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Feature Article

# Digital Radiography -- Not If, but When

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abstract

***Digital radiography can enhance the dental practice by facilitating diagnosis, enabling orderly filing and archiving, and allowing better communication with patients. Although the initial investment in equipment is substantial, it is quickly repaid and provides both a substantive and fiscal benefit. There are challenges involved in implementation, but they are quickly being overcome. It is only logical for dentistry to move along with the rest of society into the digital age and take advantage its benefits.***

Change is never comfortable. Dentists spend years learning to do something well, and then a new technique comes along and challenges the comfort of the status quo. It happens with resin composites, new bonding agents, new formulations -- yet it is hard to give up something that seems to be working sufficiently. A new impression material may or may not produce better results. While change is not comfortable, it must be recognized as inevitable. One either goes forward or falls behind -- there really is no status quo. Today's dentist is faced with a myriad of changes and decisions, many of them induced by the electronic revolution. Among the decisions to be made is whether to seriously consider digital radiography.

Digital radiography is becoming increasingly more common, and the interested practitioner is faced with a variety of choices and decisions. More than 10 systems are available, all offering different features. While digital radiography has not yet become commonplace, many dentists have expressed interest in purchasing a system. The basic decisions are whether to make the move to digital radiographs and, once the first decision is made, which digital radiographic system to purchase.

Reasons not to move from film-based radiography to digital imaging are no longer valid for most practitioners. The most-often-cited reasons for such reluctance have been image quality and cost. Both of these now favor digital radiography. A third reason has been technophobia, a general resistance to entering the digital world. Perhaps this is the issue that should be addressed first.

## The digital world

Children today are growing up in a digital world. They play with computerized toys, surf the Internet, and do their homework on computers. To the modern generation of children, the computer, with all its functions and interconnections, is just another accepted element of normal life. Computer software augments traditional learning methods. It broadens and facilitates communication. The computer is becoming commonplace in the home, the school, and in business. To many adults, however, the computer and computerized applications are still intimidating; and many are unwilling to face the learning curve necessary to become part of modern society. Such attitudes must change if the dentist is to remain technically competitive and be able to take advantage of devices such as digital radiography.

Consider the world in which we live. Supermarkets speed checkout using computer-based scanners and track the customers' marketing preferences in the process. Airline and hotel reservation systems are computer-based, and travelers can even make their own reservations from their computers. Investors rely on stock markets' use of computers to conduct business and can track the progress of their investments on their personal computers. The Internet has proven to be a rich and deep resource for learning, shopping, and communicating. Every substantial business is either using Internet marketing or investigating how to do so. All levels of government, transportation, commerce, and communication rely on computers. Even automobiles are dependent on computer processing. There would be no concern about the potential "Y2K" problem if computers were not ubiquitous in society. Whether we choose to recognize it or not, we all live in a digital world.

It is not a matter of if one is going to move to a digitally based office, but when*.* If one chooses to remain technophobic and not make the transition to the modern world, it is a conscious choice to be left behind, to stand out as an anachronistic relic of the past. The decision to be made, then, is how to effectively implement digital technology into a dental practice.

## Image Quality

When digital radiography was introduced into dentistry, the quality of the images was less than desirable. Furthermore, sensors were bulkier but had active surface areas smaller than that of traditional film. Users were forced to accommodate these limitations. This has changed. Today sensors are available that are the equivalent of the commonly used film surface area and have a comfortable thickness (**Figure 1**). Several digital radiography systems offer sensors in sizes commensurate with the surface area of traditional film, including No. 0 for pediatric dentistry, No. 1 for anterior periapical images, and No. 2, the universally used size for most imaging. The physical dimensions are easy to compare, but comparing diagnostic quality is more difficult.

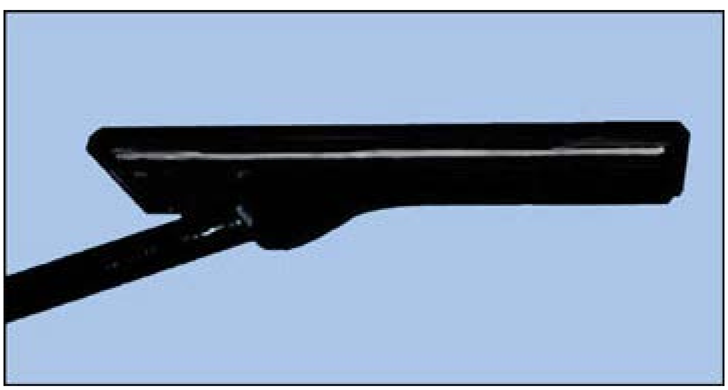

***Figure 1. Modern sensors are less bulky and more comfortable than their predecessors. The sensor shown is 3.2 mm thick.***

When comparing a digital image with film image, it is generally assumed that the film image has been acquired by selecting the appropriate voltage, amperage, and time, and that the properly exposed film was also properly processed (including adequate fixation and drying) and appropriately filed. Such films are rarely found in the real world. Film is commonly viewed without magnification and evaluated using only ambient light. If a film image was not properly exposed or processed, and does not have optimum contrast and brightness, the dentist is forced either to make a new image or to accept a less than desirable image. Because of time constraints, the latter choice is usually made. However, a digital image can be manipulated to compensate for less-than-optimal exposure variables and is always viewed in a larger format than film. Furthermore, it can be greatly magnified (the extent of the maximum magnification is dependent on the inherent pixel size of the sensor) and can be otherwise optimized without sacrificing original image integrity. Contrast and brightness can be varied to focus on the different features in the image.

## Quantifying Image Quality

The term resolution is often used to compare film and digital images. Resolution measurements attempt to quantify the smallest observable details. It is often referred to in terms of "line pairs" -- the use of an imaging instrument having successively smaller pairs of radiopaque lines. Direct digital imaging (as opposed to phosphor plate technology that has lower resolution) offers resolution from about 11 to more than 20 line pairs (**Figure 2**) while film is generally considered to resolve 15 line pairs. The unaided human eye can only see 9 line pairs, but the enhanced resolution becomes a factor upon magnification. Sensor resolution greater than 20 line pairs has only recently been possible.

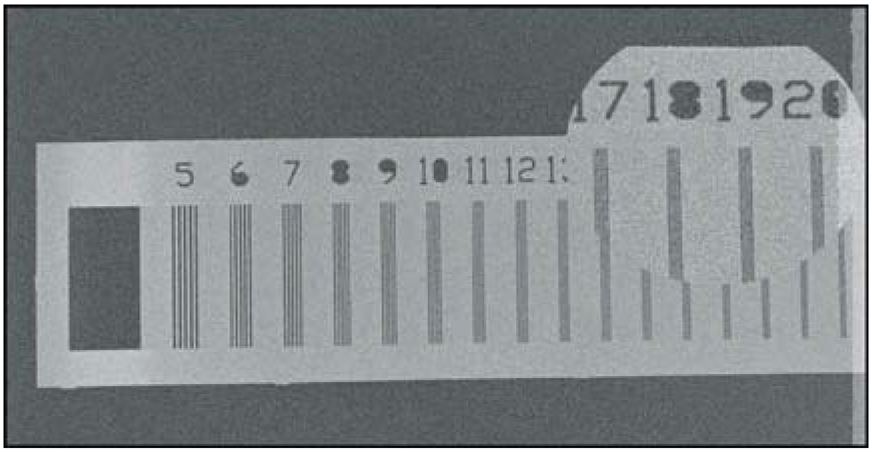


***Figure 2. A radiograph of a line pair phantom. The magnified inset shows that at 20 line pairs/mm, the separation of lines and spaces is still clearly visible.***

Resolution is only one aspect of the diagnostic quality of either film or digital images. The large format of the digital image makes visualization easier and enhances communication with patients. Once one becomes accustomed to viewing images on a large monitor rather than peering at a small film on a viewbox, it is difficult to return to film.

Dynamic range -- the blackness of blacks, whiteness of whites, and continuous tone of a complete gray scale -- is essential for adequate diagnosis. Nearly all direct digital systems provide 256 grays, the greatest number the human eye is capable of distinguishing.

Signal-to-noise ratio quantifies the strength of the signal to the background electronic noise. When magnified, film is quite "noisy." Digital radiography systems use signal amplification and background noise subtraction to produce the cleanest possible image.

## Pixel Density

Sensors are made up of a series of electronic "wells" that trap electrons. The number of electrons in each well translates into gray-scale images. The size of these wells varies with different sensors. A typical sensor will have electron wells approximately 45 m m square. Unlike film, where crystals are randomly arranged and of various sizes, the sensor has ordered rows and columns of electron wells. Each of these is an element in the image that is produced: a picture element, or a "pixel." The smaller the pixel, the greater the number of points of information that can be displayed on a screen. High-resolution sensors with pixels one-fourth the typical size are now available. Four pixels of 22.5 m m will fit into the space occupied by a 45-m m -square pixel. Therefore, the pixel density of the high-resolution systems is four times greater than the standard systems. This will manifest as a finer grain image but will not be greatly visible until the image is magnified. High-resolution images may be magnified more greatly without breaking up into visible pixels (pixelating). Sensors with more than a million pixels (megapixel sensors) are available from at least two sources, and others are sure to follow.

Regardless of what technical methods are used to make a comparison, probably the only means of really equating the diagnostic equivalency or superiority of digital images comes from the daily use of film and sensors and appreciating the quality of today's digital diagnostic systems.

### Cost

Once diagnostic equivalency has been shown, the second factor to address is cost. Film carries both direct and indirect costs. The cost of the film itself, the cost of processing chemicals and space in which to use them, the cost of waste disposal, the cost of automatic film processors, and, not insignificantly, the time it takes to process and store film all must be considered. Add to this the time required for cleanup and maintenance, and it becomes apparent that the time consumed by film radiography is significant. Rather than construct a scenario that might or might not apply to the reader, it is suggested that each reader calculate the number of films made each day in his or her office; the time consumed by the assistant, hygienist, or dentist in processing, mounting, and cleaning; and especially the cost of waiting with a patient for a film to be processed so a procedure can continue. Endodontics, implant dentistry, dowel post placement, oral surgery, and similar services may all require sequential imaging during a procedure, and waiting time can be substantial. Using these numbers, it is easy to demonstrate that the cost of digital X-ray system can be recouped in less than a year -- with many added benefits.

With digital radiography, there are no chemicals to purchase, store, or dispose of. There is no film to carry in inventory. There are no mounting procedures and no filing or loss of images. One of the great advantages of digital radiography is the orderly filing of images, with the ability to retrieve by tooth, region, or date.

### Radiation Reduction

Virtually everyone realizes that digital radiograph images require less radiation to make than film. The decrease in radiation burden is usually cited as a comparison to D speed film, since the comparison is more favorable. When the purpose of the film is to establish some gross feature, such as the position of a file in a canal, or the length of a dowel post, a radiation reduction of up to 90 percent over D speed film is possible. For more discriminating diagnosis, evaluating margins or small carious lesions, higher exposures are needed; but in any event, the radiation dose will be less than either D or E speed film.

What is important is the latitude of the system. Over how wide a range can an acceptable image be made? With a wide latitude, it is simpler to get a diagnostic quality image. It is better to err on the side of underexposure, since overexposure may cause "burnout" -- loss of image information as a result of electrons spilling out of a capture well into adjacent areas. With slight overexposure, the majority of the film will be of diagnostic quality, but some areas will be unusable.

### Remaking Images

There is another issue related to radiation reduction, and that is the re-exposure to obtain the desired image. Sometimes an image must be remade, either because the film or sensor has been mispositioned, or the X-ray cone was misdirected. Remakes may be necessitated with either film or sensors. However, when remaking a film image, the film has been removed from the mouth, several minutes have passed since it was exposed, and the chances of making a proper image the second time are not greatly better than they were with the first exposure. With a digital image, the image is displayed almost immediately, the sensor is still in position, and the X-ray tube head is still in place. Remaking the image becomes much more predictable, since the sensor or tube head can be moved from a known position to the desired position.

### Image Transmission

One of the great advantages of digital radiography is the ability to export images. This is an advantage not only for sending radiographs to third-party payers but for many other purposes. Duplicate radiographs -- whether single images or a complete mouth series, have the same quality as the originals -- at no added cost, and with virtually no additional time. These can be sent to a referring dentist or forwarded to any other treating dentist.

### Legal Issues

Concerns have been raised about the legal aspects of a virtual image, and the potential for image alteration (falsification). There are now image-tagging algorithms that mark images as being original and unaltered. Such images may be enhanced (brightness, contrast, etc.) but may not have any alteration of the image information. Such images may be transmitted and used with assurance that, as long as the image tag guarantees the image is unaltered, the image is secure. Of course, neither film nor virtual images can preclude the outright fraud of sending images for different patients or other flagrant falsification.

### High-Speed Communication Services

When transmitting multiple images, data transfer speed becomes an issue. Whereas "plain old telephone service," commonly referred to as "POTS," may be adequate for small files and infrequent transmission, if larger files are frequently sent, the office should consider other communications systems. Urban areas have many options, including Integrated Services Data Transmission (ISDN), Symmetric Digital Signal Lines (SDSL), and cable. Whereas POTS is able to send messages at no greater than a nominal 56 kilobits/second (actual transmission can be much slower), SDSL and cable can send and receive 1.5 million kilobits per second. SDSL and cable service may cost as little as $30 per month and provide Internet service 24 hours a day, seven days a week. Such service is economical, especially when compared with some telephone company services such as a T-1 line. Asymmetric Digital Signal Lines (ADSL) and satellite transmission offer only one-way high-speed transmission -- to the office, but not upstream from the office. Satellite may be an economical alternative in areas where the preferred services are not available, but input data will only move at the available modem speed.

With proper software, digital images and files can be accessed from a home computer if an emergency arises. Images may also be sent via the Internet as attachments. The destination for the image is irrelevant. It can be across the hall or across an ocean.

Similarly, images can be printed in a letter to patients or in communication for referral. Some specialists, especially endodontists, routinely send back images of pre- and postoperative radiographs embedded in a referral letter. Some digital radiography software facilitates such communication by linking to form letters that can be written with images appended directly from the original program.

### Image importing and exporting

Modern digital radiography software allows the user to import images from attached devices such as a scanner or a digital camera. In this way, film radiographs may be accurately scanned, enhanced when necessary, and digitally filed as a part of the patient's virtual chart. Other documents such as prescriptions, medical reports, or laboratory work requests can also be scanned and filed. Intraoral camera images may likewise be archived with the radiographs in a patient chart, graphically chronicling the patient's treatment and documenting progress.

### Configuration

Most dentists who do not have a computer network already installed envision beginning with digital radiography as a cart-based or portable system. The probability of a digital radiography cart being pushed from room to room is not great. Historically, those who bought intraoral cameras on a cart either did not use them or eventually supplied all the operatories with cameras.

The dentist who wants to test digital radiography may well start with a cart, but it is unlikely that the cart will be frequently moved. Another way to set up a mobile system is to use a laptop computer. Several such systems are available, using either PCMCIA slots or universal serial bus (USB) ports. Such systems make movement from room to room fairly easy, and the large hard drives on modern notebooks makes image storage reasonable for the short term. However, once images are acquired and patient folders begin to accumulate, the serious user must consider networking and linking to a practice management and virtual patient record system. It makes no sense to isolate patient X-ray images on a computer that is not interfaced with other records. In an office where the hygienist or other associates will also be using the system, isolation is unthinkable. In such situations, a digital network is a reasonable, viable solution. Once computers in the different operatories are linked, patient files can be shared and are easily accessible by everyone authorized to view them. When a practice management system and virtual patient treatment record are added, the full facility for acquiring and archiving information is present.

The thought of integrating all records is intimidating to many dentists, and the idea of linking some other software to their practice management system brings looks of horror and disbelief. It is true that in the past such integration has been problematic and unreliable with some systems; but, with well-written software and a stable network, such integration can be seamless and smooth.

When considering a network installation, one should remember that image transmission requires greater bandwidth (ability to pass information) than does text alone. Fortunately, networking costs, as most computer-related costs, have dropped; and a high-speed (100 Base T) network is the only reasonable consideration.

### Image size

As previously mentioned, high-resolution images have greater pixel density. This means larger file sizes, which affect storage capabilities. Since the legality of image compression is still unclear, it is safest to opt for lossless compression, in which no image information is discarded. Some digital systems have image storage capabilities that guarantee an original image but at the expense of maintaining a larger file. Fortunately, hard disk sizes continue to grow while costs drop. In planning storage capabilities, one should take into consideration the average number of radiographs made weekly, the file size for each image, and the total file requirement to store images each year.

### Archiving

Since X-ray images are a part of the patient's dental record, they must be archived. If one calculates the number of patients treated each year, and the number of images that each patient represents, simple multiplication will indicate a data storage problem. Images not in active use may be archived on CD-ROM, digital tape, or another server. Before long, off-site digital storage will be available at a reasonable cost and with easy access. When high-speed data transmission is coupled with off-site digital storage, the data storage and access problem is nicely solved.

### Image Capture

Part of the intimidation factor of progressing from film to digital radiography is the change in both format and function. The procedures for obtaining film images are so routine that there may be some reluctance to try anything that would be more demanding. Fortunately, many current systems simplify image acquisition with little deviation from current film-based procedures. The first noticeable difference between film and sensors is that sensors are rigid: They cannot be bent. Operators frequently bend film to accommodate oral conditions, with resultant image distortion. Thus, the rigidity of the sensor can be thought of as a positive factor in that it prevents distortion by bending, even though it requires accommodation to some oral conditions.

Sensors also require a barrier cover, since they cannot be autoclaved. Some sensors are provided with plastic barriers, others with natural rubber. The barrier should cover both the cable and the sensor -- anything that contacts the patient. Some attention should also be given to the receptacle in which the sensor will rest between uses, inasmuch as this is also a potential source of cross-contamination. A disposable insert is desirable.

Sensor positioners should accommodate either a paralleling technique or a bisected angle approach. Positioners should also allow for root canal instruments to remain in place during the imaging. In short -- the system should allow the user to continue the same practices currently used with film.

Image capture should involve as little interaction with the computer as possible. Some systems are able to sense the radiation and display the image after being initially activated, minimizing any computer interfacing. The great benefit of digital images is the ability to immediately display the image, whether it is a single image or part of a complete mouth series. The user may choose to accept the image or correct the alignment and remake it.

Once the procedure for image acquisition is learned, users usually find it as simple as using film, without waiting for the image, and with no need to develop, fix, or dry the image.

### Image Enhancement

Digital radiography software systems offer a plethora of image manipulation algorithms, some of which are rarely used. There are many advantages of image enhancement that should be mentioned. The most common is alteration of contrast and brightness. **Figure 3** shows an image that was underexposed but which was easily and quickly manipulated to improve diagnostic quality.

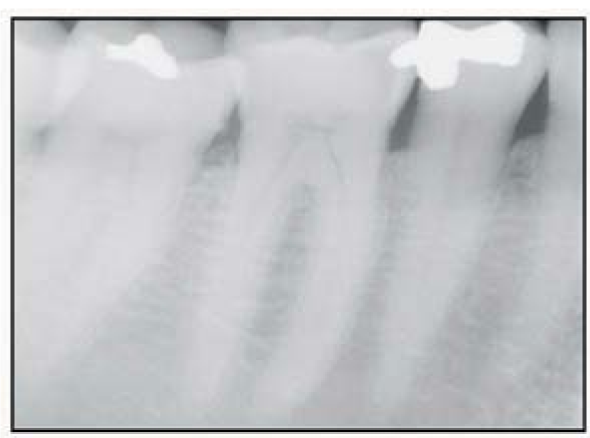

***Figure 3a. This image was underexposed.***

***Figure 3b. A simple change of contrast and brightness produces an image that is of diagnostic quality.***

Magnification is another frequently used feature. Instead of holding a film up to a light box and using loupes or a magnifying glass to see more detail, digital images may be magnified simply and easily. The pixel density of the image determines the degree of magnification possible without the image breaking up into pixels. High-resolution images with small pixels permit higher magnification. **Figure 4** shows an area of an image enlarged two times, yet the visualization is greatly enhanced.


***Figure 4. The rectangle in the main image identifies the region of interest. The inset "picture-in-picture" is a 2x magnification of the region. In reality, this image would be at least the size of this journal page rather than the small format shown.***

Colorization is frequently shown by those demonstrating digital radiography, but it is usually of only casual interest for diagnostic purposes. Colorized images are created by assigning a color to a range of grays, and the process actually discards some information. However, colorization can be helpful in defining soft tissue and, when combined with image inversion (reversing black and white), often shows trabecular patterns remarkably well (**Figure 5**).

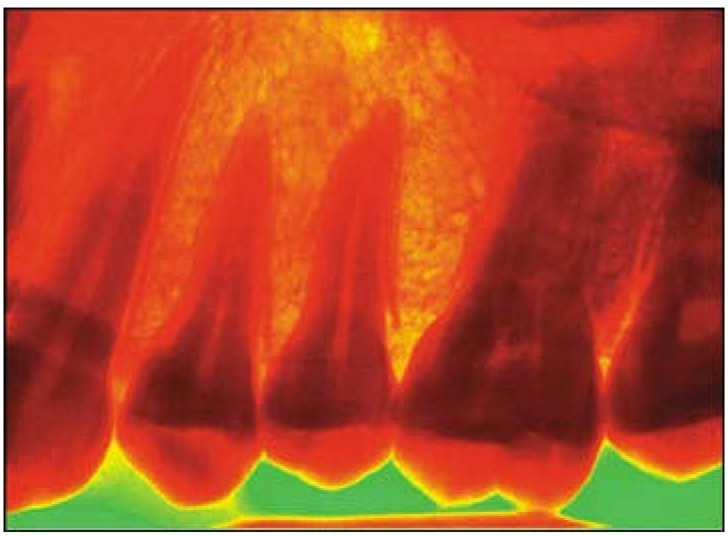

***Figure 5. A combination of the "invert" and "colorize" features accentuates trabeculation and provides an almost 3-D appearance.***

Other combinations of features can also be helpful. Measurements are often needed when performing endodontic therapy or placing a dowel post. Nearly all digital systems facilitate measurement. Measurements can not only be linear, but can also navigate root curvatures. Spot-enhancing the area accentuates contrasts and aids visualization. **Figure 6a** shows a file in a canal and short of the apex; **Figure 6b** shows the apex spot-enhanced, and the measurement made from the stop to the tip of the file. **Figure 6c** depicts the spot-enhancement with the distance from the file tip to the apical foramen. Such measurements are difficult with film. In addition to having to wait for the film to be processed, the potential for measurement error is greater.

*Figure 6a. A file placed in a mandibular lateral incisor is short of the apex.*

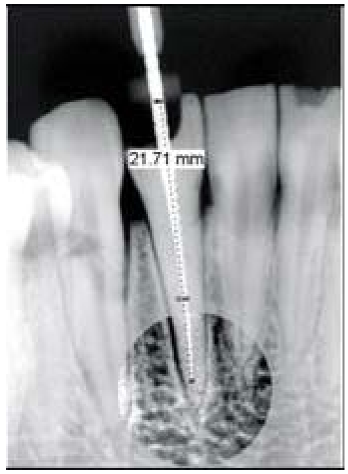


*Figure 6b. The apical region is spot enhanced to better locate the tip of the file and the apical foramen. A measurement is made from the stop to the tip of the file.*

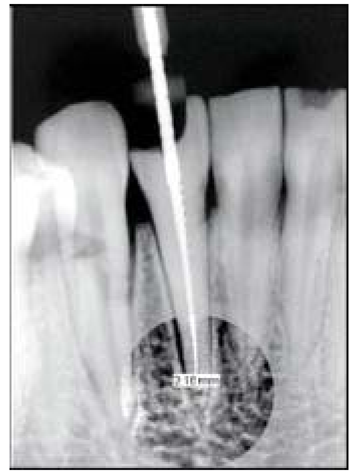

*Figure 6c. The remaining distance from the tip of the file to the apical foramen is determined.*

Image enhancement can greatly facilitate both diagnosis and treatment procedures. Digital radiography also improves communication, since the patient can be shown the large image and can see features impossible to appreciate with film. Text labeling, drawing on the image, and other communication devices help patients to visualize problems and understand the necessity of therapy.

## Summary

Digital radiography facilitates and enhances diagnosis, enables orderly filing and archiving, and allows better communication with patients. Although the initial investment may seem substantial, that sum is repaid within the first year of use and actually provides both a substantive and fiscal benefit. It is only logical for dentistry, along with the rest of society, to move into the digital age and take advantage of the profound benefits that the virtual world offers. The question the practitioner should be asking is not "Why should I use digital radiography" but, rather, "Why should I use film?"

## Author

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