Can digital radiography replace film radiography?

Chi-Lok Tsang *, BDS, FRACDS

Introduction

The collection and analysis of appropriate information is critical to decision-making in the practice of dentistry, and one essential form of the information is radiographic imaging. Radiography has been an indispensable tool for over 100 years, being widely used in diagnosis, treatment planning, disease monitoring, and operative dental procedures. Advances in computer technology are changing the way radiography is performed and used as new options and tools become available.

To create a conventional radiographic image, attenuated X-rays are passed through an object of study onto a film emulsion of silver halide where they react with a chemical processing agent. For the displayed image to have good contrast, sufficient radiation is required to affect the crystalline structure of the chemicals on the film. The subsequent process of film development is expensive, both in terms of materials and equipment, is time-consuming, and is environmentally unfriendly. A correctly exposed and processed film is, however, outstandingly detailed and long-lasting. Advances in technology have significantly improved X-ray equipment; however, because the degree of detail on film images depends upon crystal size and the emulsion, the quality of a radiographic image depends on the silver halide and other molecules in the film. There is no substitute for silver halide. Further improvements in film-based radiography cannot be expected due to physical limitations; the technology has reached its endpoint in terms of radiation exposure and image quality 1.

Comparing image quality

When discussing image quality, the greatest concern is resolution, especially spatial resolution. Resolution is expressed as line pairs per millimeter, and is one of the factors that can be measured and compared in order to rate image quality. The resolution of conventional radiographic images is limited to the inherent resolution of the film itself. In contrast, the resolution of digital imaging systems is determined by the charge-coupled device (CCD) detector and the resolution of the monitor used to view the images. Despite the rapid improvement of modern digital systems, their spatial resolution is generally inferior to film-based systems. Conventional E-speed films can provide a resolution of 20 line pairs per mm, while digital radiography provides 7 to 10 line pairs per mm 2; the use of a digital system results in a 50% drop in quality in terms of spatial resolution. However, this drop in spatial resolution should not compromise clinical diagnostic performance because the minimum contrast threshold of the human eye corresponds to a spatial frequency of 5 line pairs per cm (this is equivalent to each line pair consisting of a 1 mm-wide line and a 1 mm-wide space) 3. The human eye is less sensitive to pixel sizes smaller or larger than 1 mm 4; however, the threshold beyond which the human eye no longer benefits from increasing image resolution has not been determined.

In caries diagnosis, contrast is more important than resolution. Contrast between the lightest and darkest parts of a radiograph reveals relative differences in density. The greater the image contrast, the more subtle the differences in density that can be revealed. The contrast of a film radiograph is a result of subject contrast, film contrast, and film processing. Film processing involves several variables including development time, processing temperature, and chemical activity, and any deviation from the manufacturer’s recommendations during processing will result in a film image of less-than-ideal contrast.

Digital radiography does not require film processing and thus can avoid the pitfalls of chemical processing. Digital contrast resolution is expressed as the number of gray levels. Film provides 16 to 24 levels of gray. In current digital systems, the initial sampling of data is usually 10-bit or 12-bit, which corresponds to 1024 and 4096 gray values, respectively. These gray values are then reduced to an 8-bit image, resulting in a typical digital radiographic
image of 256 levels of gray. Digital imaging exceeds film imaging in the context of gray levels by a factor greater than 10. The human eye is able to discern roughly 100 gray levels; so the digital image is more than sufficient for clinical use. In spite of the increase in the number of gray levels, however, digital imaging cannot reveal more information than the film image because of the limits of the human visual system. Nevertheless, another methodology has been suggested for using these extra gray levels, according to the highly regarded dental radiology expert Dr. Alan Farnun, Chairman of Radiology at the University of Louisville, “while there may be few lines, the trade-off is that they contain much more information. The key to computer enhancement is the progressive peeling away of information (gray scales) that the dentist does not need to see, and the increase in contrast between the gray scales desired to reveal features that were undetectable with conventional film X-rays.” The tremendous dynamic range of gray levels can be utilized to increase the diagnostic value of digital radiography.

Comparing image displays

Several factors interact to affect the outcome of digital imaging, including detector design, resolution, gray scale range, pixel size, pixel number, line pair per mm, luminance, ambient light, color or monochrome imaging, and size of the monitor used to view the images. Most of these factors relate to the display, thus the performance of the display system is very important. The display is the final link between the acquired image and the eye-brain system of the radiologist-observer.

The eye positions of a group of radiologists were studied and recorded while they examined radiographic images on cathode ray tube monitors. Findings revealed that 20% of their viewing time was spent on the menu and toolbars. This process of dwell occurred during the first 10 seconds of film examination when the observers were using the image-processing functions very early in the examination process. The implication is that observers viewing digital radiographic images probably need more time than those viewing traditional film images on a viewing box. The final diagnostic outcome may be the same for both digital and film systems, but the time taken by the observer to make a diagnostic decision using a digital system is longer.

Perhaps surprisingly, the monitor used to view digital images may be a relatively insignificant factor. A study undertaken to determine the influence of display monitor fidelity concluded that observer performance is independent of the visual characteristics of the display monitor used. These characteristics included spatial resolution, screen size, bit depth, dot pitch, and luminance. The reason for this is probably that most monitors designed for clinical use meet the minimal requirements in these parameters: differences in monitor performance are just noticeable and are not clinically significant.

Monitor contrast, defined as the ratio of black to white, may be the most important display factor; the darker the black and the brighter the white, the better the image quality. Films are placed on a light box for examination, and every effort is made to maximize viewing conditions, including using strong light box, reducing ambient light, and using a viewing tool. In digital systems, white is determined by monitor luminance. Thus, when comparing the viewing conditions between digital and film systems, the luminance of the display monitor is compared with the light box. In order to have the same luminance as a light box, a monitor should have at least 514 candela/m². A low-luminance display increases observer fatigue, while a high-luminance display causes pupil dilatation and improves recovery time. Dilated pupils, in turn, are better able to detect low-to-moderate contrast objects. Display luminance should be at least 170 candela/m², according to the American College of Radiology Standard for Digital Image Data Management. Monitor luminance should be increased from this minimum level to sufficiently offset ambient light, which decreases the perception of image contrast. Luminance does not affect detection performance significantly, but it does significantly affect viewing time.

Since observers using digital radiography systems spend more time extracting useful data and reaching diagnostic decisions, the presentation of a good quality radiographic image is important because it reduces the time required for image manipulation and improves workflow.

Image processing

A film image is not adjustable after processing. A good conventional radiograph is the result of correct positioning of the film, optimal X-ray exposure, and chemical processing of the film. Mishandling in any of these areas can result in variations in image quality. Digital images, however, can be adjusted and manipulated after image capture. This is an advantage in which most practitioners see tremendous potential. For example, factors such as contrast and magnification can be adjusted according to the user’s needs or preferences. Digital image processing procedures are expected to be able to provide corrections to some inherent image errors and improve diagnostic value.

Image processing can be defined as any operation that acts to improve, correct, analyze, or in some way alter an image. This includes a broad class of algorithms for the
modification and analysis of images. Three functions were proposed as the primary values of image processing. First, it makes the image more suitable to the human visual system, though this is a complex psychophysical process that is rather subjective: the reaction of the observer to an image is not predictable and is affected by many factors. Secondly, image processing is designed and expected to increase diagnostic accuracy. Thirdly, the use of objective criteria in image processing can make diagnostic decisions more consistent. The improvement of diagnostic accuracy by image processing is based on the underlying assumption that the diagnostic outcome of dental imaging is in some way limited by the human visual perception. Part of the data in any digital image will not be accessible by the human eye. The capability of computer systems to extract otherwise hidden data from these images is a key benefit of digital radiography.

Image enhancement is the image processing capability most relevant to the practice of dentistry. Every application of image enhancement is expected to produce a new image which is an improved version of the original. Such an enhancement can be subjective, merely making the image more appealing to the observer by adjusting contrast, brightness, sharpness, or visual noise. Subjective image enhancement may not be correlated to or improve the diagnostic value of an image, but it may have some psychophysical influence on the observer that contributes to his or her final decision. Other objective image enhancement procedures aim to correct inherent artifacts such as removing blurs and compensating for defective pixels on the detector.

Studies exploring the effects of image processing and enhancement software have not had consistent results. Some authors agreed that image processing can improve diagnostic efficiency, while others found that it reduced accuracy. Tuning an image with respect to a certain person might not provide the best view for other readers, and images should be adjusted in accordance with the demands of the individual observer. The effect of image enhancement on the diagnostic accuracy of digital radiographic imaging is not fully understood. Users should know and understand exactly what an image processing operation is doing to their data; proper image processing requires an analytical observer.

The principal objective of image enhancement is to alter some attributes of an image and make it more suitable for analysis. Consequently, the types of image enhancement applied to each image should be used according to the specific diagnostic task at hand and the preferences of the observer. For example, higher contrast is beneficial for caries detection but may hamper the discrimination of changes in bone level. If the objective of enhancement is to provide a data set to be viewed by a human observer, it is crucial to incorporate the characteristics of the human visual system into the applied image adjustment. Digital radiographic imaging is not ‘film-like’ because the dose response of CCD-based digital systems is linear as compared with the curved (analog) response of film-based systems. Viewers have been shown to prefer a curved display function. Therefore, how the human visual system reacts to and perceives the digital image on a screen has great influence on the image’s clinical application.

**Conclusion**

Digital radiography is changing the diagnosis and treatment of dental diseases by incorporating computer technology into the field of dentistry. Few dentists received training in information technology in dental school and must therefore rely on manufacturer’s instructions, which may be biased. Before a new system is in place, we should be able to demonstrate that the new system performs at least equally well as the old one. Digital radiography is designed to do far more than simulating conventional film radiography. It is a true advance in the practice of dentistry that eliminates the tedious procedure of handling of films and developer. Instantaneous image display, easy image storage and retrieval, and teleradiology, as well as the reduction in required radiation dosage, are, no doubt, advantages to be welcomed by all dental practitioners.

Although some of the technical properties and characteristics of digital radiography systems are inferior to conventional radiography, and no digital radiography system has been proven to be superior to film radiography, this does not mean that digital systems provide a poorer level of performance compared with conventional film systems. Several studies have shown that digital systems can be as accurate as film systems and sufficient for clinical use, e.g. caries detection, landmark identification, periodontology, and endodontics. The potential of computer image processing and manipulation has not yet been fully exploited. Further studies are needed to determine the best uses of digital radiography in various disciplines of dentistry. With rapidly advancing technology, it is expected that the next generation of digital systems will surpass the quality of conventional radiography with the use of more powerful computers, better detector designs, and smarter software functions. Digital radiography offers a plethora of technical innovations to dentistry and is sure to significantly influence the arts of diagnosis, monitoring, and research, as well as the treatment of dental diseases.

**References**

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