X-ray imaging overview
Radiography & Mammography

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GE Healthcare

Imagination at work.

X-ray imaging

The topics in this presentation:

- Diagnostic radiography, which is 2D projection imaging
- Mammography/Tomosynthesis, which is 2D and 3D breast imaging

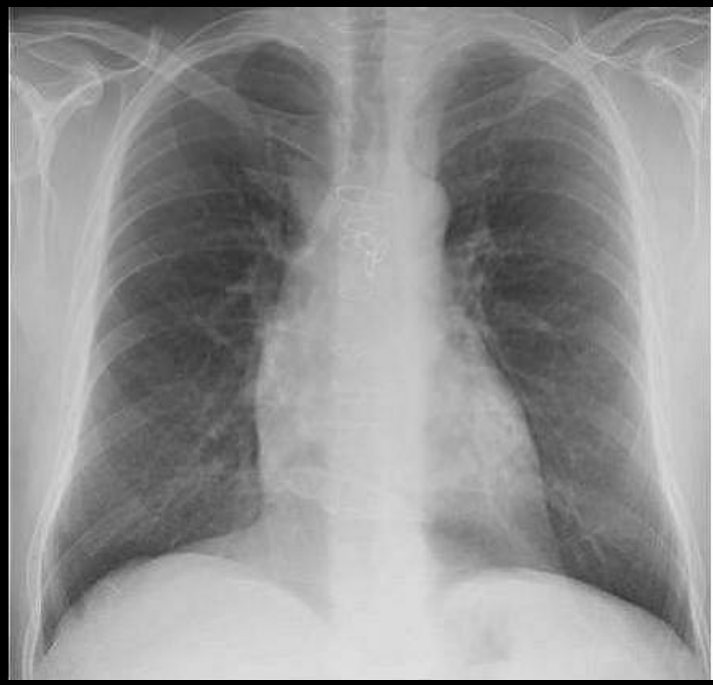
Radiography

Discovery

- Nov., 1895 - Röntgen discovers X-rays in Wurzburg, Germany
  - Observations of fluorescence when using a Crookes tube.
- Initial results published in Dec. 28, 1895, broader announcements in January, 1896.
- In the following months, reports of diagnoses of fractures, bullets, even fluoroscopy, started coming.
- Late in 1896, Siemens & GE started selling X-ray equipment.

X-Ray introduction

- X-radiation (composed of X-rays) is a form of electromagnetic radiation. Most X-rays have a wavelength in the range of 0.01 to 10 nanometers
- Due to their penetrating ability, X-rays are widely used to image the inside of objects, e.g., in medical radiography and airport security
- The major components of X-Ray radiography is a source (X-ray tube) and a detector

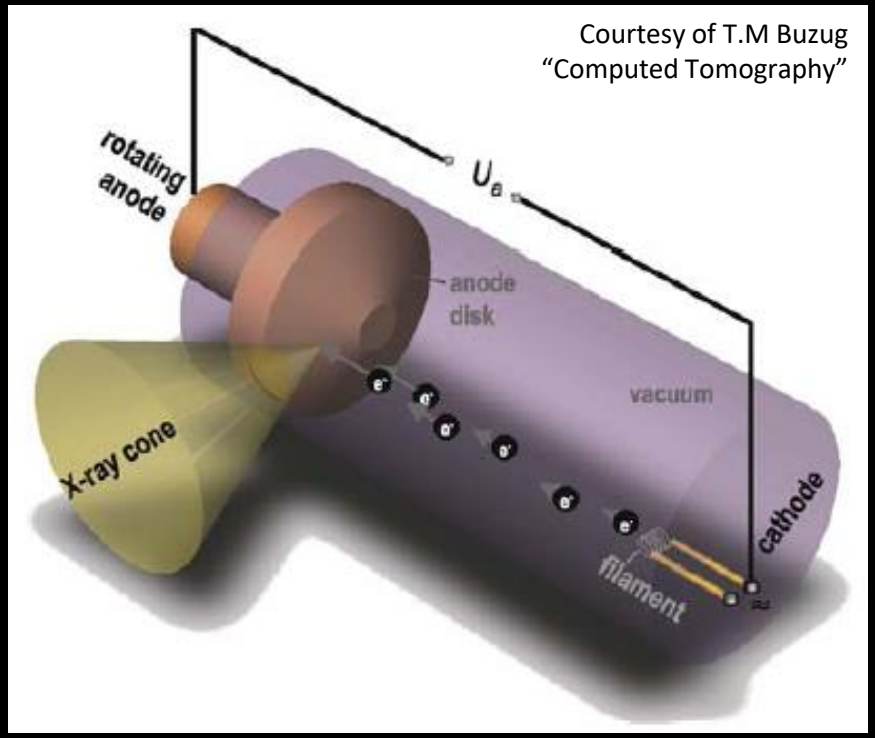


Chest X-ray

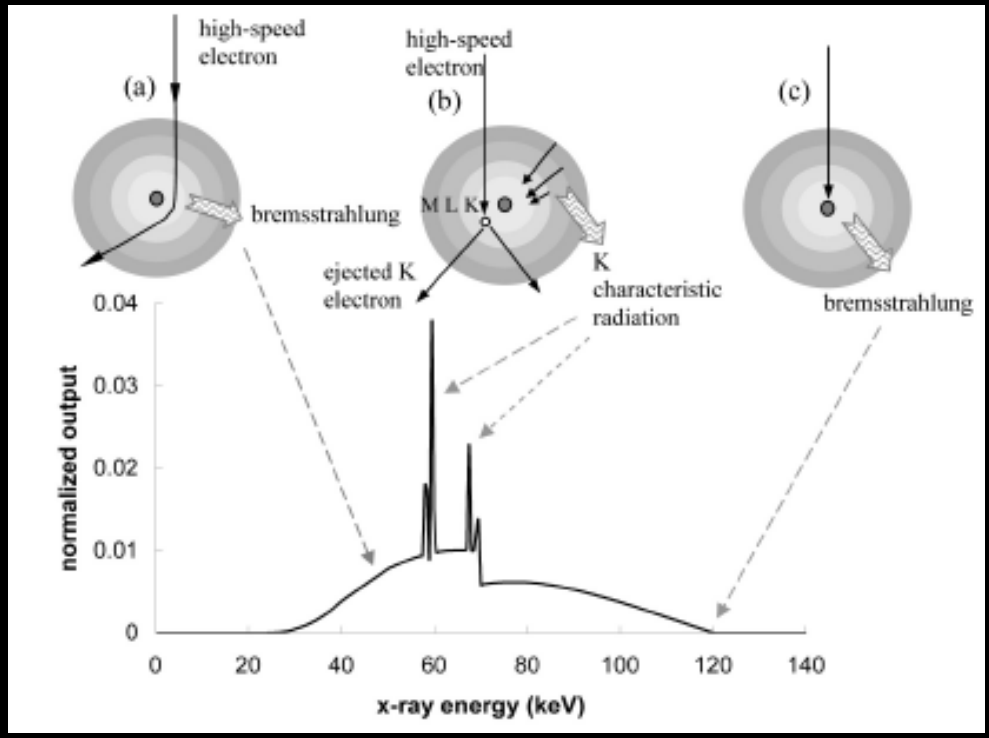
X-Ray tube

- Electrons are accelerated in an electric field between a cathode and anode. X-ray radiation emerges from the deceleration of the electrons following their entry into the anode material
- The peak X-ray energy is related to the acceleration voltage
- Total number of photons is related to cathode current

Courtesy of T.M Buzug
"Computed Tomography"



An X-ray tube



X-ray spectrum

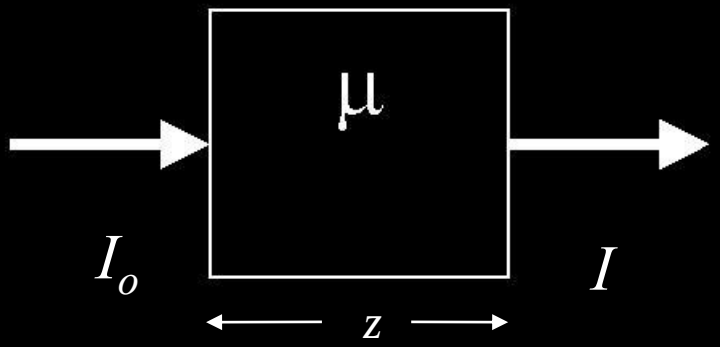
Attenuation Coefficient

For monochromatic x-ray & uniform material,

$$I = I_o \, e^{(-\mu z)}$$

where

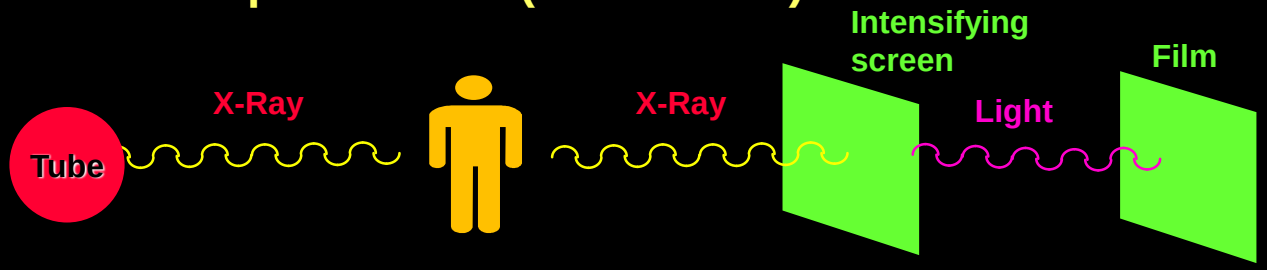
- I is the x-ray intensity at the measurement plane
- Io is the x-ray intensity at the source plane
- z is the thickness of a uniform material with attenuation coefficient μ



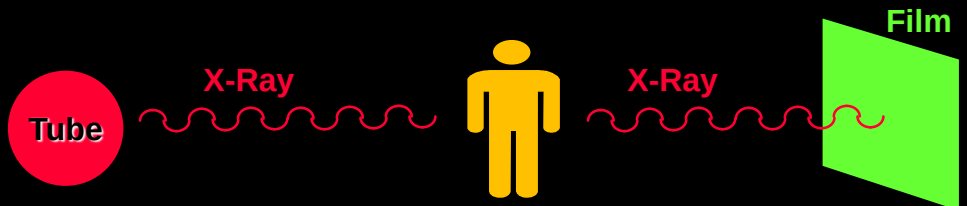
Also known as Beer-Lambert or Beer's Law

Analog Film

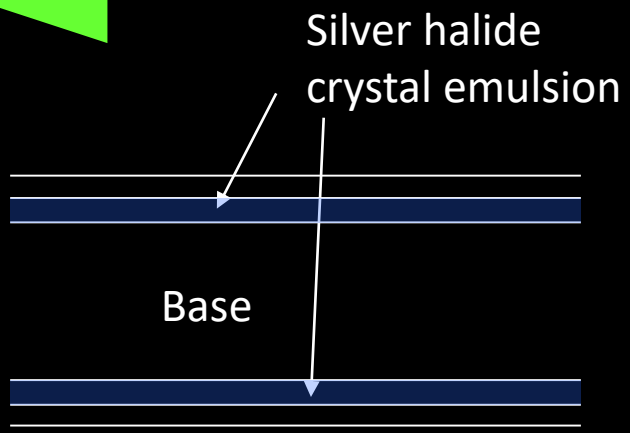
Indirect exposure film (screen film)



Direct exposure film (non-screen film)



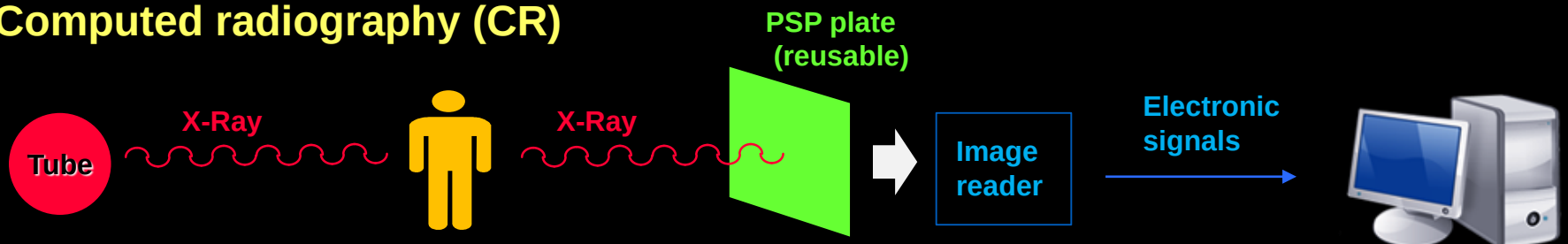
(e.g.) Dental film, Dose monitoring film



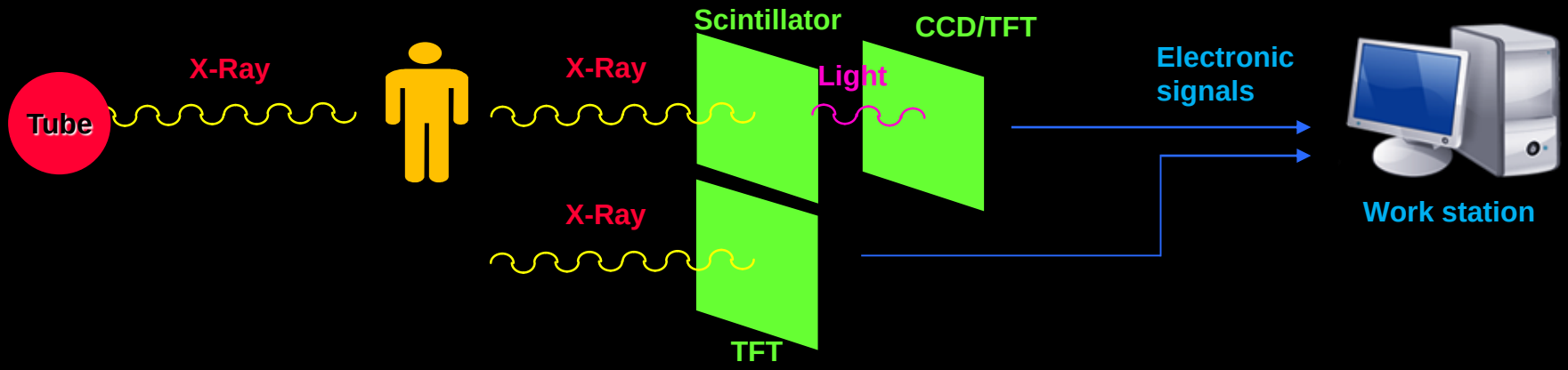
	Screen	Exposed	Resolution	Dose	Characteristic curve
Direct	Without	X-ray	More	More	No shoulder
Indirect	With	Visible light	Less	Less	shoulder

Computed/Digital radiography

Computed radiography (CR)



Digital radiography (DR)

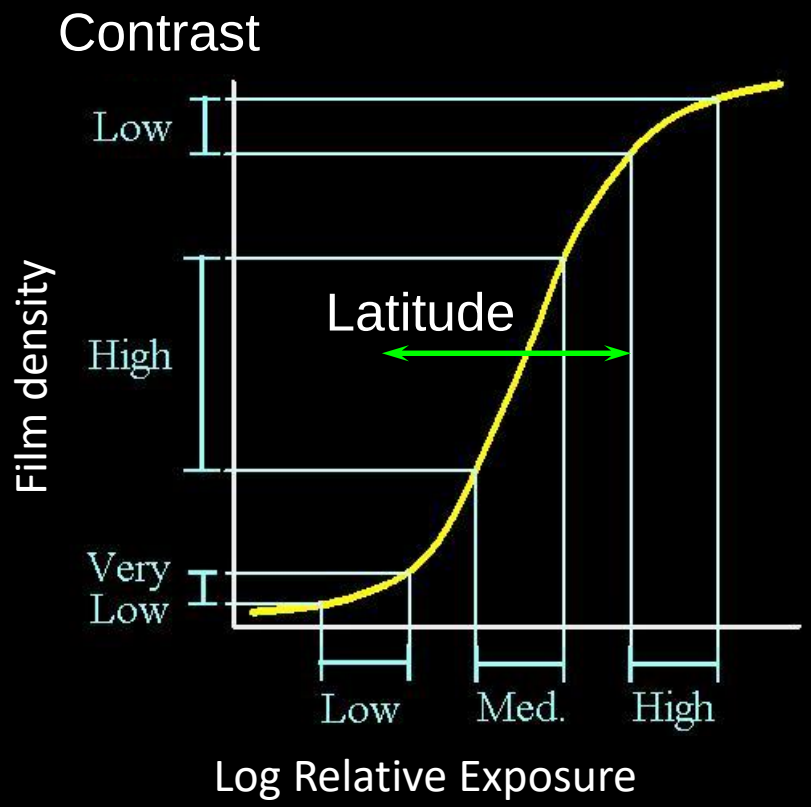


Advantage/Disadvantage

- No maintenance of chemical use & dark room & storage space of films
- Image processing capability
- Spatial resolution is a bit lower than analog film
- Contrast resolution is better than analog film

Dynamic Range (Analog Film)

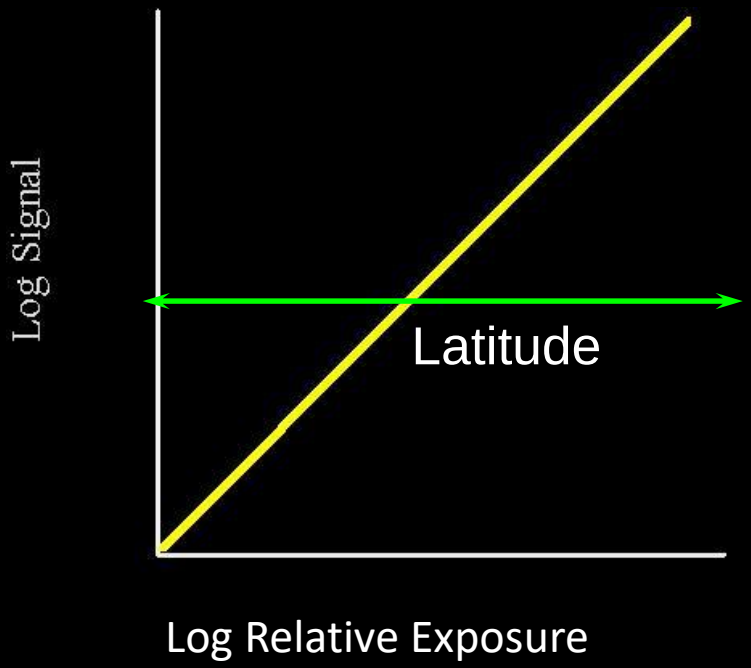
Film Characteristic Curve



- The film may be characterized by a relationship between the X-ray exposure and the resulting film density
- Film density is measured with a densitometer
- There is a trade-off between contrast vs. latitude (dynamic range)
- Analog film has a non-linear response to exposure as shown

Dynamic Range (Digital Detector)

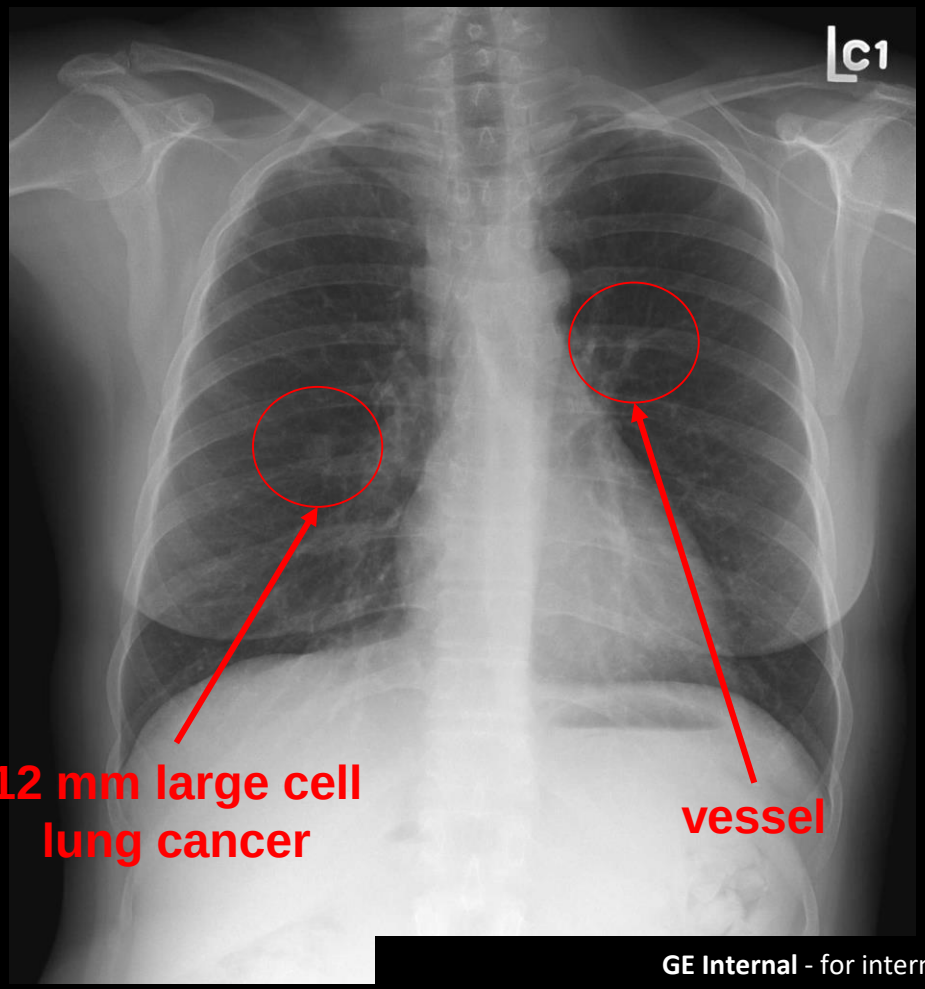
Digital Detector Characteristic Curve



- Digital detector has a linear response to exposure
- The latitude for digital detector is wider than analog film
- This results in a broader range of exposures that will produce an acceptable image

Radiography (Rad)

- Rad is most widely used x-ray procedure
- Both wall stand and table systems in widespread use



Revolution XQ/i

Revolution XR/d

Twin Robots Radiology System

GE Healthcare Mobile X-ray: Ukiah Valley Optima XR240amx Customer Story

https://www.youtube.com/watch?v=hR7mhnE89Xo

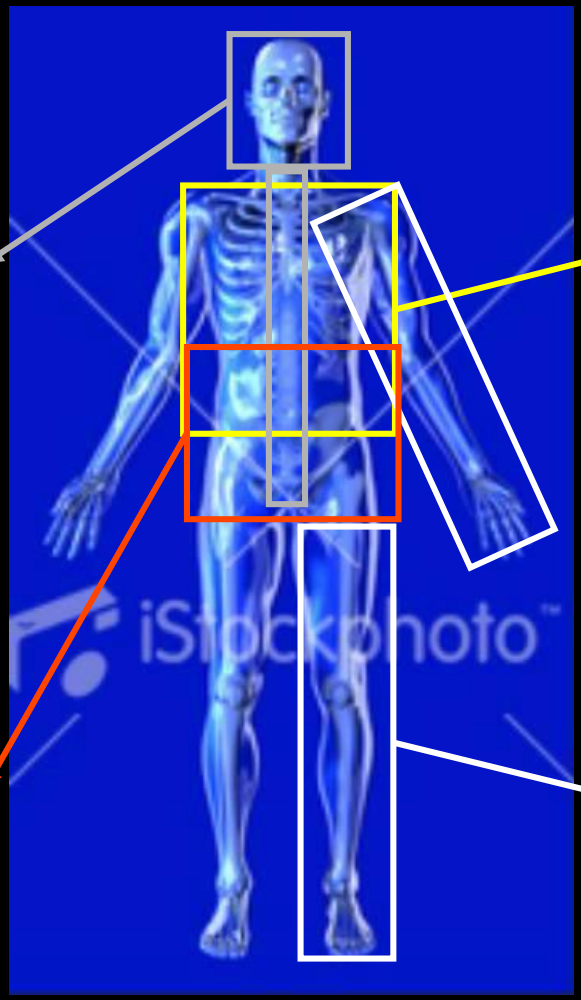
Profile of General Radiography

Spine / Head / Neck:

- Procedures: 48M/16% (US/E)
- Reimb: $154M (Medicare only)
- Diseases:
  - Fractures
  - Trauma
  - Pain management
- Challenges:
  - Fine detail

Abdominal:

- Procedures : 28M/9% (US/E)
- Reimb: $79M (Medicare only)
- Diseases:
  - Cancer
  - Renal stones
  - Obstruction
- Challenges:
  - Dynamic information
  - Fine detail



Thoracic:

- Procedures: 125M/41% (US/E)
- Reimb: $497M (Medicare only)
- Diseases:
  - Cancer (lung)
  - Contagious disease (SARS, bird flu)
  - Infections (occup. disease, pneumonia)
  - Foreign body
- Challenges:
  - Patient throughput, Clinical accuracy, Overlying structures

Extremities and Hip:

- Procedures: 107M/35% (US/E)
- Reimb: $405M (Medicare only)
- Diseases:
  - Fractures (prosthesis)
  - Necrosis
  - Tumors (malignant/benign)
  - Sports injuries
- Challenges:
  - Dynamic information, Fine detail

- >1,000,000 Patients Experience XR each DAY

care

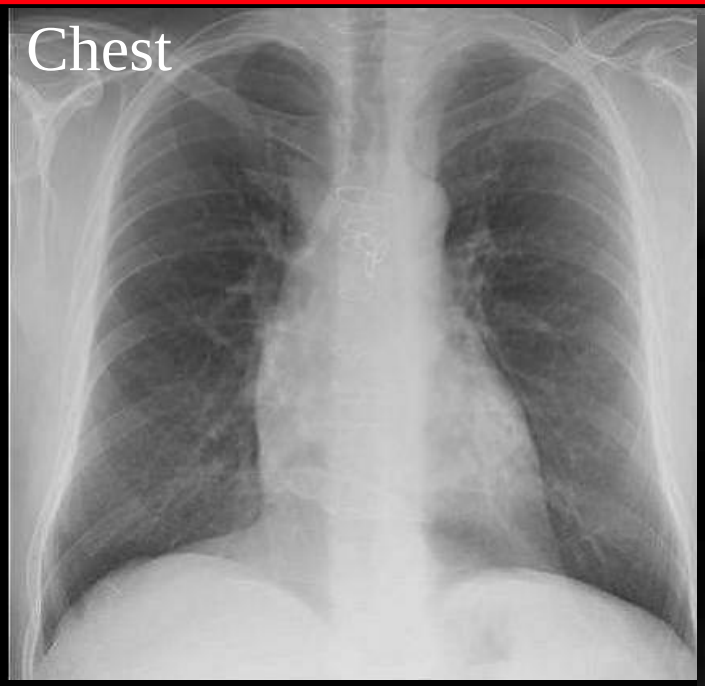
Radiography Is Used For:

- Lung Cancer detection
- Pneumonia
- Emphysema
- Heart Irregularities
- Broken Bones
- Osteoporosis
- Scoliosis
- Arthritis

You will have an X-ray at some point in your life!

Image Examples

Cervical Spine



Chest

Knee

Radiation Dose in X-Ray exams

https://www.radiologyinfo.org/en/info.cfm?pg=safety-hiw_09	Effective radiation dose	Comparable to natural background radiation for:
CT-Abdomen and Pelvis	10 mSv	3 years
CT-Chest	7 mSv	2 years
CT-Head	2 mSv	8 months
Radiography-Spine	1.5 mSv	6 months
Radiography-Extremity	0.001 mSv	3 hours
Radiography-Chest	0.1 mSv	10 days
Radiography-Upper GI Tract	6 mSv	2 years
Bone Densitometry	0.001 mSv	3 hours
Mammography	0.4 mSv	7 weeks

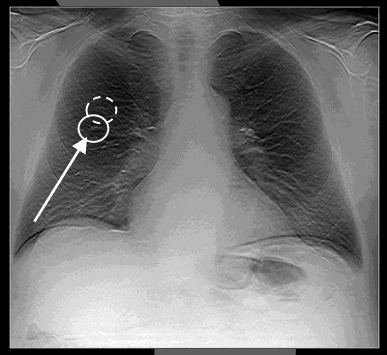
Safety-Xray and CT exams: http://www.radiologyinfo.org, 2014

Advanced Applications

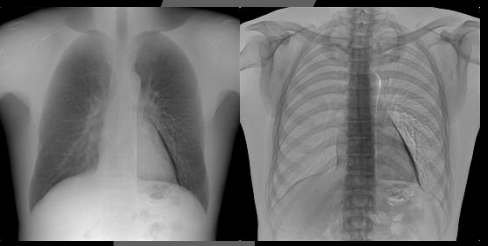
Image Pasting

Computer Aided Detection (CAD)

Temporal Processing



3D Tomosynthesis



Dual Energy

- Keys
  - Low dose, low cost
  - Early disease detection

Dual Energy

- Acquire “high” and “low” energy images
- Two technologies
  - Single exposure
  - Dual exposure

- Bone or soft-tissue images may be obtained by weighted subtraction
  - Removes ribs that may obscure pulmonary nodules
  - Visualize calcified nodules in bone image

Soft-tissue Image

Dense Tissue Image

Single Exposure (Dual Energy cont.)

- Two stacked detectors separated by copper filter
- Unattenuated portion of beam that strikes the first detector records low energy image
- Remaining photons that traverse filter and reach second detector produce high energy image
- Spectrum separation is challenging

Soft-tissue Image

Dense Tissue Image

Dual Exposure (Dual Energy cont.)

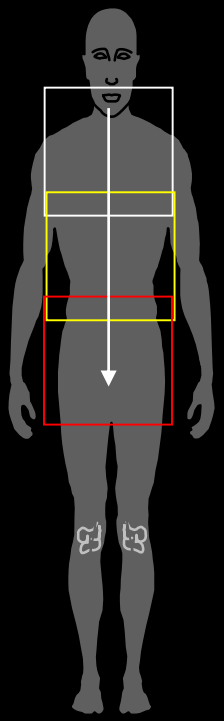
- Flat-panel detector, two exposures separated by hundreds of msec
  - 60 kV
  - 120 kV
- Better image quality with higher signal to noise ratio
- Patient motion can produce misregistration artifacts

Soft-tissue Image

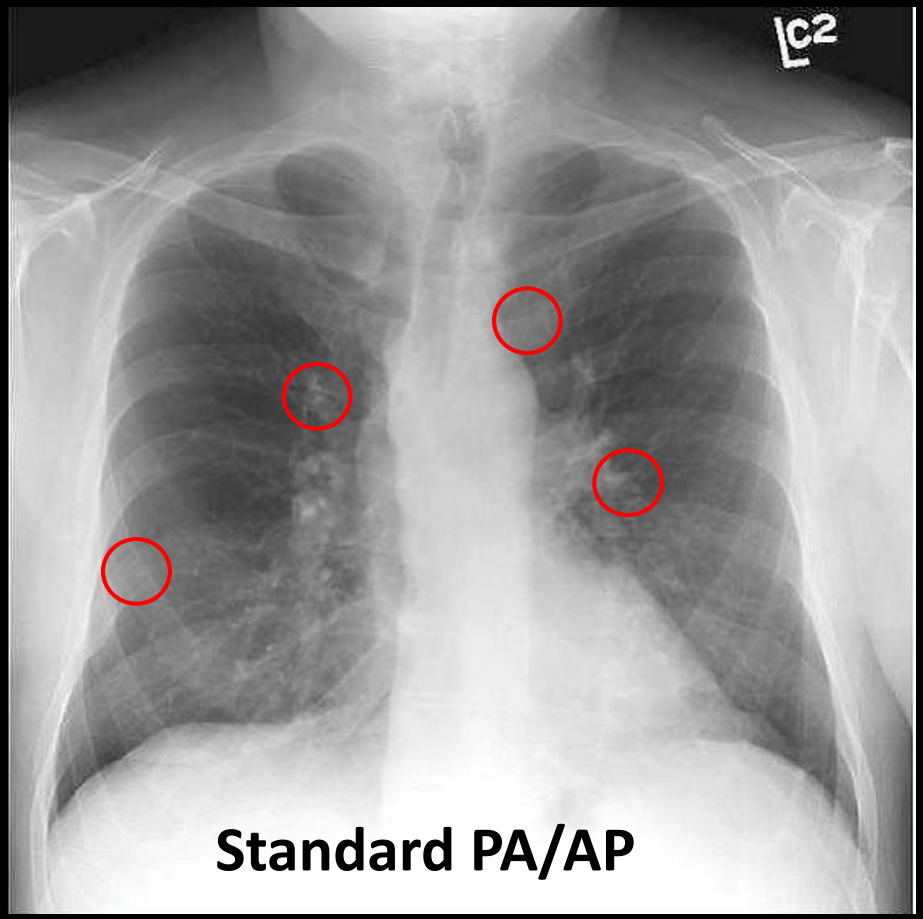
Dense Tissue Image

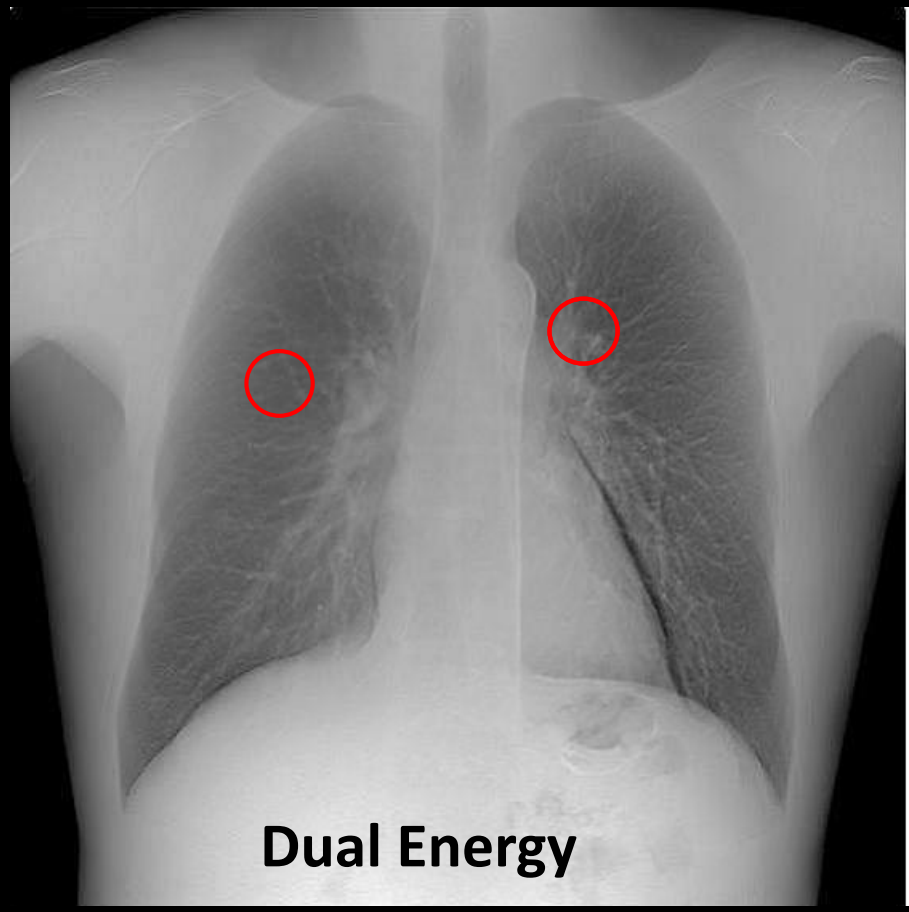
Auto Image Paste

- Acquire multiple images in one fast, seamless, highly automated exam
- Automatic stitching of the acquired images into a single composite image
- Can be performed by either wallstand or table scanner



Computer Aided Detection (CAD)





- While sensitivity (true positive rate) is high (80%), specificity (true negative rate) is low (50%)
- Some studies show dual energy increases sensitivity without specificity loss

Sensitivity and Specificity

Sensitivity

If a person has a disease, how often will the test be positive (true positive rate)?

Specificity

If a person does not have the disease how often will the test be negative (true negative rate)?

Clinical Performance Terms:

Sensitivity

Specificity

Positive Predictive Value (PPV)

Negative Predictive Value (NPV)

Accuracy

P-value

Clinical Performance Terms

Example of a diagnostic environment

100 patients

25 w/ disease ("positives")

75 healthy ("negatives")

Diagnostic Imaging Assessments

20 "ill" → 15 correct (True Positives)

20 "ill" → 5 wrong (False Positives)

80 "healthy" → 70 correct (True Negatives)

80 "healthy" → 10 wrong (False Negatives)

DI Assessment	Truth: Disease (+)	Truth: Healthy (-)
+	15 True Positives	5 False Positives
-	10 False Negatives	70 True Negatives

Diagnostic tests and radiologists may fail …

Clinical performance has to be quantified

Clinical Performance Terms

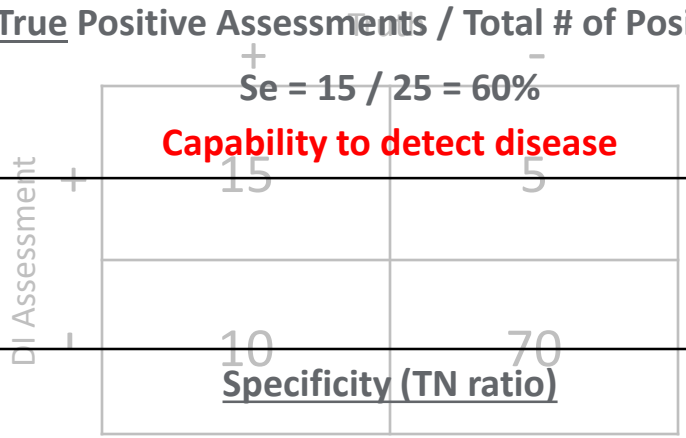
Sensitivity, Specificity

Sensitivity (TP ratio)

# of True Positive Assessments / Total # of Positive Cases

Se = 15 / 25 = 60%

Capability to detect disease



Specificity (TN ratio)

# of True Negative Assessments / Total # of Negative Cases

Sp = 70 / 75 = 93%

Capability to recognize NON-disease

Clinical Performance Terms

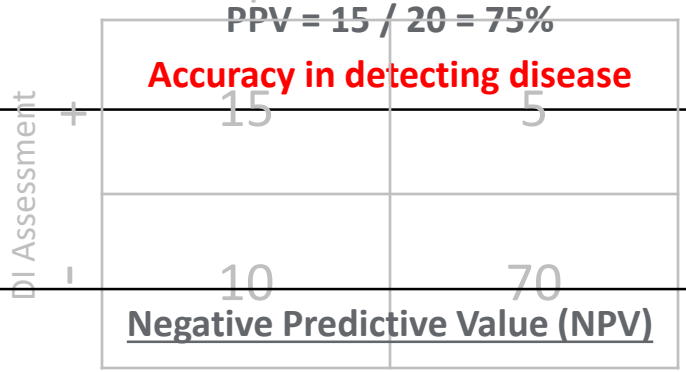
Positive / Negative Predictive Value

Positive Predictive Value (PPV)

# of True Positive Assessments / Total # of Positive Assessments

PPV = 15 / 20 = 75%

Accuracy in detecting disease



Negative Predictive Value (NPV)

# of True Negative Assessments / Total # of Negative Assessments

NPV = 70 / 80 = 87.5%

Accuracy in recognizing non-disease

Clinical Performance Terms

Accuracy

Accuracy

# of True Assessments / Total # of Assessments

Accuracy = 15+70 / 100 = 85%

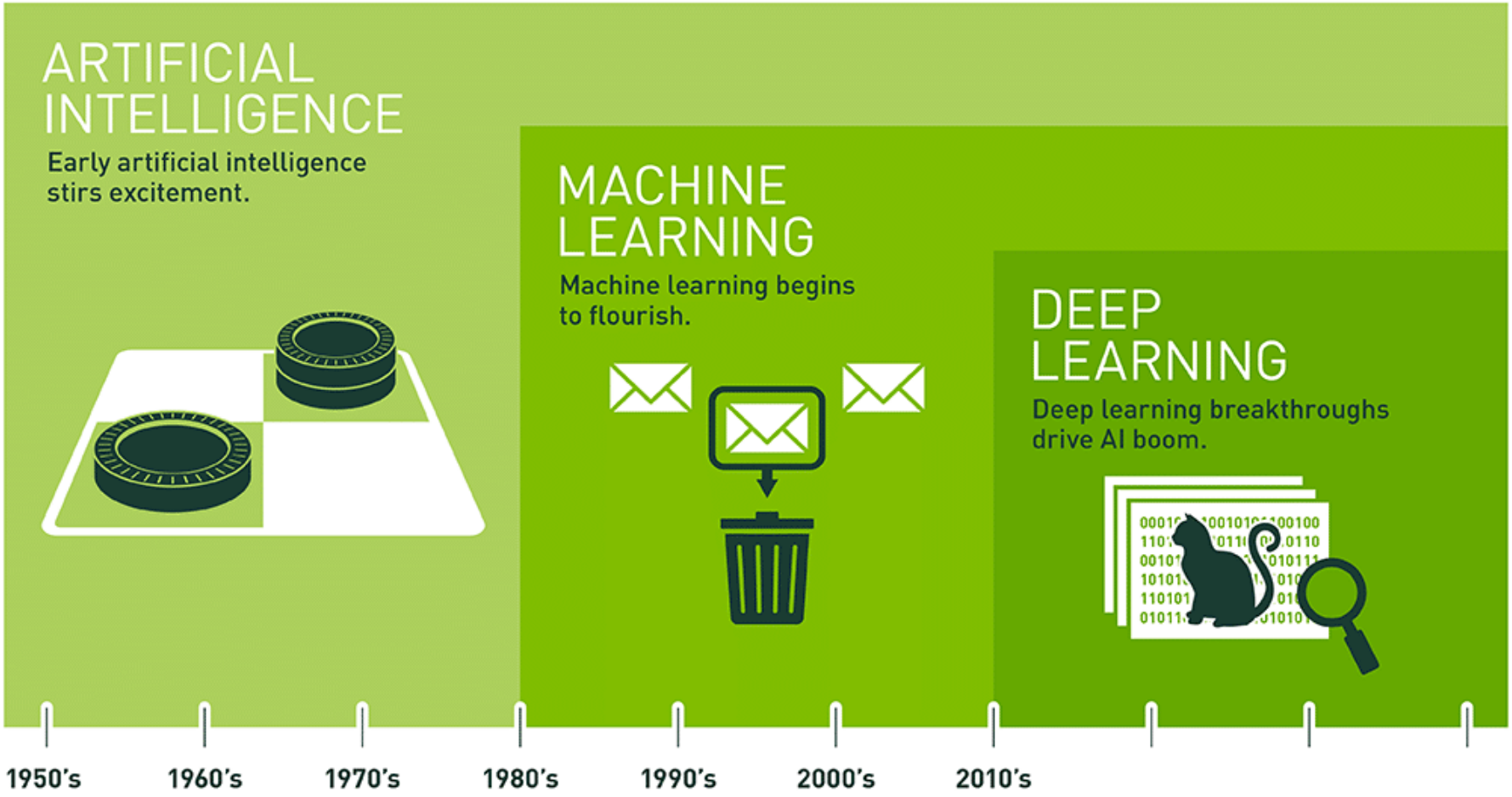
Rate of correct diagnosis

DI Assessment \ Truth	+	-
+	15	5
-	10	70

Clinical Performance Terms

P-value

- In a clinical study when you try to prove superiority of method A to method B, you need to reject the null hypothesis that the new method is similar (non-inferior) between A and B.
- P-value is the probability to be wrong in rejecting the null hypothesis, that is “accepting” the study conclusions
- P-value is calculated through statistical tests
- P-values < 0.05 are considered low enough to assume that the conclusions are statistically true
  (because the probabilty to be wrong is less than 5%)



Since an early flush of optimism in the 1950s, smaller subsets of artificial intelligence – first machine learning, then deep learning, a subset of machine learning – have created ever larger disruptions.

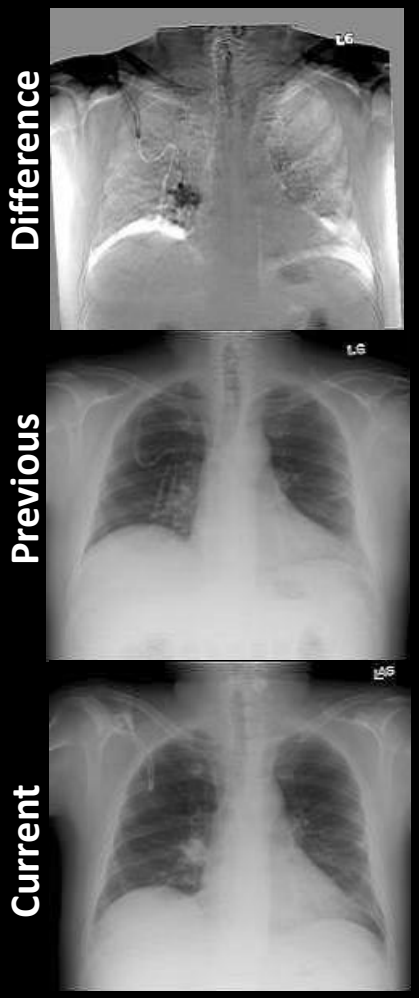
From: https://blogs.nvidia.com/blog/2016/07/29/whats-difference-artificial-intelligence-machine-learning-deep-learning-ai/

Lunit

https://www.lunit.io/en/product

Temporal Subtraction

- Case 1



Pneumonia

- Highlights change between previous & current radiograph
- Potential Applications
  - Pulmonary nodules
  - Interstitial disease
  - Pneumothorax
  - Pneumonia
- Spatial registration is challenging

- Case 2

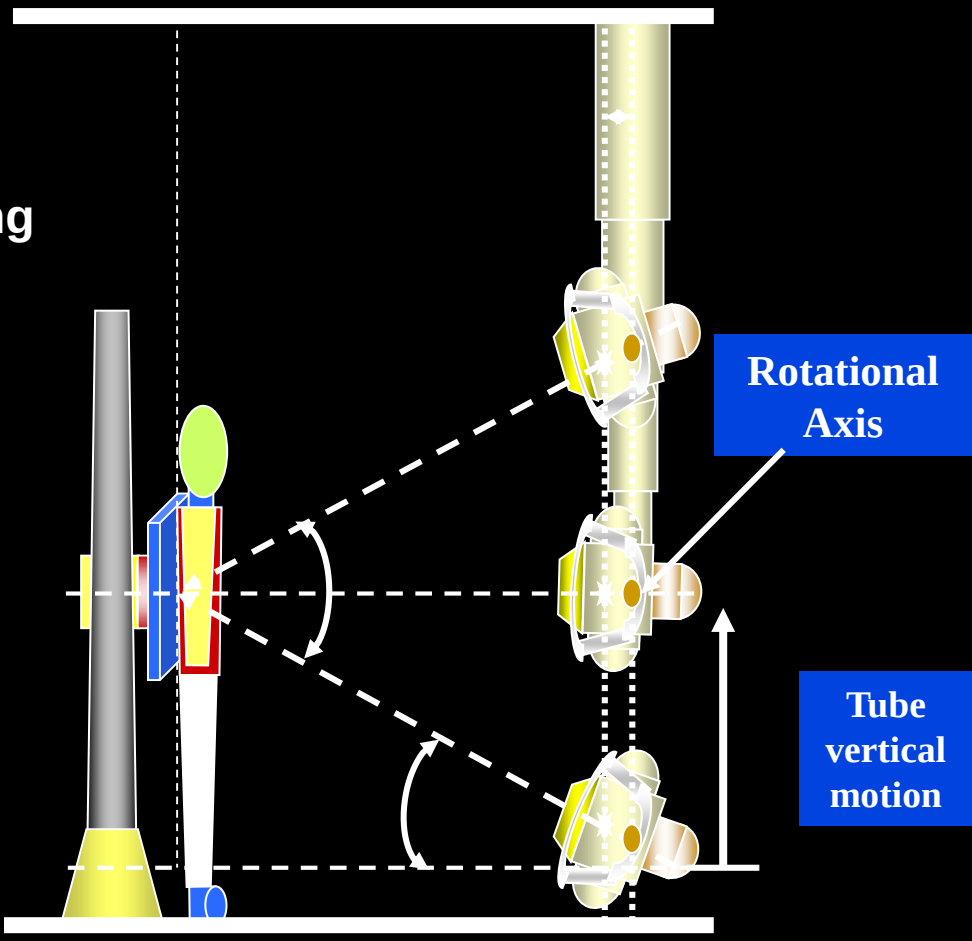
No Clinical Change

- *Images are courtesy of MD Anderson*

RAD Tomosynthesis

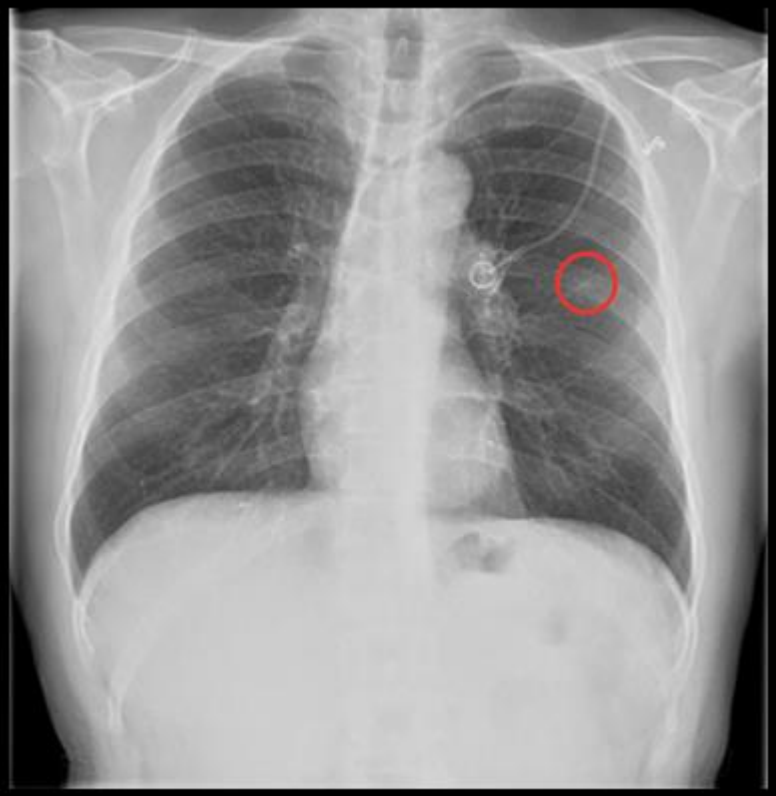
- **Goal:**
  - **Limited 3-D reconstruction to remove overlapping structure**
  - **All image planes visualized using a single seamless acquisition**

- **Acquisition:**
  - **Vertical tube motion for wallstand (horizontal for table)**
  - **Total tube angle: <40°**
  - **Number of Projected Images: 25 – 60**
  - **Exam length: 5 -11 sec (single breath-hold)**
  - **Slice thickness: ~1 cm**

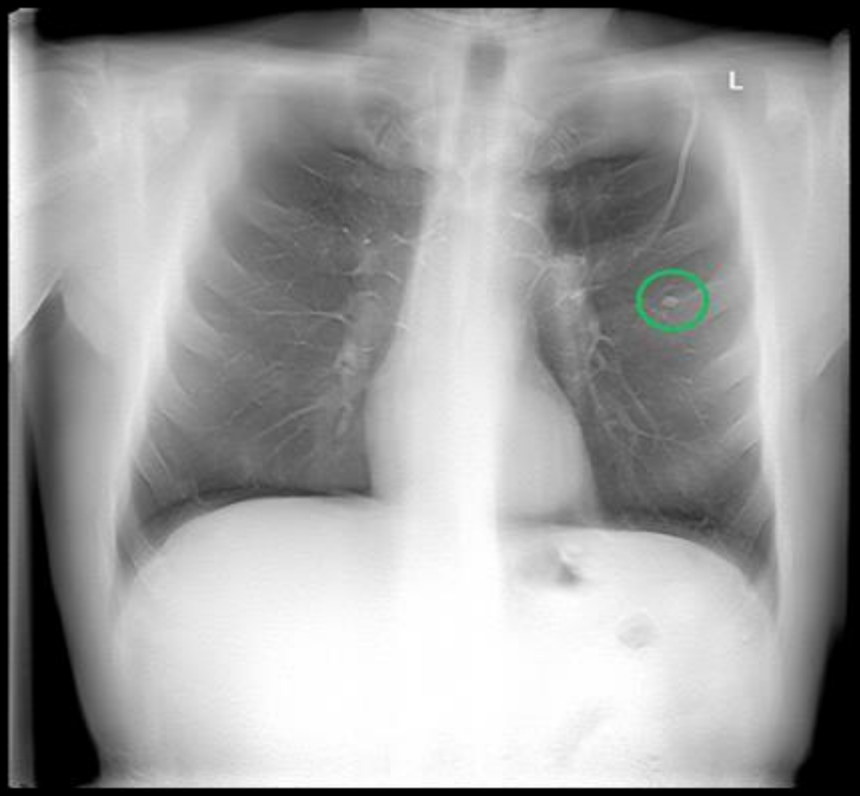


- **Small Changes to Rad System allows for 3D Imaging**

RAD vs. Tomosynthesis sensitivity



Routine PA chest
(2D)



Tomosynthesis
(GEHC VolumeRAD)

- **9.4mm nodule in left lung**
- **A study shows that 7.5x increase in lung nodule sensitivity for nodules between 4-6m**

Radiography and Fluoroscopy (R&F)

- Fluoroscopy is an imaging modality that uses x-rays to allow real-time visualization of body structures
- X-ray beams are continually emitted and captured on a screen, producing a real-time image
- This allows for dynamic assessment of anatomy and function
- High density contrast agents may be introduced into the patient to allow for greater differentiation between structures

Radiography and Fluoroscopy (R&F)

- Two types of geometry
  - Remote-control system (X-ray tube is over patient)
  - Patient-side-control system (X-ray tube is under patient)
- Gastrointestinal (GI) exam is major application
- Barium is typically used as a contrast agent

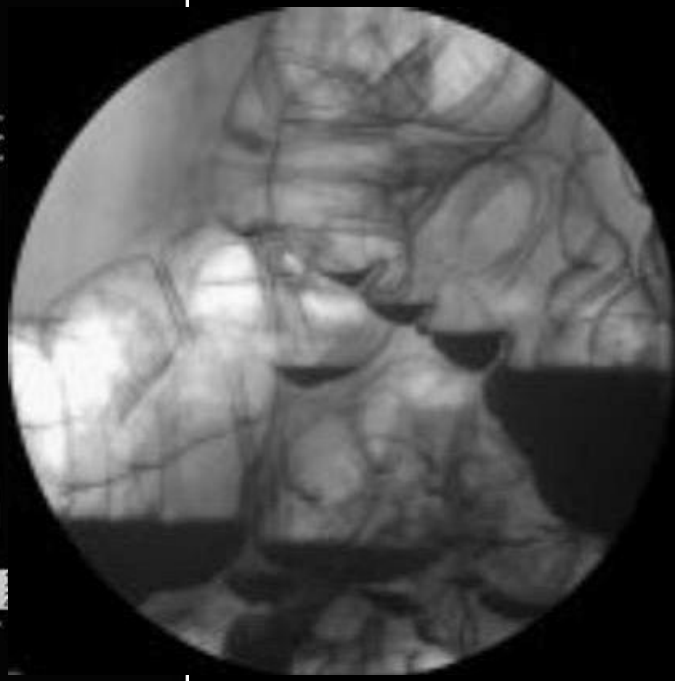
Single Contrast GI Exam

Precision RXi

Example Images

Barium Swallow

Upper Gastrointestinal stomach



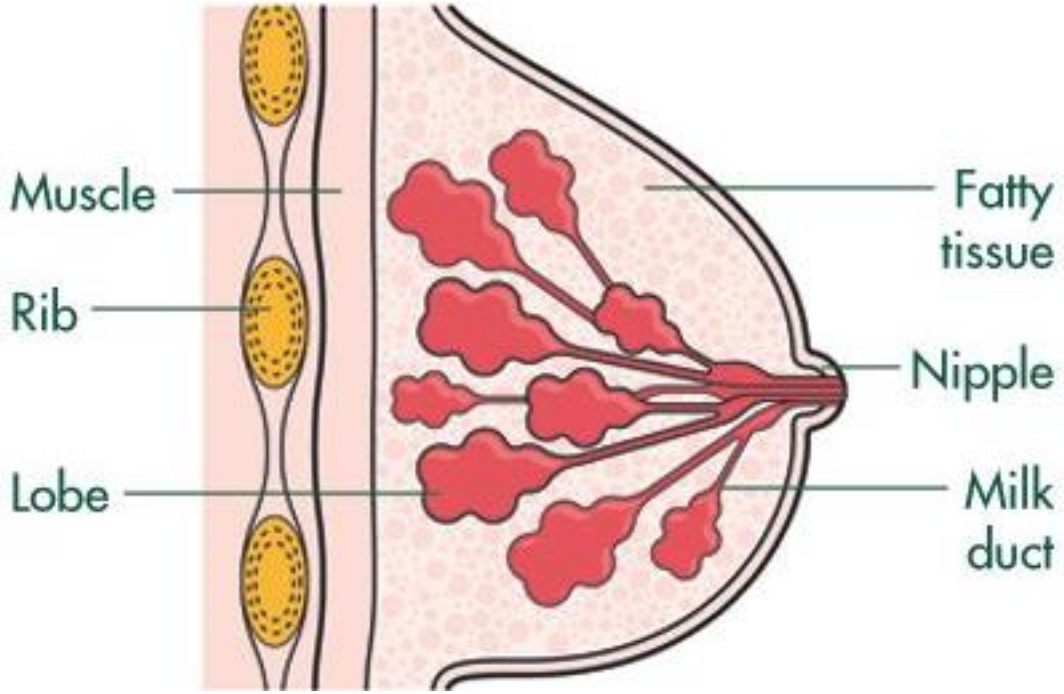
Double Contrast Barium Enema

Mammography

What is breast cancer ?

- The cells that divide and grow out of control
- Breast cancer happens most often in the ducts (the tubes that carry milk to the nipple) and the lobules (the glands that make the milk).

ducts: ống dẫn sữa
lobules: tiểu thùy: nơi sản xuất sữa



Breast cancer types

In-situ: tại chỗ
ductal carcinoma: Ung thư biểu mô
noninvasive: không xâm lấn
Lobular carcinoma: ung thư tiểu thùy biểu mô

- In-situ cases
  - Ductal carcinoma in-situ (DCIS)
    - most common type of noninvasive breast cancer
    - Cancer cells inside the ducts did not spread yet
    - Treated with surgery and sometimes radiation
    - Nearly all women diagnosed at this early stage can be cured
  - Lobular carcinoma in-situ (LCIS)
    - Cancer cells inside the lobule walls
- Invasive cases
  - Invasive ductal carcinoma (IDC)
    - Most common breast cancer
    - Cancer cells break through the wall of the duct and spread into the breast's fatty tissue
  - Invasive lobular carcinoma (ILC)
    - Starts in the milk-producing glands or lobules

Question of overdiagnosis

Invasive: xâm lấn

breast's fatty tissue: mô mỡ của vú

Breast cancer statistics in 2013

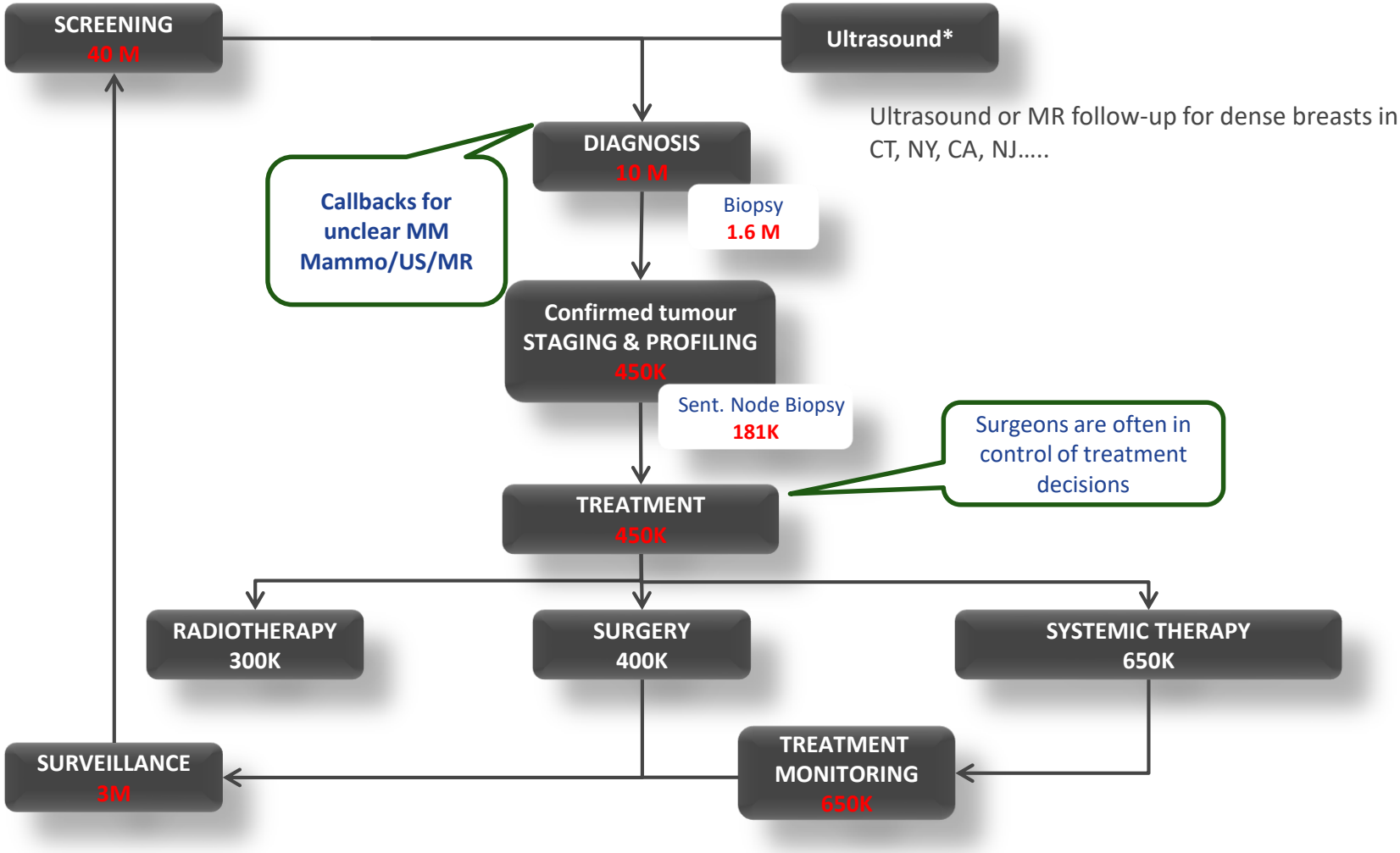
Breast cancer is the most common cancer among American women

Age (Yrs)	In Situ Cases	Invasive Cases	Deaths
<40	1,900	10,980	1,020
<50	15,650	48,910	4,780
50-64	26,770	84,210	11,970
65+	22,220	99,220	22,870
All ages	64,640	232,340	39,620

- About 12 % women in the US will develop invasive breast cancer during their lifetime.
- Breast cancer incidence and death rates generally increase with age
- During 2006-2010, the median age at the time of cancer diagnosis was 61

Data from American Cancer Society, 2014

A Patient's Journey

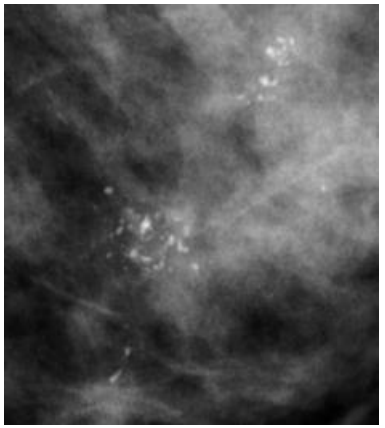


Legend: Dx=diagnosis; Horm=hormonal therapy; Tax=taxane-containing regimen; Anth=anthracycline-containing regimen; Her2=Her2 antagonist-containing regimen (lapatinib or trastuzumab; Bev=bevacizumab- containing regimen. All figures represent sum of US + EU5 patients at each stage presenting in 1 year. Numbers are directional and will be subject to further validation through Q4 2011. Sources: IntrinsiQ, IMA Oncology Analyzer MAT Q2 2011; DecsisionResources Breast Cancer Pharmacor 2011, DaVInci, various literature sources

Breast imaging modalities

Mammography (X-ray) Mammography: chụp nhũ ảnh

- Image the whole breast at once
- Microcalcifications visibility microcalcification: vi vôi hóa

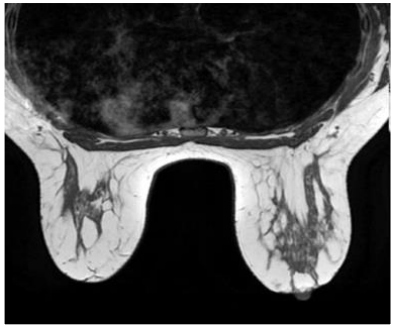


Ultrasound (Soundwave)

- Suitable for spot check spot check: kiểm tra tại chỗ
- Can see whether a lump is a cyst or a solid lump lump: cục bướu a cyst: u nang
- Often used to check abnormal results from a mammo
- Automatic Breast US as adjunct to mammo for dense breast screening

MRI (Radio frequency wave)

- Lesions that cannot be seen in mammography or US
- Evaluation of disease extent
- Uses contrast agent injection
- High risk population screening



Linver et al., Radiology, 1992

Baker, A Cancer journal for Clinicians, 1982

What is Mammography?

- Mammography is an imaging procedure that uses low-dose X-rays to examine breasts

- Most common technology in mammography
  - Full-field digital mammography (FFDM)

    2D breast imaging in which the X-ray film is replaced by digital detectors that convert X-rays into electrical signals

- New Technology
  - Digital Breast Tomosynthesis (DBT)

    3D breast imaging where the X-ray tube typically moves in an arc over the breast during the exposure

History

1965 → **2014**

1st system & tube dedicated to mammography

1973

Automatic Exposure Control (AEC)

1987

Localisation 3D

1991

Automatic parameters Control (AOP)

Dual track tube (Rh/Mo) for dense breasts

2000

1st digital detector

2002

1st computer aided detection (CAD)

2003

1st review workstation

2004

2nd generation of digital detectors

Digital stereotactic biopsy

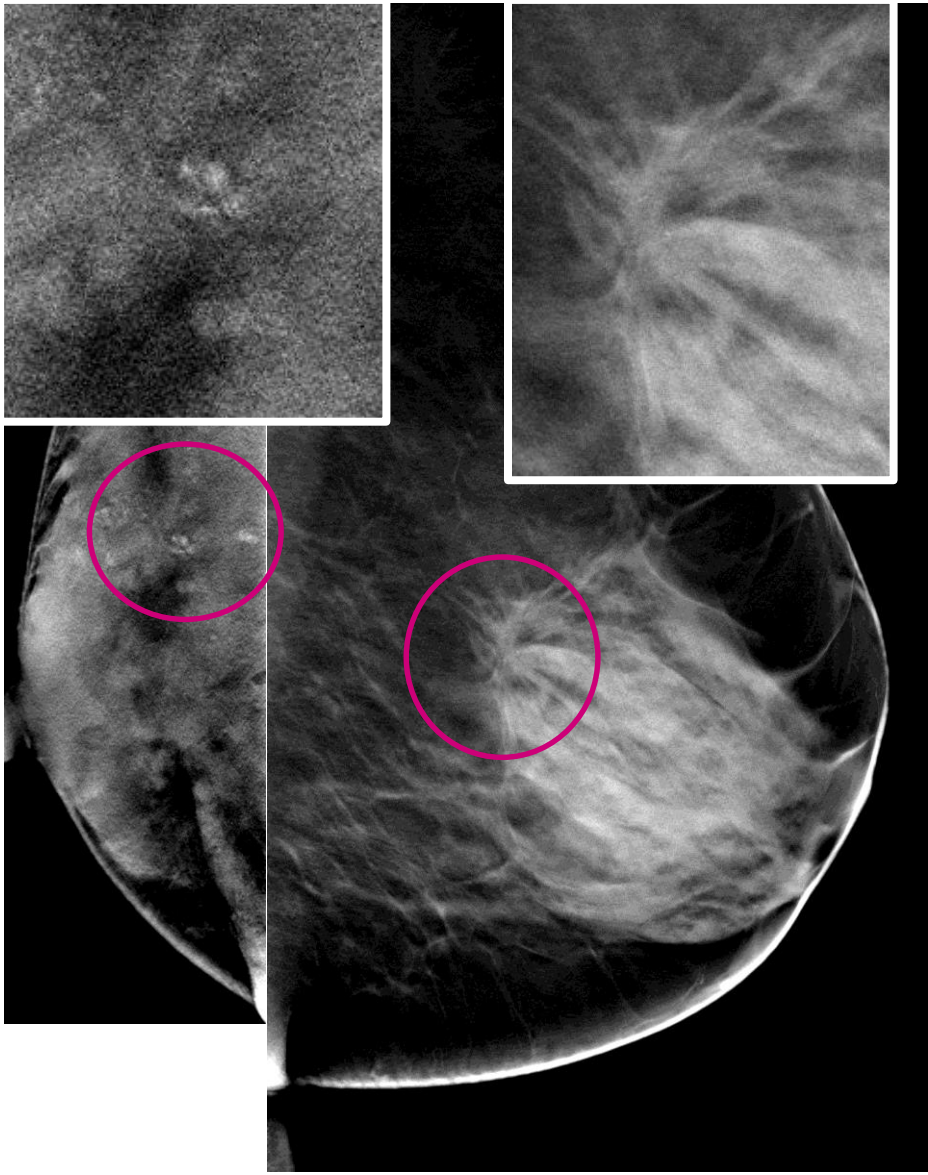
2010

Contrast Enhanced Spectral Mammography

Senoclaire 3D bresat tomosynthesis

Signs of breast cancers

- Micro-calcification calcification: sự vôi hóa
  - High density
  - as small as 100 um
  - appear as a cluster
- Mass
  - Low density
  - Large
  - Spiculated
- High contrast and high spatial resolution are needed



Courtesy of GEHC, Buc

How is the procedure performed?

- Your breast will be placed on a platform above detector panel
- Your breast is squeezed by the compression paddle
- For 2D mammo, pictures are taken in two different angles (CC, MLO) for each breast

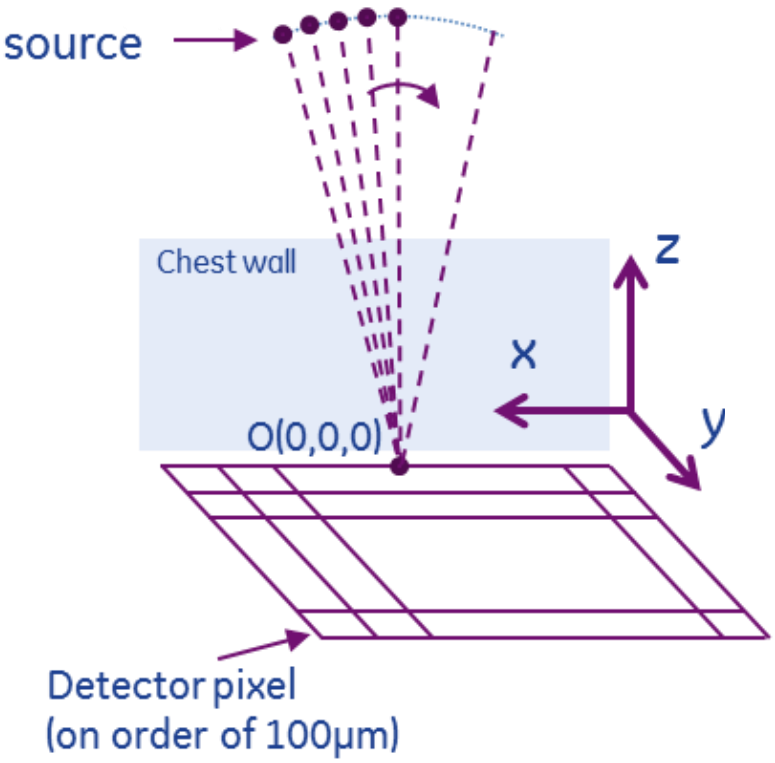
pour trouver toutes les tissues
CC: Craniocaudal; MLO: Mediolateral oblique
https://msrads.web.unc.edu/wp-content/uploads/sites/15695/2018/07/Screening-Need-To-Knows.pdf

Digital Breast Tomosynthesis (DBT)

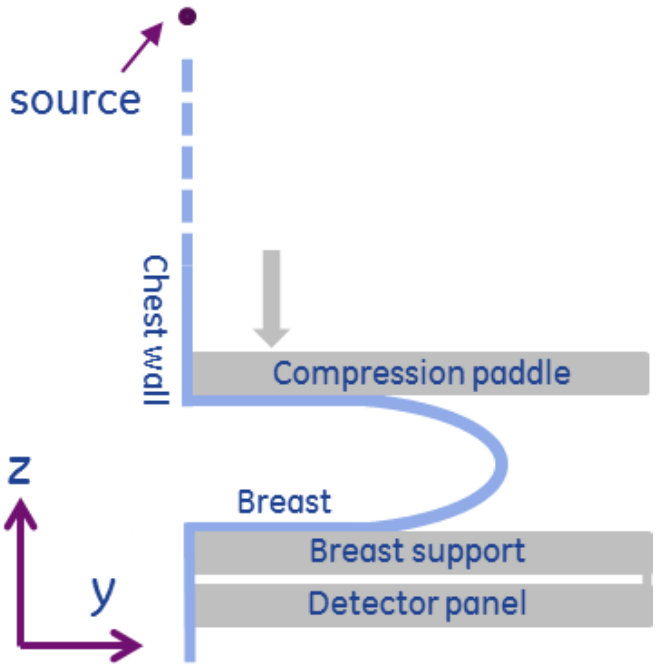
Courtesy of GEHC, Buc

- DBT is an emerging 3D imaging technique that solves limitations of 2D mammography (e.g. superposition)
- DBT is a limited-view and limited-angle geometry system
- DBT has a high-resolution detector panel (~100um)

DBT system geometry example



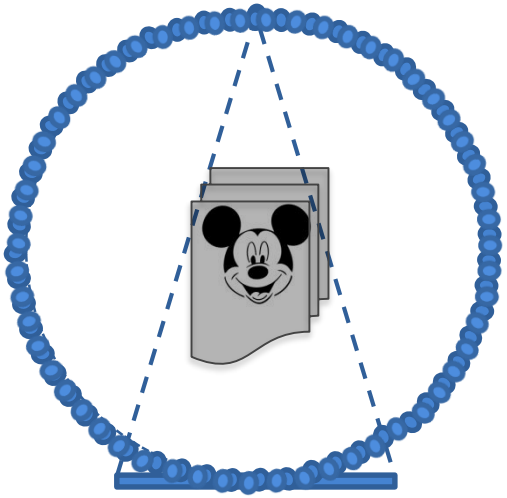
(a) Front view



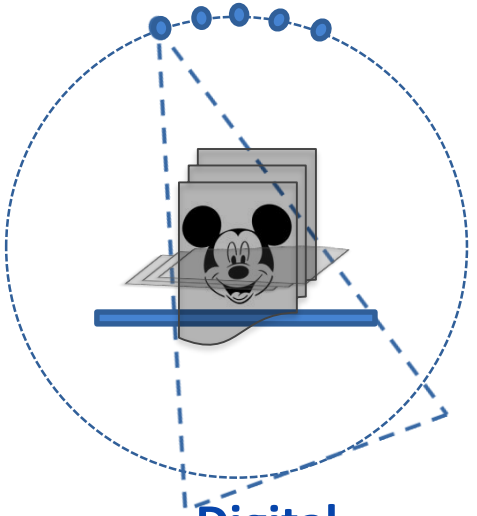
(b) Side view with breast

- **The limited-angle & few views make the problem more ill-posed**
- **Noise introduces additional challenges for reconstruction**

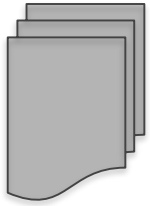
From CT to digital breast tomosynthesis

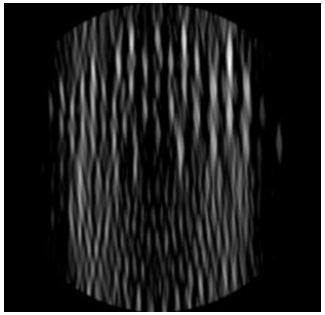


CT



Digital Tomosynthesis





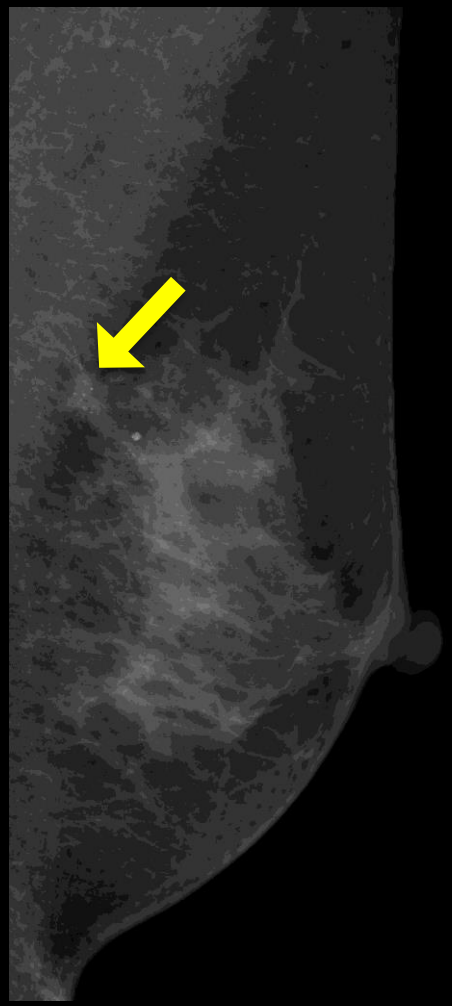
State-of-art of DBT reconstruction

DBT traditional recon techniques	Iterative	Statistical	Regularization
• Filtered Backprojection (FBP)	—	—	—
• Algebraic Reconstruction Technique (ART/SART/SIRT)	✓	—	—
• Maximum likelihood (ML/EM)	✓	✓	—
• Maximum a posteriori (MAP/MBIR)	✓	✓	✓

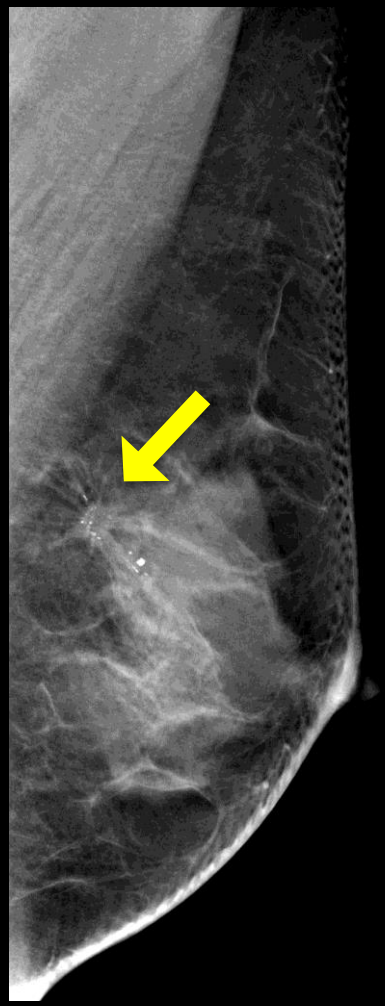
<u>Advantage</u>

Maximum-a-posteriori approach may incorporate an accurate forward model, a noise model, and prior model of image characteristics

Digital Breast Tomosynthesis – Case 1



2D MLO view



3D MLO view
"SLAB"

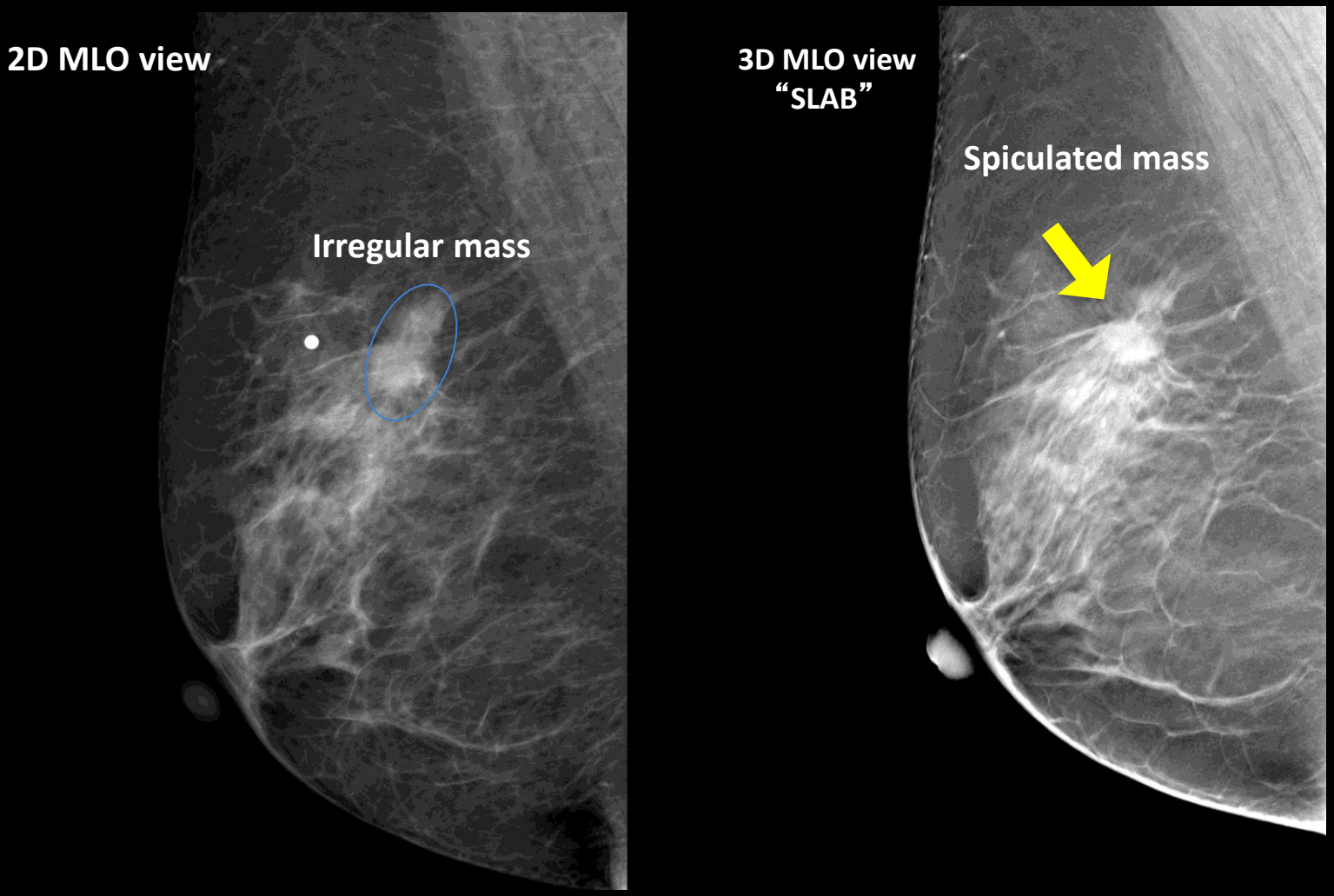
The extension of mass is more obvious

Courtesy: Dr. Kim: ASAN Medical Center/Korea

imagination at work

The option may not be available in all regions

Digital Breast Tomosynthesis – Case 2

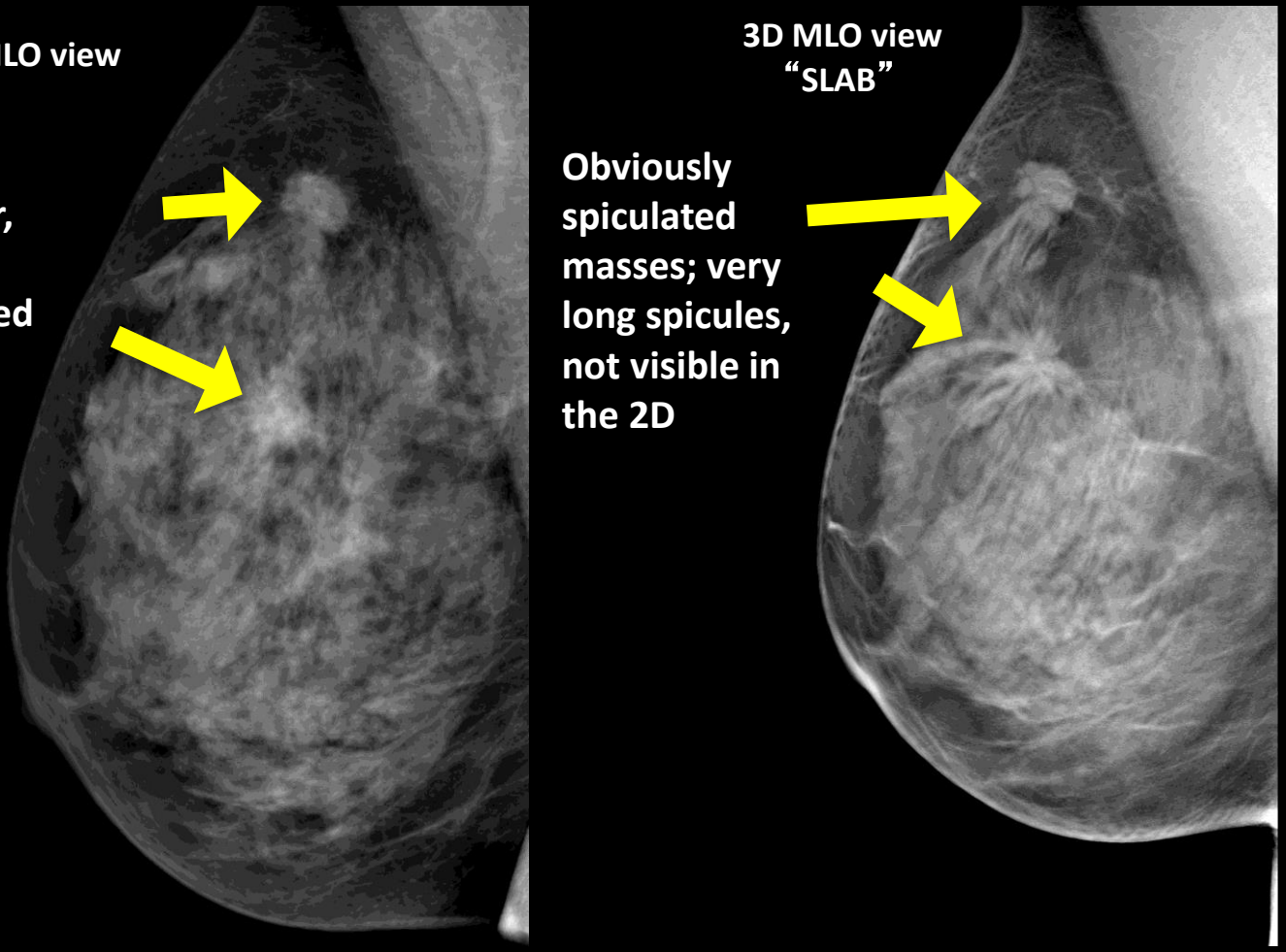


Courtesy: Dr. Kim: ASAN Medical Center/Korea

imagination at work

The option may not be available in all regions

Digital Breast Tomosynthesis – Case 3



Courtesy: Dr. Gennaro : Veneto Institute of Oncology (IOV), Padua, Italy

imagination at work

The option may not be available in all regions

Thank you.