Digital Radiography Versus Conventional Radiography in Dentistry

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SUMMARY
Since the discovery of X-rays in 1895, film has been the primary medium for capturing, displaying, and storing radiographic images. It is a technology that dental practitioners are the most familiar and comfortable with in terms of technique and interpretation. Digital radiography is the latest advancement in dental imaging and is slowly being adopted by the dental profession. Digital imaging incorporates computer technology in the capture, display, enhancement, and storage of direct radiographic images. Digital 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.

Keywords: Digital radiography, conventional radiography, dentistry

1. INTRODUCTION
In 1895, German physicist Wilhelm Conrad Roentgen discovered the X-ray. Within two weeks after Roentgen made his discovery public, the first dental radiograph was made by German dentist Otto Walkoff, who placed in his own mouth small glass photographic plates wrapped in rubber dam and exposed them for 25 minutes. The characteristics and, more specially, the sensitivity of film have been improved considerably in the intervening 110 years (1).

Conventional radiographic films that pass through all the functions of the imaging chain, namely image acquisition, chemical processing, transportation, storage and image display, have been important for image-based diagnosis. However, equipment such as cathode-ray tubes for image display, special sensors for image acquisition, and storage devices for image archiving has become more specialized. Thus, the independent performance of these functions is a key feature of digital imaging systems.

The turning point from film-based to digital radiography dates back to 1972 when G.N. Hounsfield introduced his new invention called computerized transverse axial scanning. The first unit accommodated only the patient’s head, and the scan time for one slice was approximately 4.5 minutes with an additional 1.5 minutes for reconstruction. This technique evolved into the computed tomograph, which requires only seconds to complete a full body scan and uses a helical scan with a multi-detector. Digital imaging has been applied to dentistry since the 1980s to diagnose paranasal sinus and temporomandibular joint disease (2).

The first digital X-ray sensors for use in dentistry were introduced in the mid-1980s by Francis Mouyen (Radiovisiography-RVG, Trophy Radiologie, Croissy Beaubourg, France [now Trophy, A Kodak Company, Rochester, N.Y.]). RVG is modern diagnostic method based on use of digital roentgen. Principle is use of so called CCD chip in RVG sensor (Figure 1) that put in patient’s mouth (3).

The first dental digital system was capable only of acquiring a radiographic image; the image could not be stored on disk but had to be printed. However simple it appeared to be, it marked the start of a new era. Shortly thereafter, another system was developed by Per Nelvig and colleagues (Sens-A-Ray, Regam Medical Systems, Sundsvall, Sweden), and within a decade many more manufacturers entered the market. Digital systems have improved considerably since then and now are a well-accepted and useful technology in dental diagnosis (1).

Digital radiographic images can be produced in different ways, some simple; flatbed scanners with a transparency adapter, slide scanners and digital cameras all can be used to convert an existing analog radiograph into a digital image. There are two more advanced technologies that create digital images without an analog precursor: “direct” digital images and “semidirect” 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.

Solid-state systems. CCD technology. Most solid-state sensors in digital dental radiography are based on CCD technolo-
gy. CCD refers to the design of the electronic chip that is used to capture the radiographic image. The chip converts an electronic signal to the energy of X-ray photons hitting the sensor. To increase the efficiency of this conversion, a scintillation layer is placed on top of the CCD. The scintillation layer converts X-ray photons into light photons, which then are absorbed by the CCD chip and converted into the electronic signal. This signal is sent to the computer by means of a cord between the sensor and the computer (1).

**CMOS technology.** Some solid-state sensors use CMOS technology. CMOS is not different from CCD technology in principle, but it does differ in terms of chip microarchitecture. In a CMOS chip, more of the electronic components controlling the conversion of photon energy into the electronic signal are incorporated into the chip itself. This simplifies the manufacturing process and, thus, reduces the costs of production. This architecture gave CMOS an advantage over CCD for some time. However, most digital cameras on the consumer market are based on CCD technology. The quality and production costs of CCD chips have benefited from this advantage of scale, and nowadays the image quality levels of CCD- and CMOS-based sensor systems are comparable.

2. **STORAGE PHOSPHOR PLATE SYSTEMS**

Systems using photo-stimulable phosphor (PSP)—sometimes also referred to as “storage phosphor plate”—systems use a plate covered with phosphor crystals. This phosphor layer is able to store the energy of the X-ray photons for some time. A scanner is required to “read” the image information from the plate, which it does by scanning the plate with a laser beam of near-red wavelengths. The energy is released from the phosphor layer, detected by an image intensifier and subsequently converted into digital image information. The latent image will remain in the phosphor plate before the scanning phase for minutes to hours, depending on the environment in which the plates are stored. They should not be exposed to bright light or warmth because this will release the energy before it is read by the scanner. After the plates are scanned, they are exposed to bright light that erases all remaining energy; the plates must be obtained by exposing patients to a minimal amount of radiation. Digital intraoral and panoramic radiography generally requires a lower dose per exposure than dose conventional dental radiography (2).

Practitioners and manufacturers frequently use the reduction of the radiation dose that the patient receives as a reason to implement digital radiography. There are several reasons why the dose reduction is not as large as often suggested (4). The most important reasons are dose per exposure, an increase in the number of radiographs made and an increase in the number of remakes made.

Dose per exposure: Sometimes manufacturers claim a dose reduction of 90 percent compared with film for digital sensors. The reality, however, is that the reduction compared with the current standard of F-speed film is somewhere between 0 percent and 50 percent. Storage phosphor plate systems, with their wide exposure latitude, carry the risk of using even more radiation, as the image quality will not

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Which system is the best choice for a dentist’s practice depends on how the practice is organized and how the system will be used.

3. **CCD AND CMOS SYSTEMS**

CCD and CMOS systems are connected to the computer by a cord. The connection can be via a wall box and the computer network. There are wireless systems on the market now, but these sensors are somewhat thicker than are systems with cords. The sensors are rigid and do not bend in the mouth of the patient and therefore could be more difficult for children to tolerate. The cord that connects the sensor to the computer may complicate the manipulations inside the patient’s mouth. The image produced by a solid-state sensor is available on the computer screen within a few seconds. As a result, such systems could be efficient aids in carrying out treatment such as an endodontic procedure, in which a second image easily can be made from a slightly different angle—for example, to make the second root canal better visible—with the sensor still in the same position. This could make a solid-state sensor the preferred sensor in a practice that focuses on endodontic procedures.

4. **PSP SYSTEMS**

PSP systems are flexible to some extent, which will make it more comfortable for the patient. The plates require the extra step of the scanning procedure. The scanning time is somewhere between eight seconds for a single image and two minutes for a series of plates. Some systems take the same amount of time for the scanning of a series of up to eight plates, irrespective of the actual number of plates. The advantage of PSP is that a single scanner can be shared among several operatories, similar to arrangements for a conventional film processor.

5. **EXTRAORAL SYSTEMS**

Extraoral systems, including for panoramic and cephalographic radiograph machines, exist as well in digital versions. Both CCD-based and PSP-based systems are on the market. The advantage of CCD-based systems is the direct availability of the image. Some PSP-based systems feature the ability to scan both intraoral and extraoral plates; for others, a special scanner is required to do this (1).

6. **RADIATION DOSE REDUCTION**

Radiation safety is an important issue in dental radiography. The desired amount of information must be obtained by exposing patients to a minimal amount of radiation. Digital intraoral and panoramic radiography generally requires a lower dose per exposure than dose conventional dental radiography (2).

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Dose per exposure: Sometimes manufacturers claim a dose reduction of 90 percent compared with film for digital sensors. The reality, however, is that the reduction compared with the current standard of F-speed film is somewhere between 0 percent and 50 percent. Storage phosphor plate systems, with their wide exposure latitude, carry the risk of using even more radiation, as the image quality will not
alert the practitioner to possible overexposure in the same way in which a film image would.

Increase in the number of radiographs made: Dentists indicate that the decision to make a radiograph is reached more easily with a digital system. In a Dutch study, 55 percent of clinicians using storage phosphor plates and 65 percent of clinicians using solid-state systems reported making more radiographs than they had with film (5).

Increase in the number and ease of remakes: It takes some time for the practitioner to get used to the positioning of the sensor inside the patient's mouth. It is obvious that this will result in a more frequent need to remake an image. After some time, however, when the dentist and other members of the team are trained in making digital radiographs, they still may have a tendency to decide sooner to repeat an exposure than they would have with analog radiographs. This was reported in one study by 60 percent of clinicians using phosphor plates and even by 80 percent of those using solid-state systems (6).

Digital radiography has been available in dentistry for more than 25 years, but digital imaging has not replaced conventional film-based radiography completely. Studies investigating the number of dentists using digital radiographic systems report percentages ranging from 11 percent to 30 percent; for instance, the percentage of dentists using digital radiographic systems was 11 to 14 percent in a 2001 study conducted in Norway (7), 12 percent in a 2002 study in the Netherlands and 30 percent in a 2007 study in Indiana (8).

There may be several reasons for this relatively low rate of use of digital radiography. The main reason given by general practitioners is the financial investment required to replace conventional radiography with digital imaging (9). Practitioners should remember that conventional radiography also involves costs for items such as film mounts, processing solutions and time needed for cleaning the film processor, as well as the costs of the films themselves (10).

Another explanation could be that introducing new technology in the dental practice requires a bit of courage. Some dentists have mentioned the complexity of the software and the hardware as the reason for not converting to a digital system. The dentist and his or her team will require additional training to understand the new equipment and new routines. It is not always clear beforehand how the new approach will affect existing logistics in the practice. These reasons could make the practitioner hesitate to change current procedures (11).

7. THE BASICS OF DIGITAL IMAGING

Although a digital image seen on the screen as a collection of brighter and darker areas very much resembles the traditional film-based image, the nature of a digital image is completely different. A traditional radiographic image is composed of radiolucent (dark) areas in which the silver grains in the emulsion are densely packed and radiopaque areas in which the grains are more dispersed, having been washed out during the film processing. A digital image, on the other hand, is composed of a set of cells that are ordered in rows and columns. The rows and columns form a table. 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.”

Traditional images cannot be changed once they are processed. The exposure conditions and the developing procedure determine the final result: brightness and contrast are fixed. Digital images, however, can be altered after they have been produced. The user can apply mathematical operations to alter the pixel values, which can change certain characteristics of the image. This is called “image processing.” Dedicated software is available to enable the practitioner to perform such processes.

An example of useful image processing is the optimization of contrast and brightness of an image. 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. Nevertheless, it can help to rescue an image in which exposure conditions were not optimal and thus prevent the need for a remake, saving the patient from an extra dose of radiation (12).

Digital radiography is increasingly used in general dental practice. Dentists have knowledge about what factors determine image quality in conventional film radiography. However, it takes time to acquire the same level of knowledge when a new technique, such as digital radiography, is introduced. The appearance and quality of digital dental images are affected by a number of new parameters and variables that are foreign to conventional film-based systems; this makes quality control programs for digital systems more complicated.

Image quality in radiographic imaging depends on the quality of each link in the radiographic system, and digital imaging is no exception. The weakest link determines the quality of the end product. There are reasons to believe that the display monitor is one of the weaker links. Spatial and contrast resolution and the amount of light emitted from the monitor (luminance) have a significant impact on diagnostic accuracy, and these factors can degrade over time. There are two types of display monitors: the cathode ray tube (CRT) and the flat panel display (LCD) monitor. For both technologies, performance varies depending on the design and the quality of the device. Cederberg et al evaluated three different CRT monitors and one LCD monitor to determine whether the monitors differed in the detection of low-contrast variations. Although the LCD monitor emitted less light, the study concluded that the
four monitors did not differ significantly in the detection of low-contrast differences. Today (2007), the luminance of both LCD and CRT monitors is generally high enough for use in dental radiography.

In one clinical study, it was found that film radiography was slightly better for the detection of periodontal bone lesions than digital radiography and that image processing did not improve diagnostic accuracy. Studies on diagnostic performance are usually carried out in an experimental set-up where digital system settings and viewing conditions have been optimized.

When analogue radiographs are evaluated, a room with a low level of ambient light (illuminance), a viewer and a light-box are traditionally used. There are reasons to assume that the level of ambient light also has a large impact on the evaluation of radiographic images on a display monitor. Haak et al. (13) found that full ambient lighting hampers grayscale perception on a monitor. They also found that the LCD monitor could show smaller grayscale differences in full ambient light than the CRT monitor. Enhancement programs allow the display of radiographs on a monitor to be altered in many ways. Gotfredsen et al. (14) found that their observers frequently used the program to alter brightness and contrast. Lehmann et al. (15) concluded that it is difficult for the general dental practitioner to comprehend all the possibilities in image processing.

Digitizing conventional radiographs using current high-grade digital cameras or scanners does not produce images of diagnostic quality. Improved resolution of viewing monitors is necessary to fully harness the potential of digital technology (16).

8. IMAGE ANALYSIS

A logical continuation of image processing is computer-aided image analysis. It is difficult to define the difference between image processing and image analysis. When the user adjusts the whole image to make it more suitable for diagnostic purposes, the term “image processing” usually is applied. When the user performs certain calculations extracting specific information from the image, it is considered image analysis.

An example of image analysis is the measurement of a distance in a digital image. To measure distances on conventional radiographs, a simple ruler suffices. This will not work for a digital image on the computer screen, because the user does not know the physical dimensions of the image on the screen beforehand.

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 (DSR) (17,18). This procedure allows practitioners to distinguish small differences between subsequent radiographs that otherwise would have remained unnoticed because of overprojection 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 (Figure 2).

Digital dental-imaging systems can provide adequate image quality at significantly reduced doses as compared to conventional techniques. Digital systems are especially suitable for users with low frequency of x-ray examinations (e.g. dentists in private practice), because of problems that may arise from having to develop only a small number of films. On the other hand, a drawback of digital systems could be the ease of deleting an image and performing another examination, the extent of which was not investigated (19).

Digital technology is a welcome incremental advancement in dental radiography. The combination of dental digital radiography and the Internet makes it possible to send images to anyone, anywhere in the world (provided they have a computer, an Internet connection and the appropriate software).

The transmission of radiographic images—tele-radiography—allows practitioners to submit insurance claims electronically, to forward patients’ radiographs to a dentist on the other side of town or across the country, and to obtain specialty consultations from experts wherever they may be.

A significant advantage of digital radiography is having instant, or nearly instant, images that are
archivable and retrievable at the press of a button or
click of a mouse, all without the mess and bother of
a darkroom.

A properly exposed and processed radiograph
will be viewable for decades using only a simple
light box. History suggests not. As recently as the
late 1980s, personal computers used 5-inch floppy
disks (which were truly floppy). These were soon re-
placed by 31/2-inch floppies (which were not), which
were replaced by Zip drives (Iomega, San Diego) and
CDs, which have been outdated by DVDs and Uni-
versal Serial Bus memory keys.

Except for endodontics and some surgical pro-
cedures for which instant intraoperative images are
helpful, dental digital radiography in its current in-
carnation is not likely to improve your ability to di-
agnose and treat patients. In the early days of den-
tal digital radiography, film was the gold standard
against which digital images were compared (20)
It still is. Most of the studies of the diagnostic effi-
cacy compare digital images with film-based radi-
ographs, and they generally conclude that digital im-
ages are not statistically different from film-based radiographs (21). That is, digital imaging is as good as
film, which tells us that film remains the gold-
standard image of dental radiographic diagnosis.
Dental digital radiography may improve office effi-
ciency, facilitate filing insurance claims, be useful
for marketing your practice and appeal to your in-
nner gadgeteer, but it is not likely to make you a better
dentist (22).

9. CONCLUSION

The number of dentists who have converted
from conventional film radiography to digital ra-
diography continues to grow. The movement from
analog film towards digital imaging system is based
on a number of advantages of digital imaging sys-
tem compared with conventional film radiography:
the reduction of the number of retakes because of
possibilities of image processing changing the im-
age contrast and density, the shortening of working
time from exposure to image display due to avoid-
ing chemical processing and wet processing errors,
the preventing of inferiority of image quality with
the development of storage devices. Nevertheless,
the gold standard remains analog film. Because of
competition from newer digital technologies, manu-
facturers of X-ray film continue to improve image
quality on film at lower radiation doses. Film still
has a higher spatial resolution than digital imaging
systems, but studies have not demonstrated that this
is clinically important. When newer digital recep-
tors are developed in terms of physical factor such
as spatial resolution, signal-to-noise ratio, and con-
trast resolution, when more advanced radiographic
methods such as creating three-dimensional dis-
plays of dental structure are established, and when
cost of plant and equipment is reduced, diagnostic
dentistry will truly enter a totally digital era.

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