Review Article

Digital imaging in Dentistry: An overview

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ABSTRACT

Digital radiography has been available in dentistry for more than 25 years, but it has not replaced conventional film-based radiography completely. This could be because of the costs involved in replacing conventional radiographic equipment with a digital imaging system, or because implementing new technology in the dental practice requires a bit of courage. As use of digital radiography becomes more common, many dentists are wondering if and how they can replace conventional film-based imaging with a digital system. This article presents an overview of the different technologies used for digital imaging in dentistry with a broad overview of the benefits and limitations of digital imaging. The principles of direct and indirect digital imaging modalities, image processing and image analysis will be discussed.

Key Words: *Digital imaging, digital image receptors, image processing, image analysis, radiography*

Introduction

Since the discovery of X-rays in 1895, film has been the primary medium for capturing, displaying, and storing radiographic images. Digital radiography has been used widely in medicine, but it was only in the 1980s that the first intra-oral sensors were developed for use in dentistry by Trophy Radiologie (Vincennes, France). Digital imaging incorporates computer technology in the capture, display, enhancement and storage of direct radiographic images. Unfortunately, the early systems could not capture panoramic and cephalometric images, and this made it impossible for surgeries to abandon film processing and adopt digital technology. Recently, the development of cost-effective intra and extra oral digital technology coupled with an increase in computerization of practices has made digital imaging a superior alternative in many respects to conventional film imaging. Digital imaging offers some distinct advantages over film, but like any emerging technology, it presents new and different challenges for the practitioner to overcome.

History of Digital imaging

The dawn of the digital era in dental radiography came in 1987 when the first digital radiography system called Radio Visio Graphy, was launched in Europe by the French company Trophy Radiologie. [1] The inventor of this system was Dr. Francis Mouyen. He invented a way to employ fiber optics to narrow down a large x-ray image onto a smaller size that could be sensed by a Charge Coupled Device (CCD) image sensor chip. Once the X-Ray imaging chip specifications were finalized, Trophy Radiologie contracted Fairchild CCD Imaging Company in Silicon Valley, California, USA to develop the actual CCD imaging chips. At Fairchild, a young Finnish physicist and CCD image sensor design engineer named Paul Suni helped create the enabling CCD image sensor technology that was needed to make the RVG digital radiography system a reality. The new technology was ready to expand. More than two decades after, today's digital radiographic systems have developed a great superiority and have many benefits. [2]

What is a digital image?

Although a digital image seen on the screen is a collection of brighter and darker areas very much resembling the traditional film-based image, the nature of a digital image is completely different. An analog image is a radiographic image produced by conventional film in which differences in the size and distribution of black metallic silver result in a continuous density spectrum. A digital image, on the other hand, is composed of a set of cells organized in a matrix of rows and columns. Each cell is characterized by three numbers: the x-coordinate, the y-coordinate and the gray value. The gray value is a number that corresponds with the x-ray intensity at that location during the exposure of the sensor. Individual cells are called "picture elements," which has been shortened to "pixels." A voxel refers to "Volumetric pixel" is a volume element represent the matrix of individual pixel organized in a three dimension. The numbers describing each pixel are stored in an image file in the computer. (Fig 1) This is an essential difference between analog and digital radiographs. [3]

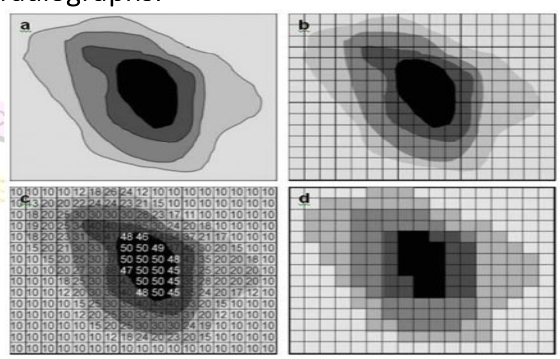

Fig.1a) X-ray shadow—the x-ray beam after it has passed through the patient
b) Image superimposed on the grid of pixels.
c) Numerical representation of the pixel values corresponding with x-ray intensities
d) Digital image on the computer screen. Each pixel of the sensor corresponds with a pixel on the computer screen

The technology behind digital radiography:

There are two more advanced technologies that create digital images without an analog precursor: "direct" digital images and "semi direct" digital images. Direct digital images are acquired using a solid-state sensor. The solid-state sensors are based on charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) based chips. Semidirect images are obtained using a phosphor plate system.

Charged Coupled Device (CCD): The CCD introduced to dentistry in 1987 was the first digital image receptor to be adapted for intraoral imaging. [4] A CCD includes a sensor that is placed in the patient's mouth. A cable leads from the sensor to an interface, which is connected to a computer in the operatory. The CCD also includes a pixel array on a silicon chip. After exposure, x-ray energy is converted to a proportional number of electrons, which are deposited in the electron wells, then transferred in a sequential manner to a read-out amplifier (charge coupling). This analog signal is converted to a digital signal and the x-ray image is visible almost immediately on the computer monitor. Sensors are available in various sizes such as size 0, size 1 and size 2 to simulate the different film sizes used clinically. (Fig 2)

Fig.2 Kodak sensors of various sizes such as size 0, size 1, size 2

For infection control, a disposable plastic sleeve is fitted over the sensor and part of the cable, as the sensor cannot be autoclaved or disinfected. [5] There are two types of digital sensor array designs: area and linear array design. Area arrays are used for intraoral radiography, while linear arrays are used in extra oral imaging. Both wired and wireless sensors can be used. Wireless sensors are thicker than wired sensors, and are typically 1.5 times as expensive as their wired counterpart. (Fig 3)

Fig.3 Wired and wireless sensors

Complementary metal oxide semiconductor: An alternative to CCD technology is complementary metal oxide semiconductor active pixel sensor technology. These sensors do not require charge transfer, resulting in increased sensor reliability and lifespan. In addition, they require less system power to operate and are less expensive to manufacture. [1]

Photostimulable phosphor plates (PSP): The PSP plates consist of a flexible polyester base coated with a crystalline emulsion of europium activated barium fluorohalide compound. For infection control, the plate is placed in a plastic pouch, which is sealed, preventing contact with oral fluids. Incoming x-ray energy is stored in the emulsion and a latent image forms on the PSP plate, analogous to the latent image that forms on a conventional emulsion. The plate is removed from the patient's mouth, the plastic pouch is discarded and the plate is placed into a laser scanner, which acts as an electronic processor. A laser beam sequentially scans the plate and the stored electrons are released as visible light, which is quantified. The time comparison for image acquisition is CCD << PSP = Film. Most conventional E speed films have a resolution of 20 LP/mm whereas with digital images the resolution ranges from 7–10 LP/mm. The image resolution comparison for various systems such as for Intraoral systems: Film > CCD > PSP; Panoramic systems: Film = CCD = PSP; and for Cephalometric systems: Film > CCD = PSP. [4] This analog signal is converted to a digital image, which is viewed on a computer monitor. Because not all the energy stored on the PSP plate is released during scanning, the plate must be "erased" by exposing it to a strong light source for seconds before it can be reused. PSP plates are available in sizes similar to sizes 0, 1, 2, 3 and 4 films, as well as larger sizes for extra oral imaging. [5] (Fig 4)

Fig.4 Digora imaging plates of various sizes and DenOptix imaging plate system hardware

Extra-oral digital imaging

Extra-oral digital imaging is available using both systems. However, the larger CCD sensors are extremely expensive and usually require the purchase of new X-ray generators, although a 'retro-fit' system has been developed in the USA. These constrictions effectively mean that the PSP method is the one most commonly used.

Panoramic radiography: The PSP method of panoramic digital imaging is very similar to conventional film. The film and intensifying screen are replaced by a storage phosphor plate. The plate is scanned after exposure, which can take up to 3 minutes or longer depending on the product used. The resolution of these systems is greater than 4 line pair/mm.

Cephalometric radiography: With CCD sensors the image is acquired over 15 seconds as the sensor and narrow X-ray beam move up the facial bones and could lead to an increase in the incidence of movement artifact. [6]

Image processing

Any operation that acts to improve, restore, analyze or in some way change a digital image is a form of image processing. Some are integrated in the image acquisition and image management software. Some are controlled by the user to improve quality of the image or to analyze its content. The software for digital radiography will include tools to optimize contrast and brightness automatically for specific diagnostic tasks. This can be used to correct overexposure or underexposure of an image, although of course it is no excuse to pay less attention to the correct exposure settings. To avoid the subjectivity of selecting image density or contrast by means of slider bars, some clinical imaging software offers the use of standard gamma optimization procedures. This is done by distributing the gray values of the pixels more evenly over the full scale of gray values. A human eye is capable of distinguishing only about 60 gray levels. As a result of wide dynamic range digital image receptors has the ability to record the wide range of tissue densities and can detect subtle difference in the density within the same tissue. The dynamic range of CCD and CMOS detectors is similar to film and can be extended with digital enhancement of contrast and brightness. PSP receptors have

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greater latitudes. (Fig 5) Other image-processing tools that are available in most clinical software are inversion of the gray scale of the image (the result of which is called "negative image") and edge enhancement. Edge enhancement converts contrast gradients into a texture that is visible as a shape. Another simple but effective tool is the ability to zoom in on an image, by using a twofold or threefold magnification, the user can recognize details more easily. To perform this action, the computer duplicates or interpolates rows and columns of the digital image, thus increasing the size of the image on the screen. [3]

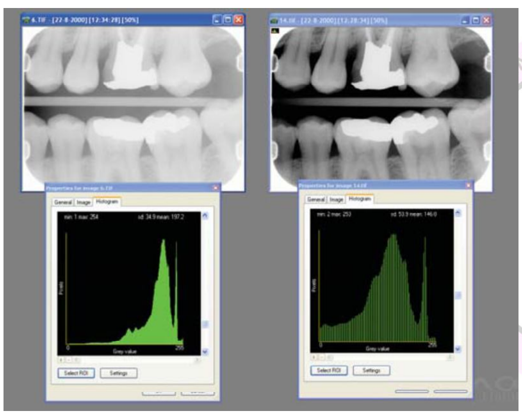

Fig.5 Automated optimization of the pixel gray values is achieved by distributing them over the full scale of gray levels.

a) Underexposed image: the histogram of gray values is moved to the right (light) side of the histogram.

b) Image after correction of the gray value distribution, in which the full scale of gray levels is used.

Image analysis

Image analysis operations are designed to extract diagnostically relevant information from the image which can range from simple linear measurements to fully automated diagnosis. An example of image analysis is the measurement of a distance in a digital image. However, when the user draws a line with the cursor in the digital image, it is easy for the software to determine the number of pixels that form the line. This can even be a curved line, something that is not easily achievable on a traditional radiograph. When the software used to measure the length recognizes which sensor was used to create the image, the software uses the correct pixel size from an internal table of sensor characteristics. This allows for measurements expressed directly as a distance in millimeters. [3, 7] (Fig 6) The tools such as digital ruler and densitometer are available, which are digital equivalents of existing tools used in endodontics, orthodontics, periodontology, implantology and with the help of these tools the size and image intensity of any area within a digital radiograph can be measured.

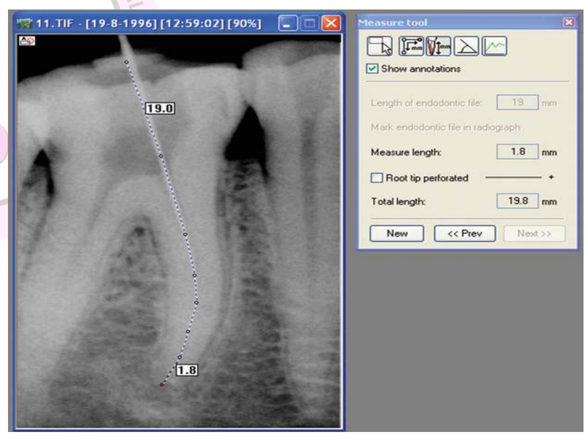

Fig.6 Calibrated length measurement in a digital image. The endodontic file length is shown in the dialog window; the correct length of the root is shown at the bottom of the dialog window.

Digital subtraction radiography (DSR): This procedure allows practitioners to distinguish small differences between subsequent radiographs that otherwise would have remained unnoticed because of over projection of anatomical structures or differences in density that are too small to be recognized by the human eye. Mathematically, subtraction radiography is quite simple. DSR software subtracts corresponding pixels of two images obtained within an interval of a few weeks or a few months, and it uses the outcome to calculate a new image. When the gray levels of the corresponding pixels are the same, the output pixel is zero. As an example, when the second image shows periodontal bone loss, the subtraction outcome in this area is different from zero, because the gray values of the corresponding pixels are different in that area. This is visible in the subtraction image as a darker area when there is bone loss (or, similarly, as a brighter area when there is bone repair). The radiographic pattern of the trabecular bone makes the recognition of these small changes difficult; for that reason, it often is called “anatomical noise.” The DSR procedure removes the anatomical noise so that the small differences stand out against the background. (Fig 7)

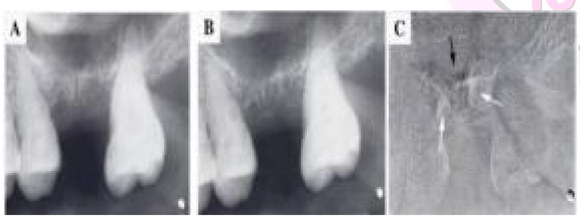

Fig.7 Example of ideal digital subtraction radiography

- **a) Digital Image after extraction**
- **b) Second radiograph obtained one month later**
- **c) Bone loss (black arrow) and deposition (white arrow).**

Advanced image analysis: More advanced image analysis tools are available with different types of imaging software. Several studies have been published that describe the diagnostic importance of digital subtraction radiography. [8, 9, 10] To perform DSR reliably, the two images being compared have to be identical with respect to gray values and projection geometry. In film radiography, this was achieved by means of a film holder with an individual bite block. The patient had to bite on the film holder to be connected reproducibly to the x-ray device and the film or sensor. Today, software tools are available to do the image matching, making DSR a procedure that easily can be carried out in general practice. The image matching makes the gray value distribution of the second image identical to that of the first image, and it re-projects the second image according to the projection direction of the first image. It even is possible to combine images made with sensors manufactured by different companies. [8] Applications of DSR in general practice include the diagnosis and follow-up of periodontal bone resorption, [9] assessment of bone levels around implants and the progression of healing of periapical lesions. [11]

Advancement in digital imaging: Within the past decade, technology termed “cone beam computed tomography” (CBCT) has evolved that allows 3-D visualization of the oral and maxillofacial complex from any plane. This imaging modality eliminates the shortcomings of 2-D imaging, produces a smaller radiation dose than that produced by medical CT and enables clinicians to make more accurate treatment planning decisions, which can lead to more successful surgical procedures. [12]

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. [13 - 17] 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. [13]

A number of studies have been conducted to explore the diagnostic efficacy of digital imaging with regard to periodontal lesions. A study has been conducted to investigate the accuracy of alveolar crestal bone detection utilizing Ektaspeed Plus film, Sidexis direct digital images, and brightness-enhanced digital images. [14] 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.

Several recent studies have been conducted to evaluate the efficacy of film and digital sensors in the detection of periapical lesions. In 2001, Wallace et al. investigated the diagnostic efficacy of film and digital sensors in the detection of simulated periapical lesions. [15] 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. 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.

A study was conducted to compare the conventional and digital radiography in the estimation of working length in mandibular molars. Sixty molar teeth were selected and divided into three groups in the basis of canal curves. After the placement of a 15 K-file, radiographs were taken with a conventional film (F speed) and a digital sensor. Canal lengths were measured in these images by two observers. The accuracy of conventional and digital radiography in the determination of the working length was in an acceptable range. [16]

A study was conducted to compare conventional and direct digital radiography in working length measurement of the root canal and to assess the significance of the different enhancement modes provided by the software to visualize the file length and it was concluded that both conventional radiography and DDR can be reliably used for working length determination. The positive and colorize modes enhancement features of DDR greatly improve the visual perception, leading to more accurate measurements. [17]

Advantages of Digital Radiography

Immediate observation of radiographic images: It is especially important in endodontic therapy, implant surgery, evaluation of crown fit, placement of posts in endodontically treated teeth, evaluation of potential overhangs or open margins in newly placed restorations, detection of radiopaque foreign objects in soft tissue, patient education and innumerable other situations.

Data storage: Pulling up specific stored radiographic images from a computer database is easy because of the highly organized nature of computer file storage.

Developing solutions and Conventional film developers: In digital radiography, maintaining and changing the radiographic developing and fixing solutions and keeping them in a functional state are eliminated, along with the darkroom that still is present in some offices that do not use automatic film processors.

Communication with other practitioners: One of the most useful advantages of digital radiography is the ability it gives clinicians to send images to other practitioners in a matter of minutes, even while talking on the telephone.

Less radiation: The reduction in radiation offered by digital radiography is 70 to 80 percent, and at times even more - allows multiple periapical images for the same radiation.

Loss of conventional films: Assuming adequate back-up procedures are observed, there is no reason to lose stored digital radiographic images. [18]

Disadvantages of Digital Radiography

Cost of devices: Initial costs of digital systems are greater than film. Subsequent costs vary greatly depending on receptor wear and tear or abuse.

Learning to use the concept: After receiving initial education to begin using digital radiography, staff members still will require significant time to master the use of the software.

Thickness of the sensor: CCD sensors vary in thickness, from more than 3 millimeters to more than 5 mm. Although this seems to be a major disadvantage, it is surprising to note the relative ease of use of CCD sensors in spite of their thickness.

Rigidity of the sensor: CCD sensors are rigid and can irritate the oral soft tissues and cause pain.

Lack of standardization: A CD ROM can hold over 30,000 images. This means that images can be stored cheaply and indefinitely.

Infection control: The CMOS and CCD sensors are used on multiple patients and must be covered by barriers. Sensors that become contaminated are incapable of being sterilized. [18]

Conclusions

Digital dental radiography, in practice of dental professional is a powerful tool. Digital radiography no longer is an experimental modality. It is a reliable and versatile technology that expands the diagnostic and image-sharing possibilities of radiography in dentistry. Optimization of brightness and contrast, task-specific image processing and sensor-independent archiving are important advantages that digital radiography has over conventional film-based imaging. With a digital system, information from radiographic images is collected more easily and in a more objective way, which will improve the performance of the diagnostic process.

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