Introduction to Radiology
RAD COURSE 366

Dr. Abdullah Abujamea

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.

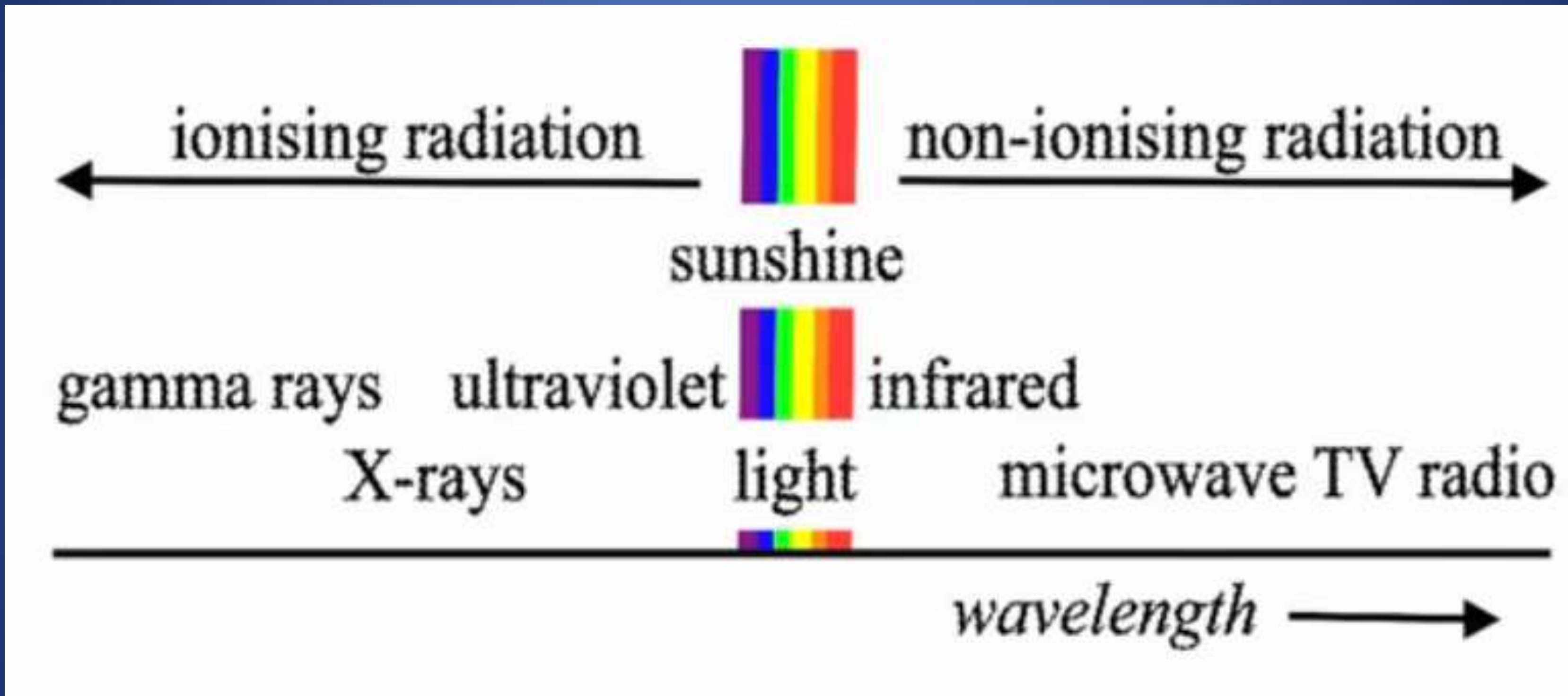
Imaging Modalities

Ionized Radiation

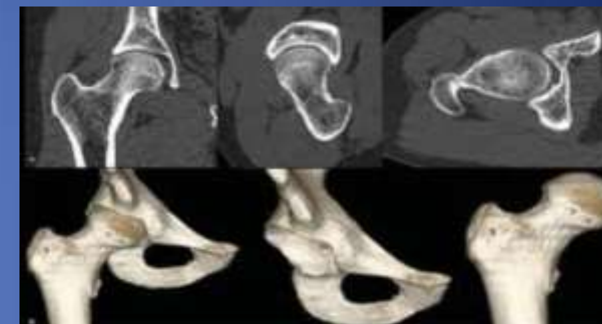
- X-Ray.
- Fluoroscopy/ Angiography.
- Computed Tomography.
- Radionuclide imaging.

Non-Ionized Radiation

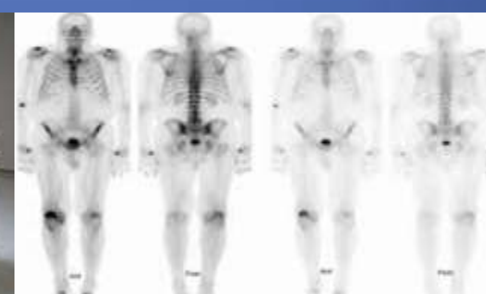
- Ultrasound imaging.
- Magnetic Resonance

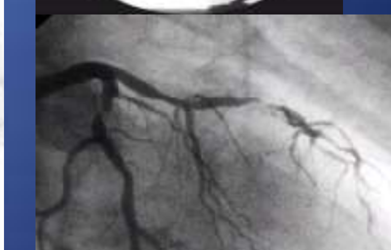

ionising radiation
non-ionising radiation
sunshine
gamma rays
ultraviolet
infrared
X-rays
light
microwave TV radio
wavelength

Ionising



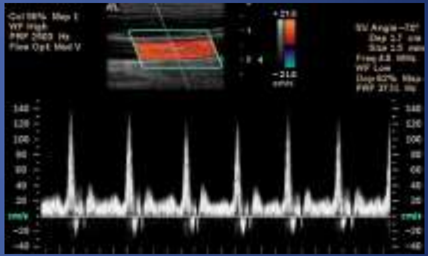
- X Ray
  Radiographs/
  mammograms
- CT
- Fluoroscopy/Angiography
- Nuclear medicine

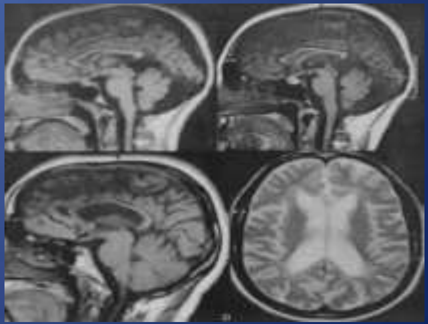




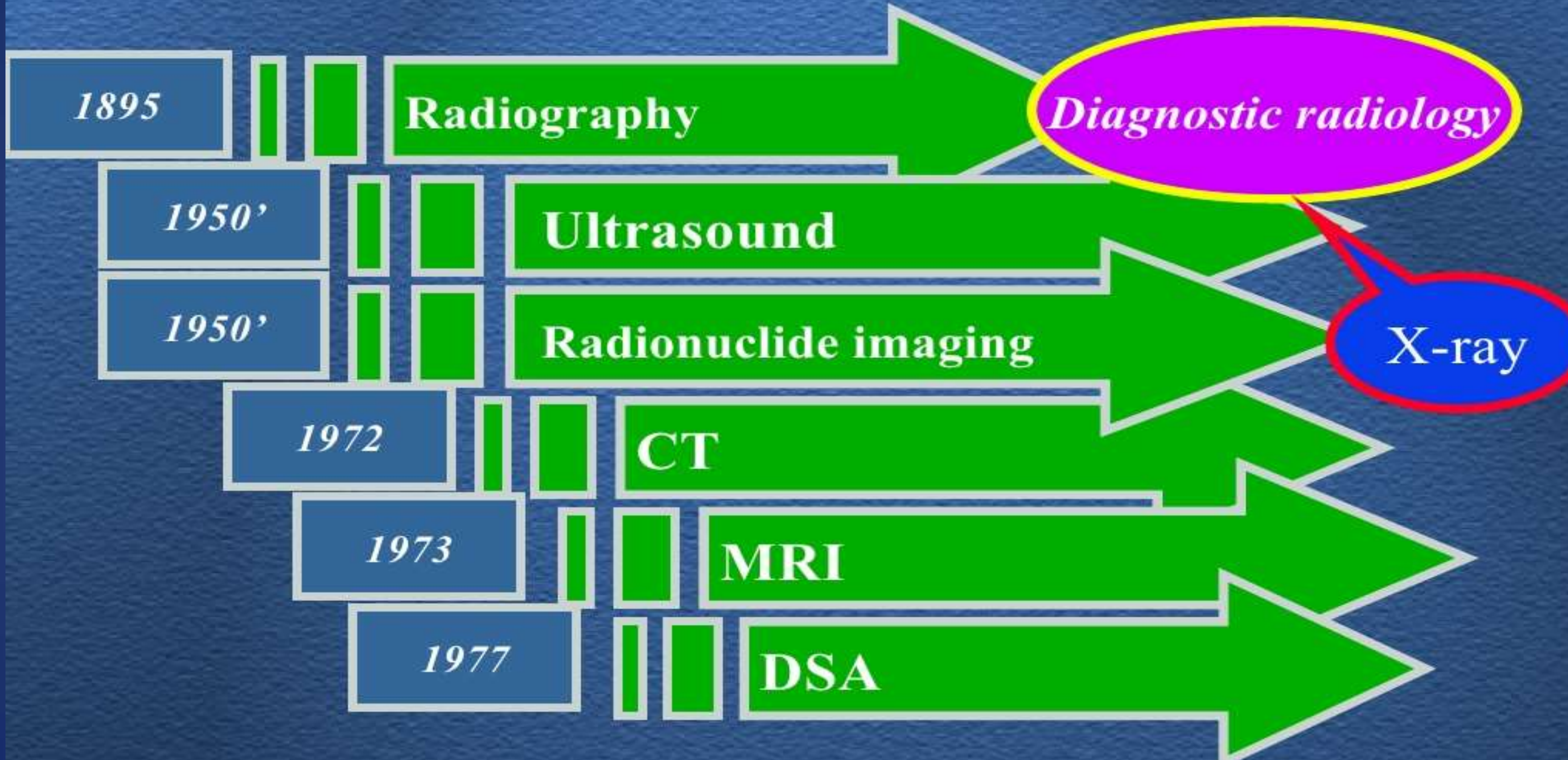
Non ionising

- Ultrasound
  - (2D/3D/4D)
  - Doppler
- MRI
  - fMRI/kinetic
  - MRI/contrast MRI

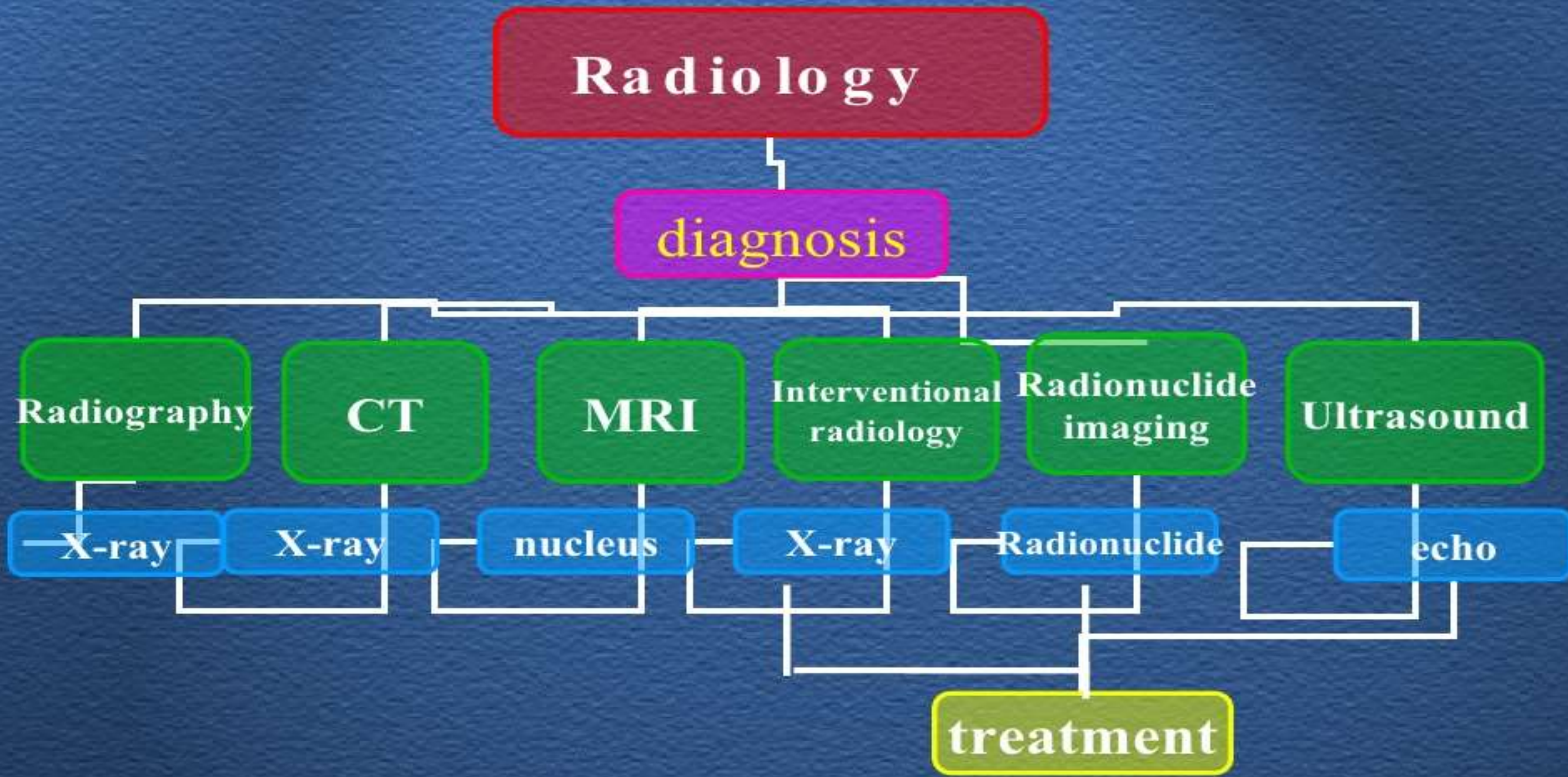




Imaging Technology



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 8th, 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

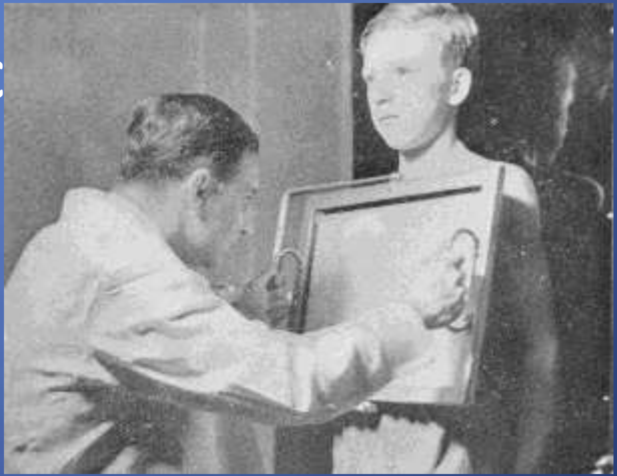
1901:Röntgen wins 1st Nobel prize in physics

www.wikipedia.com

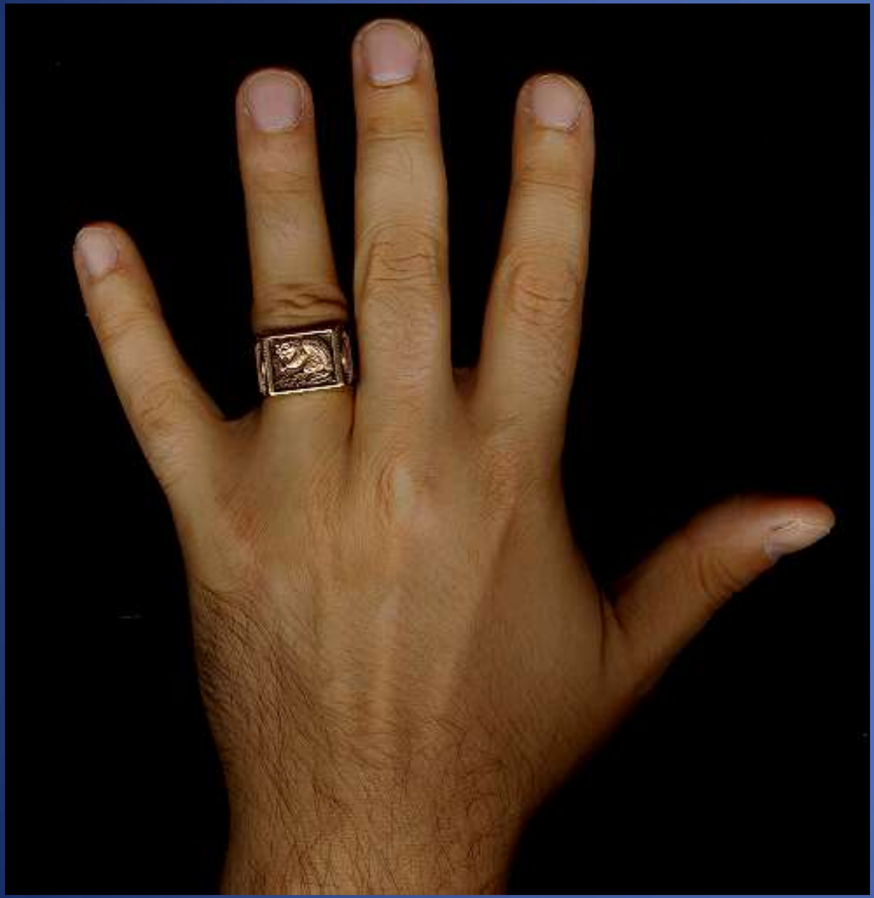
Early years in Radiologic Technology

- Nurses or nurses aides taught how to "take an x-ray"
- NO special education
- Only "ON THE JOB" training
- Exp

eac

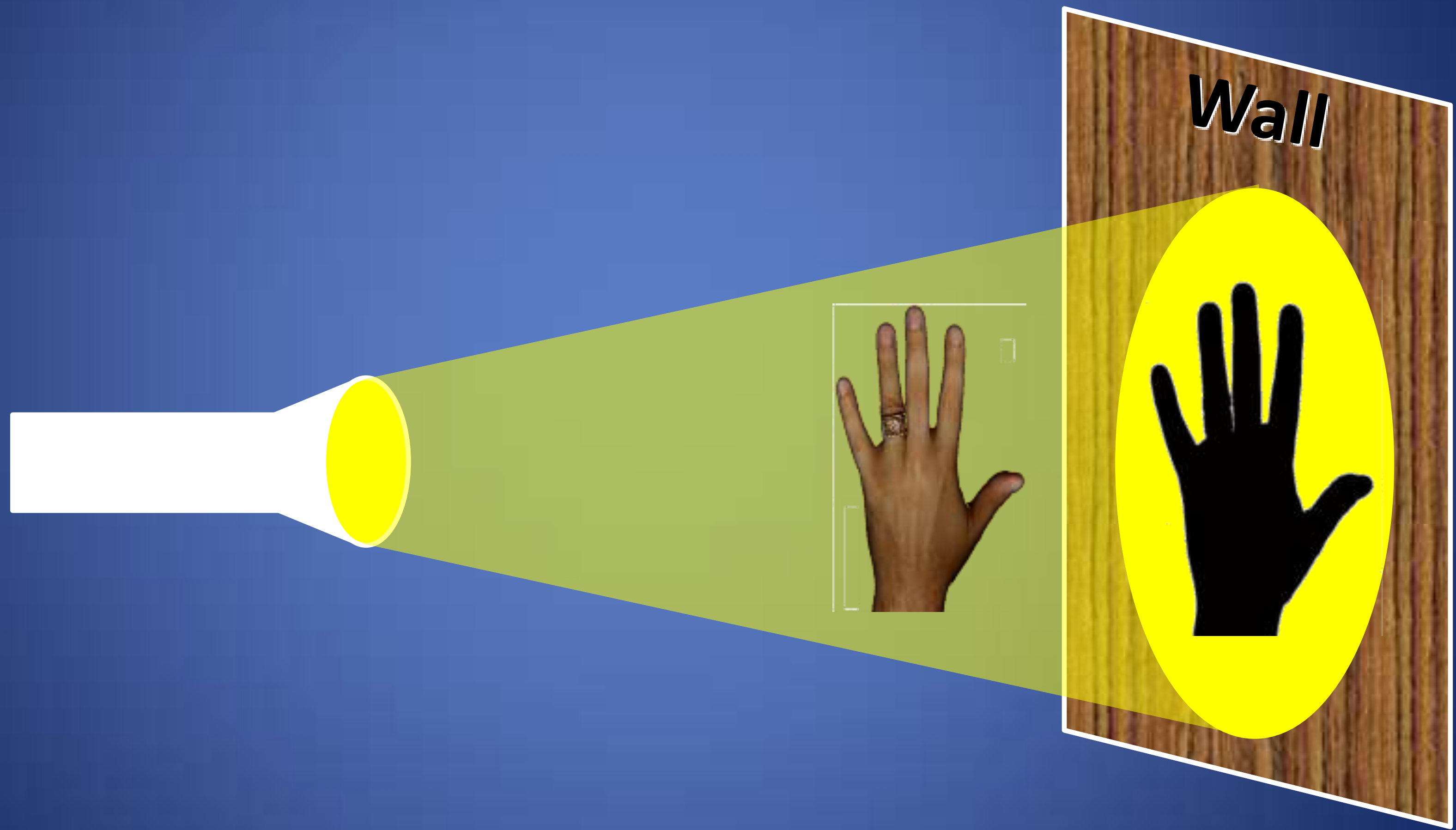


How We Make Radiographs



- 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



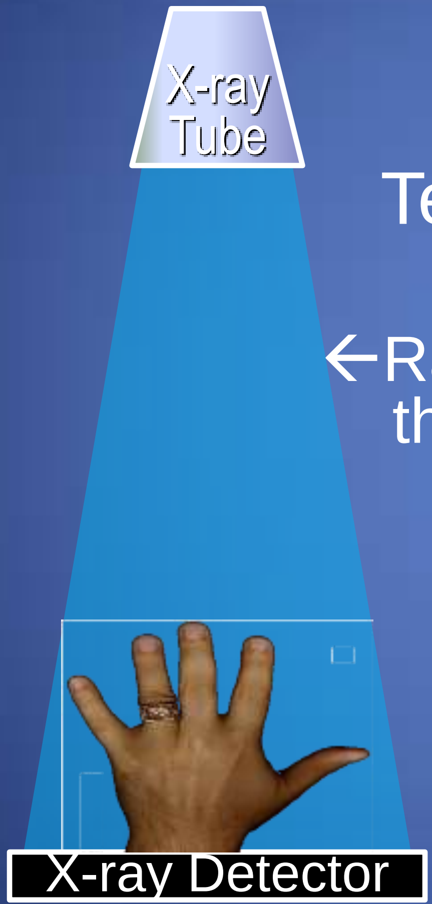
"Shadow-graph"

- 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



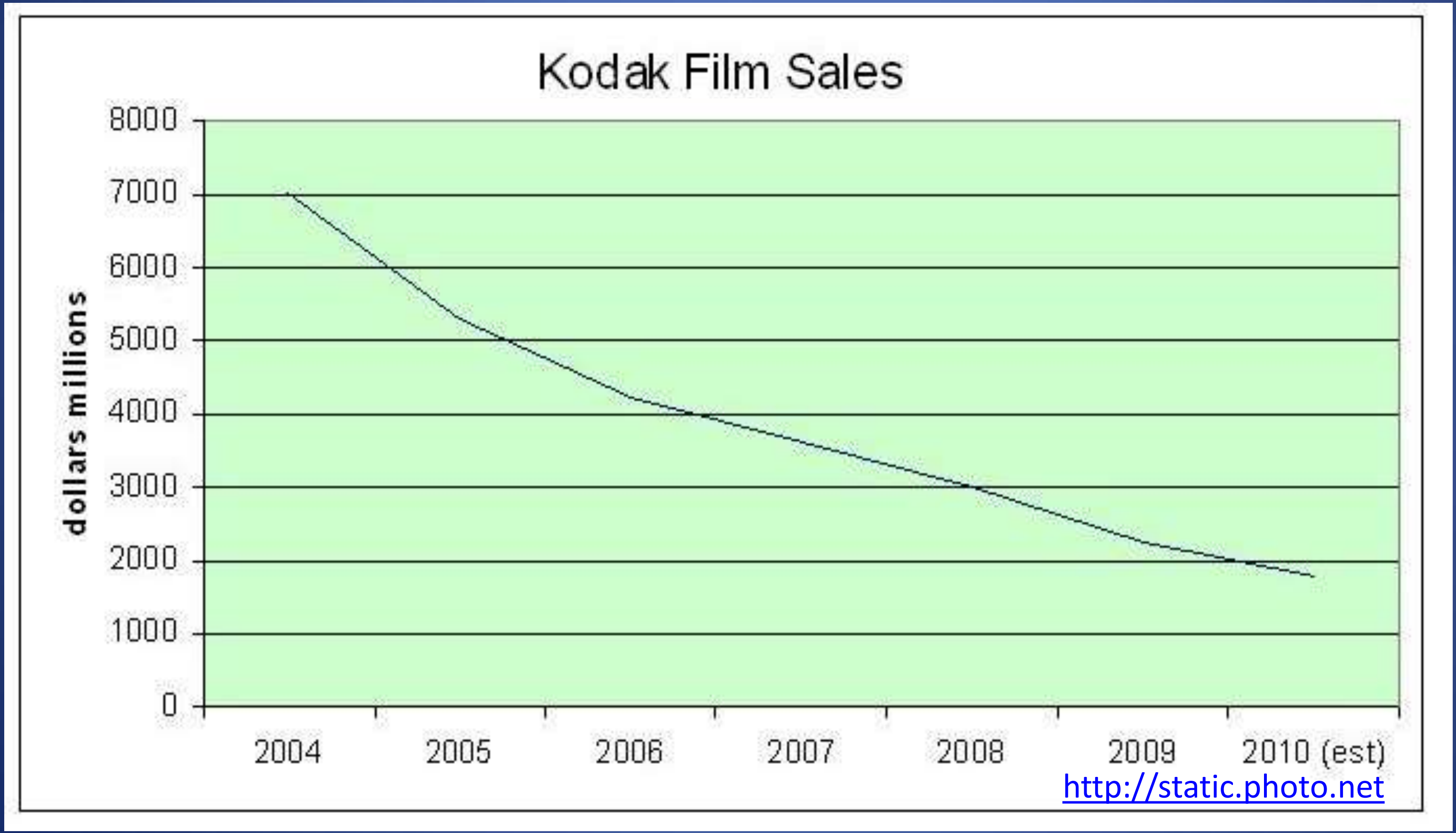
Terminology:

"X-rays":
←Rays that pass thru the patient.

The image→ is called a "radiograph"

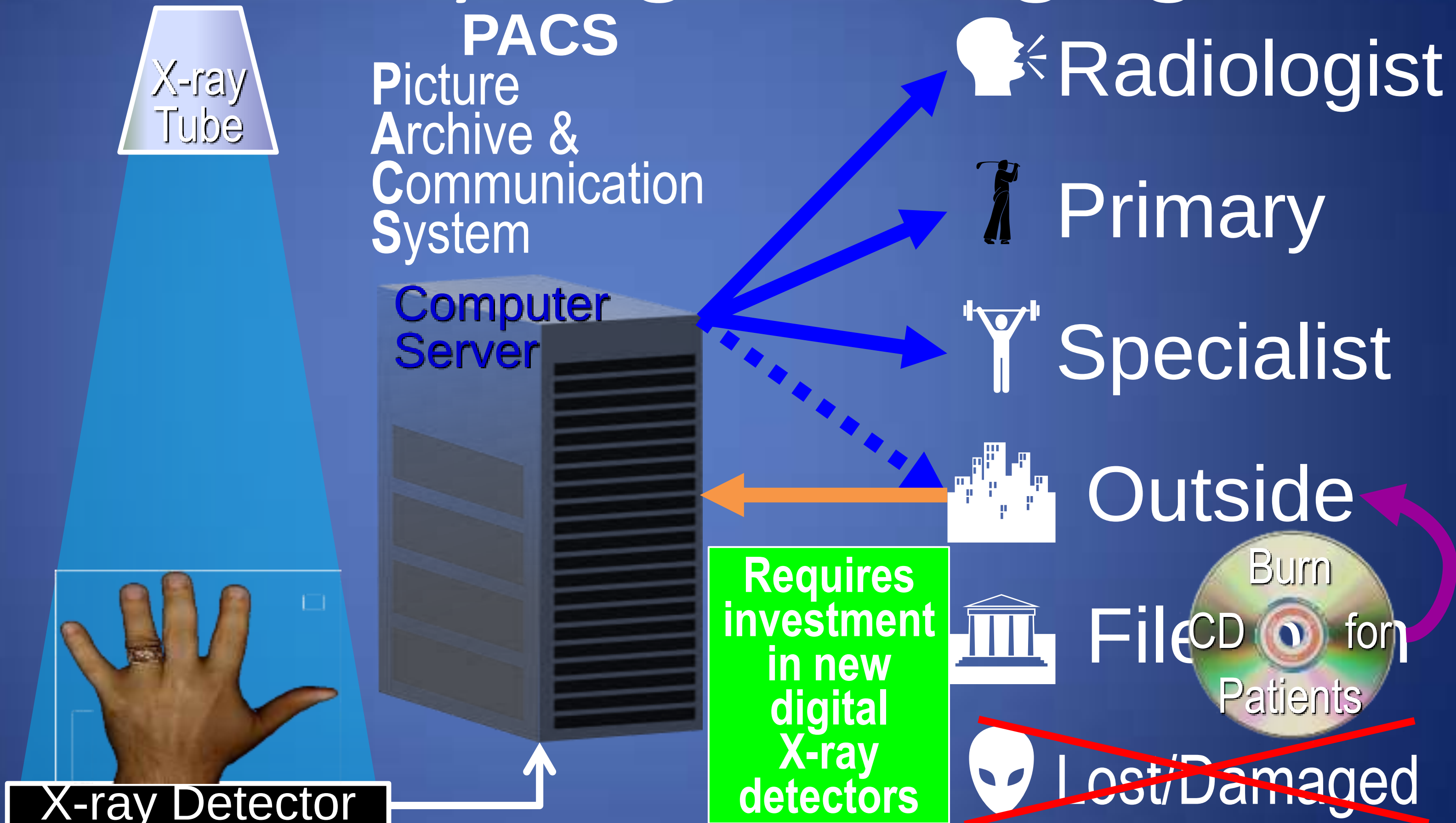
20^{th} Century: Images = Film

21st Century: Images = Film



http://static.photo.net

21st Century: Digital Imaging

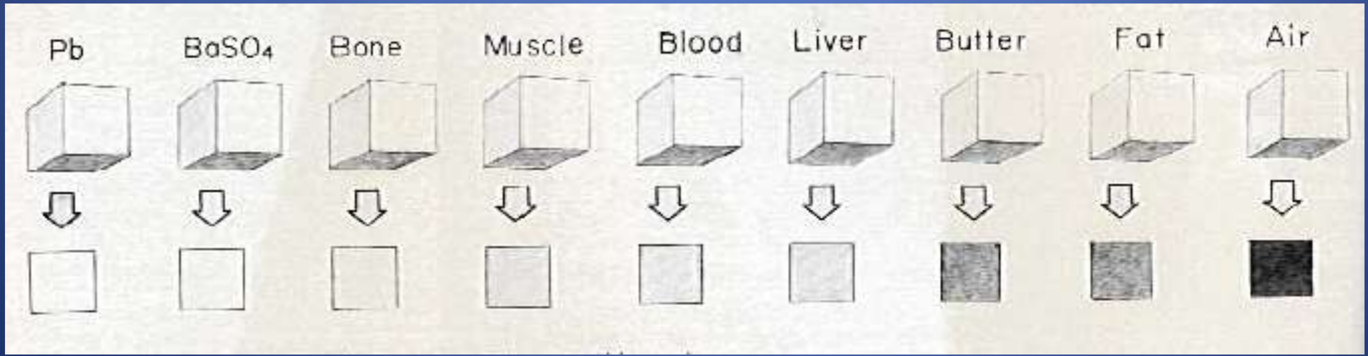


Before

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

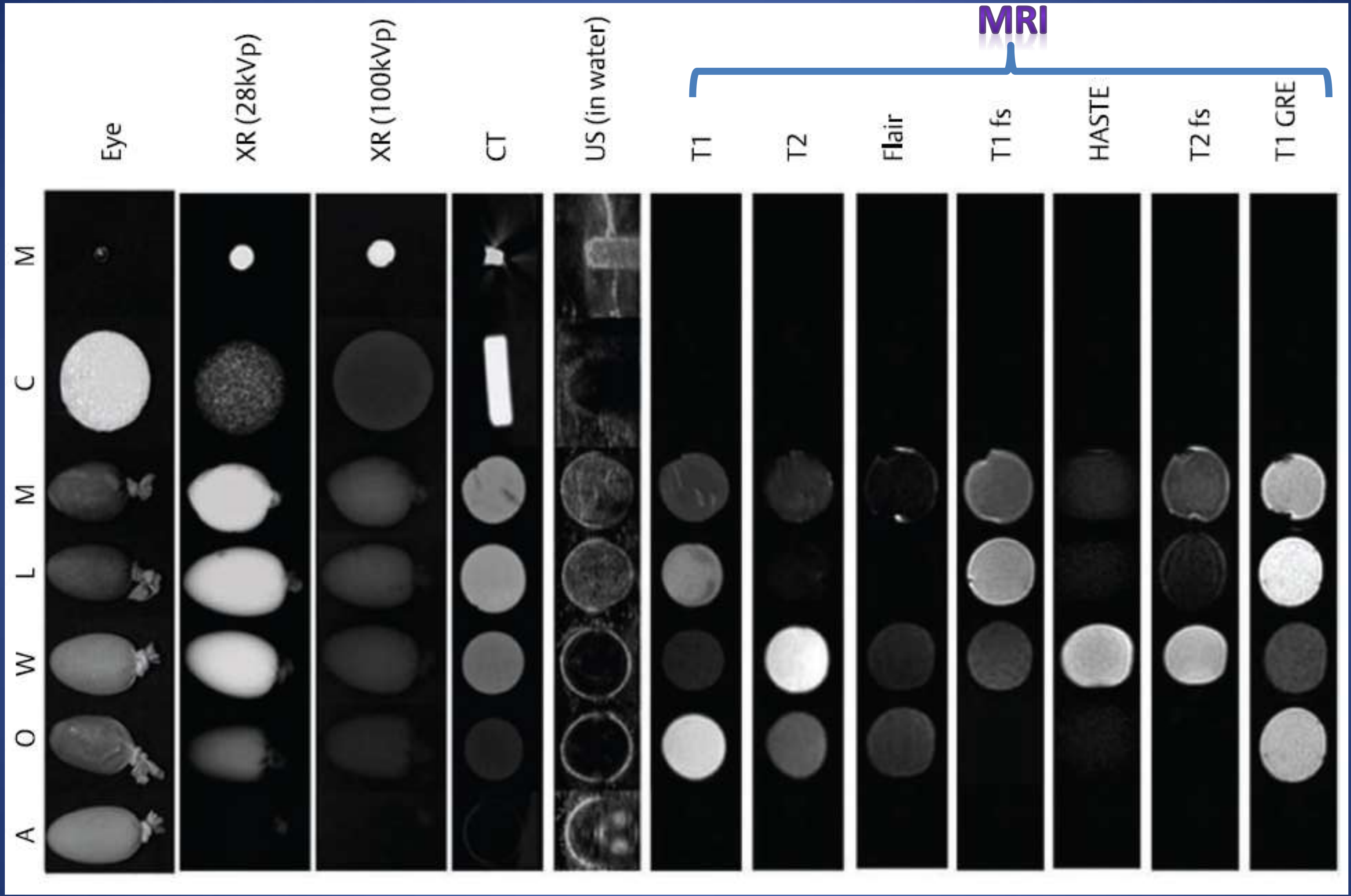
Air (black)

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

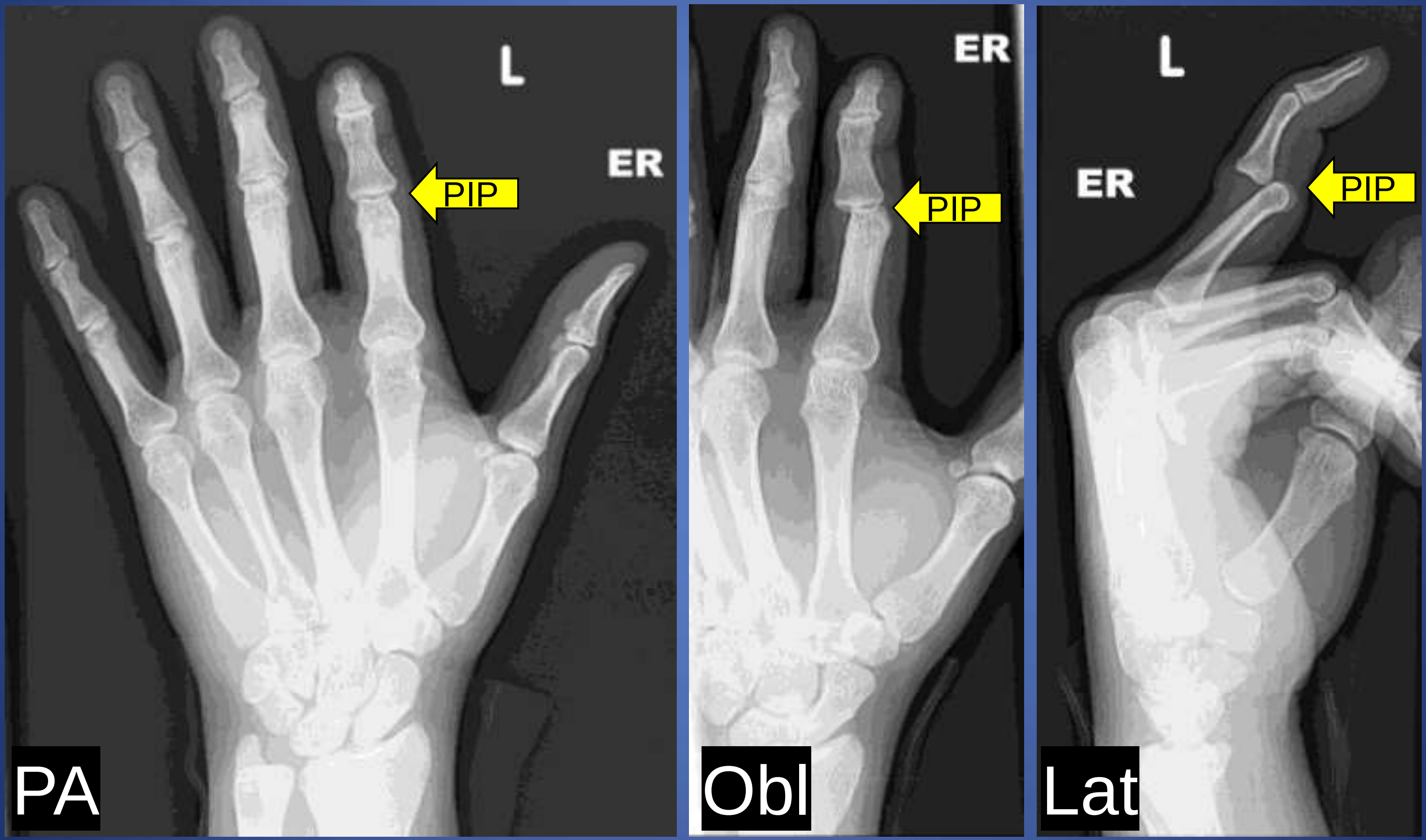
Eastman, Getting Started in Clinical Radiology

“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

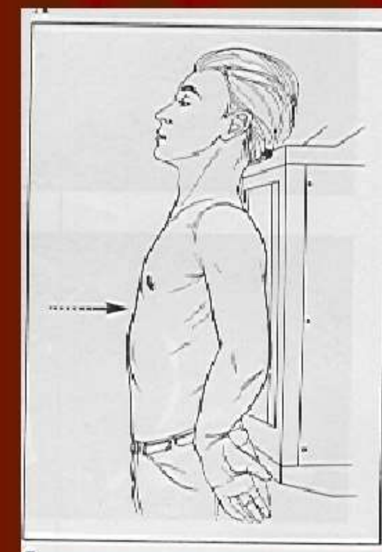
Kidney Ureter Bladder

Posterior Anterior (PA)

The nomenclature follows the direction of the beam

AP Chest

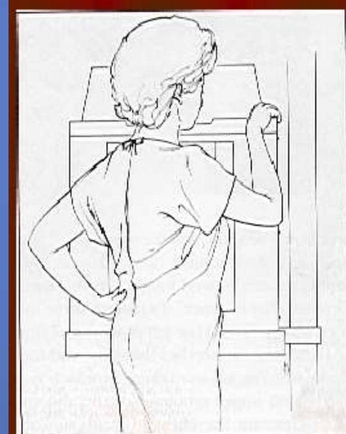
Beam Direction



Left Lateral

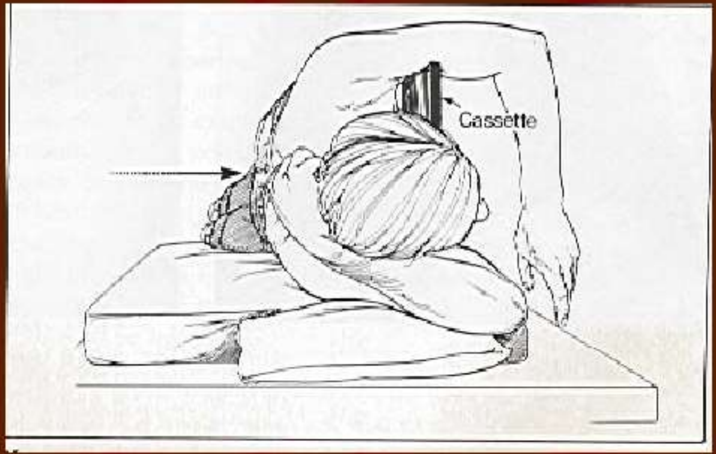
Nomenclature is dictated by the closest body part to the film

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

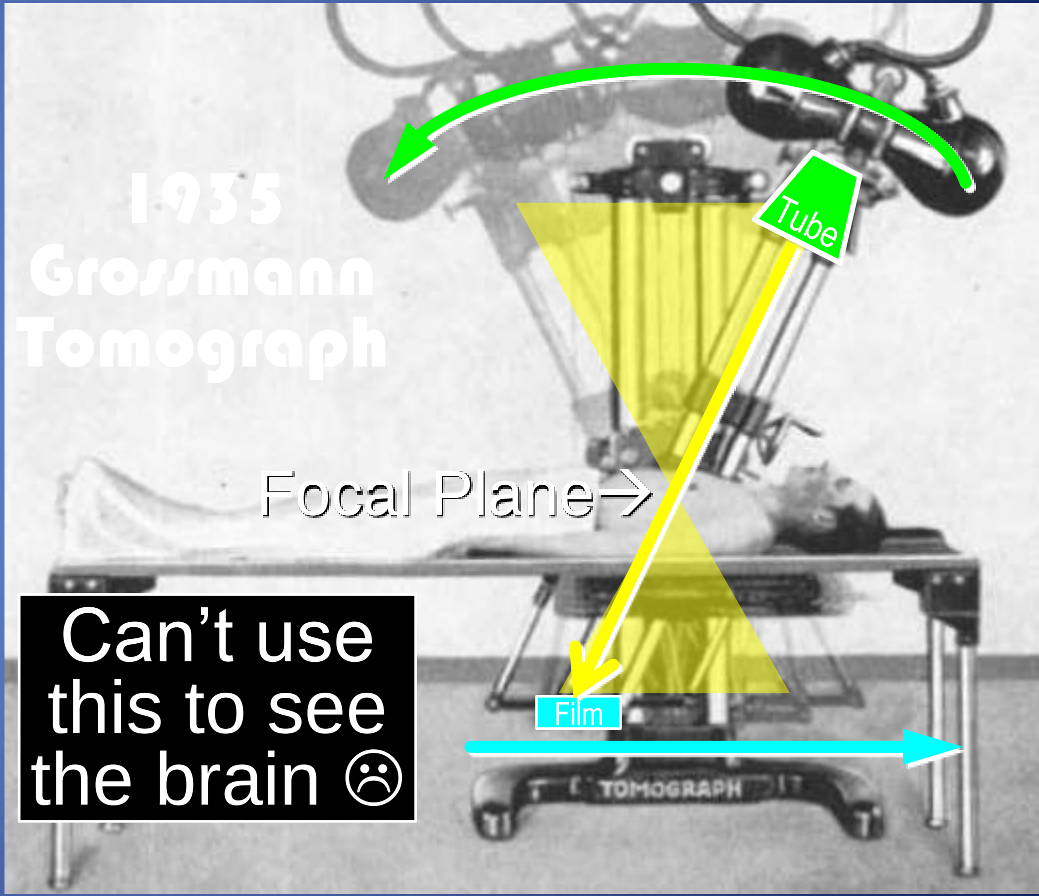
Single Contrast vs Double Contrast

Single Contrast
Barium Enema

Double Contrast
Barium Enema

Tomography: Small Step Forward

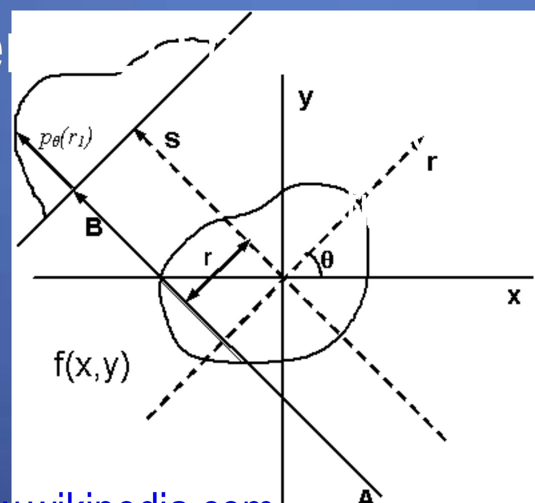
- To overcome flat 2D nature of radiographs…
  - Structures in the Focal Plane → are in focus.
  - Structures out of focal plane are blurred out.
  - At best, we got blurry pictures.
  - Long exposures = high radiation.



British Journal of Radiology 8:733-751,1935

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 ... ber ... ages of the object.



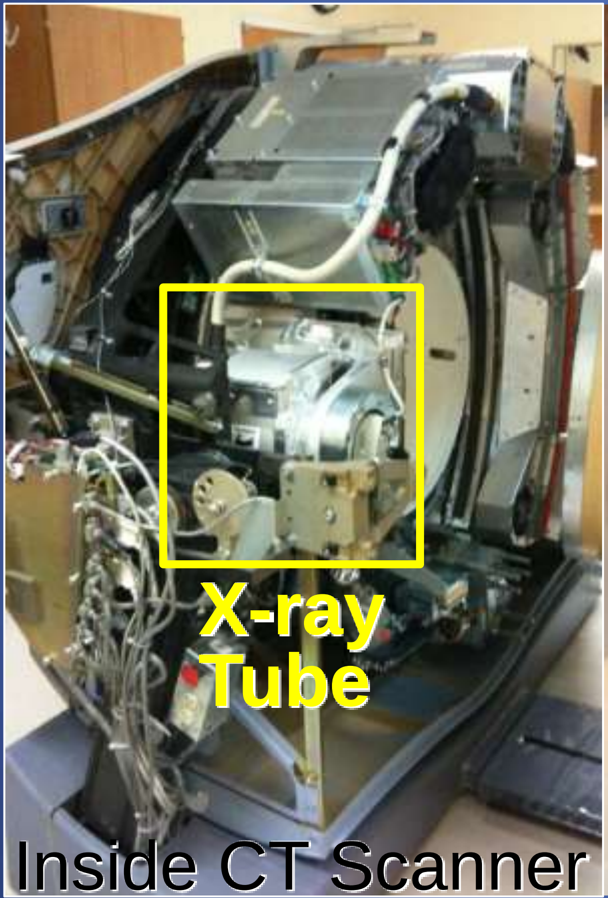
www.wikipedia.com

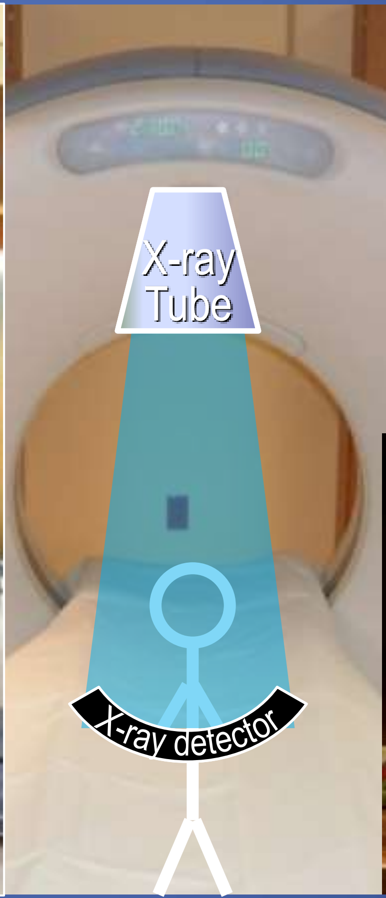
Hounsfield & EMI Brain Scanner

- 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”

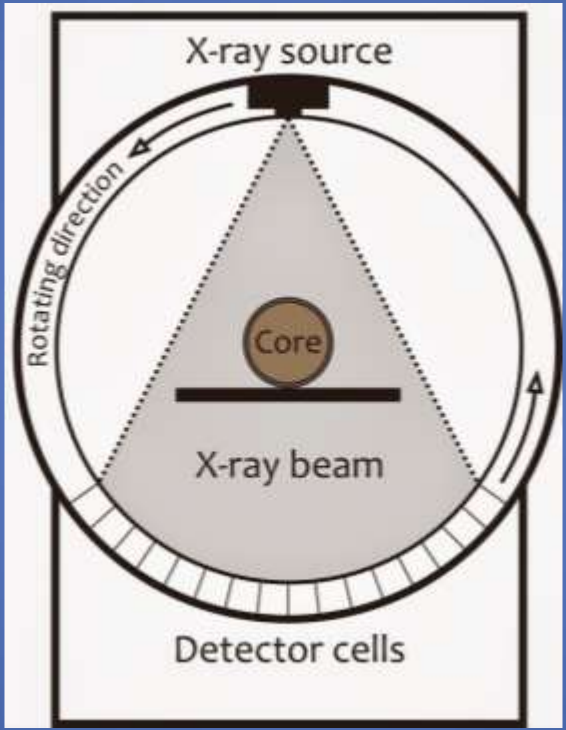
www.sciencemuseum.org.uk

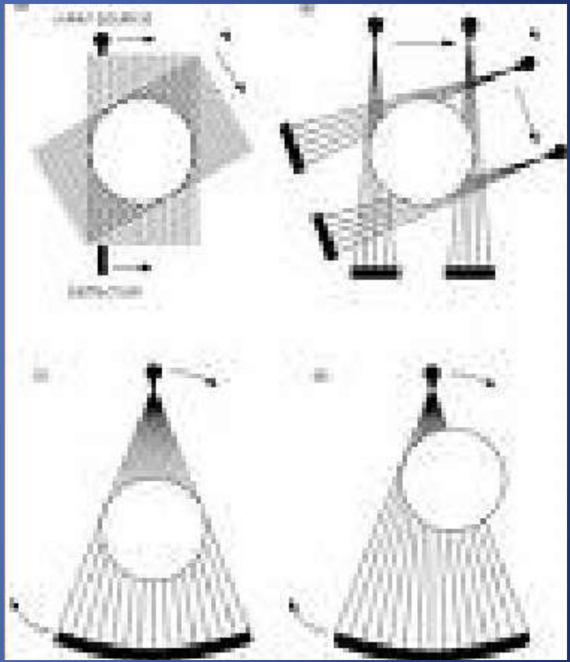
CT = Rotating X-rays



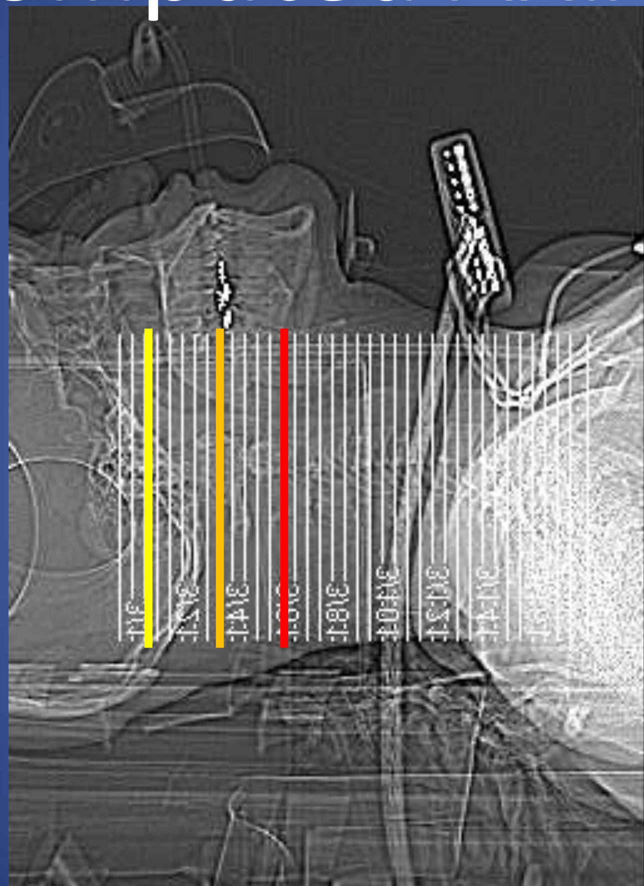


CT = Rotating X-rays



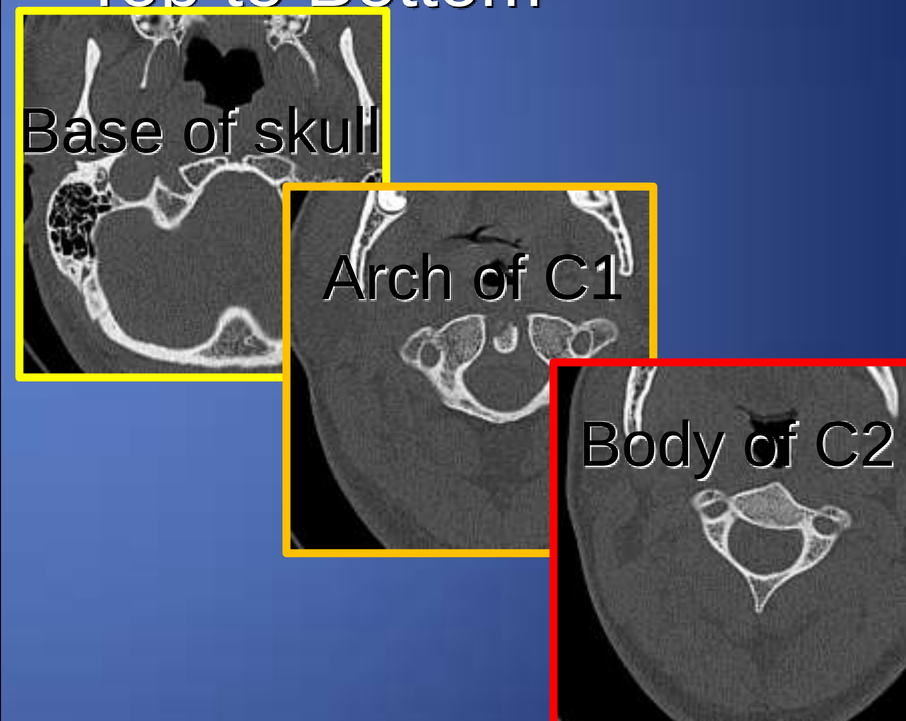


Computed AXIAL Tomography

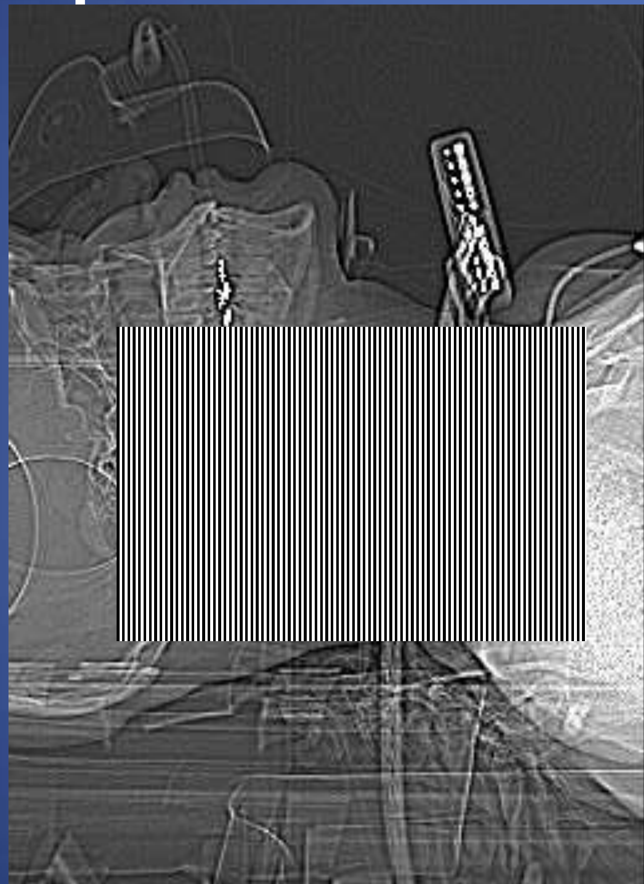


O,G 19yoM

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



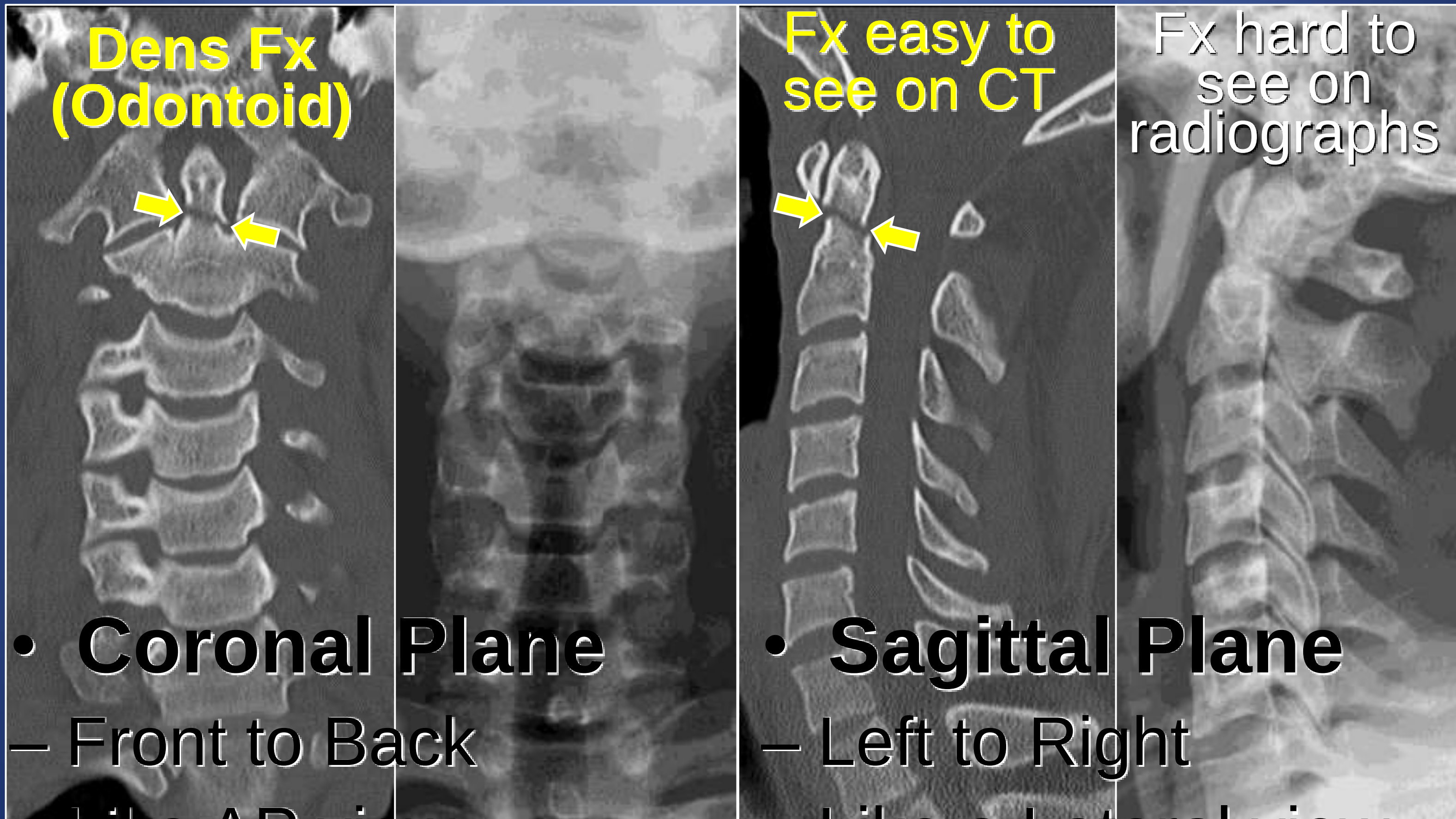
Computed VOLUME Tomography



O,G 19yoM

- Thin, continuous slices=
- Solid volume of data
- Can reformat data:
  – Any 2-D
    - Corona
  – Even in 3-D!

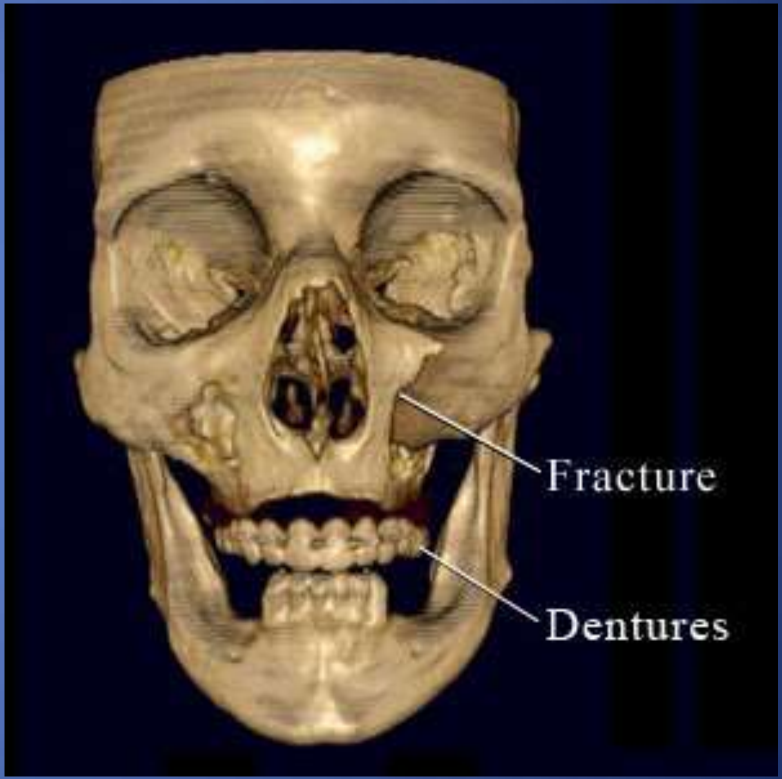
Multi-Planar Reformat



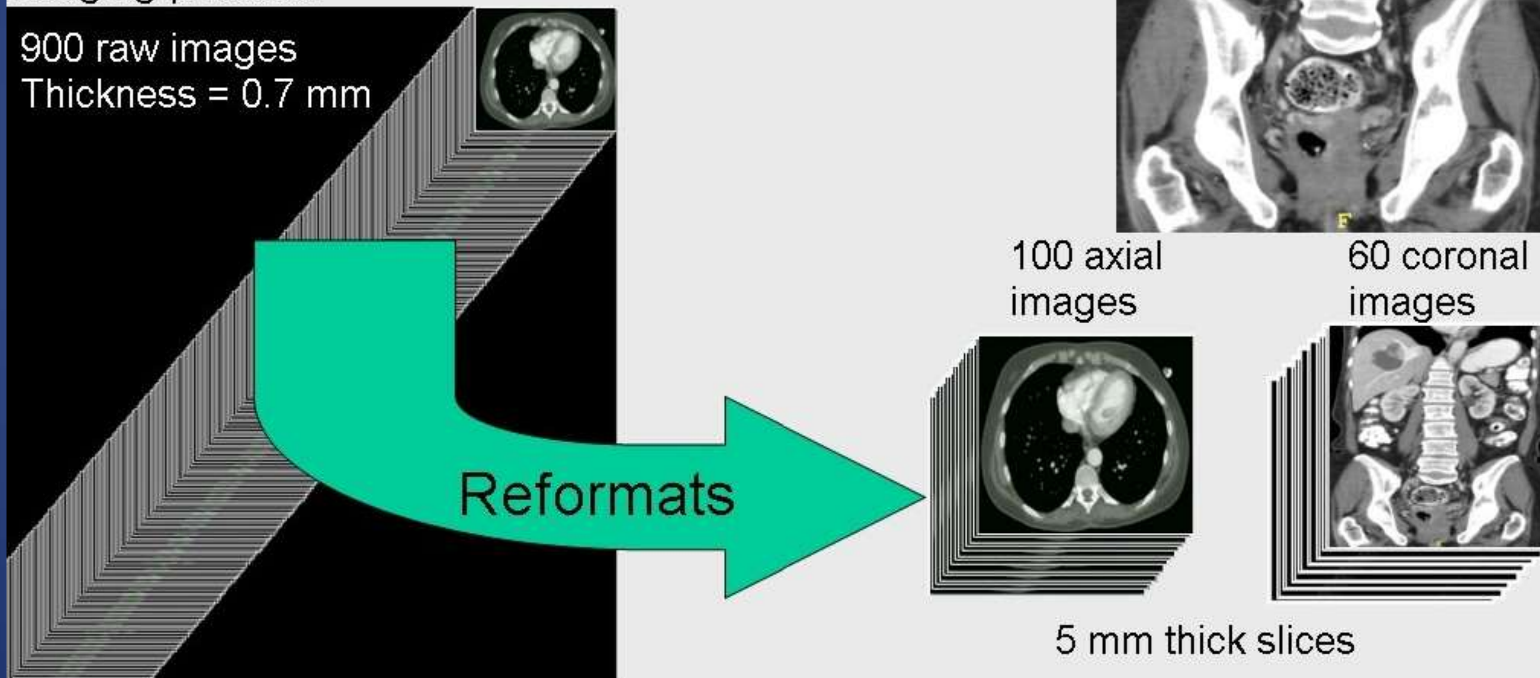
- **Coronal Plane**
  - Front to Back
  - Like AP view
- **Sagittal Plane**
  - Left to Right
  - Like a Lateral view

O,G 19yoM

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.



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**

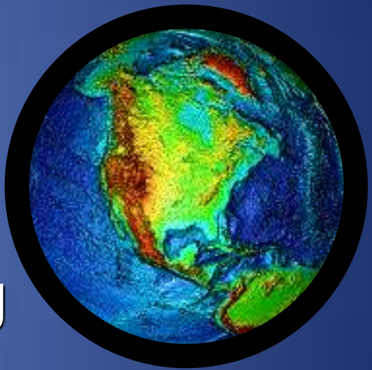
Problems with CT

- **Usually requires IV contrast**
  – 1% patients are allergic to CT contrast
  – Can affect renal function
- **Costs more than radiographs**
  – Knee radiographs (4 views): $154
  – Knee CT (no contrast): $1,200
- **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)
    - 2nd 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 ≈ 2.4mSv/year**

www.wikipedia.com

Radiation from Diagnostic Imaging

- **Ave background dose ≈ 2.4mSv/year**
  - Chest Radiograph ≈ 0.06mSv
    - ≈1 week of background radiation
  - Chest CT ≈ 7.0mSv
    - ***≈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

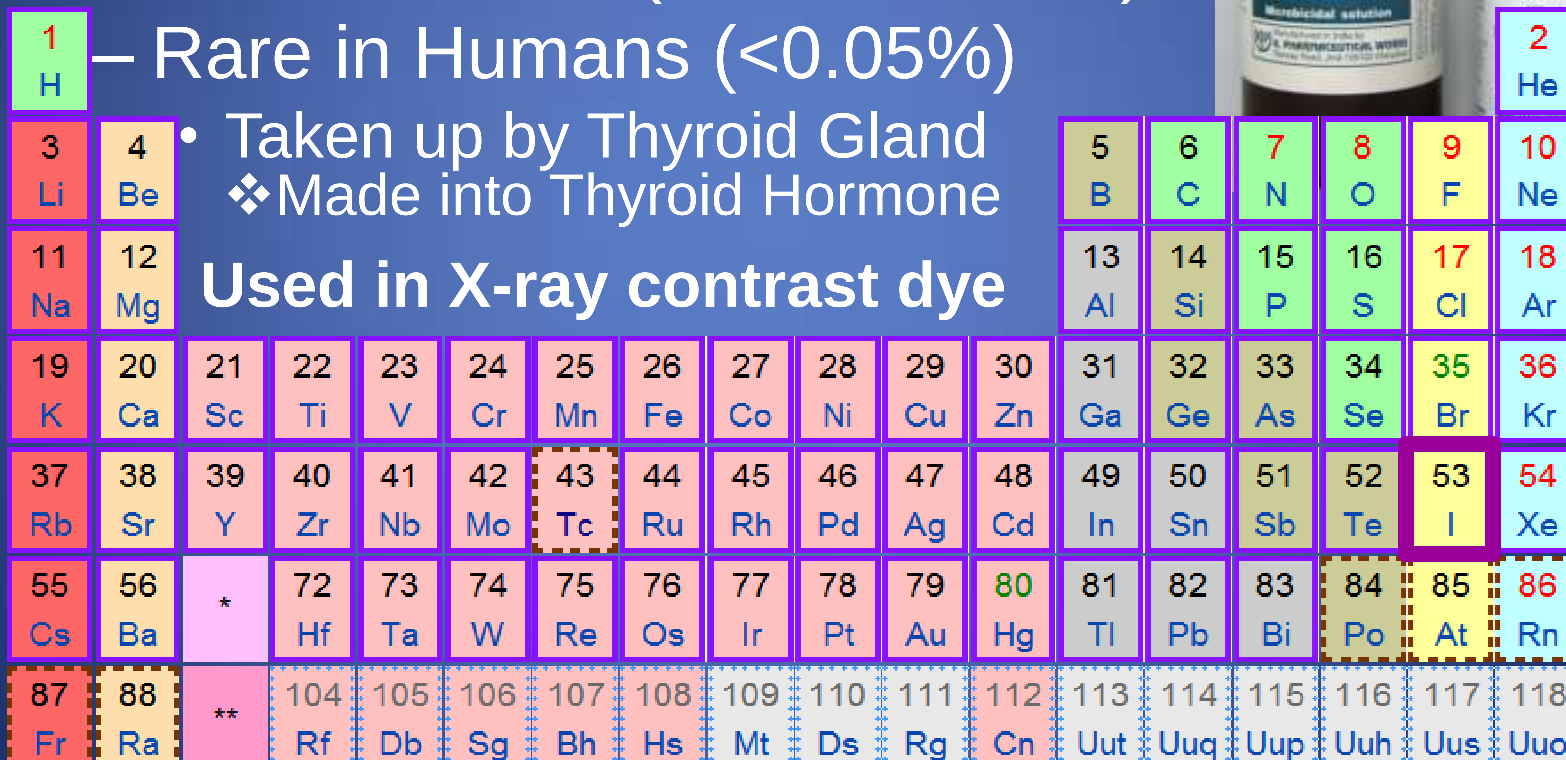
Radionuclide imaging (Nuclear Medicine)

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

Iodine

- Naturally occurring element
  - Rare on Earth (47th abundant)
  - Rare in Humans (<0.05%)
    - Taken up by Thyroid Gland
      - ❖Made into Thyroid Hormone

Used in X-ray contrast dye



wikipedia.org

Nuclear Medicine

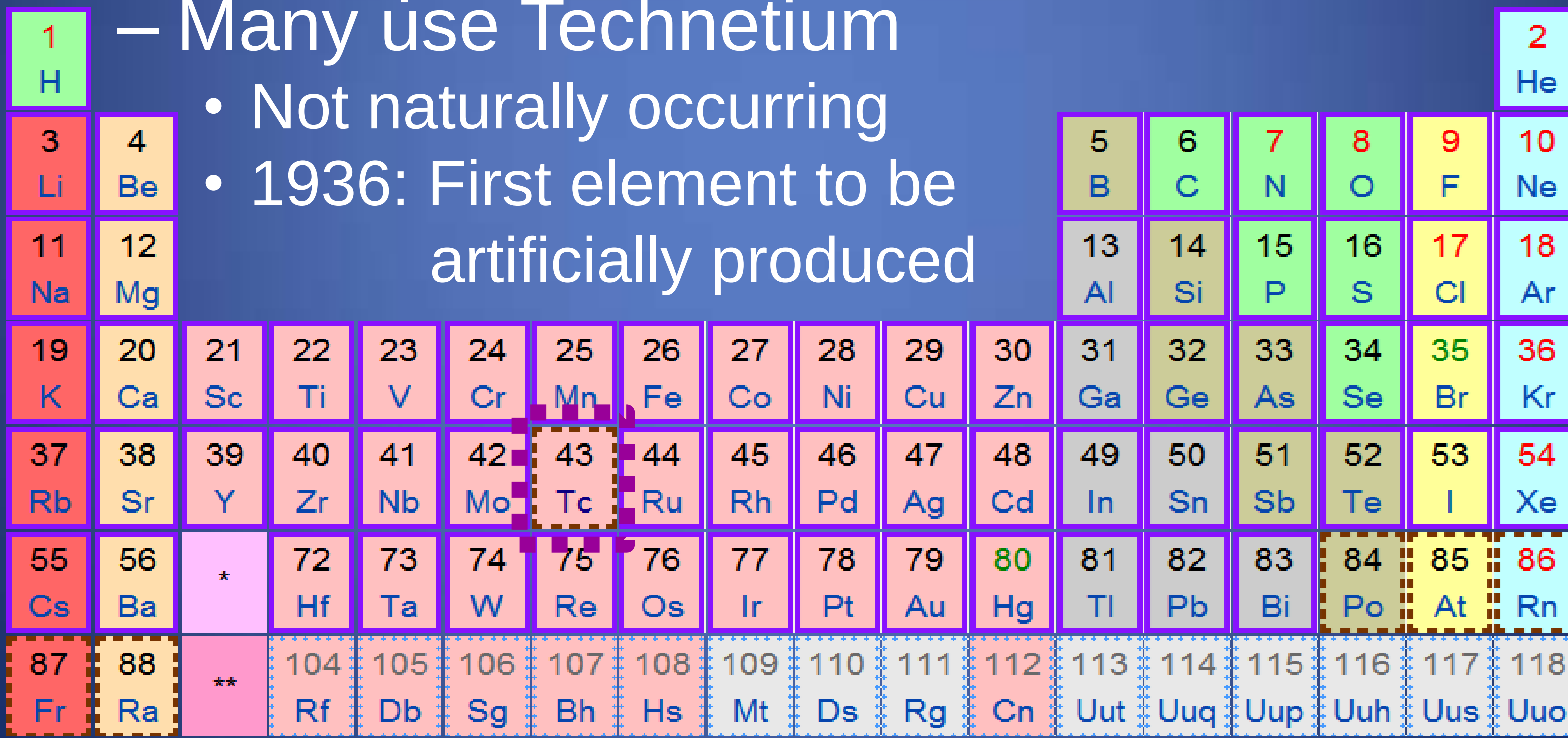
- Developed after World War II
- Research on nuclear bomb byproducts
  - Fission Uranium-235 → Iodine-131
- Naturally occurring Iodine not radioactive
- Iodine-131 is HIGHLY radioactive
  - Emits β-particles
    - Much more damaging than γ-rays
  - Accumulate in and destroys Thyroid tissue

☹ 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 γ-rays.
  - “Radiopharmaceuticals”
  - Many use Technetium
    - Not naturally occurring
    - 1936: First element to be artificially produced



Nuclear Medicine

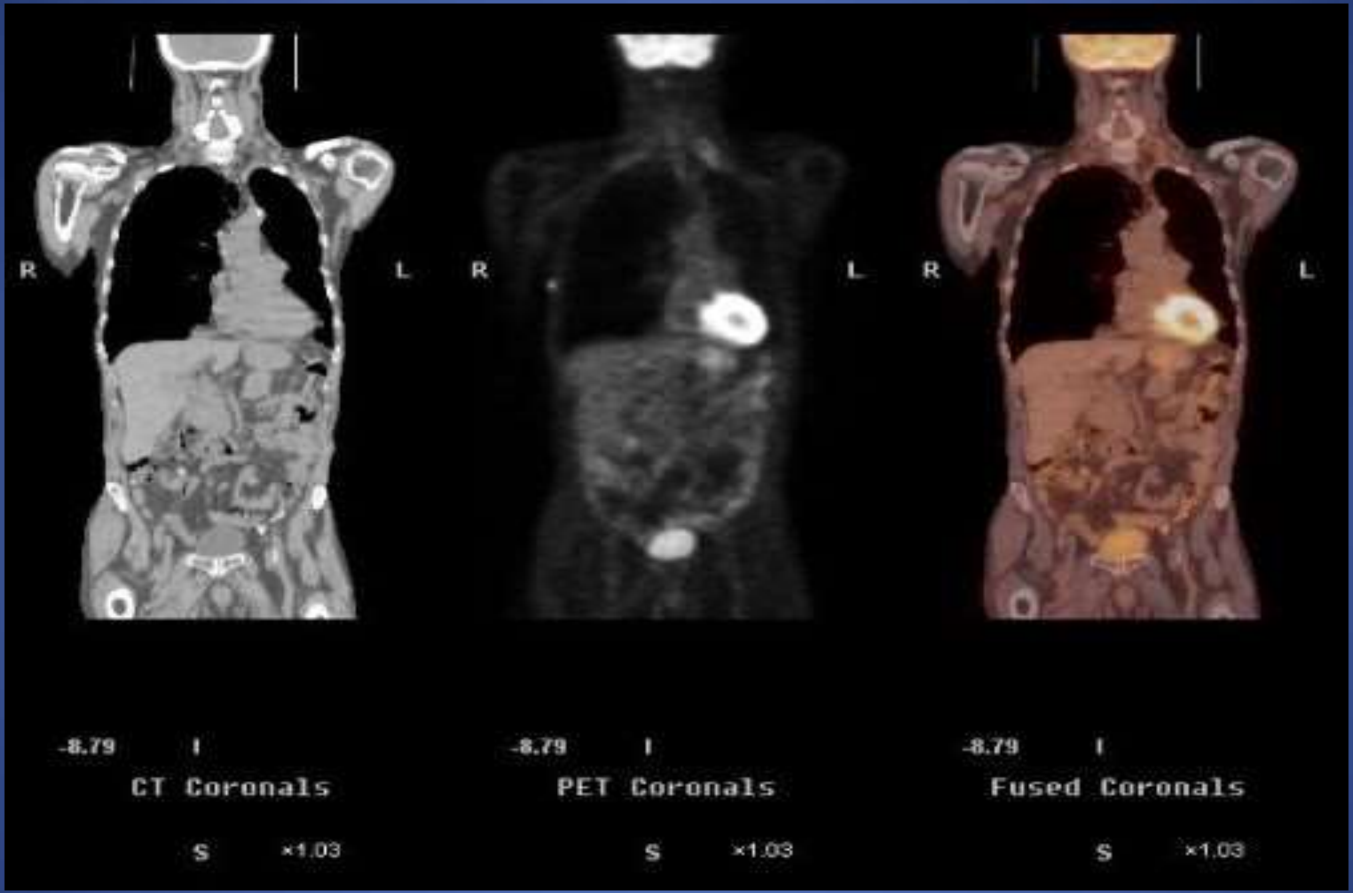
- Technetium-99m: Ideal Imaging Agent
  - Short half-life (6 hours)
    - After 24 hours 94% gone
  - Emits γ-rays
    - γ-rays pass out of the patient without accumulating
  - Good energy for gamma-camera detection
    - Dual-head cameras: Image γ-rays emitted front & back

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
    - Flourine-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


R
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-8.79
CT Coronals
S
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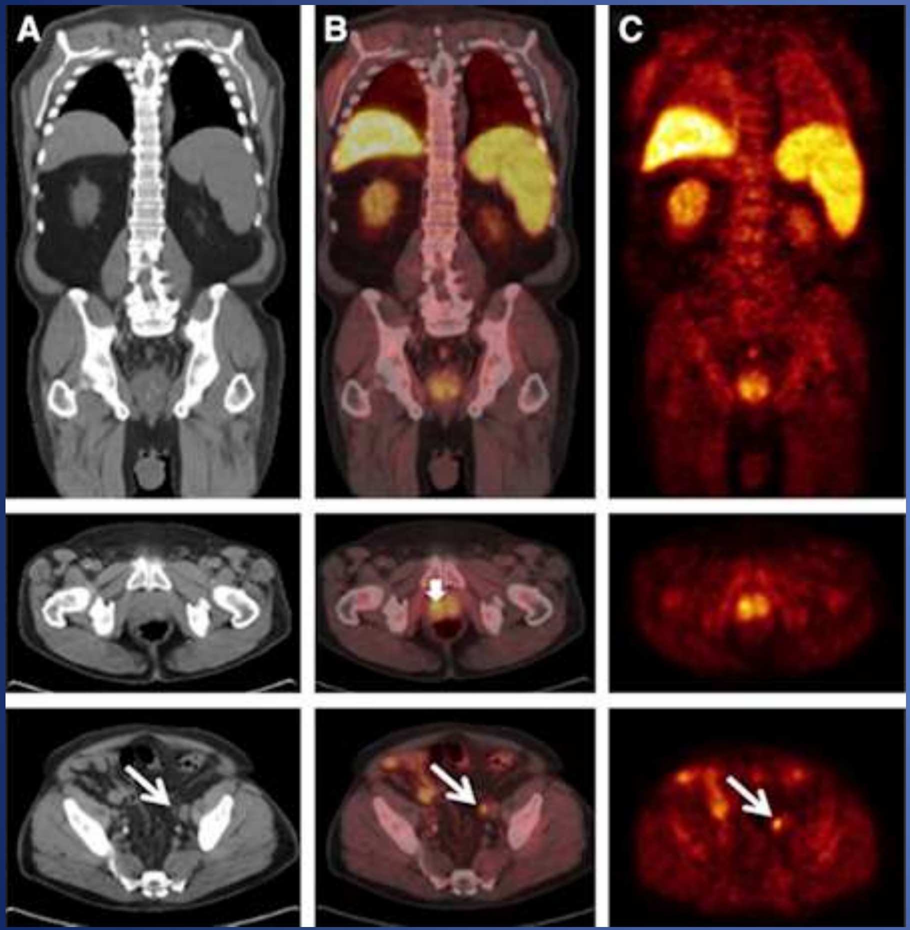
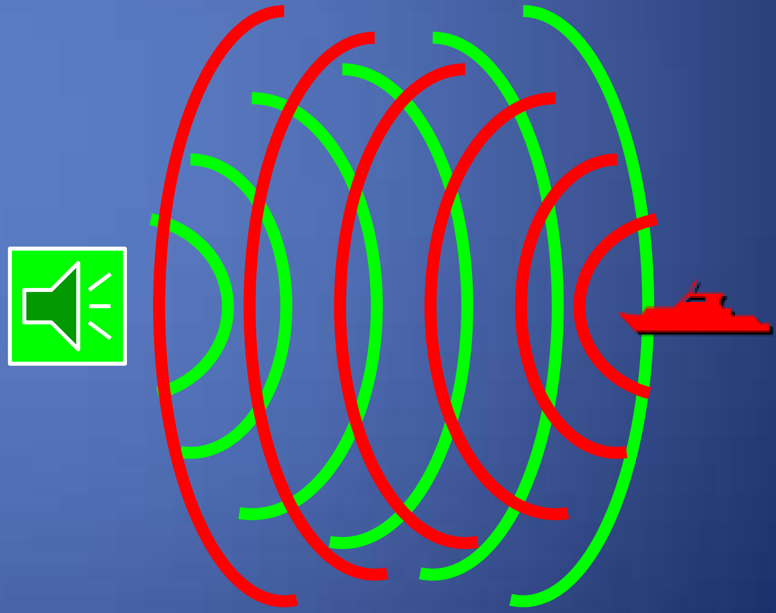
-8.79
PET Coronals
S
×1.03
-8.79
Fused Coronals
S
×1.03

CT PET PET/CT


A
B
C

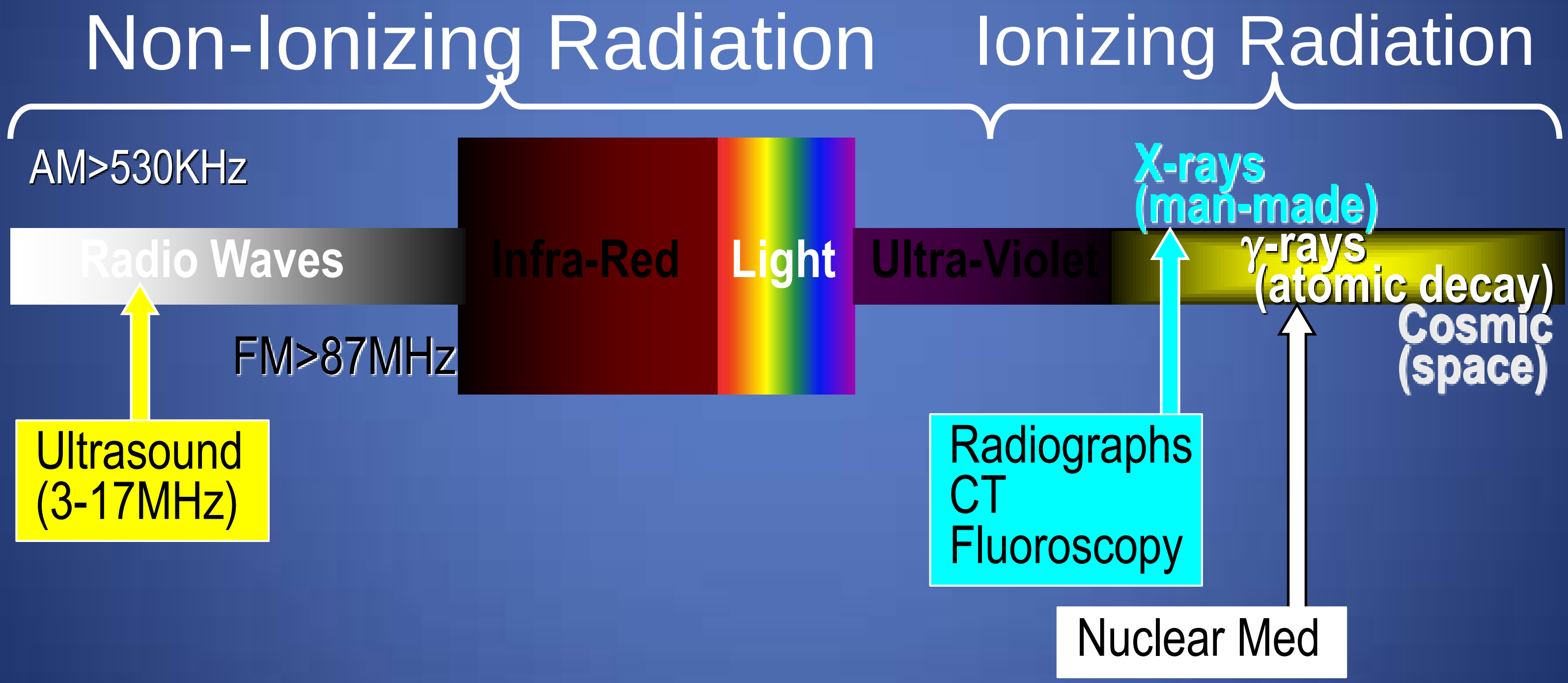

Ultrasound

- 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 (÷2) = distance from the object
  – Works best in water
    - Water transmits sound well



Sonography

- Uses radio waves (Not X-rays, γ-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 & <u>reflect</u> waves
    - Soft Tissue - muscles, fat, vessels, nodes, masses
- "**BLACK**" areas represent areas that are anechoic
    - Fluid – transmits but <u>does not reflect</u> 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

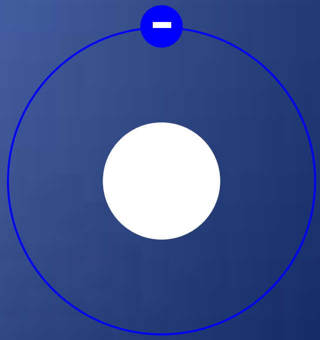
Tissue	Description of appearance on ultrasound
Bone	Appears bright due to the dramatic difference in acoustic impedance between bone and soft tissue. High frequency ultrasound does not penetrate bone effectively and therefore the screen is generally black deep to the bone
Fat	Can be bright or dark (hypoechoic), 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

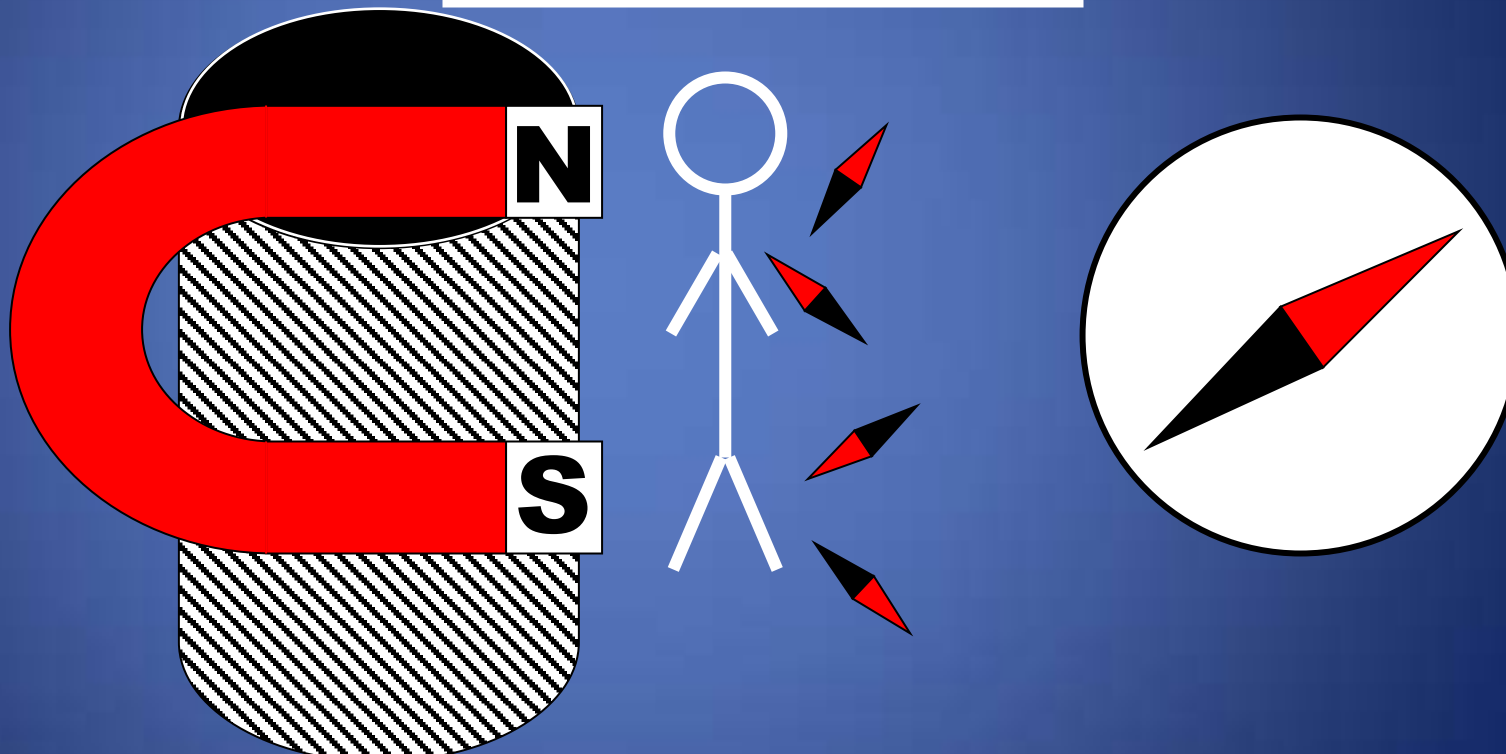
- Advantages
  - No radiation
  - Portable
  - Instantaneous (real time)
  - Excellent for cysts and fluid
  - Doppler ultrasound is excellent to assess blood flow
  - Excellent for newborn brain, thyroid, gall bladder, female pelvis, scrotum, pregnancy
- Disadvantages
  - Does not work well in large 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.

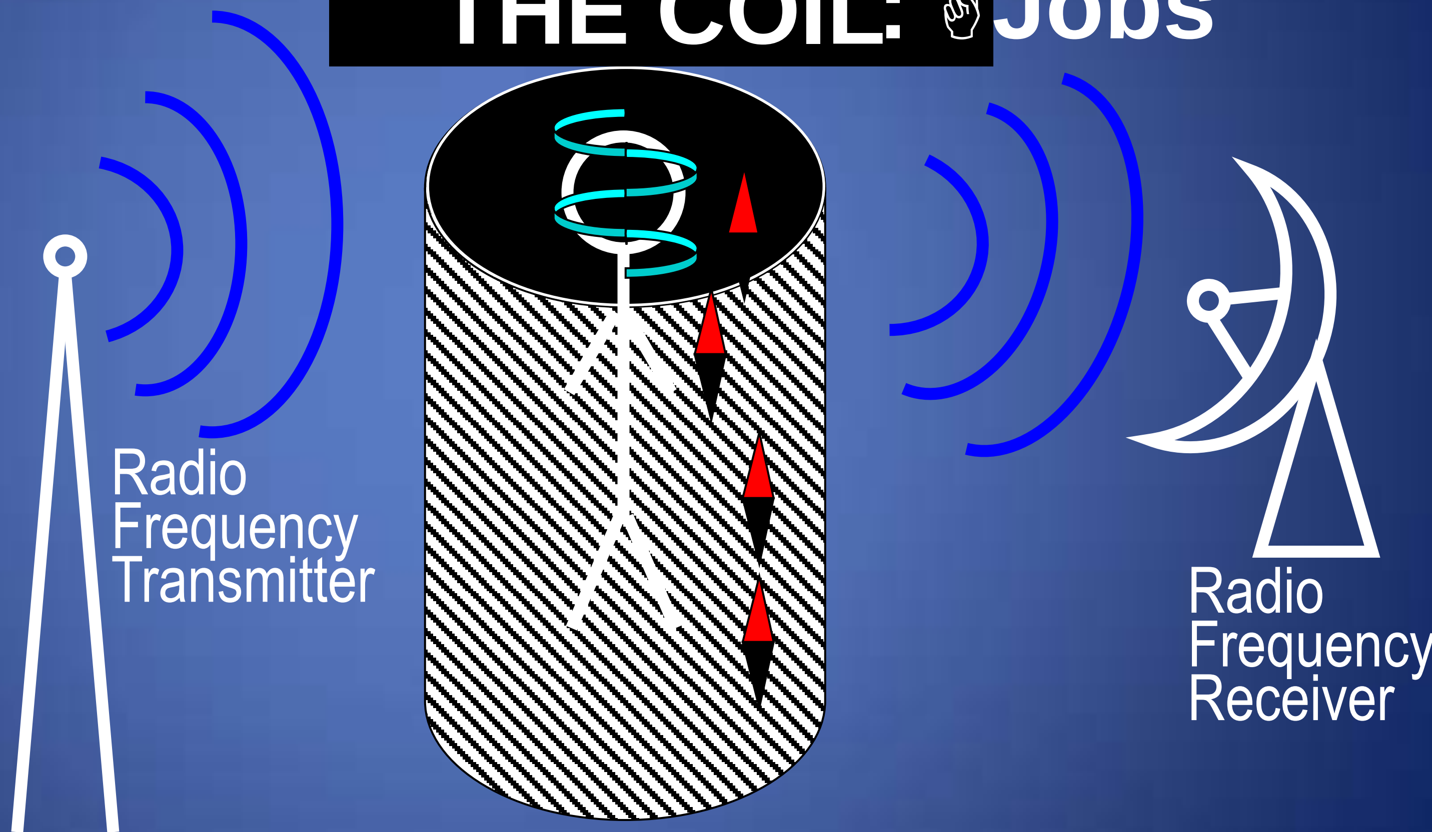


MRI Scanner: 2 Components



MRI Scanner: 2 Components

THE COIL: ✌ Jobs



How MR Scanner Works

- **Magnet**

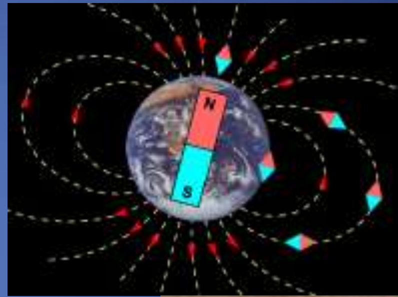
– Aligns spins of protons in hydrogen nuclei
  - Align in direction of magnetic field, B_0

- **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 µT (3×10^{-5} T)

- **Typical refrigerator magnet:**

– 3 mT (3×10^{-3} 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

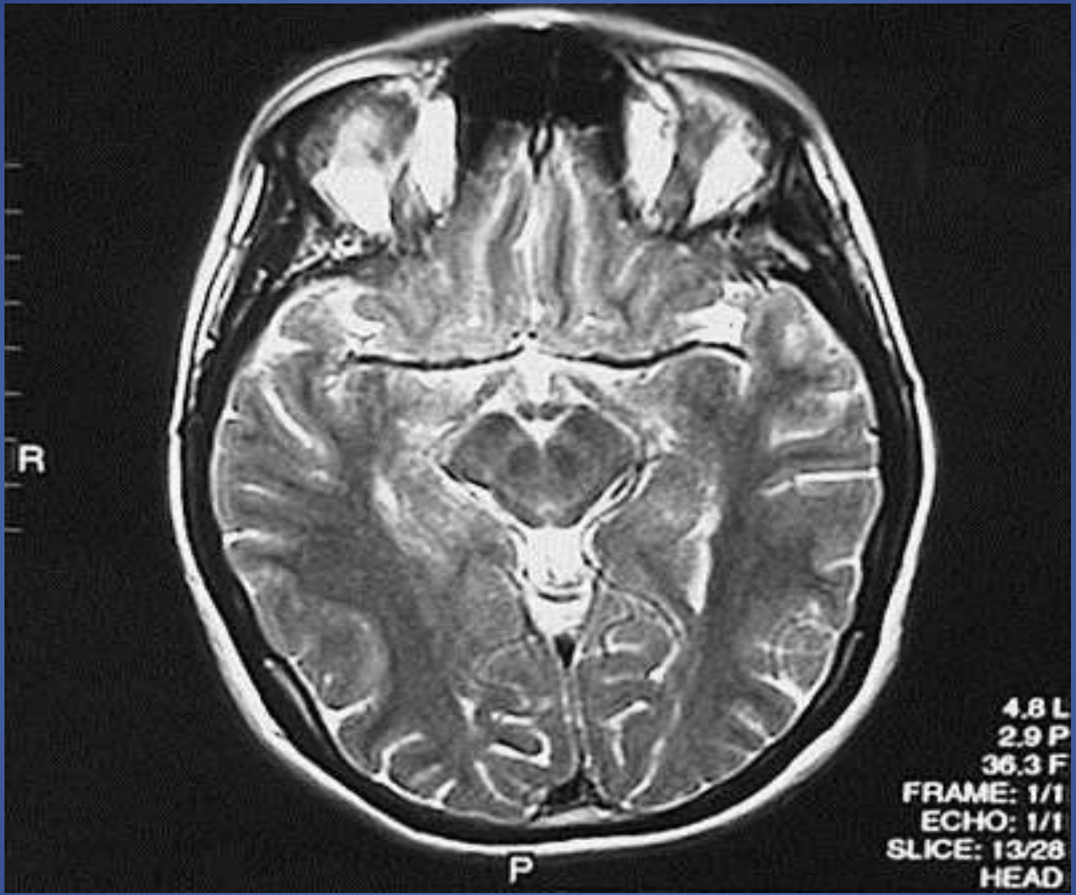
  -Excellent tool due to high soft tissue contrast resolution

  -Abundant water content of CNS allows for imaging soft intracranial tissue

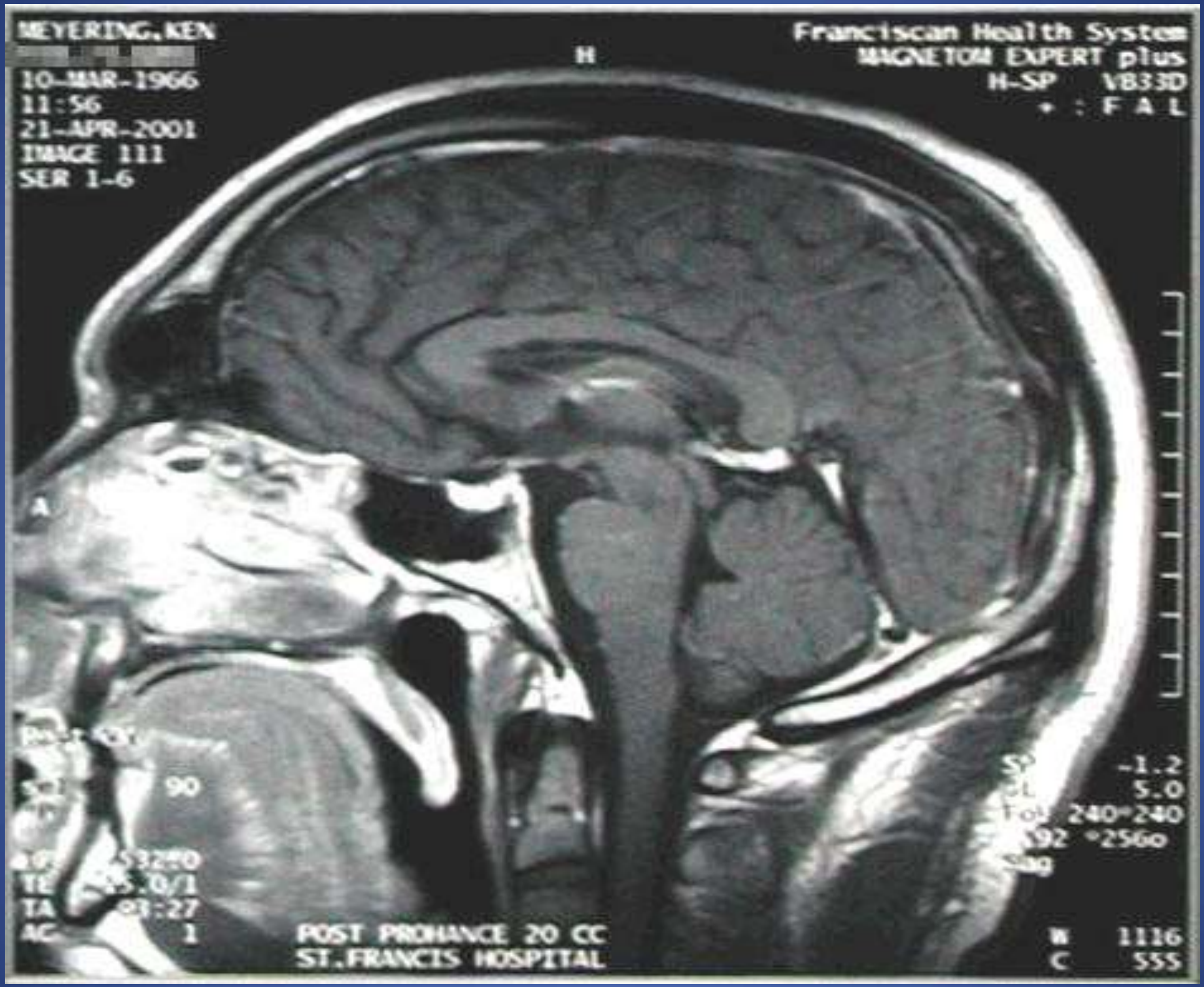
- Head and Neck imaging

  -Multi-planar capability allows for monitoring extent of disease

  -Differentiating subtle soft tissue boundaries of head and neck



MRI
Axial, T2-Weighted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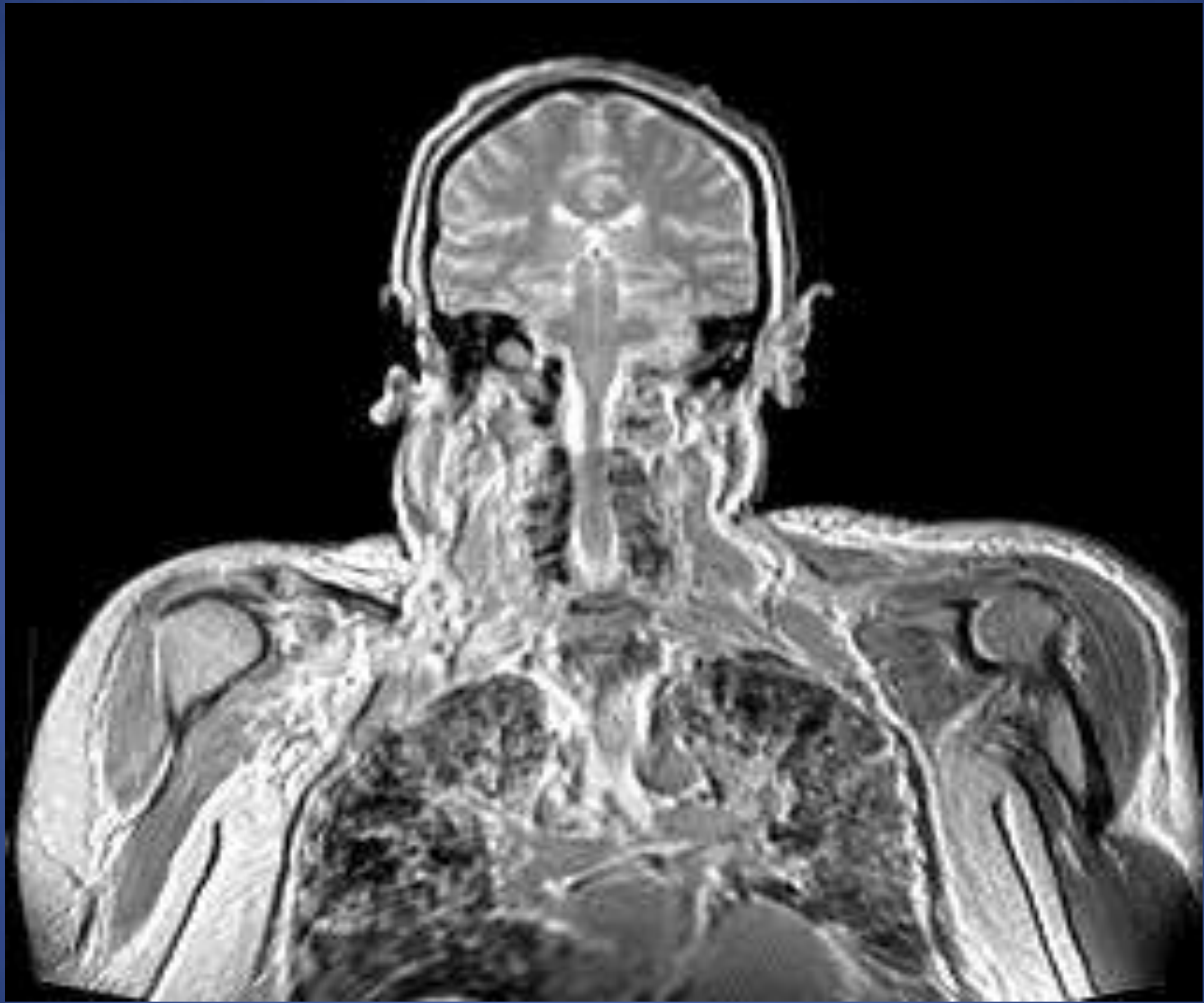
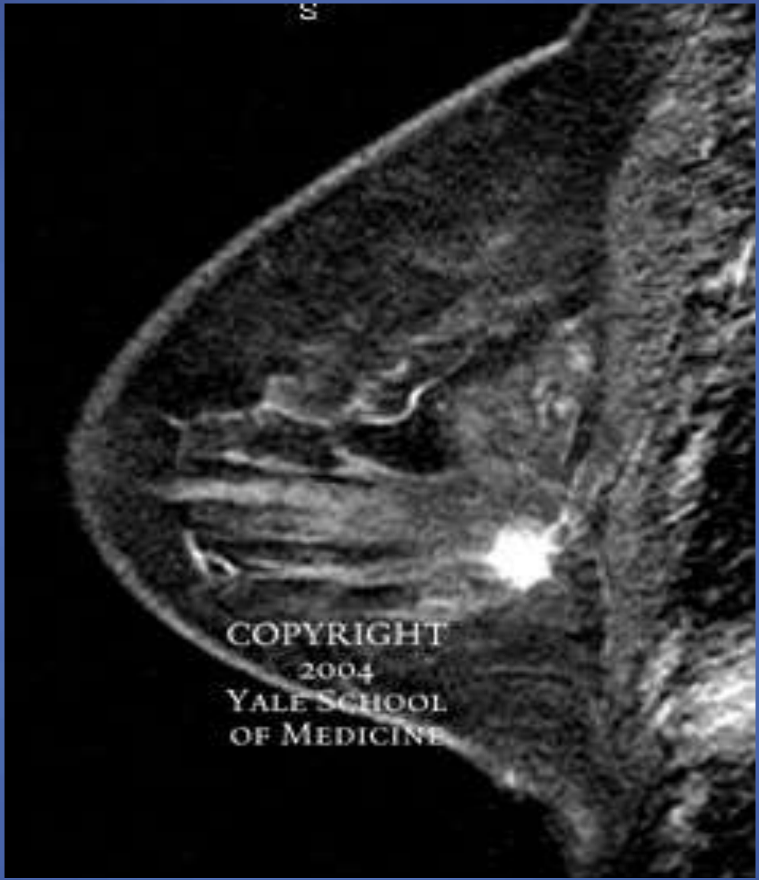
MR Applications

- 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.
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