

# Introduction to Radiology

## RAD COURSE 366

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# Objectives

- Recognize various types of imaging studies.
- Discuss the mechanism for producing images with each modality.
- List the common indications for different imaging modalities.
- Describe the precautions for ordering imaging studies.

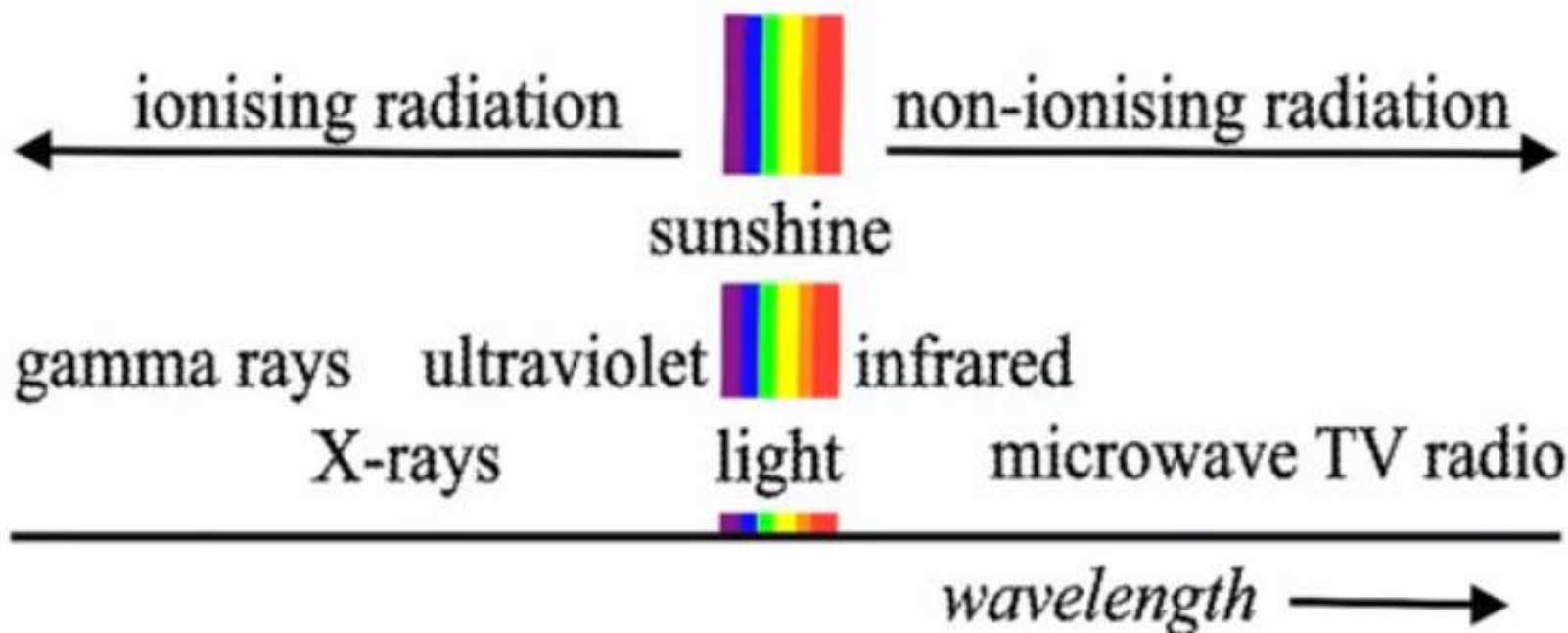
# Imaging Modalities

## Ionized Radiation

- X-Ray.
- Fluoroscopy/ Angiography.
- Computed Tomography.
- Radionuclide imaging.

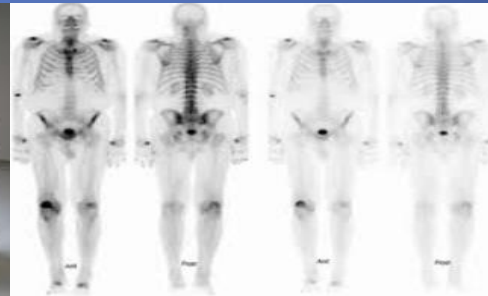
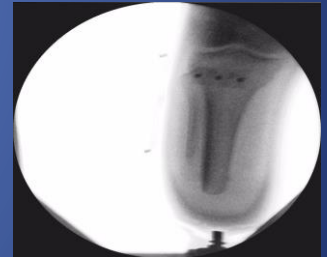
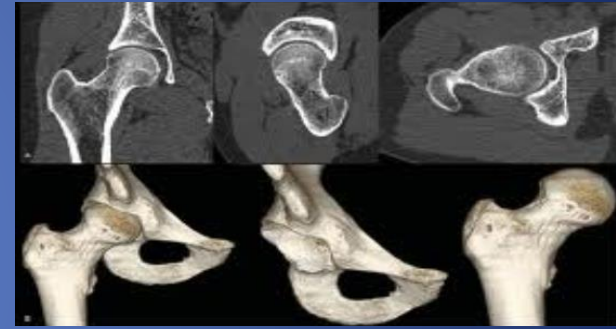
## Non-Ionized Radiation

- Ultrasound imaging.
- Magnetic Resonance



# Ionising

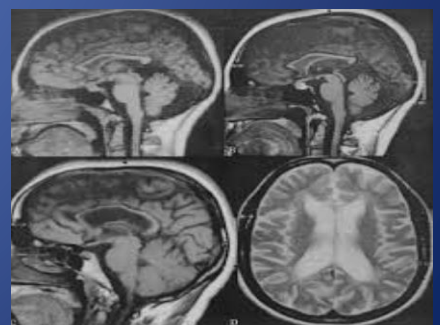
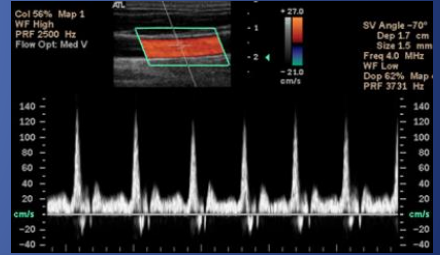
- ❖ X Ray
- ❖ Radiographs/  
mammograms
- ❖ CT
- ❖ Fluoroscopy/Angiography
- ❖ Nuclear medicine



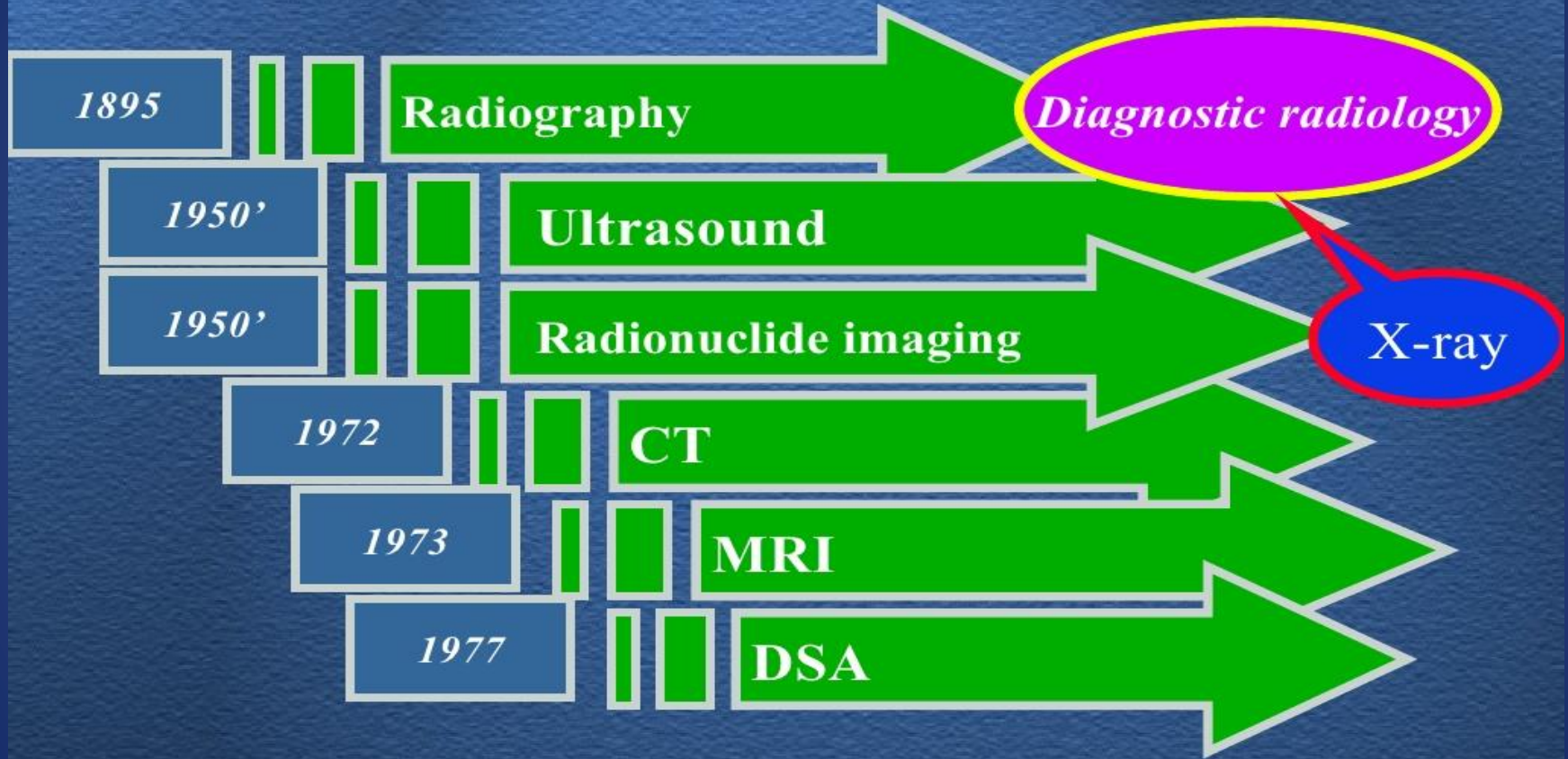
# Non ionising

❖ Ultrasound  
(2D/3D/4D)  
Doppler

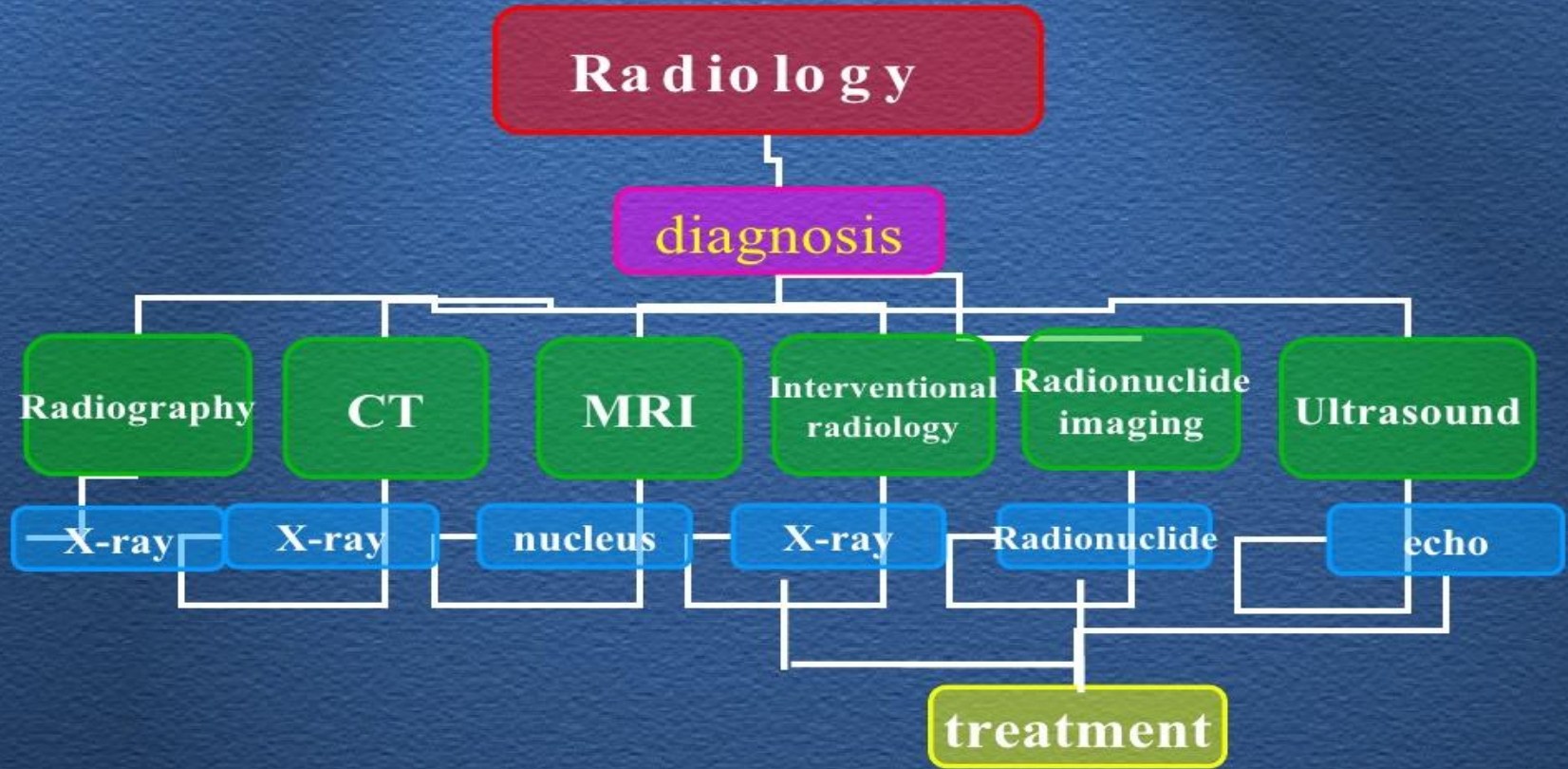
❖ MRI  
fMRI/kinetic  
MRI/contrast MRI



# Imaging Technology



# The modality of radiology





# Radiographic Terminology

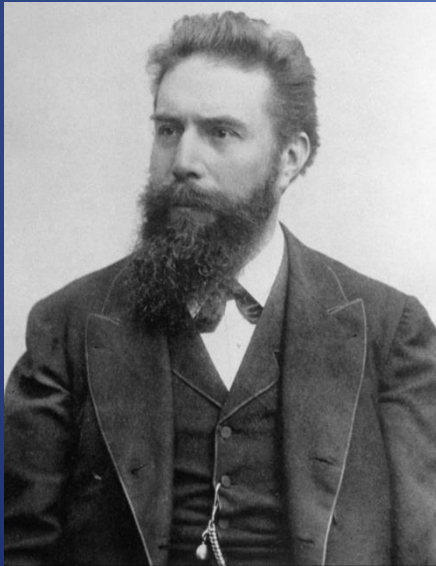
- **Radiology:** Medical specialty in which x-rays, radium, and radioactive substances are applied in the diagnosis and treatment of the patient.
- **Diagnostic Imaging:** Medical specialty in which x-rays, radium, radioactive substances, sound waves, and radio frequencies are applied in the diagnosis and treatment of the patient
- **Radiologist:** Physician who applies any form of radiation in the diagnosis and treatment of disease.

# Radiographic Terminology

- **Radiographer:** Skilled person qualified by education to provide patient services using imaging modalities as directed by a physician qualified to order and/or perform radiographic procedures (X-ray Technologist).
- **Radiograph:** a photographic record produced by x-rays through an object

# Nov 8<sup>th</sup>, 1895: The Birth of Radiology

- 11/8/1895 Wilhelm Conrad Röntgen produces “X-rays”
- 12/28/1895 Röntgen presents: “On a New Kind of Rays”
- 2/11/1896 Jones publishes: “The Discovery of a Bullet Lost in the Wrist by Means of the Roentgen Rays”



First Radiograph  
Röntgen's wife



1901: Röntgen wins 1<sup>st</sup>  
Nobel prize in physics

# Early years in Radiologic Technology

- Nurses or nurses aides taught how to “take an x-ray”
- NO special education
- Only “ON THE JOB” training
- Experience each

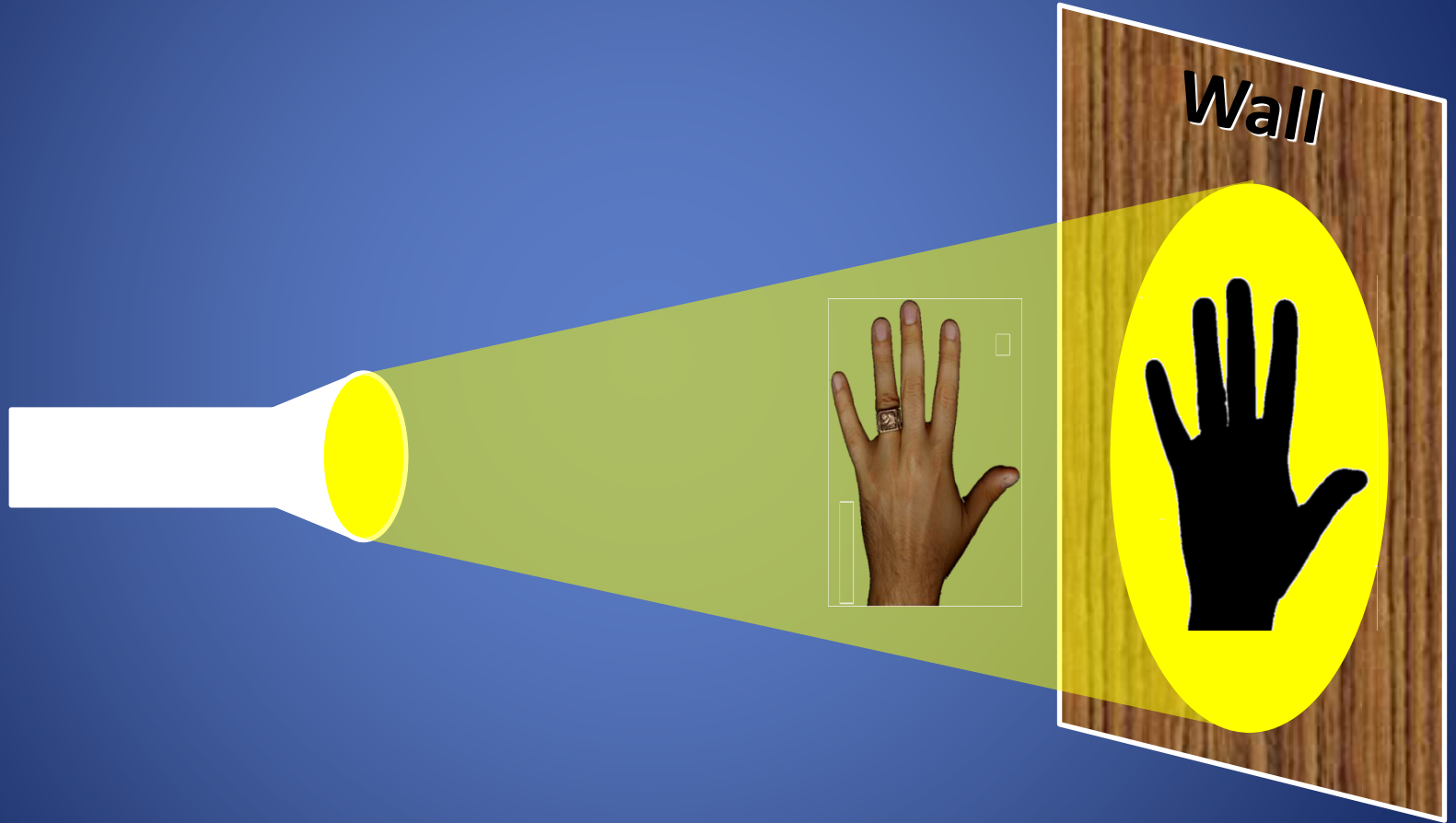


# How We Make Radiographs



- Light rays bounce off my hand and into my camera.
- We call the image:
  - “Light-Ray”
  - “Photograph”
    - Image of the light photons that bounce off my hand and into my image capture device.

# How We Make Shadows



# “Shadow-graph”



- Everywhere hand blocks the light is dark...
- Everywhere hand doesn't block the light is illuminated.
- Now, if we hang photographic film on wall we get...

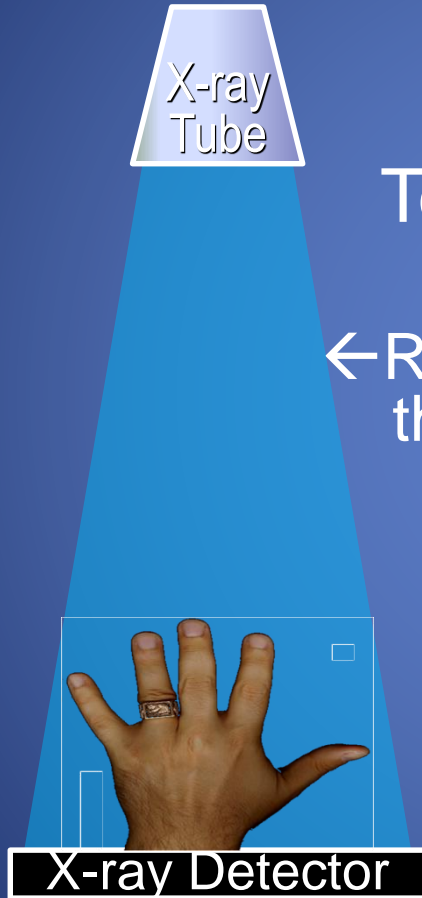
# “Negative-graph”



- Everywhere hand blocks light the film is *not* exposed and stays white...
- Everywhere hand doesn't block the light the film *gets* exposed and turns dark.



# How We Make Radiographs



Terminology:

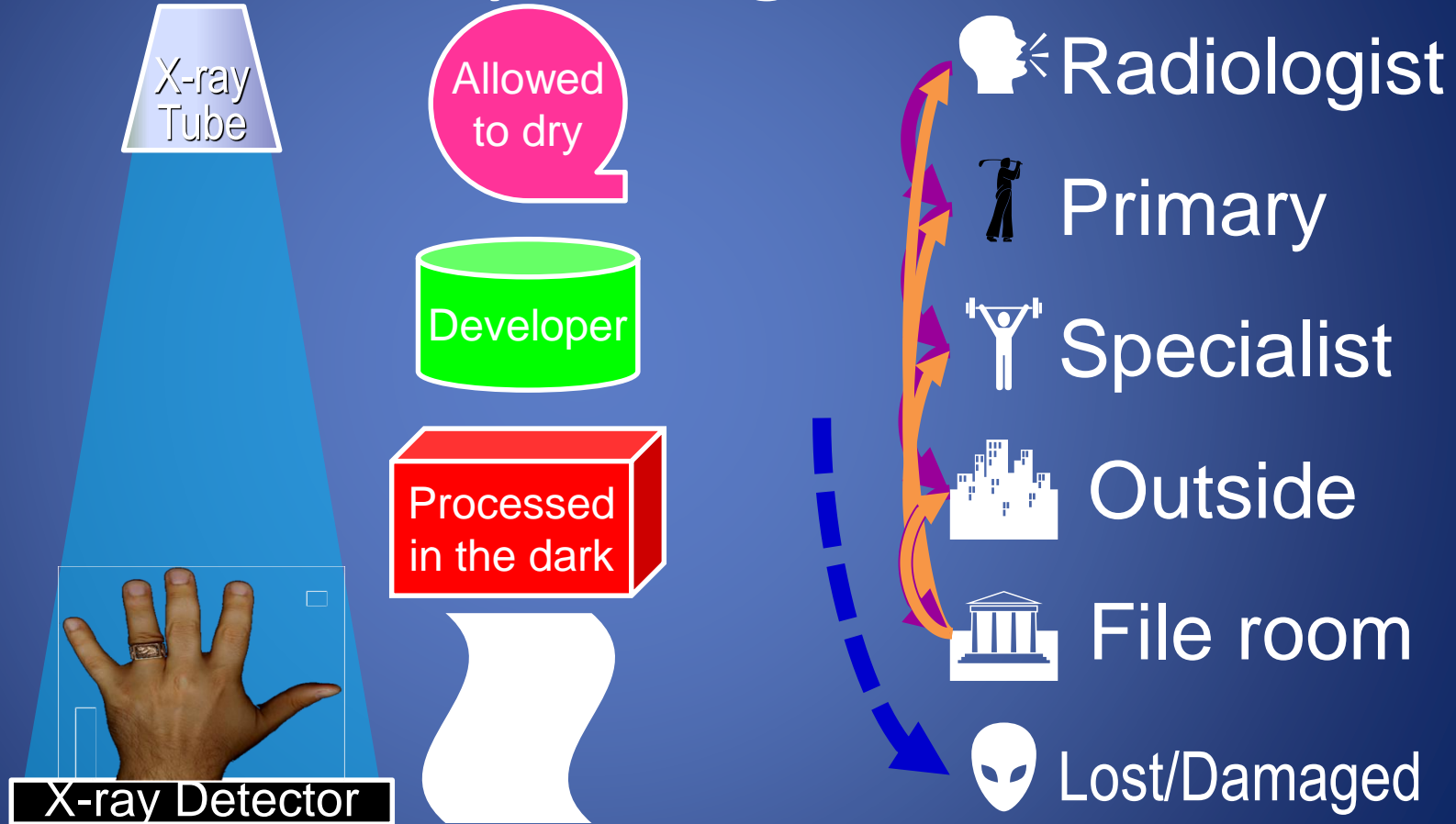
“X-rays”:

← Rays that pass thru the patient.

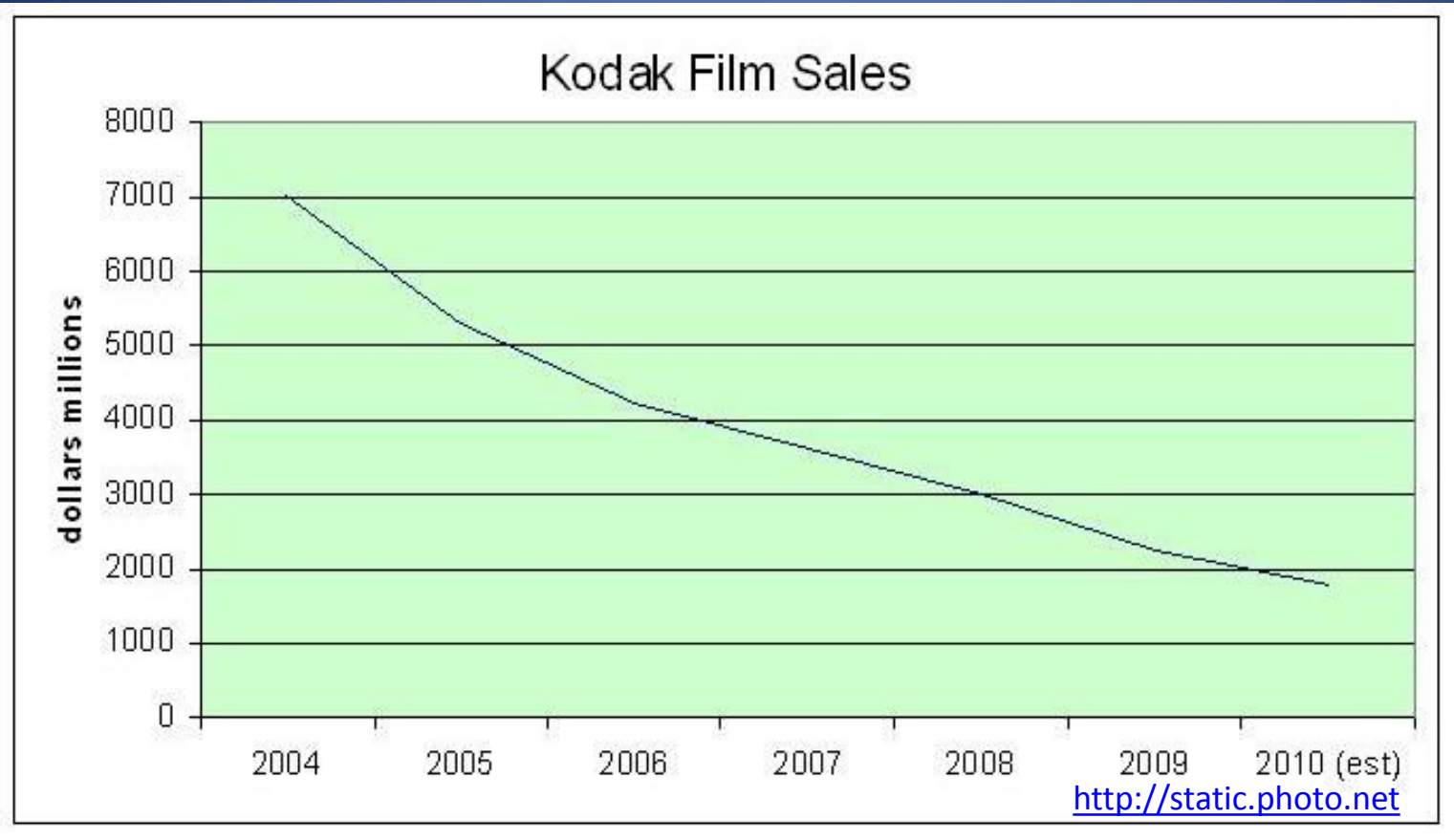
The image →  
is called a  
“radiograph”



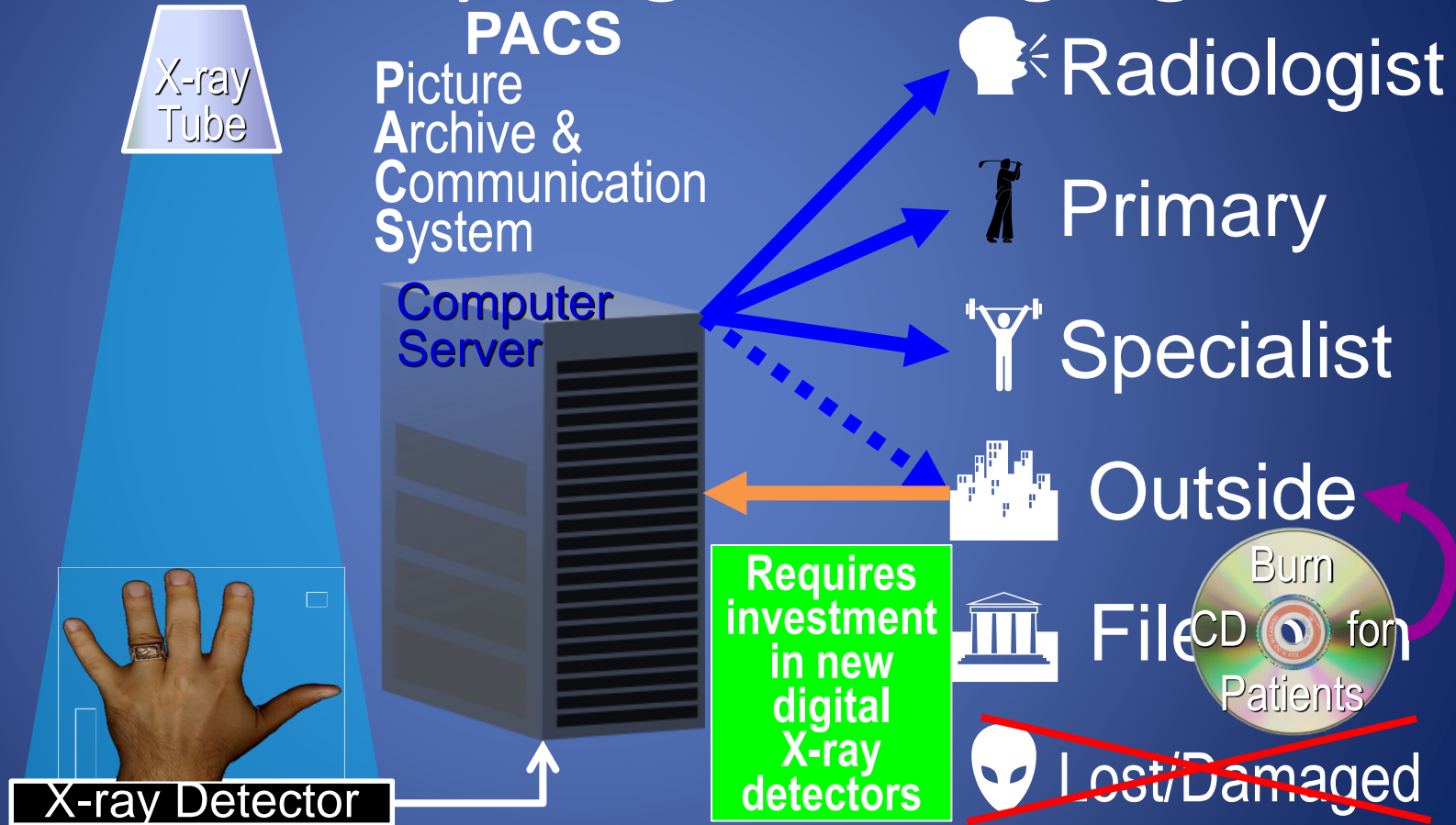
# 20<sup>th</sup> Century: Images = Film



# 21<sup>st</sup> Century: Images = ~~Film~~



# 21<sup>st</sup> Century: Digital Imaging



# Before

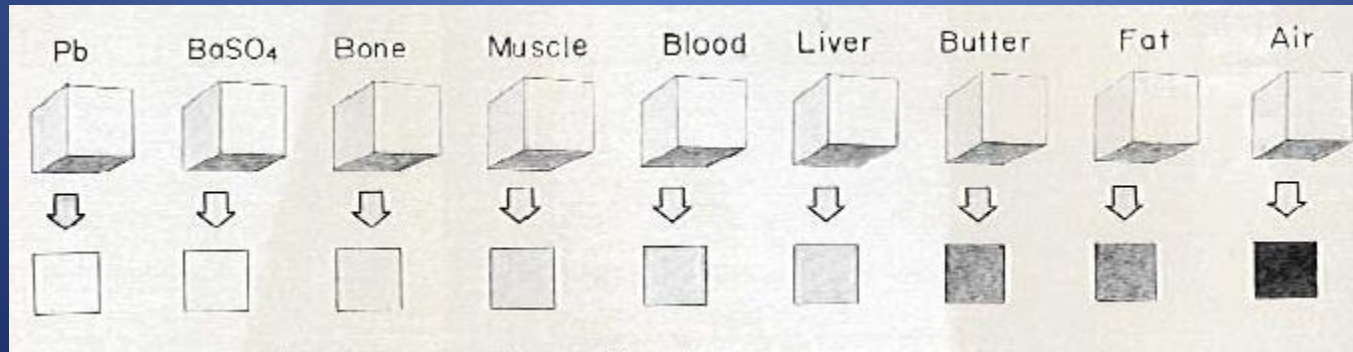


# Now



# How do x-rays create an image of internal body structures?

- X-rays pass through the body to varying degrees
- Higher atomic number structures block x-rays better, example bone
- Lower atomic number structures allow x-rays to pass through, example: air in the lungs



# Radiographs are Limited

- Radiographs can detect only four densities of tissue:

**Metal (white)**

**Bones (light gray)**

**Soft Tissues (dark gray)**

All soft tissues look the same on radiographs:

- ✓ Muscles/Tendons
- ✓ Vessels/Nerves
- ✓ Organs/Blood

**Air (black)**



# X-rays as Diagnostic Tool

- **Can see:**

- Bones
  - Fractures
- Joint width, surfaces
  - Arthritis
    - ❖ Osteophytes
    - ❖ Erosions

- **Can't see:**

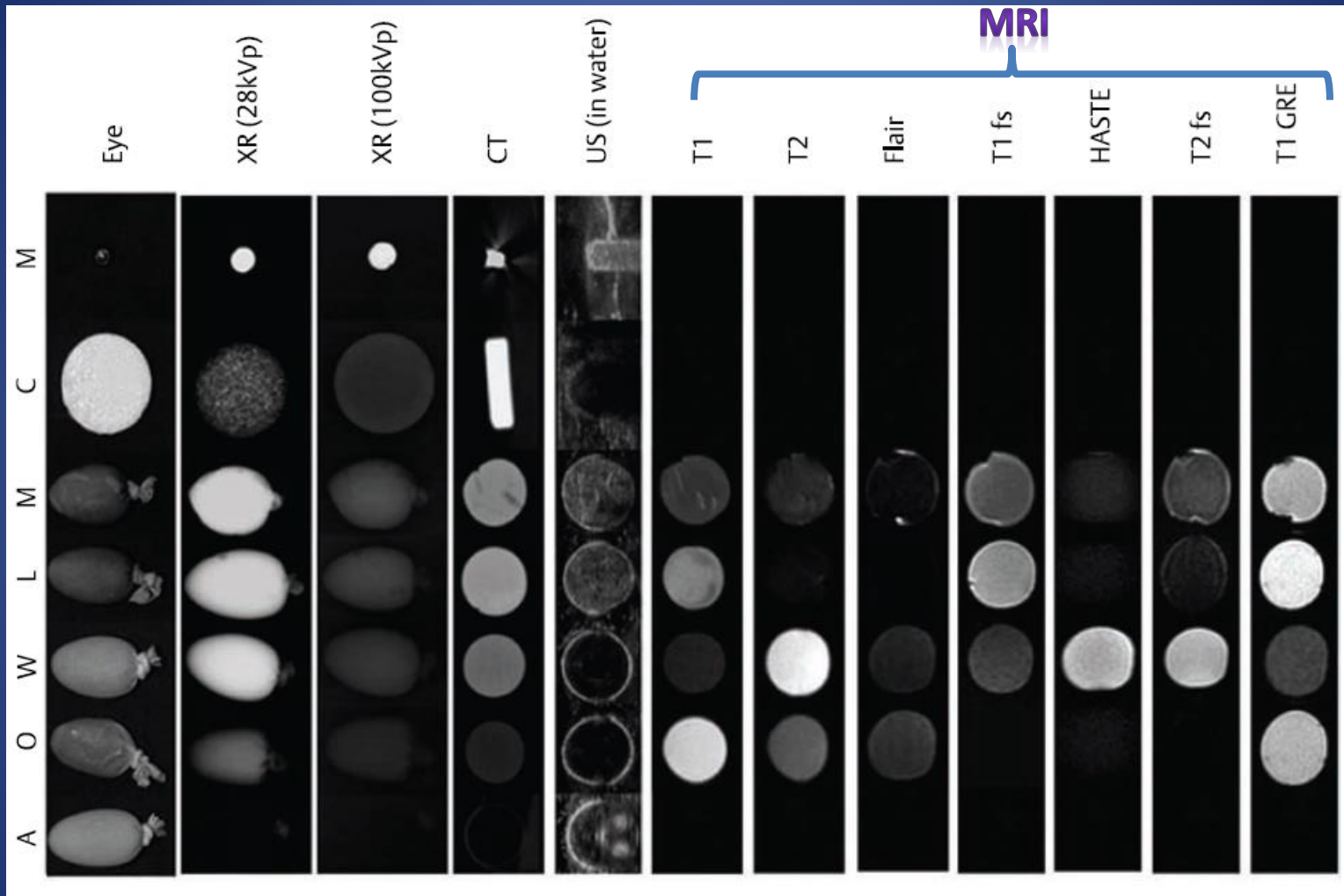
- Inside skull
  - Can't see the brain
- Inside joints
  - Can't see tears
    - ❖ Ligaments, Tendons
    - ❖ Menisci, Cartilage

- ***Radiographs: 2D projection of 3D patient***

- Radiographs flatten everything
  - Can't tell what's in front, what's behind
- With radiographs: **NEED MULTIPLE VIEWS!**

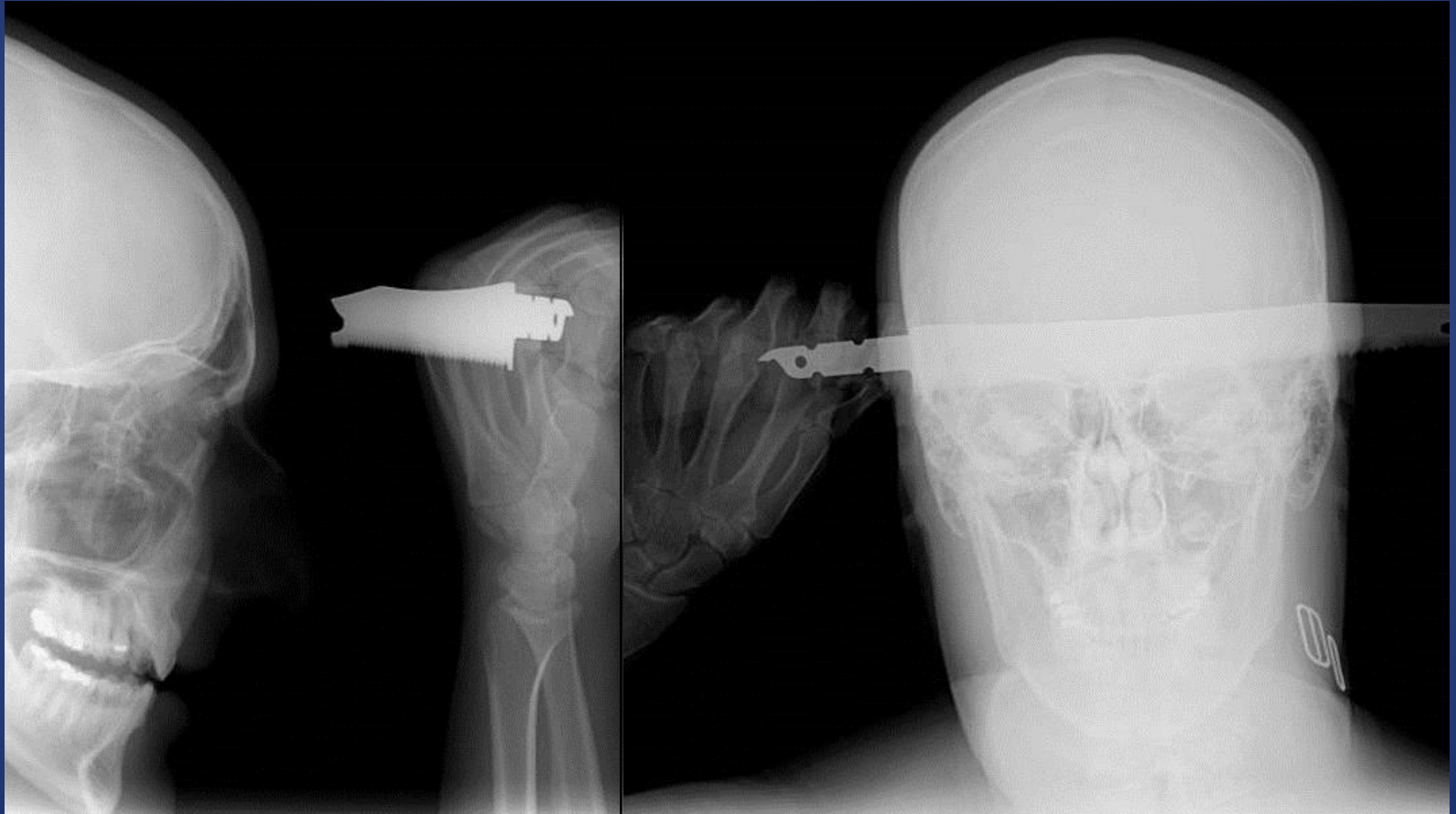
- ***“One view = No views”***





A: air; O: oil; W: water; L: liver; M: muscle; C: calcium; M: metal

*“One view = No views”*

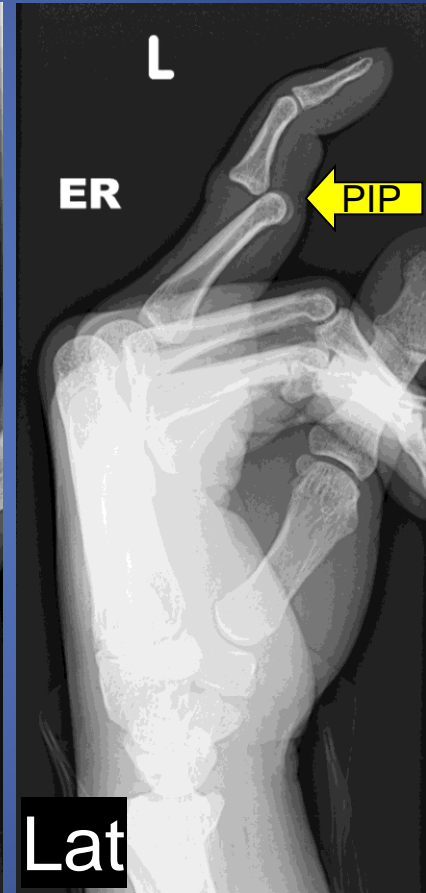


# Need Multiple Views

- Small finger
  - Not a subtle fracture
  - Fragment overlap each other so perfectly on PA view, are undetectable



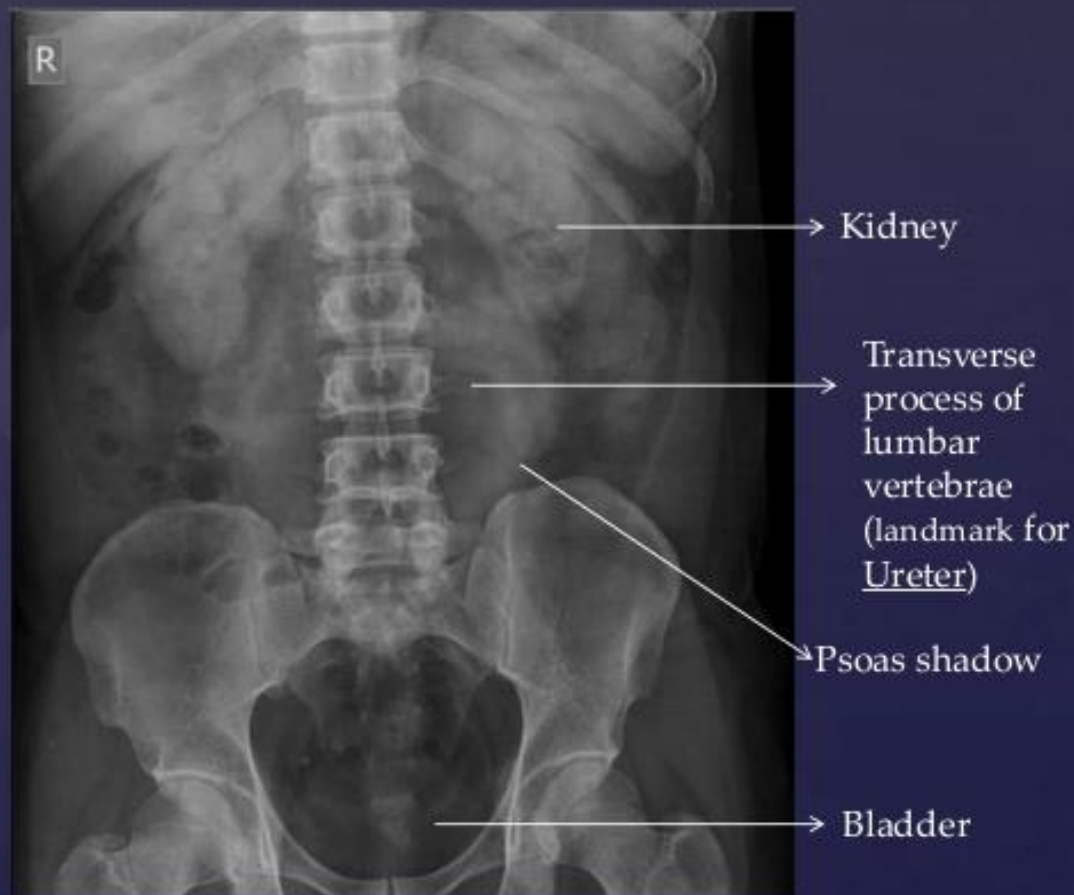
# For Joints: Need 3 Views!



# Anatomy on Abdominal X-Ray



# Kidney Ureter Bladder



## Posterior Anterior (PA)

The nomenclature follows the direction of the beam



## AP Chest

Beam Direction

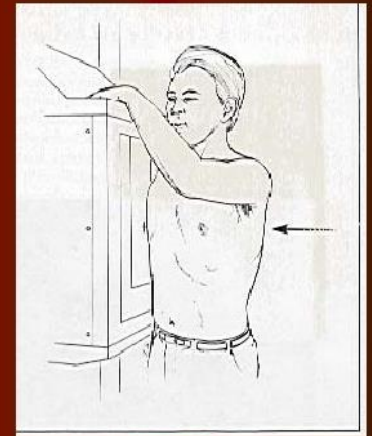


## Left Lateral

Nomenclature is dictated by the closest body part to the film



## Oblique – LAO and RAO

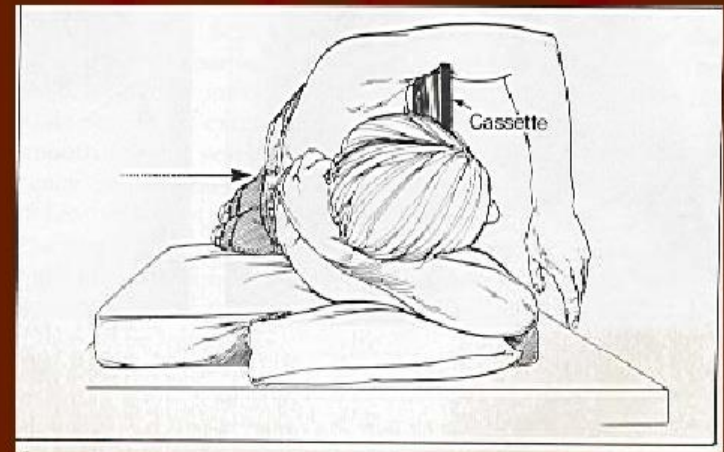




## AP Recumbant (AP supine)



## Right Lateral Decubitus

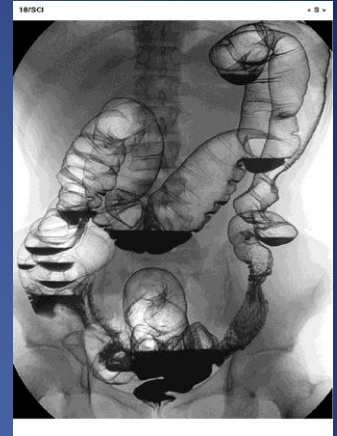


# Fluoroscopy

- Utilizes X-Rays
- Real-time imaging
- Utilizes image intensifier
- Involves use of contrast agents

# Main Uses of Fluoroscopy

- Gastrointestinal Imaging
- Genitourinary Imaging
- Angiography
- Other
  - Intraoperative
  - Foreign body removal
  - Musculoskeletal



# Single Contrast vs Double Contrast



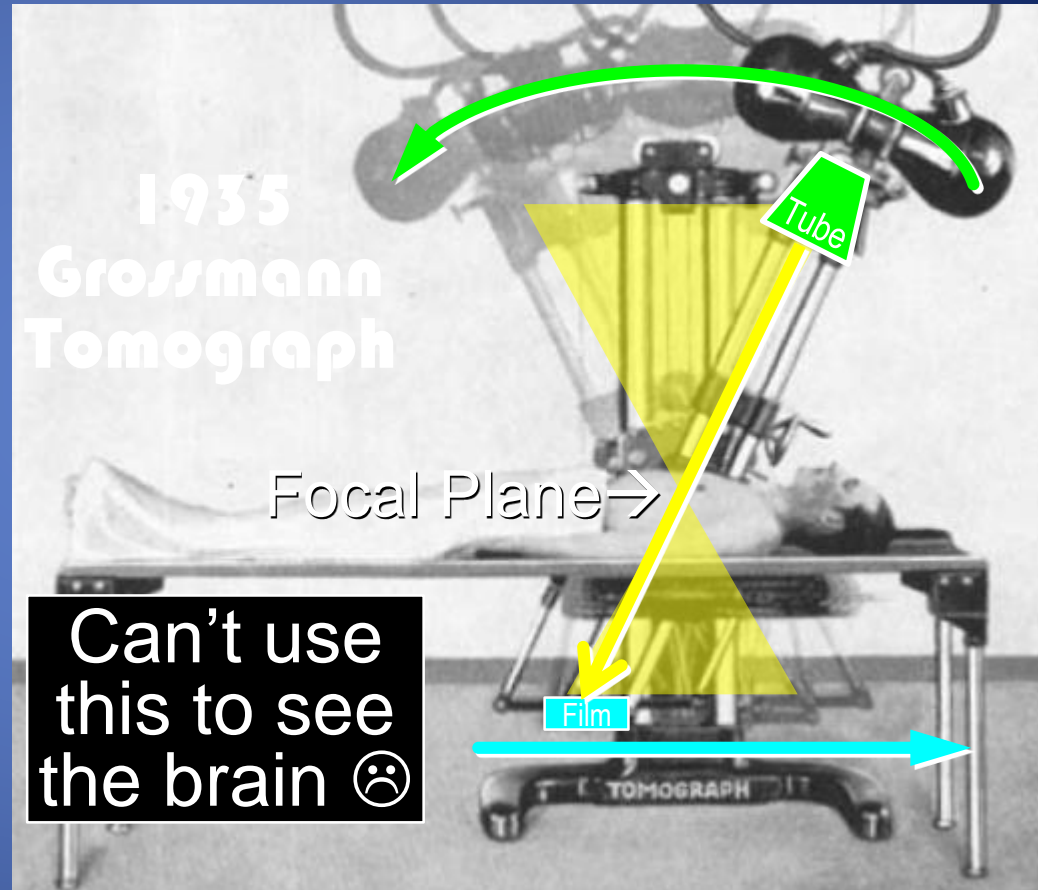
Single Contrast  
Barium Enema



Double Contrast  
Barium Enema

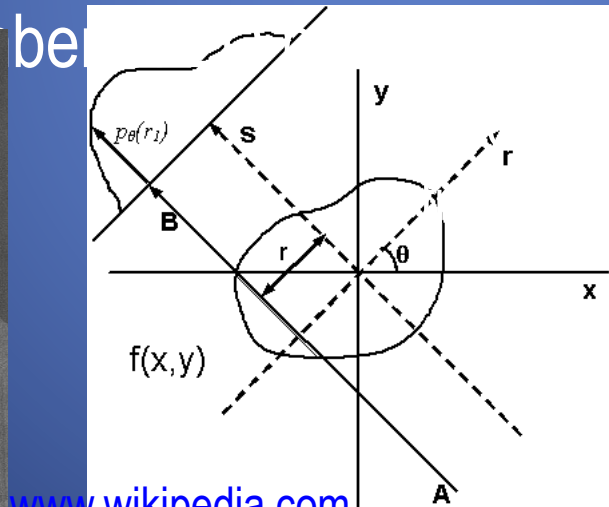
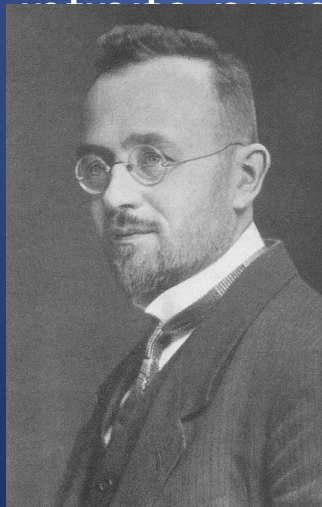
# Tomography: Small Step Forward

- To overcome flat 2D nature of radiographs...
  - Structures in the Focal Plane → are in focus.
  - Structures out of focal plane are blurred out.
  - At best, we got blurry pictures.
  - Long exposures = high radiation.



# CT: Giant Leap Forward

- CT: Computed Tomography (*Tomo* [Gr]: part, slice)
- CAT: Computed Axial Tomography
- 1917 Johann Radon, Austrian mathematician, proved image of a 3D object could be reconstructed from an infinite number of images of the object.

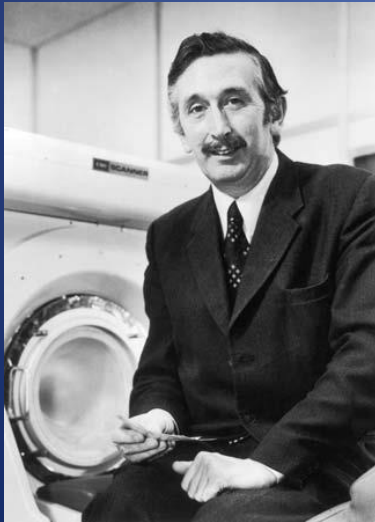


[www.wikipedia.com](http://www.wikipedia.com)

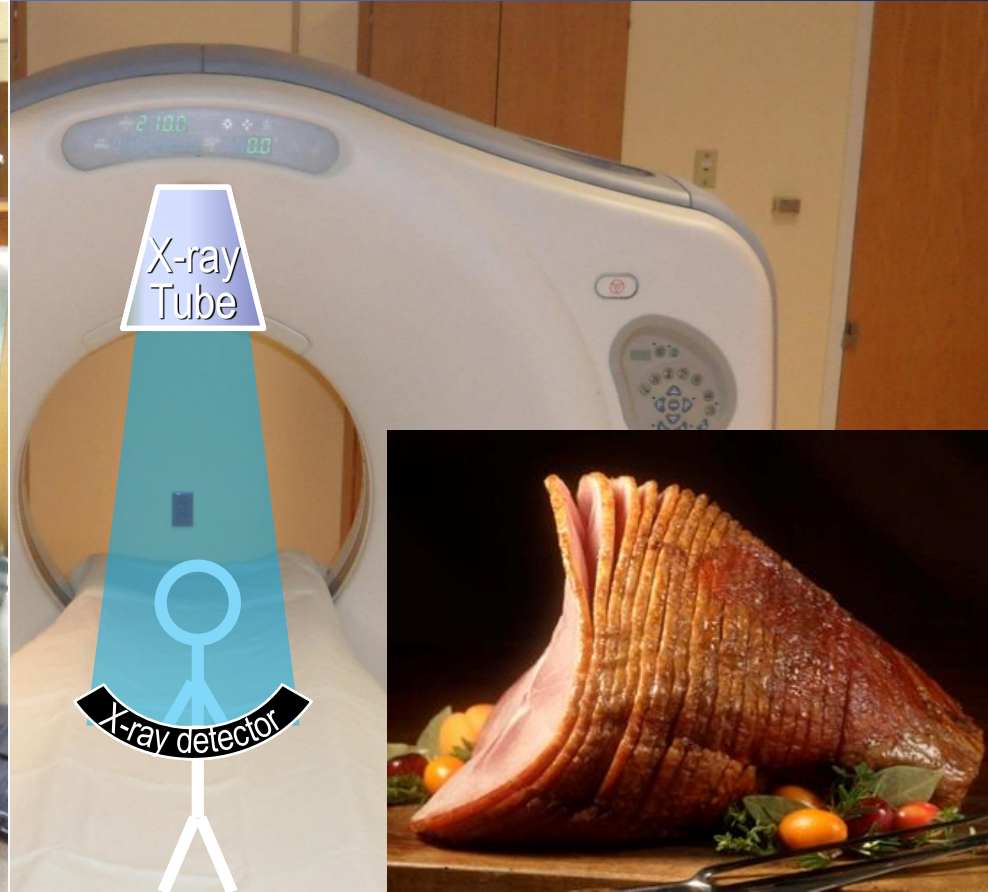
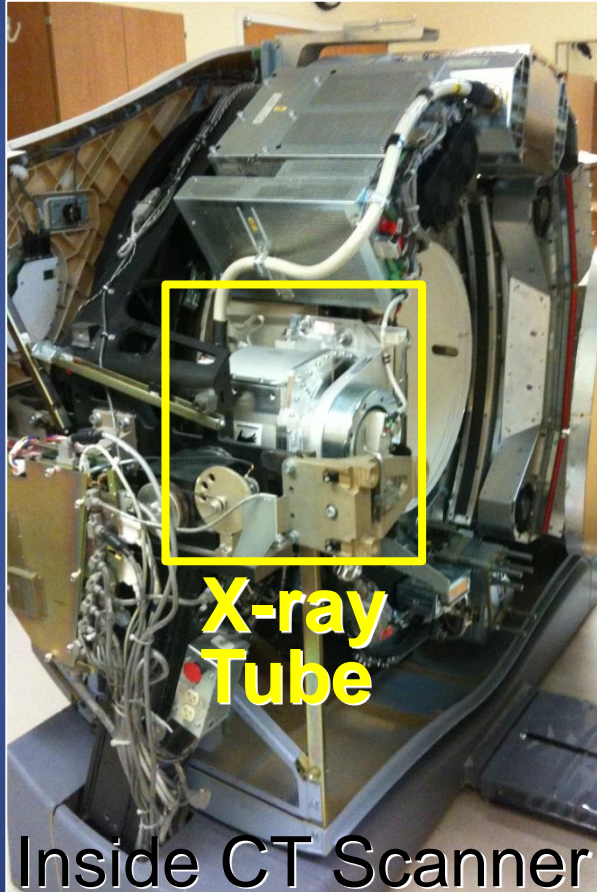


# Hounsfield & EMI Brain Scanner

- 1972: Godfrey Hounsfield, a British electrical engineer at EMI Laboratories, developed EMI Brain Scanner.
- **Finally, could see through the skull into the brain!**
  - Awarded Nobel Prize for Medicine 1979; Knighted 1981.
  - “Hounsfield Units” is the scale we use to measure CT density.
- EMI: “Electric and Musical Industries”

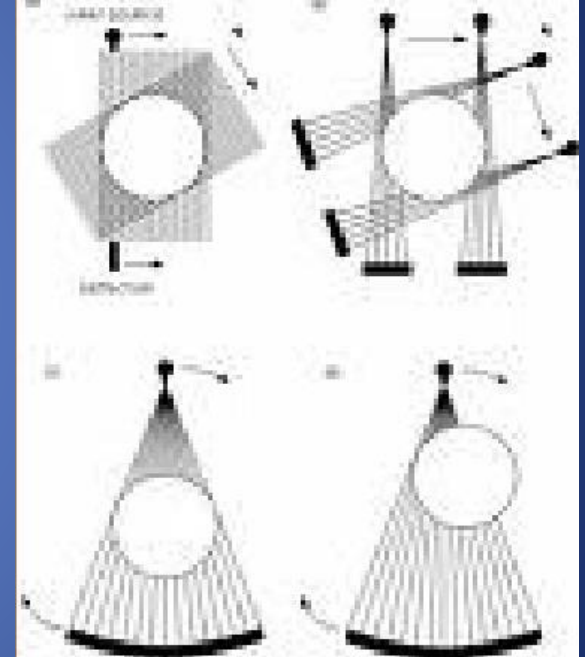
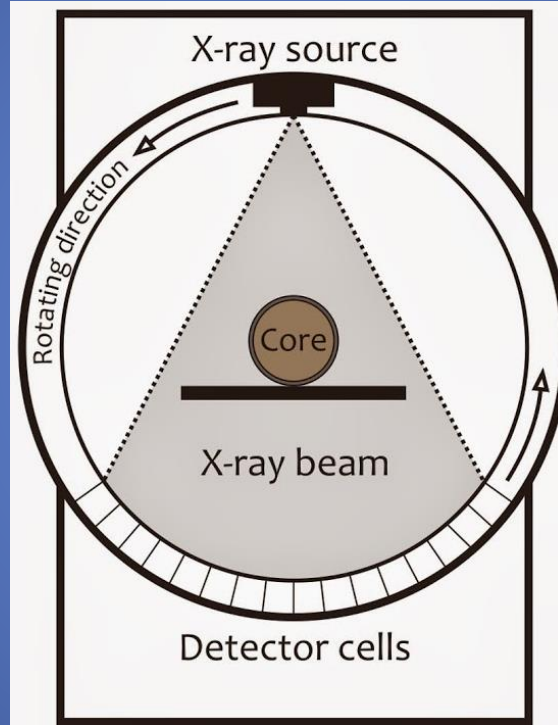


# CT = Rotating X-rays

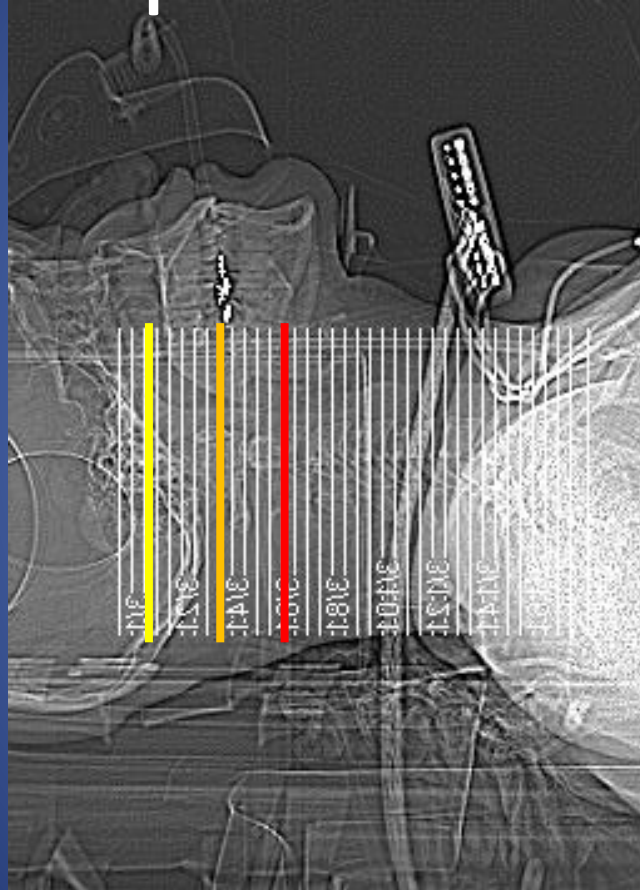




# CT = Rotating X-rays

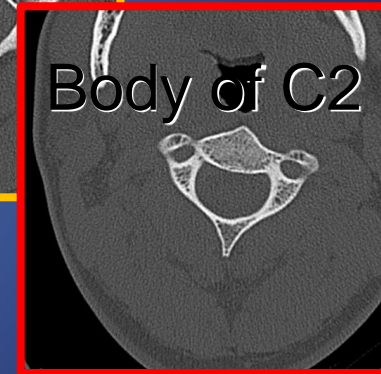
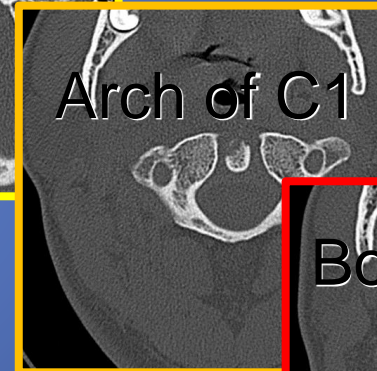
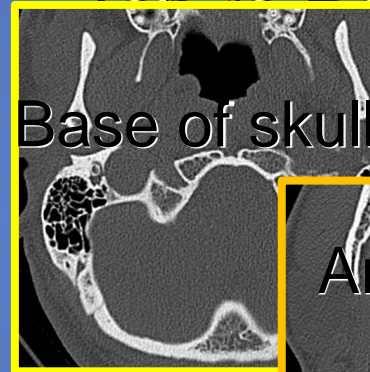


# Computed AXIAL Tomography

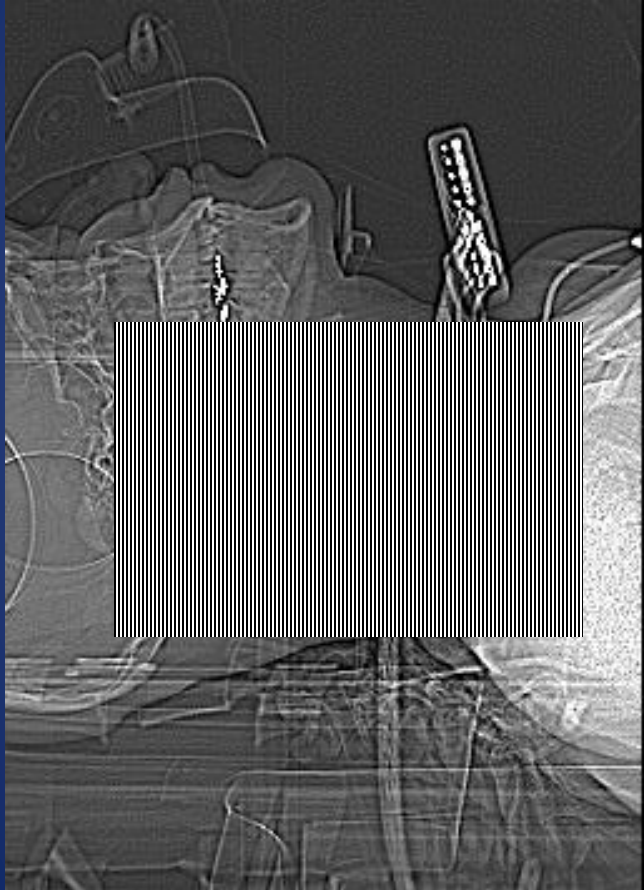


O,G 19yoM

- **Axial Plane:**
  - Top to Bottom



# Computed VOLUME Tomography



O,G 19yoM

- Thin, continuous slices=
- Solid volume of data
- Can reformat data:
  - Any 2-D plane
    - Coronal, Sagittal, Oblique
  - Even in 3-D!



# Multi-Planar Reformat



- **Coronal Plane**

- Front to Back

- Like AP view



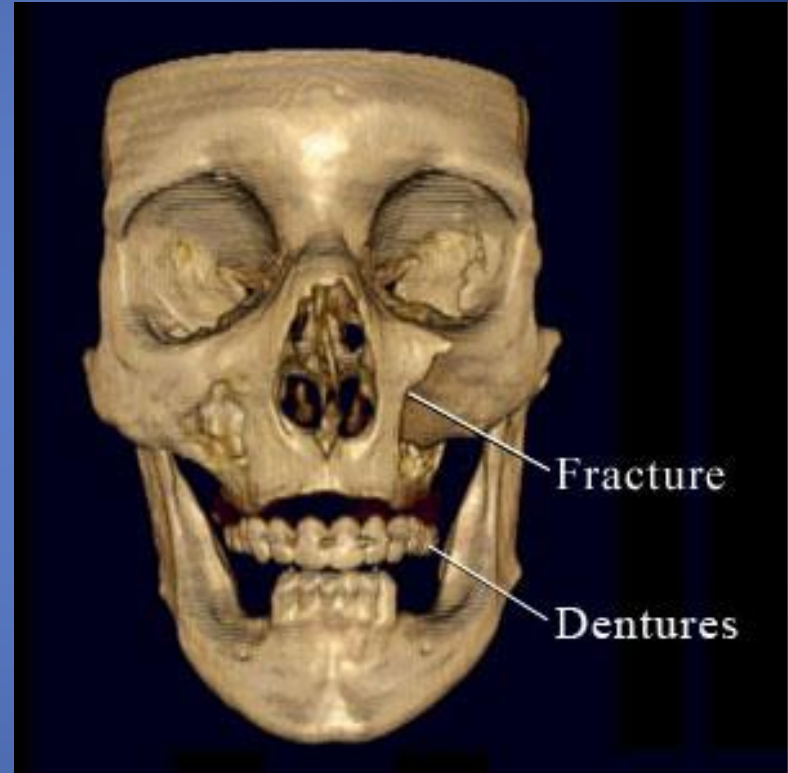
- **Sagittal Plane**

- Left to Right

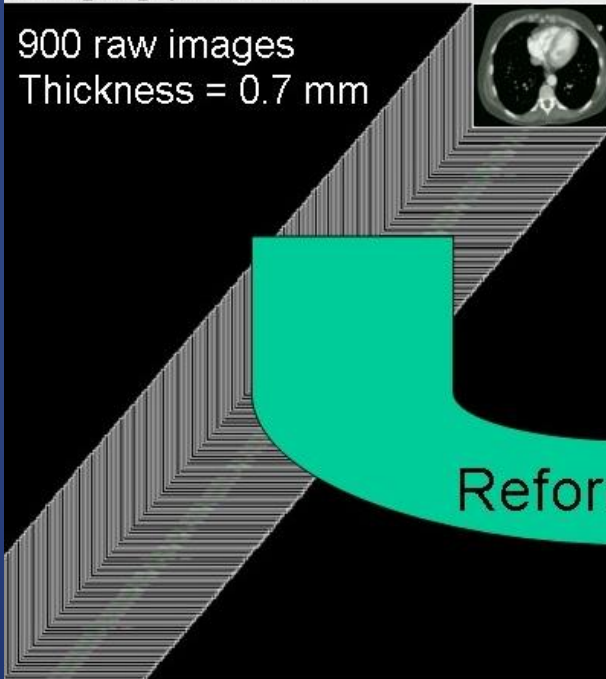
- Like a Lateral view



# Multi-Planar Reconstruction

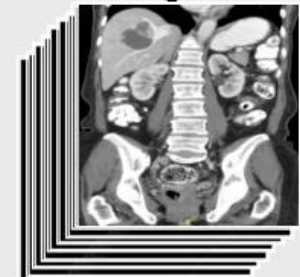
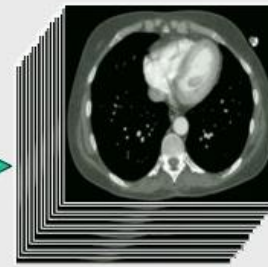


The ability to scan abdomen and pelvis with 0.7 mm thick slices has no direct diagnostic value. Axial images with a slice thickness of 5 mm are more appropriate to achieve good signal to noise characteristics. You cannot just scan with 5 mm slice thickness because that results in non-isotropic voxels and suboptimal reformats. In our clinical routine, we obtain axial and coronal reformats as part the imaging protocol.



100 axial  
images

60 coronal  
images



5 mm thick slices

In the above case “image compression” has gone from 900 to 160 images

# Why CT is So Great

- **Can see fractures otherwise missed**
  - Cervical spine, pelvis
- **Can see the brain!**
  - Strokes, bleeds, tumors
- **Can see organs (lungs, liver, bowel)**
  - Tumors, trauma, acute/chronic diseases
- **And now with ultra-fast, multi-slice...**
  - Can scan the heart in a single beat!
    - Can see coronary arteries, pulmonary emboli
- **Some hospitals have CT scanners in the ER**

# Problems with CT

- **Usually requires IV contrast**
  - 1% patients are allergic to CT contrast
  - Can affect renal function
- **Costs more than radiographs**
- **Can't see structures inside joints**
  - Knee: ☞ Menisci, ☞ Ligaments, ☞ Cartilage
  - Shoulder: ☞ Rotator Cuff, ☞ Labrum
  - Spine: ☞ Disks, ☞ Spinal Cord





# Biggest Problem with CT



- **High radiation dose**

- We are exposed to low levels of radiation every day, “Background Radiation”
  - Earth: naturally occurring radionuclides
    - Uranium-238, potassium-40
  - Atmosphere: Radon-222 (from U-238)
    - 2<sup>nd</sup> leading cause of lung cancer after smoking
  - Space: cosmic rays
    - Airline crews are more exposed to cosmic rays, doubling their background exposure.



- **Ave background dose  $\approx$  2.4mSv/year**



# Radiation from Diagnostic Imaging



- **Ave background dose  $\approx 2.4\text{mSv/year}$** 
  - Chest Radiograph  $\approx 0.06\text{mSv}$ 
    - $\approx 1$  week of background radiation
    - Chest CT  $\approx 7.0\text{mSv}$ 
      - **$\approx 3$  YEARS of background radiation**

# CT

- Advantages

- Eliminates overlapping densities
- Excellent resolution
- Excellent for detecting intracranial bleeding
- Excellent in the neck, chest and abdomen
- Excellent for evaluating fractures

- Disadvantages

- More expensive than x-ray and ultrasound
- **Much more radiation**
- Dense bone (petrous ridge for example) and metal cause severe artifacts

# Radionuclide imaging (Nuclear Medicine)

- Developed after World War II
- Research on nuclear bomb byproducts
  - Fission Uranium-235 → Iodine-131

# Iodine

- Naturally occurring element
  - Rare on Earth (47<sup>th</sup> abundant)
  - Rare in Humans (<0.05%)



1 H																	2 He						
3 Li	4 Be																	5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg																	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr						
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe						
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn						
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo						

- Taken up by Thyroid Gland
  - ❖ Made into Thyroid Hormone

Used in X-ray contrast dye

# Nuclear Medicine

- Developed after World War II
- Research on nuclear bomb byproducts
  - Fission Uranium-235 → Iodine-131
- Naturally occurring Iodine not radioactive
- Iodine-131 is HIGHLY radioactive
  - Emits  $\beta$ -particles
    - Much more damaging than  $\gamma$ -rays
  - Accumulate in and destroys Thyroid tissue
- ☹ Nuclear Reactor Fallout → Hypothyroid
  - Take Iodine pills to block I-131 from Thyroid
- ☺ Useful for treating Thyroid Cancer

# Nuclear Medicine

- Developed more agents to accumulate in specific tissues, emit low-energy  $\gamma$ -rays.

- “Radiopharmaceuticals”
- Many use Technetium

- Not naturally occurring

- 1936: First element to be artificially produced

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

# Nuclear Medicine

- Technetium-99m: Ideal Imaging Agent
  - Short half-life (6 hours)
    - After 24 hours 94% gone
  - Emits  $\gamma$ -rays
    - $\gamma$ -rays pass out of the patient without accumulating
  - Good energy for gamma-camera detection
    - Dual-head cameras: Image  $\gamma$ -rays emitted front & back



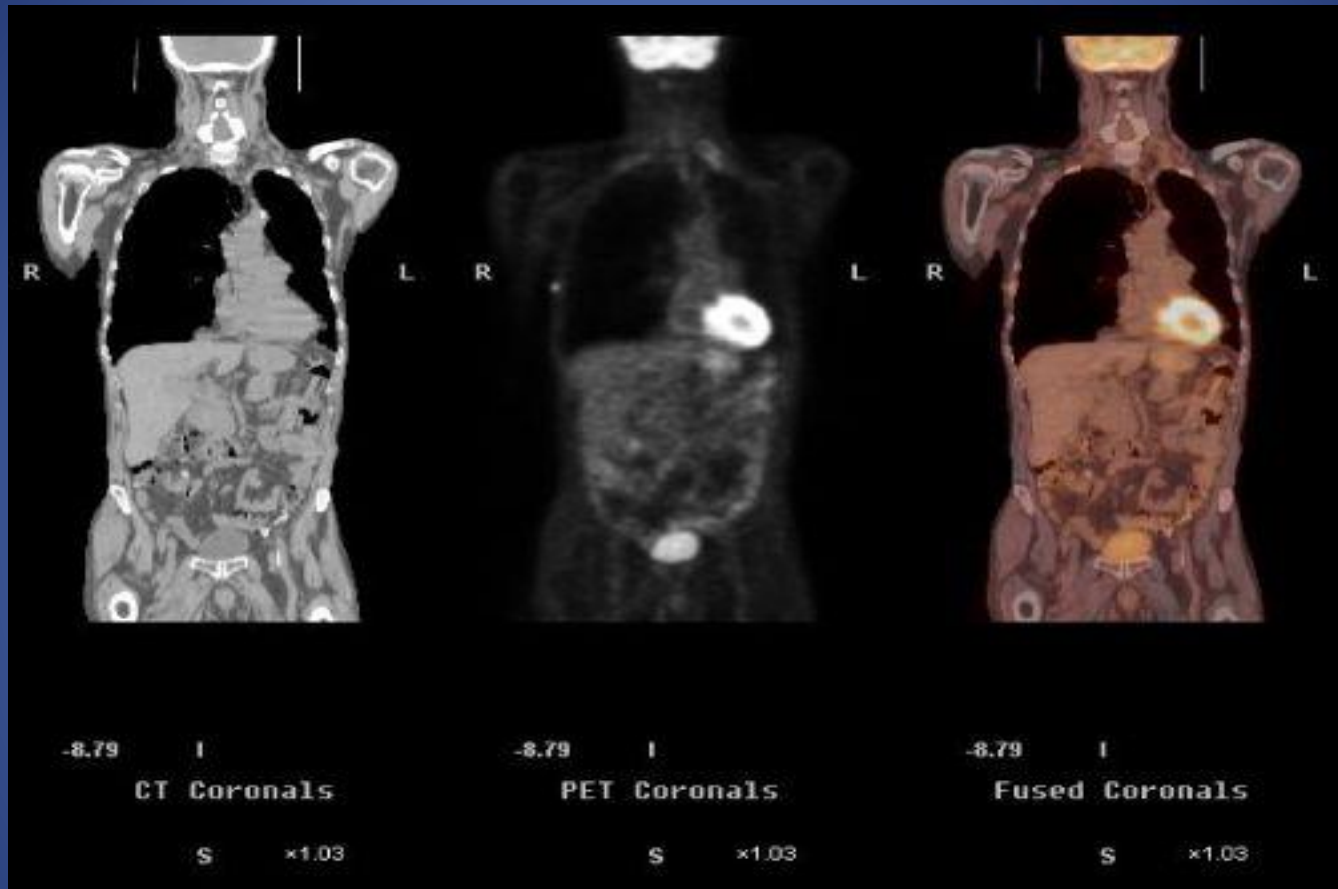


# Nuclear Medicine: Bone Scan

- Was used a lot before CT & MR
  - Shows bone pathology earlier than radiographs
- Nowadays, seldom used for *focal* lesions
- We *still* use Nuc Med Bone Scans for:
  - Looking for bone metastases in *entire body*
    - Breast Cancer
    - Prostate Cancer

# Nuclear Medicine: PET/CT

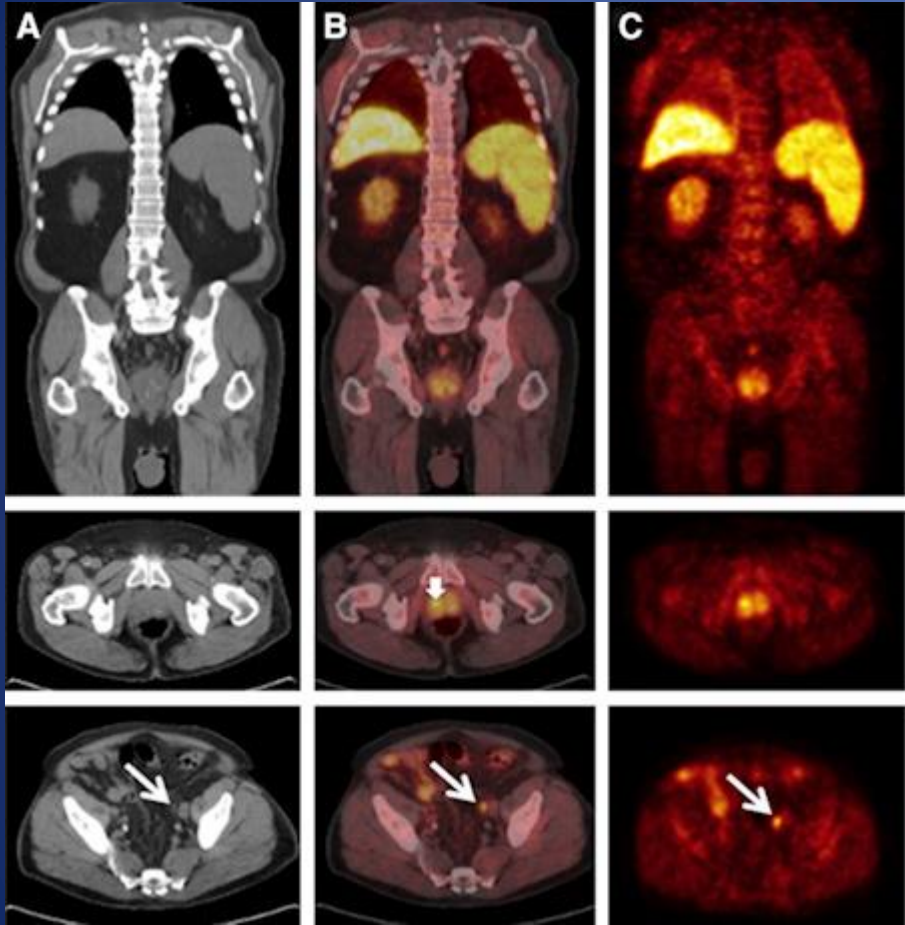
- Most recent innovation in Nuc Med
- PET: Positron Emission Tomography
  - Uses agents with *very* short half-lives
    - Fluorine-18 (100 min)
    - Oxygen-15 (2 minutes)
    - Made onsite with cyclotron
  - Agents taken up by tumors, metastases
  - **Well shows abnormal FUNCTION**
- Combined with CT (Computed Tomography)
  - **Well shows underlying ANATOMY**
  - Used for staging cancer patients



CT

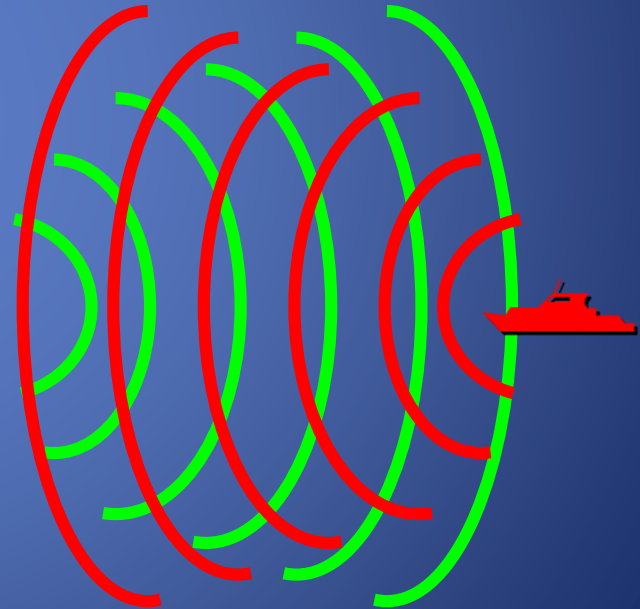
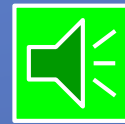
PET

PET/CT



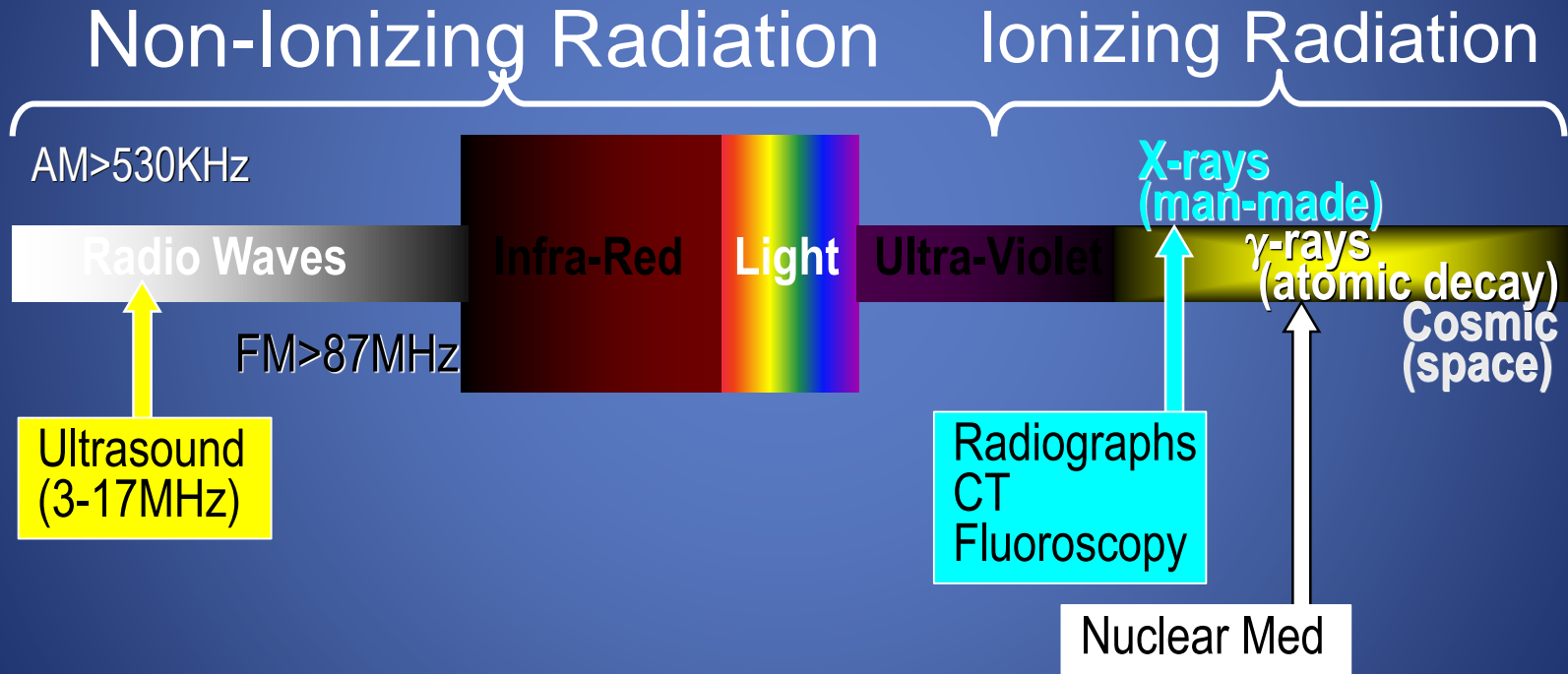
# Ultrasound

- Developed after World War II
- Based upon **SONAR**
- “**SO**und **N**avigation **A**nd **R**anging”
  - Sound wave sent out
  - If sound hits an object get reflected back
  - Measure time for the reflected echo to return
  - Multiplying the time by speed of sound ( $\div 2$ ) = distance from the object
- Works best in water
  - Water transmits sound well



# Sonography

- Uses radio waves (Not X-rays,  $\gamma$ -rays)



# Diagnostic Ultrasound

- Ultrasound is sound waves with frequencies which are higher than those audible to humans (>20,000 Hz).
- Ultrasonic images also known as sonograms are made by sending pulses of ultrasound into tissue using a probe.
- The sound echoes off the tissue; with different tissues reflecting varying degrees of sound.
- These echoes are recorded and displayed as an image to the operator.

# IMAGE INTERPRETATION

- “**WHITE**” areas represent “echogenic” structures
  - represent structures that transmit & reflect waves
    - Soft Tissue - muscles, fat, vessels, nodes, masses
- “**BLACK**” areas represent areas that are anechoic
  - Fluid – transmits but does not reflect sound waves
- “**GREY**” helps widen the representative scale of black/white “brightnesses”
- **LINES** – occur at boundary of two markedly different tissue reflectors - clear delineation of structures -



# Tissue Characteristics of Ultrasound

- Air – near total reflector (scatter reflector)
- Fluid – near total propagation (no reflection)
- Bone – near total reflection
- Soft Tissue- partial propagator, partial reflector
  - reflects every time tissue impedance changes - every “interface”
  - *ideal for ultrasound imaging!*

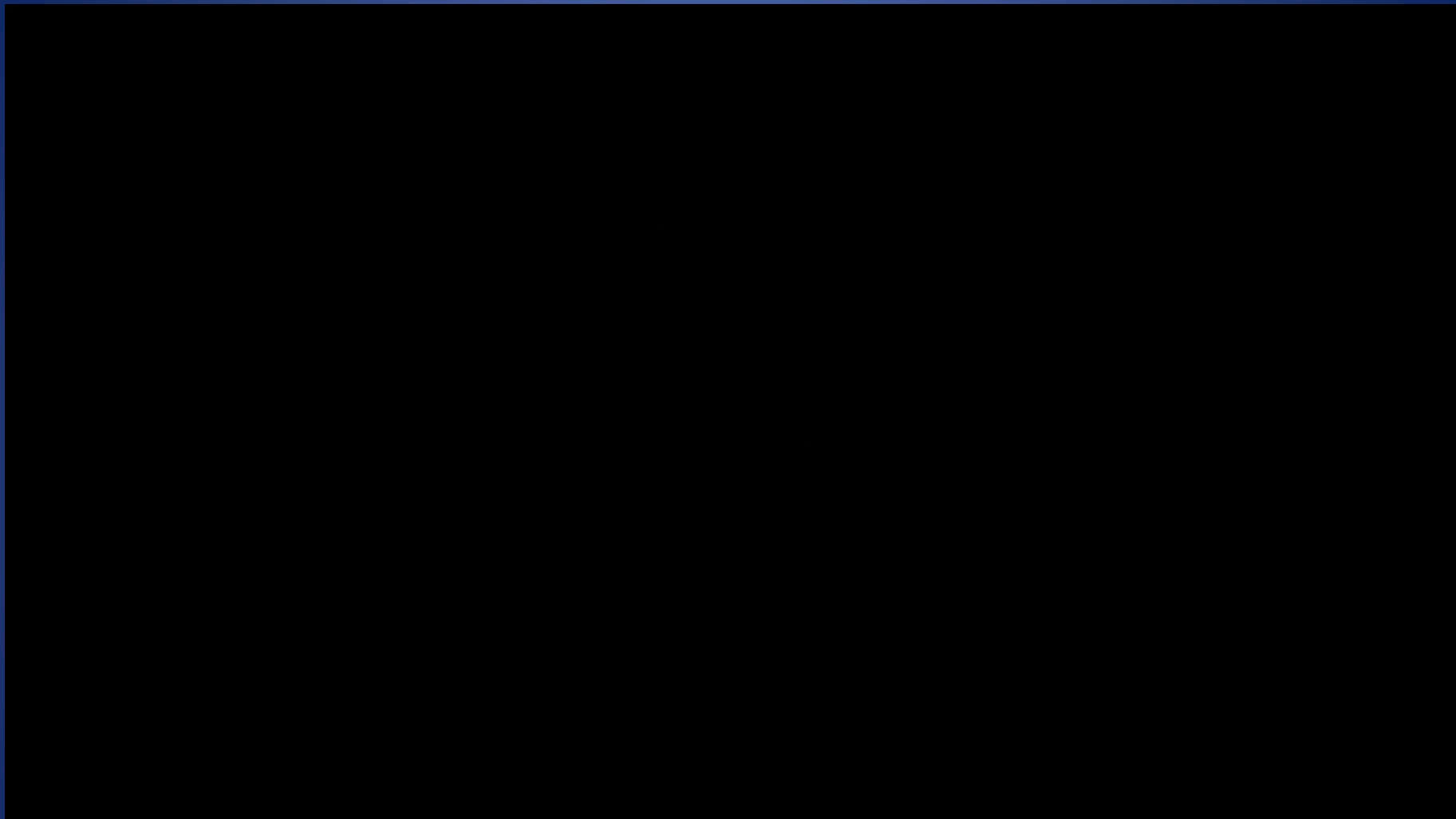
# Sonography Useful for...

- Tissues that contain/surrounded by water
  - Abdominal organs
    - Gall bladder (Gall Stones)
    - Kidneys (Kidney Stones)
  - Blood vessels
    - Blood clots (DVT: Deep Venous Thrombosis)
- Imaging without Ionizing Radiation
  - Pelvic organs
    - Uterus, Ovaries
    - Testes
  - Babies (Newborn)
  - Babies... before birth

# Obstetric Ultrasound



Tissue	Description of appearance on ultrasound
Bone	Appears bright due to the dramatic difference in acoustic impedance between bone and soft tissue. High frequency ultrasound does not penetrate bone effectively and therefore the screen is generally black deep to the bone
Fat	Can be bright or dark (hypoechoic), but subcutaneous fat is typically dark
Muscle	Is also dark, when viewed in cross section. In long section sound is reflected back by the muscle fibres and the internal structure of the collagen fibres which shows bright can be easily seen
Fluid	Be it blood, effusion or cyst is generally black (anechoic), though thicker fluids such as puss can either be bright or dark.
Tendons	Are typically bright, but this varies with their orientation relative to the probe
Nerves	Nerves are echoic tubular structures containing hypo-anechoic discontinuous segments that correspond to the fascicles



# Ultrasound

- Advantages

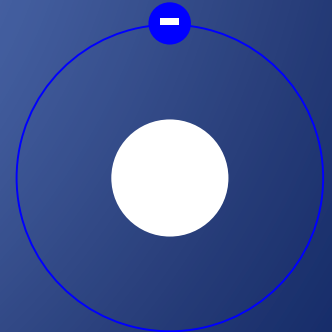
- No radiation
- Portable
- Instantaneous (real time)
- Excellent for cysts and fluid
- Doppler ultrasound is excellent to assess blood flow
- Excellent for newborn brain, thyroid, gall bladder, female pelvis, scrotum, pregnancy

- Disadvantages

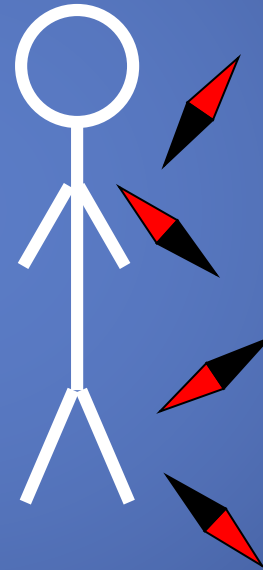
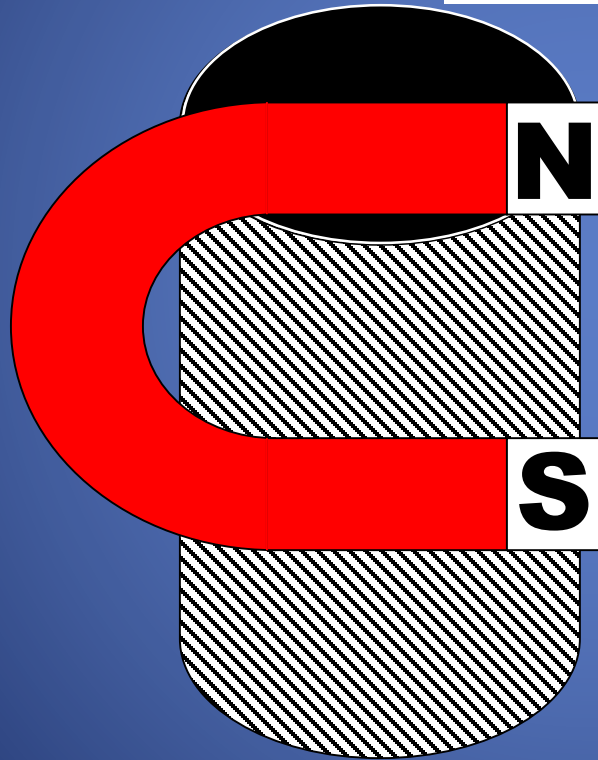
- Does not work well in large or obese patients
- Resolution less than CT and MRI
- Air or bowel gas prevents visualization of structures

# Magnetic Resonance Imaging (MRI)

- **MRI doesn't rely on X-rays to see projected shadows of patients**
  - Unlike radiographs, CT, fluoroscopy
- **MRI sees tissues based upon sub-atomic characteristics (magnetism)**
  - Proton nucleus of Hydrogen has small magnetic field that can be used to detect tissues containing hydrogen.



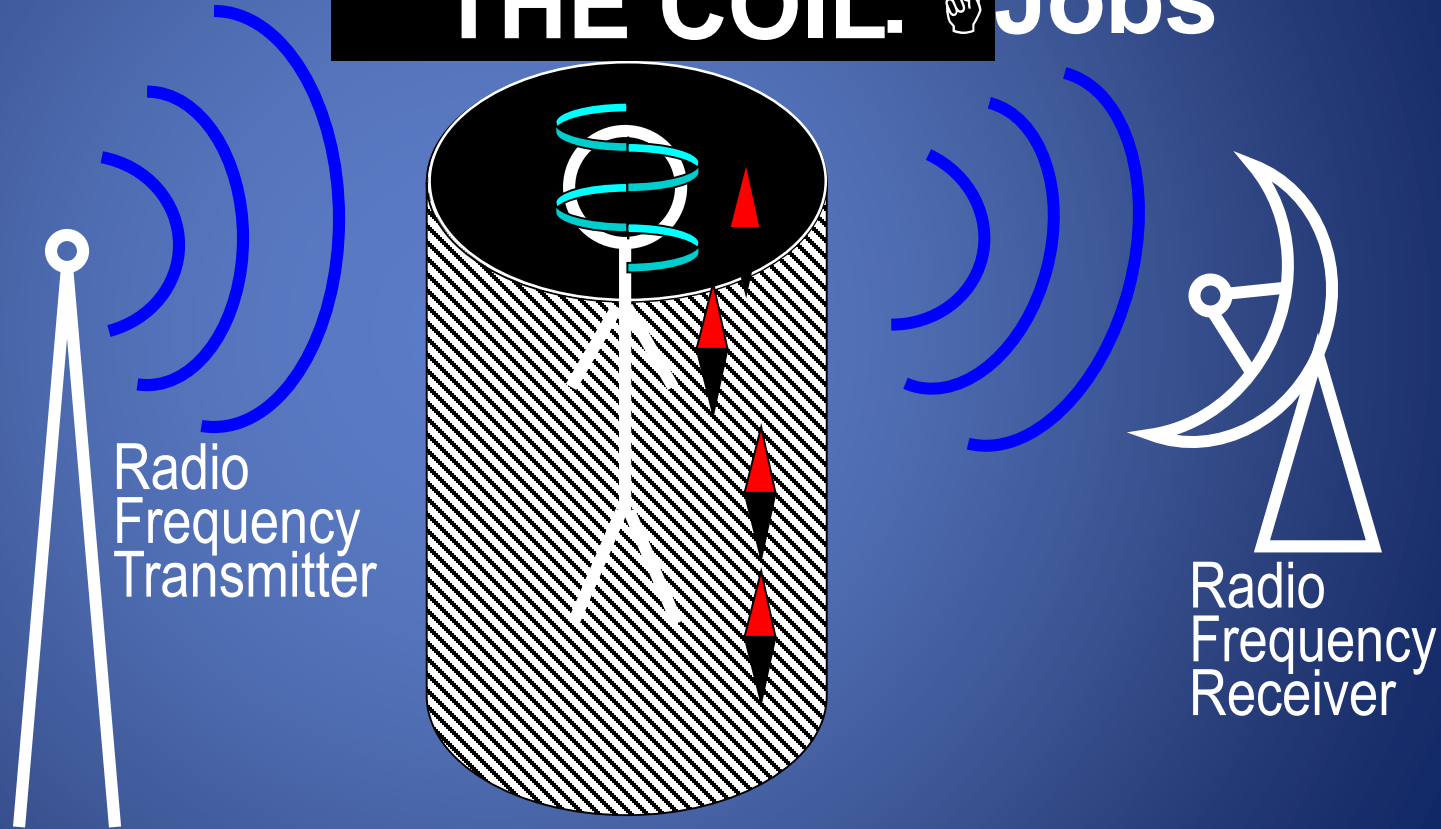
# MRI Scanner: 2 Components





# MRI Scanner: 2 Components

## THE COIL: ✌️ Jobs



# How MR Scanner Works

- **Magnet**

- Aligns spins of protons in hydrogen nuclei
  - Align in direction of magnetic field,  $B_0$

- **Coil (antenna)**

- 1) Sends RF pulse to flip spinning protons
  - After RF pulse is off, protons realign to  $B_0$
  - As protons realign, resonate RF energy

- 2) Measures strength of resonant RF echo

- **At a specific time,  $T_E$ , “Echo Time”**

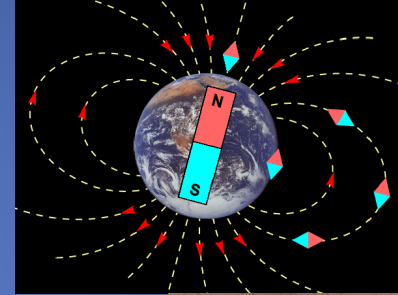
Steps 1&2 repeated many times / image slice

- **At a specific “Repetition Time”,  $T_R$**

# Tesla: Measure Magnetic Field Strength

- **Earth's magnetic field:**

- 30  $\mu\text{T}$  ( $3 \times 10^{-5} \text{ T}$ )



- **Typical refrigerator magnet:**

- 3 mT ( $3 \times 10^{-3} \text{ T}$ )



- **High Field MRI scanner:**

- 1.5 – 3 T

- 1,000 times the strength refrigerator magnet

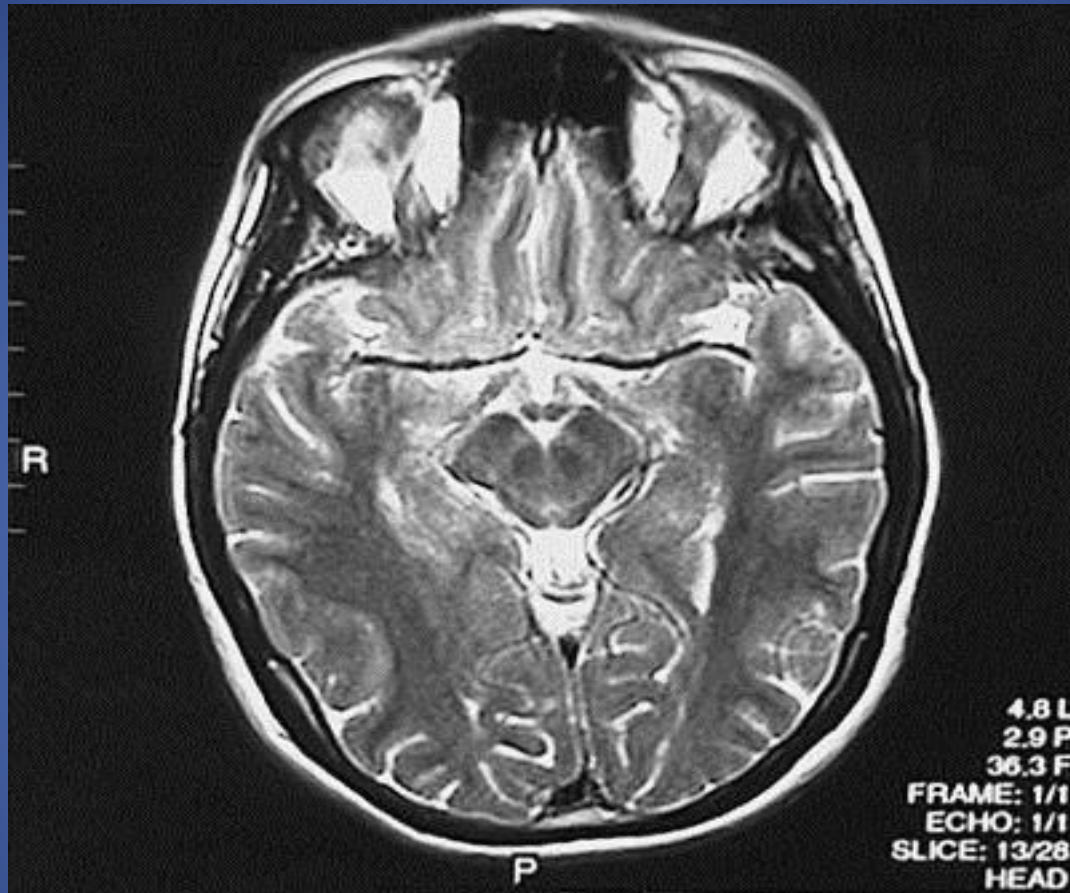
- 100,000 times the Earth's magnetic field

# MRI: Need Multiple Sequences

- **T1 shows Fat best**
  - Most normal anatomy surrounded by fat
  - In essence, T1 shows anatomy best
- **T2 shows Fluid best**
  - Most pathology contains fluid (edema)
  - In essence, T2 shows pathology best
    - Fat-suppression makes fluid more conspicuous
- **PD shows Dense Stuff best**
  - Good for meniscal and tendon tears
  - Used mostly for MRI of joint pain

# MR Applications

- Neuro-imaging
  - Excellent tool due to high soft tissue contrast resolution
  - Abundant water content of CNS allows for imaging soft intracranial tissue
- Head and Neck imaging
  - Multi-planar capability allows for monitoring extent of disease
  - Differentiating subtle soft tissue boundaries of head and neck



MRI  
Axial, T2-Weighted

MEYERING, KEN

10-MAR-1966

11:56

21-APR-2001

IMAGE 111

SER 1-6

H

Franciscan Health System

MAGNETOM EXPERT plus

H-SP VB33D

+ : F A L



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POST PROHANCE 20 CC  
ST. FRANCIS HOSPITAL

SP -1.2

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Fov 240\*240

592 \*2560

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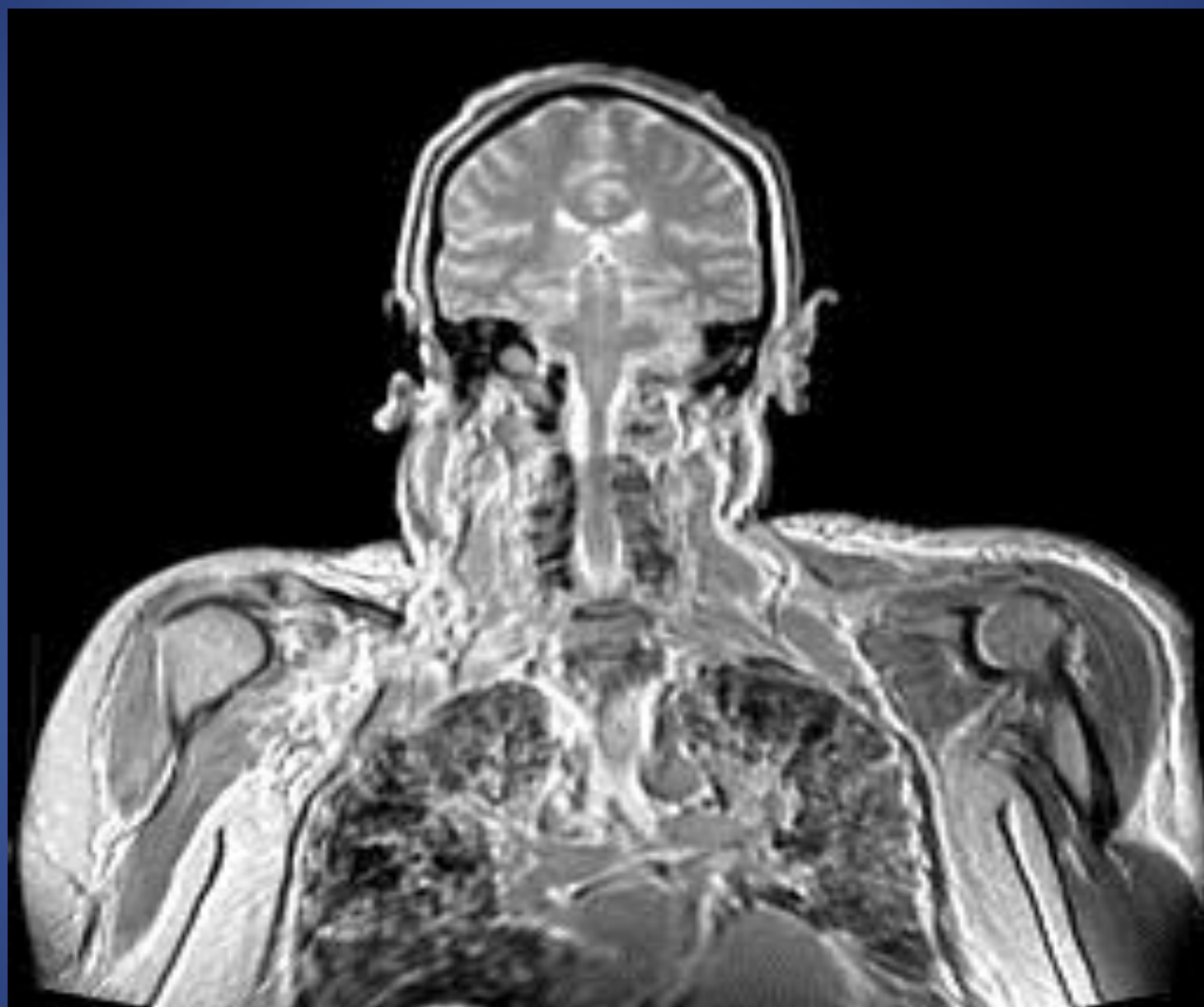
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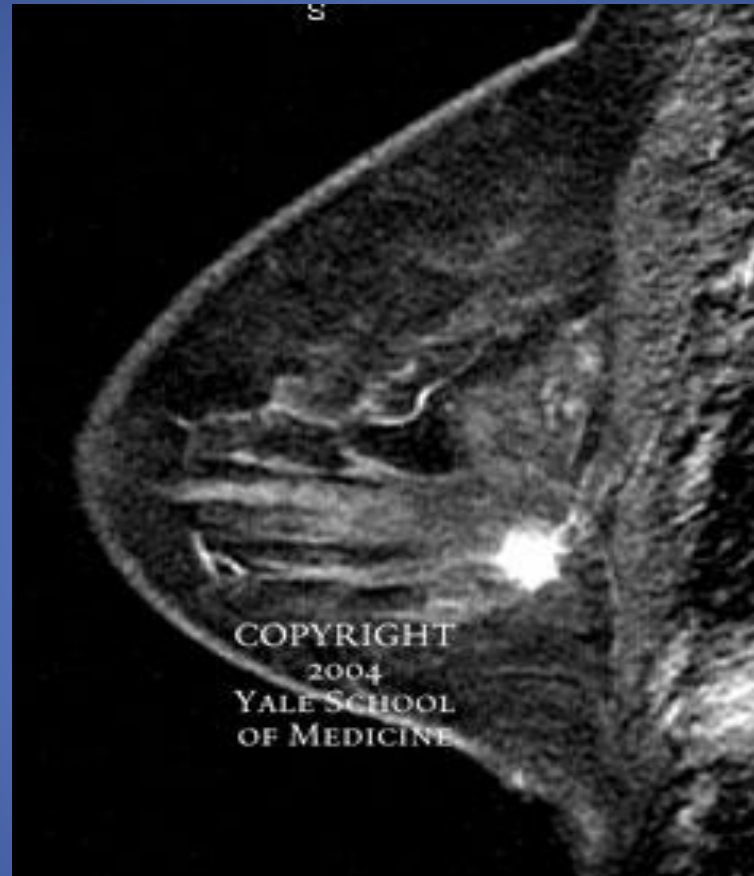
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# MR Applications

- Body Imaging
  - Thorax: mediastinal, hilar, chest wall abnormalities
- Limited lung imaging due to artifacts
- New advances in breast imaging
- Potentials for cardiac MRI with coronary MR angiography







**MRI Breast Imaging**

# MR Applications

- MSK Imaging
  - High sensitivity for neoplastic, inflammatory, and traumatic conditions of bone and soft tissue
  - T1-weighted---fluid collections and abnormalities in fatty marrow
  - T2-weighted---lesions in both marrow and soft tissue



MRI of the knee  
Sagittal, T1-Weighted

# MRI

- Advantages
  - No overlapping artifact
  - Excellent resolution
  - Very good at detecting fluid
  - Excellent for imaging the brain, spine and joints
  - No radiation
  - Multiple imaging tests within the same study (T1, T2, IR, GE)
- Disadvantages
  - Very expensive
  - Patients cannot have a pacemaker or ferromagnetic material
  - Slower to acquire images (approximately 45 minutes)

# References:

- Introduction to Radiology, Prof BL Liang, SYS U, PowerPoint Presentation.
- Evolution of Radiology, An introduction for Non-Radiologists, Ken L Schreibman PhD/MD, UW-Madison PowerPoint Presentation.
- Introduction to Medical Imaging, Jeff Benseler, D.O., PowerPoint Presentation
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