# Image Quality and Artifacts in Digital Imaging

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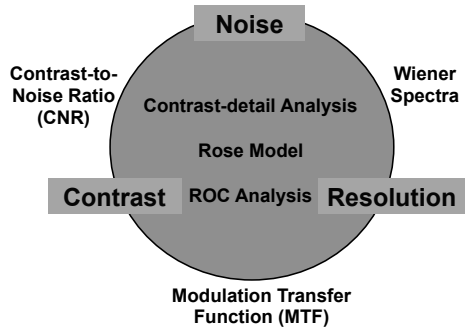
## Outline

- **Concepts of image quality**
- **Contrast**
- **Resolution**
- **Noise**
- **Factors affecting image quality in digital imaging**

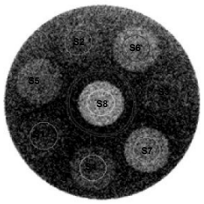
## Image quality



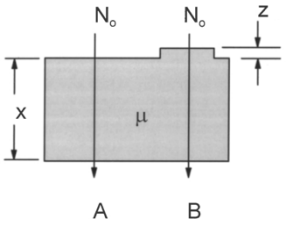

Hasegawa BH, *The Physics of Medical X-ray Imaging*, 2nd Ed, 1991.

## Contrast

- **The difference in image brightness between areas in the radiography.**



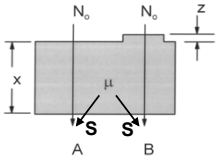
## Contrast




$$C = \frac{A-B}{A}(\times 100\%)$$

-
-

## Scatter reduces contrast

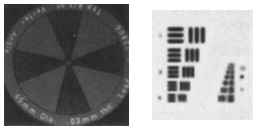



$$C = \frac{(A+S)-(B+S)}{(A+S)} = \frac{A-B}{A+S}$$

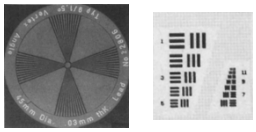
## Spatial resolution

- **The smallest distance that 2 objects can be separated and still appear distinct.**

**Large focal spot**

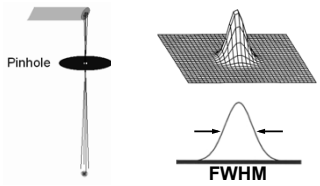


**Small focal spot**



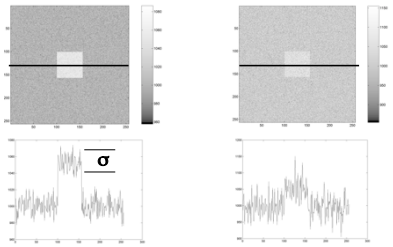
## Spatial resolution

- **Spatial resolution can be measured as "point spread function (psf)"**
- **Psf is the image of an ideal point object.**




## Noise

- **The uncertainty or imprecision with which a signal is recorded.**




**5% contrast, 1% noise** **5% contrast, 3% noise**

## Quantum Noise

- average number of x-rays interacting in the screen may be constant across the field (a uniform beam).
- The actual number interacting in any given small area will obey a statistical law called the POISSON DISTRIBUTION.
- (doesn't have to do with quantum mechanics, but with the fact that x-rays come as individual photons or quanta)

## The Signal-to-Noise Ratio: A Way to Quantify Noise

If the signal is composed of N photons

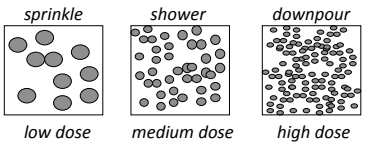
and if the noise is given by s = sqrt(N),

then the signal-to-noise ratio is given by

SNR = signal/noise = N/sqrt(N) = sqrt(N)

SNR is the inverse of the fractional noise (noise/signal)
Bigger SNR is better (within dose constraints).

## Poisson Statistics: Raindrops Analogy




| | | | |
|---|---|---|---|
| N | = | 10 | 40 | 100 |
| σ | = | 3.2 | 6.3 | 10 |
| SNR | = | 3.2 | 6.3 | 10 |

## Contrast-to-Noise Ratio (CNR)

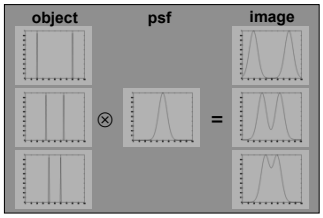
- **Low contrast detectibility can be directly related to CNR.**
- **CNR is proportional to SNR, or square-root of NEQ (Noise equivalent quanta).**

$$CNR = \frac{\Delta S}{\sigma} = \frac{\Delta S}{S} \times \frac{S}{\sigma} = C \times SNR$$

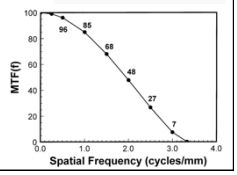
## Modulation Transfer Function (MTF)

- **The contrast produced by an imaging system as a function of the spatial frequency of the object or input signal.**

$$MTF(u) = \frac{Output\_\mathrm{modulation}(u)}{Input\_\mathrm{modulation}(u)}$$




$$Modulation = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$




## Detective Quantum Efficiency (DQE)

- **The efficiency for a detector system to use x-ray to generate images with adequate SNR.**

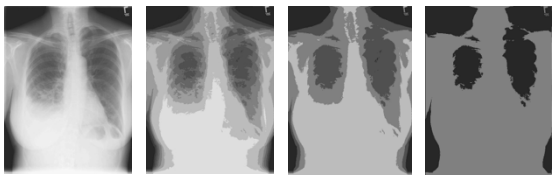

$$DQE = \left( \frac{SNR_{out}}{SNR_{in}} \right)^2$$

## Factors affecting "contrast"

-
-
-
-

## Bit Depth

- **Number of bits used to represent gray levels for a pixel**



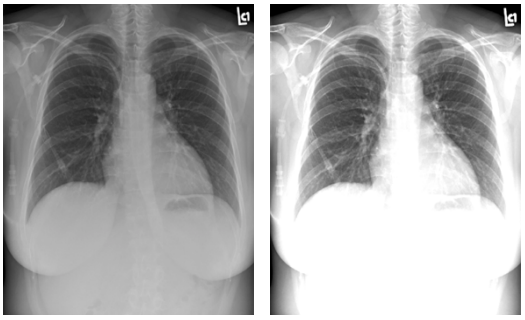

## DR density is adjustable and arbitrary

- **Acquisition is independent from display**
- **Code values in the raw DR image can be translated to any display level**
- **This allows DR to compensate for over- and under-exposure, producing a consistent appearance**

## DR compensates for incorrect exposure factor selection

Underexposed Overexposed

## Window/Level



## Appropriate technique includes appropriate means of scatter reduction

- **Scatter degrades *contrast* and contributes to patient dose.**
- **CR/DR may be more sensitive to scatter than conventional film/screen.**
- **Appropriate collimation reduces scatter and irradiated area of patient.**
- **Use of grids improves *contrast* while increasing patient dose.**
- **Unfortunate choices of grid line rates can result in *artifacts*.**
  - **moiré patterns with pixel sampling rate**
  - **moiré patterns with the display pixel rate**

## Factors affecting "spatial resolution"

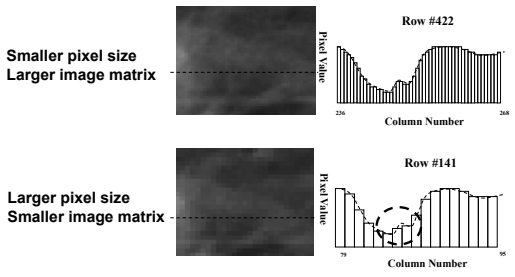
-

-

-

## Pixel size, Matrix size and FOV

*Pixel size = FOV/# of rows (columns)*




## DR system and resolution

- **Factors besides sampling compromise *sharpness***
  - ***X-ray focal spot dimensions***
  - ***Blur in Indirect DR and CR***
  - ***Optical and mechanical imprecision in IDR and CR***
  - ***Afterglow in fast-scan dimension in CR***
- **Limit of resolution is where *MTF* has decreased to 10%**

## Factors affecting "noise"

-

-

detector energy response

- DQE

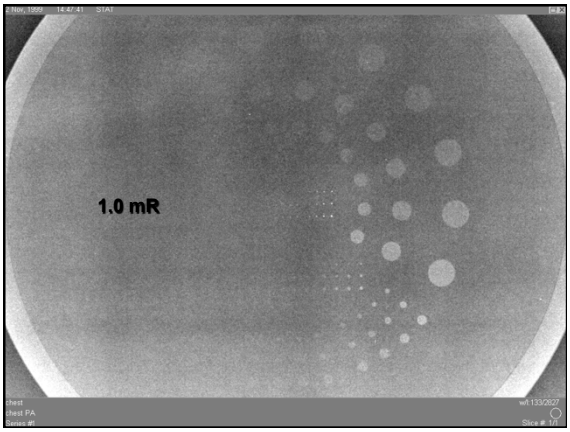
## Optimization of CR/DR imaging cannot ignore patient dose!

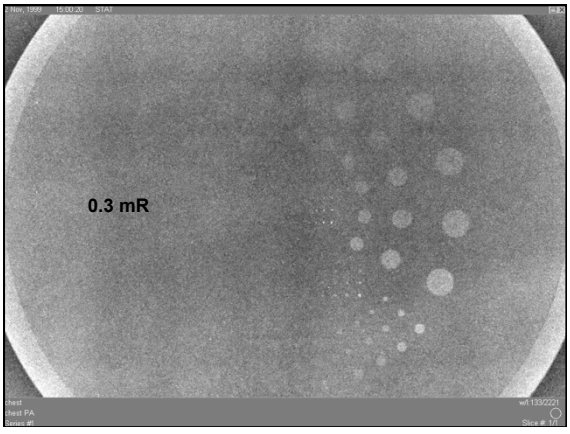
- **In order to make a digital radiographic image, a sufficient number of x-rays must reach the detector.**
- **Unfortunately, the x-rays must pass through the patient to reach the detector.**
- **The *ALARA* Principle dictates that the examination should be performed with the lowest reasonable dose to the patient.**

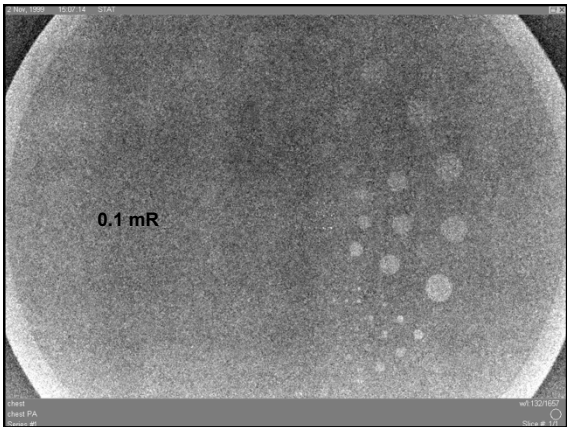
## Sufficient x-rays must reach the detector to produce the radiographic image.

- **At the same dose, the smaller the pixel size, the fewer x-rays in each pixel, and the worse the *noise*.**
- **The larger the pixel size, the worse the *sharpness*.**

| *Exposure (mR)* | *Photons /100μpixel* | *Noise (%)* |
|---|---|---|



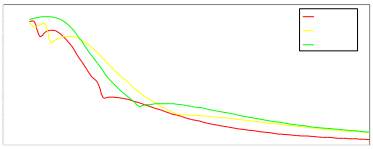



The proper quality of x-rays must reach the detector to ensure optimum efficiency.

- **The energy preferred by the detector is different from many conventional film/screen systems.**
- **The energy that reaches the detector is influenced by the kVp, filtration, the patient thickness, etc.**

Absorption Efficiency



## Artifacts and Digital Systems

- Artifacts are any fault impressions appear on the images
- Digital imaging produces different kinds of artifacts commonly found in conventional screen/film

## Artifacts and Digital Systems

- Recognizing artifacts in digital radiograph can avoid misinterpreting those distracting patterns as pathological findings
- Can be generated from users who are not aware of proper imaging techniques or image processing selection

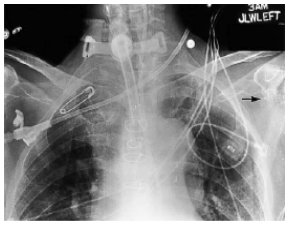
## Classification of artifacts in digital imaging

- Hardware
- Software/Image processing
- Image display
- Operator error

## Hardware – Image Plate

- Image plate are susceptible for cracking
- Deterioration progress appears from the middle of the plate
- Debris that blocks IP emission of light when scanning with laser will make image appear bright at the site
- Back-scatter can also produce artifacts due to high sensitivity to scatter radiation of the IP

## Image plate artifact

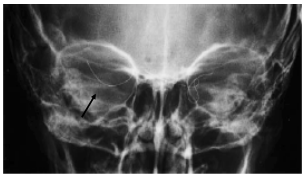



Residue from adhesive tape used to attach lead markers to the outside of the cassette

## Image plate artifact

CRACK OF THE IP:
Image shows artifacts appears in anatomical region

## Image plate artifact



Static caused a hair to cling to the IP on this skull image.

## CR Artifacts

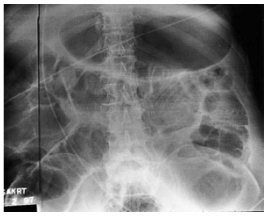
Crack in IP : looks like a foreign body

L J CESAR,

## Image plate artifact

Debris from IP crack:
Normally radiologist can tolerate, sometimes confusing with foreign bodies

## Image plate artifact



The dark line along the lateral portion of this upper abdomen is caused by backscatter transmitted through the back of the cassette.
The line corresponds to the cassette hinge where the lead coating was weakened or cracked.

## How to solve these problems from image plate artifacts

- Clean IP plate regularly
- Refer to vendor's recommendation regarding methods for cleaning
- Frequency of cleaning depends on the usage

## Manufacterer's recommendation

2 Storage Conditions/Daily Maintenance

2.1 Storage Conditions

(1) Store IPs under the following environmental conditions.
Packed: Under 35°C
Unpacked: Under 33°C and 80% RH

(2) Store IPs in a place where they are not exposed to direct sunlight or excessive ultraviolet rays or various radioactive rays.

(3) Do not bend IPs or impose strong force on them.

## Manufacturer's Recommendation

2.2 Daily Maintenance

(1) Do not use damaged IPs because image diagnosis can be affected.

(2) Handle IPs as carefully as possible. Do not damage or stain IPs.

(3) Do not bend IPs, hit them against some other objects or drop on the floor or table.

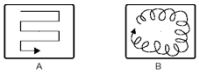
## Manufacturer's Recommendation

2.3 Cleaning

(1) Materials required
Lint free non-woven cotton
Gauze (100% cotton),
Lens cleaner

(2) Method

1 With a dry cloth of materials listed above, wipe off the IP surface as illustrated below (A or B).




2 For stains which fail to come off by cleaning with dry cleaning cloths, dampen the above cloth with ethanol anhydride (JIS standards or special standards) before cleaning. (Do not use another cleaning agent.)

When the IP surface has been cleaned using ethanol anhydride-dampened cloths, slightly wipe it off with dry cloths listed above. Make sure the surface of the IP is completely dry before use.

!! Frequent cleaning with ethanol anhydride can cause yellowing of the IP edges.

## Manufacturer's Recommendation

(3) Precautions

1 Be sure not to damage the IP.
2 Never use eraser or any other solvents.
3 Do not scratch the IP with your nails.
4 Never moisten the IP with water to wipe off stains.

!! Do not apply light to the IP exposed but not yet processed.

## Hardware: Image reader

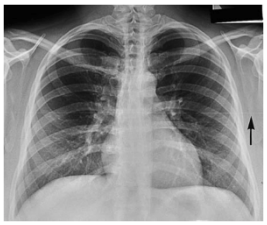
- Normally IPs are automatically reased after used
- IPs must be manually erased after not in use for a period of time
- For incorrect (intense) exposure, IPs should be erased with longer erasure cycle
- Incomplete erasure can produce artifacts

## Plate reader artifacts

The electronic board that controlled the photomultiplier tube was malfunctioned.

Call in service engineer

## Plate reader artifacts



Dirt on the light-guide cause line artifact

## Plate reader artifacts

Plate reader artefact. This artifact occurred because the plate reader loaded two imaging plates (IPs) in a single cassette. After an exposure, the bottom IP was extracted, read and replaced as usual, leaving the top IP to be exposed numerous times. Artefact remedy: double-loaded cassettes will be discovered during routine IP cleaning. If a cassette containing two IPs is discovered, the IPs should be erased before being put back into use.

## Plate reader artifacts

Plate reader artefact. This bilateral knee image was spoiled when the incorrect erasure setting was used to eliminate a previous femur image. Evidence of this is the residual image of the lead marker in the top corner of the image, the tissue line from the previous image (upper arrow) and the additional line of collimation along the bottom of the image (lower arrow). Artefact remedy: radiographers must select the correct erasure setting according to the type of exposure that has occurred.

## Erasure Cycle

**Secondary Erasure**

Even when stored in a room, an IP is very sensitive and absorbs and accumulates natural radioactivity such as cosmic rays or radiation energy emanating from radioisotopes contained in construction materials such as those used for floors and walls. Perform secondary erasure for IPs which have not been used that day.

For the detailed operation procedure, refer to Chapter 2, section 2.4, **Conducting Exposure Using a Cassette (IP) Left Unused for 8 Hours or More [SECONDARY ERASURE]**.

## Erasure Cycle

**Primary Erasure**

The following IPs must always be submitted to primary erasure prior to use for exposure.

(1) Over-exposed IP

(2) Incorrectly exposed IP

For the detailed operation procedure, refer to Chapter 2, section 2.3, **Conducting Image Erasure Only [PRIMARY ERASURE]**.

## Image processing

- Proper image processing should be employed to avoid appearance of artifacts
- Keep in mind that we cannot create anything that is not part of the patient
- Image processing cannot correct for everything!

## Image processing artifacts

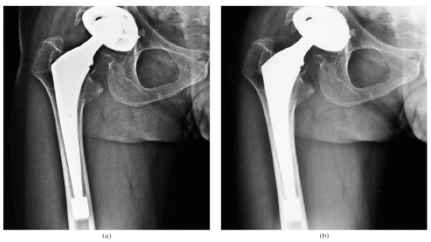


Figure 8. Image processing artefact. (a) When too large a kernel size is selected for image enhancement, artefacts like the black halo surrounding the prosthesis can create the appearance that the prosthesis is loose. (b) The same image as (a) processed with a smaller kernel size.

## Image processing artifacts

**Inadequate image processing**

**Mismatch technique/post processing**

## Image processing artifacts

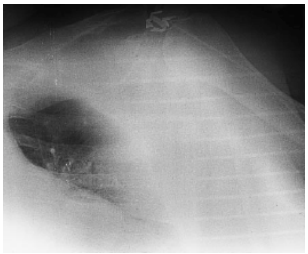
**Figure 10.** Image processing artefact. Owing to lack of primary beam collimation on this lateral lumbar spine, the amount of unattenuated radiation striking the imaging plate (IP) (anterior and posterior to the patient) altered the histogram so that it was outside the normal range for that body part selection. Artefact remedy: use the smallest IP practicable and collimate the beam to the body part. This is particularly important on small or slim patients.

## Image Display: Laser printer artifact


## Operator Error Artifacts

- Radiographers can create artifacts
- Care should be taken when working with CR
- Learning about patterns of artifacts and remedy are encouraged

## Operator error



## Operator error

**Figure 14.** Operator error. The moiré pattern seen in this knee image was caused by using a grid with a frequency of 33 lines $cm^{-1}$, which was oriented with the grid lines parallel to the plate reader's scan lines. Artefact remedy: use grids with no less than 60 lines $cm^{-1}$. In addition, grid lines should run perpendicular to the plate reader's laser scan lines.

## Operator error

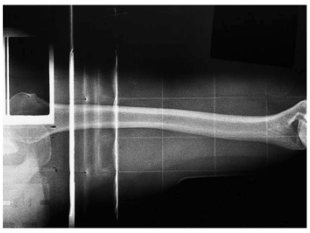


**Figure 15.** Operator error. This axillary shoulder was exposed through the back of a cassette. Artefact remedy: be sure radiographers are well educated about how to use the entire computed radiography system.

## Operator error

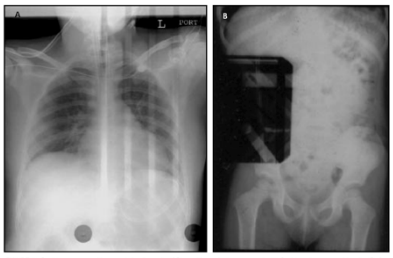


*FIGURE 11. Double exposures with computed radiography (CR) requiring a single repeat study. (A) Backboard or gurney side rails. (B) Cassette left in bucky tray during fluoroscopy. Images were acquired on an Agfa CR system (Agfa Medical Systems, Ridgefield Park, NJ).*

## Other types

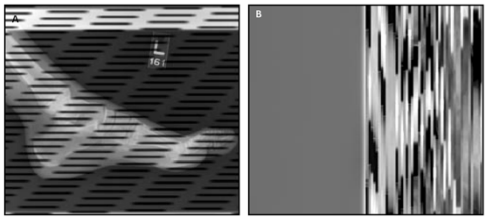


*FIGURE 10. (A and B) Missing lines or pixels in computed radiography (CR) can indicate memory problems, digitization problems, or communication errors. Images were acquired on an Agfa CR system (Agfa Medical Systems, Ridgefield Park, NJ).*

## Other types

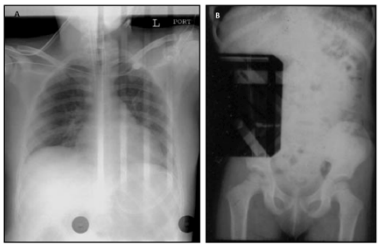


*FIGURE 11. Double exposures with computed radiography (CR) requiring a single repeat study. (A) Backboard or gurney side rails. (B) Cassette left in bucky tray during fluoroscopy. Images were acquired on an Agfa CR system (Agfa Medical Systems, Ridgefield Park, NJ).*

## To avoid artifacts in CR

- Aware of cause of artifacts
- Learn about appearance of different artifact types
- Clean your IP
- Make sure service people come in regularly

## Conclusions

- **Good image quality is essential for both sensitivity and specificity of lesion diagnosis.**
- **General description of image quality includes contrast, spatial resolution, noise and artifact.**
- **Contrast, spatial resolution and noise are all inter-related which can be characterized by CNR, MTF and noise spectrum.**
- **Factors affecting image quality in DR need to be taken into account when optimizing the radiographic protocols.**