COMPUTED RADIOGRAPHY

Background...

The concept of the photo-stimulated storage phosphor imaging plate used in Computed Radiography (CR) was first introduced by Fuji Film Company LTD in 1981. Two years later the first clinical use of this new technology was successfully performed in Japan. Today, there are several thousand CR units in operation around the world. They are the heart of the digital x-ray department. The imaging plate system allows a Radiology Department to utilize their existing x-ray technology, while allowing a department to move into the newest presentation technology by connecting to a PACS (Picture Archiving and Communications System). It’s a perfect marriage between a hospital’s aging x-ray equipment and the very latest in technology. In contrast DR (Digital Radiography) is an extremely expensive solution because it utilizes all new equipment. For example, a hospital with 4 X-ray rooms would have to purchase new equipment for all 4 rooms to utilize DR at an approximate cost of $360-400,000; whereas, CR would only require the purchase of a single reader at a cost of about $150,000.

Major Components...

The four major components associated with CR are:

1. Photostimulable phosphor image plates
2. Laser imaging plate reader
3. Computer for processing images
4. QA Monitor
**Concept...**

The older technology, *Conventional Radiography*, is strictly a film based technology, in that film is utilized at all levels. Acting as the base for the silver halide crystals during latent image formation, the film is the image receptor upon which the light rays from the intensifying screens strike. When processed, the manifest image develops on the film and the film itself is then used as both a viewing and storage medium. Computed Radiography makes possible “filmless” x-ray exposures, while retaining the same outward appearance and familiarity as conventional film/screen combination cassettes. This familiarity is very important when trying to blend new technology with old and have it readily accepted. The two minor differences between traditional cassettes and CR cassettes are (1) CR cassettes have a barcode identification window and a green orientation strip along one edge. If this orientation strip is not placed at the top or on the patient’s right side (AP), the image will appear upside down when processed. Computed Radiography offers extremely wide latitude as compared with conventional film. The dynamic range of exposure for photostimulable phosphors is linear over a range of 10,000 to 1 vs. analogue screens which is roughly 40 to 1.

**The Photo-stimulable Storage Phosphor Crystal Image Plate...**

Although appearing quite similar to a regular intensifying screen, an imaging plate (IP) functions quite differently. Both intensifying screens and imaging plates rely on the principle of electron excitation. Intensifying screens use a rare earth phosphor that is a fluorescent material that emits light photons within $10^{-8}$ seconds after stimulation by x-rays. These photons are converted to a latent image on the film using silver halide crystals as a storage medium; whereas, an imaging plate uses a phosphorescence material that emits light after a delay of beyond $10^{-8}$ seconds. By using a europium activated Barium Fluorohalide Phosphor ($\text{BaFx:Eu}^{2+}$, $X=\text{Cl, Br, I}$), to trap and hold electrons, a latent image is formed directly on the imaging plate itself; therefore, the term *filmless*. Like intensifying screens, imaging plates are coated with several different layers to achieve its optimum luminescent quality.
Description of Intensifying Screen and Imaging Plate Layers...

**Protective Layer:** A thin layer of transparent film that protects the phosphor.

**Rare Earth Phosphor Layer:** A closely dispersed layer of fine-grained crystals of yttrium, gadolinium or lanthanum, which immediately convert x-rays into visible light, with a minimum of afterglow.

**Barium Fluorohalide Phosphor Layer:** A closely dispersed layer of fine-grained, Photostimulable europium-activated, barium Fluorohalide crystals, that store the latent image until released when re-stimulated during processing.

**Light reflective Layer:** This layer increases the intensity of light being emitted from the crystals by reflecting it back toward the reader, instead of it being absorbed.

**Conductive Layer:** This is a light absorbing layer, made up of conductive needle-like crystals that absorb any un-reflected light as well as any electrostatic charges.

**Polyester Support Layer:** Made from a polyester material, this layer gives structural rigidity and a base for the coating of all of the other layers. Polyester is used because of its excellent stability as well as its durability and flexibility.

**Light Shielding Layer:** This is a carbon particle layer that prevents the light from leaking from the rear of the imaging plate.

**Backing Layer:** This is a protective layer made from a soft polymer that prevents scratching when the plates are stacked during the manufacturing process.
**Imaging Plates...**

**Image Capture**

During the primary electron excitation phase, the high energy x-ray photons cause a photoelectric reaction with the europium, resulting in the excitation of many low energy electrons \((\text{Eu}^{2+} + \text{photon} \rightarrow \text{Eu}^{3+} + e^-)\) that are free to migrate within the crystal. This migration results in electron holes being held at the europium site. About one-half of the migrating electrons and electron holes immediately recompose, emitting an initial light intensity. However, unlike conventional radiography, this initial luminescence is not used to produce an image. The other half of the bound electrons are trapped at the halogen ion sites. These trapped electrons are later re-energized during the reading phase, resulting in almost complete recombination and luminescence. There is a higher concentration of trapped electrons and electron holes where the x-ray intensity has been the greatest or where less dense or no tissue was present. And vice versa, where the x-ray intensity was the least or where the tissue was the densest there will be fewer electrons and electron holes. These areas of trapped electrons and electron holes are then called color centers or F-centers. The pattern of stored energy intensities on the imaging plate, is the latent image (Mixdorf,16). This stored image will degrade approximately 25% within the first 8-hours; so long term storage is not possible. Also, imaging plates are very sensitive to background and scatter radiation and should be erased before use if stored for more than 72 hours (Burns, 32)
**Image Reading**

Reading the imaging plate involves loading the exposed cassette into an image reader, where the imaging plate is removed from the cassette and travels to the reading area where it is scanned with a tightly collimated, He-Ne Laser. This is called the image retrieval or secondary excitation phase. The color centers absorb the electromagnetic radiation from the red laser, causing the trapped electrons to be released and migrate to the trapped holes, where they recombine and generate europium luminescence. Note that the energy level of the crystalline lattice is less than that of the original laser used to excite them out of the trap. The linear wavelengths of the emitted photons are in the 350nm to 450nm, so they appear purple and blue (Curry, 133).

The emission of light when stimulated by an electromagnetic radiation and later re-emitting light, after a second stimulation of energy is called Photostimulable Luminescence, and is why the crystal is called a photostimulable phosphor (Mixdorf, 16).

Once the purple-blue photons are emitted, they have to be separated from the red laser light. This is done by placing a filter in front of the fiber optic cable, which removes...
the red laser light. The output of the fiber optic cable is then fed into a photomultiplier tube, where it induces an electric signal for a continuous point by point scan of the image. A photomultiplier tube is used to convert the very small energy of a single photon into a significant electrical signal by accelerating the electrons from level to level by increasing the voltage.

From the output of the photomultiplier the signal goes through an amplifier and then is digitized by assigning numerical values using an analog-to-digital converter. Digital codes are stored as a series of binary numbers (i.e. 10110101011…etc.). Once the information is stored in the computer in this digital format it can be manipulated or enhanced. Various techniques can be used to alter the image such as edge sharpening, smoothing, gray scale mapping, and histogram or look up table equalization. After enhancement, the new digitized image is stored as a DICOM formatted image and sent to PACS. If a printed image is required it must be converted back to an analog and sent to the laser film printer.

After the plate is read then it is erased by exposing it to a white light and then replaced back into the cassette. The imaging plates can be reused indefinitely unless they become scratched or otherwise damaged. Unlike film, imaging plates are not exposed by normal room light and may be removed from the cassette for cleaning or inspection.

A summary of an exposure cycle is shown in the picture at the right.
Imaging Plate Characteristics...

Since the CR system does not have the sensitivity (or speed) limitations found in regular film/screen combinations, imaging plates can be used over a wide latitude of exposure ranges. For example, if the relative speed of a film/screen combination is fixed at 200, then a comparable imaging plate could cover any speed from as low as 20 to as high as 2000, depending on the body region and exposure method.

The response curve for a CR system is essentially linear. The increased latitude provides visualization of structures, such as the mediastinum and lateral rib margins (where the exposure is low), without the loss of lung structures due to overexposure. (Burns, 26). However, just because the increased latitude allows the density to remain relatively constant, it does not assure a quality image. Underexposure is evident by a noisy or mottled appearance on the image, and a high “S” number >500. Overexposure is evident only by a very low “S” number <75.

"S"-Values and mAs...

Although the CR system corrects for sub-optimal exposure technique, there are limits to what can be corrected. To evaluate the exposure of an image the “S” value must be evaluated. The “S” number corresponds to the sensitivity setting of the photomultiplier tube necessary to obtain a preset density level. The “S” number is inversely proportional to the exposure in milliroentgens (mR) reaching the imaging plate. A high “S” value indicates underexposure, while a low “S” value shows overexposure.

<table>
<thead>
<tr>
<th>S-Value</th>
<th>2</th>
<th>20</th>
<th>200</th>
<th>2,000</th>
<th>20,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>mR</td>
<td>100</td>
<td>10</td>
<td>1</td>
<td>0.1</td>
<td>0.01</td>
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</table>
The following “S” number ranges should prove as an acceptable guide when accessing exposure recommendations.

- **Skull**: 100-400
- **Abdomen**: 100-400
- **Spine**: 100-400
- **GI**: 100-300
- **Extremities**: 75-200
- **Chest, General**: 200-400
- **Chest, Portable**: 100-400
- **Chest, Pediatric**: 200-400
- **Abdomen, Pediatric**: 200-400

Properly exposed images should fall within the above guidelines. “S” values above 600 indicate the image was underexposed by 300% and may need to be discarded. An “S” value less than 100 indicates substantial overexposure and the technique should be re-evaluated. Finally, an “S” value below 50 is so drastically overexposed, that complete erasure of the latent image may not be possible. This would cause the next exposure done using that imaging plate to show a loss of contrast due to the residual energy remaining.

**Other factors contributing to the “S” number are:**

- Scatter (more scatter-higher “S” number)
- Distance – SID and OFD (dose and scatter)
- Collimation (correct collimation reduces scatter)
- Examination selected at the IDT (due to histogram analysis)
- Delay in processing from time of exposure
Tips for acquiring a good CR image...

1. Pediatric patients are considered to be those three (3) years old and under. Over the age of three, process as an adult.

2. Use the smallest Imaging Plate (IP) available for the exam.

3. The green stripe refers to the hanging protocol of the image and is generally oriented to the top (cephalic) or to the patient’s right side. For 8x10 only, the green stripe or dots should be cephalic or to the patient’s right side.

4. If a cassette has not been used in 48 hours, you should erase it using the Secondary Erasure. Use Primary Erase for direct x-ray exposures (exposure errors) on the IP.

5. When part thickness is greater than 3” a grid is recommended, i.e., shoulder and knee.

6. Appropriate kVp for Portable chest (non-grid) should be 70-85kVp. Do not use above 90 kVp without a grid. Portable chests with a grid, the kVp should never be higher than 110.

7. Approximately kVp for Portable Abdomens with Grid should be 65-85 kVp.

8. Centering and positioning are very important! Keep the patient well centered on the cassette.

9. When doing extremity work, you can do two or more views on one cassette. Keep the views close together and use lead strips to mask the views. Take caution not to overlap exposure areas.

10. Collimate to the proper field size: avoid having extra anatomy in the image.
**Effects of variations in kVp...**

Unlike conventional film/screen combinations that can only produce acceptable images over a very narrow range of kVp settings, CR has a very wide range in which images can be considered diagnostic. A simulated portable neonatal radiology comparison study was used to evaluate the response to variation in kVp between these two modalities. The study was performed at the Indiana University Hospital for Children using live anaesthetized rabbits in place of neonates. The resulting films were read and scored by three Pediatric Radiologists. Each film was assigned a rating of (1) no useful image (2) inadequate (3) adequate (4) excellent, with only the last two being counted as acceptable. These charts depict graphically the results of this comparison study.

The results clearly show the value of CR in achieving consistently acceptable portable images, often under less than optimal conditions. “This ability suggests that CR should eliminate the need for repeat examinations in cases where the incorrect kVp settings would have resulted in an unacceptable image (Broderick,349)”
Density...
While the great latitude of CR allows it to maintain a consistent density for exposure errors of greater than 50 times, associated low contrast, high mottle or lack of sharpness will result in suboptimal results. Since CR does not completely correct for exposure errors of greater than 2 times, techniques must be chosen carefully, not only to produce optimal images but to prevent the reckless overexposure of patients.

Contrast...
To achieve the desired optimum contrast level, the kVp should be selected with the same criteria as with conventional film, with some minor exceptions. Technical factors that cause low contrast are high kVp, non use of a grid and incorrect collimation. Additionally, other sources of low contrast with imaging plates are: incomplete erasure, fogging caused by overexposure and/or prolonged storage of more than 72 hours. Any exposure requiring more than 80 kVp should be done with a grid, including chests. Otherwise scatter fogging will result in a substantial loss of contrast. It is important to note that special care must be taken in the selection of a proper CR grid. For a 14” x 17”
imaging plate a vertical grid with 85 lines per inch should be used, so that it does not interfere with the horizontal scanning frequency of the reading laser. If a horizontal grid is used, a *Moiré Effect* will be visible. An advantage of using an 85 line/inch grid over a 103+ line/inch grid is that the former is less expensive.

The Fuji CR utilizes a post-processing *look-up table* to alter the slope of the image processing curve. The algorithm effectively looks up each pixel in a predetermined table and assigns a corresponding shade of gray to each, according to its intensity range. Since value limits are employed on both minimum and maximum values. Areas of overexposure or underexposure will appear to have a density even if there was not any on the image. For example, a pixel might have a minimum value of 20 and a maximum value of 300, so even if there was no exposure for that pixel it will still be assigned a value of 20 and a corresponding gray value. Correct techniques and positioning are very important when using look-up tables or pathology may be lost. Even more important is that the correct body part be assigned! Using an abdomen protocol on a chest will give erroneous results and should be repeated with the correct protocol. Using a look-up table method is the fastest post processing technology, because no calculations are required.

**Positioning...**

Incredible as CR may seem, it will never be able to correct for positioning errors. In fact, positioning plays a much more important role with a CR system than it does with conventional film, because of inherent problems in reading the imaging plate. Histograms are designed for each body part, taking into consideration the expected distribution and exposure according to the shape and density of the part. If the anatomical structures are not centered, if the x-ray beam is not aligned parallel (within 3 degrees) with the edge of the imaging plate, or if the collimation is in excess (leaving large unexposed areas), the computer will misinterpret the data and will not be able to fit it to the preprogrammed algorithm for that part. The resulting image will have unexpected density fluctuations and/or contrast errors. Using gloves or other blocking devices will cause similar problems as will the overlapping of additional body parts. However, if the computer has been preprogrammed, and expects to have large collimated areas, such as those found when
taking “babygrams” and if the correct protocol is selected, then the resulting image will be correct. Remember the most important factors in getting an optimal image are:

1. Positioning and centering
2. Choosing the correct protocol
3. Using a proper grid and correct cassette size
4. Selecting the correct technique

**Computed Radiography Image Processing...**

Various other methods of post-processing can be used to enhance a digitized image. These would include:

*Histogram Equalization:* This technique employs a histogram or graph to plot the number of gray levels vs. the number of pixels at each gray level. This method attempts to spread evenly the gray levels over the entire dynamic range to change the contrast distribution of the image to achieve a more favorable histogram. This method involves many calculations and therefore will increase the processing time and will also give the image a more equalized uniform grey appearance.

**Image Smoothing:** Used to reduce random noise by averaging neighboring pixel intensity values. Averaging causes the odd pixel to blend with the surrounding pixels, thereby reducing its sharpness to the eye; however, some detail is lost.
**Image Sharpening:** This filtering process enhances the edge detail to increase the detail of small, high contrast structures. This technique is often used to evaluate C-spines or other small boney areas.

![Normal View and Edge Enhanced](Image)

**Disadvantages of Computed Radiography...**

CR has a hidden danger in that the unnecessary high exposure doses cannot easily be detected by observing the image. Close monitoring by each facility must be employed, with close attention being paid to the “S” numbers being generated. Training and supervision must go hand-in-hand if high quality images and patient protection are to be had.
Advantages of Computed Radiography...

The advantages of CR are many:

1. Elimination of repeat exposures
2. Ability to produce consistent high quality images
3. Ability to deliver images quickly to those who need to make critical decisions
4. Low cost of storage, retrieval and expansion
5. The ability to interface with the Radiology Information System
6. Decreased time to acquire images thereby increasing patient throughput
7. Increased Radiologist reading capacity and the ability to have instant comparison images along with previous reports
8. Ability to have wide are distribution to Doctors offices
9. Ability to print on paper or make CD media instead of film, saving thousands of dollars