on the monitor.

*Image Source: Patterson Dental Supply Inc., St. Paul Minnesota*

**Figure 8.** One of the most frequently reported intraoral digital imaging errors is cutting off of the teeth crowns. This error is more common with rigid intraoral sensors than flexible plates.
Both film-based and digital formats produce comparable images with spatial resolution of 3-4 lp/mm for PSP receptors and 6-8 lp/mm for CCD receptors. As with intraoral digital imaging, elimination of the darkroom, the ability to enhance and analyze the image, and the convenience of image storage, duplication and retrieval are beneficial. With extraoral imaging, the file size is considerably larger than intraoral imaging and must be reduced by compression techniques that facilitate storage but do not compromise the diagnostic quality of the image.

Radiation Safety and Protection
Because x-rays remain the energy source for producing radiographic images whether film-based or digital, the clinician should still adhere to the radiation protection principle, ALARA (As Low As Reasonably Achievable). Although the dose of ionizing radiation to the patient is less than film-based imaging, protection principles for both the patient and operator should continue to be practiced. As usual, the patient should be shielded with a thyroid collar (for intraoral imaging only) and lead apron and the operator should stand at a remote position, whether behind an adequate primary barrier or at a 6’ distance and between a 90°-135° angle to the x-ray beam.

Familiarity with the program software, proper handling of the receptor and adherence to technique guidelines will help the clinician avoid unnecessary retakes. Numerous retakes undermine the exposure reduction gained with digital imaging, and in many circumstances digital surveys equal the exposure of film-based imaging due to increased numbers of retakes. In a 2003 study conducted by Berkhout et al., it was concluded that general dentists using digital radiography were more inclined to take radiographic images than dentists using conventional radiography. Those who used solid-state intraoral receptors took more images than PSP and film users. The most common reasons for taking more images were that digital imaging requires less exposure than film and for the purposes of error correction. In some cases the dose reduction was cancelled out by the increase in the number of images taken. The investigators determined that for solid-state receptor users who take 50% more radiographic images, the actual exposure reduction was closer
to 25% than in the commonly reported range of 50% to 80% dose reduction. Several studies have indicated that the procedure for retaking digital images is so convenient that the clinician may be more inclined to repeat more exposures when compared to film.

**Imaging Processing**

One of the advantages of digital imaging is that once acquired, the image can be changed and viewed in a variety of ways. Image processing is a computer operation that can be applied to improve, correct, analyze or alter a digital image. Image processing can be broken down into different classifications; image enhancement, image restoration, image analysis, image compression and image synthesis. The following discussion will focus on the most commonly used image processing tools; image enhancement, some aspects of image analysis and image compression.

**Image enhancement software** operations are performed to change the visual appearance of the image. Common enhancements tools include:

1. brightness and contrast adjustments
2. black/white reversal
3. pseudocolor application
4. sharpening
5. zoom

1. **Adjustment of the brightness and/or contrast** can salvage an image that would not be diagnostic if film-based. Ideally, digital receptors should be exposed at proper exposure settings. If the pixels are not oversaturated with radiation, it is possible to alter the brightness or density so that the image is readable. This can be accomplished through the addition or subtraction of the same value to each pixel. Contrast can be adjusted by altering the distribution of the gray levels in the image. This distribution is depicted in the image histogram, which displays the frequency of each gray value that appears in the image. Histogram stretching redistributes the original range of gray levels over the entire range without changing the image itself. The contrast can be adjusted to produce high contrast visualization, which is desirable in caries interpretation, and lower contrast, which may be desirable when looking for subtle changes in periodontal disease.

2. **Black/white reversal** option is to view structures by inverting or reversing the image so that radiolucent structures appear radiopaque and vice versa (Figure 10). This tool may be useful in visualizing the trabecular pattern of bone and pulp canal and chamber anatomy.

3. **Pseudocolor enhancement** converts the gray scale of the image into colors. The application of pseudocolors is not considered to be an effective tool to segment or view particular objects within the image. Although the application of color may be developed

![Figure 10. Image enhancement tools allow the clinician to view the captured image in a variety of ways. One option is image reversal in which radiolucent structures appear radiopaque and radiopaque structures appear radiolucent.](image-url)
4. **Sharpening enhancements** are utilized to better demonstrate edges and margins and are accomplished by various filtering techniques. Sharpening may make images appear more appealing to the eye, but there is no scientific evidence that there is any actual improvement in the diagnostic quality of the image.\textsuperscript{38}

5. **Zoom** feature allows magnification of any portion of the image to better view details. The window display allows the clinician to determine the zoom location by framing the area on the original image.

**Digital subtraction** is categorized as an image enhancement but will be presented as a separate topic in subsequent text.

**Image Analysis**

Image analysis operations are used to acquire nonpictoral information from the image.\textsuperscript{35} Measurement is the most commonly used analysis operation in clinical digital radiography. Typical measurement tools include single or multiple linear measurements, angle determination, grid application and calibration of known objects and their depiction on the image.\textsuperscript{39} Pixels can be measured individually or along a straight line in either vertical or horizontal histogram displays.\textsuperscript{39}

**Image Compression**

Image compression is a process of file reduction. The purpose of image compression is to reduce computer storage space and facilitate image retrieval and transmission. Compression becomes a more important issue as the number of patient records and image files to be stored increases over time.

There are two types of image compression methods, lossless and lossy. Lossless compression retains all of the information in each pixel of the original image and essentially is identical to the image first acquired by the digital imaging system. Lossless compression algorithms provide a very limited degree of file reduction in the range of 1:2\textsuperscript{36} to 1:3\textsuperscript{40} ratio, approximately one-half to one-third reduction. Lossless compressed images require more memory to manipulate the image and longer transmission time to send an image to a remote site. Lossy compression affords higher compressibility but results in some loss of data. Lossy compression is accomplished through the division of the image into smaller blocks and selective discarding of data.\textsuperscript{40} Lossy compressed images require less memory to manipulate the image and the transmission time is reduced.

**Joint Photographic Experts Group (JPEG),** is a common compression protocol that can support both lossless and lossy compression.\textsuperscript{40} A number of research studies have investigated the extent that image files can be compressed and still be diagnostic. In 2002 Eraso et al.\textsuperscript{40} determined that high compression ratios had a severe negative impact on the diagnostic quality of digital images in the detection of periapical lesions. The results of the study indicated that compression ratios lower than 1:32 can safely be used for diagnostic procedures in endodontics.

In another investigation of the effects of compression and the detection of chemically-induced periapical lesions, Koenig et al.\textsuperscript{41} found no significant differences between compressed and original images at the level of 1:23 and 1:28 JPEG lossy compressions. With respect to caries diagnosis, Pabla et al.\textsuperscript{42} studied the effects of compression on proximal caries detection. They concluded that Joint Photographic Experts Group File Interchange Format (JFIF) compression at a 1:16 ratio could be used without significant deterioration in diagnostic accuracy in the detection of proximal caries.\textsuperscript{42} An earlier investigation by Wenzel et al.\textsuperscript{39} concluded that compression rates of 1:12 could be used for caries diagnosis before accuracy and image quality was significantly affected. Research to investigate image compression and its effects on diagnostic tasks in dentistry is ongoing.

**Digital Subtraction Radiography**

Digital subtraction radiography (DSR) is a technique used to determine qualitative changes that occur between two images taken at different points in time. The first image is the baseline image and the second image shows the changes into a more useful tool in the future, its utility as an enhancement has not yet been demonstrated.\textsuperscript{20,37}
that have occurred since the time the first image was taken.\textsuperscript{36} DSR involves subtracting the pixel values from the first image from the pixel values of the second image.\textsuperscript{36} The result of the subtraction process is visualization of the changes only because everything unchanged has been removed. In order for images to be subtracted, they need to be nearly identical, have the same image projection geometry, receptor placement and file size so that the subtracted image provides the desired information. Reconstruction software has become available to correct placement and image projection geometry to make DSR more feasible for use by clinicians.\textsuperscript{36} Also, digital images have standard file sizes and number of pixels in each image, which facilitates the operation.\textsuperscript{14}

Subtracted images may reveal a continued disease process or demonstrate the effectiveness of a particular treatment. In 1998, Parsell et al.\textsuperscript{14} studied various methods to detect oral cancellous bone lesions and found that digital subtraction radiography with or without enhancement improved the likelihood of a correct cancellous defect diagnosis. In another study by Danesh et al.,\textsuperscript{45} DSR was used to compare radiographic crestal alveolar bone mass and change in clinical periodontal attachment level following guided tissue regeneration. The investigators found strong agreement between digital subtraction radiographic assessment of crestal alveolar bone mass and clinical attachment level.\textsuperscript{36} These and other studies suggest that digital subtraction radiography will prove to be a useful tool in the diagnosis and treatment of dental disease.

**Diagnostic Utility**

A number of studies have been conducted to evaluate the diagnostic utility of digital radiography in comparison to film-based imaging. Although the conclusions are not unanimous, the majority of current evidence suggests that digital images are equal to film-based images for typical diagnostic tasks performed in dentistry. The following discussion will cite several investigations regarding the diagnostic utility in caries, periodontal disease and periapical disease diagnosis.

A number of research studies have been conducted to determine whether direct and indirect digital receptors are as accurate as film in caries diagnosis. The results indicate that current intraoral digital receptors appear to provide a diagnostic outcome as accurate as film.\textsuperscript{46-48} A number of subsequent studies have evaluated the performance of particular digital systems compared to each other and film. In 2002, Hintze et al.\textsuperscript{49} investigated the accuracy of caries detection with E-speed film and four storage phosphor systems at two different exposure times. For approximal caries, no significant differences were found in diagnostic accuracy between E-speed film and three PSP systems (Dentopix, Digorablue, Digorawhite) at the longer exposure time (25% of film exposure).\textsuperscript{49} For occlusal caries, shorter exposure (10% of film exposure) of the PSP systems yielded less accurate results than film but at the higher setting only one PSP system, Digorablue, proved to be as accurate as film.\textsuperscript{49}

A 2004 study by Jacobs et al.\textsuperscript{50} investigated the accuracy of 2 CCD (Dixi, Sidexis) and 2 PSP (Digora, Dentopix) systems in approximal caries measurement. They concluded that radiographic images obtained by Dixi and Digora systems were more accurate than Sidexis and Dentopix in the measurement of carious lesion depth. With regard to occlusal caries detection in primary teeth, Dias de Silva et al.\textsuperscript{51} found that direct digital radiography was as effective as conventional radiographic examination and visual inspection when the lesions involved dentin.

Various investigators have studied the diagnostic efficacy of digital imaging in alveolar bone evaluation and periodontal lesions. Nair et al.\textsuperscript{52} found no significant differences in the ability of E-speed film and enhanced and unenhanced Sidexis CCD digital images to accurately detect alveolar crestal bone. In another investigation, De Smet et al.\textsuperscript{53} determined that conventional and digital intraoral imaging methods provided acceptable accuracy of peri-implant bone level measurements. Pecoraro et al.\textsuperscript{54} found that alveolar bone measurements were reproducible on both digital and conventional radiographic images.

Several studies have been conducted to evaluate the efficacy of film and digital sensors to detect periapical lesions. Paurazas et al.\textsuperscript{55} conducted a study regarding the detection of periapical lesions using Ektaspeed Plus film, CCD, and CMOS-APS imaging systems. No significant difference in diagnostic performance was found among the three modalities in the detection of
periapical bony lesions. By comparison, Wallace et al.\textsuperscript{56} investigated the diagnostic efficacy of film and digital sensors in the detection of simulated periapical lesions and concluded 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. In 2002, Friedlander et al.\textsuperscript{57} compared PSP digital images with film in the perception of fine endodontic files and periapical lesions and found that phosphor-plate digital radiography was inferior to conventional radiography for clarity of fine endodontic files at working length or periapical radiolucencies. And no significant differences were found between intraoral film, high resolution complimentary metal oxide semiconductor digital imaging and cone beam computed tomography (CBCT) in detecting vertical root fractures in mandibular single-rooted teeth.\textsuperscript{58}

**Image Output**

Once an image is acquired, the clinician can evaluate the result on the computer monitor. But in order to share the information with other dental professionals, the image either must be printed or sent electronically to another site. The image as viewed on the monitor often appears different from the printed version.\textsuperscript{59} The outcome is dependent on the printer and paper used. There are a number of printers and media (e.g. transparencies, thermal paper, glossy paper, etc.) available to print digital images. The cost of the unit, paper requirements, output resolution and gray scale are important considerations in selecting a printer. A 600 dpi printer should be able to accurately display image resolution of approximately 12 lp/mm.\textsuperscript{14} In addition, the printer must be able to produce an image with $2^8$ or 256 shades of gray.\textsuperscript{14}

**Teleradiography**

The transfer of a digital image to a distant site is called teleradiography. In order to accomplish this task, the sender and receiver must be able to generate an image that can be read by various software programs or have the same software. The file size affects transmission time as discussed under image compression. Teleradiography has the potential for off-site consultation, insurance submission and improved access to care for patients in remote locations. The ability to expand these capabilities and share information securely is facilitated by the DICOM Standard.

**DICOM Standard**

The DICOM (Digital Imaging and Communications in Medicine) Standard is a protocol that describes the formatting and exchange of images and related information. The medical profession developed and adopted the DICOM Standard to overcome issues related to problems with imaging system communication and difficulties exchanging data.\textsuperscript{60} This standard is now internationally recognized for biomedical imaging and provides a logical physical format for exchanging data between different manufactured systems.\textsuperscript{60} Dentistry has faced some of the same obstacles as medicine with the incorporation of dental digital imaging into dental practice. Digital radiography vendors are producing systems that have adopted DICOM Standard capabilities. Digital radiographic systems that are DICOM compliant utilize file formats that are universally accepted, thus permitting image transfer or teleradiography for a variety of purposes, including consultation and research.\textsuperscript{14}

**Conclusion**

Digital radiography is the latest advancement in radiographic imaging in dentistry. Digital radiography systems utilize computer technology and radiation sensitive detectors that capture the image, convert it into numeric data and permit image display on a monitor. Digital images may be enhanced once acquired, conveniently stored, accessed, printed or transmitted. Digital radiography reduces patient radiation exposure and eliminates the need for the darkroom and chemical processing. The quality of the images produced remains dependent on the technical skills of the clinician. Digital radiographic images are considered to be equivalent to film in their ability to diagnose caries, periodontal bone loss and periapical lesions.
Course Test Preview
To receive Continuing Education credit for this course, you must complete the online test. Please go to:

1. Analog data is defined or characterized as ________________.
   a. information represented by numbers 0 and 1
   b. a continuous gray scale from black to white
   c. the quality of the primary x-ray beam
   d. discrete bundles of photon energy
   e. the average of pixel energy quantity

2. ________________ is considered to be a disadvantage of digital radiography.
   a. Teleradiography
   b. Easier image storage
   c. The greater dynamic range
   d. The initial cost of digital system
   e. The elimination of chemical processing

3. A solid-state detector used for intraoral radiography has all of the following characteristics except ________________.
   a. a thick, rigid receptor construction
   b. pixels laid out in a linear array design
   c. the availability of wired and wireless formats
   d. images that are acquired and viewed almost instantly
   e. the active area to record the image is smaller

4. A ________________ digital imaging receptor requires a scanning process to digitize and view the image.
   a. complimentary metal oxide conductor
   b. photostimulable phosphor plate
   c. fiberoptically-coupled sensor
   d. scintillation screen sensor
   e. charge-coupled device

5. ________________ is NOT descriptive of intraoral storage phosphor plate receptors.
   a. Thin and flexible construction
   b. Wireless, no cable attached
   c. Erasure required before reuse
   d. Susceptible to emulsion scratches
   e. Same plate used to take each view

6. In digital intraoral radiography, ________________ errors can be corrected without taking a retake.
   a. overexposure
   b. placement
   c. crowns cut off
   d. overlapping
   e. cone cut
7. Intraoral digital receptors provide equal or greater dose reduction compared to ____________ film.
   a. D speed
   b. E speed
   c. F speed
   d. screen
   e. duplication

8. Although ionizing radiation is used to generate digital radiographs, the dose is so low that patient and operator protection measures need not be followed. The ease of retaking digital radiographic images contributes to unnecessary repeat exposures and undermines dose reduction.
   a. Both statements are true.
   b. The first statement is true. The second statement is false.
   c. The first statement is false. The second statement is true.
   d. Both statements are false.

9. In digital radiography, contrast can be adjusted by ________________.
   a. altering the brightness
   b. redistributing the gray levels
   c. application of pseudocolors
   d. reversing the image black to white
   e. filtering the image to remove noise

10. The preferred technique for taking intraoral periapical digital images is the ______________.
    a. paralleling technique
    b. tab bitewing technique
    c. bisecting angle technique
    d. tomographic technique
    e. topographical occlusal technique

11. Typically, receptor instruments can tolerate sterilization methods like steam autoclaving before reuse. The recommended method for the disinfection of intraoral digital sensors is the spray-wipe-spray technique.
    a. Both statements are true.
    b. The first statement is true. The second statement is false.
    c. The first statement is false. The second statement is true.
    d. Both statements are false.

12. Panoramic digital radiography eliminates both processing and patient positioning errors. Extraoral digital imaging can be accomplished with either CCD or PSP digital receptors.
    a. Both statements are true.
    b. The first statement is true. The second statement is false.
    c. The first statement is false. The second statement is true.
    d. Both statements are false.

13. Image analysis includes all of the following computer operations except ________________.
    a. object calibration
    b. digital subtraction
    c. grid application
    d. angle determination
    e. linear measurements
14. Digital radiography produces images comparable to film-based imaging with respect to the detection of caries, periodontal disease and periapical disease. Film-based radiography produces images with greater spatial resolution than PSP digital imaging systems.
   a. Both statements are true.
   b. The first statement is true. The second statement is false.
   c. The first statement is false. The second statement is true.
   d. Both statements are false.

15. The purpose of applying a sharpening image enhancement feature is to ______________.
   a. alter density or degree of darkness
   b. reverse radiolucent and radiopaque objects
   c. demonstrate the edges or margins of structures
   d. enlarge or magnify certain aspects of the image
   e. apply colors to demonstrate variation in gray levels

16. A description of the lossy compression techniques is that it ______________.
   a. preserves all information in each pixel of the original image
   b. requires greater transmission time when file is sent offsite
   c. decreases the amount of memory needed to store the image
   d. reduces file size in the range of a third to half the original
   e. is not an acceptable method for archiving dental images

17. High compression ratios above 1:32 have a severe negative impact on the diagnostic quality of the digital image. Lossless compression is achieved by the division of information in smaller blocks and selectively removing data.
   a. Both statements are true.
   b. The first statement is true. The second statement is false.
   c. The first statement is false. The second statement is true.
   d. Both statements are false.

18. ______________ is an inaccurate description in regard to digital subtraction.
   a. Two images taken at different times
   b. Method for detecting subtle changes
   c. Process removes all information that is changed
   d. Images for subtraction should be nearly identical
   e. Subtracted images may reveal a continued disease process

19. Teleradiography is ______________.
   a. a mechanism for determining printer dpi
   b. a method for backing up numerical data
   c. a technique for enhancing digital images
   d. the transfer of a digital image to a distant site
   e. the ability to alter image file format

20. ______________ is an inaccurate description in regard to the DICOM standard.
   a. Protocol for formatting and exchanging images
   b. Internationally accepted standard for biomedical imaging
   c. Permits interaction between various manufactured systems
   d. Facilitates the ability to submit data electronically for consultation
   e. Requires both sender and receiver to have the same software programs
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