

KODAK MEDICAL SYSTEMS WHITE PAPER

Image Capture Chain Performance of Kodak's Next Generation of DIRECTVIEW DR Systems



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Introduction

For nearly 100 years, photographic film has been used to record x-ray images. For over 60 of those years, intensifying screens have been used with x-ray film to provide high-quality images that were the standard for medical imaging because of their image quality, dose efficiency, and functional utility. In modern terminology, x-ray film–screen systems enabled radiologists to acquire, display, communicate and store patient image data.

It has become technically possible and economically feasible for digital imaging technologies to challenge film in the area of projection radiography. In particular, CsI (cesium iodide) scintillator detectors have evolved and improved with better performance and stability compared to their first clinical appearance. The combination of this CsI detector technology and Kodak's advanced proprietary IP (image processing) results in superb digital radiography images with the added benefit of enhanced examination workflow and productivity.

In any x-ray system, it is the complete imaging chain that contributes to the final image quality starting with the x-ray generation and ending with image presentation. The acquisition detector itself is only one component in a complex imaging chain. Kodak has a long history of image processing expertise as well as more than a century of understanding and adapting to the critical requirements of a radiological environment.

Acquisition Technology

Kodak's next generation of digital radiography flat-panel imaging system now offers its customers the most efficient method for obtaining high quality diagnostic images. With any radiographic imaging system, the imaging chain begins with the x-ray tube, producing x-rays of an optimal quality and quantity, closely followed by the detecting technology used to capture the x-rays. Table 1 provides an indication of the more important detector characteristics inherent to this system at the capture stage.

Table 1 KODAK DIRECTVIEW DR System detector characteristics.

Characteristic	Value
Pixel pitch	143 μm
Effective active area	429 x 429 mm
Image Matrix size	3000 x 3000 pixels
Optical fill factor	~ 68%
Geometrical fill factor	100%
CsI:Tl Absorption layer	500 μm
ADC	14 bits
Sampling rate	2 MSPS

One of the important parameters to consider is the fill factor. From Table 1, two definitions for fill factor are possible to characterize the detector: the optical fill factor and the geometrical fill factor. The optical fill factor is the fractional area of a pixel that is sensitive to the light emitted from the CsI phosphor layer. For KODAK DIRECTVIEW DR Systems this optical fill factor has been measured to be approximately 68%.

The geometrical fill factor is defined as the fractional area of a pixel that is sensitive to the absorption of an x-ray. In other words, this can be considered to be the x-ray detection fill factor. Since the optical signal from a single absorbed x-ray is distributed over more than one pixel, this x-ray detection fill factor is effectively 100% for the flat panel detector. In this situation, there is no "lost" x-ray absorption events. In essence, for the flat panel imager, the effect of pixel fill factor is to reduce the signal produced by an absorbed x-ray rather than to reduce the absolute number of x-rays detected.

Figure 1 illustrates, in some detail, a cross-sectional view of the detector. In summary, the main component of this device is an x-ray scintillator layer composed of a thin layer of CsI(Tl), which converts the incoming x-ray energy to visible light photons. This is the same material used for many decades on the input side of image intensifier tubes. This same layer is optically coupled to a flat panel array composed of light sensitive pixels that record the intensity of the light output from the scintillating layer, commonly referred to as a flat-panel a-Si:H array, as the readout mechanism. The light sensitive components of the individual pixels convert the incident light into an electrical charge that is then stored internally in each pixel element. The charge collected at each pixel is amplified and quantized to a digital value for that pixel element by the underlying readout electronics. The digital values are then transferred to the external system for storage and further image processing.

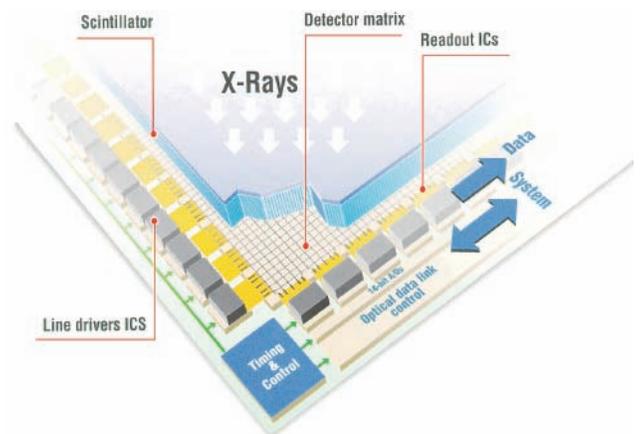


Figure 1 Structure cross-section showing elements of the Kodak's flat panel detector.

X-Ray Transducer

The x-ray imaging detector is one part of the complete imaging chain. Its optimal functionality is dependent on many physical factors described herewith.

The x-ray detection material selected as the scintillator material is cesium iodide doped with thallium CsI(Tl). In doping with thallium, the crystal becomes a scintillator emitting at a wavelength that is a good match for photodiodes.

The CsI(Tl) used as the scintillator material is grown in a needle structure, similar to vertical shafts, or vertical pipes tightly packed (Figure 2). The needle structure ensures there is a minimum of photon spreading when x-rays are converted to visible light photons. Light spreading is a direct cause of poor detector spatial resolution. Growing the scintillator material in this type of configuration also allows for a thicker layer to be constructed. Thicker layers of scintillator material increase the x-ray photon absorption efficiency, thereby increasing the achievable image quality. A graph of the x-ray photon absorption of a 500 μm thick CsI(Tl) layer as a function of input x-ray energy is shown in Figure 3.

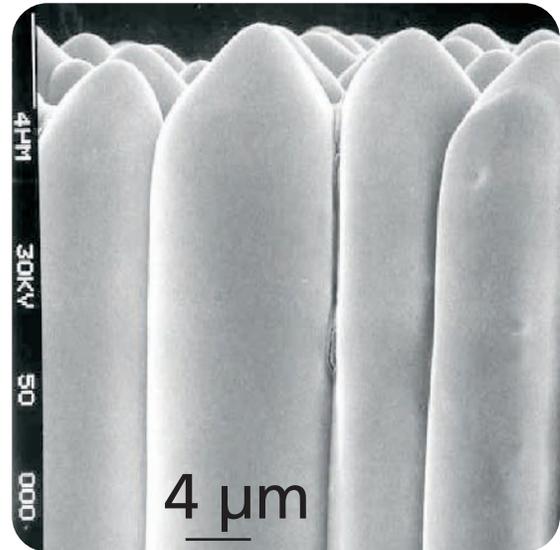


Figure 2 Electron micrograph of the CsI(Tl) needle structure.

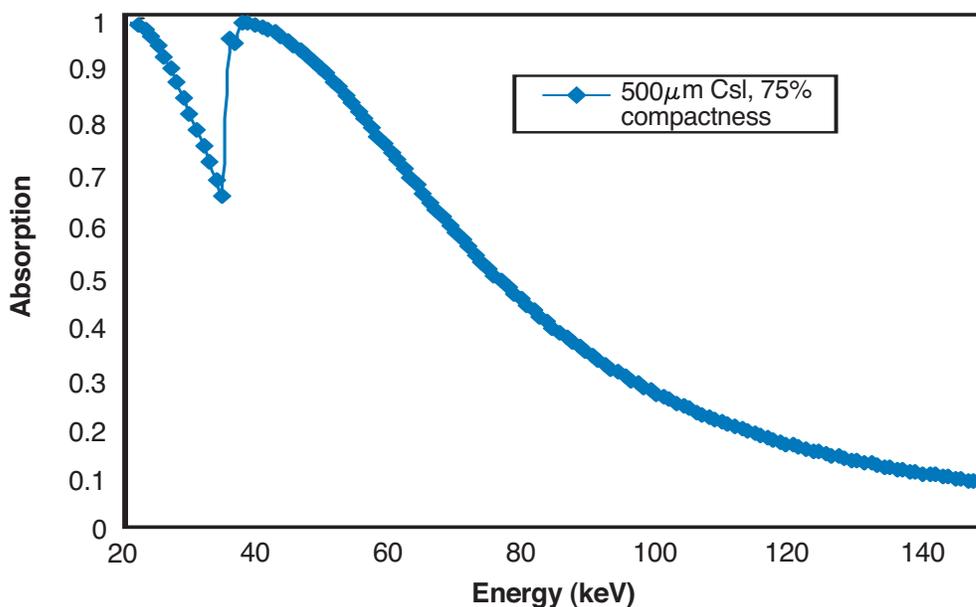


Figure 3 X-ray photon absorption of 500 μm thick CsI(Tl) as a function of x-ray energy.

Table 2 Physical Characteristics of RQA beam qualities according to IEC 61267.

Beam Quality	Physical Characteristics (added filtration, kV, Half Value Layer (HVL))
RQA3	12.5mmAl, 50kV, 4.0mmAl
RQA5	23.5mmAl, 70kV, 7.1mmAl
RQA7	32.5mmAl, 90kV, 9.1mmAl
RQA9	42.5mmAl, 125kV, 11.5mmAl

The excellent match between the CsI(Tl) output spectrum and the photon absorption quantum efficiency of the a-Si:H sensing photodiode is shown in Figure 4 below. There are two conversion phases that need to be considered at the detecting stage in order to determine the total efficiency of the detector. The first conversion phase is from x-rays to visible light. This has been measured to be about 15% representing the total energy of visible photons as a function of absorbed x-ray energy. The second conversion phase occurs from the transition of visible light to electrons.

This measure is usually described as the effective quantum efficiency and, in this case, is about 50%. Figure 4 below shows the emission spectrum of the CsI(Tl) and the spectral sensitivity of the a-Si:H sensing photodiodes.

The global conversion factor from electrons to x-rays is about 800 e⁻ / incident x-ray assuming an x-ray beam quality of RQA5. An RQA5 beam has very specific quality characteristics, and is defined within an international standard IEC 61267 (see Table 2 for specifications of commonly used RQA beams).

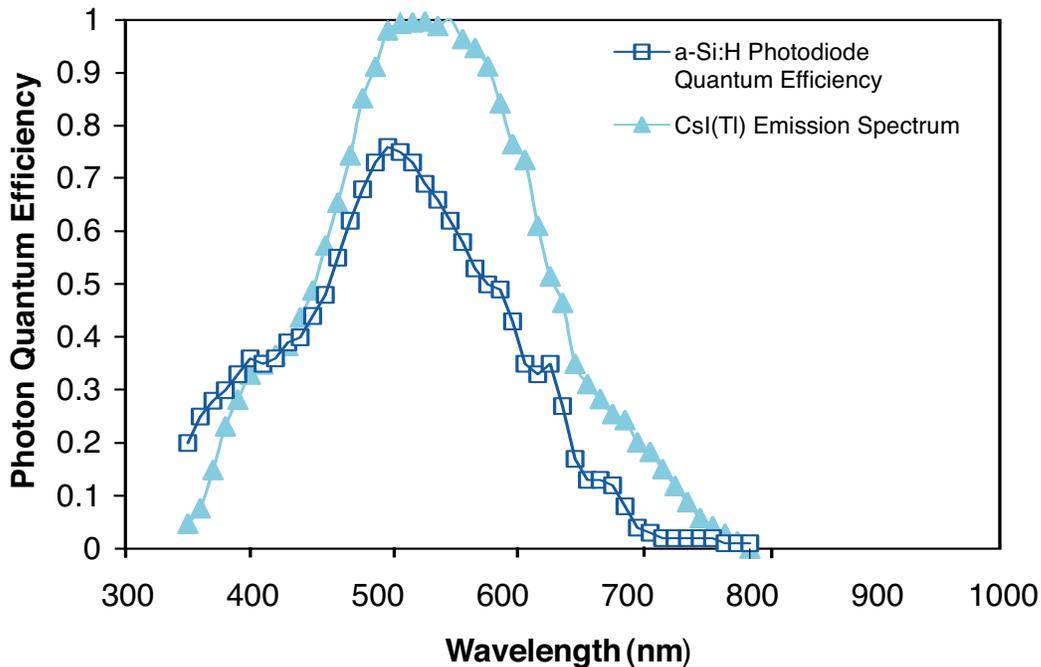


Figure 4 CsI(Tl) emission spectrum and a-Si:H photodiode quantum efficiency as a function of wavelength.

Photosensitive Diodes

Another important section of the physical detecting system is the ability of the detector to convert the visible light into electrons. This conversion is achieved with the use of photosensitive diodes. Recall in the previous section that as a consequence of CsI being doped with thallium, the wavelength of the visible light emitted by CsI(Tl) and the wavelength that the photodiode is most receptive to are well matched (Figure 5).

A representative pixel layout is shown in Figure 5 below. An individual pixel is made of one large area photodiode and one small area switching diode, in a back-to-back configuration. In this figure, switching diodes are connected to horizontal readout control lines and photodiodes are connected to vertical data columns.

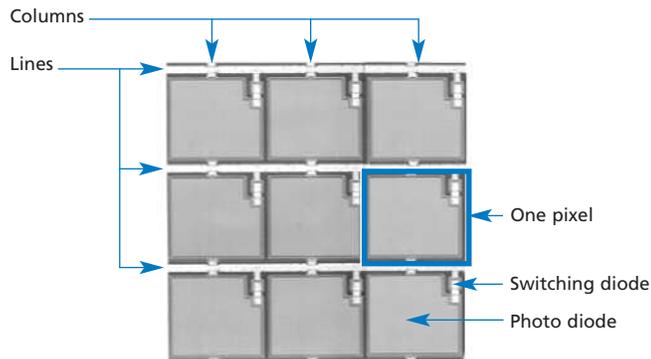


Figure 5 Photograph of 3x3 pixel section showing details of pixel design.

Detector Characteristic

A particular characteristic of the detector system is the detective quantum efficiency (DQE). This measurement describes the image capabilities of the detector as a function of frequency. The value plotted is dependent on several factors, such as the inherent noise of the system and its limiting resolution. Figure 6 shows the measured DQE of the detector measured with an RQA-5 beam quality. These measurements were performed as directed in the IEC 62220-1 standard for DQE measurement. The results shown are for an input exposure of ~ 1.7 mGy (or about 0.2 mR).

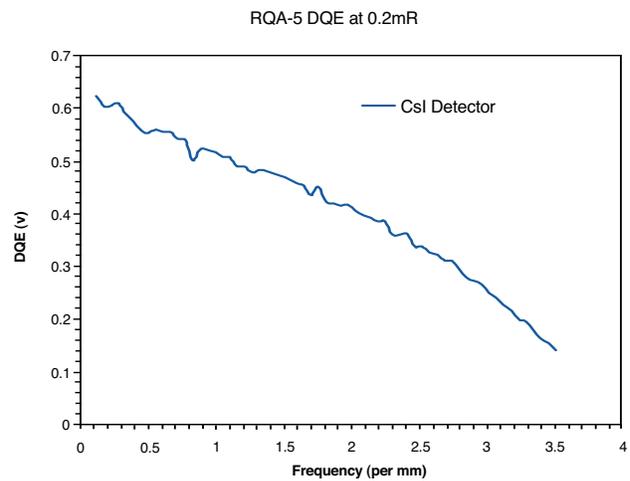


Figure 6 DQE (v) for the detector measured according to IEC 62220-1 standard.

Image Processing

Eastman Kodak Company has a very long history of developing image processing tools that have been extensively tested and validated clinically. Our core suite of patented image processing algorithms form a common platform across our digital acquisition devices. With the next generation of the Kodak's digital acquisition detector, the core image processing algorithms – with some additional bone enhancement features– provide the viewer with high image quality.

Image processing software optimization began with the PTS (perceptual tone scale) algorithm, followed by EVP (enhanced visualization processing), which was shown clinically to exploit the full exposure range of digital image data. The image processing sequence begins with a 14 bit image that is subsequently segmented and analyzed, then proceeds to the PTS algorithm (Figure 7).

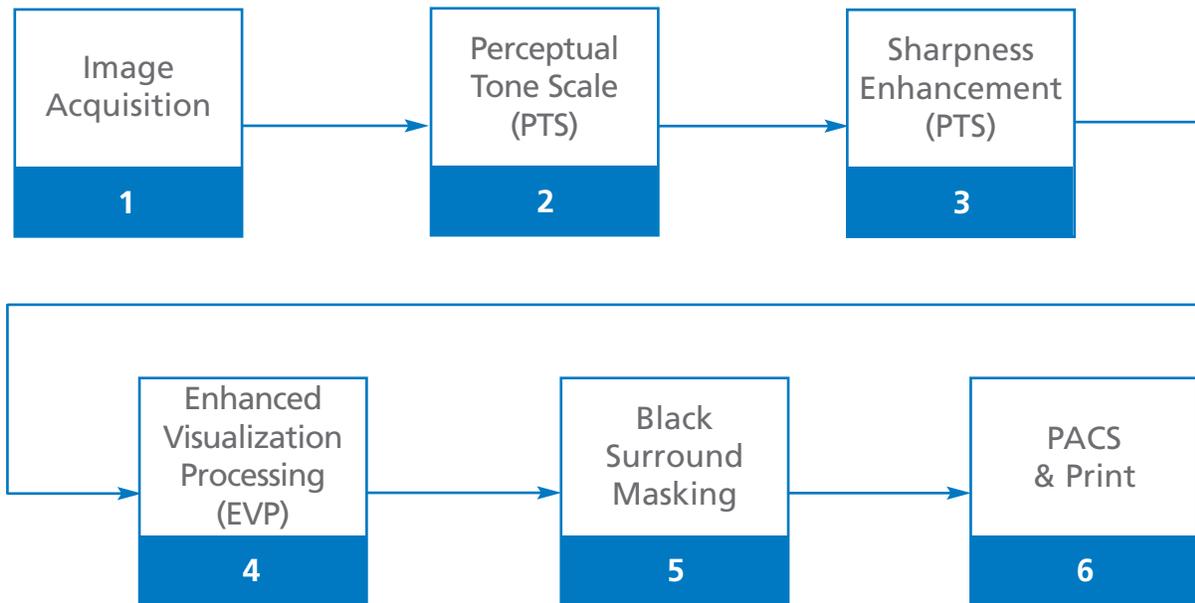


Figure 7 Image processing steps from acquisition of raw image data to image presentation.

PTS

PTS is the first patented image processing software improvement in the Kodak digital suite, which all other improvements and subsequent developments are based upon. In analog imaging, the tone scale is inherent to the film design and can not be changed after the patient anatomy has been exposed. In digital radiography, this is no longer valid. Input code values are directly related to the output code values representing equal brightness intervals. Image optimization requires a tone scale that properly incorporates human visual characteristics, one that is perceptually linear, mapping equal changes in log exposure to equal changes in perceptual brightness. When the

tone scale is parameterized, flexibility is gained in adjusting the ensuing curve shapes reflecting itself in visual effects, similar to the familiar speed curves of analog radiographic film.

PTS was extensively clinically tested and validated (Figure 8). Ten board certified radiologists rated image pairs (control vs. test) on a nine-point diagnostic preference rating scale ranging from a score of 1-Very Dissatisfied to 9-Very Satisfied. In total, over 3000 independent ratings were obtained. PTS failure rate was determined to be less than 4%, when all exam types were considered.

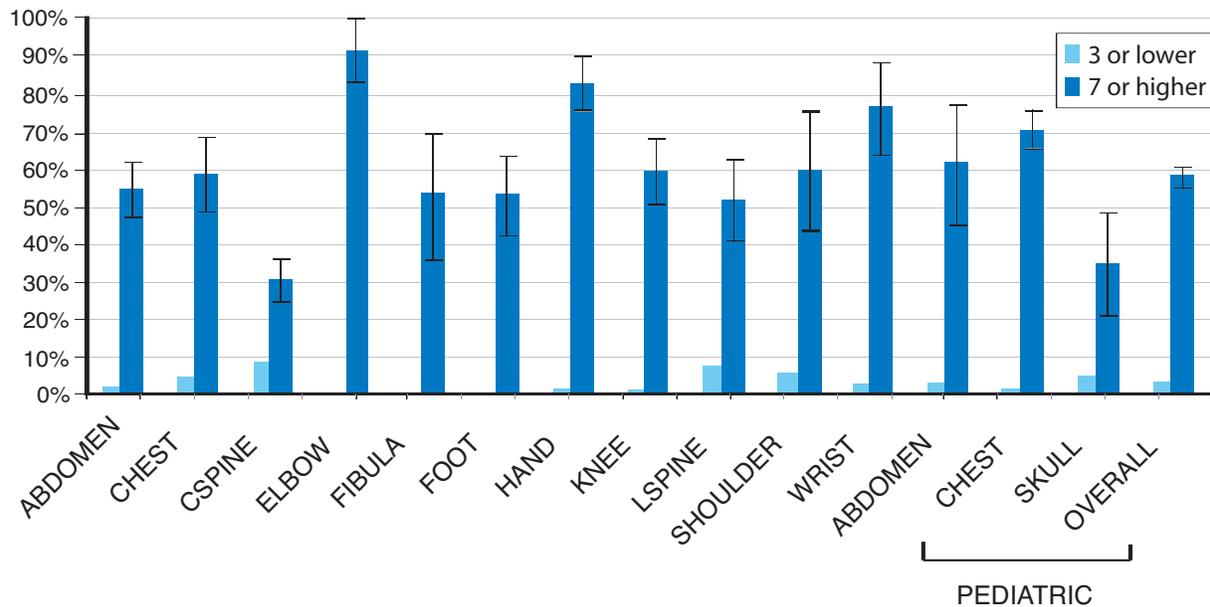


Figure 8 Percentage of images rated 7 or higher and 3 or less. 3 or lower indicated images for which radiologists were dissatisfied. Images rated 7 or higher indicated radiologists' satisfaction with the presentation of the images.

EVP

The next generation of patented image processing software in the Kodak suite was the development of EVP, an enhanced visualization image processing software algorithm exploiting the full exposure range of computed radiography image data. The EVP algorithm has been shown to overcome the traditional trade-off between exposure latitude and contrast detail and provides an opportunity to improve both diagnostic accuracy and radiologist productivity. The software algorithm is applied to a radiographic image after edge enhancement and tone-scale analysis, but before the application of the tone scale to the image data. The EVP algorithm divides an

image into low and high frequency component images. The contrast of the low-frequency image is reduced, thus increasing the range of exposures visible in the image, and the contrast of the high-frequency image is enhanced, thereby preserving the visual contrast of the image detail. The low and high frequency images are then recombined by the EVP algorithm and the tone scale is applied. The clinical study consisted of ten board certified radiologists using the nine-point diagnostic preference rating scale as in the PTS study, reading paired images (control vs. EVP) for a total of 1400 independent ratings. EVP images were clearly preferred (Figure 9).

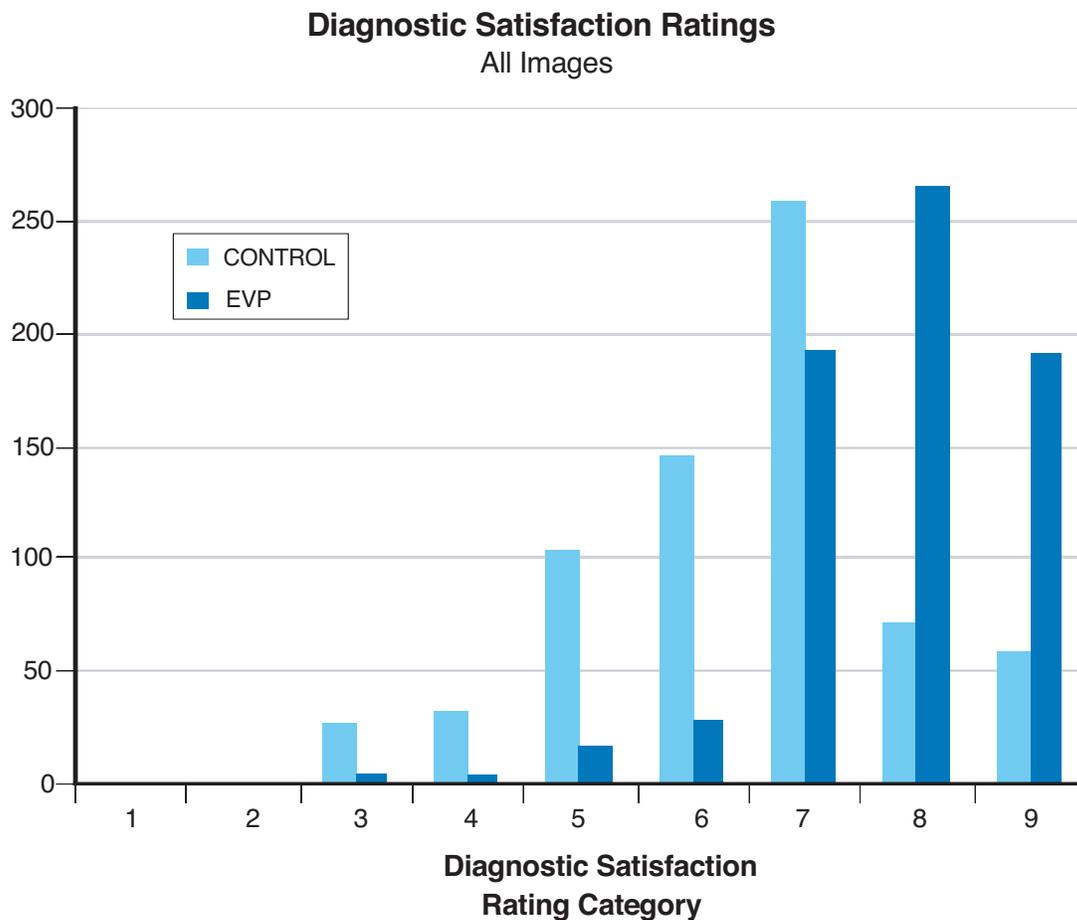


Figure 9 Diagnostic satisfaction rating means. With EVP the mean is 8, while with the Control it is 7, a clear indication that EVP is preferred over the Control images ($p=0.05$).

Image Optimization for the Next Generation of Direct Radiography Systems

Given the strength of the signal to noise ratio of this next generation of DR systems, it is possible to manipulate the digital image using theorems from digital signal processing science. As shown in Figure 10 below, the MTF (modulation transfer function) can be enhanced in the spatial frequency domain, relevant to diagnostic imaging. Figure 11 is a series of digital images representing the application of the sharpness enhancement algorithm.

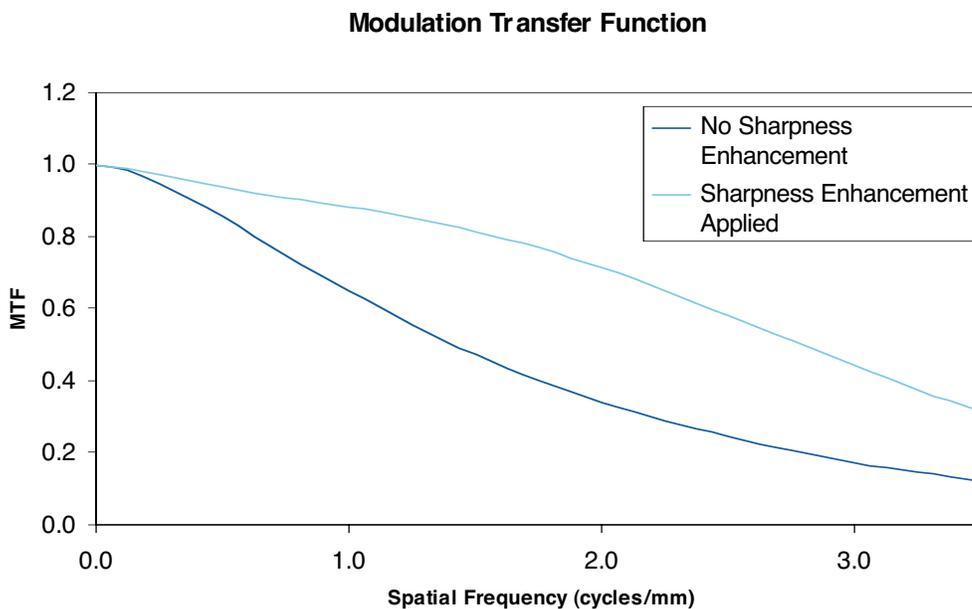


Figure 10 Modulation transfer function frequency dependency demonstrating sharpness enhancement. Sharpness enhancement greatly improves the MTF thereby enhancing the image presentation detail.



Figure 11 Sharpness enhancement applied to bone.

(a) No enhancement applied

(b) Sharpness enhancement applied

Clinical Evaluation

In clinical evaluations of Kodak's digital radiographic system, three experienced board certified radiologists with a combined professional life of over 60 years and one senior radiology resident from a busy Level 1 Trauma centre and University teaching hospital, scored 100 image pairs (control vs. device). A nine-point scoring system was used, ranging from very satisfied to very dissatisfied. Even though each radiologist had their own viewing preferences, reflected in features representing their radiology sub-specialty, not one scored the images below 5, indicating that each image was diagnostically acceptable. Figure 12 illustrates graphically the delta diagnostic rating attributable to the detector and edge restoration algorithm. Noise levels were considered to be less than their previous experience with a DR system. Radiologists consistently commented on the improved noise appearance and improved detail in low signal areas.

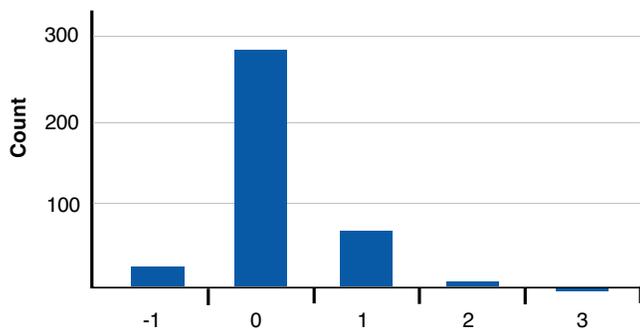


Figure 12 Distribution of delta diagnostic ratings (Kodak's next generation device images minus the Control device images) indicating a preference for Kodak's imaging device.

Summary

Image presentation is very much dependent on user preferences and not only on the physical characteristics of the digital acquisition imaging system. It has been shown in a clinical study that the next generation of KODAK DR systems, according to very experienced radiologists in demanding sub-specialties, images to contain less noise and more detail. These comments from very highly experienced radiologists with demanding sub-specialties, exemplified the superb image quality acquired with the KODAK digital radiography imaging system. The physical characteristics of this detector have been determined and image processing algorithms have been applied to achieve edge restoration, especially important for bone fine detail imaging.

Development and commercial availability of radiographic imaging products built upon Kodak's next generation of Direct Radiography systems represents a continued and focused direction leading to enhancing the clinical diagnostic environment. The KODAK DIRECTVIEW DR System provides an opportunity to minimize retakes while providing the highest quality images. Add to this the product's ease of use for technologists, enhanced productivity capabilities. The result is a new standard for x-ray image capture ideally suited to digital projection radiography.

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More information

To learn more about the KODAK DIRECTVIEW DR Systems—and Kodak's complete family of DR systems – contact your Kodak representative. Call 1-877-TO-KODAK (1-877-865-6325), ext. 227, or visit www.kodak.com/go/dr.

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