Image Quality
Bushberg – Chapter 10
RSNA & AAPM Physics Curriculum: Module 7
Lecture 2 of 2

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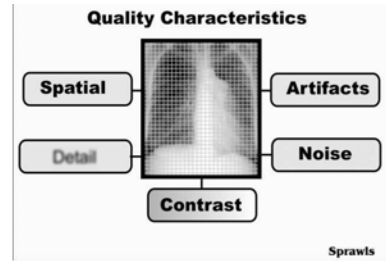
a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html

Module 7: Basic Imaging Science & Technology: Module 7 Curriculum



7.1 Basic Statistic
review on your own
Bushberg chapter 10 (pg 274-277)

7.2 Image Properties
- 7.2.1 Image Representations
- 7.2.2 Contrast (LCR)
- 7.2.3 Spatial Resolution (HCR)
- 7.2.4 Noise
- 7.2.5 Dynamic Range
- 7.2.6 Contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), detection efficiency (DQE)
- 7.2.7 Temporal Resolution
- 7.2.8 Sampling and Quantization

http://www.sprawls.org/resources/DIGRAD/imgchar.jpg

Module 7: Basic Imaging Science & Technology: Module 7 Curriculum

7.3 Image Processing
- 7.3.1 Pre-processing
- 7.3.2 Segmentation
- 7.3.3 Grayscale processing
- 7.3.4 Frequency processing
- 7.3.5 Reconstruction
- 7.3.6 Three-dimensional
- 7.3.7 Image fusion/registration
- 7.3.8 Computer-aided detection and diagnosis

7.4 Display Characteristics & Viewing Conditions

7.5 Perception

7.6 Informatics

Module 7 Curriculum:
Image Properties

Contrast

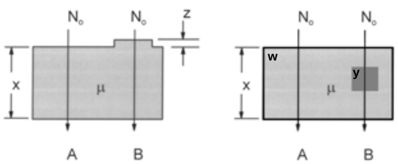
- The difference in the image grayscale between two closely adjacent regions on the image
- Contrast in an image is a direct result of image acquisition, processing, and display
- Subject contrast vs detector contrast
- **Subject contrast** – *BEFORE* the signal is recorded; the measureable difference in signal that is the consequence of spatially dependent events or time-dependent phenomena (e.g. DSA or MRI)
  - Different interactions between the type of energy used in a modality (e.g. x-rays or MR signal) and the patient's anatomy/physiology

Module 7 Curriculum:
Image Properties

Contrast

- **<u>Subject contrast</u>**

$$C = \frac{A-B}{A}$$



- On the left: homogeneous beam of photons incident on a slab of tissue with linear attenuation coefficient μ and thickness x; additional attenuation through a thickness (x + z) which results in contrast b/w A & B
- On the right: in a patient, a pulmonary nodule filling what would be air in the lungs
  - Subject contrast increases if:
    - Difference in thickness (A vs B) increases
    - Difference of linear attenuation coefficients (μ) of materials 'y' and 'w' increases; however, <u>μ is also dependent on energy of incident photons</u>

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 257.

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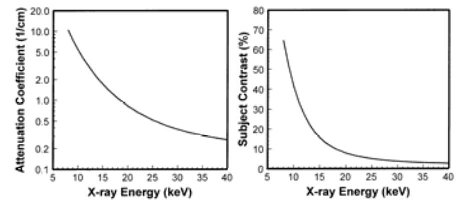
Module 7 Curriculum:
Image Properties

Contrast

- **<u>Subject contrast</u>**
  - Mammography – breast tissue exhibits low x-ray contrast at conventional x-ray energies (35-70 keV), but if the attenuation properties of the breast tissue are exploited, by lowering the incident x-ray energy, there is an increases in soft tissue contrast



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 258.

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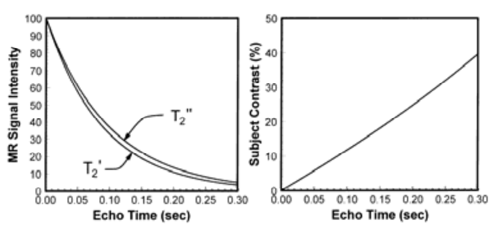
Module 7 Curriculum:
Image Properties

Contrast

- **<u>Subject contrast</u>**
  - MRI – contrast is related to the nuclear relaxation properties of tissues; two adjacent tissues have different T2 relaxation constants
    - Increasing the echo time (TE) increases subject contrast
    - Example of time-dependent tissue properties affects the spatial contrast in the image



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 258.

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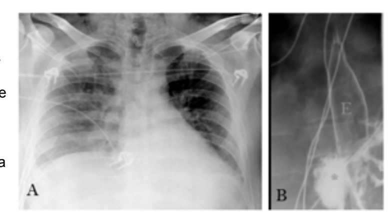
Module 7 Curriculum:
Image Properties

Contrast

- **<u>Subject contrast</u>**
  - Contrast agents
    - Air
      - "negative" contrast agent – lower μ than soft tissue or bone
    - Barium – visualized in GI tract
      - High attenuation properties – high atomic number and physical density (both increase photoelectric absorption)

Example: The example below shows a patient's chest film (Figure 18A), where the esophagus is not even visible, and a study where an oral contrast agent was given to the patient (Figure 18B). In Figure 18B the contrast material can be seen as very white. It outlines the normal esophagus (E) but also leaks out of the esophagus (*) indicating that this patient has a ruptured esophagus which is leaking.



c.f. RSNA Online Physics Modules – Basic Concepts in Radiography.

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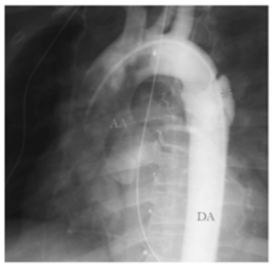
Module 7 Curriculum:
Image Properties

Contrast

- **Subject contrast**
  - Contrast agents
    - Iodine – intravenous or intraarterial injections
      - High attenuation properties – high atomic number and physical density (both increase photoelectric absorption)



Example: Ordinarily the vessel would be invisible on a radiographic image. When contrast (typically an iodine-containing agent) is given, however, the vessels can easily be identified, as shown in this aortogram. Here the ascending aorta (AA) and descending aorta (DA) are visible because of the injected contrast. Also visible is a tear in the aorta (*) which occurred as the result of a motor vehicle accident

c.f. RSNA Online Physics Modules – Basic Concepts in Radiography.

Module 7 Curriculum:
Image Properties

Contrast

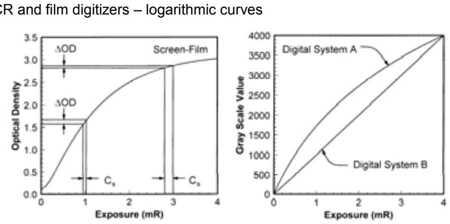
- **Detector contrast**
  - Small changes in input energy striking the detector (i.e. subject contrast) can result in concomitant changes in the registered signal (i.e. image contrast)
  - Therefore, detector characteristics play an important role in the final image contrast
  - Detector contrast – principally determined by how the detector "maps" detected energy interactions into an output signal (ultimately the image contrast can either be amplified or washed out)
    - Detector efficiency
    - Characteristic curves (e.g. H&D curve in SF radiography) show how input energy is mapped to output signal

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 258.

Module 7 Curriculum:
Image Properties

Contrast

- **Detector contrast**
  - Screen-film systems – radiographic contrast is the change in optical density (ΔOD) due to the non-linear characteristics of the H&D curve
  - Digital systems – contrast is the slope of the characteristic curve
    - Some linear characteristic curves
    - CR and film digitizers – logarithmic curves



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 259-260.

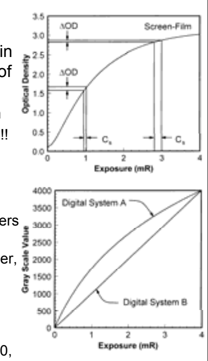
Module 7 Curriculum:
Image Properties

Contrast

- **Detector contrast**
  - Screen-film systems – radiographic contrast is the change in optical density (ΔOD) due to the non-linear characteristics of the H&D curve
    - Contrast = $OD_A - OD_B$ where A & B are different region on film
    - ***Contrast cannot be adjusted or enhanced on analog films***!!!
    - More info in Chapter 6 on SF combinations, H&D curves, etc
  - Digital systems – contrast is the slope of the characteristic curve
    - Some linear characteristic curves, but most CR and film digitizers are logarithmic curves
    - Digital processing – subtraction of a constant & arbitrary number, k (an offset value); recall the contrast equation

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

    - If k = A/2, contrast is doubled; if A = k contrast is infinite; if k < 0, contrast is reduced



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 259-260.

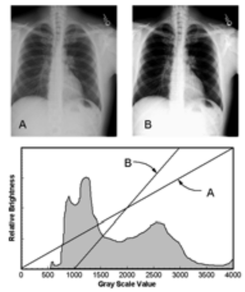
Module 7 Curriculum:
Image Properties

Contrast

- **Detector contrast**
  - Because of arbitrary choice in k, a more useful and frequently used measure of contrast in digital imaging is the **contrast-to-noise ratio** (CNR)

$$CNR = \frac{A - B}{\sigma}$$

  - CNR is not dependent on k, or the digital processing of the image
  - More importantly, CNR is a more relevant description of image contrast potential than the contrast itself
  - ***Display of digital images – appearance can be changed***!!
    - Post-processing
    - Display – look-up tables (window width & level)



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 262.

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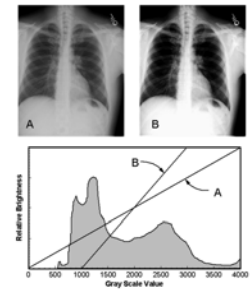
Module 7 Curriculum:
Image Properties

Contrast

- **Detector contrast**
  - Display – 12-bit display = grayscale of 0 to 4095
  - Histogram – shows frequency of each grayscale value used in an image
  - Chest radiographs generally have no values less than 550; adjustment of look-up tables allows for efficient the display system's relative brightness (about 15% waste in grayscale values)
  - **Dynamic range** (also known as **latitude** in SF radiography) – refers to the range of exposures that produce acceptable grayscale values (or ODs in film)
  - Digital systems contrast affected by:
    - Detector characteristics
    - AND choice of display look-up table



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 262.

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Module 7 Curriculum:
Image Properties

Contrast Resolution or Low Contrast Resolution (LCR)

- Detection of low-contrast objects in the presence of noise
  - As noise decreases, contrast is more perceptible
  - Implies more subtle objects (e.g. lesions in the liver) can routinely be seen
  - How do we improve LCR? Recall: the relative noise is the noise perceived by the observer and is related to the number of photons per pixel (and therefore the standard deviation, σ)
    - To improve LCR
      - Decrease noise by increasing # of photons per pixel
      - … but we increase dose (tradeoff!!)
- LCR is related to SNR
  - Rose's criteria – SNR > 5.0 implies probability of detection is ~100%; if SNR < 5, then the probability of detecting low contrast objects in a uniform background is less than 100%

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 262.

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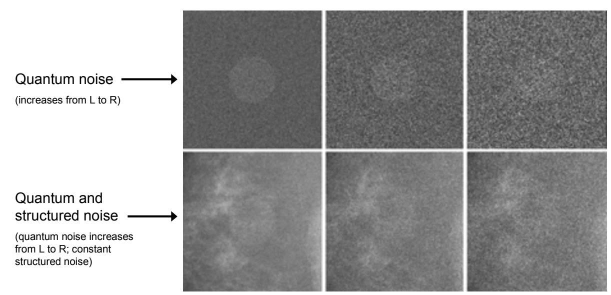
Module 7 Curriculum:
Image Properties

Contrast Resolution or Low Contrast Resolution (LCR)



- Structure noise affects LCR – structured noise from normal anatomy (e.g. breast parenchyma) can mask subtle lesions and reduces LCR

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 281.

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Module 7 Curriculum:
Image Properties

Sampling

- Nyquist criterion (or limit) – our conceptual sinusoidal input signal needs to be sampled such that each cycle is sampled at least twice; if Δ = spacing between samples

$$F_N = \frac{1}{2\Delta}$$

- If the frequency component (sampling frequency) exceeds the Nyquist frequency, it will be sampled less than twice per cycle, and it will be aliased (high-frequency signal is wrapped back onto the image at a low-frequency)
  - UNDERSAMPLING results in aliasing – can occur in time or space
- Important for MRI (frequency/phase encoding of k-space), ultrasound (transmit/receive pulses, Doppler U/S), fluoroscopy (temporal aliasing, e.g. heart beating faster than the image acquisition rate will result in a heart beat that appear to be slower than reality)

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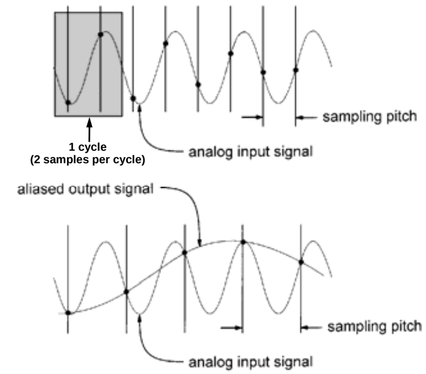
Module 7 Curriculum:
Image Properties

Sampling



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 284.

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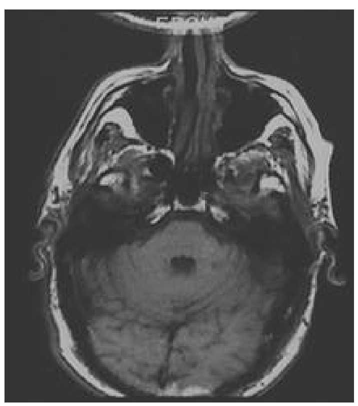
Module 7 Curriculum:
Image Properties

Sampling



c.f. http://www.mritutor.org/mritutor/alias.htm

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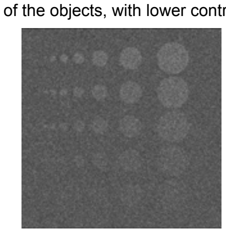
Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Contrast-Detail (C-D) Curves
  - DQE(f) is a good *quantitative* way to combine the concepts of spatial resolution (MTF(f)) and contrast resolution (SNR) of an imaging system
  - *Qualitative* to combine both spatial and contrast resolution is a C-D curve
  - The x-axis of the C-D phantom corresponds to the size of the objects (detail), with smaller objects toward the left
  - The y-axis corresponds to the contrast of the objects, with lower contrast towards the bottom of the image



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 287.

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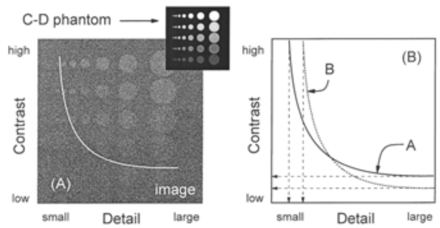
Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Contrast-Detail (C-D) Curves
  - As the objects get smaller and lower in contrast, their SNR is reduced and they become harder to see on the image
  - The white line on the image corresponds to the transition zone, where objects above and to the right are visualized, and objects below and to the left of the line are not seen



System A – higher spatial resolution, lower contrast resolution

System B – lower spatial resolution, higher contrast resolution

Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Receiver Operating Characteristics (ROC) Curves
  - Compare diagnostic abilities or diagnostic performance of a system
  - Diagnostic goal: separate normal from abnormal subjects
    - Usually significant overlap in terms of appearance on image – some normal patients have abnormal-looking films and vice versa
    - Decision criterion – based on a number of criteria or factors that yield an overall impression
    - While there is usually an overall in normal vs abnormal, radiologists are charged with making a diagnosis: either normal (L) or abnormal (R)

THE 2 × 2 DECISION MATRIX

	Actually Abnormal	Actually Normal
Diagnosed as Abnormal	True Positive (TP)	False Positive (FP)
Diagnosed as Normal	False Negative (FN)	True Negative (TN)

Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Receiver Operating Characteristics (ROC) Curves
  - The <u>true-positive fraction</u> *(TPF) – probability of detection*

$$TPF = \frac{TP}{TP + FN}$$

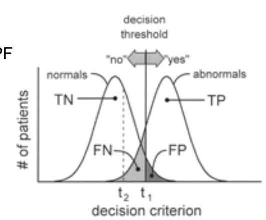
  - The <u>false-positive fraction</u> *(FPF) – probability of a false alarm*

$$FPF = \frac{FP}{FP + TN}$$

  - The ROC curve is a plot of the TPF versus the FPF

THE 2 × 2 DECISION MATRIX

	Actually Abnormal	Actually Normal
Diagnosed as Abnormal	True Positive (TP)	False Positive (FP)
Diagnosed as Normal	False Negative (FN)	True Negative (TN)



Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

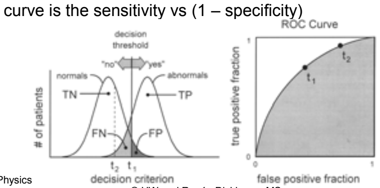
- Receiver Operating Characteristics (ROC) Curves
  - Sensitivity is the fraction of abnormal cases that are actually diagnosed abnormal

    Sensitivity = TPF = probability of detection
  - Specificity is the fraction of normal cases that the radiologist actually diagnosis as normal

    Specificity = 1- FPF = fraction of people w/out disease who test negative

$$Specificity = \frac{TN}{TN + FP}$$

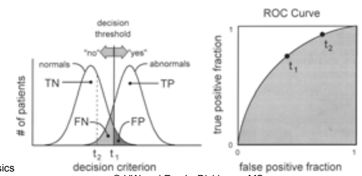
  - An ROC curve is the sensitivity vs (1 – specificity)



Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Receiver Operating Characteristics (ROC) Curves
  - Sliding along the ROC curve allows one to trade-off sensitivity for specificity
  - Example – mammo – a radiologist had a bad experience w/ a lawsuit, so she may subconsciously (or consciously) slide her decision threshold toward better sensitivity, compromising specificity; therefore, her benign biopsy rate would increase relative to that of a colleague



c.f. Bushberg, et al. The Essential Physics Medical Imaging, 2nd ed., pp. 288.

Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Receiver Operating Characteristics (ROC) Curves
  - The positive predictive value (PPV) refers to the probability that the patient is actually abnormal, when the diagnostician says the patient is abnormal

$$PPV = \frac{TP}{TP + FP}$$

  - The negative predictive value (NPV) refers to the probability that the patient is actually normal, when the diagnostician says the patient is normal

$$NPV = \frac{TN}{TN + FN}$$

THE 2 × 2 DECISION MATRIX

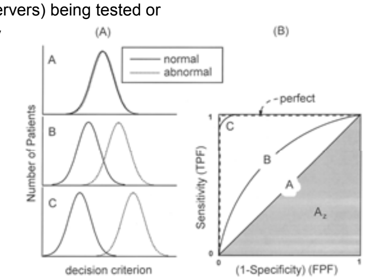
	Actually Abnormal	Actually Normal
Diagnosed as Abnormal	True Positive (TP)	False Positive (FP)
Diagnosed as Normal	False Negative (FN)	True Negative (TN)

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 288.

Module 7 Curriculum:
Image Properties

Viewing Conditions, Display and Perception

- Receiver Operating Characteristics (ROC) Curves
  - The ROC curve is essentially a way of analyzing the SNR associated with a specific diagnostic task
  - A_z: area under the curve – concise description of the diagnostic performance of the systems (including observers) being tested or
  - Measure of detectability
  - A_z = 0.5 guessing
  - A_z = 1.0 perfect



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 291.

Module 7 Curriculum:
Review Questions

Image receptor contrast (as opposed to subject contrast) depends on:

A. H&D characteristic curve of the film.
B. kVp.
C. Screen-film contact.
D. Source-to-image receptor distance (SID).

Module 7 Curriculum:
Review Questions

Low contrast detectability refers to the ability of a system to distinguish:

A. A calcified lung nodule.
B. A non-calcified lung nodule.
C. Between overlying and underlying tissues.
D. The size of a small fracture.
E. Vessels during the arterial phase of a normal angiogram.

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Module 7 Curriculum:
Review Questions

Image contrast-to-noise ratio could not be increased by using:

A. Lower tube voltages
B. Higher-ratio grids
C. Larger x-ray beam areas
D. Screens with lower conversion efficiency
E. Slower films

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Module 7 Curriculum:
Review Questions

Sensitivity is given by:

A. False positive fraction (FPF)
B. True positive fraction (TPF)
C. False negative fraction (FNF)
D. True negative fraction (TNF)
E. Area under ROC curve (A_z)

Specificity is given by:

A. The true-negative fraction (TNF)
B. The true-positive fraction (TPF)
C. (1 – TPF)
D. (1 + TNF)
E. Area under the ROC curve (A_z)

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Module 7 Curriculum:
Review Questions

A ROC curve is used to measure diagnostic imaging:

A. Performance
B. Accuracy
C. Specificity
D. Sensitivity
E. Cost benefit ratio

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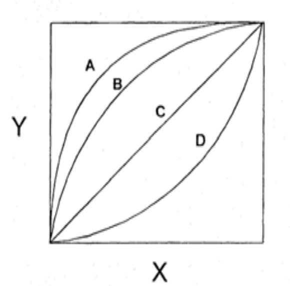
Module 7 Curriculum:
Review Questions

1. In Figure 5, showing an ROC curve, the X-axis should be labeled (circle all that are correct):

2. In Figure 5 showing the ROC curves, the Y-axis should be labeled (circle all that are correct):

   A. True Positive Fraction
   B. False Positive Fraction
   C. Sensitivity
   D. Specificity
   E. 1 – Specificity

Figure 5:



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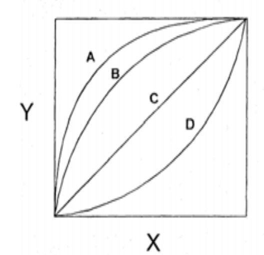
Module 7 Curriculum:
Review Questions

1. Curve letter ___________ represents pure guessing.

2. Curve letter ___________ represents the best diagnostic approach.

3. Curve letter ___________ represents an A_z value of about 0.3.

Figure 5:



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