Radiography Image Quality and Dosimetry

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Outline

- Radiography imaging geometry and technical factors
- Radiography image quality
  - Image contrast
  - Spatial resolution
  - Noise and Signal-to-noise ratio
  - Image artifacts
- Radiation dose in radiography

Radiography Geometry

- X-rays produced diverge as they travel away from the x-ray tube.
- X-ray beam becomes larger in image area and less intense with increasing distance from the source.
  - Magnification
  - Inverse-square law

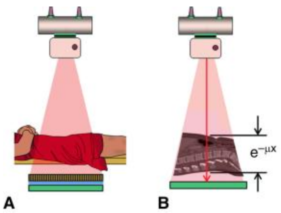
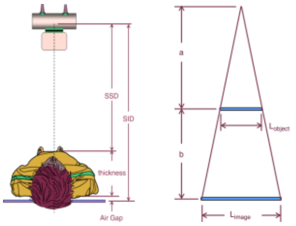


Image Magnification

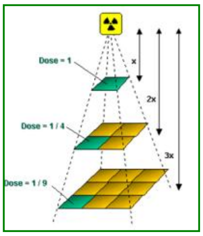
- Because of beam divergence, radiography results in some magnification of the object being imaged.
- The magnification will always be greater than 1.



$$M = \frac{I}{O} = \frac{SID}{SSD}$$

Radiation Dose: Inverse Square Law

- Radiation spreads out as it travels away from the X-ray source.
- The intensity of the radiation follows Newton's Inverse Square Law.
- The intensity of radiation becomes weaker as it spreads out from the source since the same about of radiation becomes spread over a larger area.
- The intensity is inversely proportional to the distance from the source.



Primary Technique Factors

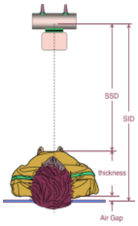
- mA – tube current
- s – duration of exposure
- mAs – controls total number of x-rays
- kVp – maximum electron kinetic energy
- AEC

<u>X-ray Beam Intensity</u>:

- Proportional to mAs
- Proportional to kVp^2

Primary Equipment Factors

- Focal spot size
- Beam filtration
- Field size (collimation)
- Grid use
- Geometry
  - Source-object distance (SSD)
  - Source-image distance (SID)



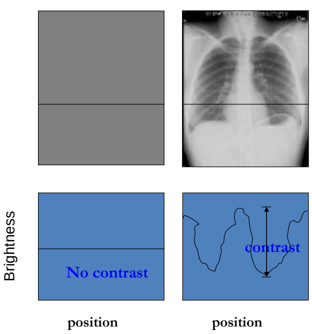
Selection of radiographic technique often involves consideration of trade-offs between various measures of image quality and exposure.

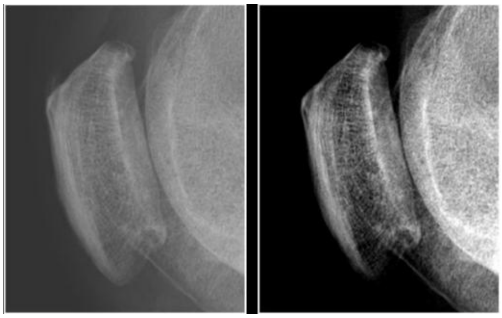
Image Quality

- Goal: to provide adequate image quality necessary to render a reliable diagnostic decision at the lowest possible dose to patient.
- Components of image quality:
  - *Contrast*
  - *Spatial Resolution*
  - *Noise and Signal-to-noise ratio*
  - *Artifacts*

Contrast

- Contrast is the difference in the image gray scale between closely adjacent regions on an image.
- Contrast is generated primarily by differential attenuation of x-rays by different materials within the body.

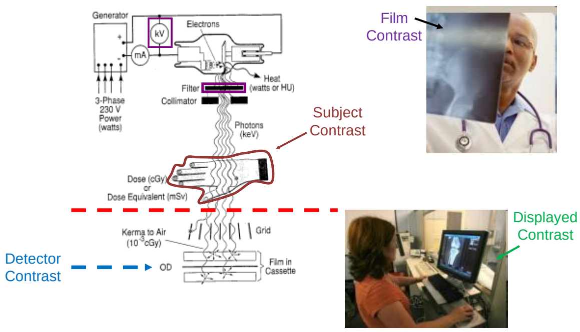




- A low contrast image (left) and a high contrast image (right) of a knee radiograph.

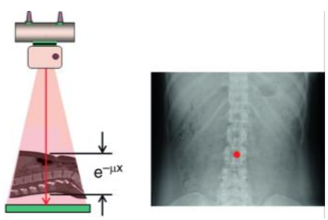
http://external.learn.rsna.org/Kview/CustomCodeBehind/customization/courseware/scorm/rsna_scorm12courseframe.aspx

Levels of Contrast



Subject contrast (C_s)

- Difference of the signal prior to it being recorded.
- A result of Imaging mechanisms, and the patient's anatomy or physiology.
- Affected by changing Imaging parameters



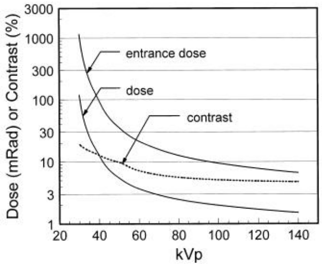
X-ray contrast b/w two features depends on differences in:

thickness

density

composition

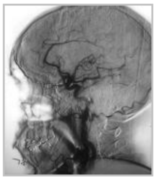
Subject Contrast



- *Linear attenuation coefficient (μ) decreases with increasing kVp*
- *In turn, subject contrast decreases with increasing kVp*

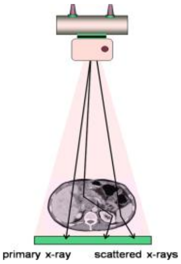
Manipulating Subject Contrast

- Changing parameters of the imaging system
  - kV, mA, exposure time
- Contrast agents
  - Barium – barium enema, barium swallow
  - Iodine – angiography



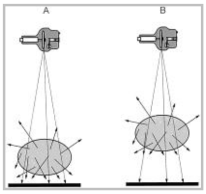
Scatter Steals Contrast

- Scatter to Primary Ratio (S/P): Ratio of scattered to primary x-ray photons exiting the patient
- Can be 5:1 or more
- Depends on:
  - *- X-ray beam energy*
  - *- Patient Thickness*
  - *- FOV*



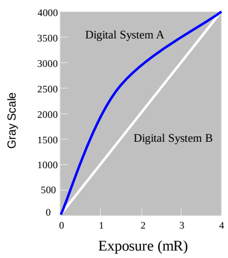
Combat the Effect of Scatter

- Collimation down: anatomy of interest only!!
- Antiscatter Grid:
  - better scatter cleanup
  - Greater patient dose
- Air gap:
  - Scatter ↓↓
  - FOV ↓
  - M ↑ → image blur ↑



Detector Contrast

- Detector's characteristics play an important role in producing contrast in the final image.
- Detector contrast determined principally by how detector maps detected energy to output signal.
- In digital radiography, contrast can be adjusted after image acquisition by various image processing methods.
- Due to the ability to post-process digital images, contrast-to-noise ratio (CNR) is a more relevant description of the contrast than simply the contrast itself.



Digital Image Contrast

- Permits changing the contrast displayed.
- Best example: window/level & look-up table.

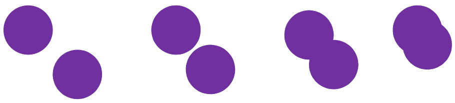
W = 1024, L = 512

W = 512, L = 256

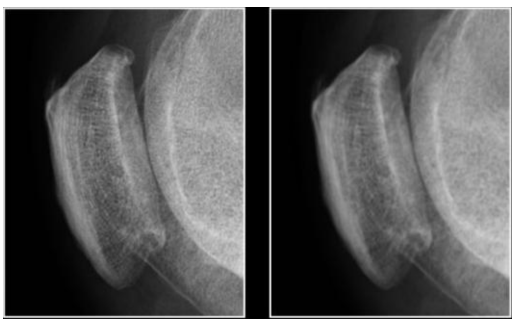
W = 512, L = 768

Spatial Resolution

- Spatial resolution is the ability of a viewer to distinguish two adjacent objects as separate.



- To See Details
- To Detect Objects



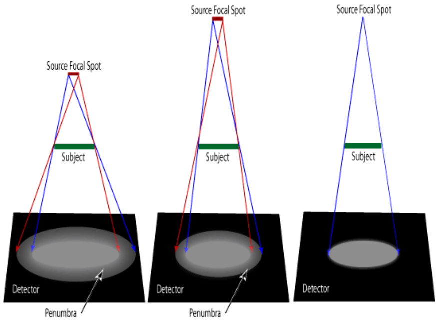
- A high resolution image (left) and a low resolution image (right) of a knee radiograph.

http://external.learn.rsna.org/Kview/CustomCodeBehind/customization/courseware/scorm/rsna_scorm12courseframe.aspx

Where Is Unsharpness From

- Size of focal spot
- Magnification
- Detector resolution
- Patient motion (involuntary, cardiac, etc)
- Image processing

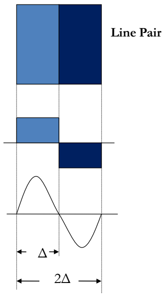
Effect of FS Size and Magnification

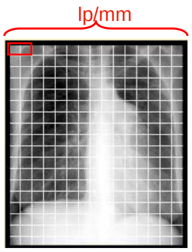


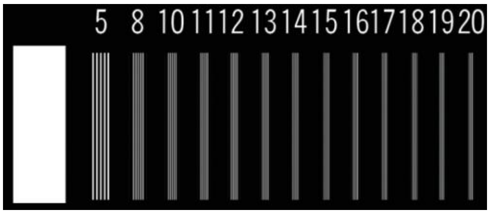
https://www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Graphics/Penumbra1.gif

Spatial Frequency
A Way to Quantify Spatial Resolution

- Spatial frequency: a different way of thinking about the object size
- Spatial frequency: lp/mm (line pair/mm)







- Film-screen system: 6~8 lp/mm
- Digital system: 3~3.5 lp/mm

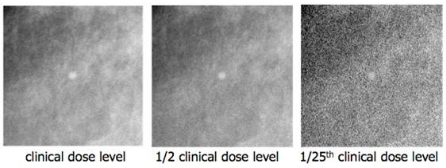
Signal and Noise

- Signal: x-ray attenuation information from patient
- Noise: a structured or random fluctuations or variations within an image that interfere with the ability of the clinician to render an accurate diagnosis.
- Noise can be expressed as a standard deviation (σ) about a mean.
- Signal-to-noise ratio (SNR) is given by

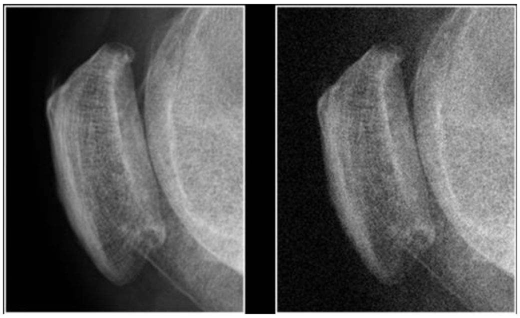
$$\mathrm{SNR} = \frac{\mathrm{Signal}}{\mathrm{Noise}} = \frac{\mathrm{N}}{\sqrt{\mathrm{N}}} = \sqrt{\mathrm{N}}$$

Quantum Mottle

- Quantum Mottle is a significant contributor to the overall image quality.
- It is primarily dependent on the number of x-ray photons used to form the image.
- Noise is minimized primarily by controlling exposure factors.



Few x-rays -- less dose, noisy picture
More x-rays -- more dose, less noisy



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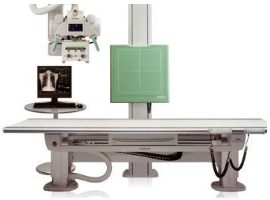
http://external.learn.rsna.org/Kview/CustomCodeBehind/customization/courseware/scorm/rsna_scorm12courseframe.aspx

Image Artifacts

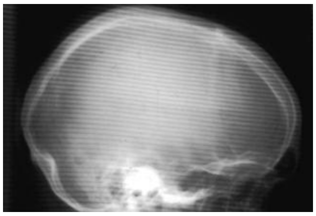
- Image artifacts could arise from any point of the imaging chain.
- Type of radiography artifacts
  - Acquisition artifacts
  - Detector artifacts
  - Image processing artifacts



http://digital-radiology.fujimed.com/images/home/dr-solutions.jpg

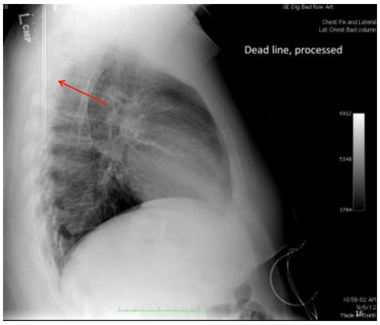
Grid Artifact

- Suppression of grid lines
  - Moving grids or high grid frequency
  - Grid removal software



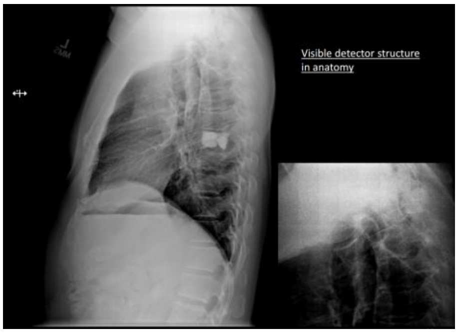
http://www.upstate.edu/radiology/images/education/rsna/radiography/artifact/index_clip_image002_0010.jpg
http://210.0.231.168/Files/AlwaysOnLearning/3646Artifact_in_DR__CR_leungcy.pdf

Detector Artifacts



http://amos3.aapm.org/abstracts/pdf/77-22656-312436-101909.pdf

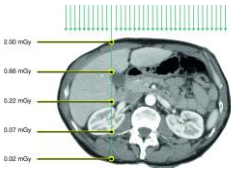
Detector Artifacts

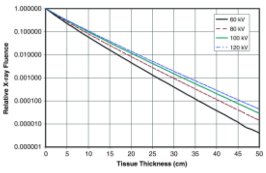


http://amos3.aapm.org/abstracts/pdf/77-22656-312436-101909.pdf

Radiation Dose in Radiography

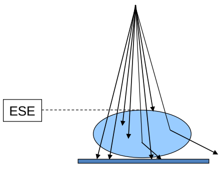
- Absorbed dose in a patient is inhomogeneous and changes with depth in a patient making accurate dose assessment difficult.

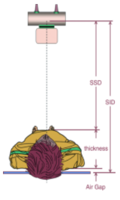


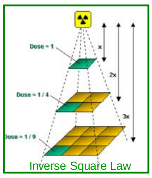


Entrance Skin Exposure (ESE)

- ESE is a clinically practical and conservative way to estimate radiographic patient dose.
- ESE is exposure measured at the surface of skin.
- ESE depends on the source to skin distance, SSD.
- ESE is measured in units of Roentgen (R) or milli Roentgen (mR).







Effective Dose

- Biological tissues vary in sensitivity to the effects of ionizing radiation.
- Effective dose: a tissue-weighted sum of equivalent doses to all relevant tissues and organ.
- It relates the amount of radiation to the health risks of the whole body.
- Tissue weighting factors were established by ICRP.
- Effective dose is expressed in Sv or rem.

Radiation Dose to Patients from Common Imaging Exams

Procedure		Approximate effective radiation dose	Comparable to natural background radiation for
ABDOMINAL REGION	Computed Tomography (CT) — Abdomen and Pelvis	10 mSv	3 years
	Computed Tomography (CT) — Abdomen and Pelvis, repeated with and without contrast material	20 mSv	7 years
	Computed Tomography (CT) — Colonography	6 mSv	2 years
	Intravenous Pyelogram (IVP)	3 mSv	1 year
	Radiography (X-ray) — Lower GI Tract	8 mSv	3 years
	Radiography (X-ray) — Upper GI Tract	6 mSv	2 years
BONE	Radiography (X-ray) — Spine	1.5 mSv	6 months
	Radiography (X-ray) — Extremity	0.001 mSv	3 hours
CENTRAL NERVOUS SYSTEM	Computed Tomography (CT) — Head	2 mSv	8 months
	Computed Tomography (CT) — Head, repeated with and without contrast material	4 mSv	16 months
	Computed Tomography (CT) — Spine	6 mSv	2 years
CHEST	Computed Tomography (CT) — Chest	7 mSv	2 years
	Computed Tomography (CT) — Lung Cancer Screening	1.5 mSv	6 months
	Radiography — Chest	0.1 mSv	10 days

Organ Dose

- Organ dose: the probability of stochastic effects (mainly cancer induction) as the absorbed dose averaged over an organ.
- The most accurate way to assess patient dose.
- Organ dose is expressed in Gray or rad.
- <u>Patient specific</u>: age, gender, body size and organ radiosensitivity are considered.

UNSCEAR 2000 Report

- Effective dose should not be used directly for estimating detriment from medical exposure.
- Such assessments would be inappropriate and serve no purpose in view of the uncertainties arising from potential demographic differences (in terms of health status, age and sex), between particular population of patients and those from general populations for whom ICRP derived the risk coefficients.
- It is possible to use effective dose for medical diagnostic exposure as long as this is done only for comparative purposes and for the same or similar patient populations.

Factors Contributing to Image Quality and Dose

- Technical factors (kVp, mAs)
- Image geometry and magnification (SID, SSD)
- Focal spot size
- Beam filtration
- Collimation (field size)
- Grid
- Detector performance
- Image processing

Image Quality and Dose Optimization

- Image quality and dose often go hand in hand.
- Typically a higher dose can provide less noise and better image quality.
- Optimization needs to include both the acquisition and the processing factors.
- For any particular application, it is important that the imaging procedures are performed in an optimized fashion providing the highest image quality at the lowest possible patient dose.

References

- Bushberg et.al. The Essential Physics of Medical Imaging, 3rd Edition, Lippincott Williams & Wilkins, 2012
  - Chapter 4.1~4.9, 7.6, 11.7
- RSNA/AAPM Physics Modules
  - Projection X-ray Image: (4) Image quality and dose in radiography