Henry Ford Health System

RADIOLOGY RESEARCH

Application of the ILO International Classification of Radiographs of Pneumoconioses to Digital Radiographs
NIOSH Scientific Workshop
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Image Presentation: Implications of Processing and Display

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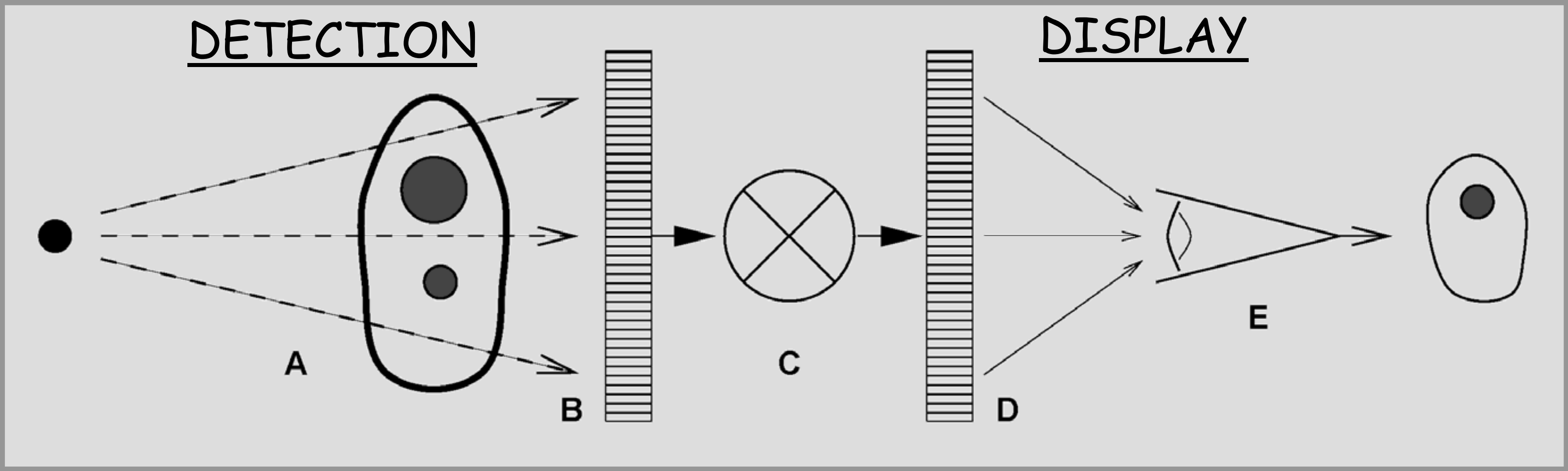
Henry Ford Health System

Display processing is used to transform digital radiography data to display values for presentation using a workstation or film printer.



(A) Subject contrast

(B) is recorded by the detector

(C) and transformed to display values

(D) that are sent to a display device

(E) for presentation to the human visual system.

Intro - Disclosure

The presenter is a designated principal investigator on research agreements between Henry Ford Health System and the following companies (alphabetical);

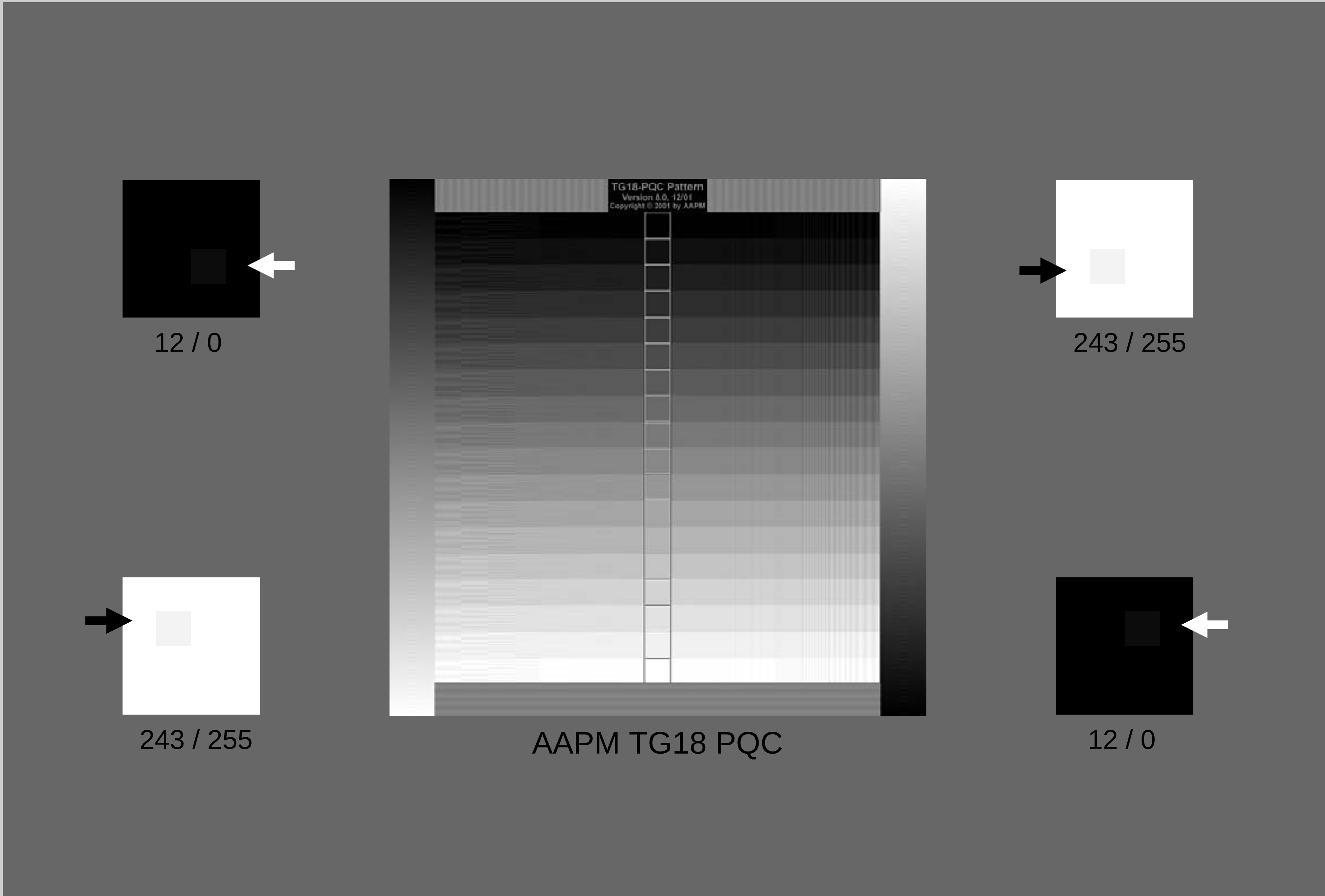
* Agfa Medical Systems
  Brown & Herbranson imaging
* Eastman Kodak Company
  Shimadzu Medical Systems
  Roche Pharmaceuticals

The presenter has provided consulting services over the last 12 months with the following companies (alphabetical);

  Gammex-RMI
* Vidar Systems Corp.

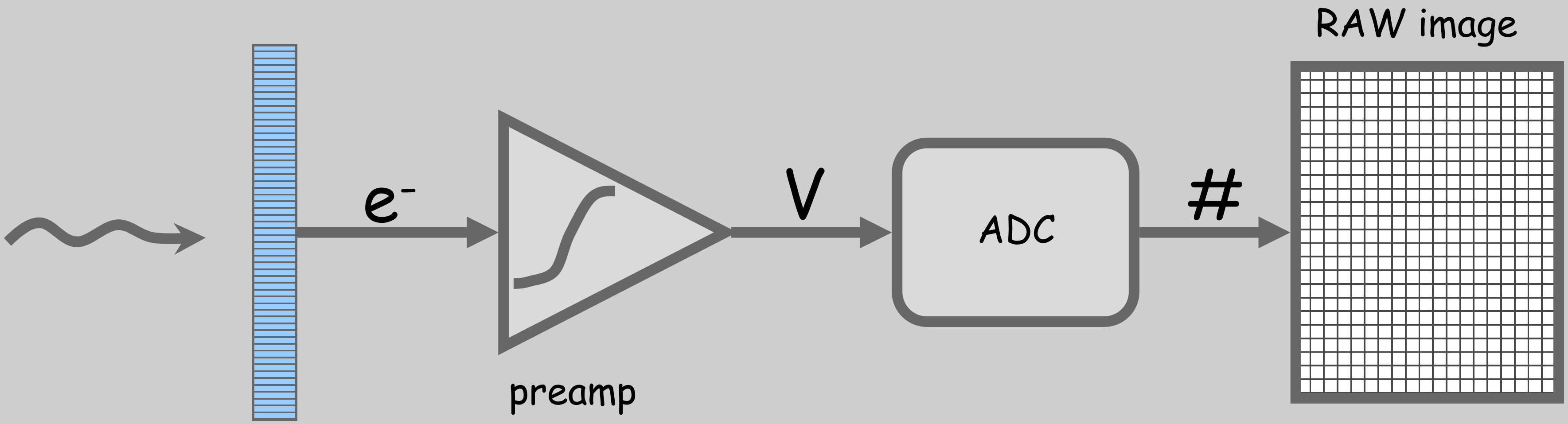
* Involves DR image processing

Projection Test Pattern

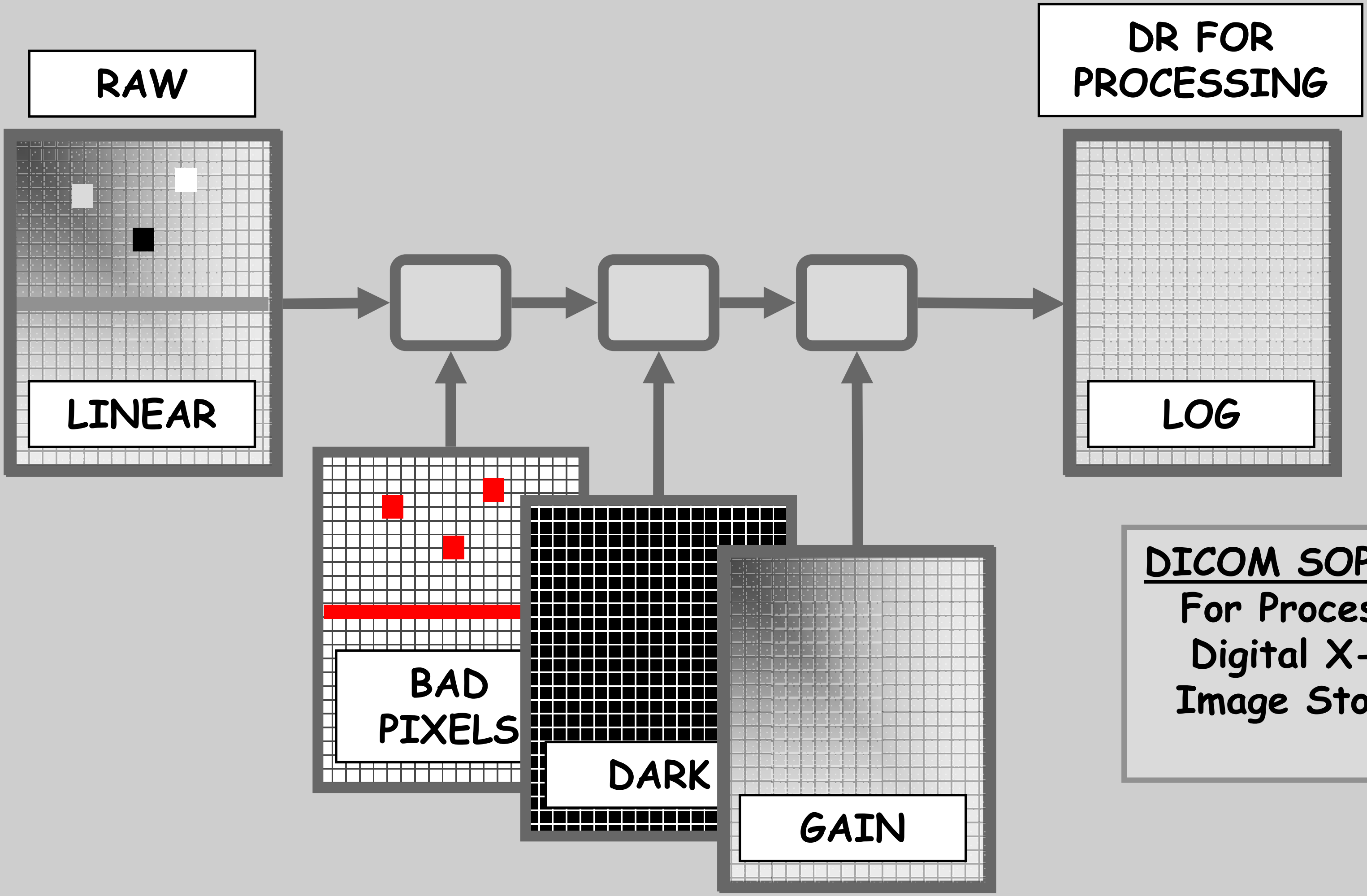


1. Preprocessing
2. Display Processing
3. Display Presentation
4. Chest Case Example

- For CR and DR systems, radiation energy deposited in the detector is converted to electrical charge.
- Preamplifier circuits then convert this to a voltage which is digitized using analog to voltage converter (ADC) to produce RAW image values.



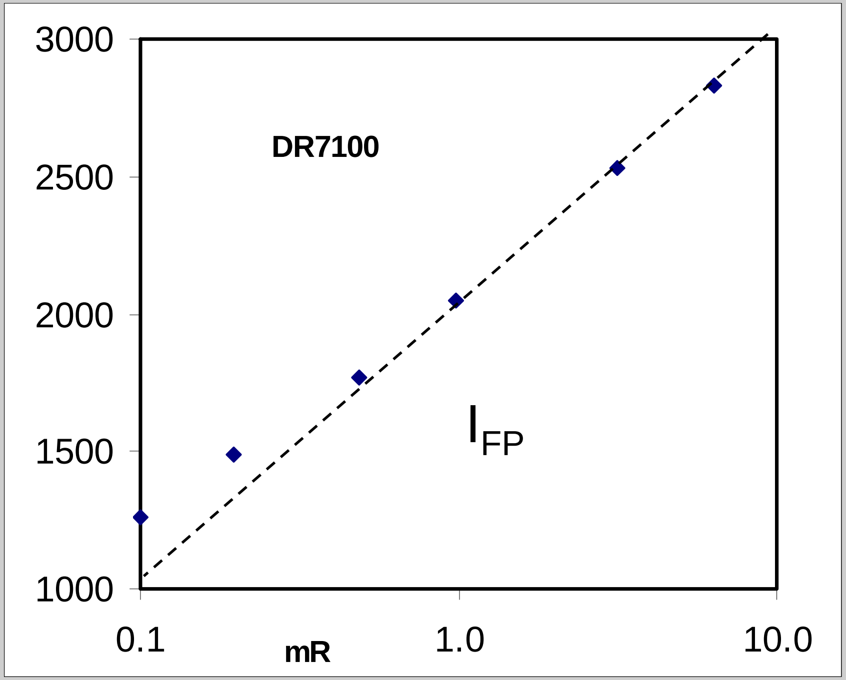
RAW data from the detector is pre-processed to produce an image suitable for processing.



DICOM SOP Class
For Processing
Digital X-ray
Image Storage

UID 1.2.840.10008.5.1.4.1.1.1.1.1

- Most 'for processing' image values are proportional to the log of the exposure incident on the detector.
- Samei et.al., Med Phys 2001
  - Agfa, PV = 1250 * log(cBE) -121
  - Fuji, PV = (1024/L)*(log(E) + log(S/200))
  - Kodak, PV = 1000*log(E) +Co



For I_{FP} values stored as a 12 bit number (0 – 4095), a convenient format has a change of 1000 for every factor of 10 change in exposure.

$$I_{FP} = 1000 \log_{10}(\text{ mR }) + 2000$$

AAPM Task group 116 draft report

"Recommended Exposure Indicators for Digital Radiography"

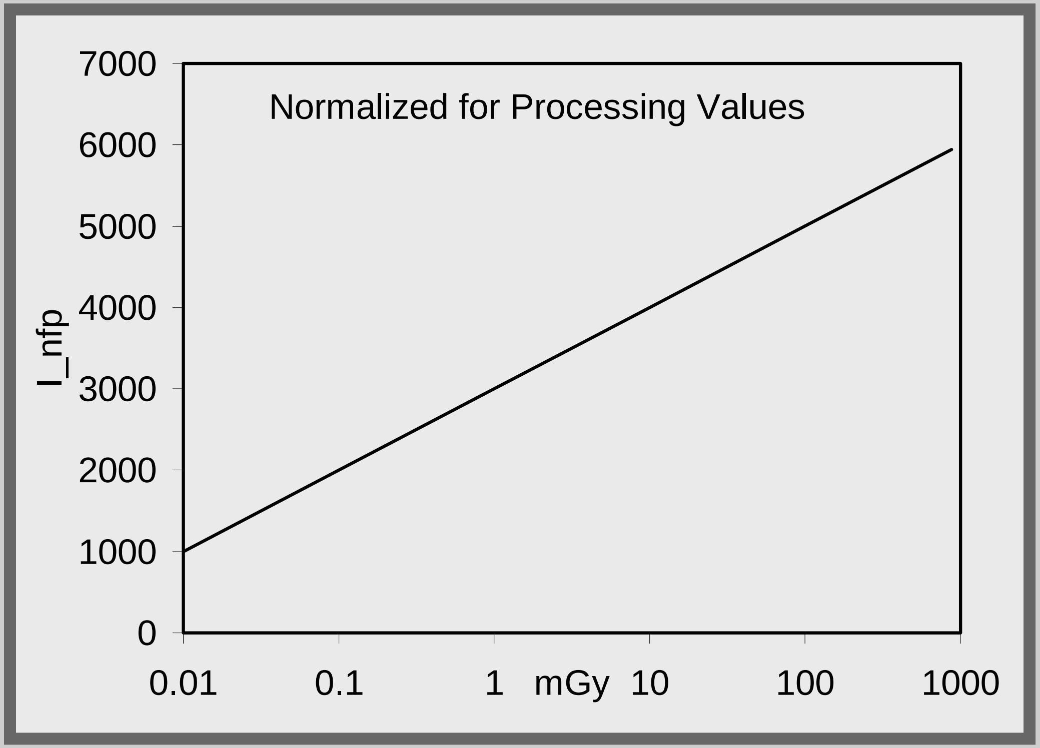
Normalized For Processing Pixel Values (I_{NFP})

"For-processing pixel values, I_{FP}, that have been converted to have a specific relation to a standardized radiation exposure (E_{STD}). ..,"

I_{NFP} = 1,000*log10(E_{STD}/Eo) ,

E_{STD} in micro-Gray units,

Eo = 0.001 micro-Gray,



1. Preprocessing
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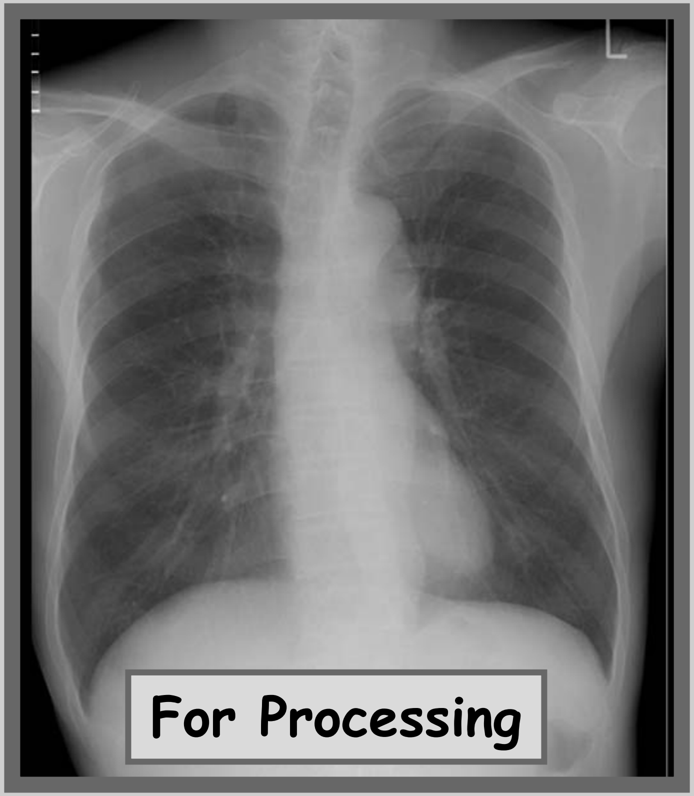
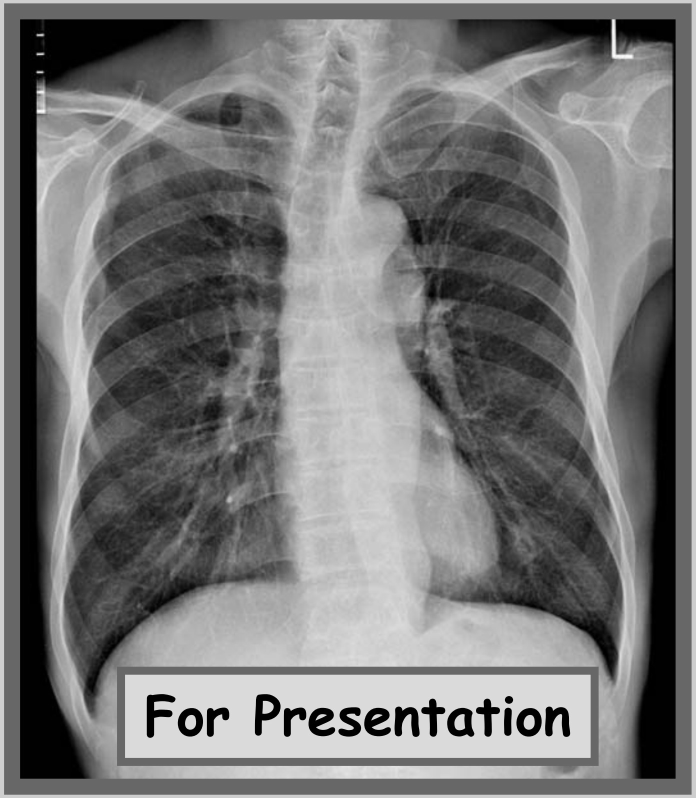
2 - Five generic processes

⇒	**Grayscale Rendition:**	Convert signal values to display values
⇒	**Exposure Recognition:**	Adjust for high/low average exposure.
⇒	**Edge Restoration:**	Sharpen edges while limiting noise.
⇒	**Noise Reduction:**	Reduce noise and maintain sharpness
⇒	**Contrast Enhancement:**	Increase contrast for local detail





2A - processing sequence

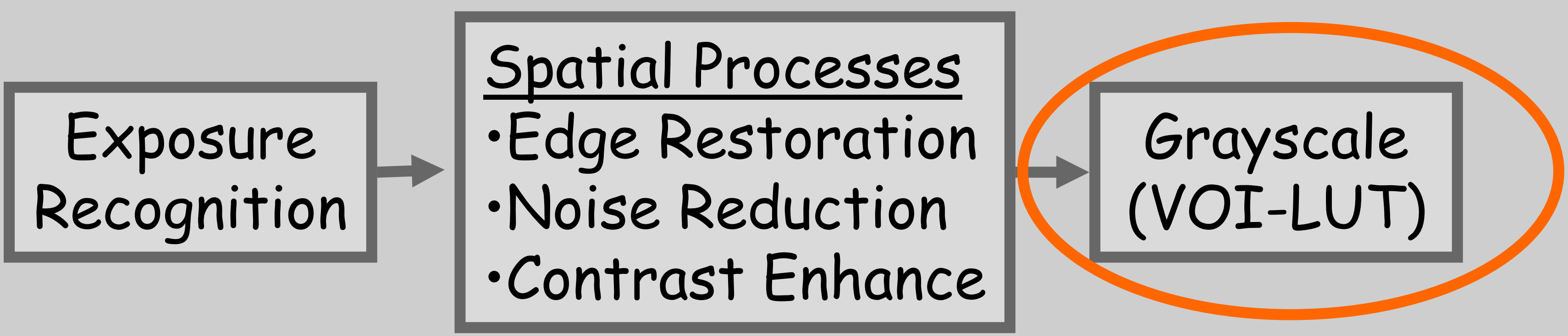
⇒ **Grayscale Rendition:** Convert signal values to display values

⇒ **Exposure Recognition:** Adjust for high/low average exposure.

⇒ **Edge Restoration:** Sharpen edges while limiting noise.

⇒ **Noise Reduction:** Reduce noise and maintain sharpness

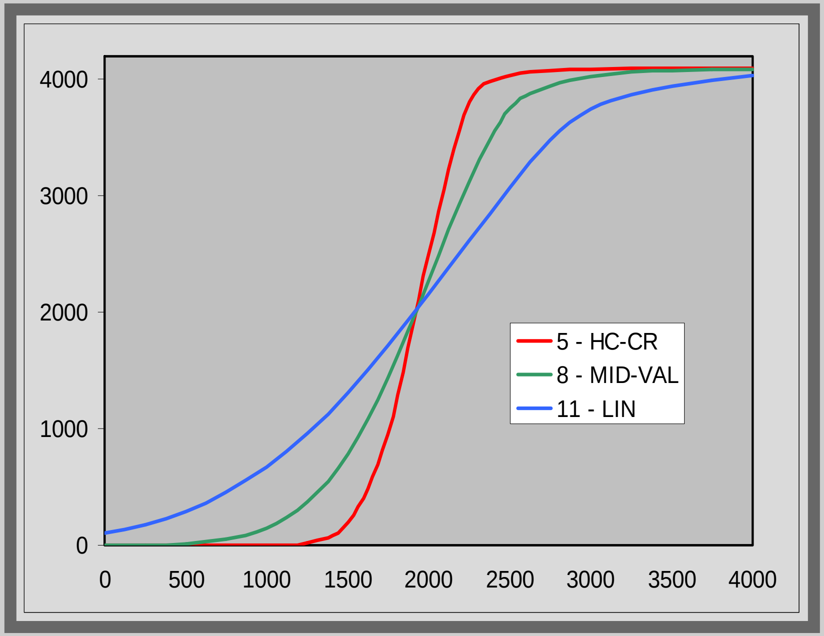
⇒ **Contrast Enhancement:** Increase contrast for local detail

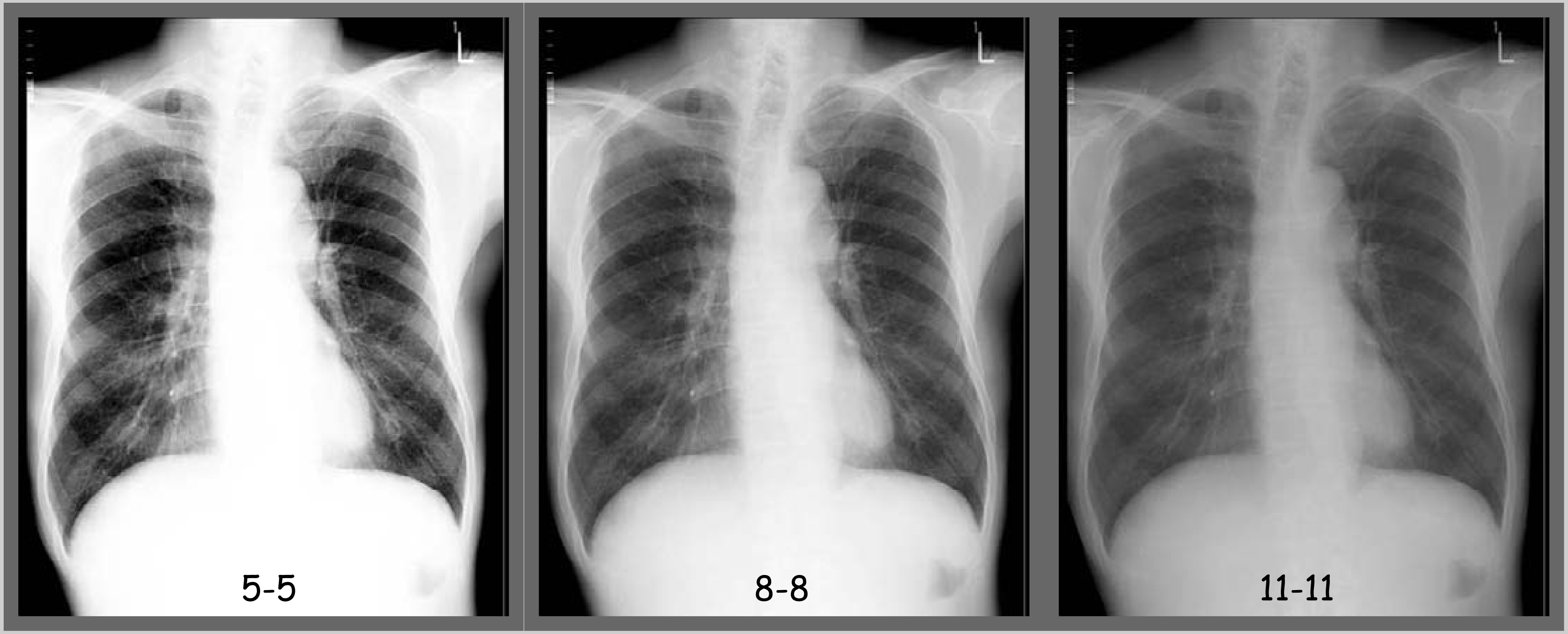


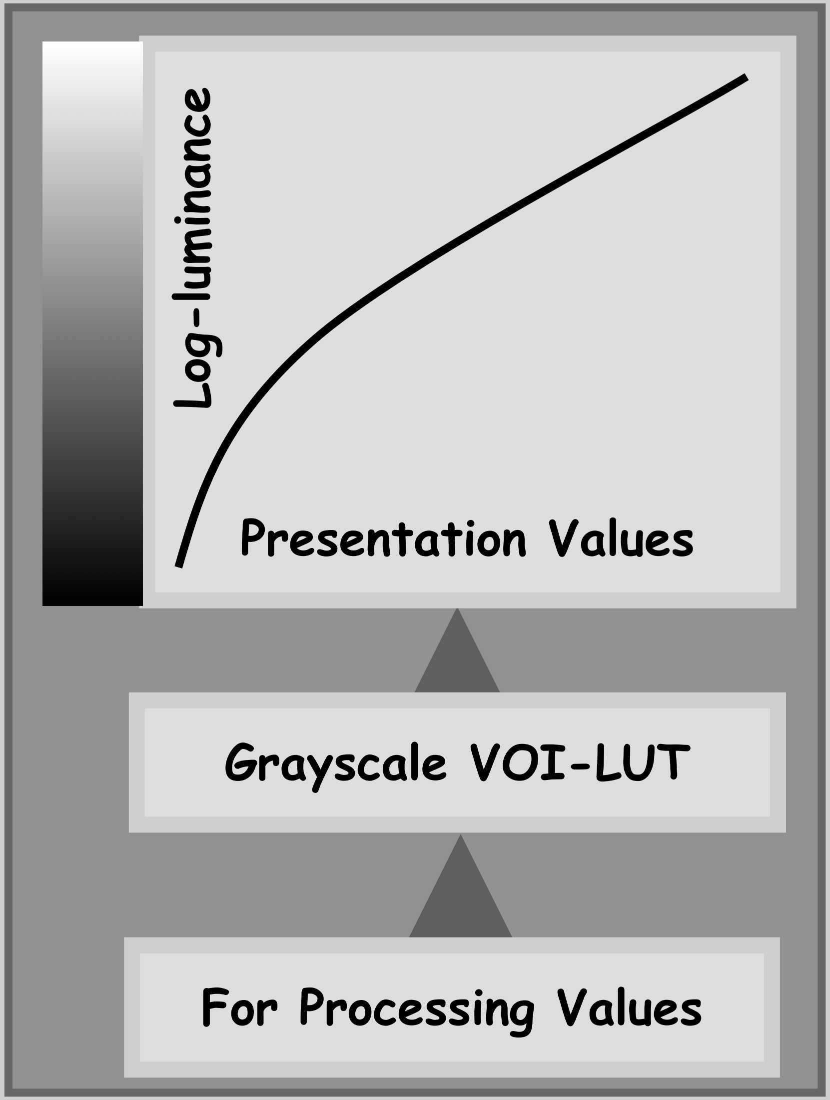
2A - Grayscale Rendition

Grayscale LUTs

'For Processing' data values are transformed to presentation values using a grayscale Look Up Table

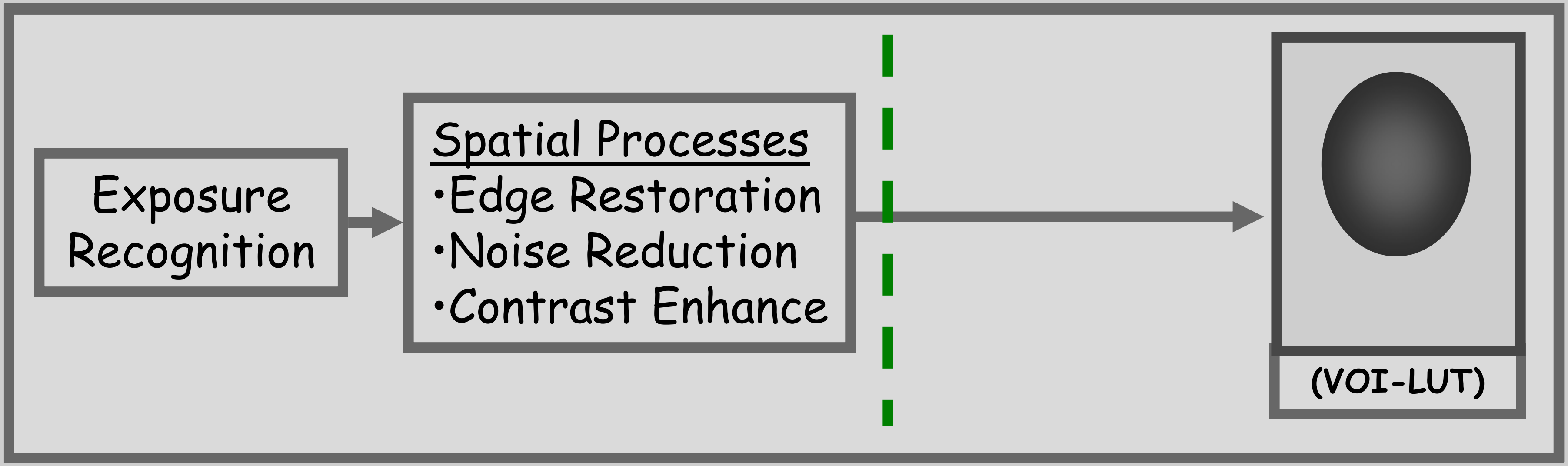






- ⇒ The Grayscale Value of Interest (VOI) Look up Table (LUT) transforms 'For Processing' values to 'For Presentation Values.
- ⇒ Monitors and printers are DICOM calibrated to display presentation values with equivalent contrast.
- ⇒ The VOI-LUT optimizes the display for radiographs of specific body parts.

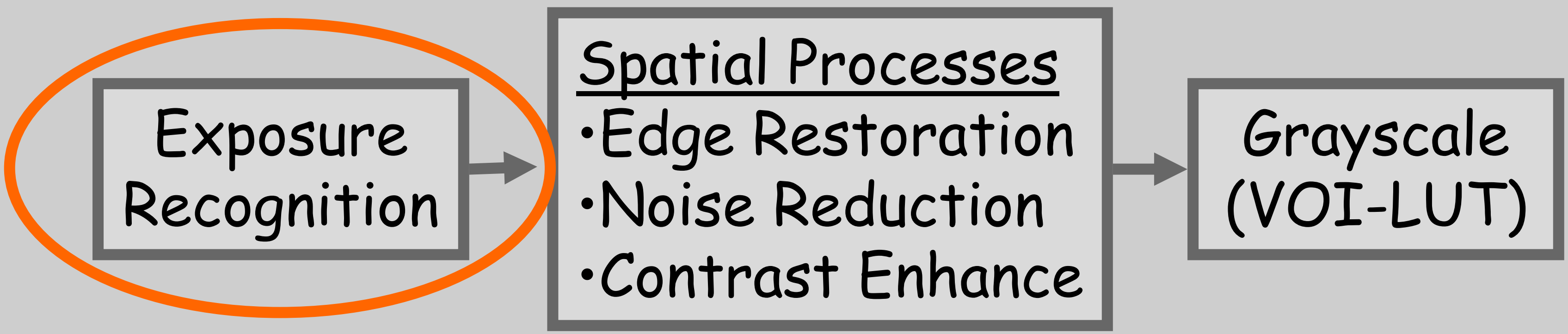
The VOI-LUT may be applied by the modality, or sent to an archive and applied by a viewing station



DICOM PS 3.3 2007, Pg 88

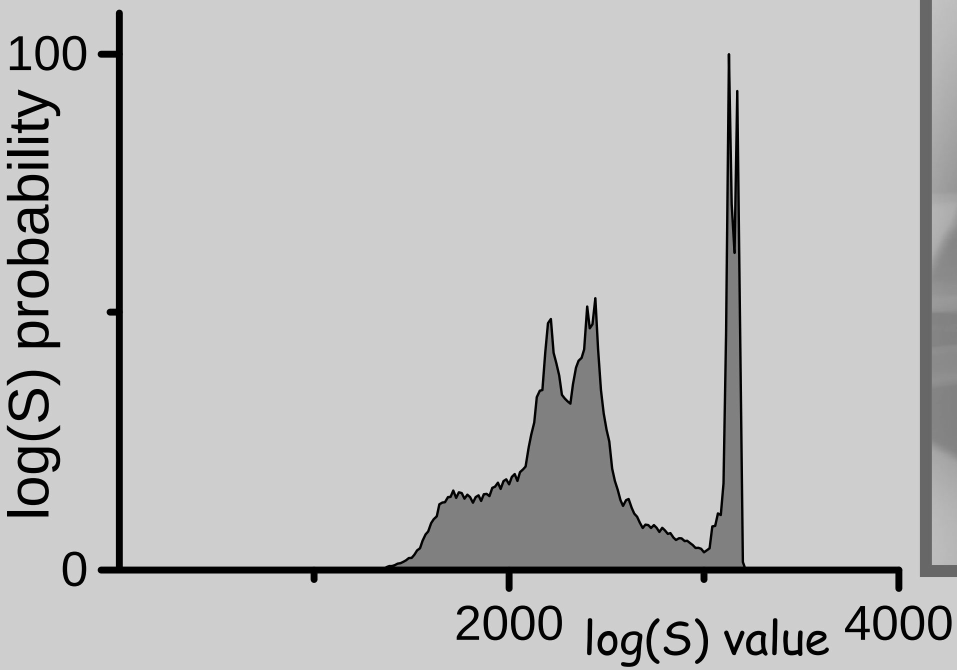
- When the transformation is linear, the VOI LUT is described by the Window Center (0028,1050) and Window Width (0028,1051).
- When the transformation is non-linear, the VOI LUT is described by VOI LUT Sequence (0028,3010).

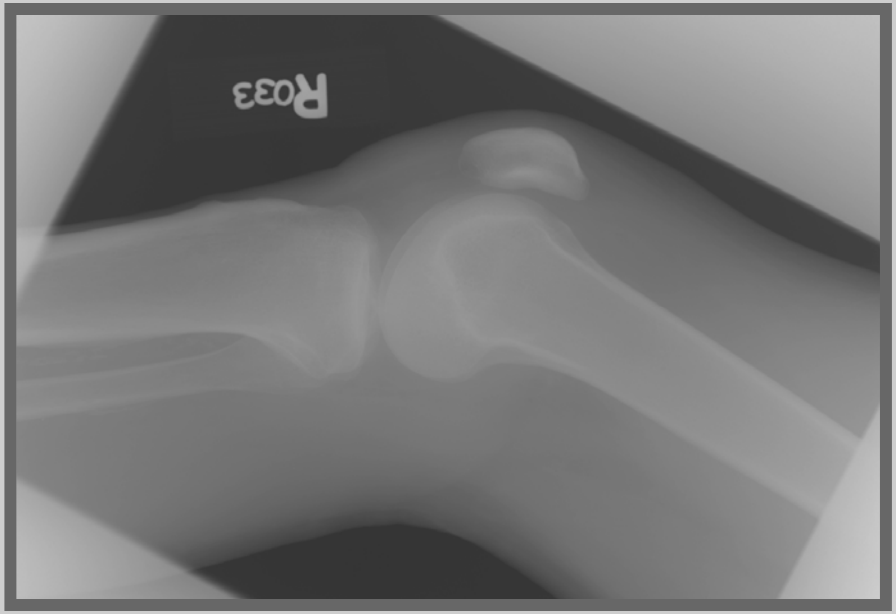
- ⇒ **Grayscale Rendition:** Convert signal values to display values
- ⇒ **Exposure Recognition:** Adjust for high/low average exposure.
- ⇒ **Edge Restoration:** Sharpen edges while limiting noise.
- ⇒ **Noise Reduction:** Reduce noise and maintain sharpness
- ⇒ **Contrast Enhancement:** Increase contrast for local detail



Signal Range:

A signal range of up to 10^4 can be recorded by digital radiography systems. Unusually high or low exposures can thus be recorded. However, display of the full range of data presents the information with very poor contrast. It is necessary to determine the values of interest for the acquired signal data.

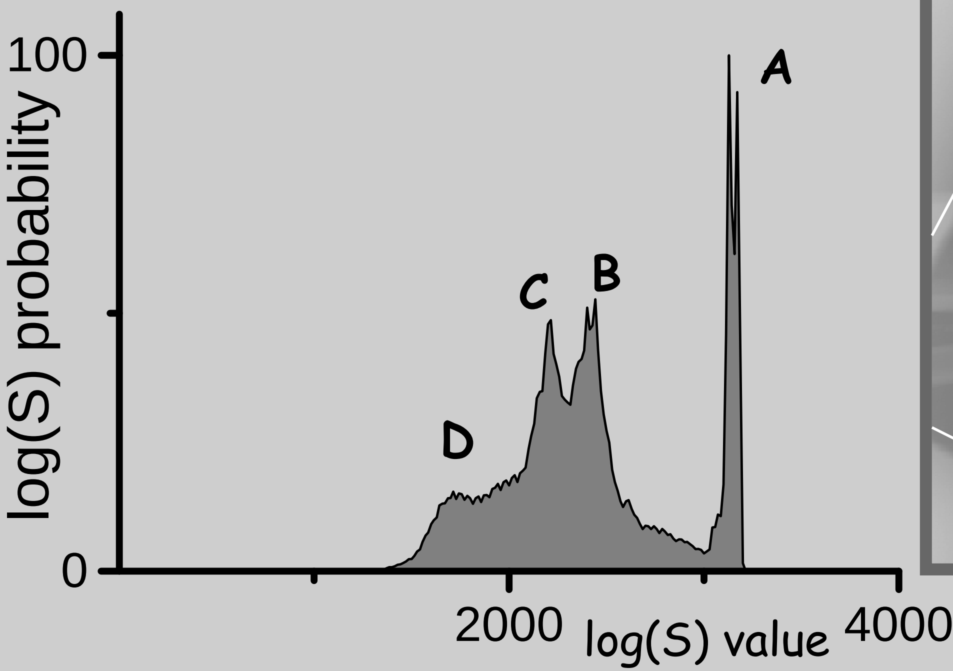


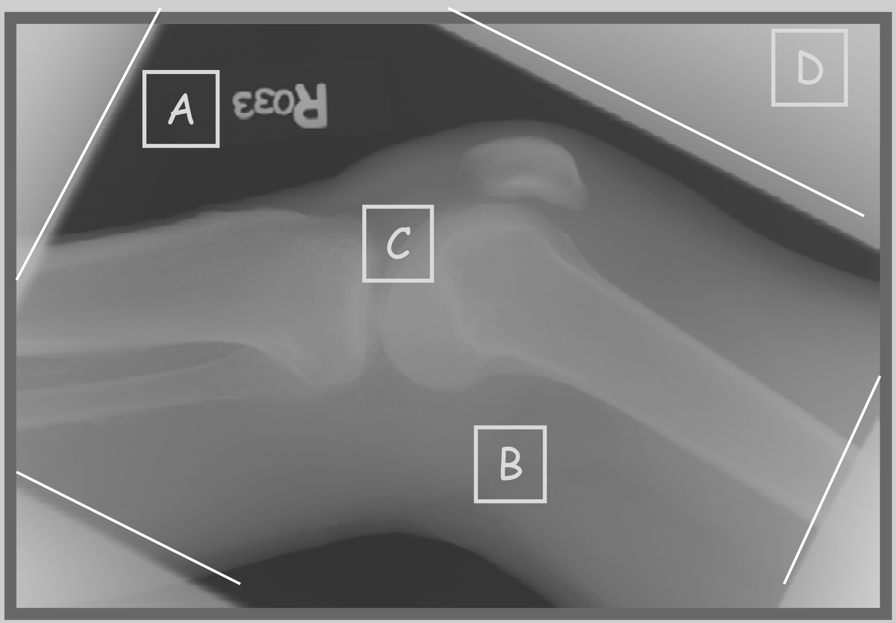


2B – Exposure recognition: regions

Exposure Recognition:

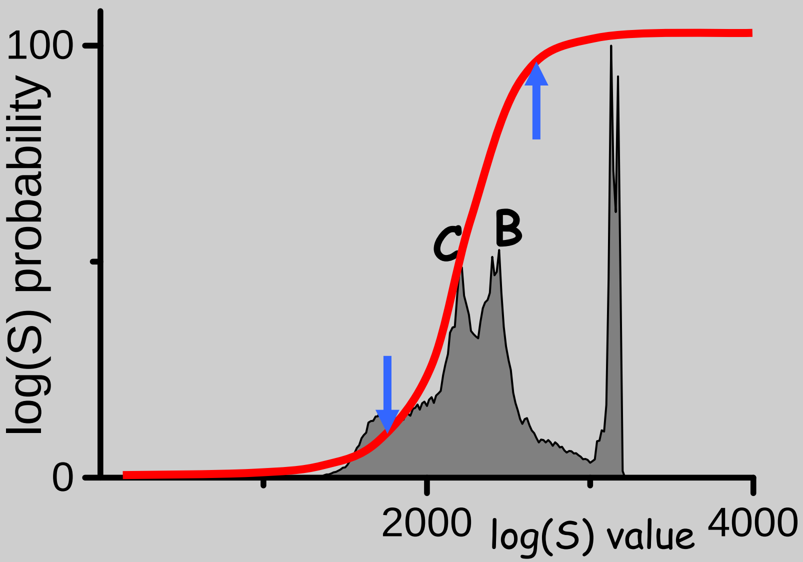
All digital radiographic systems have an exposure recognition process to determine the range and the average exposure to the detector in anatomic regions. A combination of edge detection, noise pattern analysis, and histogram analysis may be used to identify Values of Interest (VOI).





VOI LUT Level and Width:

- The values of interest obtained from exposure recognition processes are used to set the level and width of the VOI LUT.
- Areas outside of the collimated field may be masked to prevent bright light from adversely effecting visual adaptation.



- DR systems report a metric indicating the detector response to the incident radiation exposure.
- The methods used to deduce this metric are all different
  - The regions from which exposure is measured vary.
  - Reported exposures may increase proportional to the log of exposure or may vary inversely with exposure.
  - The scale of units varies widely with factor of 2 changes in exposure associated with changes varying from 0.15 to 300.

• Fuji:	$S = 200/E_{in}$	80 kVp, unfiltered
• Agfa:	$lgM = 2.22 + \log(E_{in}) + \log(S_n/200)$	75 kVp, 1.5 Cu (mm)
• Kodak:	$EI = 1000 \log(E_{in}) + 2000$	80 kVp, 0.5 Cu 1.0 Al

AAPM Task group 116 draft 8b

"Recommended Exposure Indicators for Digital Radiography"

Indicated Equivalent Air Kerma (K_{IND}) [IEC, Exposure Index]

- An indicator of the quantity of radiation that was incident on regions of the detector for each exposure made. …
- The regions .. may be defined in different ways ..
- The value should be reported in units of microgray ..

Relative Exposure (E_{REL}) -> Deviation Index [IEC]

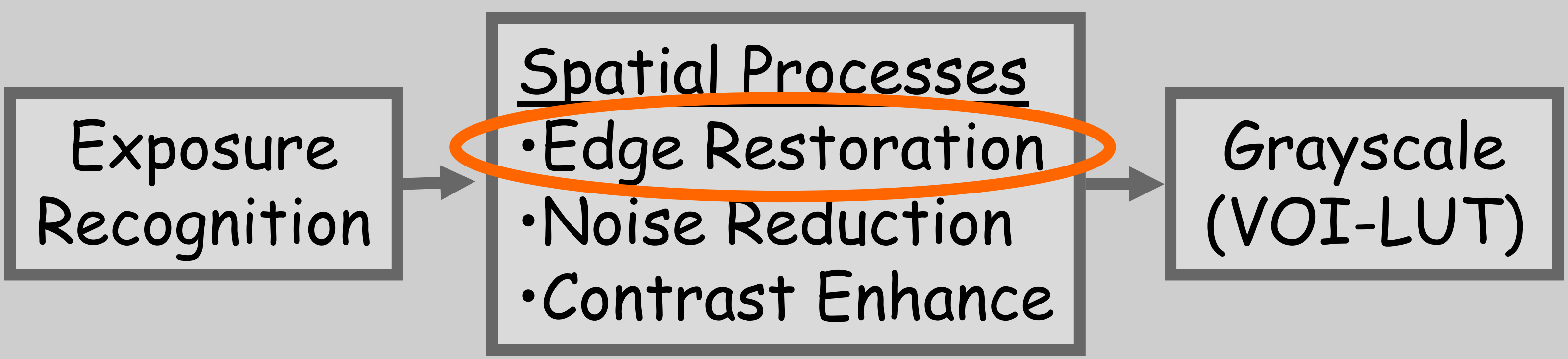
- An indicator as to whether the detector response for a specific image, K_{IND}, agrees with K_{TAR}(b.v).
- Relative exposures are to be reported as

$$E_{REL} = \log_{10}(K_{IND}/K_{TAR}(b,v))$$

- E_{REL} is intended as an indicator for radiographers and radiologists as to whether the technique used to acquire a radiograph was correct.

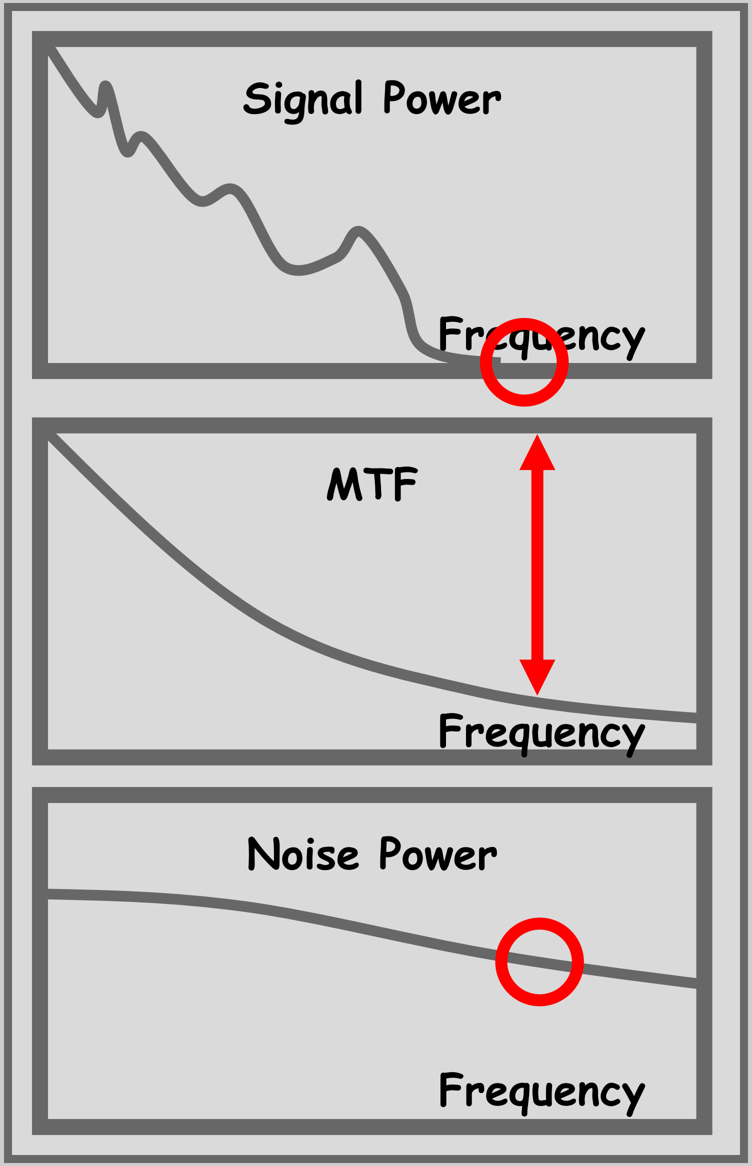
2C – Edge Restoration

- ⇒ Grayscale Rendition: Convert signal values to display values
- ⇒ Exposure Recognition: Adjust for high/low average exposure.
- ⇒ **Edge Restoration: Sharpen edges while limiting noise.**
- ⇒ Noise Reduction: Reduce noise and maintain sharpness
- ⇒ Contrast Enhancement: Increase contrast for local detail

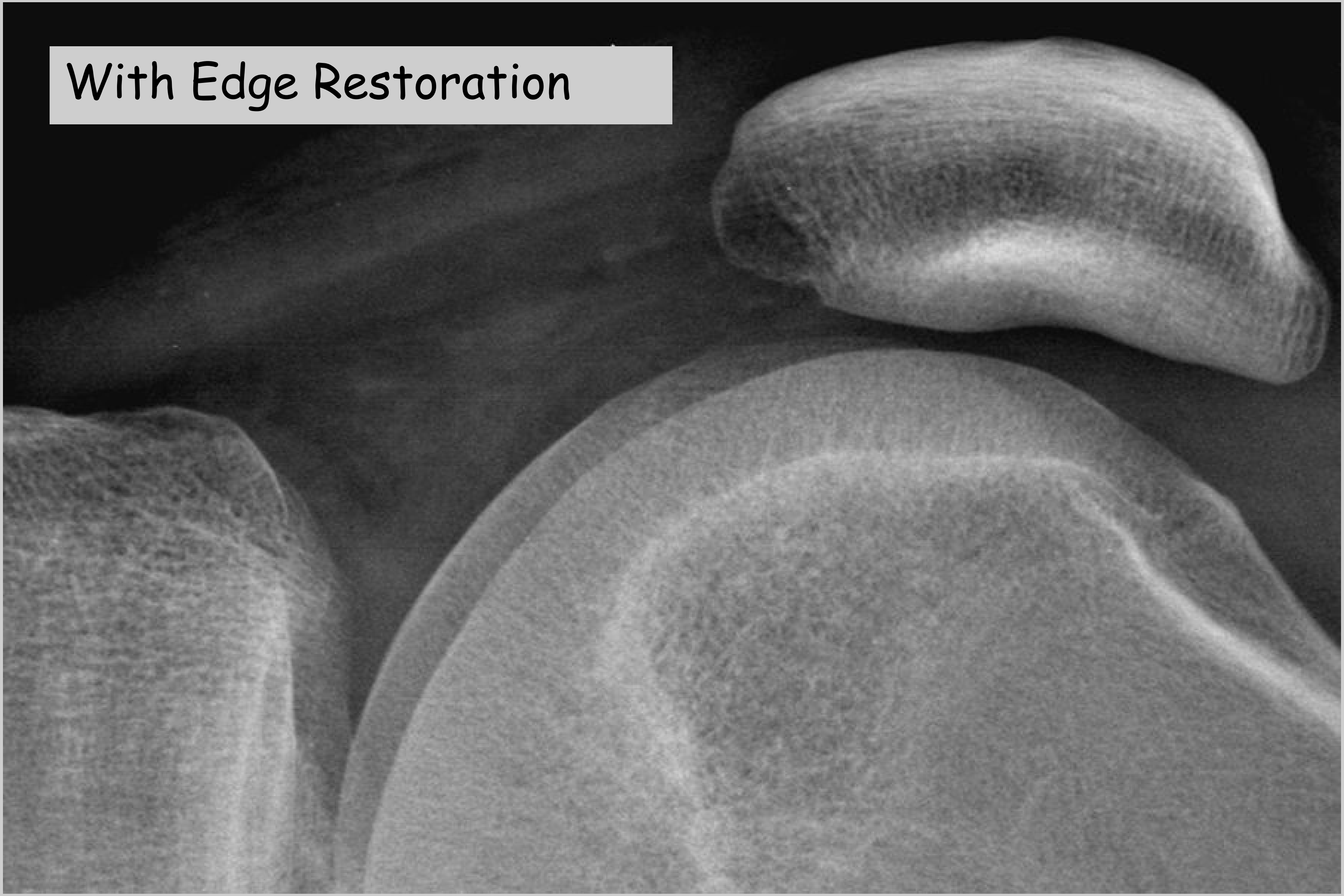


2C – Edge Restoration

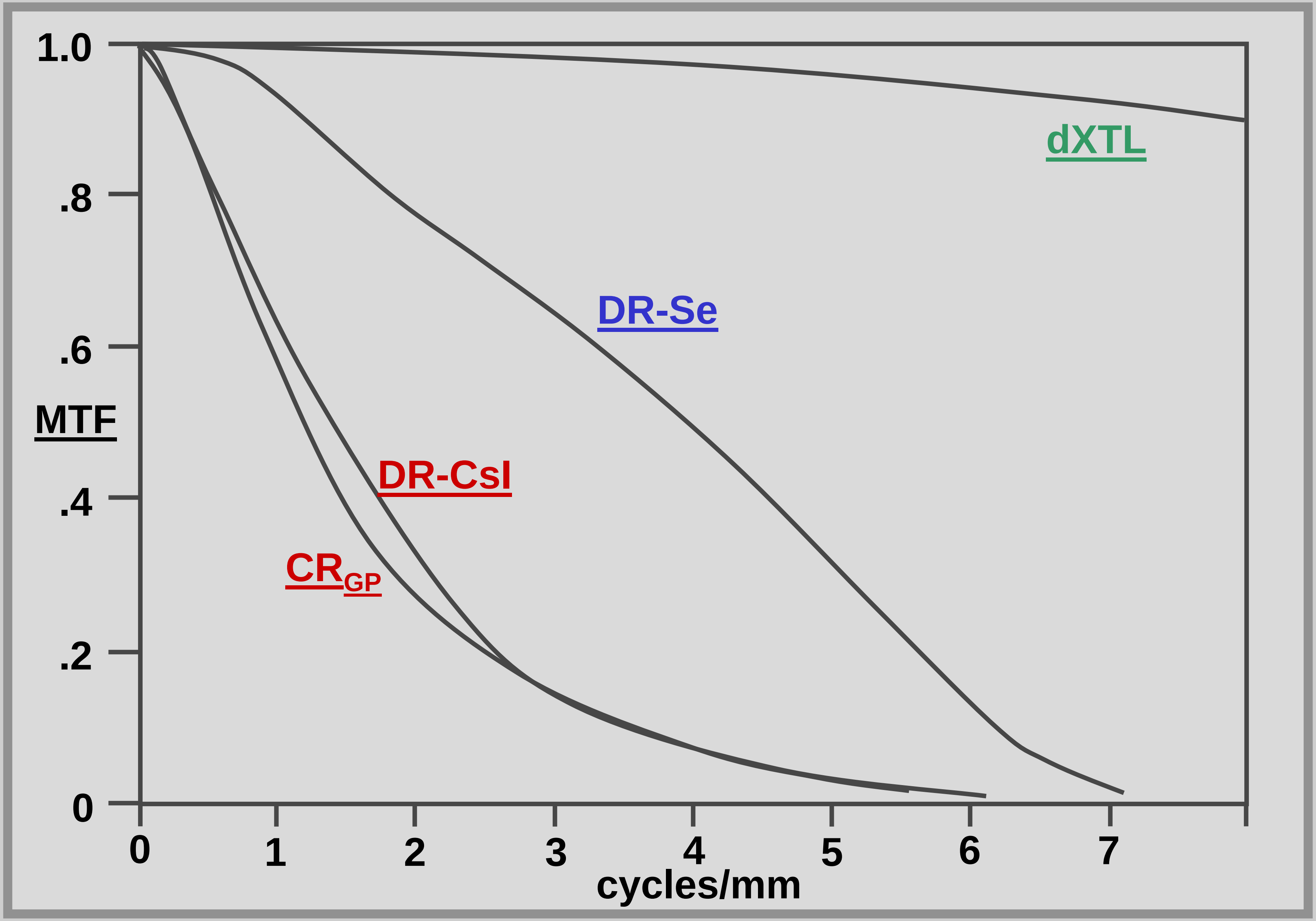
- Radiographs with high contrast details input high spatial frequencies to the detector.
- For many systems the detector will blur this detail as indicated by the MTF.
- Enhancing these frequencies can help restore image detail.
- However, at sufficiently high frequencies there is little signal left and the quantum mottle (noise) is amplified.
- The frequency where noise exceeds signal is different for different body parts/views



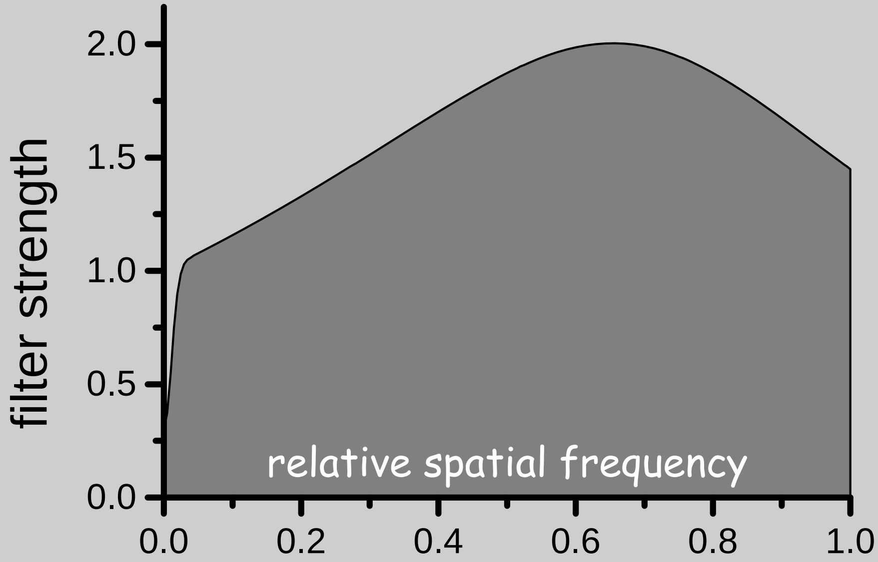
2C – With / Without



2C – MTF – CR, DR, and XTL



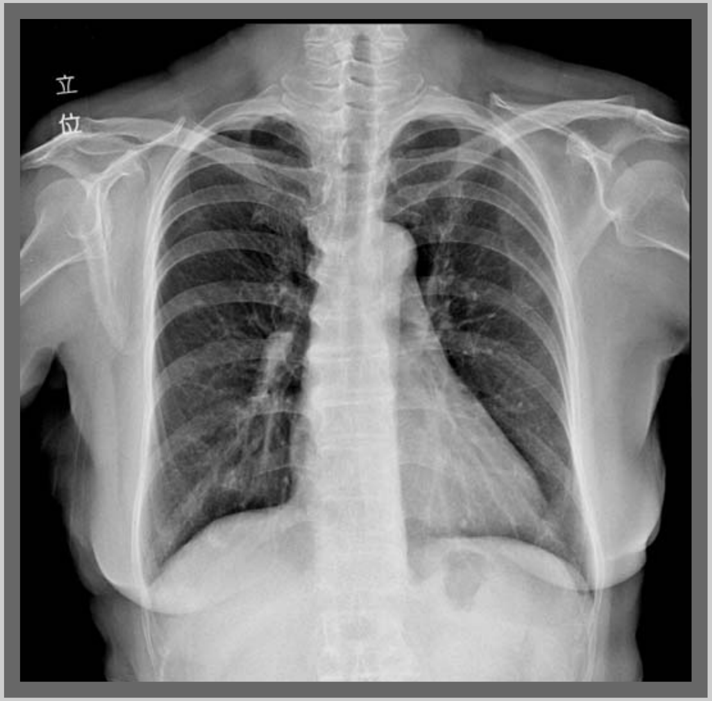
2C – Skeletal Edge Restoration

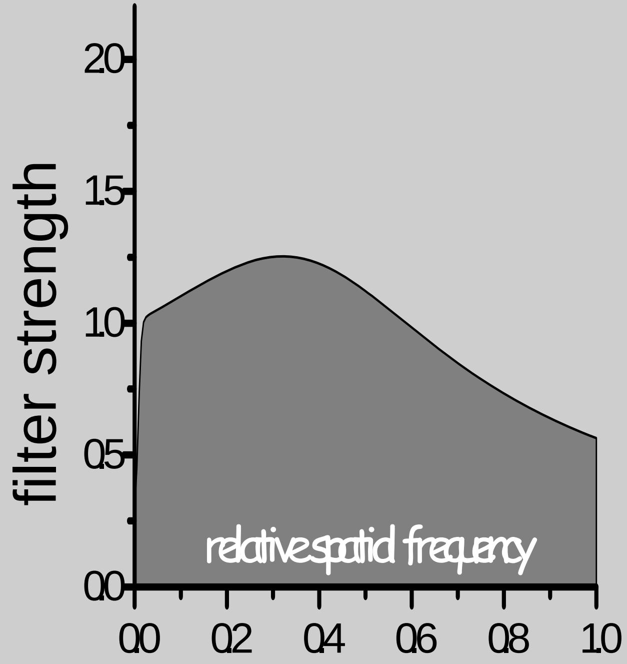


Skeletal Processing

- **Edge restoration** may be extended to high frequencies particularly if high resolution screen are used. Noise is generally not problematic for extremity views.
- **Restoration versus enhancement:** 1/MTF edge processing as shown restores object detail to that which would be recorded with a perfect detector. The term restoration is recommended rather than enhancement.

2C – Chest Edge Restoration



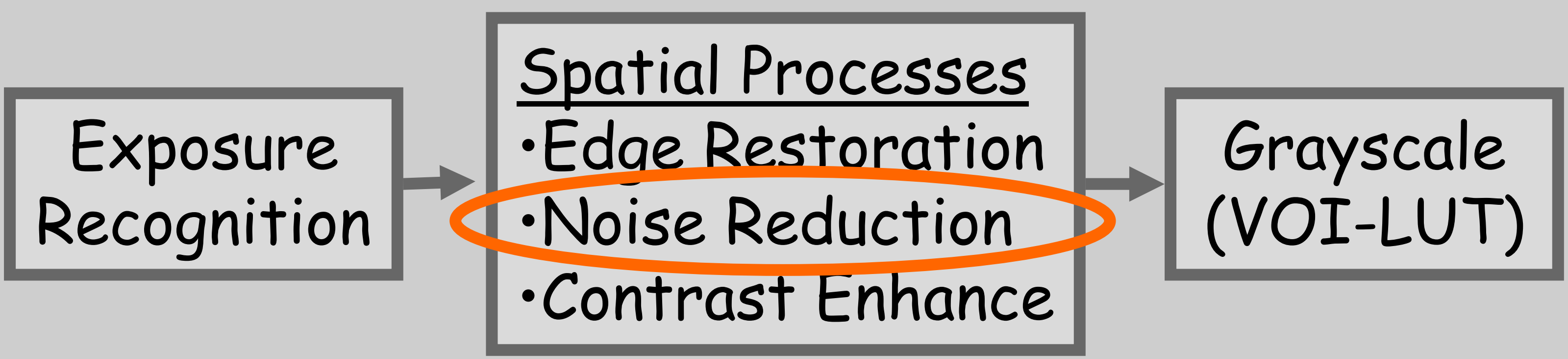


Chest Processing

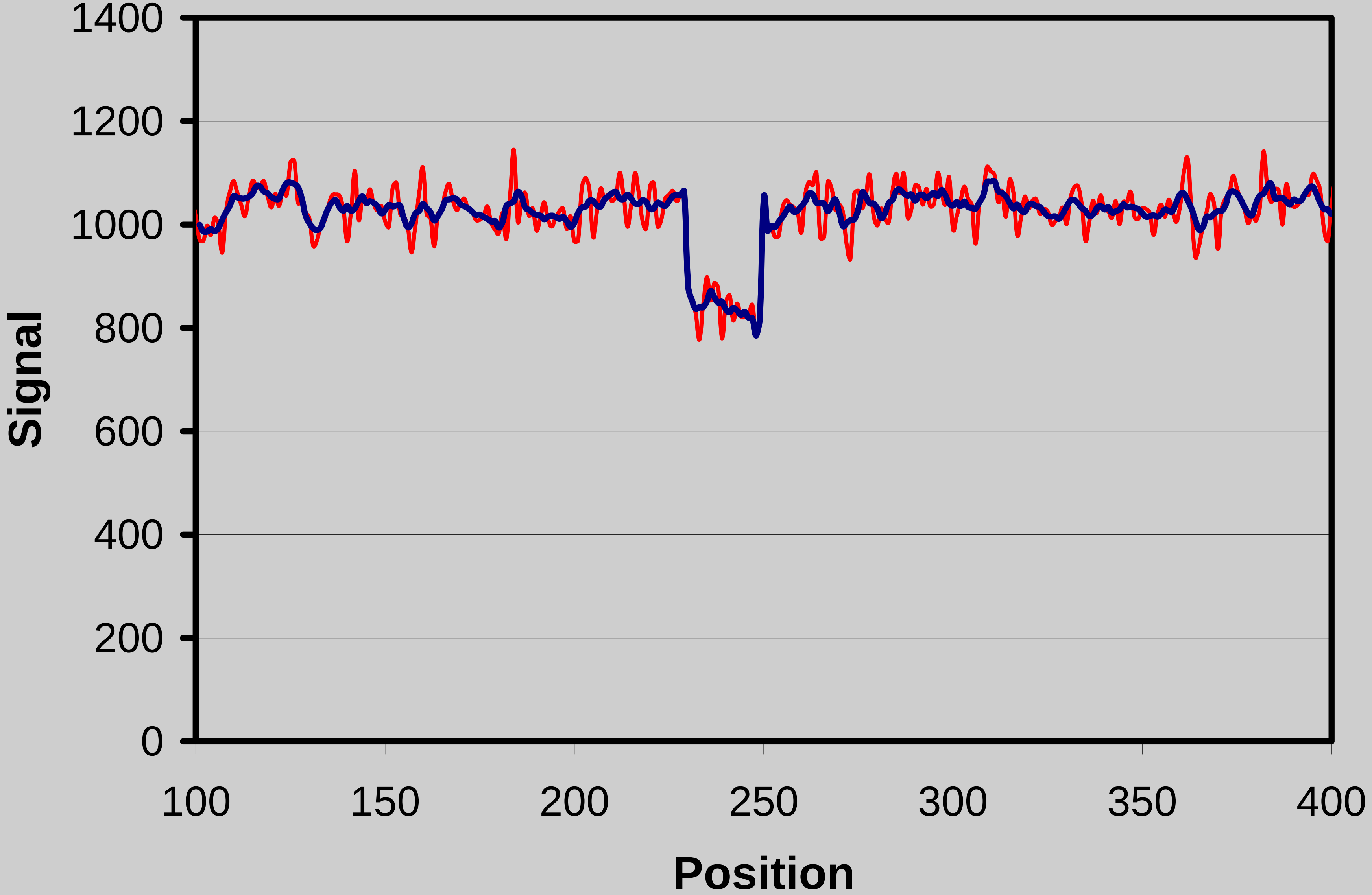
- **Edge restoration:** lung tissue typically produces low frequency signals and the chest radiograph has high quantum noise. Thus, very modest edge restoration should be used.
- **Quantum mottle in the abdomen:** Low exposure and thick tissue result in significant quantum mottle below the diaphragm. Inverse MTF filters need to be damped at high frequency to prevent excessive noise (Metz filter).

2D – Noise Reduction

- ⇒ <u>Grayscale Rendition:</u> Convert signal values to display values
- ⇒ <u>Exposure Recognition:</u> Adjust for high/low average exposure.
- ⇒ <u>Edge Restoration:</u> Sharpen edges while limiting noise.
- ⇒ **<u>Noise Reduction:</u>** **Reduce noise and maintain sharpness**
- ⇒ <u>Contrast Enhancement:</u> Increase contrast for local detail



Comparison with and without adaptive noise reduction

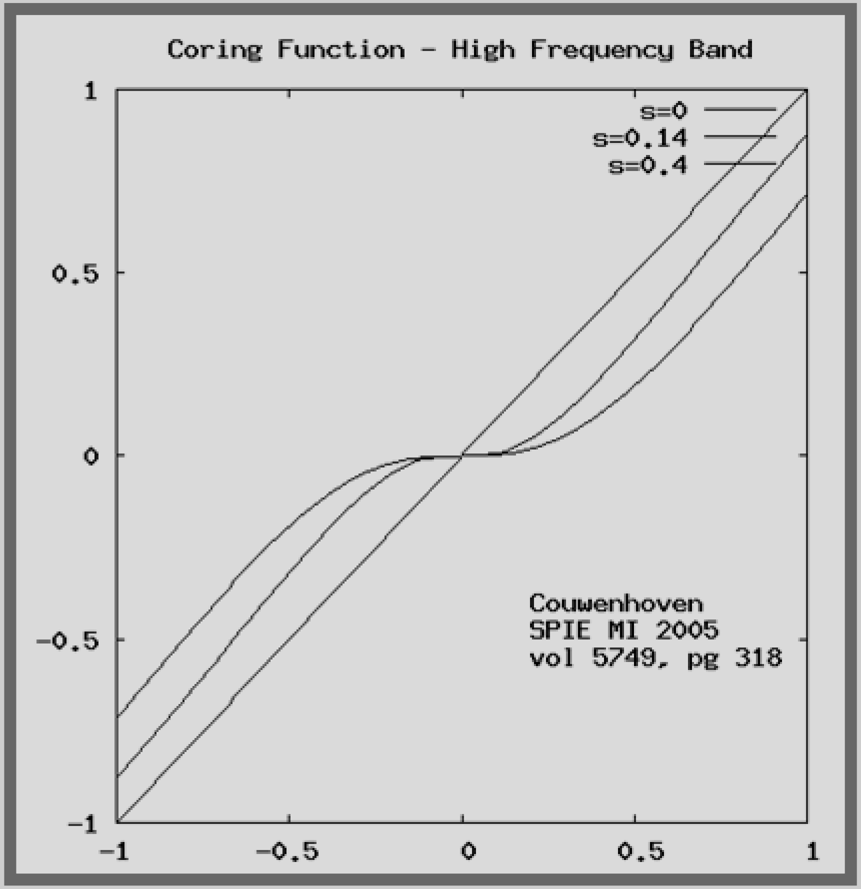


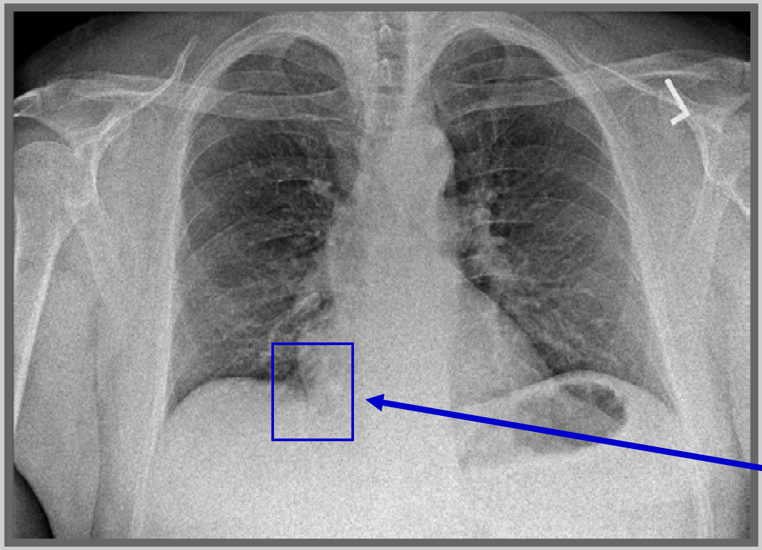
Couwenhoven, 2005, SPIE MI vol 5749, pg318

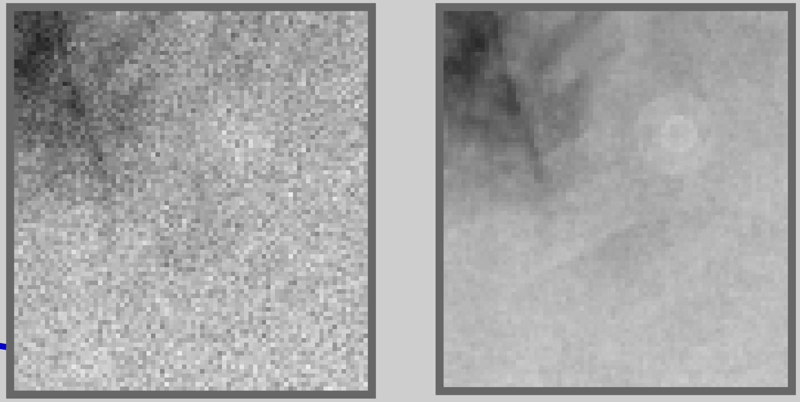
- High frequency sub-band
- Coring function

$$P = P/(1+s/P^2)$$

- Adaptation
  - Signal amplitude
  - Signal to noise

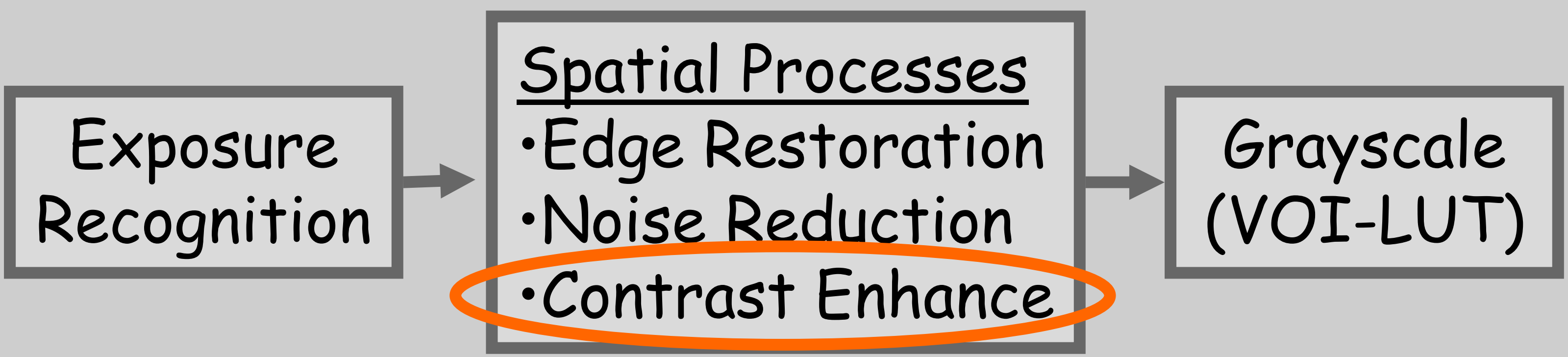






2E – Constrast Enhancement

- ⇒ Grayscale Rendition: Convert signal values to display values
- ⇒ Exposure Recognition: Adjust for high/low average exposure.
- ⇒ Edge Restoration: Sharpen edges while limiting noise.
- ⇒ Noise Reduction: Reduce noise and maintain sharpness
- ⇒ **Contrast Enhancement:** Increase contrast for local detail

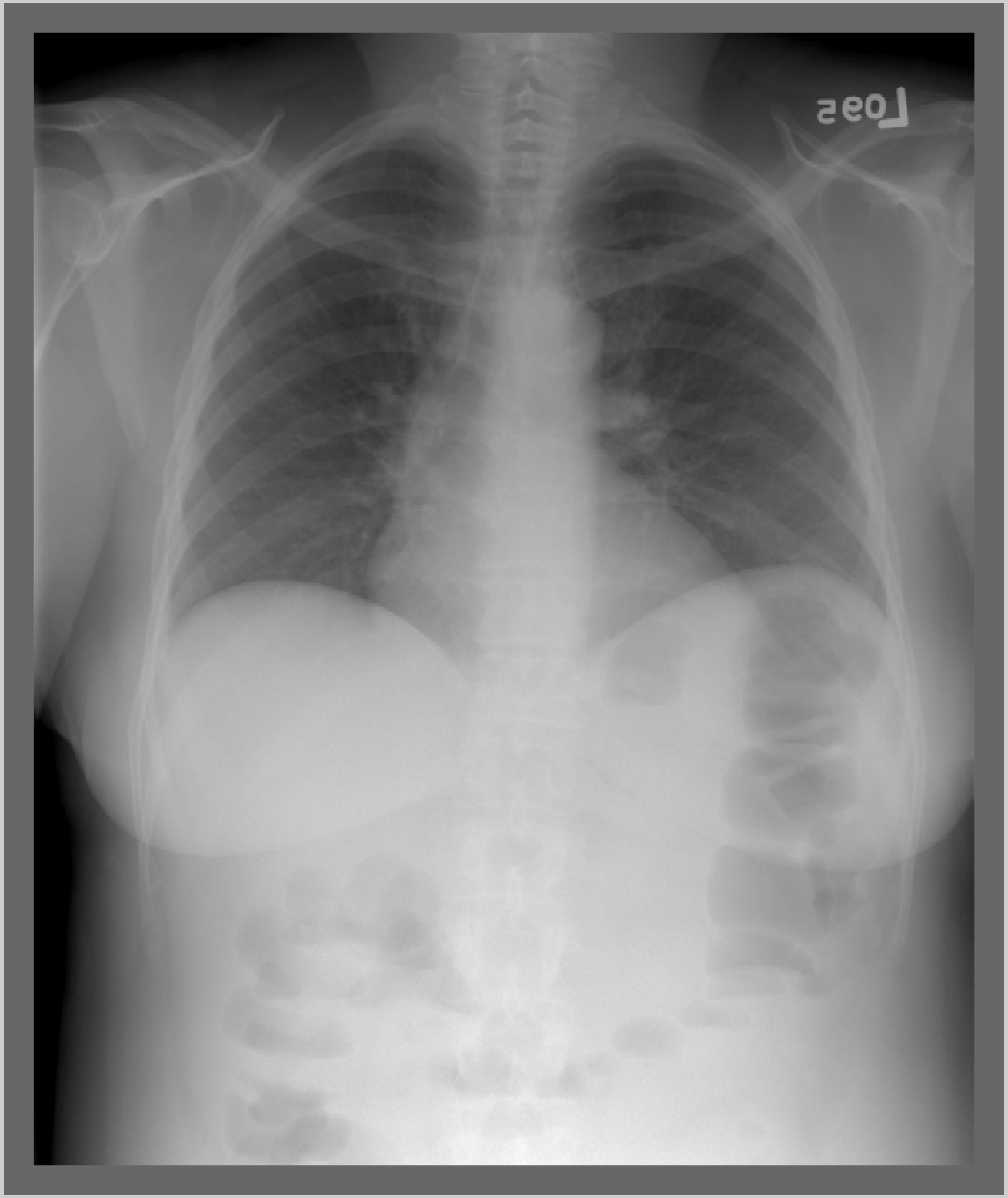


2E – Contrast Enhancement

- A wide range of log(S) values is difficult to display in one view.
- Lung detail is shown here with low contrast.

Contrast Enhancement:

Enhancement of local detail with preservation of global latitude.



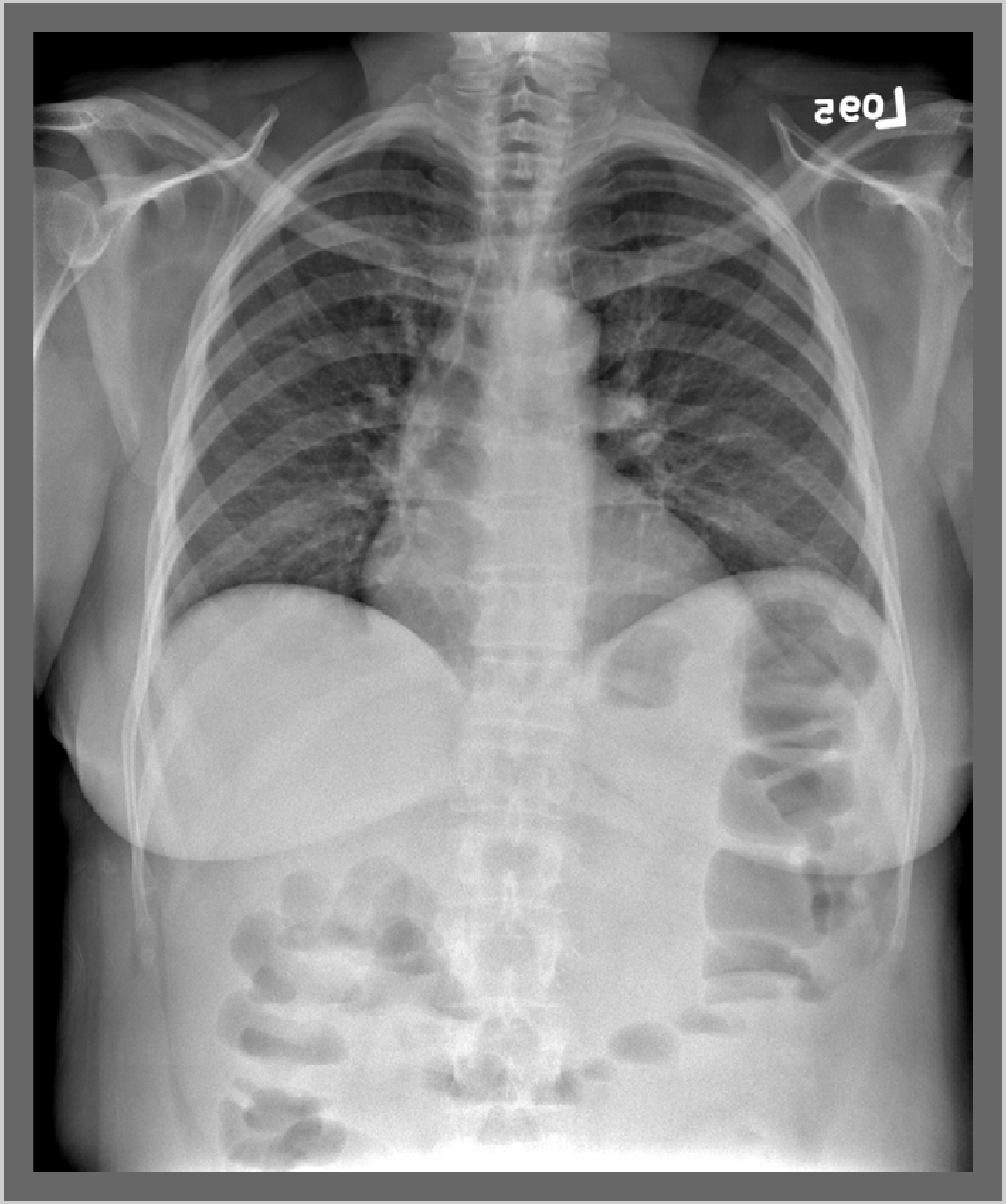
2E – Unsharp Mask

- A highly blurred image can be used to adjust image values.
- The Unsharp Mask can be obtained by large kernel convolution or low pass filter.
- Note that the grayscale has been reversed.

2E – Detail enhancement

The difference between the image and the unsharp mask contains detail.

This is added to the image to enhance detail contrast



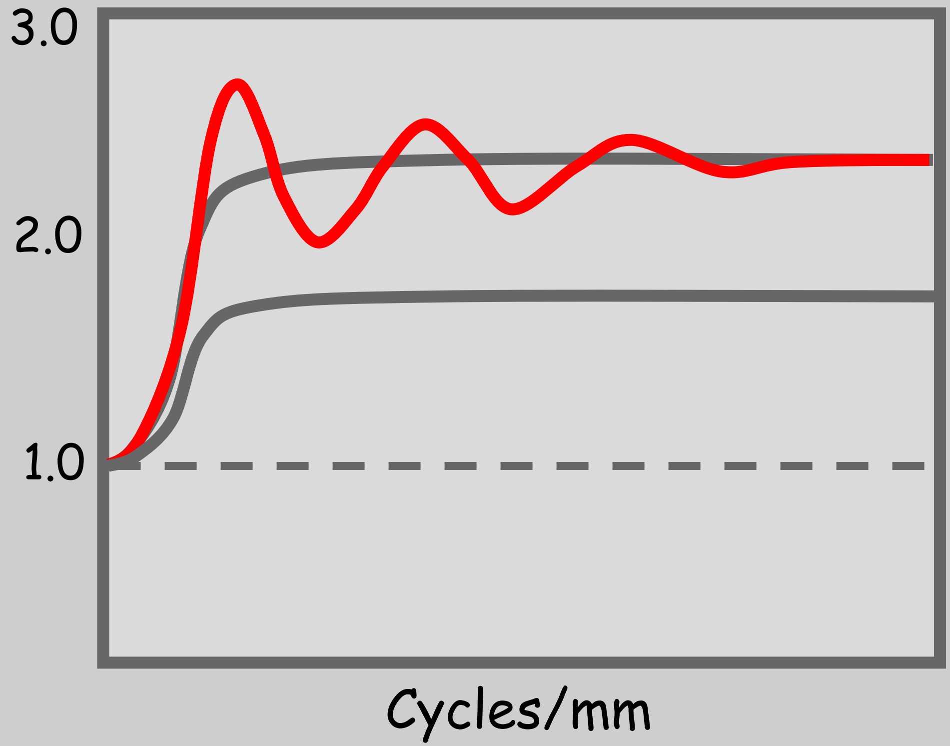
The contrast enhanced image has improved lung contrast and good presentation of structures in the mediastinum.

2E – Selecting contrast enhancement

In practice, the amount of contrast enhancement can be selected by first defining a grayscale rendition that achieves the desired latitude, and then applying a filter that enhances detail contrast.

The enhancement gain is adjusted to amplifying the contrast of local detailed tissue structures.

Methods using large kernel of equal weight have poor frequency response characteristics.

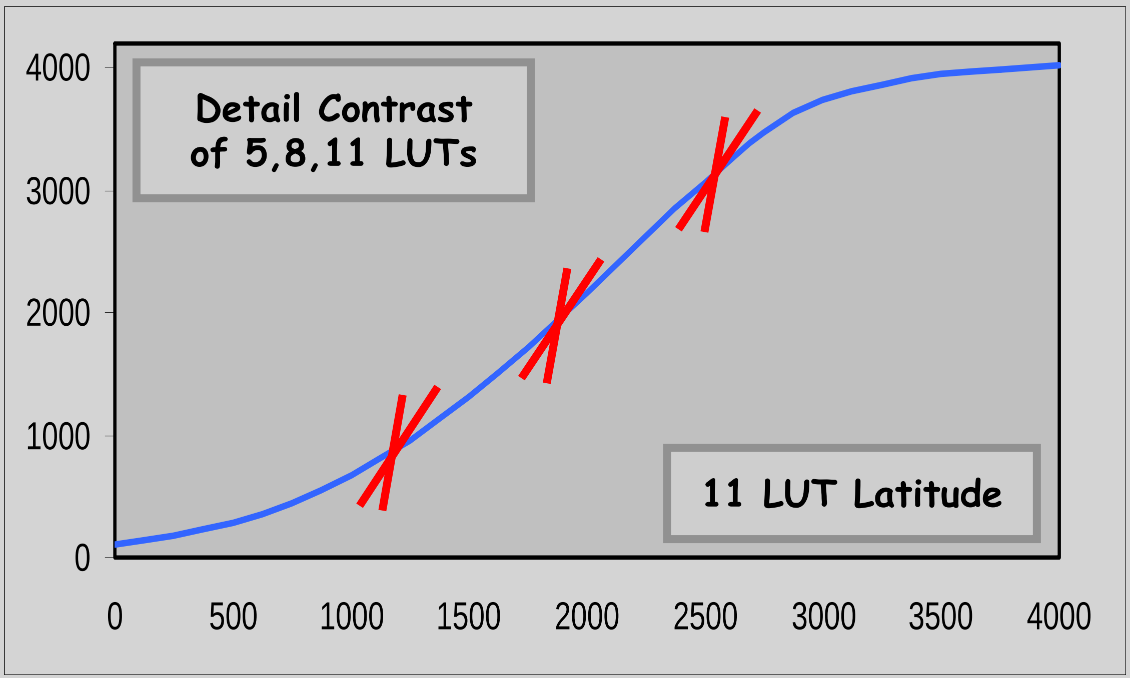


2E – Detail Contrast, Latitude, and Gain

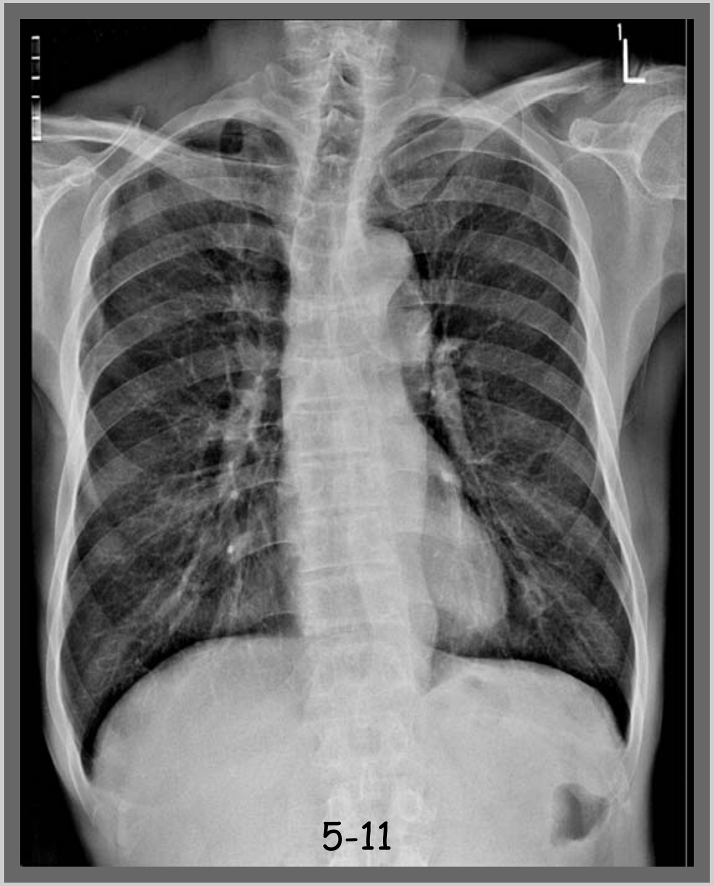
For a specific grayscale rendition,

detail contrast can be progressively enhanced.

- Latitude – the range of the unenhanced LUT.
- Detailed Contrast – the effective slope of the enhanced detail at each gray level.
- Gain – the increase in LUT local slope.



Extended Visualization Processing (EVP, Kodak).

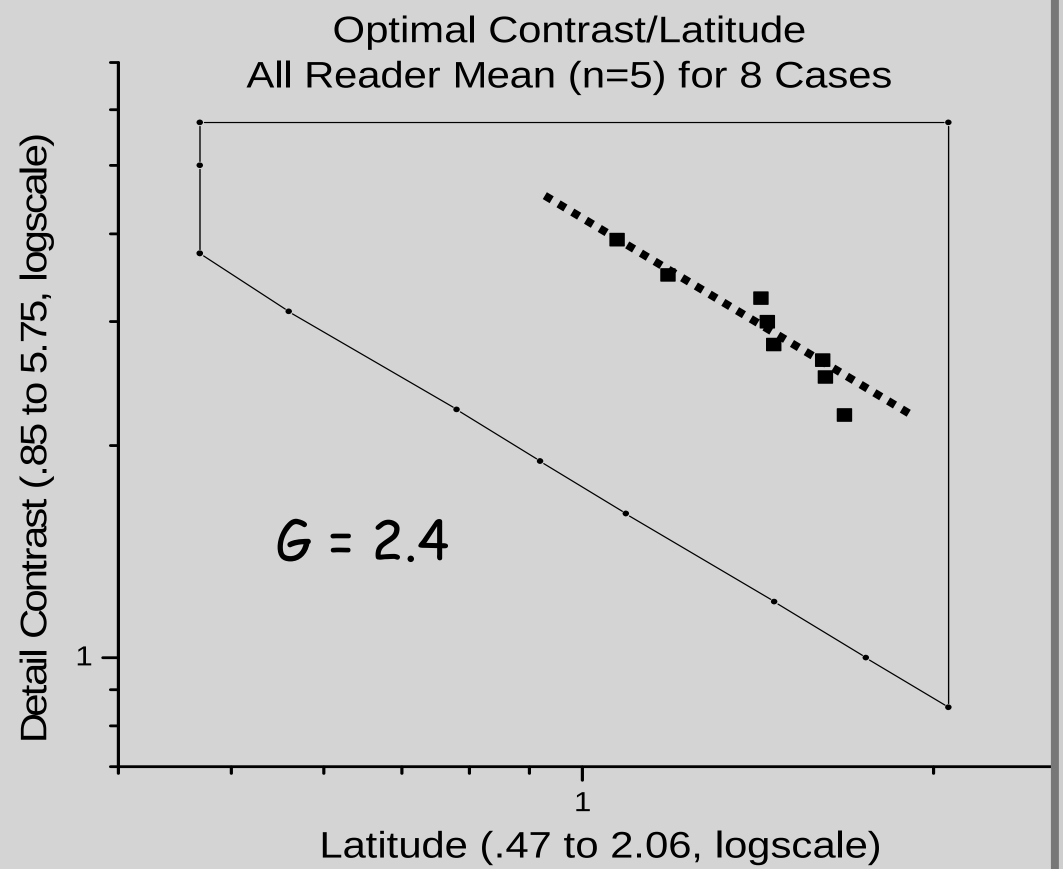


Gain = 2.6

2E – Optimal PA chest gain

5 thoracic radiologists at 3 medical centers preferred a gain of 2.4 for the interpretation of PA chest radiographs of any latitude.

SPIE 4319, 2001



8 PA chest Radiographs

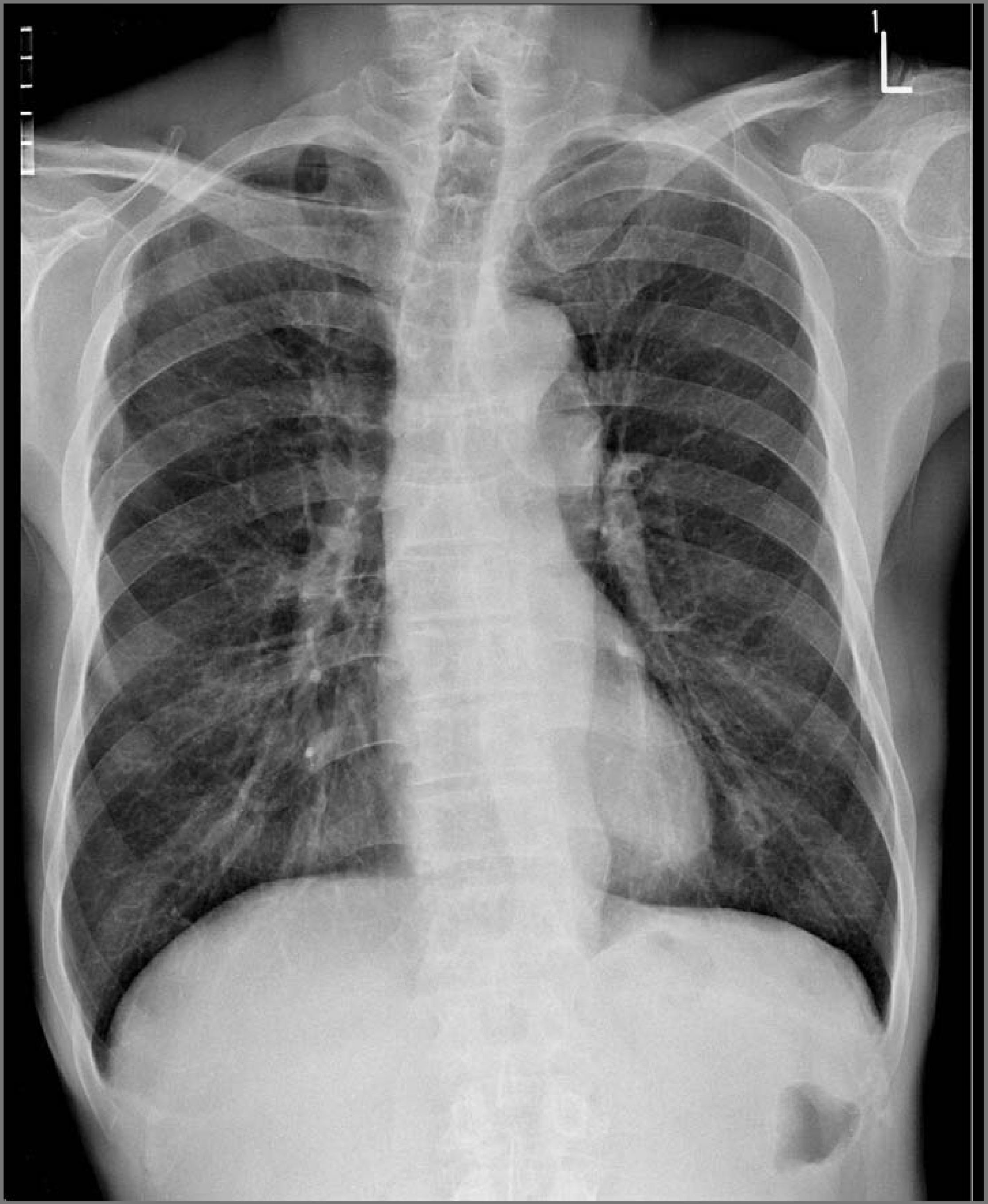
- 52 display processing conditions for each radiograph.
  - EVP gain varied from 1.0 to 6.8.
  - Detail contrast set to 8 values (rows).
  - Latitude set to 10 values (columns).

2E – chest, wide latitude

T1-c

- Lat = 1.68
- Con = 2.21
- G = 2.4

2E – chest, low latitude



T3-c

- Lat = 1.44
- Con = 3.00
- G = 2.4

1. Preprocessing
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The performance of the **human visual system** (HVS) can be used to derive display specifications for the primary interpretation of radiographic images.

Viewing Distance

Display Size

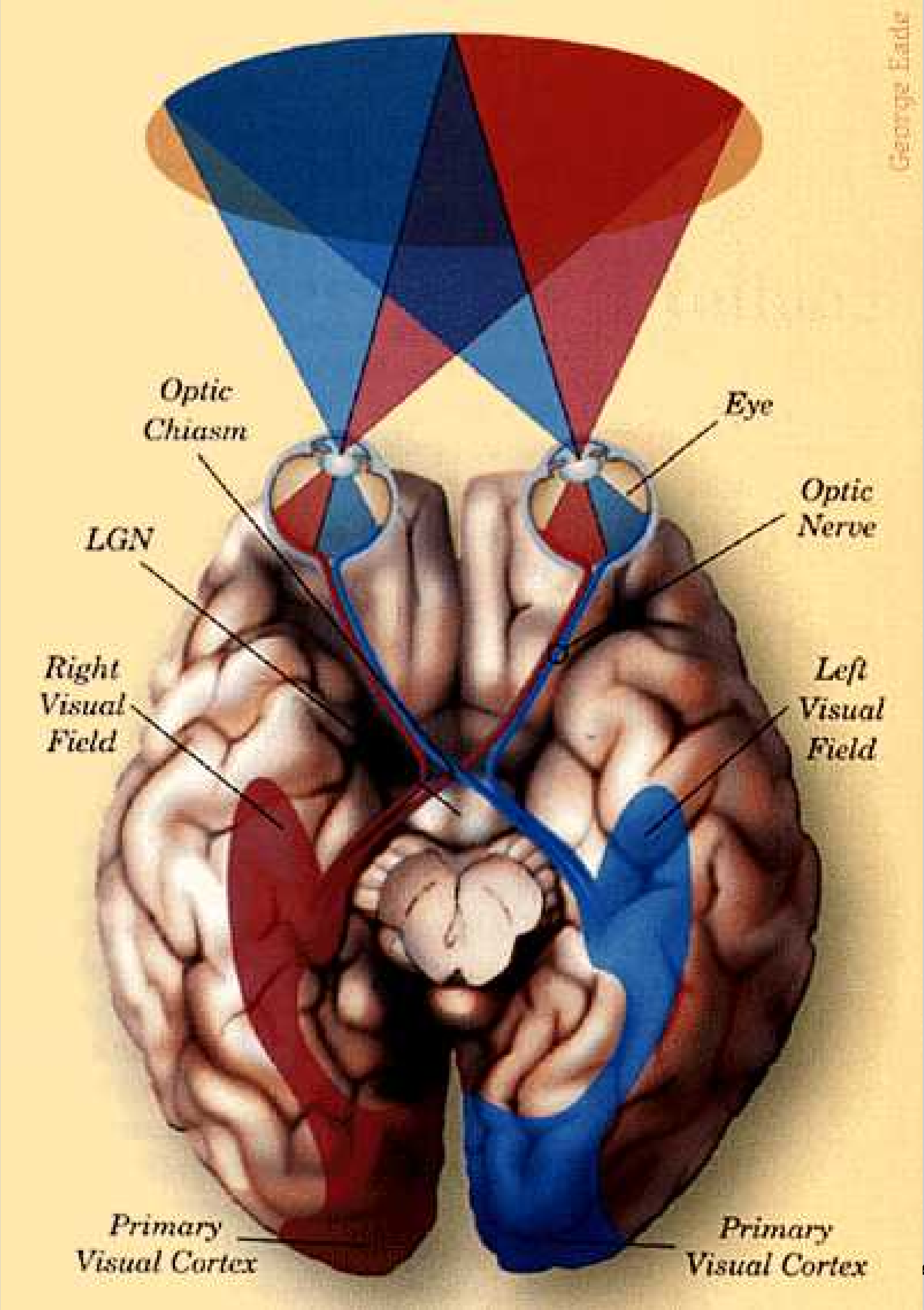
Pixel Size

Equivalent Contrast

Viewing Distance?

- Vergence
- Accomodation

- Vergence (convergence) allows both eyes to focus the object at the same place on the retina.
- The closer the object, the more the extraocular muscles converge the eyes inward towards the nose.



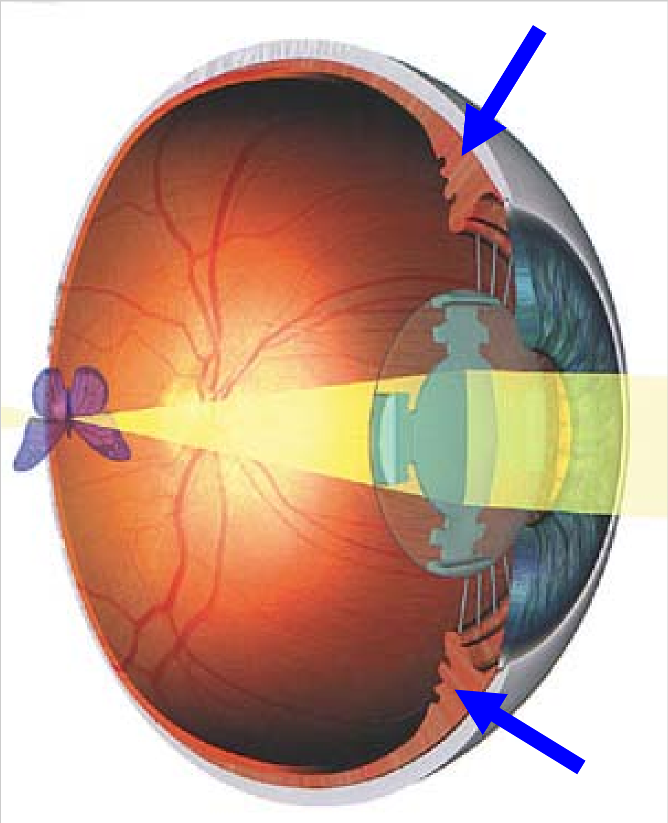
Resting Point of Vergence

- The eyes have a resting point of vergence of about 40 inches.(Jaschcinsk-Kruza 1991).
  - Objects closer than the resting point cause muscle strain.
  - The closer the distance, the greater the strain (Collins 1975).
- Every one of the subjects studied by Jaschinski-Kruza (1998) judged the eye to screen distance of 20 inches to be too close. All accepted a 40 inch distance.
- Grandjean (1983) reported an average preferred viewing distance of 30 inches.

→Arms length viewing distance

Resting Point of Accommodation

- The ciliary muscle changes the shape of the lens to focus the object.
  - The eyes have a resting point of accommodation which is the distance that the eye focuses to when there is nothing to look at (Owens 1984).
  - This resting point averages about 31 inches (Krueger 1984).

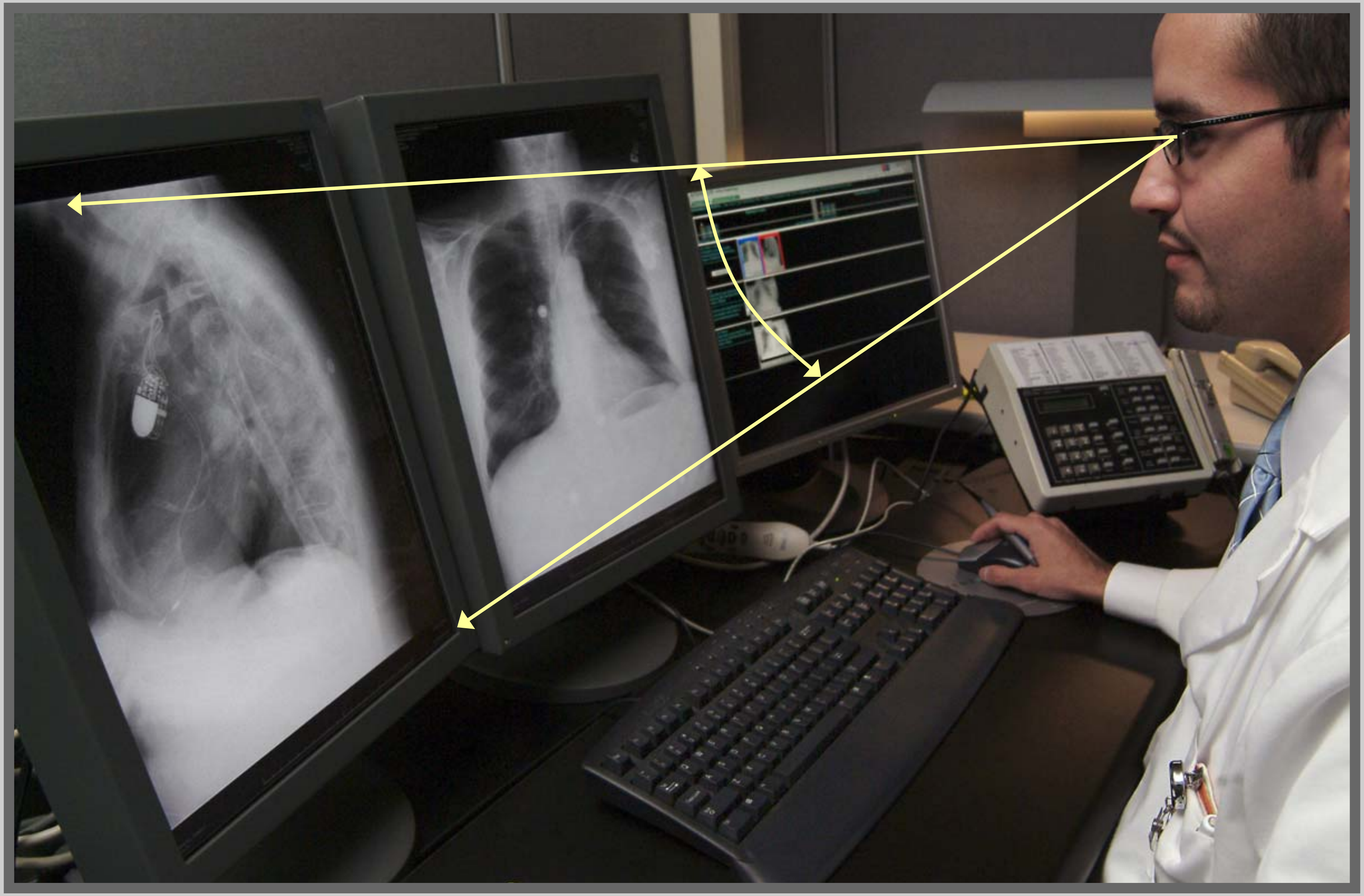


- Prolonged viewing of a monitor closer than the resting point of accommodation increases eye strain (Jaschinski-Kruza 1988). The ciliary muscle must work 2.5 times harder to focus on a monitor 12 inches away than it does to focus at 30 inches.

→Arms length viewing distance

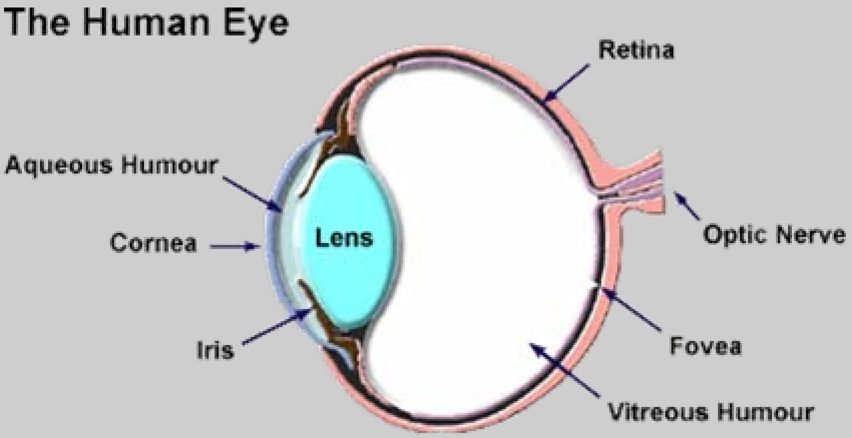
Display Size?

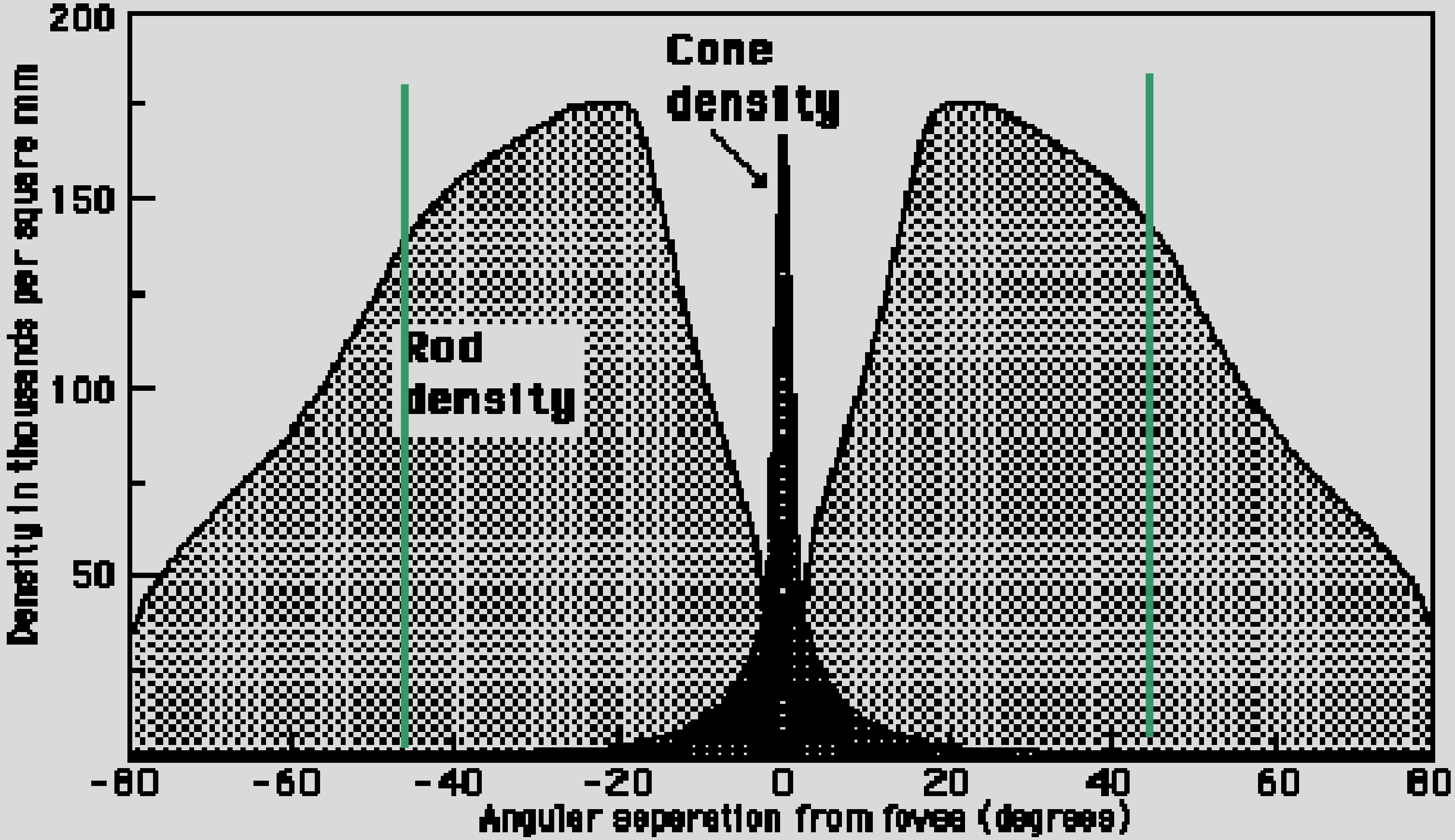
Field of view in relation to viewing distance.



HVS: peripheral response

The retina contains a large number of rod receptors (160 M) distributed over the peripheral field.



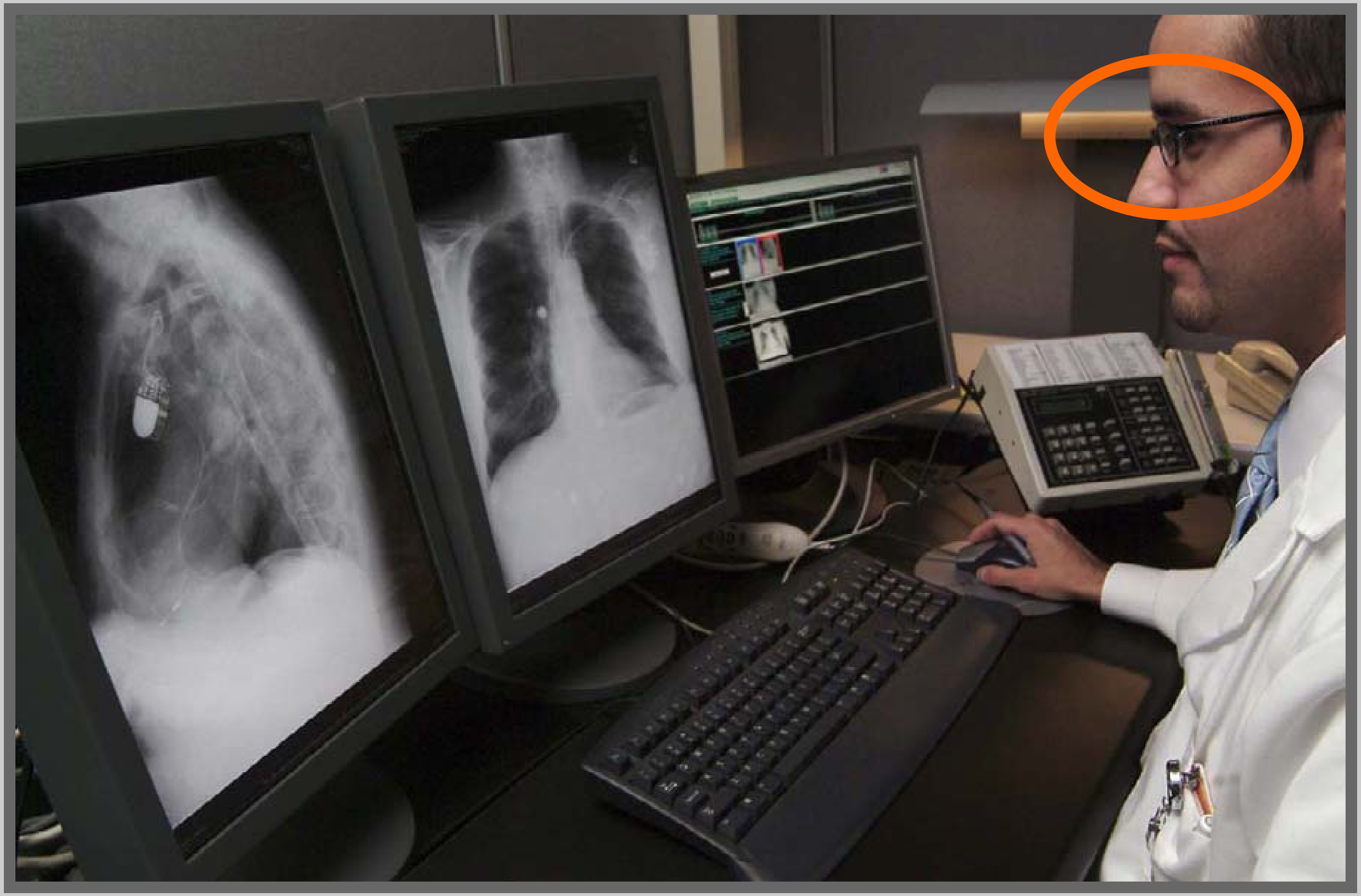


For a specific viewing distance the diagonal dimension should be about 80% of the viewing distance. (44^o)

Task	Viewing Distance	Diagonal Size
Close Inspection	1/3 meter	10.4 inches
Normal viewing	2/3 meter	20.8 inches
Consultation viewing	1 meter	31.5 inches
Teaching Conference	3 meters	110.1 inches

Field of View

21 inch (diagonal) monitors with a field of 32 x 42 cm provide an effective field for radiographic images viewed at a normal distance (2/3 m).

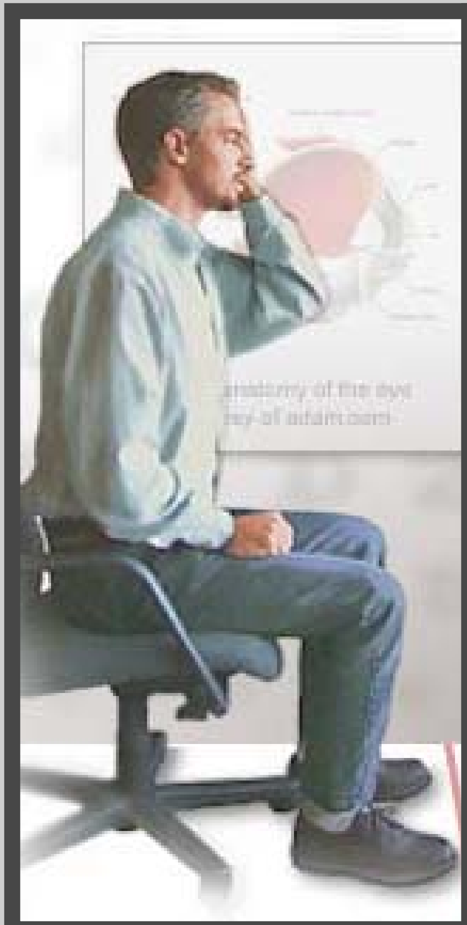


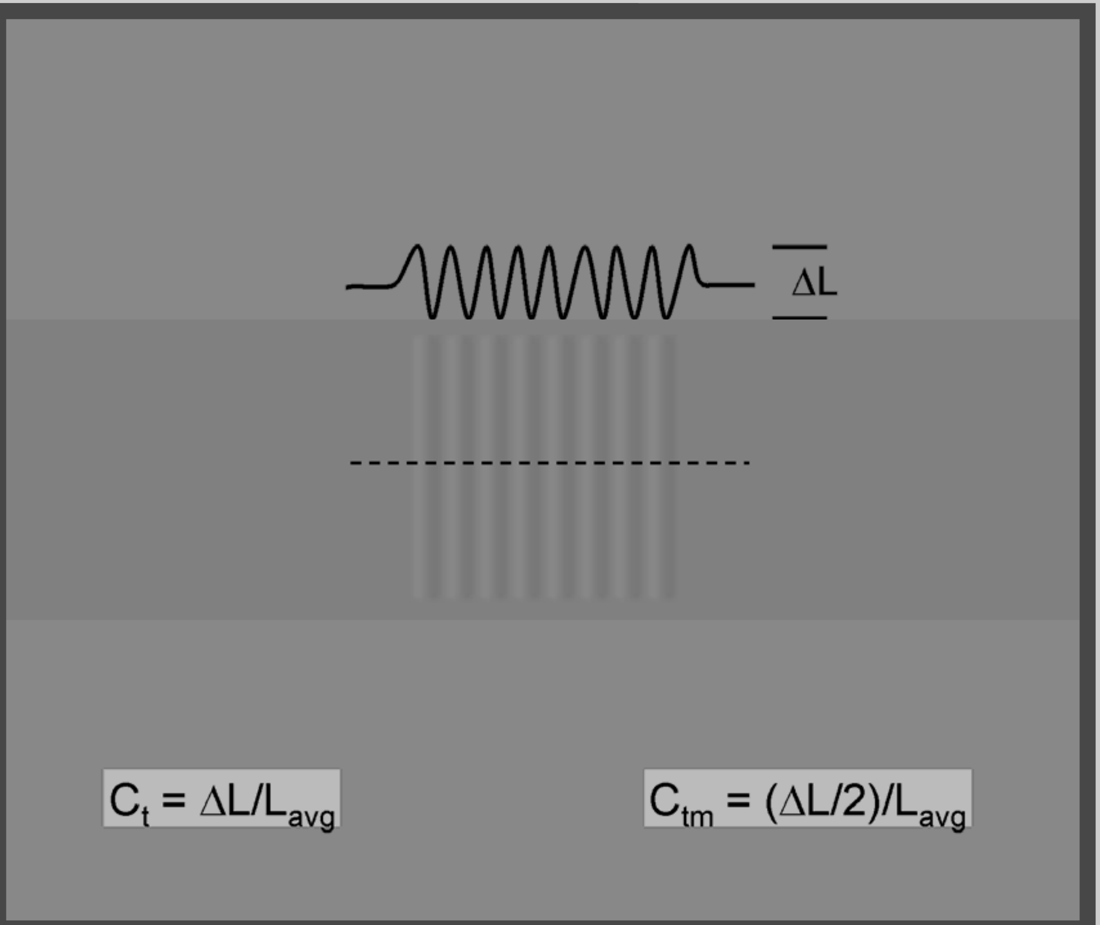
Eyeglass lens should be optimized for a normal viewing distance

Pixel Size?

- Visual Acuity
- Contrast Sensitivity

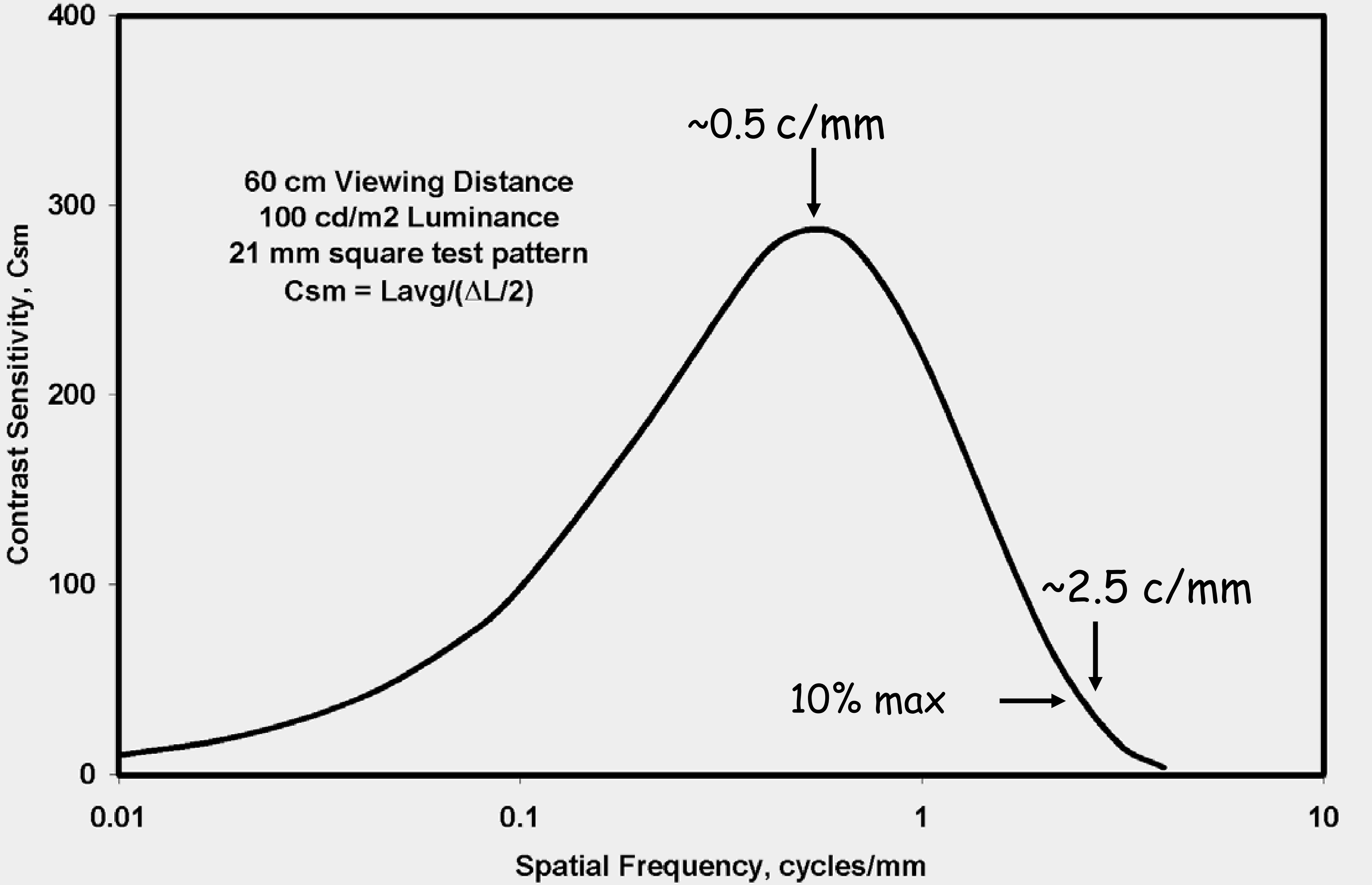
A variety of test patterns are used to assess visual acuity. Clinical measures are done typically with a Snellen eye chart. Much psychovisual research has been done using sinusoidally modulated test targets.





Contrast Sensitivity as a measure of spatial acuity

Contrast sensitivity is the inverse of contrast threshold: $C_s = 1/C_t$



Pixel Size at Maximum Spatial Acuity

- The visual spatial frequency limit and associated pixel size can be defined as that for which Cs = 10% of maximum.
- The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance.

Distance	frequency	pixel size
Close inspection (0.33 m)	5 cycles/mm	0.100 mm/pixel
Normal viewing (0.66 m)	2.5 cycles/mm	0.200 mm/pixel
Consultation view (1.00 m)	1.7 cycles/mm	0.300 mm/pixel
Conference room (3.00 m)	0.5 cycles/mm	1.000 mm/pixel

- The pixel size and the field of view dictate the pixel array size and the total number of pixels.
- Megapixels alone is not a good descriptor of quality.

Field of View	pixel size	array size	MegaPixels
21 inch	0.100 mm	3200 x 4200	13.4
21 inch	0.200 mm	1600 x 2100	3.4

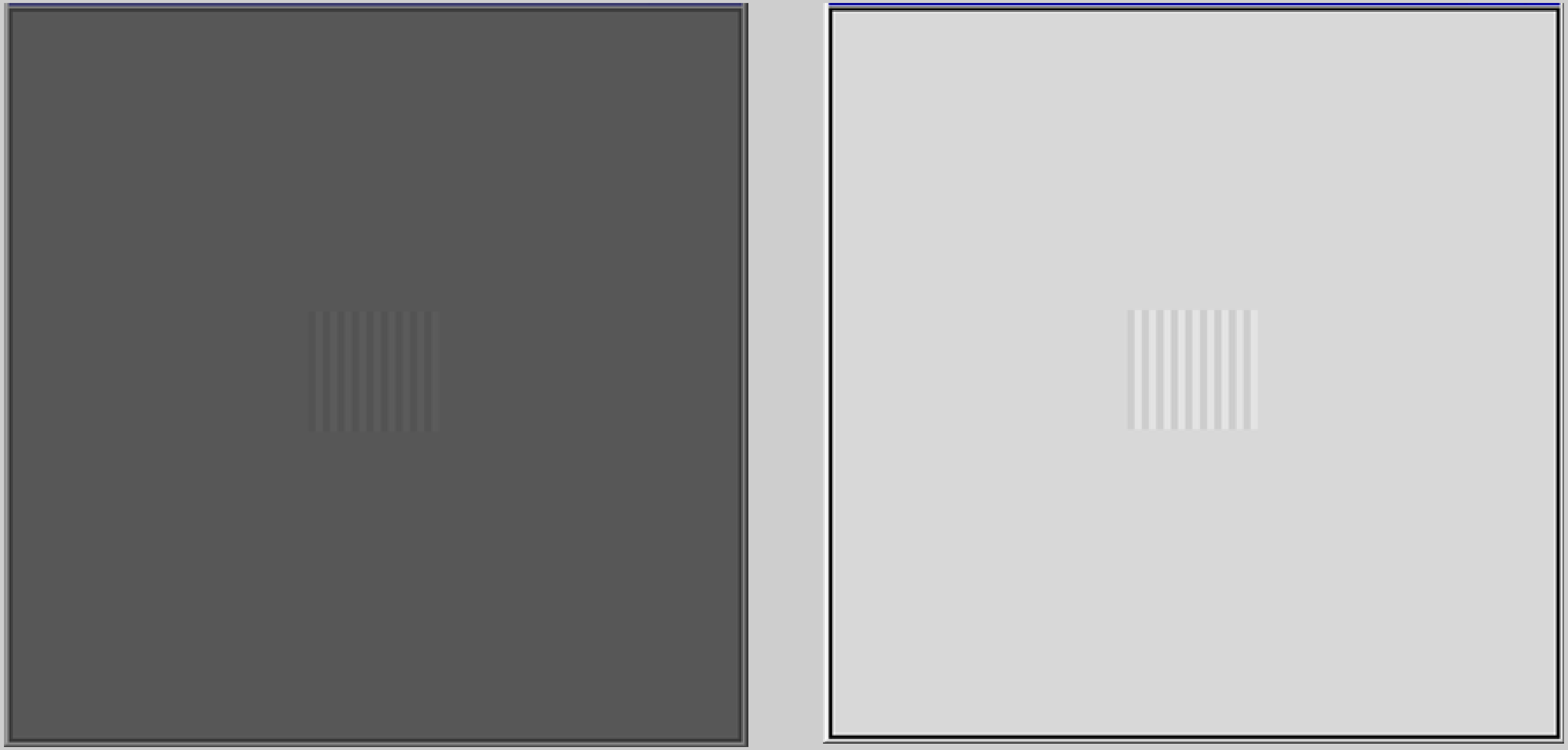
- idtech 3 MP panel
  20.8 inch (32 x 42 cm) 3.1 megapixels (.207 mm pixels)

Equivalent Contrast?

- Luminance response (grayscale)
- Luminance ratio (L'max/L'min)

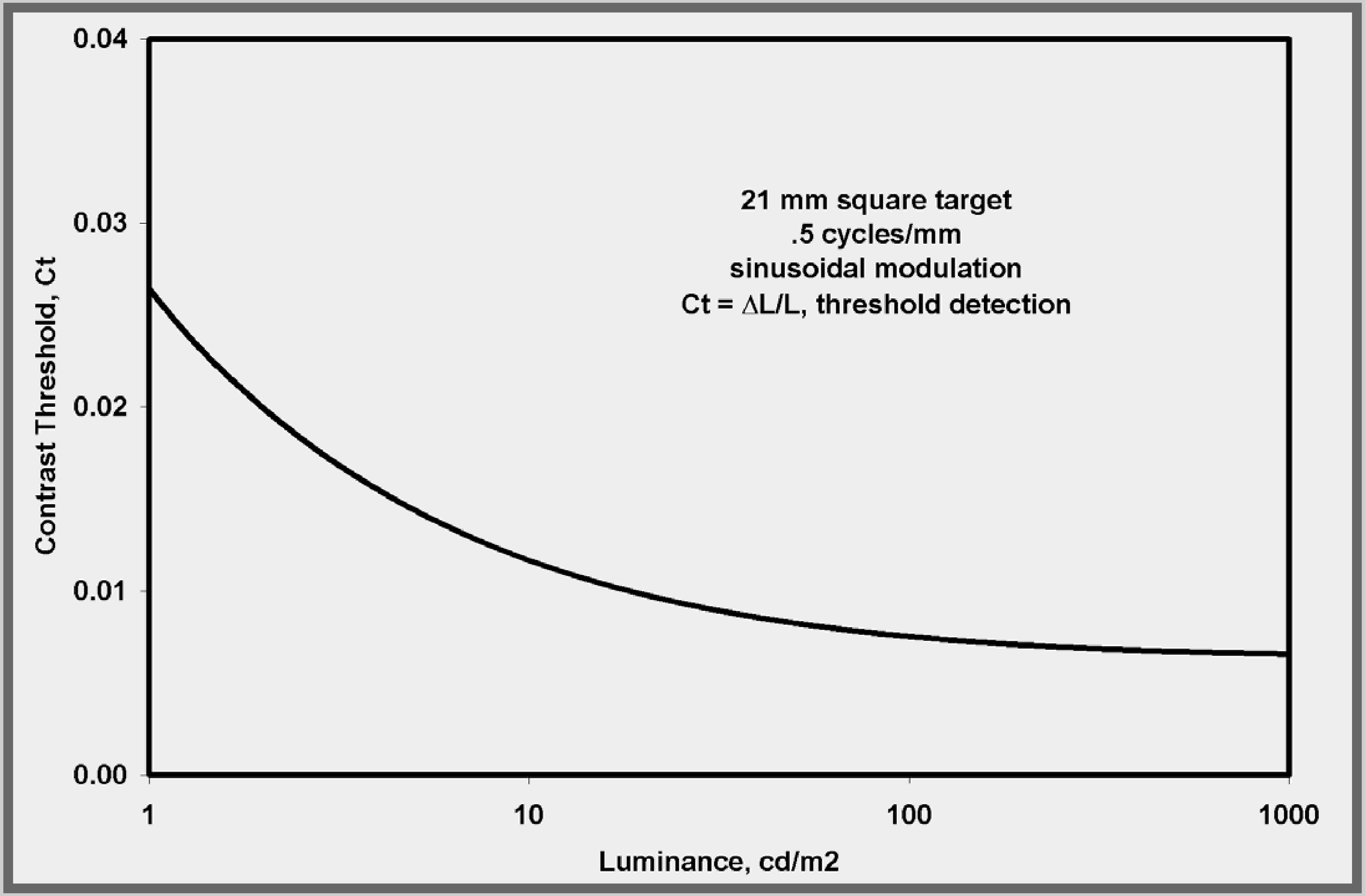
Contrast detection in relation to brightness

- Contrast detection is diminished for images with low brightness.



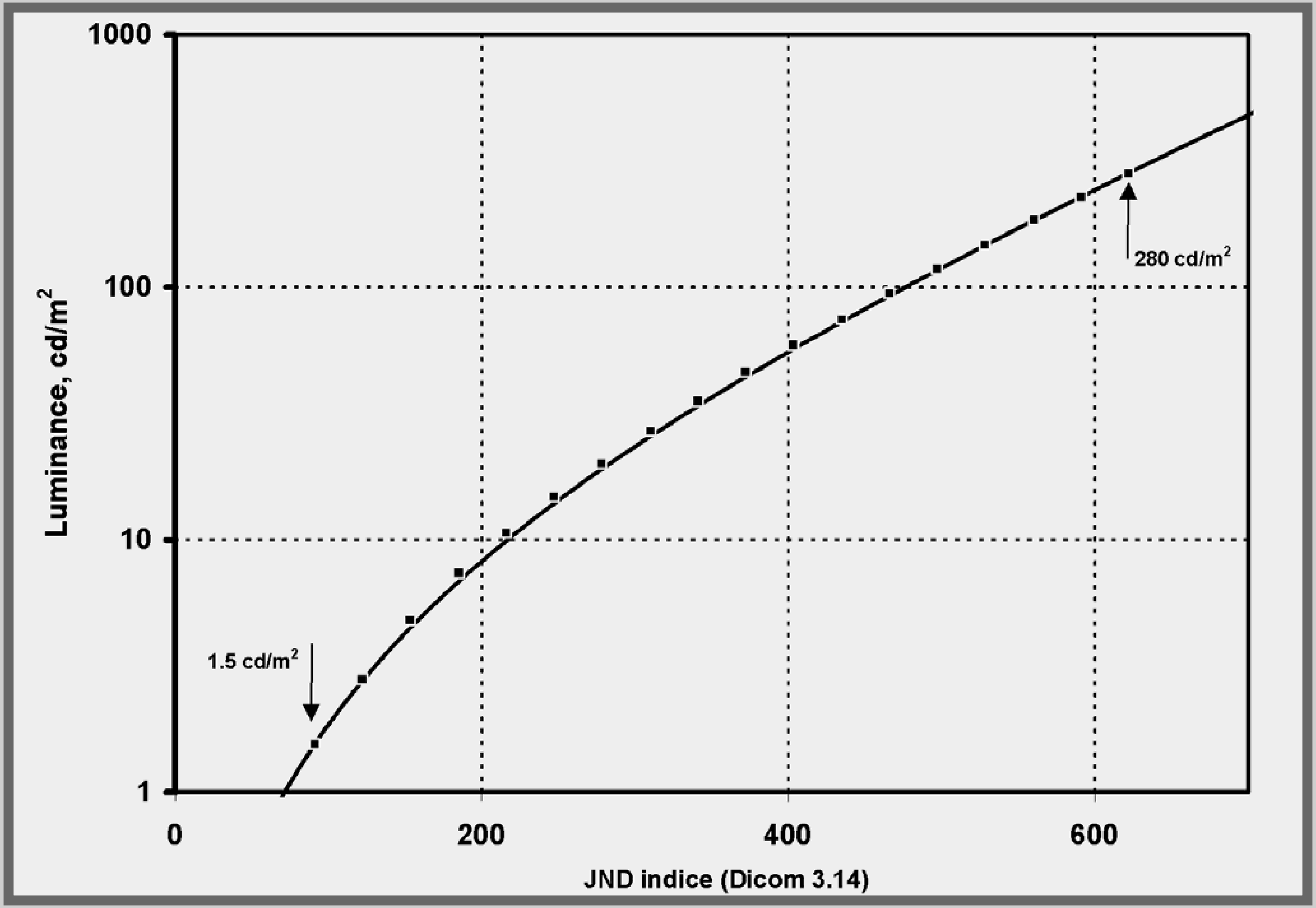
- Extensive experimental models have documented the dependence of contrast detection on luminance, spatial frequency, orientation and other factors. The empirical models of either S. Daly or J. Barton provide useful descriptions of this experimental data.

Contrast threshold vs luminance

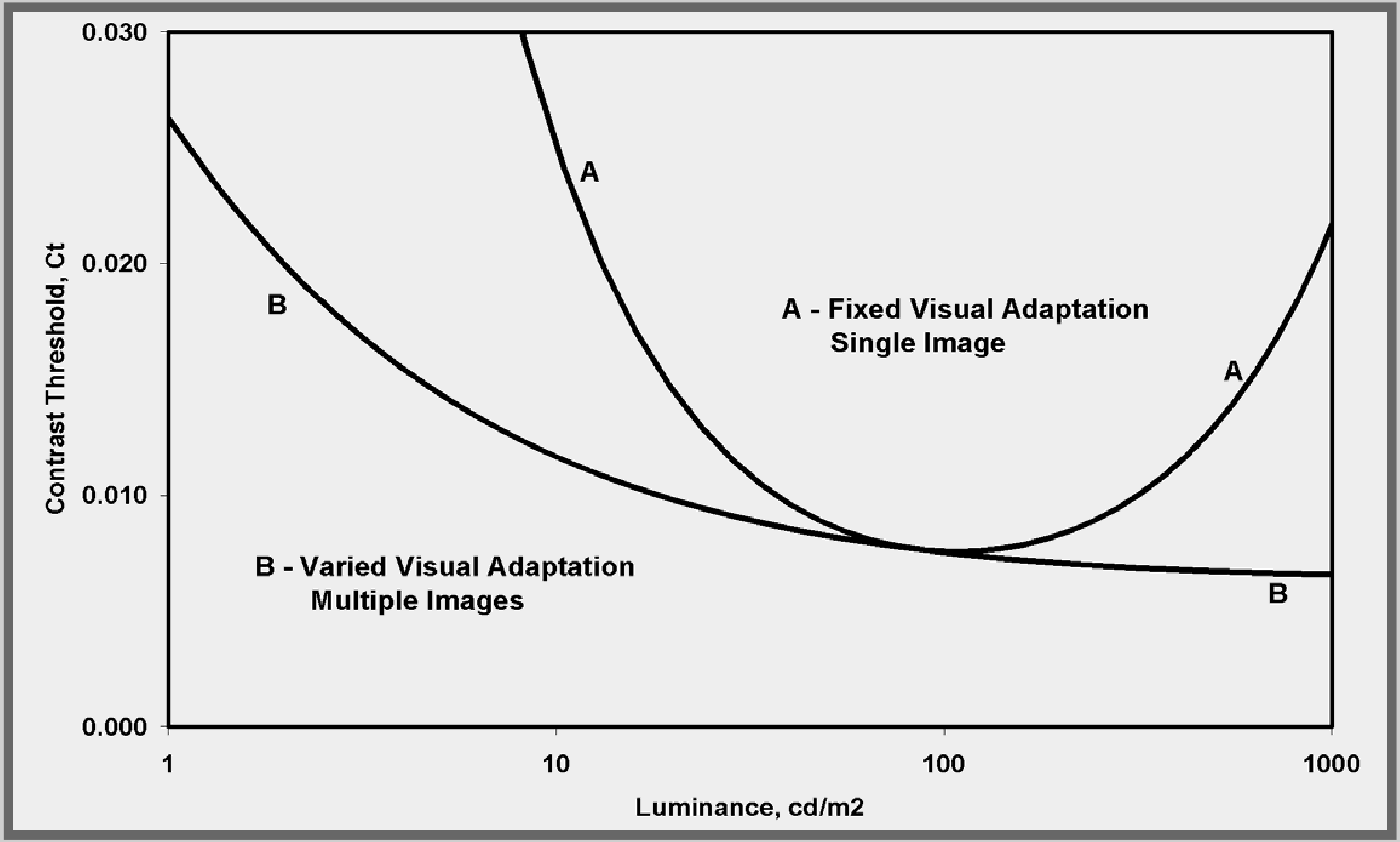


The Barton model describes the average contrast threshold of normal observers. Significant differences exist for individual observers for different test methods

DICOM part 3.14 describes a grayscale response that compensates for visual deficits at low brightness

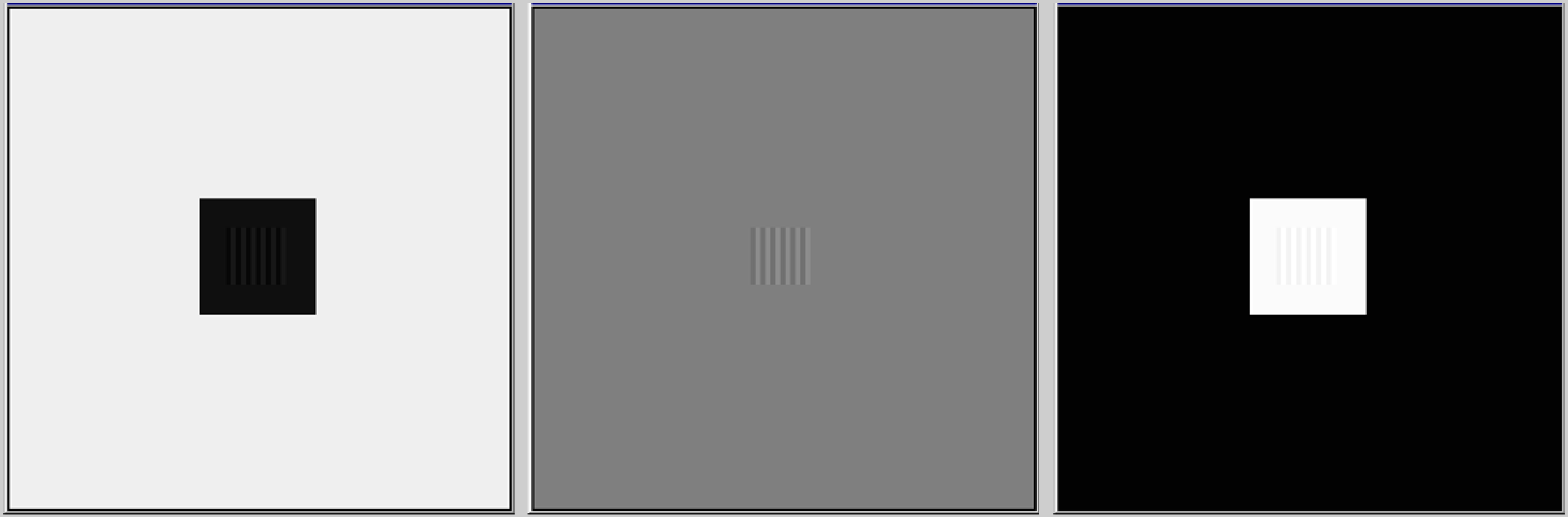


Fixed versus variable adaptation



Contrast threshold for varied visual adaptation (A, Flynn 1999b) and fixed (B) visual adaptation: The contrast threshold, $\Delta L/L$, for a just noticeable difference (JND) depends on whether the observer has fixed (B) or varied (A) adaptation to the light and dark regions of an overall scene.

Observer performance is best when visual system is adapted to the average scene luminance.

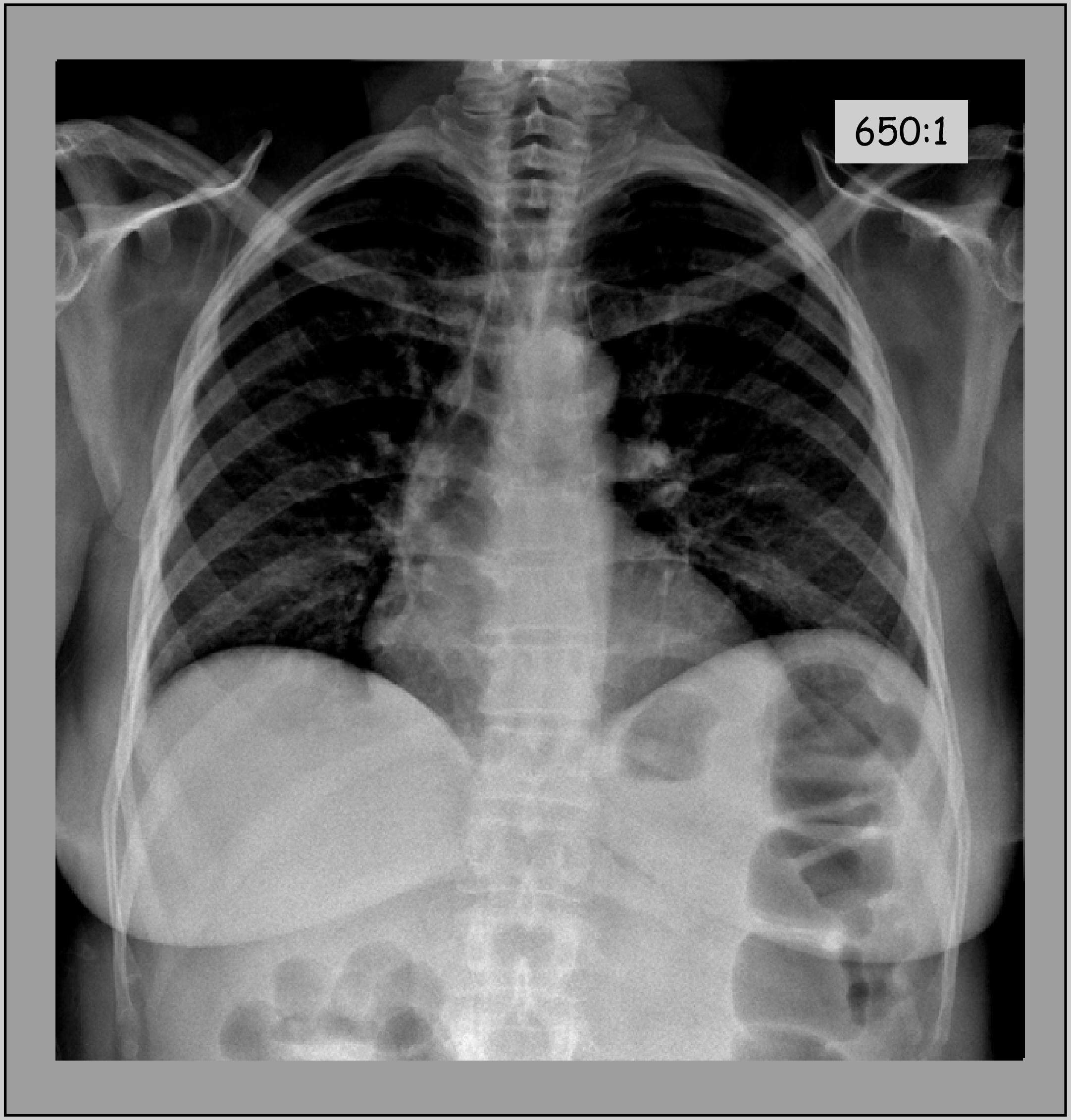


A B C

Effect of Lmax/Lmin

250:1 → .1 to 2.50 OD
350:1 → .1 to 2.65 OD
650:1 → .1 to 2.90 OD

- Digital radiographs should be displayed using over a luminance range of 250-350:1.
- Images prepared for range of 250 that are display on a monitor with large range will have poorly perceived contrast in dark regions.



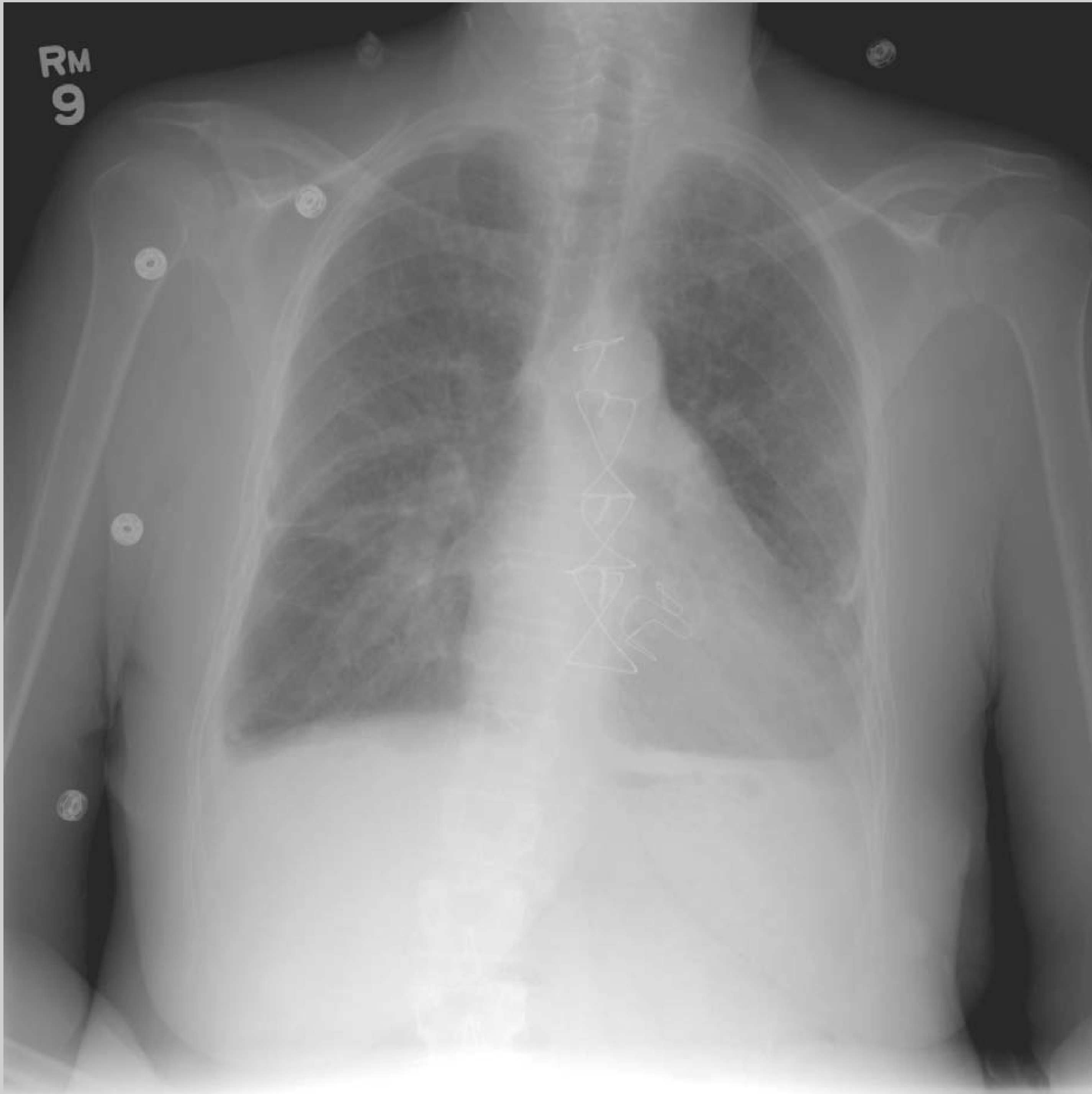
Display Specifications
Summary

- GSDF luminance response with *LR* = 350.
- Maximum brightness of 450 candelas/m^2 or more
- Pixel pitch of 0.210 mm or less.
- Diagonal size of 20-24 inches with 4:3 or 5:4 aspect
- L_{amb} less than 1/4th of L_{min}.

1. Preprocessing
2. Display Processing
3. Display Presentation
4. Chest Case Example

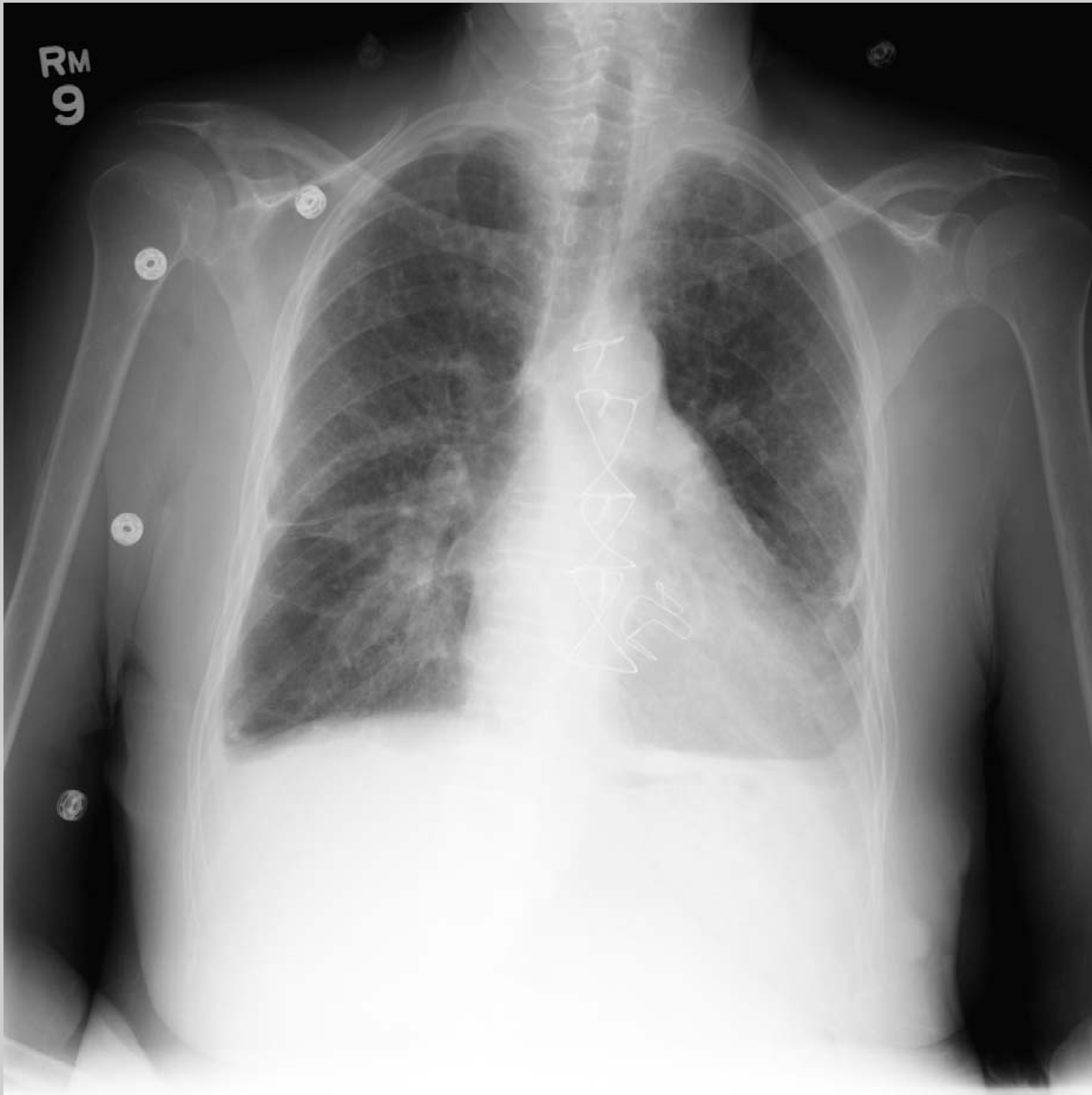
Chest PA - A

Linear presentation of For Processing image data.



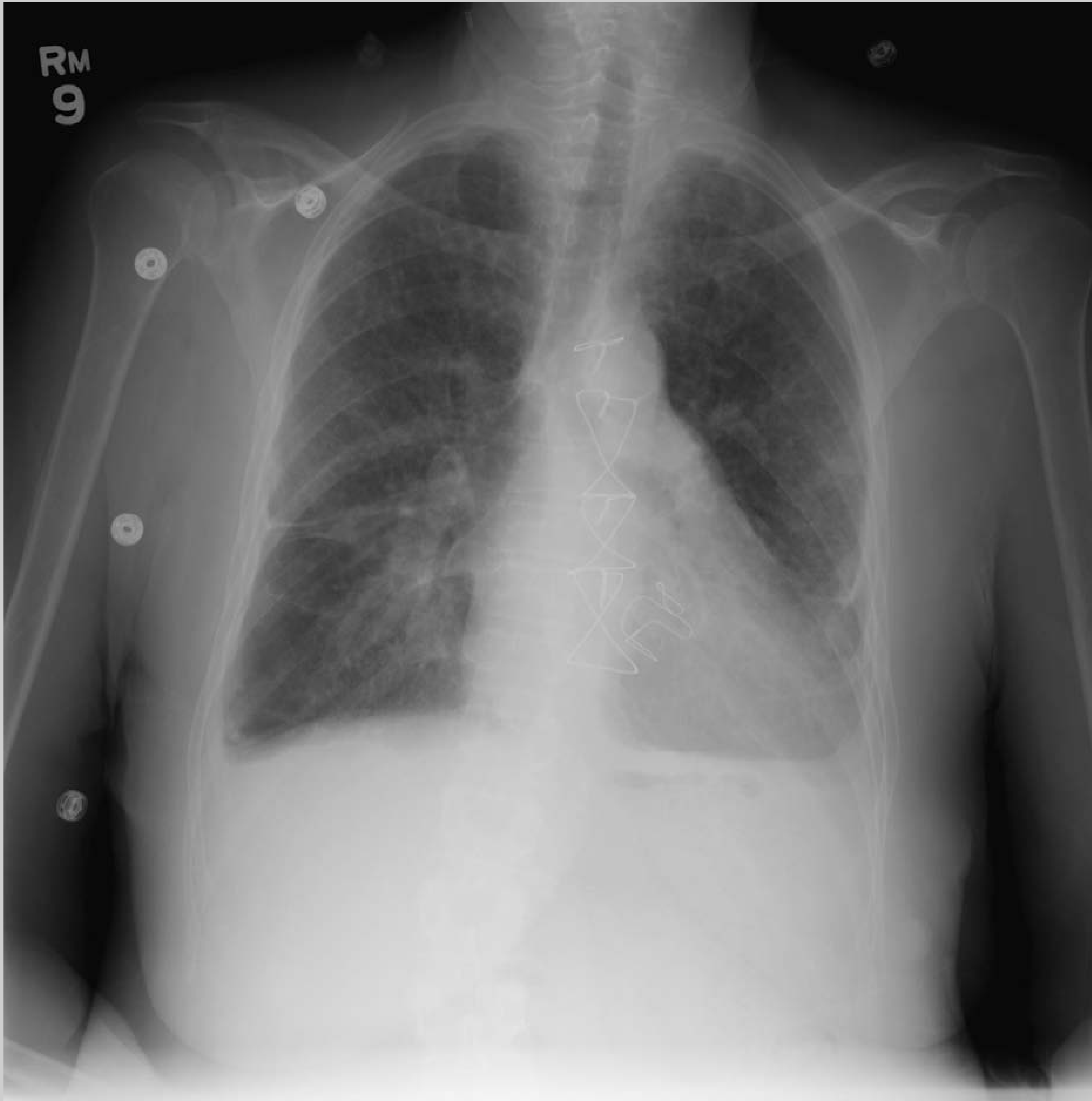
Chest PA - B

One gamma tonescale produces an appearance similar to classical film screen systems



Chest PA - C

Two gamma tonescale produces an appearance similar to modern chest film screen systems

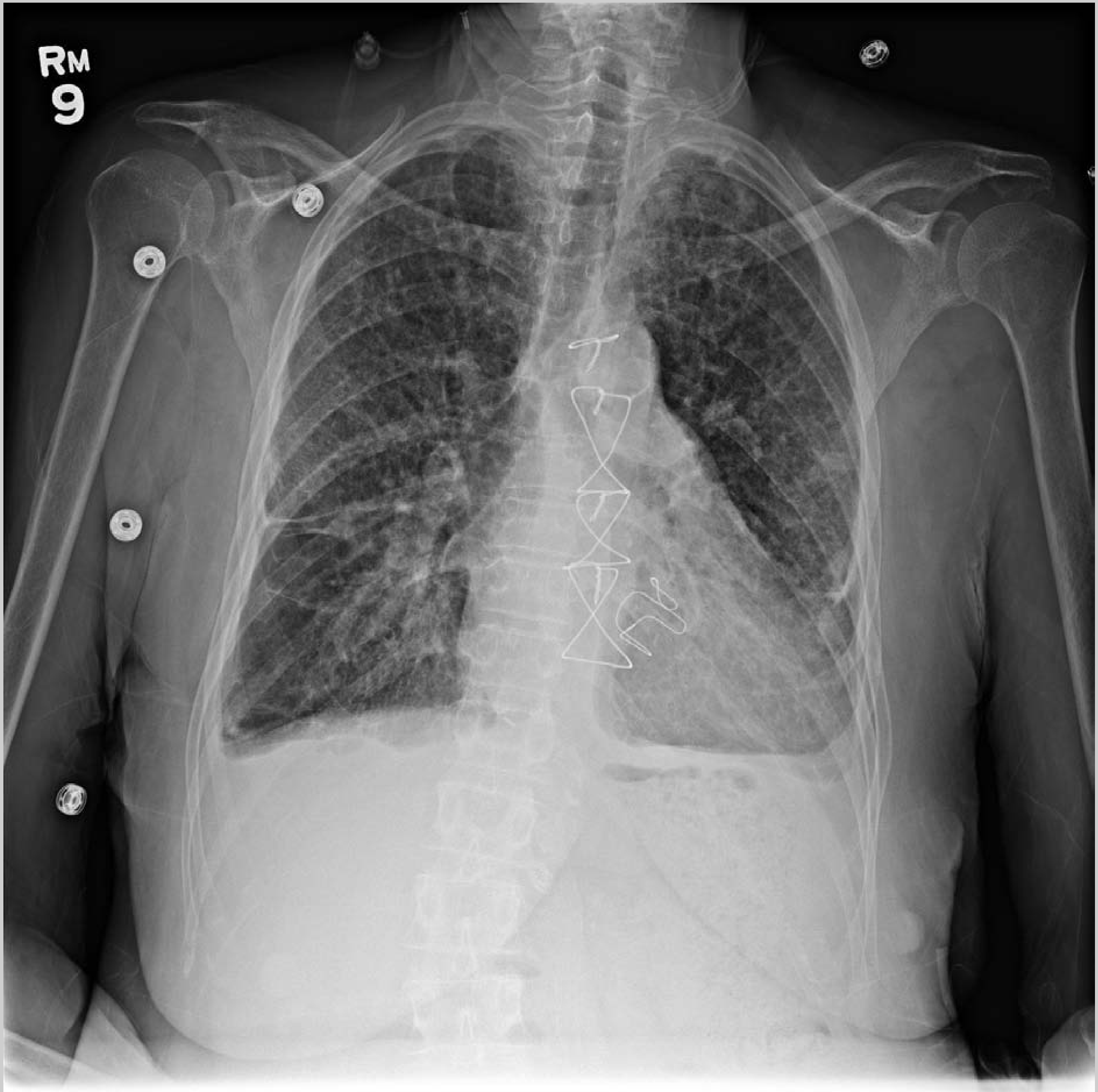


Chest PA - D

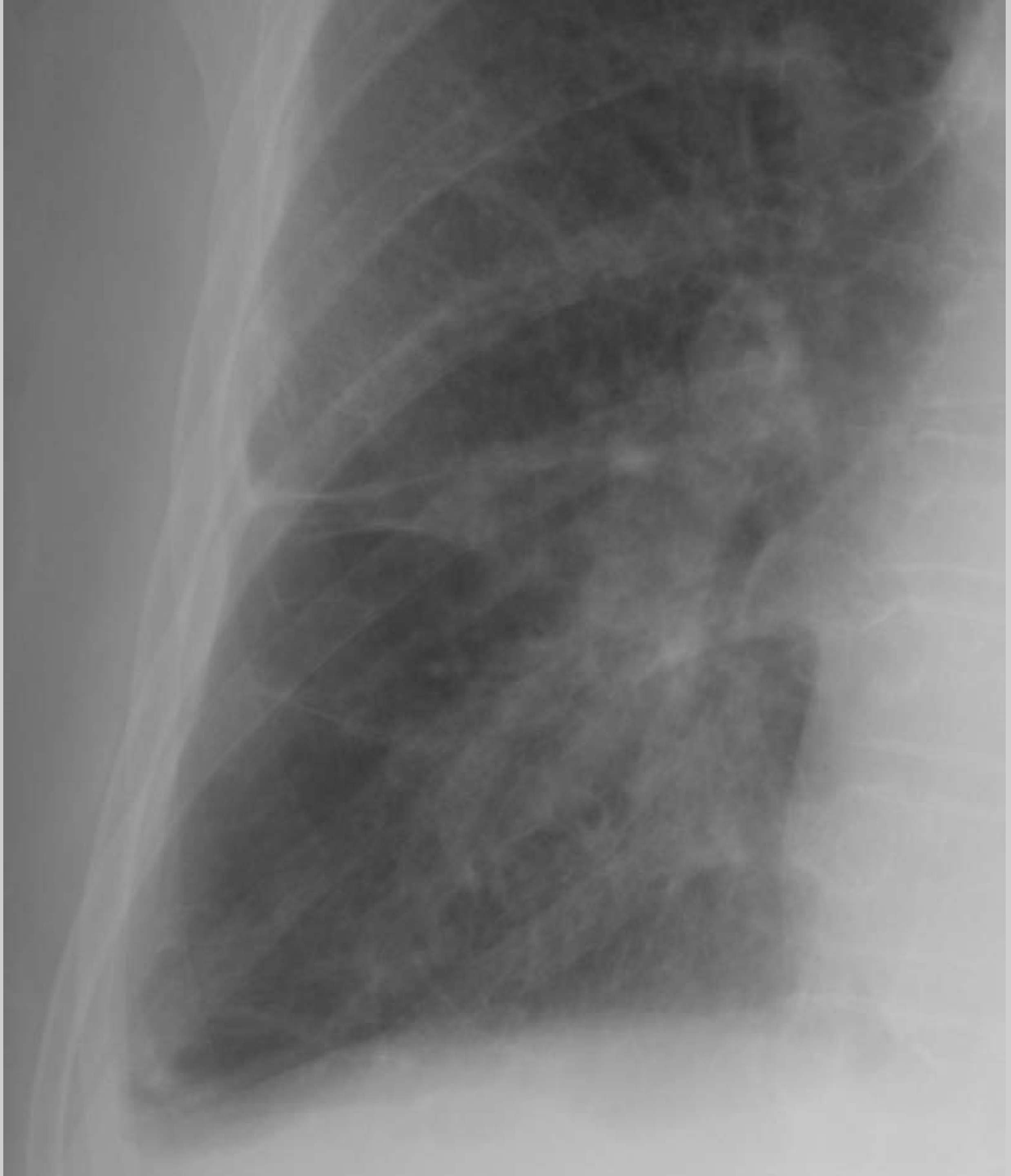
Enhanced processing by a commercial system (EKC) as sent to a clinical PACS system

Chest PA - E

Enhanced processing with edge restoration (HFHS +Show application)



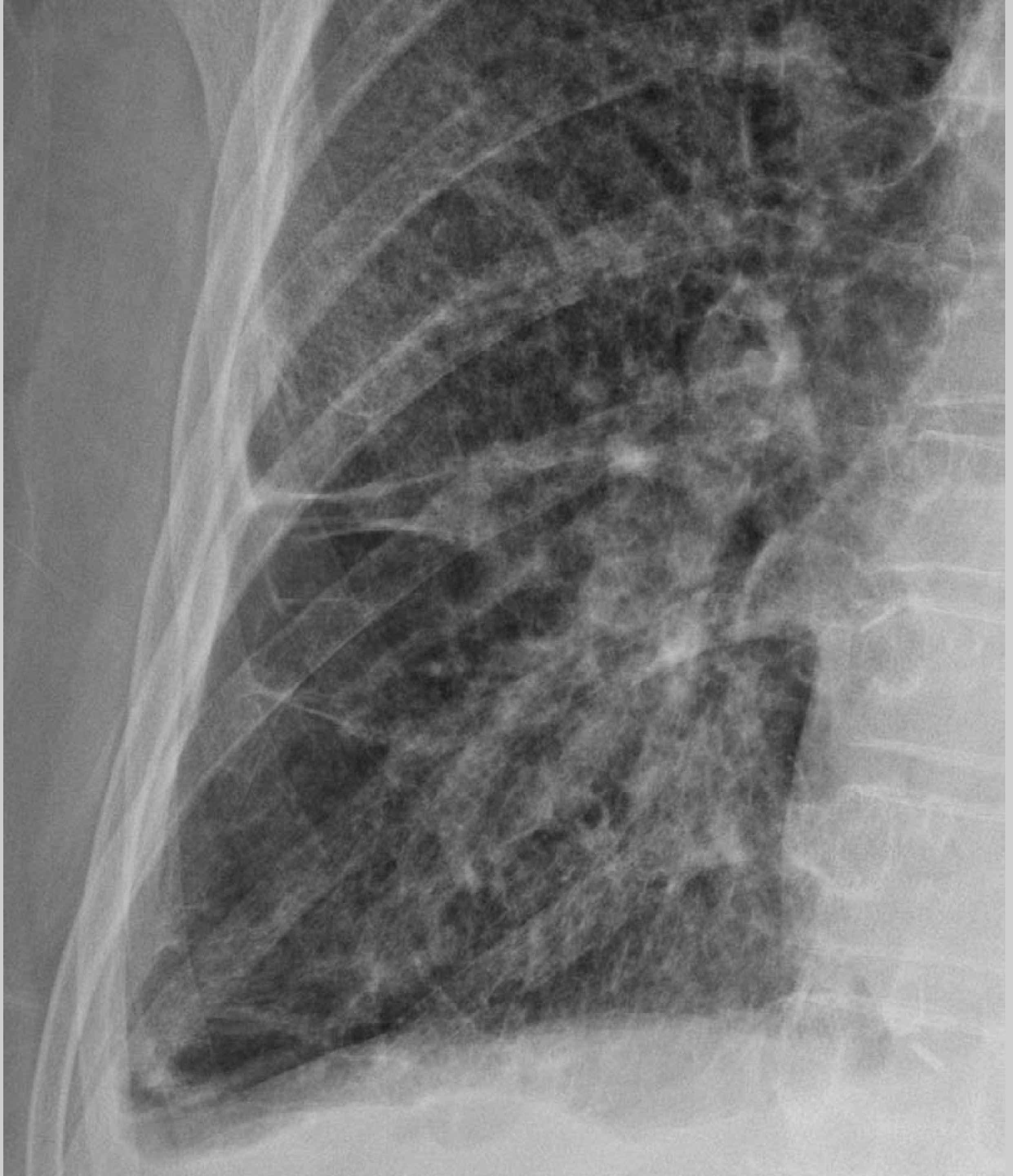
Chest PA - F



Two gamma tonescale produces an appearance similar to modern chest film screen systems

Chest PA – G

Enhanced processing with edge restoration (HFHS +Show application)



Questions ?

?

1. Preprocessing
2. Display Processing
3. Display Presentation
4. Chest Case Example

Appendix

Commercial display processing implementations

3A – Fujifilm Medical Systems USA

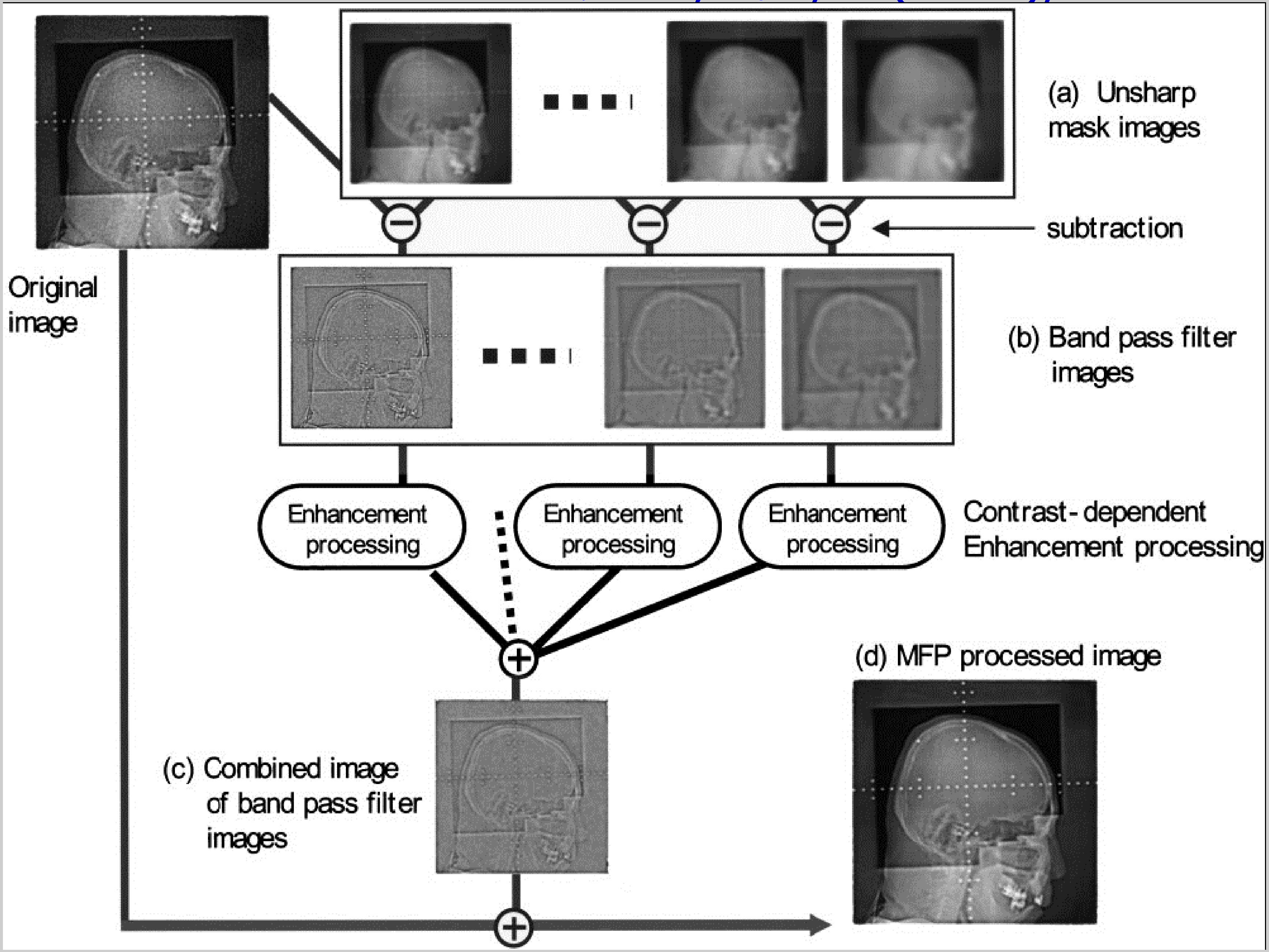
MFP (Multi-Frequency Processing)

An optional software applicable for all types of FCR imaging. MFP is an enhanced version of Fujifilm's renowned Dynamic Range Control (DRC), and uses frequency enhancement to provide greater diagnostic information from a single exposure image.

FNC (Flexible Noise Control)

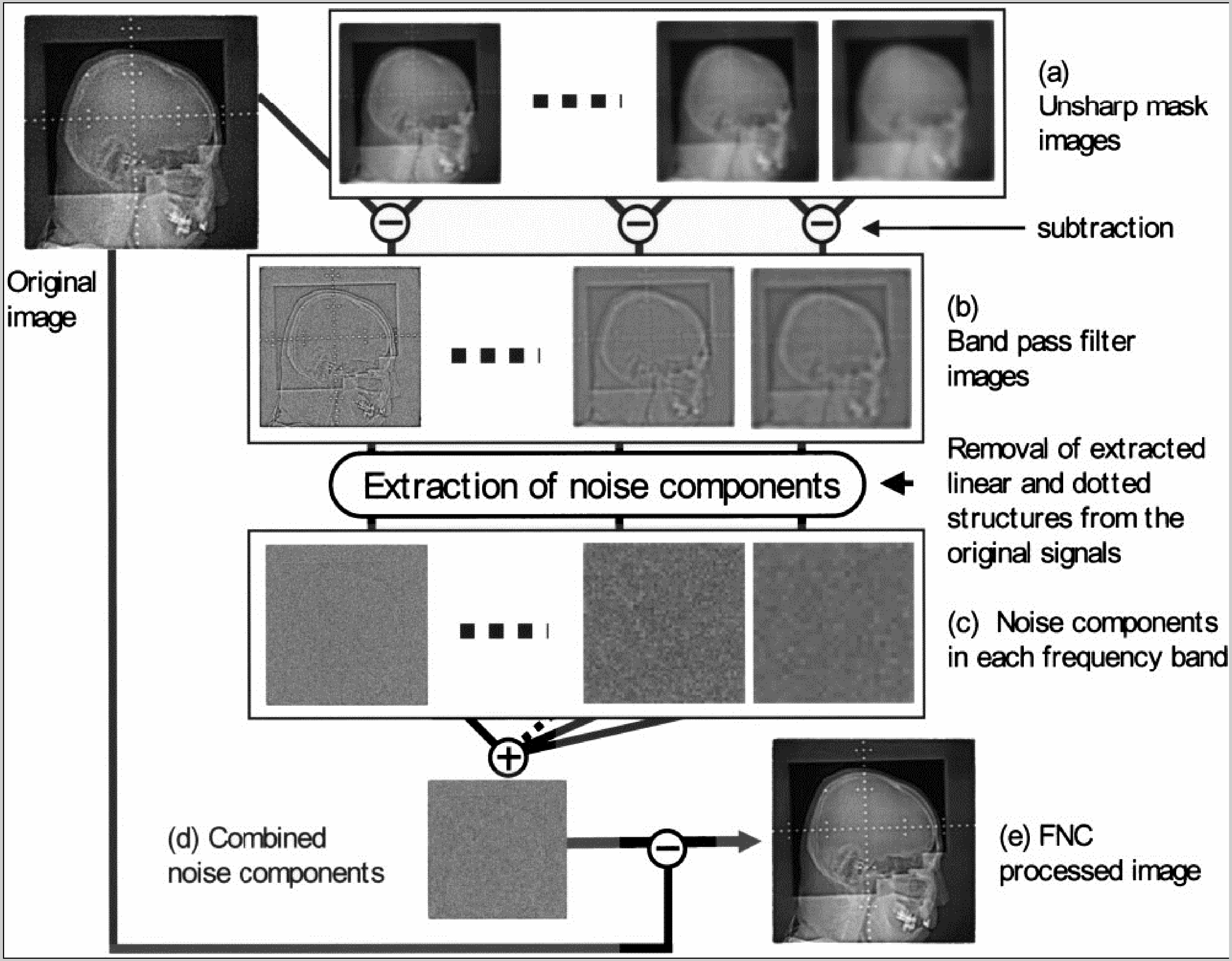
Through separation of the noise and signal of an image, it is possible to selectively decrease the noise level. Maximum selective exclusion of unnecessary information translates into easier diagnosis.

Yamada , BJR,78 (2005), 519-527



M. Flynn 2008

Yamada , BJR,78 (2005), 519-527

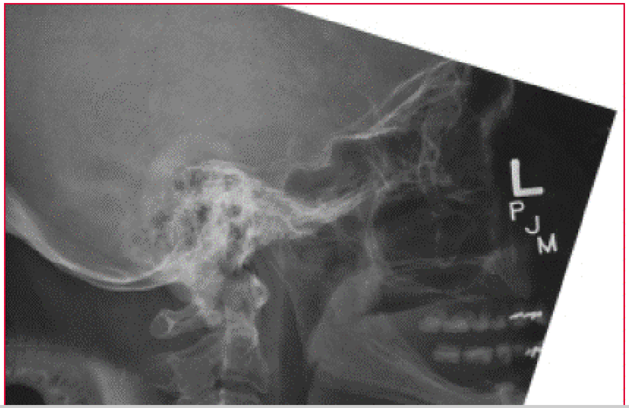


- 1997 SPIE3034
  Senn, skinline detection
- 1998 SPIE3335
  Barski, ptone grayscale
- 1999 SPIE3658
  Barski, grid suppression
- 1999 SPIE3658
  Van Metter, EVP
- 2001 SPIE4322
  Pakin, extremity segment.
- 2003 SPIE5367
  Couwenhoven, control
- 2004 SPIE5370
  Wang, auto segmentation
- 2005 SPIE5749
  Couwenhoven, noise

Kodak

Increased latitude without loss of detail contrast

Introducing – and validating for diagnostic preference – an enhanced visualization image processing software algorithm that exploits the full exposure range of computed radiography image data

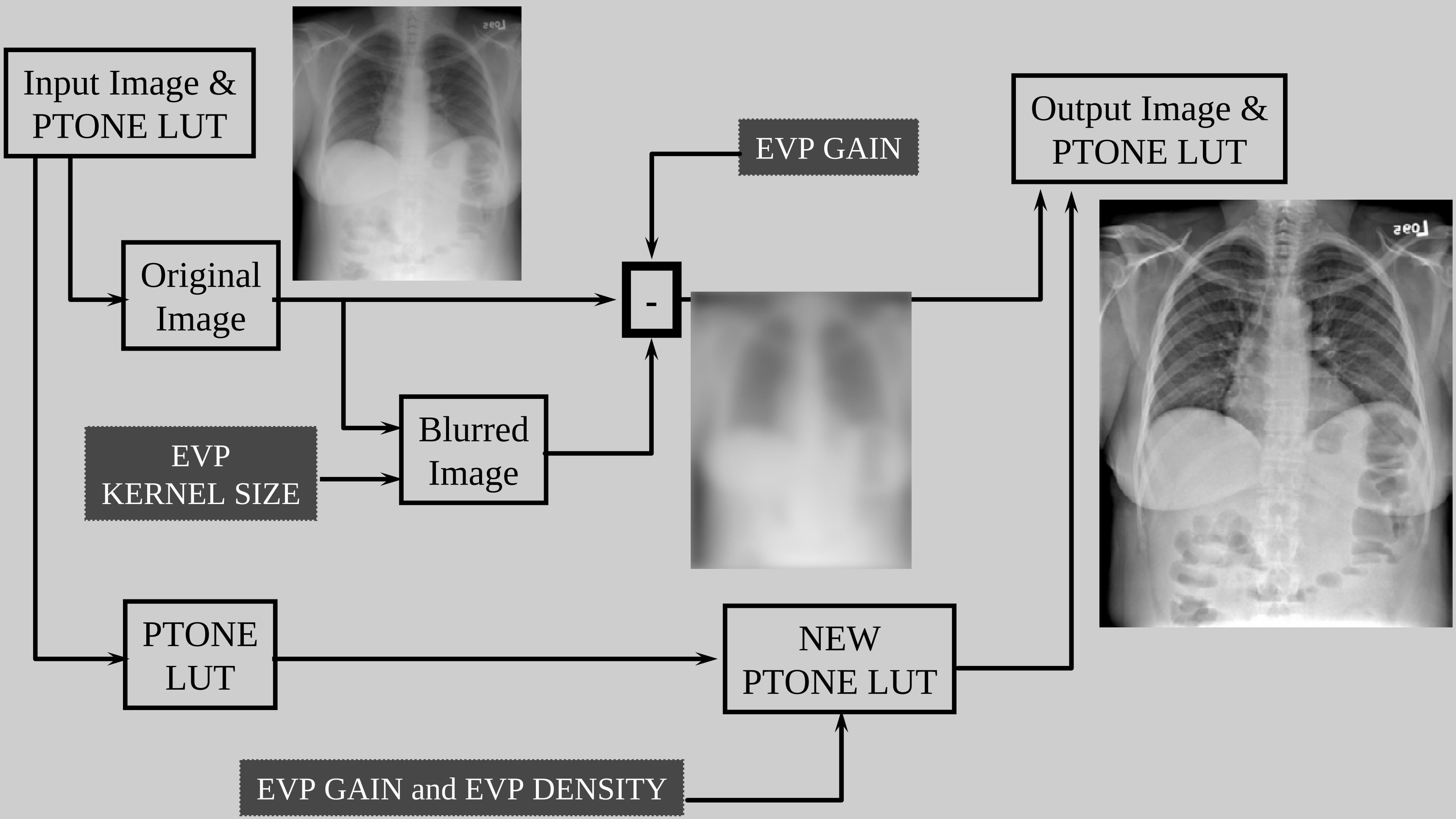


EVP

A series of proceedings articles describes the image processing approaches used by Eastman Kodak Company

3B – EKC Signal Equalization (Kodak EVP)

Wang, AAPM '06, CE



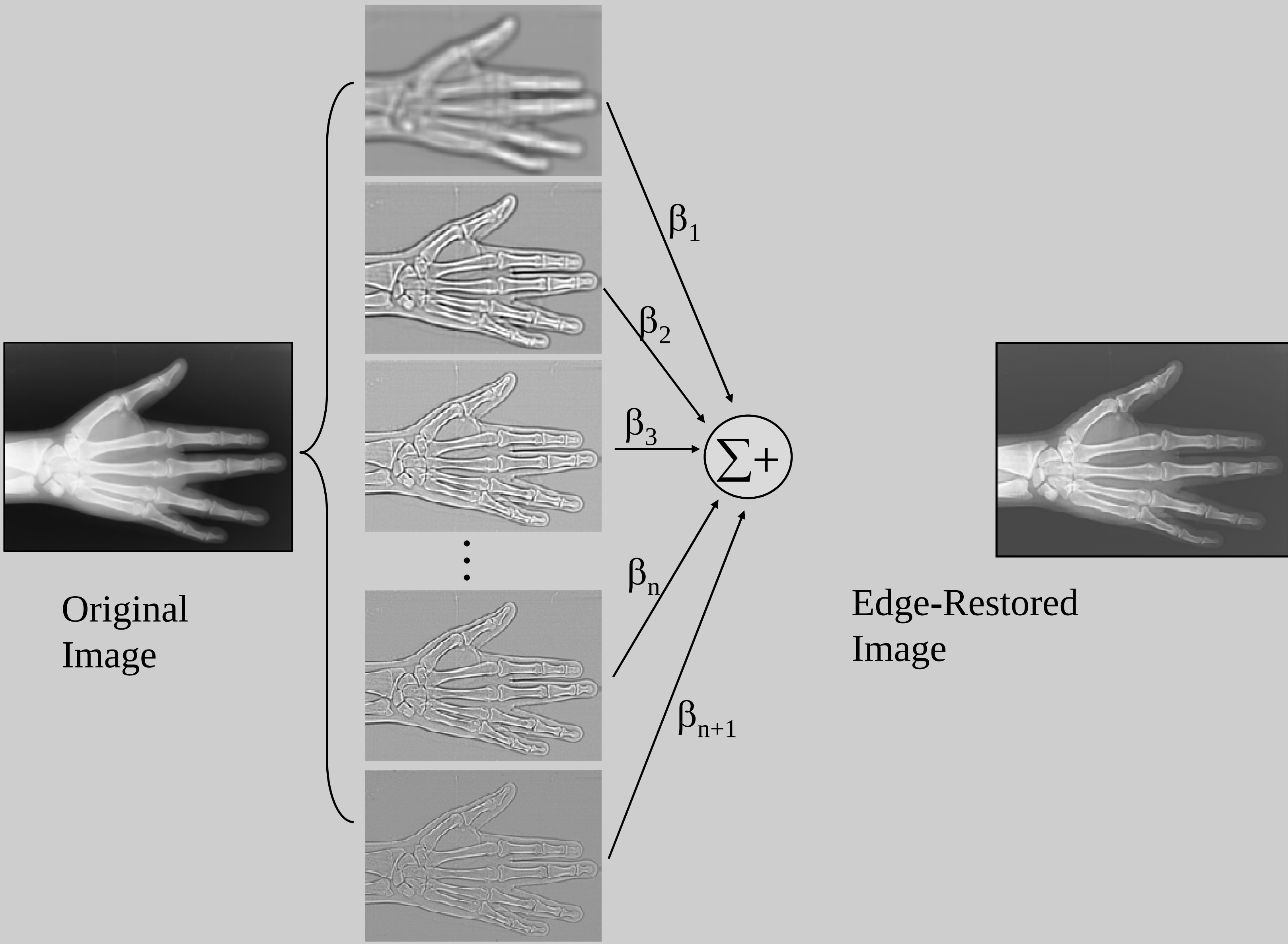
$$E'(i,j) = \alpha \bullet \{ E(i,j) \otimes K \} + (1 - \alpha) \bullet E_{mid} + \beta \bullet \{ E(i,j) - (E(i,j) \otimes K) \}$$

$$D(i,j) = \rho[E'(i,j)].$$

"Enhanced latitude for digital projection radiography," R. Van Metter and D. Foos, Proc. SPIE 3658, 468-483, 1999.

3B – EKC Multi-Frequency Processing

Wang, AAPM '06, CE

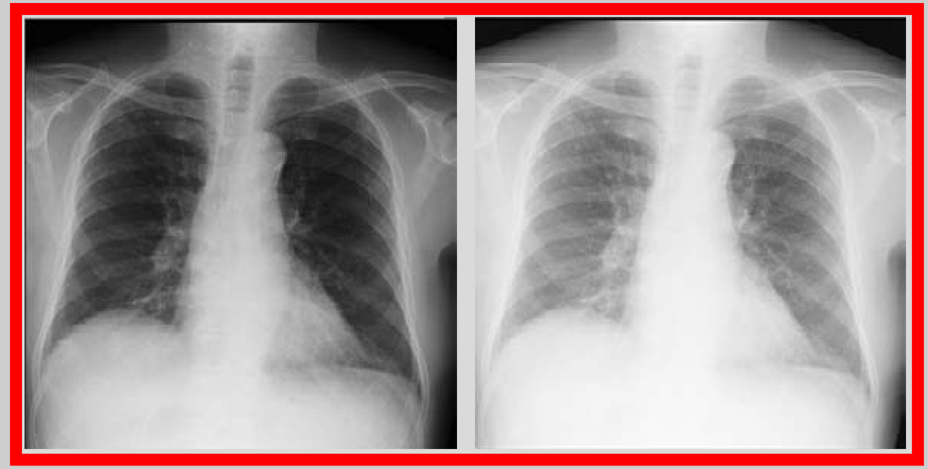


3B – EKC control variables.

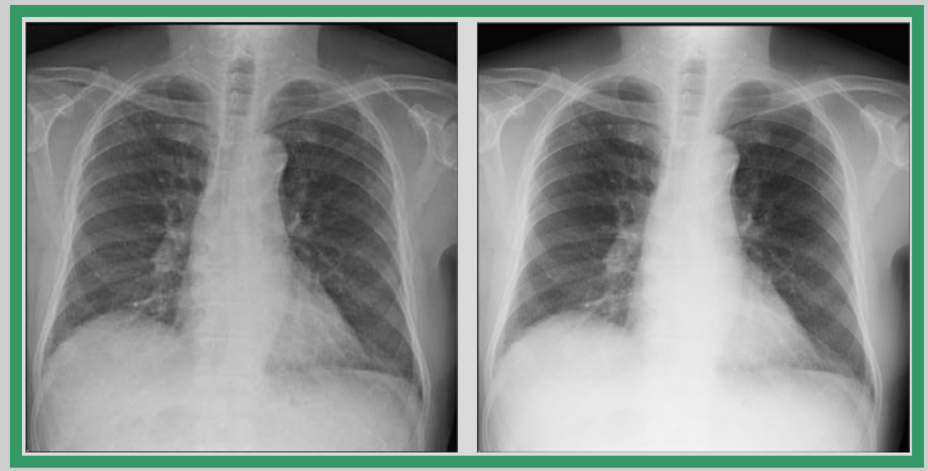
Couwenhoven,
RSNA Inforad
2005

1st World Congress
Thoracic Imaging
2005

Brightness



Latitude



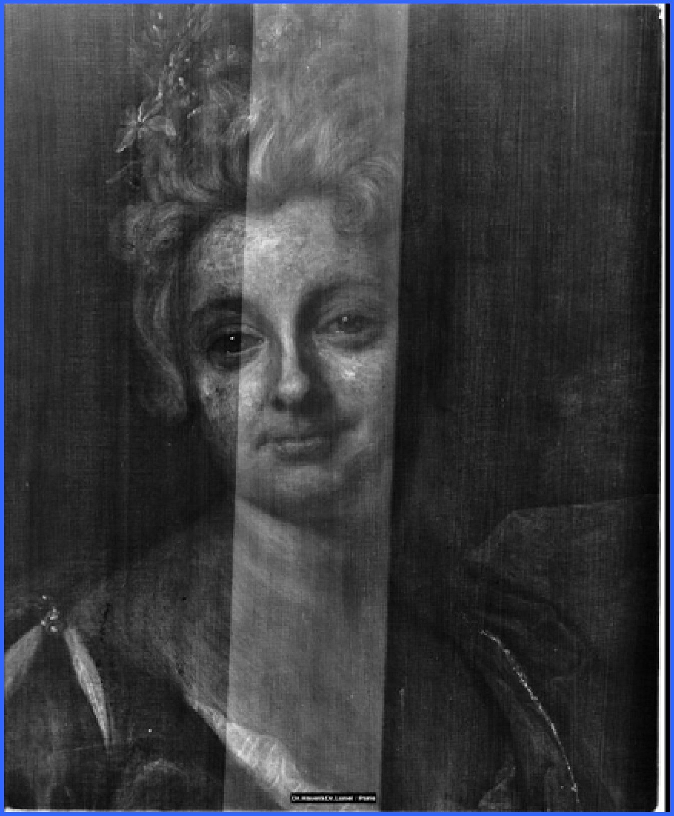
Contrast

GXR, Th. Rohse, November 2005

PHILIPS

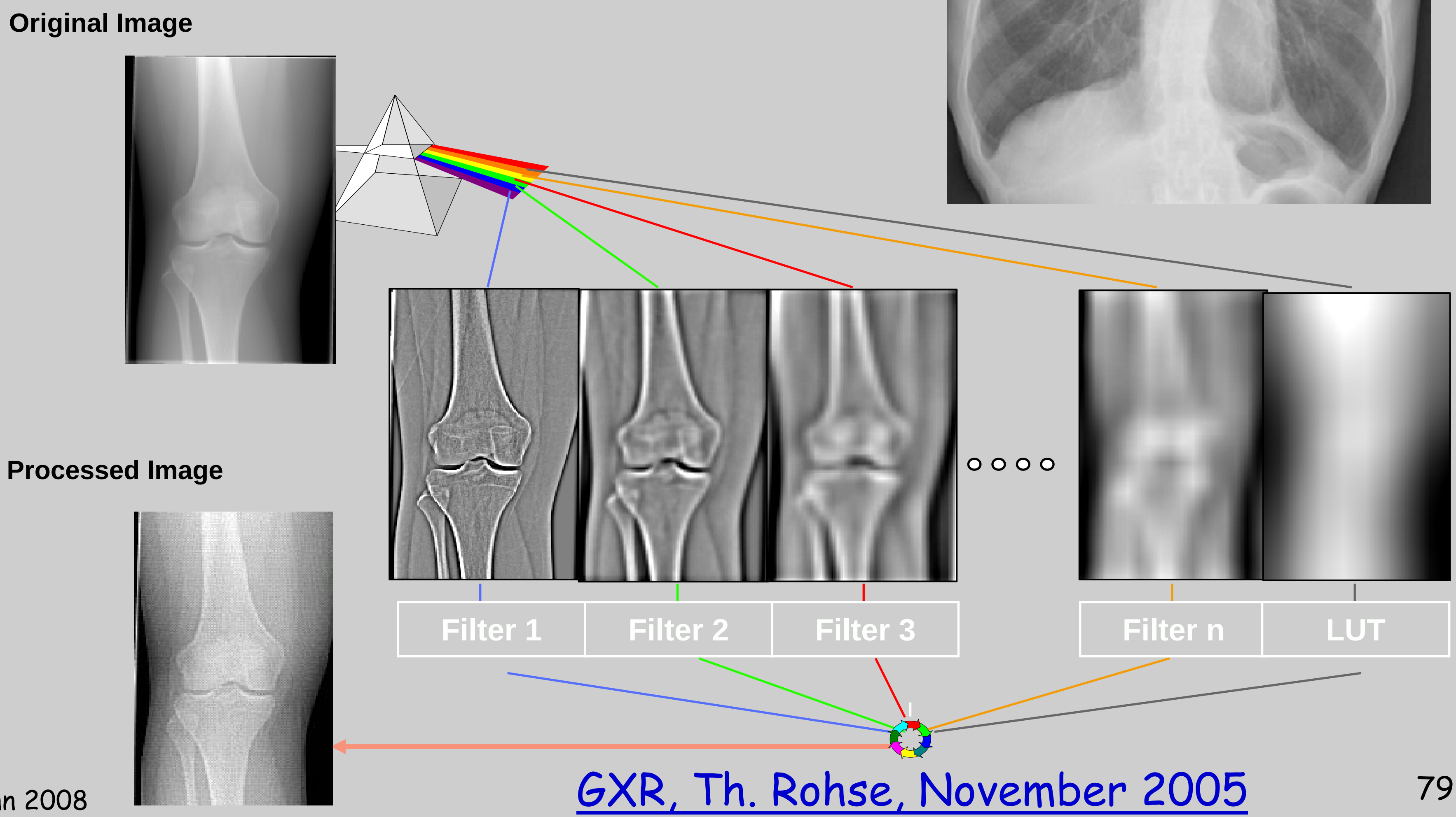
UNIQUE

UNified **I**mage **QU**ality **E**nhancement



UNIQUE Principle

Multi-Resolution Decomposition



GXR, Th. Rohse, November 2005

3D – Agfa MUSICA

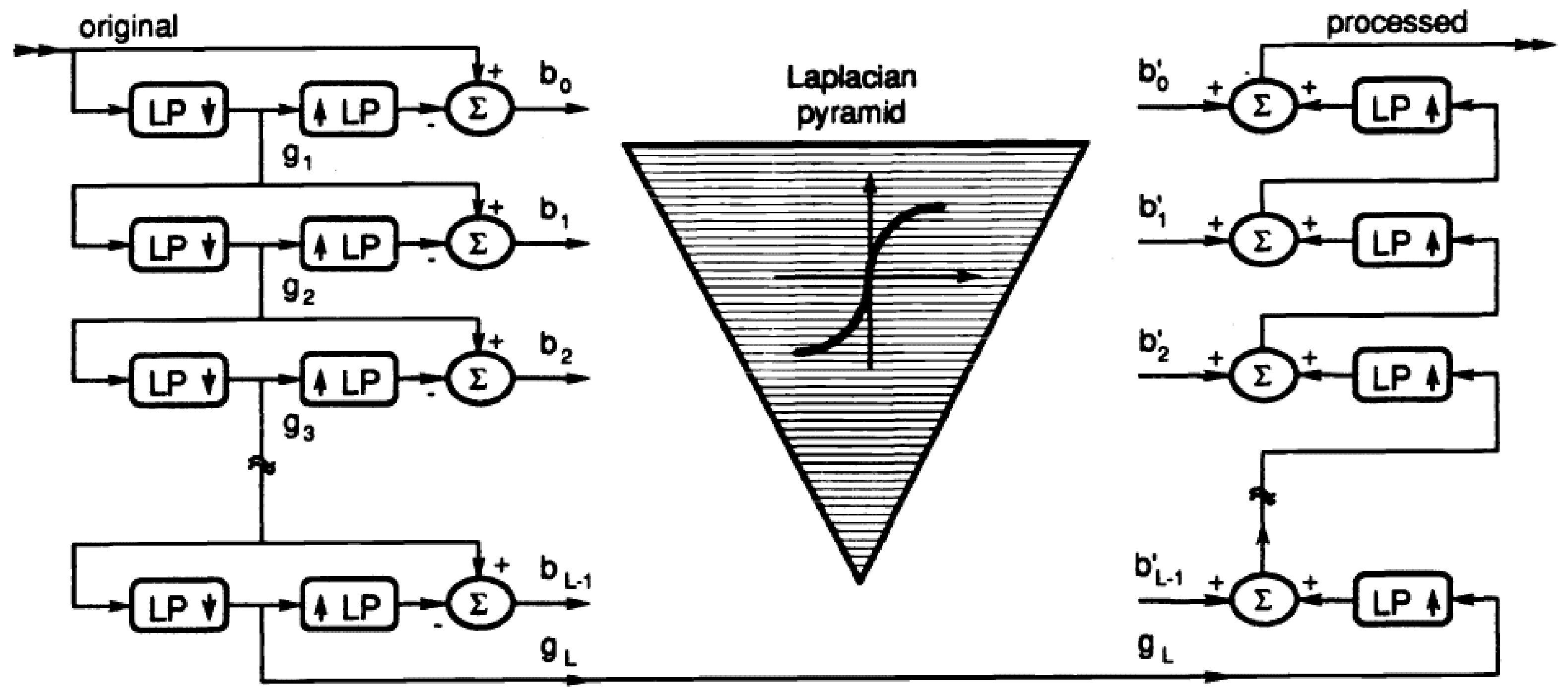
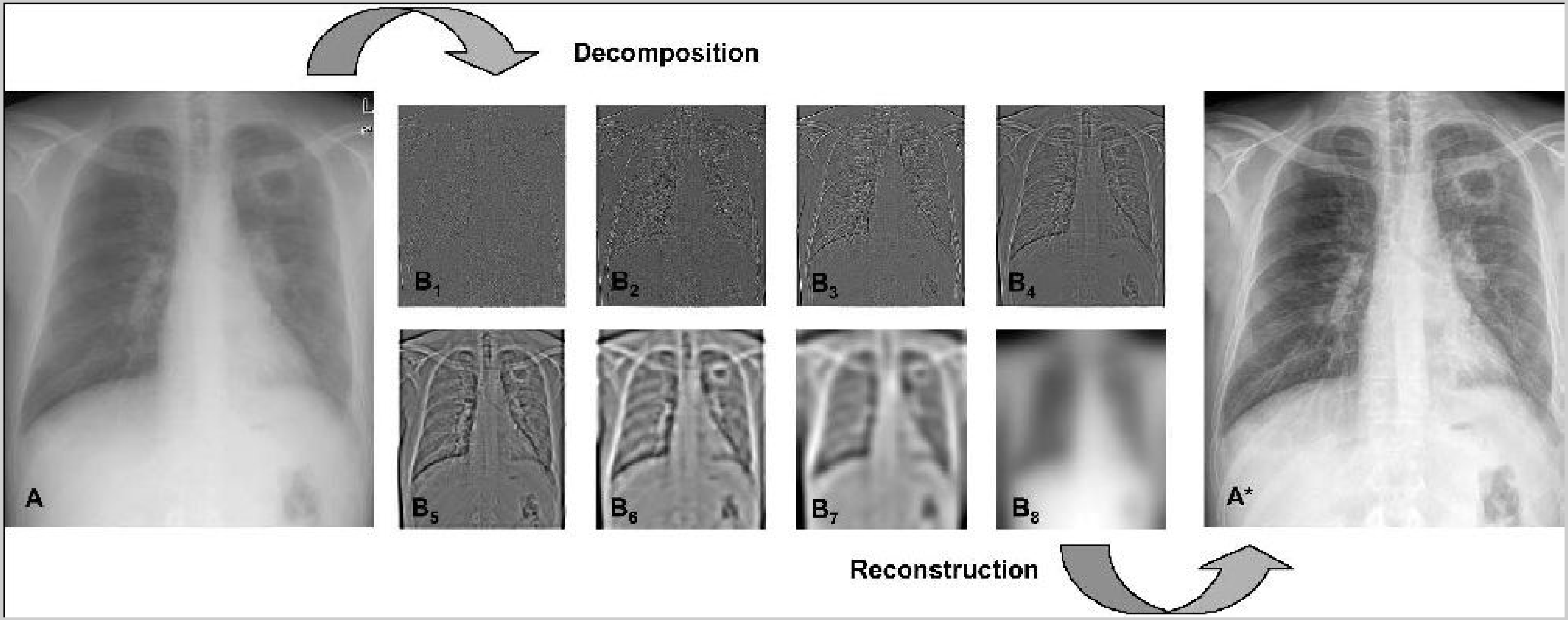
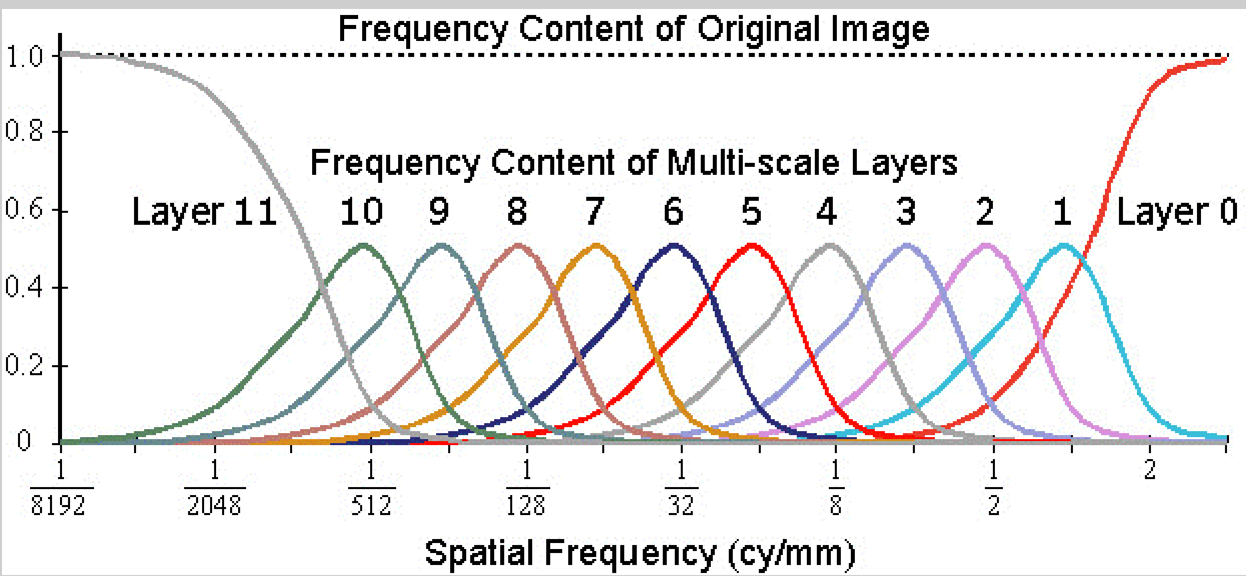


Fig. 3. Flow diagram of the MUSICA-algorithm.

- Vuylsteke P, Schoeters E, Multiscale Image Contrast Amplification (MUSICA), SPIE Vol 2167 Image Processing, pg 551, 1994
- Burt PJ, and Adelson EH, "The Laplacian pyramid as a compact image code", IEEE Trans. On Communications, Vol. 31, No. 4, pp. 532-540, 1983.

Prokop, J.Thoracic Img., 18:148-164,2003





3D – Agfa, non-linear transfer

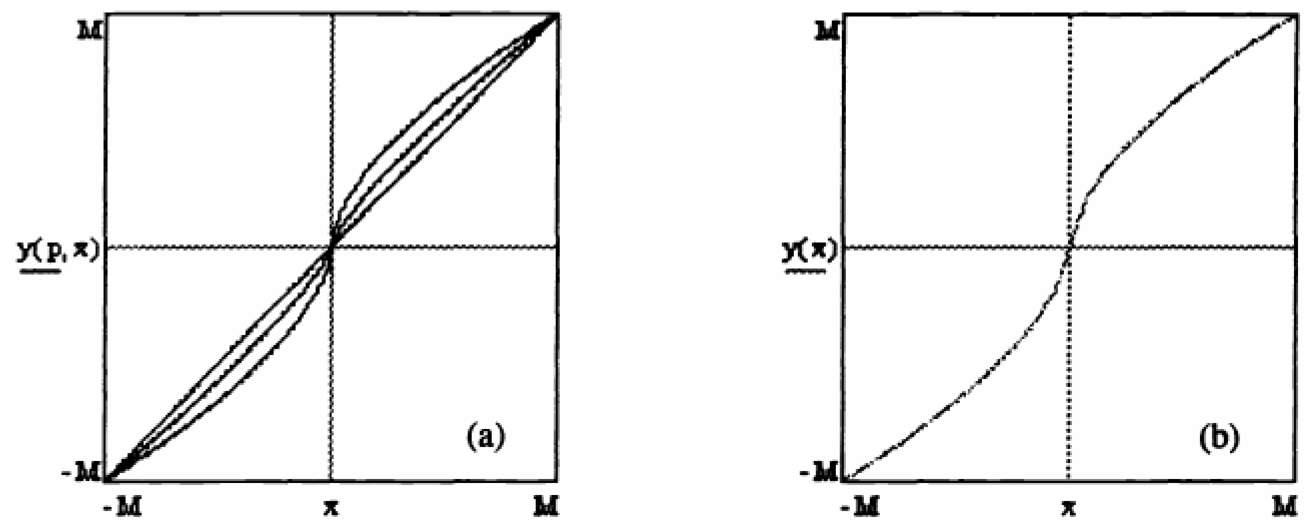
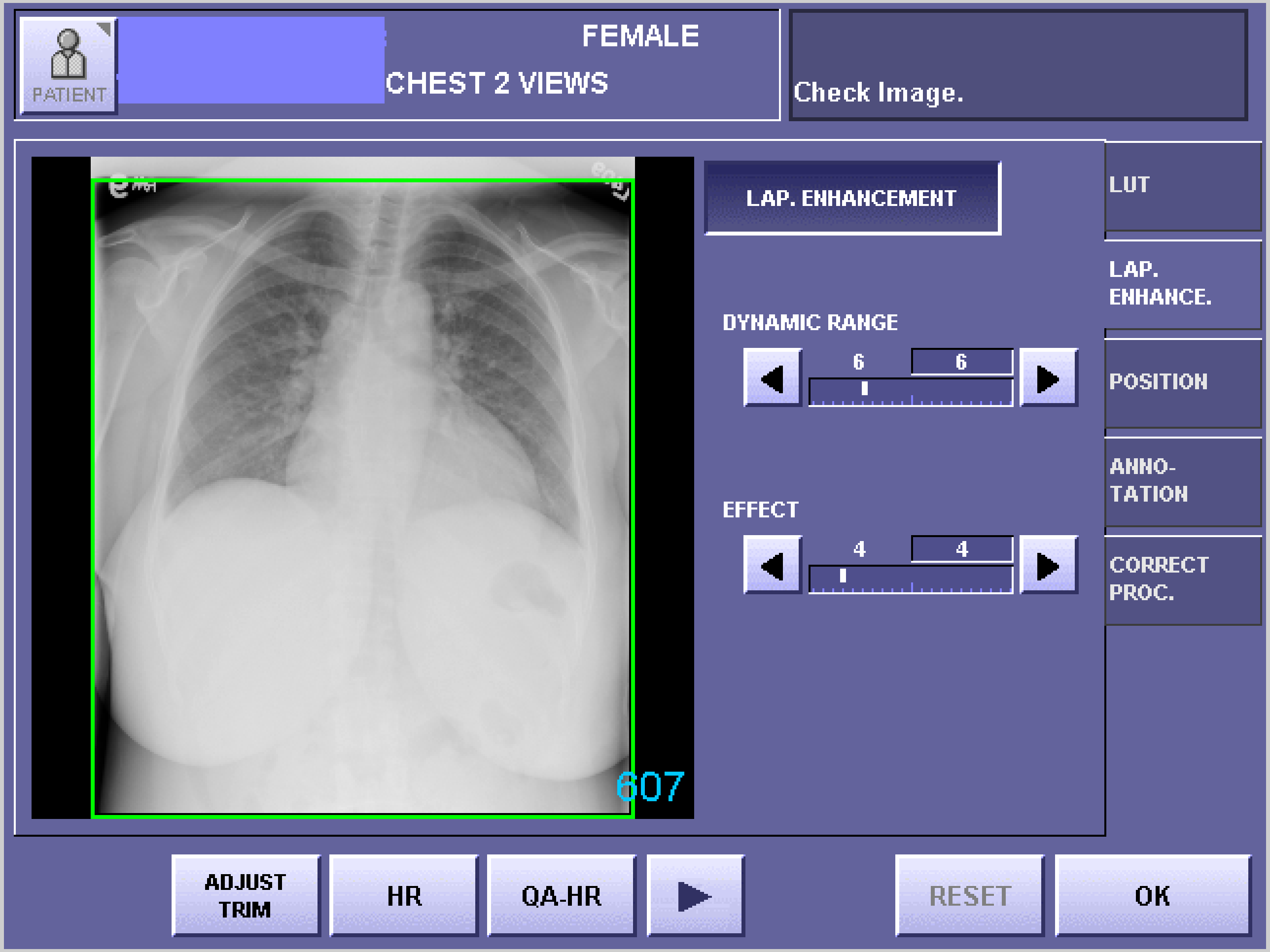


Fig. 5. (a) Power functions for modifying the transform coefficients, exponent values $p = 0.6, 0.8, 1.0$. (b) composite function for modifying transform coefficients $p = 0.6$, with linear part around origin for limiting the amount of amplification.

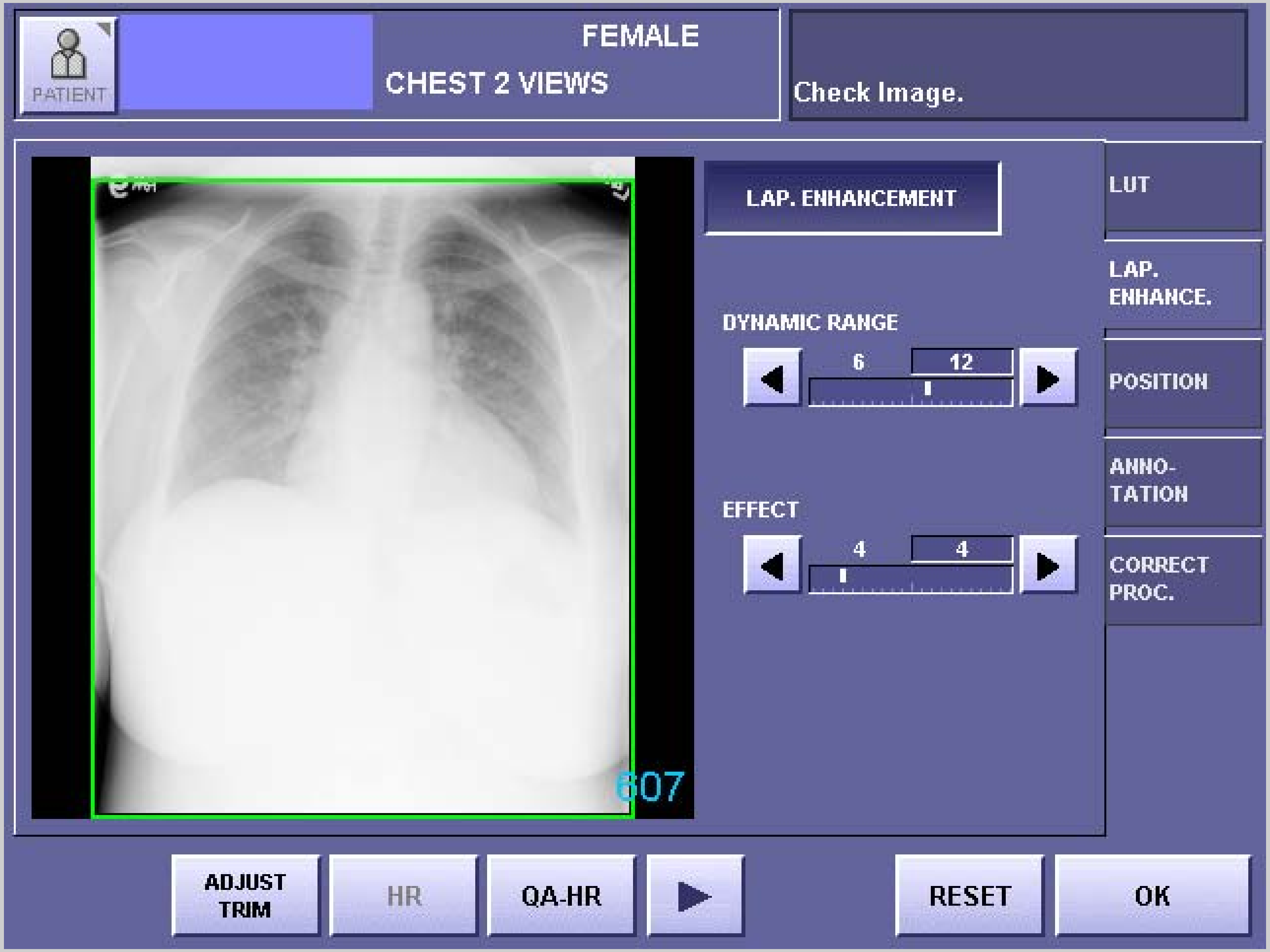
Non-linear transfer functions alter the contrast in each frequency band to amplify small signal contrast while controlling noise.

- The recently released Musica-2 provides a more unified approach to the processing of all bodyparts.
- In general, Musica-2 has the ability to provide more aggressively processed appearance.

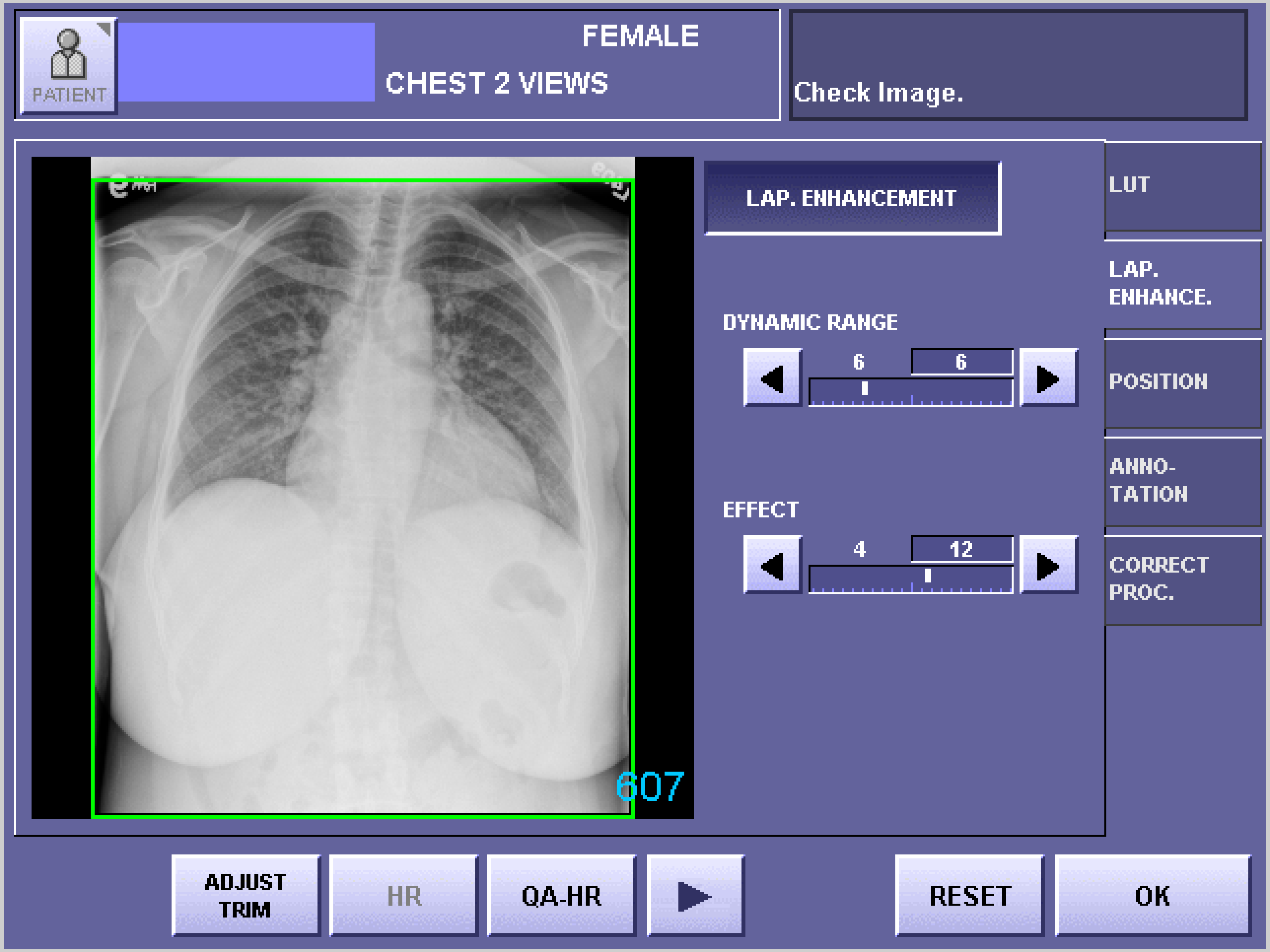
Multi Frequency Adjustment Window



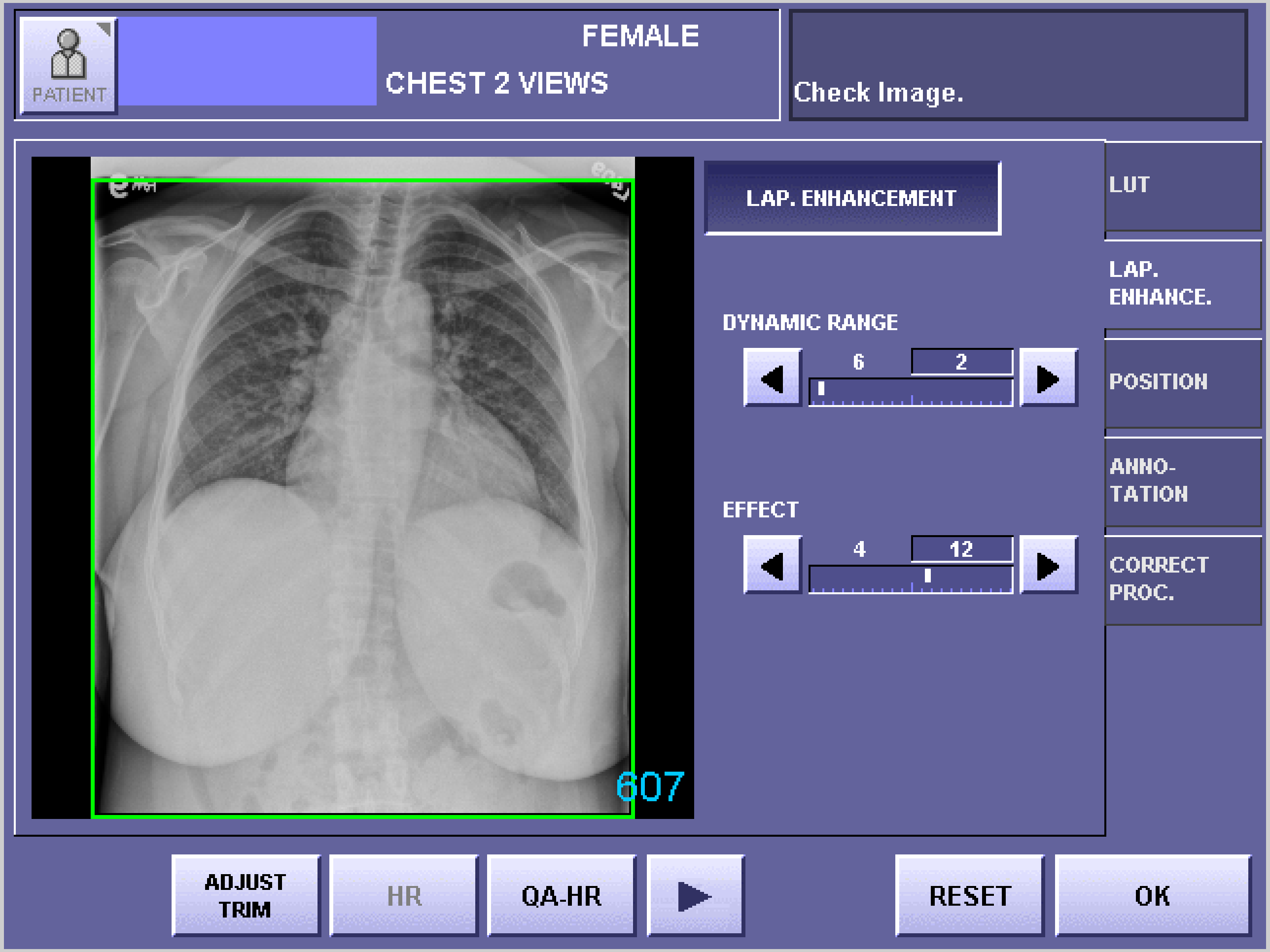
Narrowed Signal Range



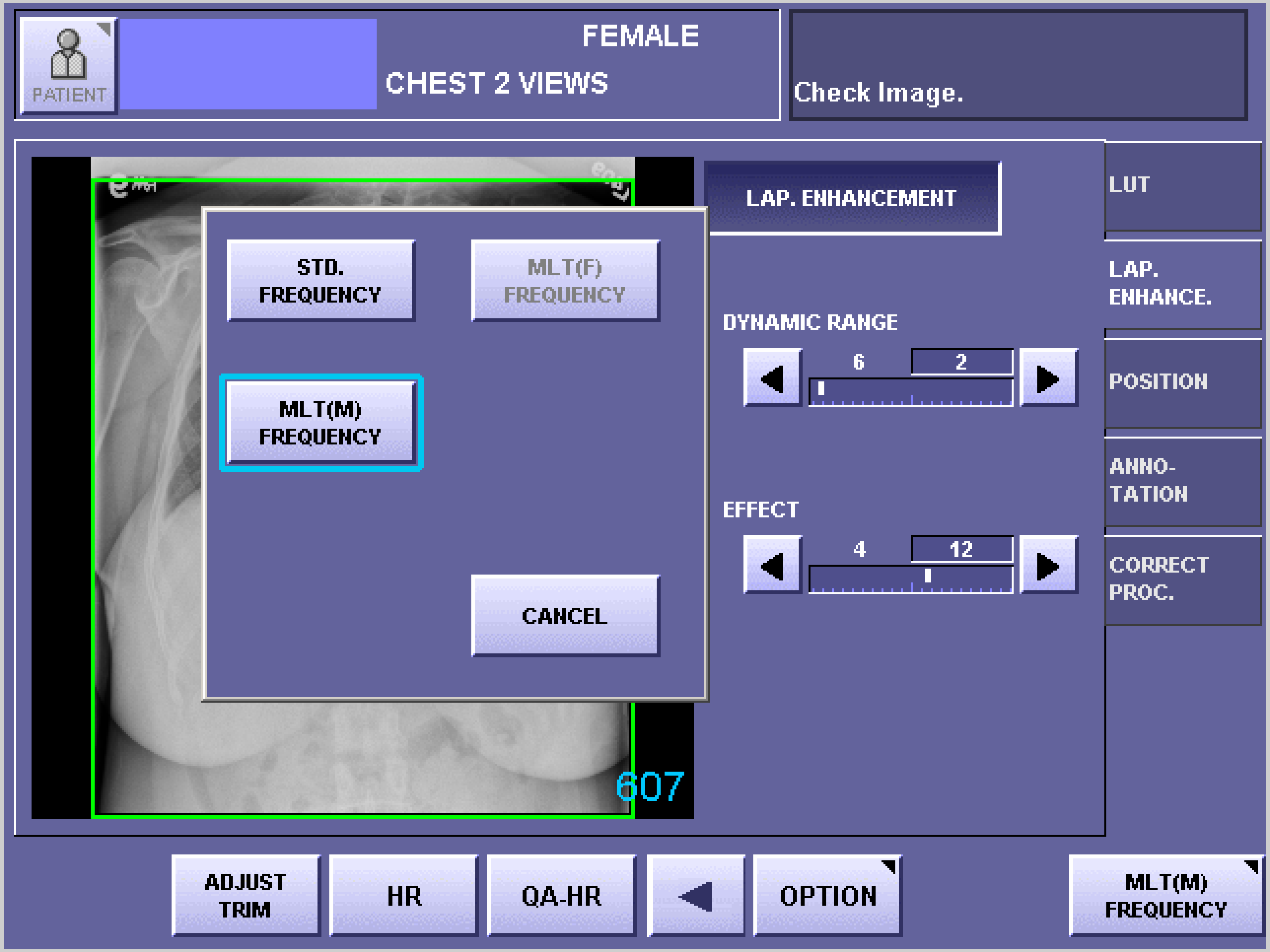
Increased Detail Contrast



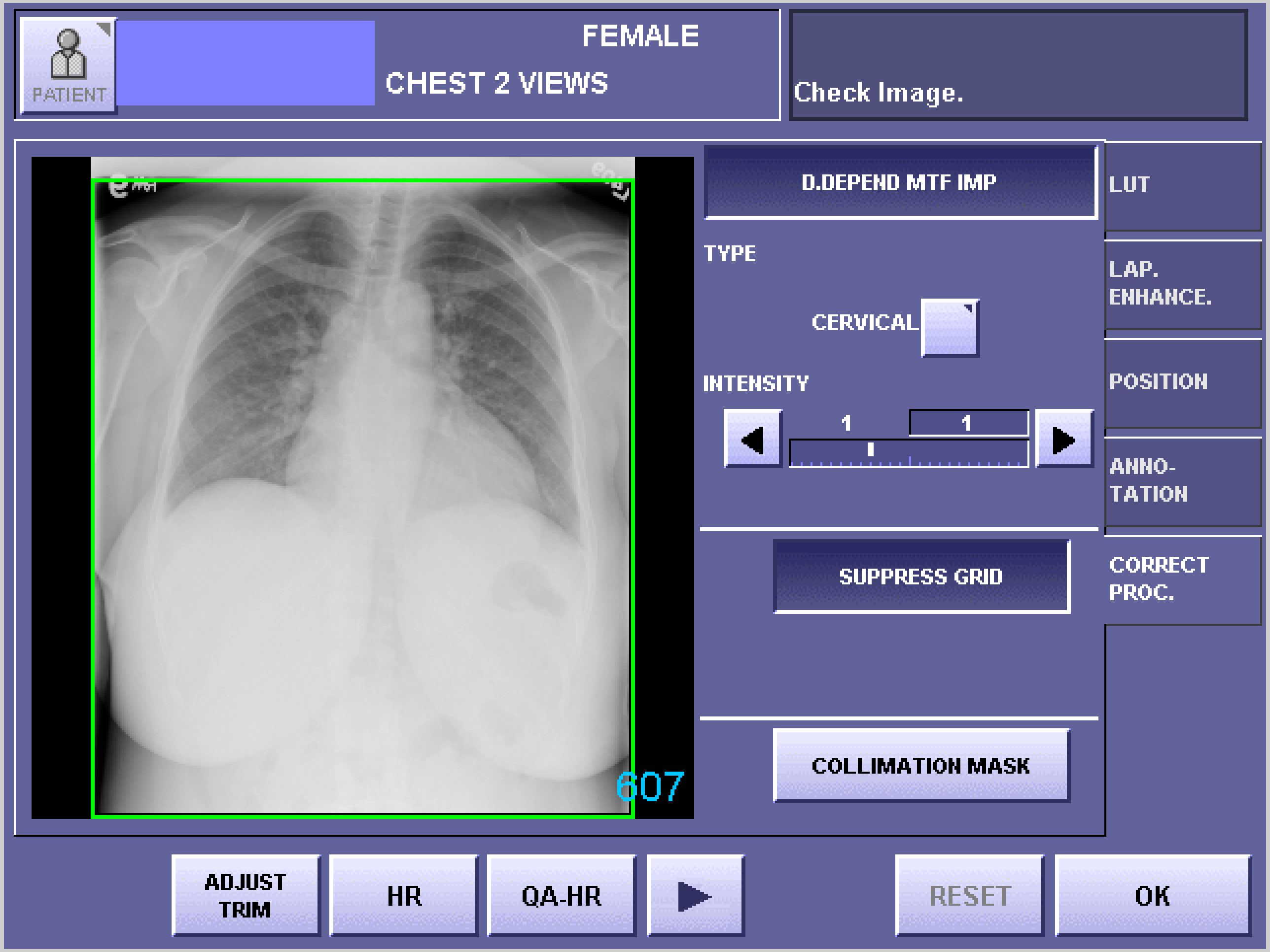
Wide Latitude
High Detail Contrast



Enhancement may depend on licensed options



MTF Dependant Edge Enhancement



In General

- Linear Filters

  Linear filters implemented with Fourier transforms or convolution with large area, variable amplitude kernels can achieve equalization and edge restoration with full control of the frequency transfer characteristics.

- Multi-scale Filters

  Multi-scale filters have coarse control of frequency transfer characteristics but can apply non-linear transformations to achieve noise reduction and prevent high contrast saturation.

- Del Medical Systems Group
- GE Healthcare
- Hologic, Inc
- Imaging Dynamics Co, Ltd
- Infimed Inc
- Konica Minolta Medical Imaging
- Lodox Systems
- New Medical Ltd
- Shimadzu Medical
- Siemens Medical Solutions
- Swissray International
- Vidar Systems Corp.

- Image processing is provided by all CR/DR suppliers under a variety of trade names.
- While the computation approaches differ, the effect on the radiograph is similar.
- The processed digital image can appear very much different that a traditional screen film radiograph.
- It is possible to set up systems from different suppliers to provide similar appearance (but difficult). Harmonized processing is needed.

- Processing parameters for equalization, grayscale rendition, and edge restoration are set specifically for each body part / view that may be done.

- This requires close cooperation between the user and the supplier to set up tables that conform to the body part-view used in a department.

- Dependence on body part size complicates processing

- New industry developments may provide processing software that automatically selects the proper parameters from the image data and makes adjustments for body part size.