# CHAPTER 2

# REVIEW OF RELATED LITERATURES

## 2.1 Theory

### 2.1.1 Introduction

Radiography has evolved from screen-film imaging to a highly integrated, high quality image and information acquisition, display, archival, and retrieval system. The characteristics of images produced and processed for analog standards are the result of many consultations with radiologists over decades, which led to improved discrimination of image detail; the same is now true of digital imaging. As with conventional x-ray film-screen imaging, radiographic image quality for digital imaging remain driven by radiologist preference and their tolerance for image noise. Through much consultation with radiologists and the American College of Radiologists digital standards that display fine image details and yield high sensitivity and specificity are now in place. These standards are continuously being evaluated and are a part of an ever evolving DICOM language. Notwithstanding, the radiographer still controls certain factors that determine the quality of a digital image including: the use of ionizing radiation, handling raw image data to be sent to PACS or to film printing, and patient positioning. The principle of digital radiographic imaging is that when practiced by the technologist may enable the radiologist to resolve diagnostic issues. Time has proven that the generic performance of x-ray equipment, radiographic technique selection (mAs and kVp), and film processing within a given institution and between institutions is variable enough to make optimal imaging for all viewers under screen-film standards impossible. The need for optimization of radiographic images has spawned a new way in which radiographs are acquired-digitally. The use of computers to capture and process radiographs have given the viewer new tools that allow for dynamic manipulations of digital images through processes like changing algorithms and windowing. Windowing allows the viewer to change the contrast and density of an image to ones liking but does not permanently change the stored raw data. With digital imaging each viewer has the flexibility to control subject and radiographic density while viewing a radiograph. A fundamental difference between PACS and computed radiography (CR)/direct digital radiography (ddR) is that CR/ddR allows the technologist to change the raw data prior to saving it. If the technologist changes the raw data prior to sending it to PACS it is permanently lost to PACS and therefore to diagnostic and clinical workstations. Radiographer professionals must understand when and how we may manipulate raw digital image data and its impact on others who may make algorithm and windowing changes when viewing stored images from PACS.

In addition to achieving high quality digital images with CR/ddR imaging, implementing ALARA (as low as is reasonably achievable) has been very difficult. The difficulty lies in trying to use dose reduction techniques commonly practiced with analog film imaging. Principles that apply to film/screen imaging, mainly selecting mAs, kVp, source-to-image distance (SID), decreasing object-to-image receptor distance (OID) , or trying to achieve wide latitude techniques with automatic exposure control have transferred nicely to digital imaging. But maintaining high diagnostic imaging standards within the noise tolerance most radiologists will accept and practicing ALARA has been very difficult with digital imaging. Analog film

production has reached its full potential for achieving wide exposure latitude and minimal patient dose; however, better communication and display of radiographic images, as well as film duplication and archiving are fixed in antiquity. Fixed images on a film can only be viewed by one set of observers and requires shuttling between physicians to be viewed. Furthermore, the incidences of lost films and archiving pitfalls of analog imaging have reached the limits of radiographers' tolerance.

Digital computerized radiographic imaging (CR) has achieved technological improvement over analog film imaging by optimizing each function of radiographic imaging from production and its subsequent communication layers of image display, archiving, and image retrieval as independent developments that enhance the total diagnostic process. The basic advantages of CR and direct digital radiography over analog imaging is the optimization of image acquisition, optimization of image display, optimization of image transmission, and optimization of image storage as independent but closely networked functions. The management of digital images through PACS has many functions within each specific layer, for example, digital images can be stored on multiple servers, on optical disk, and on digital linear tape for back-up files. The advantage is that these images are never lost, easy to retrieve, easy to purge, easy to distribute, and privacy is protected by passcode and user authorization. These optimizations are not possible or cost effective with analog films. PACS should be an integral part of any CR/ddR system, and existing radiographic equipment can be used with CR and PACS with minimal modifications.

Computerized x-ray like imaging is not unique to radiography; it is used throughout the scientific community in areas like molecular biology and chemistry for autoradiography and pulsed-field gel electrophoresis. Its wide spread use is due to the sensitivity of photostimulable phosphors and improvements in light detector technology. Modern detectors can differentiate light emission by photostimulation for electromagnetic radiation exposures of slightly greater than 100 milliroentgen (mR), and as low as 0.195 alpha particles per square millimeter equivalency for particulate radiation. This makes photostimulable phosphor technology a very useful and powerful tool in resolving radiation patterns traditionally captured in radiographic film from X-ray diffraction, protein crystallography, and electron microscopy techniques.

Computerized radiography is a digital imaging science that uses photostimulable phosphors to create images rather than photographic screens and film.

### 2.1.2 History of computed radiography

As early as 1975 the Eastman Kodak company patented a device that used thermoluminescent infrared stimulable phosphors thereby releasing a stored image. Unfortunately its design application was towards improving a nearly antiquated microfilm storage system. The FUJI Photo Film Company recognized the far reaching possibilities of this new discovery and in 1980 patented the first process that made use of photostimulable phosphors to record a reproducible radiographic image. The basic common finding of both applications was that some phosphors (called storage phosphors) could capture an image from absorbed electromagnetic or particulate radiation. Part of the energy stored in the phosphor was afterwards released when stimulated by a high frequency helium-neon laser. By detecting the phosphor's luminescence using a photomultiplier tube (PMT) to generate an electrical

signal that was ultimately reconstructed into a digital radiographic image-computerized imaging was started.

### 2.1.3 Fundamentals of Computed Radiography (CR)

The fundamental difference between computed radiography and analog imaging is the replacement of film-screens with photostimulable phosphor plates. Digital plates require a plate reader, a port of linkage to patient text data (i.e. RIS, or HIS), and connection to an output device such as a printer, or to a PACS network. The technologists need a CR imaging system that includes storage phosphor cassettes, storage phosphor reader(s), bar code scanner, remote operator panel for entering patient data, and a clinical workstation for reviewing and printing from PACS. Currently CR is a more popular system over ddR because existing radiographic equipment (X-ray tube systems, x-ray tables, portable machines, etc) does not have to be modified. These pieces of equipment alone do not constitute the full requirement to operate a CR system. It should be remembered that a major reason for investing in CR/ddR imaging is that it is the entry point for general diagnostic imaging into PACS. The advantages of CR imaging over conventional analog imaging are huge and well worth the upgrade.

### 2.1.4 Photostimulable plate and cassette

Radiographers have needed to understand the mechanism of image production using screen-film technology in order to maximize image quality; the same is true of the photostimulable phosphor plate technology used in CR imaging. Furthermore, it is imperative that the radiographer understands the basic characteristics of storage phosphors and how they differ from their analog counterpart. Computerized radiography and direct digital radiography will in the near future become the standards of radiographic imaging because of its digital link to PACS and potential for internet connectivity. In this section we will discuss the characteristics of these storage phosphors and what is accepted as the "theoretical" mechanism by which they store and release a latent image. The structure of the phosphor screen and cassettes is also important to our study, as well as the process of digitation of the storage phosphor image.

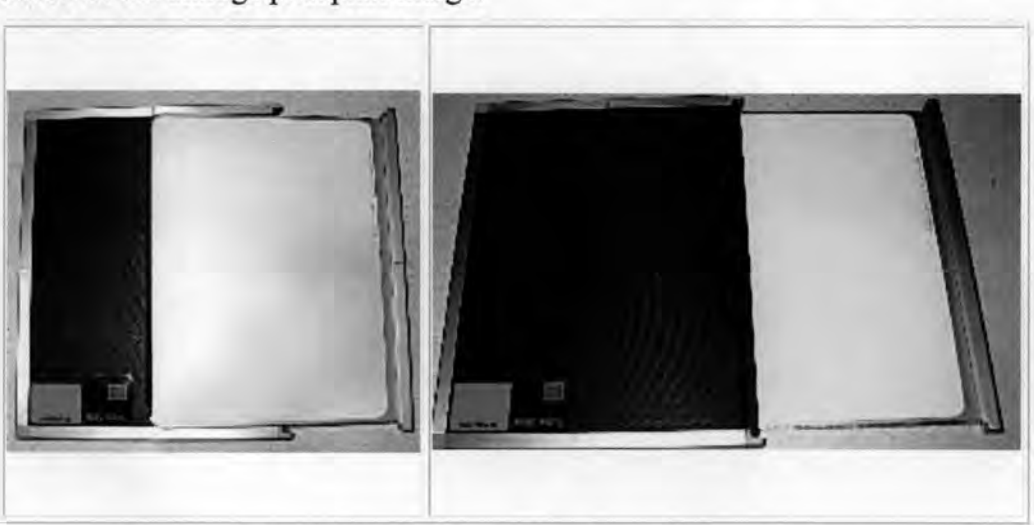

**Figure1.** Imaging plate

The basic component of CR image capture is the photostimulable phosphor cassette. The phosphors used to coat the screen are europium-activated barium fluorohalide crystals (BaFX:Eu2+ where X is a halogen of either iodine or bromine). These phosphors are not all together unique to CR imaging, for years screens made of photostimulable phosphors have been used in intensifying screens for conventional film-screen imaging. The phosphors in these screens fluoresce upon exposure to ionizing radiation emitted from the x-ray tube. Radiation energy causes the phosphors to fluoresce, releasing a high fraction of the absorbed energy from the screens; the remnant energy is stored in the phosphors as a latent image. It is the stored energy in the form of a latent image that is used to produce the CR image, but the image must be released from the phosphors and further processed. When stimulated with infrared or white light photostimulable phosphors release light proportional to the stored energy which can be detected by a photomultiplier tube(s) as an image signal.

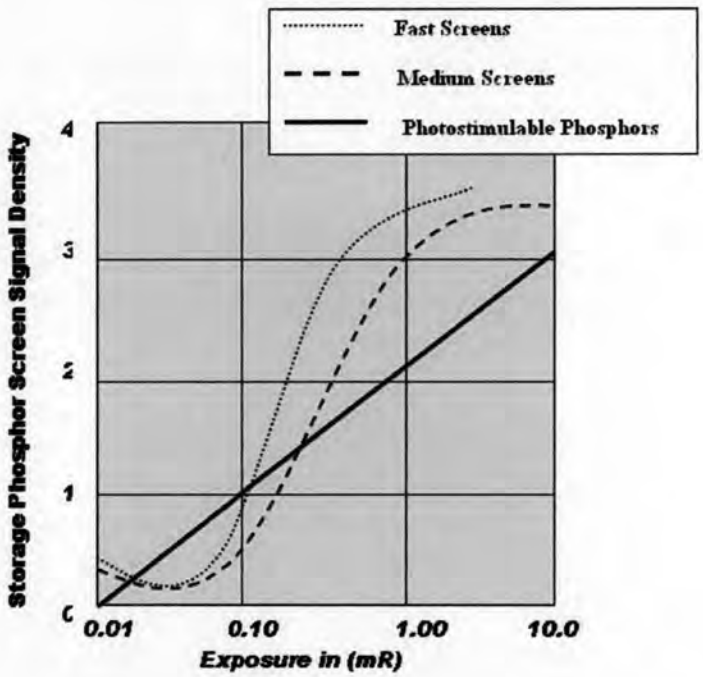


**Figure 2.** Characteristic curve of CR system

### 2.1.5 Mechanism(s) of image storage in phosphors

The exact mechanism(s) of photostimulated luminescence is not completely understood; however, there are a few very good current theories that explain luminescence and the linear response of photostimulation over wide exposure values seen in diagnostic imaging. Consider that the dynamic range of exposure for photostimulable phosphors is linear over a range of greater than 10,000 to 1, whereas for analog radiographic images produced by screens it is roughly 40 to 1. What this means is that over exposure or underexposure of radiographic images seen in conventional film-screen imaging is virtually eliminated by photostimulable phosphor technology imaging. This does not mean that images acquired at the extreme low and high values can be optimized into high a quality image, it simply means that all values of an exposure can be represented on the final image and be discriminated. Computed radiography can detect exposures up to and greater than 100 Milliroentgens (mR)

which is far beyond Dmax for screen-film imaging. Digital radiography has been demonstrated to produce images at high energy values used in radiation oncology to treat cancer. It even can detect low energy from particulate radiation, (0.195 alpha particles per square millimeter).

Although there are several theories on the mechanism of photostimulated luminescence we will describe the most commonly accepted model for BaFBr:Eu2+ phosphor photostimulated luminescence:

The simplest explanation for luminescence is that impurities in the crystal lattice are responsible for luminescence. As the concentration of impurity ions increase the greater the intensity of the luminescence. CR screens use barium fluorohalides doped with europium (europium is the impurity in the crystal). When phosphors are stimulated with x-ray photon energy electron pair holes are created. In effect, europium is raised to an excited state and upon luminescence it is returned to its ground Eu2+ state. This mechanism holds for both spontaneous luminescence and photostimulated luminescence. The shifting of europium from its excited state back to its ground state for both spontaneous and photostimulated luminescence is about 0.6 - 0.8 microseconds. With screen-film imaging these crystals spontaneously luminescence to expose a film, but with CR imaging the luminescence occurs, then there is also photoluminescence that occurs when the screen is stimulated by a narrow beam of infrared light.

The holes or vacancies in the lattice are portions of the lattice normally occupied by halogens (fluoride, bromide, or iodine). These vacancies will trap free electrons when irradiated and are called Farbzentren centers or F-centers. Within the BaFBr:Eu phosphors there are two potential types of F-centers that trap electrons: F(Br-) and F(F-), these represent electrons trapped in the bromide and fluoride vacancies. When the photostimulable plate is exposed to high frequency light, usually from a helium laser, the electrons in these F-centers are liberated and cause luminescence at readout.

### 2.1.6 Structure of the phosphor screen and cassette

There are some differences in the structure of phosphor screens and cassettes by different manufacturers, for example, Kodak cassettes are designed to withstand 400lbs of pressure. The strength of a cassette system is very important, for example, if standing feet x-ray images are routinely performed at an orthopedic clinic, the technologist must be able to safely obtain them on patients of varying weights. The cassette front is made of carbon fiber and the backing of aluminum. But notwithstanding, the phosphor screens are made of a base, a phosphor layer, and a protective coating The figure below demonstrates a cross section of a Kodak Photostimulable plate and cassette.

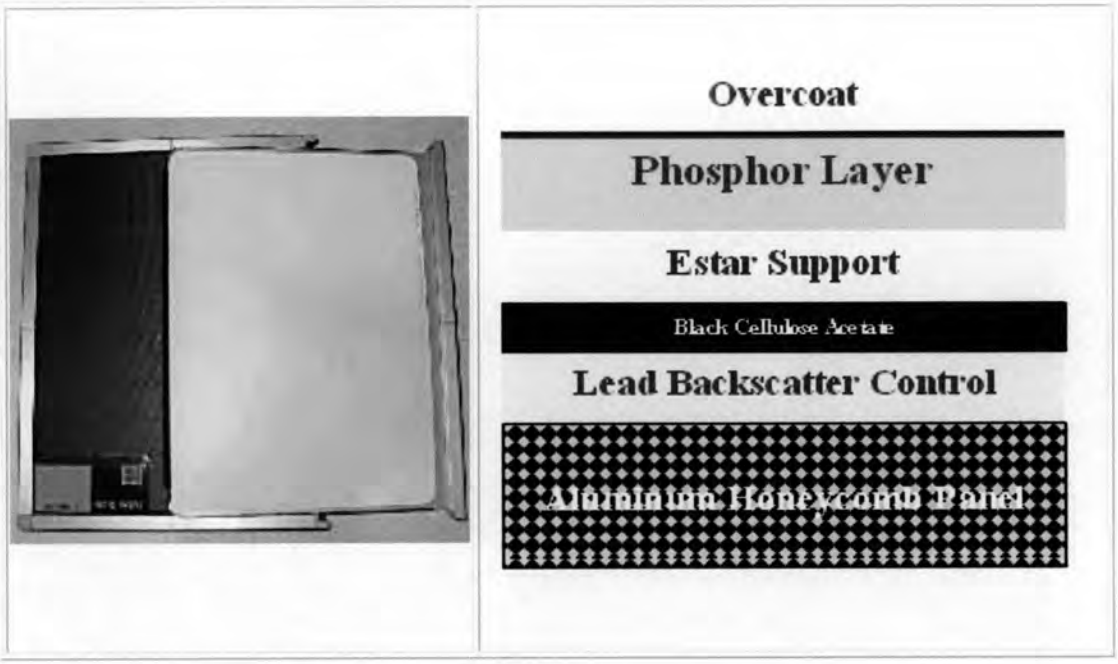


**Figure 3.** Structure of imaging plate

These screens are designed slightly different than screens for film imaging. They are balanced for x-ray absorption characteristics, light output, laser light scatter and screen thickness. These variables affect electronic noise, image resolution properties, and the speed of the imaging system. BaFBr:Eu2+ phosphor is coated onto base (Estar) using polymers that act as glue to hold it. Then a clear coat solvent is coated over the phosphor to seal it, protecting it from physical damage. A black reflective base under the phosphor helps improve image resolution by reducing dispersion of light as the laser exposes the phosphors at reading; the black base also allows for a thicker phosphor layer into which photon energy is trapped. These are all mounted onto a lead sheet that absorbs excess photons and reduces backscatter, and to an aluminum panel that is mechanically removed from the cassette during scanning.

On the back of the panel is a label indicating the speed of the cassette, which in CR imaging is the brightness of the phosphor, speed is also used in calculating the exposure index.

### 2.1.7 Cassette scanning and plate reading

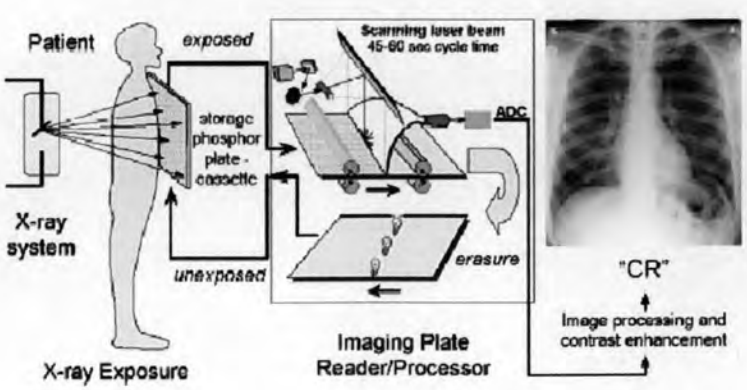


**Figure 4.** Diagram of imaging reader

The three pictures above are of the Kodak series of CR units: the first picture is of the 8 cassette multiloader, and the other two are of the single loader reader that is sufficient for low volume institutions. There are five processing functions of the reader that are important to the technologist: Unloading of the photostimulable plate, laser scanning of the plate, light collection onto the PMT, erasing the plate for reuse, and reloading of the plate into the cassette. Unloading the cassette is all mechanically driven with care not to touch the photostimulable phosphor side of the plate. The purpose of the reader is to scan the photostimulable phosphor plate releasing the latent image. Within the "reader" light emitted by stimulating the phosphor to luminescence is converted to an electrical signal. The plate is then erased and reloaded into the cassette for reuse.

To recover the latent image the screen is scanned with a helium-neon laser that uses a low 20 milliwatt 633 nm wavelength output laser. The photostimulable screen is scanned in a raster fashion. The wavelength of light required to stimulate phosphor luminescence is different from the wavelength released from the phosphors during luminescence. From the figure below we see that the wavelength of light released from the phosphor screen is about 400 nanometers. The laser emits light in the range of 600 nanometers, which is required to cause stimulation of photostimulable phosphor luminescence. Thus there is an energy difference between the emitted light at stimulation, and the light emitted from the laser to cause photo stimulated luminescence. The light from the laser should not be part of the CR image and must be extracted from the image data.

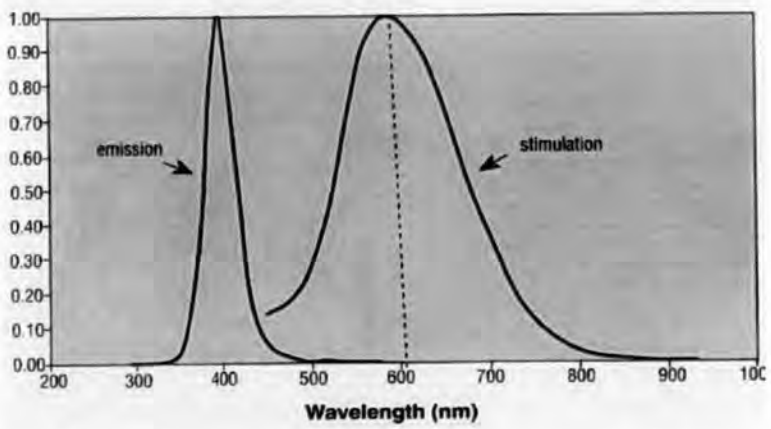


**Figure 5.** Stimulation and emission spectra for **BaFBr**:Eu2+

In addition to the difference in the wavelength of light required to stimulate phosphor luminescence and the wavelength of light thereby emitted, there is residual energy trapped in the phosphors following stimulation. To release all of the stored energy the phosphor plate must be exposed to white light following stimulation by the laser in a process that erases the plate for reuse (the picture below shows the white fluorescent bulbs used to erase the plate after acquiring the latent image).

Did you notice how large the study size is for each image? This is why the storage capacity for PACS must be sufficiently large enough to accommodate long-term image capture from not only CR, but from all imaging modality. Especially if data is received from multiple radiology modalities such as CT, MRI, Nuclear Medicine, etc. The memory requirements for PACS networking in order to have fast

archive retrieval need creative networking such as archiving on a (NAS) with a capacity in the order of terabytes.

Light is emitted in all directions as an inherent physical characteristic of screen fluorescence; the same is true of photostimulated luminescence. Therefore emitted light must be focused by a collector onto the photomultiplier tube (PMT). The PMT is a device that converts light from the photostimulated screen to an electronic signal that can be further converted to digital "bits". Depending on the CR system there can be from one to five photomultiplier tubes. Remember, the laser's light is in the red spectrum in the order of 633 nm while the luminescent light is 400 nm. Therefore, an optical filter is placed in front of the collector to filter the laser light prior to it reaching the PMT.

The PMT is calibrated to the storage characteristics of an exposed photostimulable phosphor plate. This calibration that affects the overall brightness of the extracted image is based on a delay of 15 minutes from the time of exposure to the time of scanning since the signal in the phosphor degrades exponentially over time. This time delay is not apparent to the technologist and the plate can be scanned anytime within 24 hours without appreciated loss of image data that would warrant a repeat exposure. Calibration of the image from the PMT is set at about 3000 pixels. All PMTS in a unit must be calibrated so that the reading across the plate is equalized and balanced.

The electronic data signal from the PMT is then sent to a device that converts the analog data to digital data. This device is called an Analogue-to-Digital Converter and associated Input Look-Up Tables (ILUT) are referenced. These LUT contain circuitry for manipulating digitized data so as to correct for any aberrations in the image data caused by the converting of it from a light latent image to an electronic image, and to a digital image. The process of digitization is complex but briefly, the signal must be amplified and passed through several filters such as a Bessel Filter for anti-aliasing. An anti-aliasing filter is used to smooth edges in an image and smooth jagged diagonal lines caused by seamed transfers to produce seamless final images. Photomultiplier tubes are about 20-25% efficient in light compilation from the stimulated luminescence; therefore, the image is acquired over four decades of exposure and requires optimization before viewing. Tone scaling is a type of contrast enhancement that involves remapping of gray scale values using special look-up tables. Look up tables are a common way of converting digital data from different modalities such as ultrasound and MRI into digital format. The process of tone scaling involves transforming the raw data in three or 4 steps into a finished image. First the collimated field is detected using the raw data image as a guide. Next the anatomic region is defined, the image is then tone scaled, and final reprocessing is applied.

The process of enhancing the raw image data is called **image segmentation**. The CR image is acquired over four decades of exposure:

1) Light release from storage phosphors
2) Conversion to an electronic signal by the PMT tube
3) Identifying the collimated image border
4) tone scaling the image.

These are the post processing functions that must take place before the image is presented on the CR reader monitor. The image must then be fixed before the data is sent to PACS, then to workstations, or is printed. The raw data is subjected to various algorithms and LUT that define areas of interest and collimated areas. The

average density and LUT control the overall density and contrast of an image. The final image is first available on the CRT monitor at the reader or on remote operator panels (ROP). What is important for the technologist to understand is that the image released from stimulating the phosphor plate is not a readable diagnostic image and requires post processing. Specific software algorithms must be applied to the image prior to presenting it as a finished radiograph. These modifications of the image occur in the reader programs and at the workstation using look-up tables as references.

Regardless of the CR imaging system the technologist must view the image on the CRT monitor and either accepts it based on the exposure index, or rejects the image. An accepted image is then sent to PACS for image review on network workstations, or the image can be printed for conventional reading and filing.

**Figure 6.** Three different vendor CR units.

The left image of the Agfa CR system multi-loader and CRT monitor for approving images; the middle picture is of the Kodak remote operator panel (ROP) which is a remote display CRT that can be mounted anywhere in the department to reduce clutter around the reader; the right picture is of a FUJI CR system multi-loader and CRT image monitor.

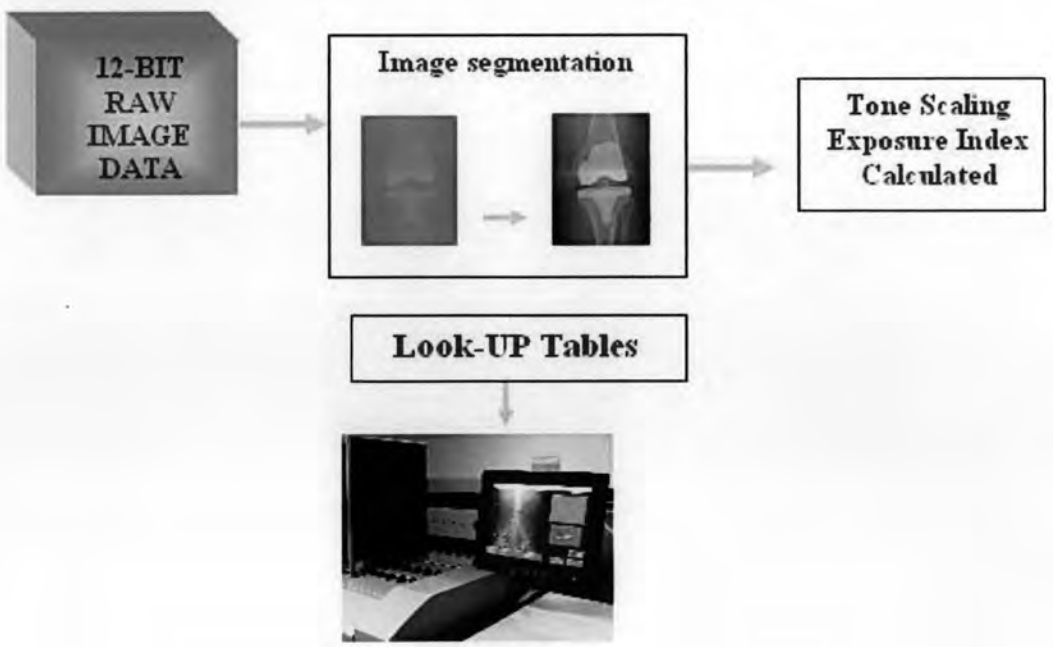


**Figure 7.** Image processing

### 2.1.8 Exposure Index

Because the CRT monitor image is post processed using workstation algorithms and Look-up Tables, the technologist needs feedback on the exposure to the phosphor screen that produced the image. Most technologists understand that storage phosphor screen exposure can be optimized and therefore is not overly concerned with over or under exposure. Because of the increased exposure latitude enjoyed with CR imaging radiographers tend towards higher than necessary exposures desiring to see less noise on radiographs displayed on the CRT. The exposure index is a tool provided for the technologist to monitor their plate exposure; it is analogous to the optical density used in screen-film imaging. The exposure index is not a measure of the patient's exposure; however, if the exposure is greater than the recommended exposure index range the patient has been overexposed. The degree of that over or underexposure can be correlated but is not commonly done except for the log of the exposure index recorded for viewing on the workstation and film.

The PMT calibrated exposure index is set by the manufacturer and this calibration of the PMT is not variable. Then it follows that when different speed screens are used (for Kodak the phosphor speed is equivalent to 200 screen-film speed, FUJI plates are approximately 400 screen-film speed) the PMT reads an exposure index of 2000 for a 1 mR screen exposure. Each vendor will calibrate the exposure index differently.

There are several possible factors within the technologist controls that can alter the exposure index. The primary controller is technique selection. Others include improper centering on the cassette, and placing two or more views on the same cassette. Most CR readers calculate the exposure index starting from the center of the cassette and outward, even though the cassette is read in raster fashion. Sometimes when three views such as a finger or the wrist is placed on one cassette the anatomic and non-anatomic regions of the image are not correctly identified by post processing software. This causes an improper calculation of the exposure index that is not taken from the relevant portions of the image and the image may appear dark. The improper reading of the CR image due to multiple images on a plate that give false over or under exposure indices are called image segmentation failure. Although in theory, it is impossible to over or under expose an image, the image may appear over or underexposed due to the image segmentation algorithm that handles the raw data. Generally speaking, a segmentation failure results in a high exposure index. What is important is how the technologist handles these awkward exposure indexes when they occur. The scenario is that the radiographic image on the CRT monitor appears overexposed and the technologist desires to manipulate the raw data to make an eye-pleasing image prior to sending it to PACS.

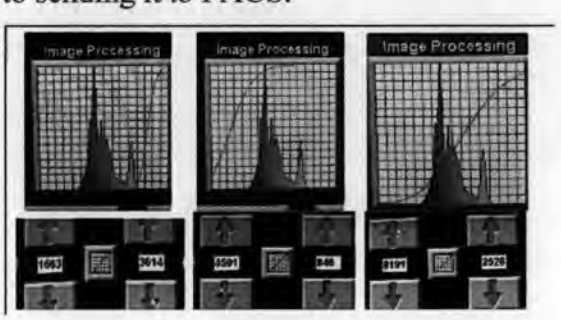


**Figure 8.** Adjusted the image using the raw data controls below each picture

In each of the three graphs in figure 8, notice that the slope of the line also changed indicating that raw data is being lost that may affect image detail characteristics that can be windowed at the workstation. The technologist should remember that workstation software can adjust windowing and leveling. Therefore, if the image can be windowed from the raw data on the CRT monitor, it can also be windowed to form a high-resolution image on the workstation. In this regard it should be left alone and the data saved to be manipulated at the workstation. In this way pertinent image data is not erased just to make an eye-pleasing radiograph on the CRT, a low resolution monitor.

### 2.1.9 Overview on using the CR System

**Figure 9.** X-rays in computed radiography

One of the many advantages of CR imaging is that existing radiography equipment can be used with just a few modifications in how images are acquired by the system. For the most part there are four equipment items that sponsor the trafficking of information into the CR/DR system for image display. These are the data entry, examination algorithm selection, post image processing, and networking into PACS for storage/retrieval.

A CR system can be added to PACS network as a node on the Bus topology with servers that share patient file information from the HIS/RIS broker. The first step in digital and CR imaging is that specific data fields must be entered into the CR or DR unit. This is because all digital images must have patient information such as the patient's name, medical record number, exam number, date, and time, etc., printed on each image document as it is sent to storage, else it is inaccurately retrievable from archive. Specific data fields are filled by the HIS/RIS broker, a type of server that links text information from RIS to the base CR/DR unit and to PACS. Once the RIS/HIS server receives data that is the patient's radiology request any base unit on the network can accesses this information as part of the examination database using a workflow dialog box. There are several ways to begin the process of patient selection. Some unites such as the FUJI system uses a magnetic I.D. card that can access the patient file. Other systems such as advanced FUJI and Kodak systems use a barcode reader to directly populate text fields through a HUB to the RIS broker.

Advanced FUJI and Kodak systems use the full capabilities of the HIS/RIS server and CR units to transfer patient information data directly to a workflow

manager. Radiology orders are entered into the RIS computer from any link and are received by the radiology clerk. The RIS broker is a server that networks patient information directly to the base CR unit and to PACS and can be accessed from the workflow list functions of the base unit. This is generally done using barcode technology and the patient radiology request. Barcode technology linkage is ubiquitous throughout the PACS network because DICOM contains a barcode subclass operations protocol. The technologist uses the patient request and a barcode reader to access the patient file already in the workflow list. Each study will have its own request, study I.D. and barcode as part of the workflow manager function. So the technologist uses the patient exam request and a barcode reader to begin the imaging process.

The next step in the CR imaging process is to set the study algorithm the reader should process the exposed plate under. This function is also controlled by a barcode reader. The technologist selects the appropriate study, e.g. ABDOMEN, CHEST, FOREARM, KNEE, etc., from the programmed list. The reader must then be told what cassette contains the image. This is done by barcoding the cassette with the appropriate algorithm selected at the reader or ROP.


**Figure 10.** CR cassette and barcode system.

The cassette is registered using barcode at the remote operator panel. This information can be entered either before exposure or after exposure.

Once the study is selected and the cassette is bar-coded and the technologist may proceed using the cassette just as they would a screen-film cassette. In digital imaging, algorithms are selected rather than cassette types. In screen film imaging the

technologist may use a different screen-film type for a KUB than they would for a forearm image. In digital imaging, the same cassette is used but the computer's software selects the appropriate processing algorithm to process the photostimulable plate. This is a very important difference between screen film imaging and CR. Being able to use any cassette for imaging is a huge time savings to the technologist. It eliminates darkroom time spent to load special extremity cassettes with extremity film, or the repeats that occur when the extremity cassette is loaded with non extremity film. Remember having to load special chest film into "chest" cassettes and a failure to do so resulted in a high contrast chest x-ray. These issues are eliminated by algorithms that can be changed if the image of a chest is processed under a foot algorithm, a feature unique to digital imaging.

**Figure 11.** The components of the CR system required for imaging.

The patient data entry panel uses a magnetic card to enter patient information as a white arrow in the figure. Once the technologist selects the proper image processing algorithm the cassette can be barcoded with the barcode reader (blue arrow) and placed into the reader for processing. The CRT monitor on the unit will display the processed image for the technologist to approve and send to PACS or to be printed.

### 2.1.10 Acquiring the CR Image

A characteristic that is unique to CR imaging is that there is only one screen type for all studies so that the same cassette is used for portable radiography, bucky radiography, tabletop radiography. There is no need to look for special detail cassettes for extremity work, or high speed screen with low scale contrast for chest radiography. These functions are handled by the software performing algorithm functions. Even the grid lines commonly seen with screen-film imaging can be removed from the digital image using LUT for that specific function.

The CR cassette can be placed in the bucky tray or used tabletop just as would a screen-film cassette. If Automatic Exposure Control (AEC) is used it may have to be calibrated for CR cassette exposure otherwise the technologist must strive through manual techniques to produce consistent exposure index in the range of 1800-2200 for Kodak CR, and 50-200 for FUJI CR. Manual techniques are extremely important in digital imaging for tabletop radiography because a variable-kVp or variable mAs Chart will help the technologists achieve uniform exposure indexes for tabletop and portable images.

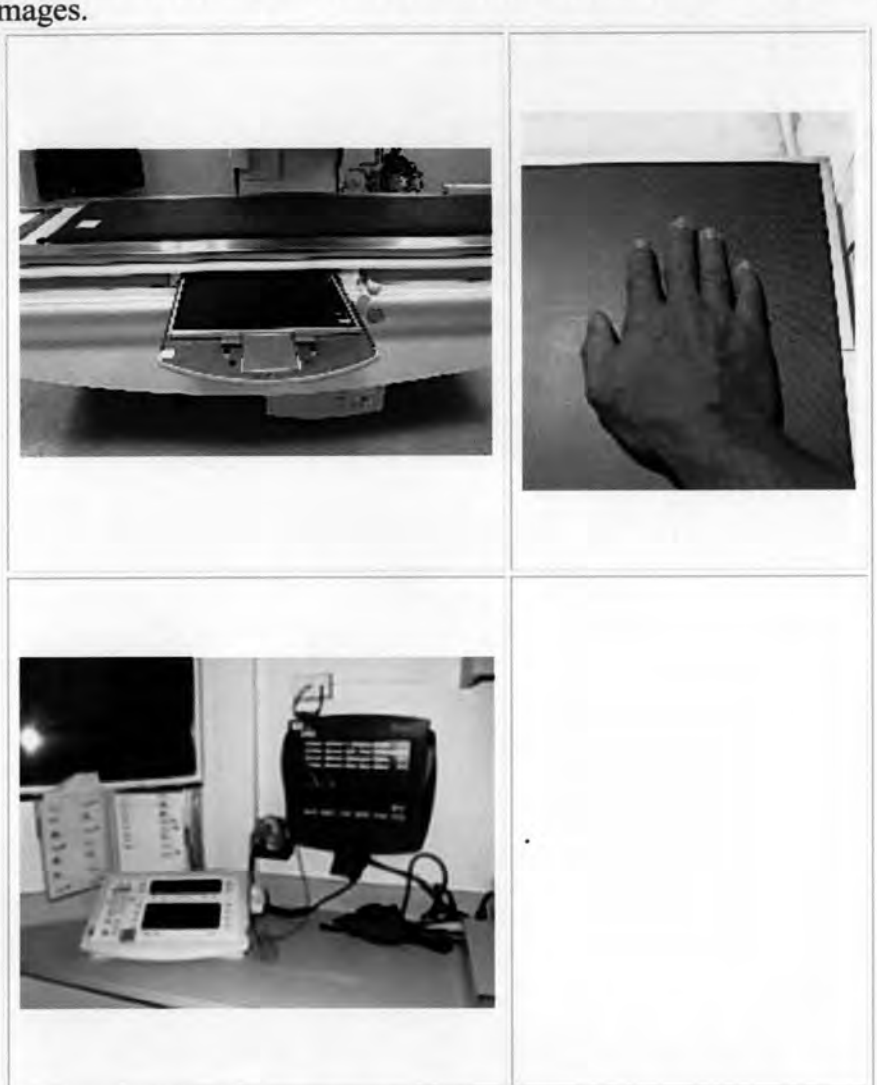

**Figure 12.** CR cassettes. Above, the same cassettes can be used in the bucky tray or tabletop. Left, by placing ROP's in locations near the exposure console, the technologist is able to enter and approve images between radiographic exposures

The chronology of the image processing following exposure is as follows: the exposed cassette is placed on the reader where the cassette is mechanically opened and the photostimulable plate removed. Inside the reader a laser is passed over the plate in raster fashion using a wavelength of 633nm to stimulate luminescence of the phosphors. This stimulated luminescence releases the latent image in the form of light that is filtered and collected onto a photomultiplier tube (PMT). The PMT converts the light signal to an electrical signal that is then converted from analog-to-digital data bits by a special converter. The raw data is subjected to algorithms and Look-up

Tables (LUT) that interpolate data points and allow for manipulation of digital information. Through a process of image segmentation it is optimized. Finally the image is presented on the CRT-monitor for technologist viewing. All of this takes place in a matter of seconds rather than minutes as in conventional screen-film image processing.

One of the niceties of computed radiography is that image data is already in digital form so it can easily be linked onto the PACS network. Because computerized radiography adheres to DICOM standards, these units adhere to the various subclass standards for compatibility. From the reader a link can be established directly to a wet or dry laser printer using DICOM Print Management Service Class, and to PACS storage servers using DICOM Query/Retrieval Service Class. The images can also be displayed to any workstation in the PACS network which significantly decreases ER/Trauma wait time.

This is a summary of the special advantages of digital computed radiography that cannot be achieved by analog screen-film imaging for the following reasons. 1) X-ray exposure and display of the image are uncoupled; therefore characteristics of image presentation, mainly optical density and contrast become less significant in the raw data. 2) There are a limitless number of "original images" available for viewing which can be outputted to multiple stations simultaneously without intermediate copying of the images as with screen-film radiographs. 3) Digital images can be transferred over a LAN or WAN without any deterioration for all degrees of image spatial frequency. This includes CD-ROM, Internet, and teleradiology. 4) A film cost savings is definitely possible if viewing over a workstation is the primary means of display and multiple images printed on a single sheet when measurement is not a consideration. 5) The digital image can be adapted to any viewer's requirements by image processing algorithms and post processing functions of software.

## 2.2 Related literatures

During the late 1960s, high-kVp (120-140) technique replaced low-kVp (70-85) technique for the most common chest radiography method. Two primary reasons for this change are the wider latitude of the high-kVp technique and the increased availability of higher capacity generators. With the higher kVp technique, there are relatively more Compton scattered photons; therefore, methods of scatter reduction are required. Both antiscatter grids and air gap techniques impose higher load requirements on the generators. The Half value layer (HVL) of diagnostic x -rays in tissue is about 4 cm. This means that an error of only 2 cm in estimating patient thickness can result in an error in mAs setting of up to 50%. The wider latitude of the 120-kVp technique increases the margin for error in setting the exposure factors and hence reduces the retakes. A well-trained technologist who carefully measures the thickness of every patient can obtain high-quality radiographs with either technique.

Correctly exposed radiographs obtained with the two techniques have different appearances. The 70-kVp technique produces a higher contrast radiograph that should improve nodule visibility and detection in those regions of the lung where the film response is on the linear portion of the film H & D curve. On the other hand, nodule visibility may be some what reduced in these areas by the lower contrast of the 120-kVp technique, but it should be improved in regions such as the apices of the lungs and in the heart and mediastinal shadows, where the film response is near the ends of

the H & D curve.Thus, there are two conflicting trends in changing from 70 to 120 kVp, one to improve nodule detection as the kVp is lowered, the other to improve nodule detection as the kVp is raised.

Newell and Garneau investigated the effects of kVp on image quality and concluded that the decrease in image contrast with higher kVp was greater for ribs and bones than it was for soft-tissue nodules [7]. They concluded that higher kVp technique would improve nodule visibility in chest radiography. Christensen et al. also investigated the effect of kVp on lung nodule detection[8]. They used a phantom consisting of a section of lung and exposures of 70, 100, 200 and 300 kVp. They concluded that the true-positive rate also increased with increasing kVp.

Herman *et* al. investigated the effect of kilovoltage on the visibility of lung structures at 90, 140 and 350 kVp[9]. They found that the images obtained at 90 kVp were slightly superior to the images obtained at higher kVp. They used lungs obtained at postmortem examinations and limited their evaluation to comparisons of detectability and sharpness of round and linear opacities and confluent shadows. The images did not contain any overlying ribs or mediastinal images, and so were limited to structures in isolated lungs only.

Martin *et* al. have investigated effects of kVp on image quality to compare the visibility of anatomic structures in direct-detector chest radiographs acquired with different tube voltages at equal effective doses to the patient [10]. The institutional internal review board approved the study protocol, and written informed consent was obtained from all patients. Postero-anterior chest radiographs of 48 consecutively selected patients were obtained at 90, 121, and 150 kVp by using a flat-panel–detector unit that was based on cesium iodide technology and automated exposure control. Delineation of most anatomic structures and overall image quality were ranked superior in digital radiographs acquired with lower kilovoltage at a constant effective patient dose.

Aldrich JE., Duran E, Dunlop P. and Mayo JR. investigated the surface doses to patients during chest, abdomen and pelvic radiography over a period of 3 years [11]. During this time, the computed radiography (CR) and digital radiography (DR) systems are introduced to replace film–screen systems. The surface doses from film–screen and CR were measured using thermoluminescent dosimeters. For DR the surface doses were calculated from the dose–area product (DAP) meter readings. Measurements were made for each type of examination and detector type on 10 average-size patients. Measurements were made immediately after the new systems were introduced, and subsequently as adjustments were made to optimize dose and image quality. Published diagnostic reference levels were used as target values in this optimization. Initially, CR doses were the same as or higher than for film–screen, and the doses were lower for DR compared to film–screen. Subsequent clinical experience with the systems led to changes in the technique used for chest examinations both for CR and for DR. For CR, it was possible to change the algorithm and decrease the dose to one quarter of the initial value with acceptable image quality. For DR, it was decided to reduce noise by increasing the dose by a factor of two. No changes were made to abdomen or pelvic imaging techniques for either CR or DR. The final patient surface doses using CR were similar to published diagnostic reference doses; for DR, all patient doses were less than published reference levels.