# Chapter 6

# Digital X-Ray Systems

## Analog vs. Digital

An **analog** system uses an intensifying screen to create a latent image on x-ray film. The film is then processed, creating a manifest image that can be interpreted by a physician. It is later stored in the file room.

Analog radiography has been around since 1895 and there are some limits to analog radiography that aren't present with digital radiology. This is similar to the limits encountered when using film in a camera compared to digital photography. Analog radiography has limited dynamic range, that is, there are fewer combinations of technical factors that will produce a diagnostic image. An analog film can only be viewed at one location a time. Analog images can't be viewed immediately, we must wait for them to be processed. Maintaining a properly operating an automatic x-ray film processor can be difficult and expensive.

**Digital** Imaging is any modality that creates an image that can be viewed or stored on a computer.

Both analog and digital imaging systems consist of the same **four** basic stages. The **first stage** is image acquisition that is, using the x-ray beam to create a latent image. A *latent image* is an image that exists but cannot be seen until it has been processed. The **second stage**, image processing, is how we convert the latent image from an image that can't be seen into a *manifest image* that can be seen and interpreted by a physician. Image Display, the **third stage**, is how we view the image, for example a view box for viewing an analog radiograph or a computer monitor for viewing a digital image. Finally the **fourth stage**, image storage is where we keep the images for viewing at a later date.

Digital Imaging Modalities

- ✓ CT
- ✓ Fluoroscopy
- ✓ MRI
- ✓ Nuclear Medicine
- ✓ Mammography
- ✓ Ultrasound
- ✓ X-Ray

## CR vs. DR

A digital x-ray system replaces of a conventional x-ray film processor and produces images on a monitor instead of a sheet of x-ray film. There are (2) standard equipment types used in producing digital x-ray images. CR (Computed Radiography) equipment and DR (Direct Radiography). Digital x-ray systems do not inherently reduce the radiation exposure to our patients.

**CR** (also known as computed radiography), refers to conventional projection radiography, in which the image is acquired in digital format using a reusable phosphor imaging plate inside of a

cassette rather than film. Computed radiography (CR) systems offer great sensitivity, they can detect very small structures. CR also offers **wide exposure latitude**, *or the ability to produce acceptable images over a range of exposures*. If a system has wide latitude, it is possible to image parts of the body that vary in thickness or density with only one exposure. A system of lesser latitude would require a lower exposure over the thin section and a greater exposure where the body part was larger or thicker and absorbs more of the x-ray beam. CR images can also be viewed on workstation. The images will be quickly transmitted electronically and display on a monitor assisting the radiologist in making high quality diagnosis. Furthermore, storing images on digitally will facilitate efficient archiving, even when space is limited. The image is available for display in approximately 45 to 60 seconds. CR systems are filmless but still use a cassette.

**The phosphor plates used in computed radiography are not as sensitive to light as x-ray, but are extremely sensitive to even low levels of scatter radiation.**

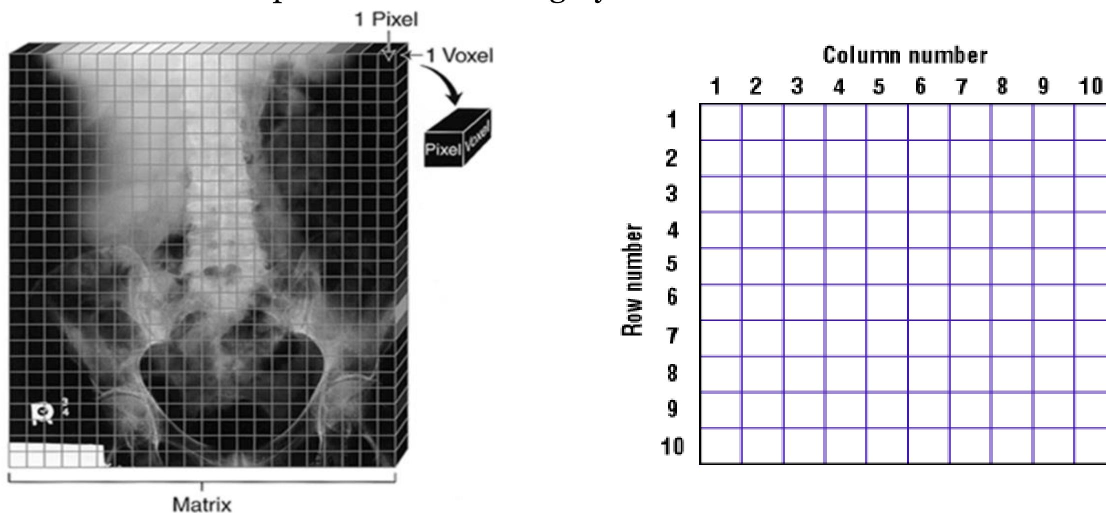
**DR** (also known as direct or direct capture radiography), refers to a system of radiography, in which the image receptor is composed of an array of electronic sensors that respond to the radiation exiting the patient. Instead of X-ray film, digital radiography uses a digital image capture device. These sensors send that information in digital format directly to a computer. The image receptor may be built in to the x-ray machine or moveable from one Bucky to another. It also may have wires attached to it or it may transmit the information wirelessly. Advantages include time efficiency through bypassing chemical processing and the ability to digitally transfer and enhance images. DR does not use a cassette or any intermediate step. The patient is simply positioned and after the exposure is created the image appears on a monitor near the control panel.

This gives advantages of immediate image preview and availability; elimination of costly film processing steps; a wider dynamic range, which makes it more forgiving for over- and under-exposure; as well as the ability to apply special image processing techniques that enhance overall display of the image.

# Digital Basics.

## Image Matrix

The digital image is created on a matrix which is composed of columns and rows. The intersection of each column and row is a pixel. The more pixels there are the smaller they are and the greater the potential detail of the image. Each pixel is assigned a numeric value that represents a shade of gray.




## Shades of Gray

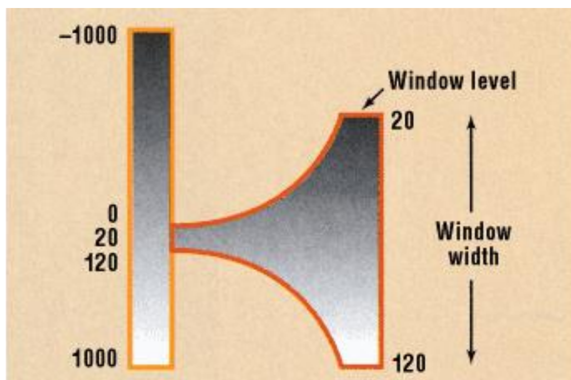
Medical images produced by digital x-ray systems typically contain between 12–16 bits/pixel, which corresponds to 4,096 to 65,536 shades of gray. On the other hand, we see that these images are being visualized by means of medical displays (physician's monitors) that have much lower available number of gray shades (typically 256 or 1,024). Visualization is also often limited to 8 bits because most viewing applications (technologist's monitors) only support 8 bits or 256 shades of gray. Moreover, it can be difficult for the computer to transmit the very large files that higher bit systems are composed of, slowing the system down considerably. The computer can't process the information very quickly. Another consideration is the limitation of our eyesight. Human observers can only perceive around 720 shades of gray on a typical medical LCD.

| 8 bits | 256 shades of gray |
|---|---|
| 10 bits | 1024 shades of gray |
| 12bits | 4,096 shades of gray |
| 14 bits | 16,384 shades of gray |
| 16 bits | 65,536 shades of gray |

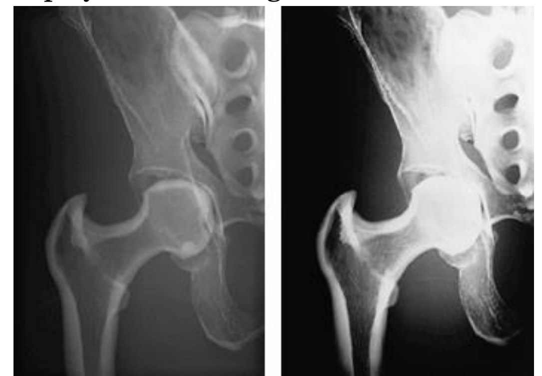
# Post Processing

## Window Level and Window Width

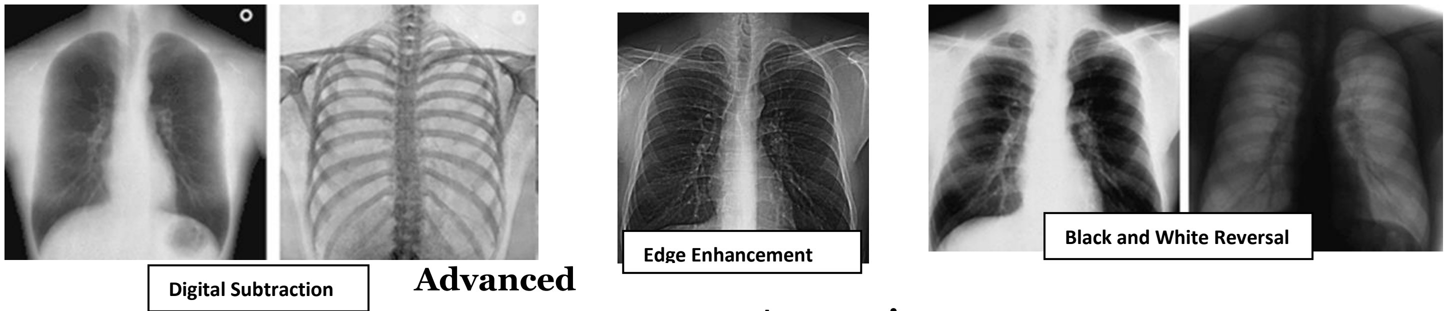
To overcome this large difference in bit depth between the image that has been captured and the image that we can see and to avoid the loss of critical information, radiologists have the ability to apply window leveling and window width to the displayed images. In this way, all grayscales present in the input image can be visualized just not all at the same time. Of course window leveling increases the time needed to analyze a medical image.




The *window* is the portion of the available shades of gray that are displayed in the image at one time. The *window level* determines which shades of gray are used. This makes the image appear darker or lighter. In digital radiography we refer to the darkness of a radiograph as darkness not density. Brightness is altered by adjusting the window level. The higher in the scale we move the window, the darker the image becomes and the lower the window, the lighter the image becomes. The window width refers to how many shades of gray we use. The wider the window the more shades of gray that become available.

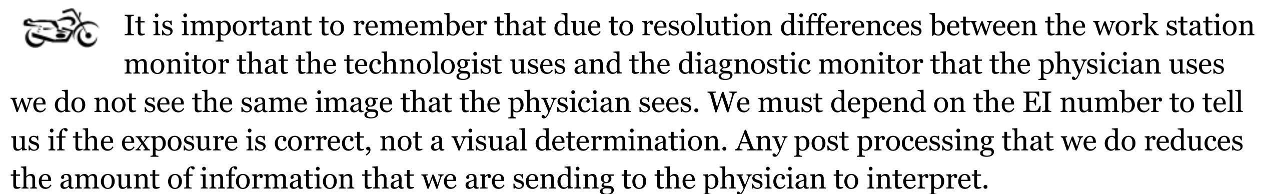


## Additional Post Processing




### Advanced Annotations

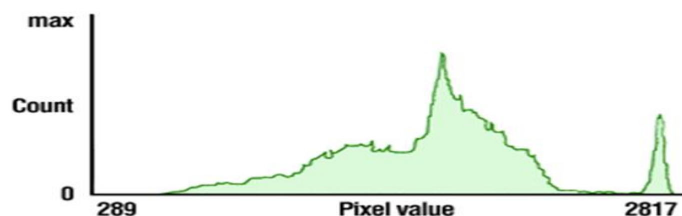
- Positioning Markers
- Add predetermined text or free text
- Zoom and roam image
- Invert image
- Apply shutters
- Show/hide histogram
- Advanced measurement options (Orthopedic Application)
- Stitching for full leg/full spine



It is important to remember that due to resolution differences between the work station monitor that the technologist uses and the diagnostic monitor that the physician uses we do not see the same image that the physician sees. We must depend on the EI number to tell us if the exposure is correct, not a visual determination. Any post processing that we do reduces the amount of information that we are sending to the physician to interpret.

## Histogram

This is a histogram created from a radiograph. The x-axis represents the pixel value while the y-axis represents the number of pixels with that value.




## Exposure Index

Exposure index (EI) is the measure of the amount of exposure received by the image receptor (IR). The EI is used by radiographers to determine if the correct exposure has been used to

create the image. It is dependent on mAs, total detector area irradiated, and beam attenuation. The exposure index is indicative of the image quality. Equipment manufacturers provide a recommended EI range for optimal image quality (Bontrager & Lampignano, 2005, p. 52).EI in digital radiography can be compared to film speed and blackening in film-screen. When film was used, the accuracy of the exposure was obvious based on the appearance of the image. Digital systems post-process images and display adequate contrast and brightness at a much wider range. Therefore, adequate exposure can only be assessed through image noise or burn-out. Secondary workstations such as those used by technologists for image review, are often of lower resolution and brightness than those used for diagnosis. Because of this, it is often difficult to assess whether an image is noisy or not. The exposure index is meant to be an indication of whether the noise levels are acceptable (AAPM, 2009).

Errors in the calculation can occur resulting in an inaccurate EI. This can arise when the software fails in determining which part of the image is the patient anatomy, for example, in the presence of gonadal shielding or prosthesis. EI cannot be solely relied on, therefore the technologist must remain critical of the appearance of the image and the accuracy of the EI (AAPM, 2009).

EI is derived from the mean detector entrance exposure which is derived from the mean pixel value of the image. Most systems use a histogram analysis in order to calculate the mean pixel value (Neitzel, 2004, p. S231).

Although EI is always derived from the IR exposure, equipment manufacturers calculate the numeric value differently, resulting in different ranges and definitions (Carlton & Adler, 2006, p. 367; Neitzel, 2004, p. S231). Also, there is variation between units purchased from the same manufacturer based on different IRs and software (Carlton & Adler, 2006, p. 367). Different IRs have different detective quantum efficiency (DQE). A high DQE results in lower noise levels (AAPM, 2009, p. 3). Therefore, all systems have a different index and are difficult to compare across systems. If the EI is within the manufacturers range it indicates that the correct exposure (mAs) has been used. If the EI is below the range the exposure was insufficient and the image needs to be repeated. If the EI is greater than the range then the exposure was too high, however the image might not need to be repeated.

### Fuji CR

Fuji uses a sensitivity number (S) that is related to the amount of amplification required by the photomultiplier tube to adjust the digital image. S is inversely proportional to exposure. Properly exposed images should have an S between 150-250 (Carlton & Adler, 2006, p. 367).

### Carestream

Carestream uses the term Exposure Index, which is directly proportional to exposure. Properly exposed images should have an EI between 1,800-2,200 (Carlton & Adler,

2006, p. 367). A change of 300 in the EI indicates a change of a factor of 2 in the exposure to the IR.

### Agfa CR

Agfa uses log median exposure (LgM). This system compares the exposure level of the image to a baseline established for the department. Since it is based on a log system, an increase of 0.3 means the dose was doubled (Carlton & Adler, 2006, p. 367). An optimal exposure lies between 1.9 and 2.5.

### Philips DR

Philips uses an EI that is inversely proportional to exposure. This index is represented in bigger discrete steps (eg., 100, 125, 160, 200, 250, 320, 400, 500, etc). Each step requires a 25% change in exposure to occur (AAPM, 2009). An optimal exposure lies between 200 and 800.

## DICOM

**DICOM** is the format that nearly all medical images are displayed in. It is similar to JPEG or GIF formats for images in computer languages. The **Digital Imaging and Communications in Medicine (DICOM)** Standard describes the means of formatting and exchanging medical images and image related information to facilitate the connectivity of medical devices and systems.

The DICOM Standard endorsed by the National Electrical Manufacturers Association (NEMA) is a result of joint efforts of users and manufacturers of medical imaging and healthcare information technology.

DICOM defines formats & exchange mechanisms for

- Images
- Findings, Measurements & Reports (Clinical Documentation)
- Waveforms

DICOM enables the connectivity and exchange of data between

- Image Acquisition Devices / Modalities: X-Ray, CT, MR, NM, US
- Diagnostic Workstations
- Image Management Systems (PACS)
- Storage and Archive Products

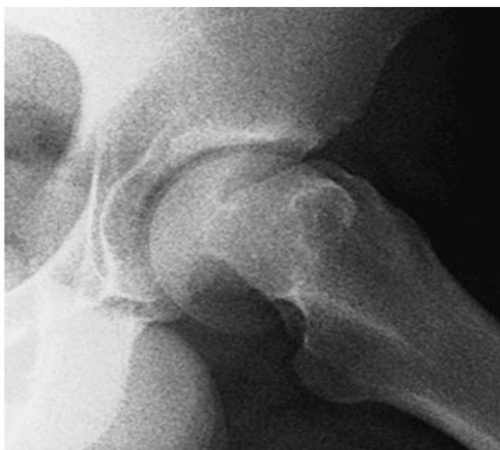
- Radiology Information Systems (RIS)
- Cardiology Information Systems (CIS)
- Radiation Therapy Planning Systems

# Technical Factors

Our new digital world has a new philosophy. This is something that we need to relearn. In the analog world, when a film was light there was nothing we could do to fix it. This is why when we were unsure of a technique we would always opt for the higher exposure (mAs). This concept is completely different in the digital world. Our philosophy is to get a great image using the least exposure possible. Using lower mAs means that we will necessarily need to use higher kVp.

The objective in digital radiography is to create a great image using the smallest exposure that gives us a diagnostic image. An image is diagnostic if there is no "noise" present on the image. The combination of technical factors used with digital imaging can be significantly different than those used with analog systems. Because we have the ability to adjust the window width of our images optimal contrast is significantly different for digital x-ray. It can be difficult for a technologist that has become used to using analog techniques to make the adjustment to digital techniques; however, by using higher kVp we are also using much lower mAs and significantly reducing the dose to the patient.

Every x-ray room must have an accurate technique chart near the x-ray control panel. I have included some very good digital technique charts at the end of this chapter that were developed by Dennis Bowman R.T. (R). Find the one that is appropriate for your x-ray machine. The detailed instructions are included.



*The grainy appearance of this radiograph indicates the presence of noise. Noise occurs as a result of not enough x-ray photons reaching the image receptor. The exposure (mAs) was too low.*

| DIGITAL OPTIMUM kVp | |
|---|---|
| Body Part | kV |
| Chest (Bucky/Grid) | 110-130 |
| Chest (Non Grid) | 80-90 (105) |
| Abdomen | 80-85 |
| Abdomen (Iodine) | 75-80 |
| Extremities (Table Top) | 65-75 |
| Extremities (Grid) | 80-90 |
| Extremities (Bucky) | 80-95 |
| AP Spines | 80-95 |
| C-Spine Lateral | 80-100 |
| T-Spine Lateral | 80-100 |
| L-Spine Lateral | 80-100 |
| Ribs (Upper and Lower) | 80-90 |
| Skull | 80-90 |
| Infant Extremities | 50-65 |
| | |

## Considerations When Preforming the Study

As we previously stated EI numbers are a very dependable way to determine if we have used the correct exposure to create an image. This is true only if our collimation and centering are accurate.

**Algorithms** The digital imaging system uses a series of algorithms to produce the optimal diagnostic image. Each body part that we study is processed using different algorithms. It is critical that the computer know what body part we are studying so that the image can be processed correctly. We tell the computer which body part we are studying by selecting it on the user interface before we begin the exam. It can be tempting to skip this step, perform the exam then go back in and change the label to read the correct body part on the finished image. This is a problem because if the computer thinks we are imaging a chest and we perform a study on a wrist for example, it will be processed improperly and not be the best image that we can present to the physician.

**Centering and Collimation** Proper centering is very important. The exposure index is easily corrupted if the computer cant find the body part on the portion of the image receptor where it expects to find it. It will not only produce an image that is poor visualy but the EI number will be off and you will be unable to use the image. Collimation is also a serious concern; make sure that you show at least a little collimation on all four sides of the image, this also helps the computer to identify the proper algorithms. IR size must be considered as well. If more than 33% of the IR

**Multiple exposures on a Single IR** The reason that we put multiple images on a single image receptor when we are using an analog system is to save money on x-ray film and processor chemicals. When using a digital IR these are not concerns, because we are not using consumable products. The computer cannot differentiate between two separate objects. The EI number is going to be inaccurate. Therefore we only place one projection at a time on an image receptor. IR size is important as well, we must use the correct IR size. Collimated fields using less than 33% of the IR will produce a corrupt EI.

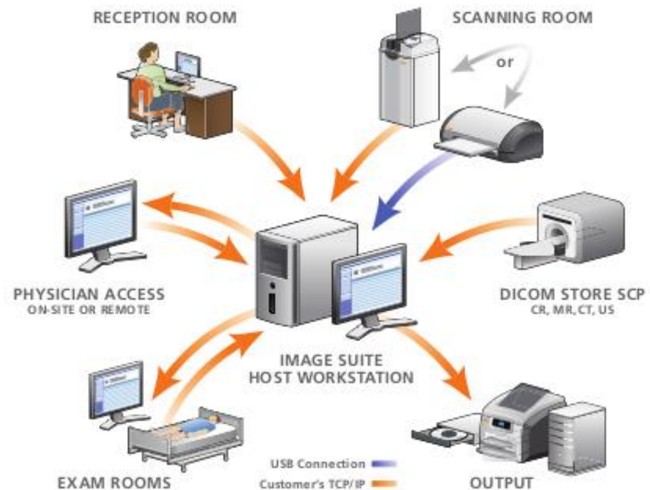
# Radiation Protection and Digital X-Ray

With digital x-ray systems it is way too easy to repeat an image. It is like taking a picture with your digital camera. Remember that whenever we repeat an exposure we are doubling the exposure to our patient. This is not to say that if a projection needs to be repeated we should not do that. What you need to remember is that our goal is to NEED to repeat as few images as possible.

Because of the wide exposure latitude we discussed earlier it is possible to produce images that look great across a very wide range of exposures. The limiting factor is the presence of noise, that grainy appearance that is the result of not enough exposure (mAs). With this in mind the tendency is to use too much exposure in order to ensure that the image does not need to be repeated. The result of this increasing exposure is that it becomes larger and larger over time. This is referred to as **dose creep.** The best way to avoid dose creep is to consistently use your technique chart and to pay close attention to the EI numbers that are produced with your radiographs.

# PACS

A **picture archiving and communication system (PACS)** is a medical imaging technology which provides economical storage of and convenient access to, images from multiple modalities (source machine types).[1] Electronic images and reports are transmitted digitally via PACS; this eliminates the need to manually file, retrieve, or transport film jackets. The universal format for PACS image storage and transfer is DICOM (Digital Imaging and Communications in Medicine). Non-image data, such as scanned documents, may be incorporated using consumer industry standard formats like PDF (Portable Document Format), once encapsulated in DICOM. A PACS consists of four major components: The imaging modalities such as X-ray plain film (PF), computed tomography (CT) and magnetic resonance imaging (MRI), a secured network for the transmission of patient information, workstations for interpreting and reviewing images, and archives for the storage and retrieval of images and reports. Combined with available and emerging web technology, PACS has the ability to deliver timely and efficient access to images, interpretations, and related data. PACS breaks down the physical and time barriers associated with traditional film-based image retrieval, distribution, and display.




## Some Advantages of having a PACS system.

- The display that the technologist uses is not high enough resolution to be considered diagnostic, the image needs to be sent to a diagnostic monitor for interpretation.
- Faster delivery of medical images to the clinicians that evaluate and report on them. Resulting in faster availability of results.
- No lost or misplaced images, which means fewer patients being postponed or cancelled for consultations or surgery while waiting for new images.
- Flexible viewing with the ability to manipulate images on screen, which means patients can be diagnosed more effectively.
- Instant access to previous images and patient records.
- Better collaboration, as PACS can be viewed from multiple terminals and locations by a range of clinicians, allowing discussion over diagnoses.

- Fewer unnecessary re-investigations, which will in turn reduce the amount of radiation to which patients are exposed.
- The computer with the x-ray machine is not appropriate for image storage PACS offers image storage without requiring additional space.

Notes

# Digital Imaging Systems

1. A "cassette-based" digital x-ray system is termed:
A. digital radiography (DR).
B. computed radiography (CR).
C. direct conversion.
D. indirect conversion.

2. The advantages of using CR and DR include:
   1. low doses to the patients.
   2. a wide dynamic range.
   3. ability to see images very fast.
A. 1 and 2
B. 1 and 3
C. 2 and 3
D. 1, 2, and 3

3. Which of the following must be used with digital-based systems to ensure that the ALARA concept is practiced?
A. A grid
B. A 40-inch SID
C. An exposure technique chart
D. Added aluminum at the port of the x-ray tube

4. Noise occurs in digital images if:
A. the time is set to "long."
B. the mA is set to "high."
C. the kVp is set to "high."
D. the exposure is too low

5. The storage phosphors in the CR plate are hypersensitive to:
A. small levels of scatter radiation exposure.
B. red safelight filters.
C. low kVp or low mA settings.
D. incandescent or fluorescent room light.

6. Which of the following is a true statement regarding the centering of the body part when using digital systems?
A. The part must be placed off-center by about 2 cm.
B. The part must be placed in the center of the plate or detector.
C. The part should be placed near one of the four edges.
D. The part can be placed anywhere on the plate or detector.

7. When examining the wrist using a digital imaging system how many images may I put on a 10x12 inch image receptor?
A. 1
B. 2
C. 3
D. 4

8. An image that exists but can't be seen until it is processed is referred to as a
A. Manifest image
B. Inverted image
C. Wide image
D. Latent image

9. Analog x-ray systems have the advantage of immediate availability of the image.
A. True
B. False

10. The number that we use to determine whether or not the correct exposure has been used when producing a radiograph is termed the
A. E.I.
B. kVp
C. REM
D. TGIF

11. When using a Carestream CR system if the E.I. is 1732 the resulting image will have
A. received too little exposure but does not need to be repeated
B. received too much exposure and needs to be repeated
C. received too little exposure and needs to be repeated
D. received too much exposure but does not need to be repeated

12. If we want to make a digital image on the monitor look darker we would
A. Make the window width wider
B. Make the window width narrower
C. Make the window level higher
D. Make the window level lower