REVIEW ARTICLE

Recent advancements in dental digital radiography
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Abstract
For more than a century, now radiographs have been taken using radiographic film. Digital imaging has been replacing traditional films in private practice, academic institutions in the last two decades. As use of digital radiography has become more common in the last decade with rapidly evolving changes in the way healthcare is administered, coupled with the amazing recent advances in imaging, many dental professionals are thinking of using digital system as a substitute to conventional film system. This has necessitated a review of the different technologies used for digital imaging in dentistry with broad overview of the principles in digital system, equipment, digital imaging receptors, procurement, enhancement process, transfer, and storage developments along with comparisons of film-based imaging, processing and image analysis.

Keywords
Digital imaging, digital image receptors, image analysis, image processing, teleradiology

Introduction
Accurate oral diagnosis and treatment are very closely linked to the quality of dental radiographs. A portion of a glass imaging plate exposed was the first original dental roentgenogram taken by Dr. Otto Walkhoff in January 1896. He took it in his own mouth for an exposure time of 25 min.[1] Dental imaging since then has shown tremendous progression along with its varied applications in fields of dentistry.

The disadvantages of film-based radiography such as need and maintenance of darkroom, chemical handling, and associated processing errors have been proven unnecessary with the advent of digital radiography.

This revolution is the resultant of a combination in the advancement of technologic innovation in image acquisition processes and the development of networked computing systems for image retrieval and transmission.

Digital Radiography
The very first system that was introduced in digital radiography in dentistry was radiovisiography (formerly Trex-trophy Radiology Inc., Marietta, GA) by Trophy in France in 1987.[2] Digital radiography is a method of reproducing a radiographic image using a technology sensor of solid-state, which are broken into electronic pieces, and presented and stored as an image using a computer.

A digital image is a collection of brighter and darker areas same as that of a film based image, but the nature of the digital image is totally different from that of film. A digital image is composed of a set of cells arranged 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.[2]

There are two advanced technologies that create digital images without an analog precursor;
1. Direct digital images
2. Semi-digital digital images.

Direct digital images are acquired using a solid-state sensor. The solid-state sensors are based on charge coupled device (CCD) and complementary metal oxide semiconductor (CMOS) and CMOS-active pixel sensor (CMOS-APS) based chips.

Semidirect digital images are obtained using a phosphor plate system.[3]

CCD
A CCD is an image sensor that is consists of an array of photoelectric devices, or pixel sensors. It adds image sensing
capabilities to devices, such as cameras, and allows the user to convert a real life scene into a digital image.

The CCD was first introduced to dentistry in 1987 that was mainly adapted for intraoral imaging.

The CCD contains two main parts:
1. The color filters
2. The pixel array.\(^2\)

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 an organized 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.\(^3\)

There are two types of digital sensor array designs: Area and linear array design. Intraoral radiography uses area arrays, while extraoral imaging uses linear arrays. Both wired and wireless sensors can be used. Wired sensors are thicker than wireless sensors, and are typically 1.5 times as expensive as their wired counterpart.\(^3\)

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.\(^3\)

The CMOS

The CMOS sensor, also known as the APS, is a type of image sensor used in many consumer devices. Unlike its technological competitor, the CCD, CMOS sensors have most of their required circuitry and components integrated into the sensor, resulting in a smaller, and a less power consuming system overall.\(^2\)

Schick Technologies (Long Island City, NY) was the first vendor to replace the CCD by a CMOS for the purpose of solid state intraoral radiographic imaging. The CMOS was an active array technology invented in Scotland in 1988. For CMOS detectors, pixels are read individually, so blooming is not the problem it can be with CCDs. The CMOS sensor contains four main parts:\(^4\)
1. The color filters
2. The pixel array
3. The digital controller
4. The analog to digital convertor.

Light comes through the lens and is processed by the color filter before reaching the pixel sensor array. When the filtered light reaches the pixel array, each pixel sensor converts the light into an amplified voltage signal that can be further processed by the rest of the CMOS sensor.\(^4\)

When the pixel array receives the signal from the digital controller, the pixel sensors capture the intensity levels of the wavelength-filtered light and output the result as an analog voltage signal. The analog signal is converted into digital by the ADC so that the final signal leaving the CMOS sensor can be used and further processes by other digital components on the printed circuit board of the device. On comparison with CCD’s CMOS do not require charge transfer, hence providing an increased sensor reliability and lifespan.\(^5\)

Photostimulable phosphor (PSP) plates

The PSP plates consist of a flexible polyester base coated with a crystalline emulsion of europium activated barium fluorohalide\(^5\) compound.

Storage photostimulable plates (SPPs) includes a:
1. Reusable photostimulated screen
2. A readout scanner
3. A photomultiplier tube
4. A digital interface card
5. A computer and software.

When X-ray photons strike the phosphor layer included on the plate, a latent image is formed. The phosphor screen releases the stored energy as light photons when scanned by the readout device by means of photostimulation. Careful transfer of plates is must followed by insertion into a scanning device where there is the application of laser beam of helium-neon that releases energy in the form of light. The intensity of the emitted light is directly proportional to the amount of X-ray energy absorbed by the phosphor plate. The light that is captured is intensified by a photomultiplier tube, which thereby converting the light into an electronic signal. The data are digitized by an analog-to-digital converter and the image is displayed on the computer monitor. There would be remnant energy within the plates which must be removed or erased before reusing the plates. This is brought about by exposing the plates to view box light or by utilizing erasure feature in case of newer scanner models.\(^6\)

The intensity of the light emitted is proportional to the X-rays absorbed by the plate.

PSP is flexible, wireless receptors that are similar to film in regard to size and thickness.\(^7\)

There are various number of phosphor plate systems available for digital imaging. The primary advantage is exposure reduction, have wider dynamic range, with lower spatial resolution on comparing it with direct sensors and film and also a larger active area.\(^7,8\)

Like a conventional film, a processing step is required thereby delaying image display. The time delay can vary from few seconds to few minutes depending on the system, type, and number of projections taken. The plates require careful gentle plate handling to avoid image artifacts. A study conducted by Bedard et al.\(^9\) found that the number of scratches produced is dependent on plate placement in the scanner drum and it increased with usage per plate and on investigating the durability of phosphor plates and the degradation of image quality due to emulsion scratches they stated that PSP’s may have to be replaced after 50 uses. In another study, Ergün et al.\(^10\) determined that phosphor plates can be used up to 200 times. Martins et al.\(^11\) stated that there is a loss of image density based on the effects of different storage
conditions along with varying time intervals between exposure and scanning of the plates. In a study to support the previous study, Sogur et al.\(^{[12]}\) inferred that there is a direct proportional effect on pixel intensity degradation and the ability to detect occlusal caries due to plate delays. For infection control, the plate is placed in a plastic pouch, which is sealed, preventing contact with oral fluids.

**Use of Bluetooth and Remote Controls for Image Transfer**

**Bluetooth**

Recent intraoral sensors in direct and semidirect digital technology use Bluetooth wireless transmission from the control module to the CPU. While the sensor is corded, Bluetooth eliminates the time, expense, and complexities of hardwiring the operatory. Sensor and control module can be easily moved among operatories, lowering equipment cost and bulky USB control boxes and other types of receivers, considerably reducing the investment to share the system among multiple treatment rooms [Figure 1]. Bluetooth transmits image data with greater stability and consistency than any other wireless choice.

**Remote controls**

The sensors in CCD’s use remote control that contains all the electronics of the sensor. The button on the remote control activates, at a distance, the acquisition interface in the imaging software. The remote control is connected to the computer with its USB 2.0 connector.

In the present market, there are variable sensors manufactured with a wide variety of features. A few of them are mentioned in Table 1.

**Intraoral Digital Radiography**

Digital imaging system are provided with receptor instruments that adapt to sensor size, allow positioning inside the patient’s mouth and follow the principles of paralleling technique [Figure 2].\(^{[1]}\)

The procedure followed for the same is explained in Table 2.\(^{[13]}\)

**Extraoral Digital Radiography**

As with intraoral digital radiography, extraoral digital images can be obtained either by direct or indirect digital imaging systems. Linear array CCD or CMOS detectors or PSP plate sensors, any of these are utilized in digital panoramic and cephalometric machines. In regard to CCD or CMOS extraoral imaging, there is the presence of a long, vertical, rigid digital receptor.\(^{[14]}\) In case of PSP receptors, the plate designed has same dimensions as that of the panoramic or cephalometric film. Thus can be placed directly into the cassette but with the intensifying screens removed.

**Imaging Processing**

An operation that aids to improve, restore, analyze or in any way alter a digital image is image processing.

Image enhancement software operations are utilized to alter the visual appearance of the image. Commonly used enhancements tools include:
1. Adjustment of the brightness and/or contrast: A poor diagnostic image can also be recovered. There is a possibility to modify the brightness or density when the pixels of the image are not over-saturated with increased radiation. By the addition or subtraction of the same value to every pixel this can be achieved. By adjusting the distribution of the gray levels in the image contrast is adjusted. In caries interpretation the contrast is adjusted to produce high contrast visualization, and for visualization of subtle changes in periodontal disease lower contrast is desired.

2. Black/white reversal: This option is used to invert or reverse the image so that radiopaque structures appear radiolucent and vice versa. This tool is useful to visualize the trabecular pattern of bone and pulp canal.

3. Pseudocolor enhancement: This tool aids in converting the image’s gray scale of into color scale. This tool is not very effective to view particular objects within the image. The application of color may be a useful tool in the future, but its utility presently has not yet been established.

4. Sharpening enhancements: This tool is utilized to demonstrate edges and margins more clearly. By sharpening the images they appear more appealing to the human eye, but there is no evidence that it improves the diagnostic quality of the image.

Image Analysis

Image analysis operations are helpful to obtain non-pictorial information from the image. The most commonly used analysis operation in digital radiography is measurement. Various measurement tools included are single/multiple linear measurements, determination of the angle, application of grid and calibration of known objects and their representation on the image.

Digital Subtraction Radiography (DSR)

DSR is used in diagnosing and following up of periodontal bone resorption, analyzing bone levels around implants and also to assess the healing process of periapical lesions. A study in 1998, Pansell et al. studied detection of oral cancellous bone lesions with various methods and found that DSR improved the diagnosis of a cancellous bone defect. Another study by Danesh-Meyer et al. assessed post guided tissue regeneration of the radiographic crestal alveolar bone mass comparing the change in clinical periodontal attachment level using DSR. They concluded that crestal alveolar bone mass and clinical attachment level showed accurate relationship on digital subtraction radiographic assessment.

Table 1: Detector specifications provided by manufacturers

| Manufacturer                        | Sensors | Technology | Resolution (lp/mm) | Additional features                                      |
|-------------------------------------|---------|------------|--------------------|----------------------------------------------------------|
| Eastman Kodak, Rochester, NY        | RVG 6500 | CMOS      | <20                | Wi-Fi enabled; iPad compatible                           |
| Eastman Kodak, Rochester, NY        | RVG 6200 | CMOS      | 25                 | Customized image contrast; cable wires 20% thinner than previous models |
| Air Techniques Inc., Hicksville, NY | RVG 6100 | CMOS      | <20                | Fastest display of images in <2 s                         |
| Visiodent, St. Denis, France        | RSV5    | CMOS      | 25                 | Available as single size that fits all the types of intraoral X-rays |
| Gendex                              | GXPS-500 | PSP       | 15.5               | Touch less PSP plates mode safeguards against scratches and fingerprints to promote long plate life |
| GE/Instrumentarium Imaging, Tuusula, Finland | BIO-RAY Sigma | CCD | 25               | Better resolution                                          |
| Schick Technologies, Inc., Long Island City, NY | SCHICK 33 | CMOS | 30               | Dynamic image enhancer, image preference presets features available |
| Schick Technologies, Inc., Long Island City, NY | SCHICK Wi-Fi | CMOS | 9                | 360° axis; Wi-Fi access; easily portable                  |
| Sirona, Bensheim, Germany           | XIOS SCAN | PSP     | 22                 | Five sizes available; with scratch free scanning         |

Table 2: Steps in intraoral digital technique

| Steps | Procedure |
|-------|-----------|
| 1     | Create a patient file template for the images |
| 2     | Prepare and cover receptor, place in holder instrument |
| 3     | Pre-set the exposure time |
| 4     | Place radiation shield on patient and explain procedure |
| 5     | Place covered receptor in patient’s mouth in proper position |
| 6     | Align vertical, horizontal and central X-ray beam |
| 7     | Prepare software for exposure move behind and expose |
| 8     | Remove the receptor and view image directly |
| 9     | Evaluate result; retake, enhance and/or save as needed |
| 10    | Or acquire additional images as needed and repeat steps 8 and 9 |
Diagnostic Utility

The diagnostic utility of digital radiography in comparison to film-based radiography has been assessed in various studies. Although the conclusions are not concordant, the majority of evidence suggests that digital images are at par to film-based images for accurate diagnostic tasks performed in dentistry.

The results of various studies indicate that presently used intraoral digital receptors appear to provide a diagnosis as detailed as that of a film.\textsuperscript{[21,22]} Hintze et al. in 2002 assessed the accuracy of caries detection comparing E-speed film with four storage phosphor systems at two different exposure times. The study concluded no significant differences in diagnostic accuracy between E-speed film and three PSP systems (Dentopix, Digorablue, Digorawhite) at the longer exposure time (25% of film exposure) for proximal caries.\textsuperscript{[19]} In case of occlusal caries, shorter exposure (10% of film exposure) of the PSP systems yielded less accuracy than regular films, but at the higher exposures only one of the PSP system, Digorablue, proved to be of same diagnostic value as that of conventional film.\textsuperscript{[19]}

The efficiency of digital imaging as a diagnostic aid in the alveolar bone evaluation and periodontal lesions has been studied several times. A study by Nair et al.\textsuperscript{[23]} found no changes significant to accurately detect alveolar crestal bone comparing the ability of E-speed film and Sidexis CCD (enhanced and unenhanced digital image). Another study by De Smet et al.\textsuperscript{[24]} states that there is the considerable accuracy of peri-implant bone level measurements comparing both conventional and digital intraoral imaging process. Pecoraro et al.\textsuperscript{[25]} in their study found that alveolar bone measurements are consistent on both digital and conventional radiographic images with the same accuracy. Paurazas et al.\textsuperscript{[4]} conducted a study to diagnose periodontal lesions using Ektaspeed Plus film, CCD, and CMOS-APS imaging systems and found no significant difference in diagnostic performance.

Teleradiography

The process of transferring a digital image to a farer site is termed teleradiography. In order to execute this task, both the users namely the sender and receiver should be able to produce an image that can be viewed by various software programs. Teleradiography has the ability for off-site consultation, improved access to patients in remote locations and insurance submissions. This entire process to expand these capabilities and share the information in a protective manner is provided by the digital imaging and communications in medicine (DICOM) Standard.\textsuperscript{[3]}

DICOM Standard

The DICOM standard is a set of instructions that explains the formatting and exchange of images and associated information. DICOM standard was adopted by the medical profession to overcome issues related to difficulties in imaging system communication and exchanging data.\textsuperscript{[22]} This is an internationally recognized standard for biomedical imaging and provides a platform for physical format of exchanging data among different manufacturing systems.\textsuperscript{[22]} Dentistry too had to face obstacles same as medicine with the incorporation of dental digital imaging. Presently, many of the digital radiography vendors have adopted DICOM standard for manufacturing systems. Digital radiographic systems that are DICOM compliant are universally accepted, thereby permitting image transfer or teleradiography for varied purposes.\textsuperscript{[22]}

Conclusion

Digital radiography is no longer an experimental technique. It is a technology that is reliable and versatile. Digital radiography in dentistry has expanded the diagnostic value and image-sharing possibilities. The information from radiographic images is collected in a more objective way and more easily through these digital systems hence improves the diagnostic process. This article suggests that due to the requirement of a processing like a film and thus, image display being delayed and need for better care of handling during scanning the SPPs, makes CCD’s and CMOS more durable for long time uses. A better manufacturing of SPP’s might with the use of recent advancement of Bluetooth and Wi-Fi aid in making these of indefinite use like the other systems.

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Digital intraoral radiography

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