

Imaging of Cancer



Imaging of Cancer:

Subtitle: What actually happens in a Radiology Department?

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Molecular Imaging Program, NCI

Imaging of Cancer

- Imaging is a key element of:
 - Screening (e.g. lung cancer, breast cancer)
 - Staging (has it spread locally? Metastasized?)
 - Monitoring of treatment (Better or worse?)
 - Recurrence (Has it come back?)
 - Prognosis (What will happen?)

The Main Imaging Devices

- Computed Tomography (CT)
- Magnetic Resonance Imaging (MRI)
- Ultrasound (US)
- Single Photon Emission Computed Tomography (SPECT)
- Positron Emission Tomography (PET)
- Optical Imaging

The Main Imaging Devices

Quiz: Name that Scanner



CT



MRI



US

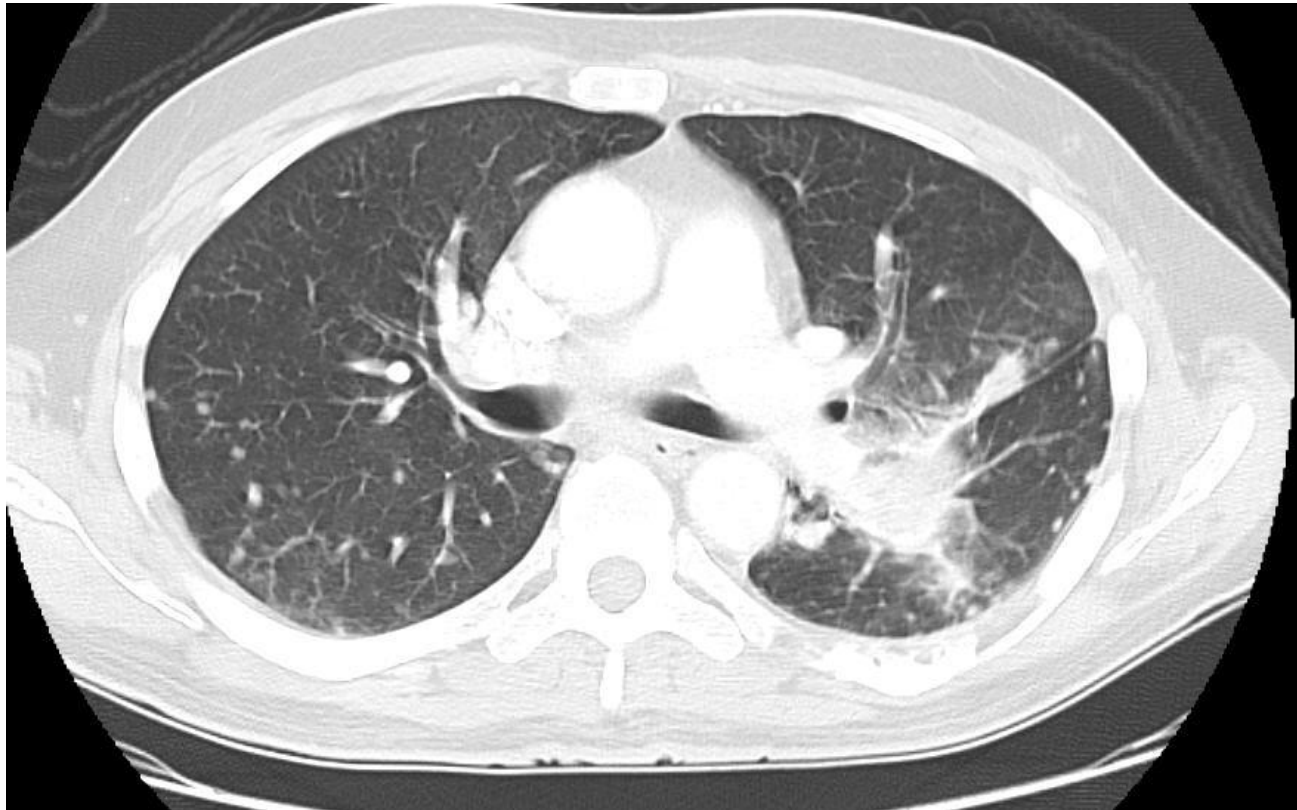


SPECT



PET

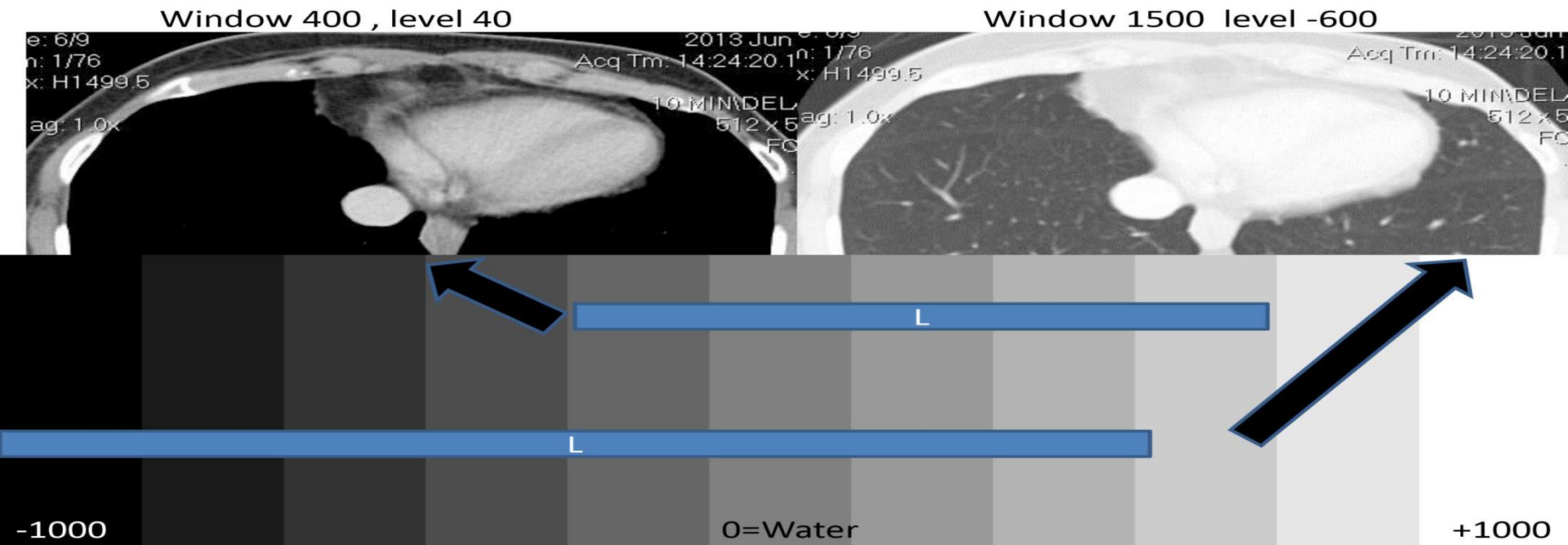
Computed Tomography



CT

Windowing a CT

“Windowing” a CT



Advantages of CT

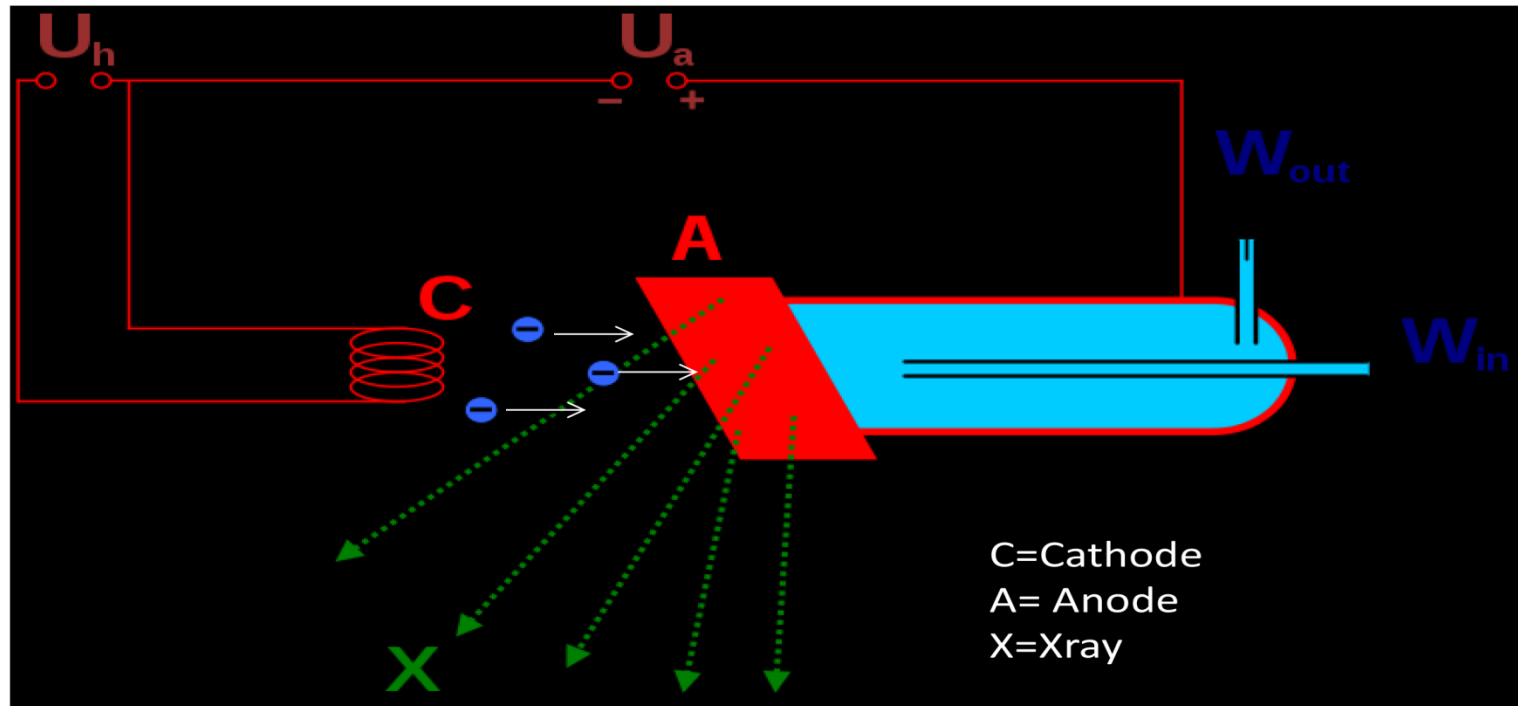
- Widely available
- Minimal prep (NPO, drink contrast)
- Very rapid (2-3 seconds neck to pelvis)
- High resolution
- Relatively inexpensive

Disadvantages

- **Radiation**
- Often requires iv contrast media
 - Allergic reactions (minimal)
 - Kidney damage (only in high risk patients)
- Anatomic information only

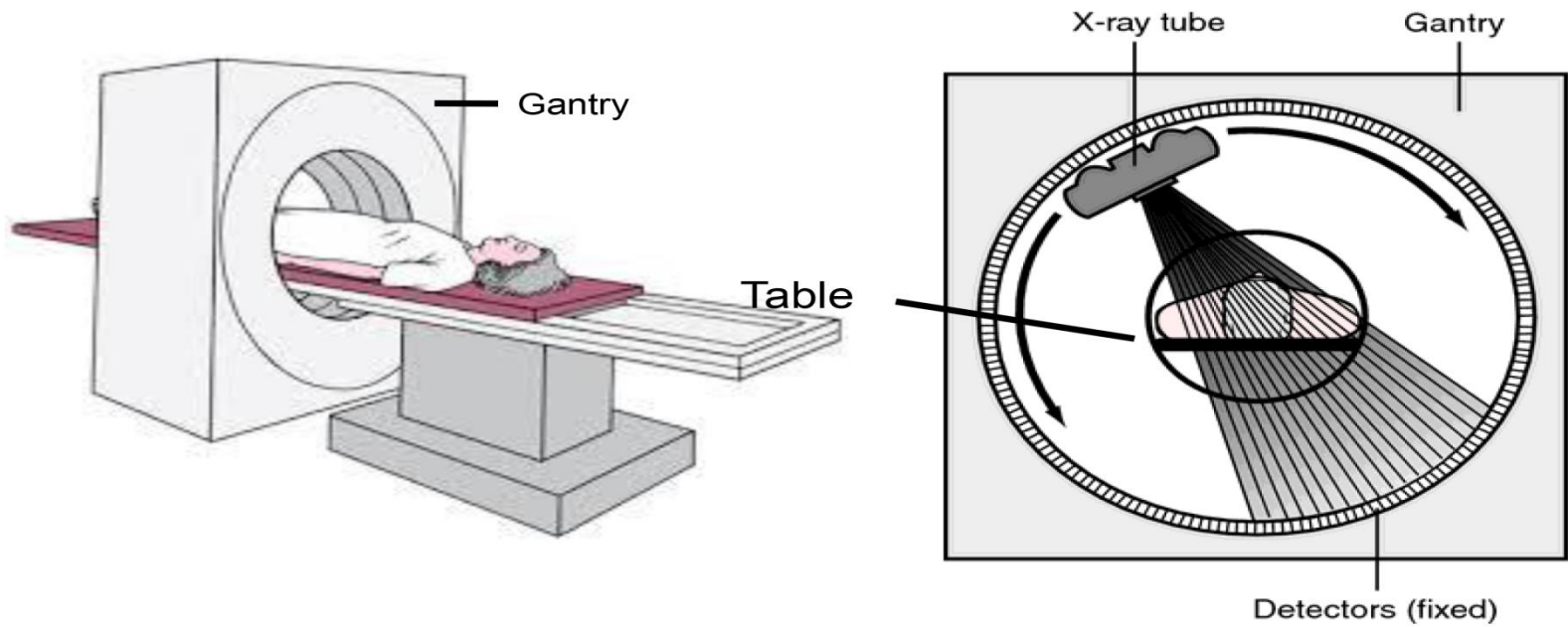
X-ray production

X-ray production: cathode ray tube



Basics of CT

Basics of CT



CT projection

Filtered Back Projection

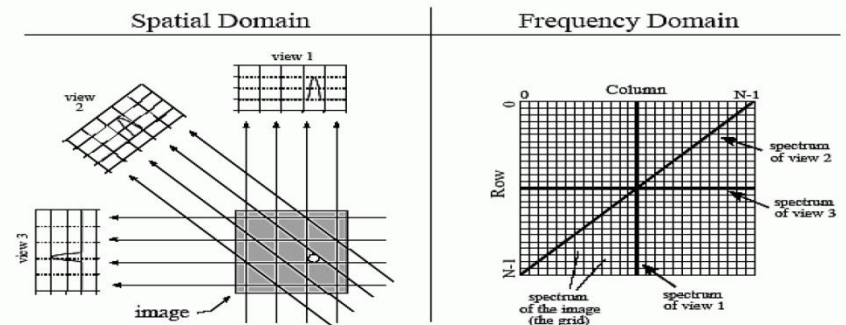
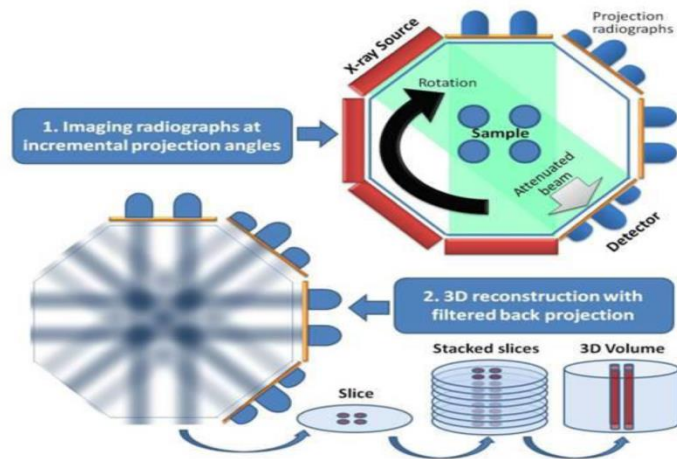
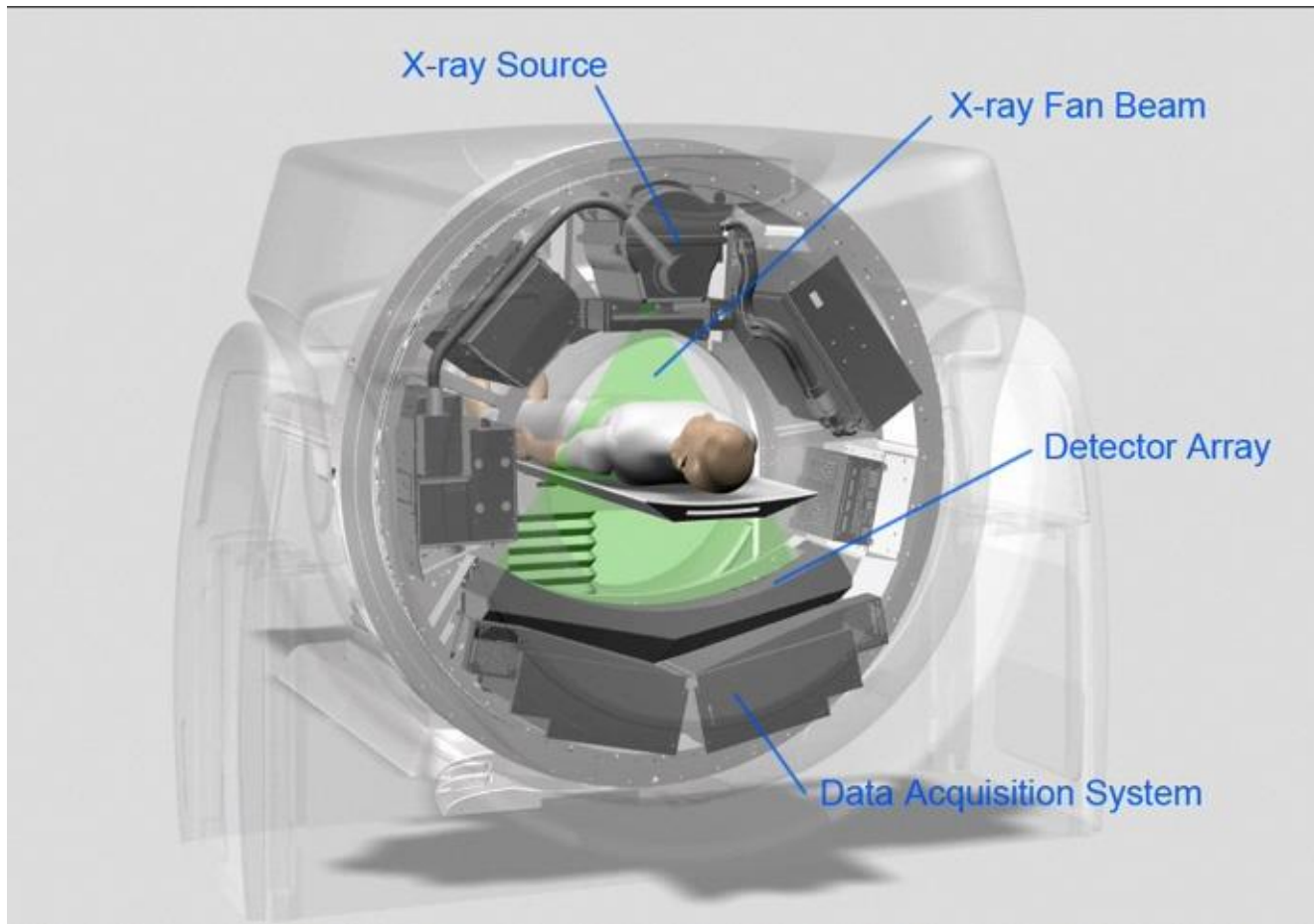
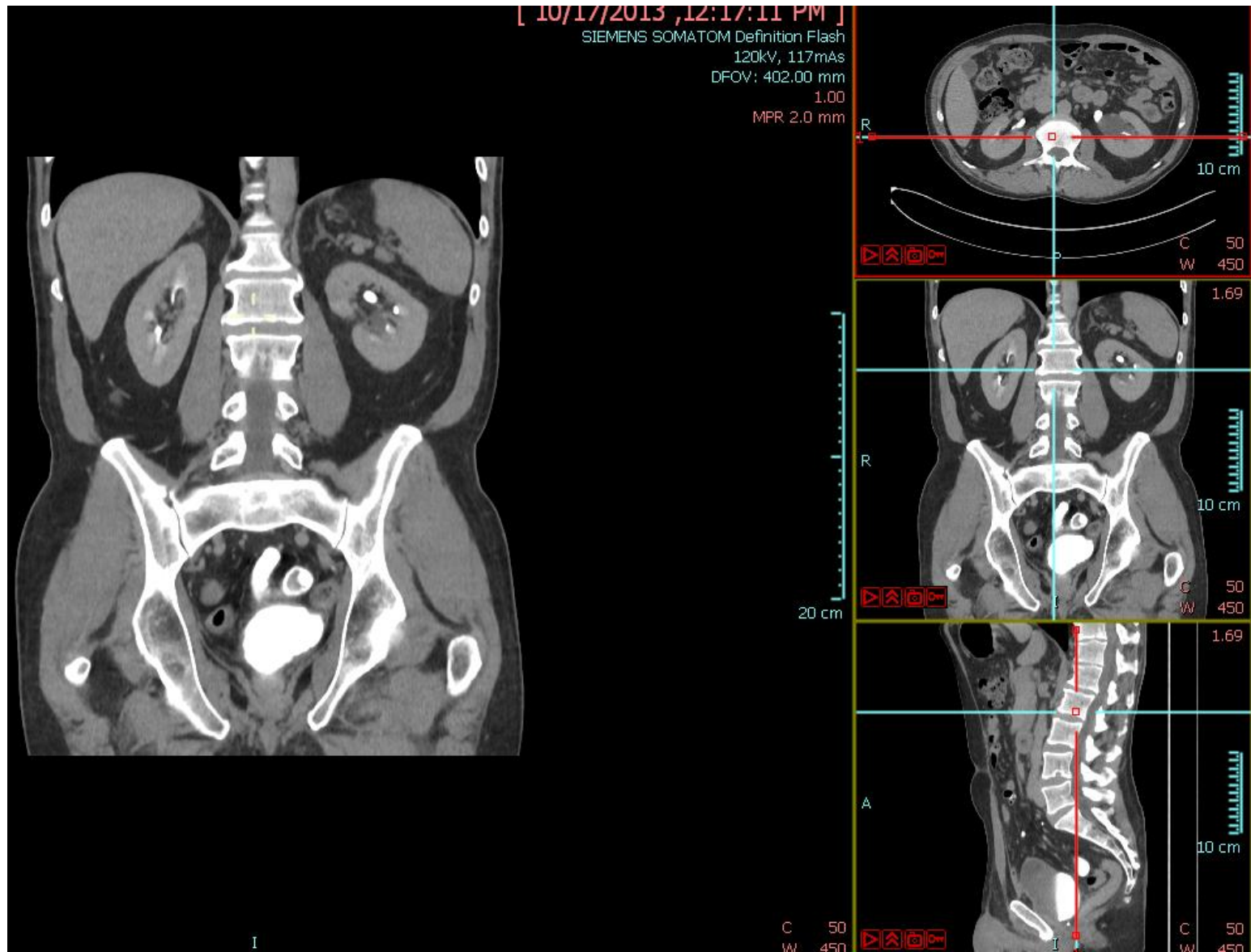


FIGURE 25-18
The Fourier Slice Theorem. The Fourier Slice Theorem describes the relationship between an image and its views in the frequency domain. In the spatial domain, each view is found by integrating the image along rays at a particular angle. In the frequency domain, the spectrum of each view is a one-dimensional "slice" of the two-dimensional image spectrum.

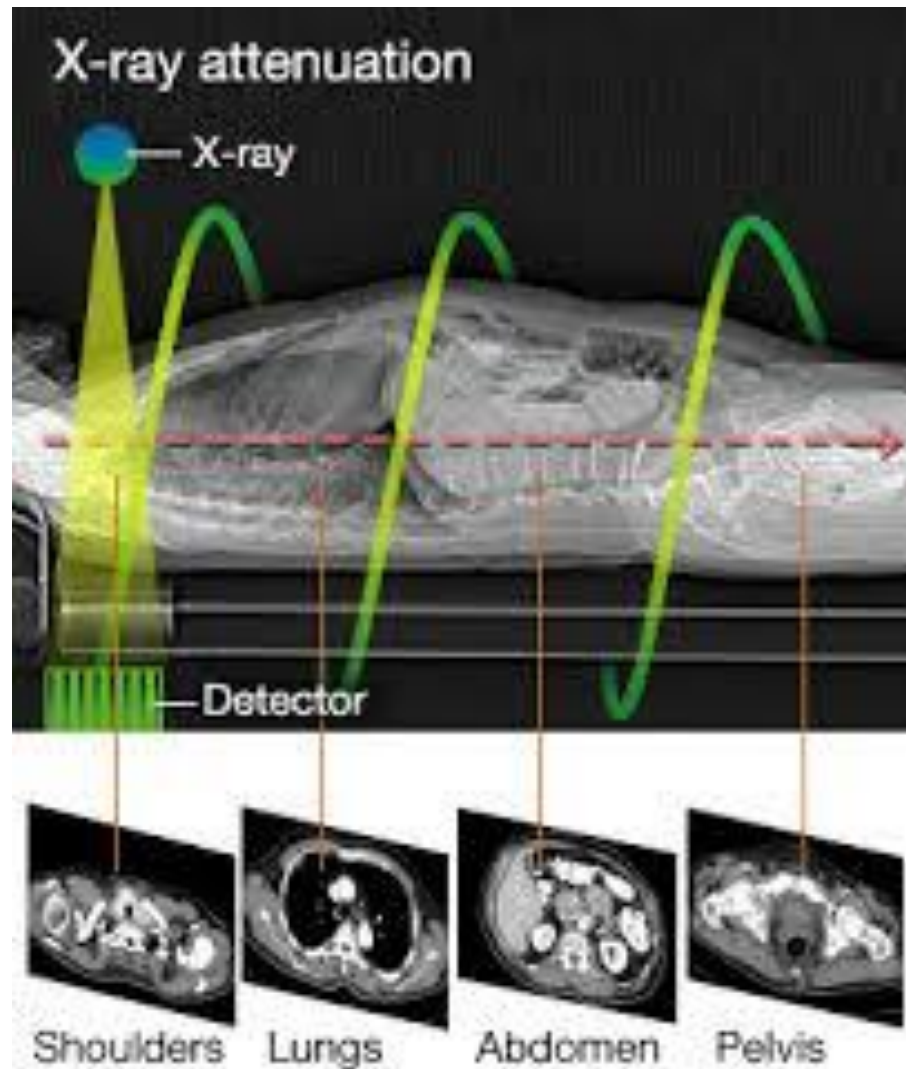
Cross section of a CT Scanner



“Volume” CT imaging



Attenuation differences thru the body

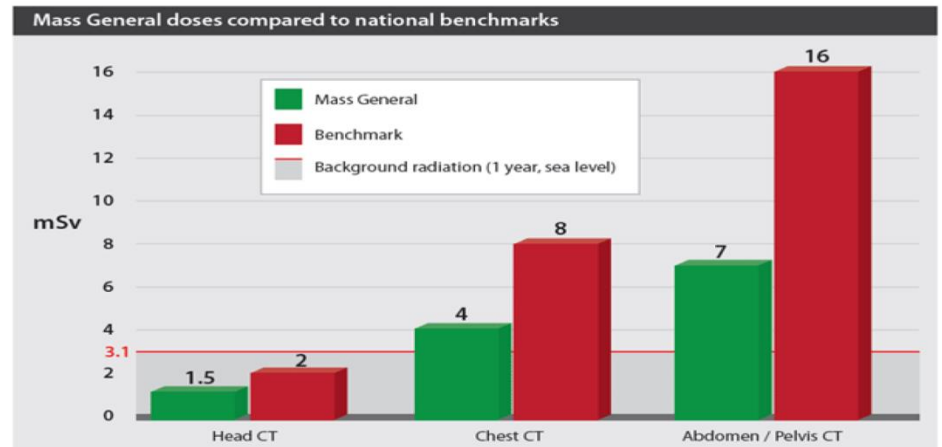


Radiation reduction on CT

Radiation

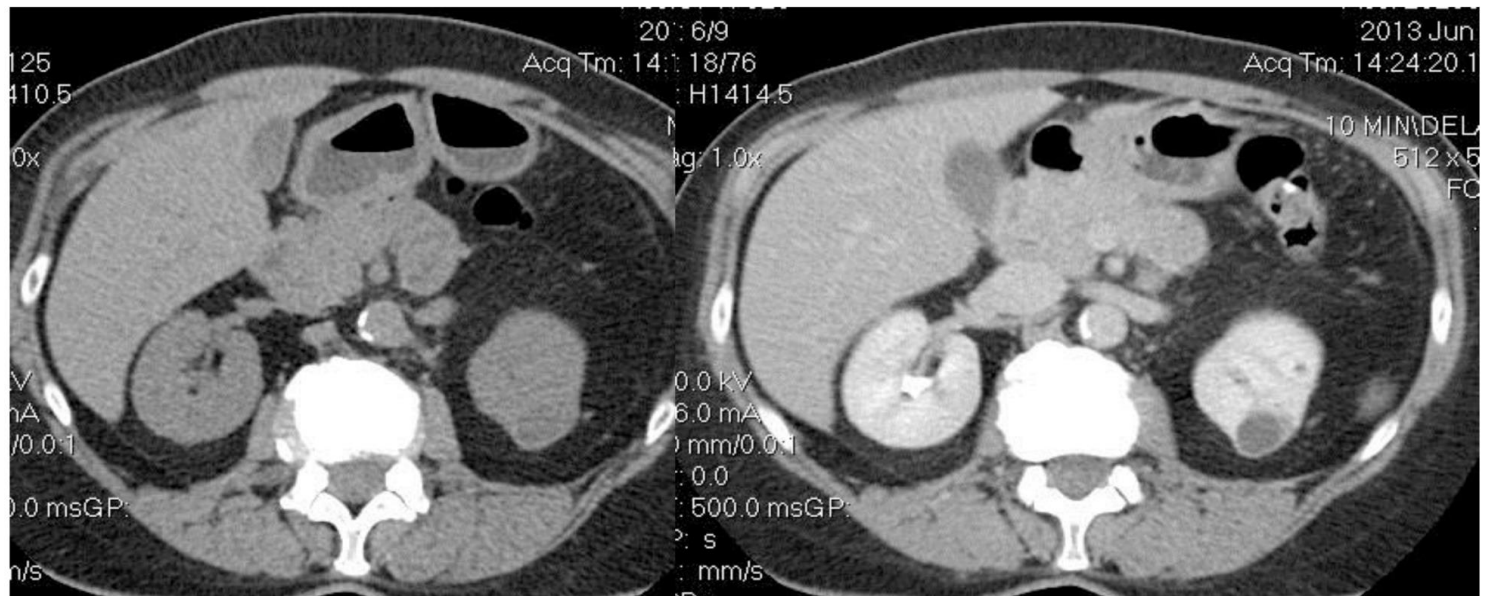


Lower kV (energy) x-rays
More sensitive detectors
Better reconstruction algorithms
“Synthetic” images



Contrast Media

Iodinated Contrast Media



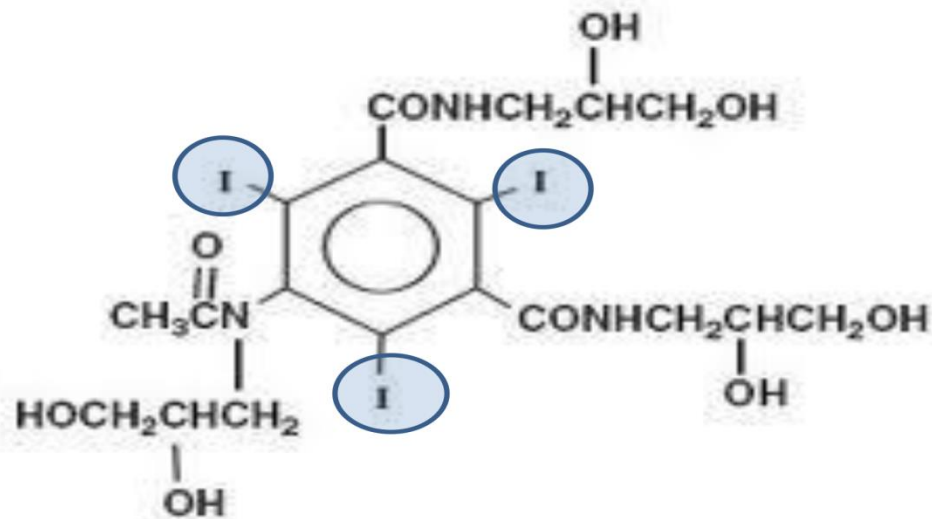
Iodinated Contrast

Iodinated Contrast



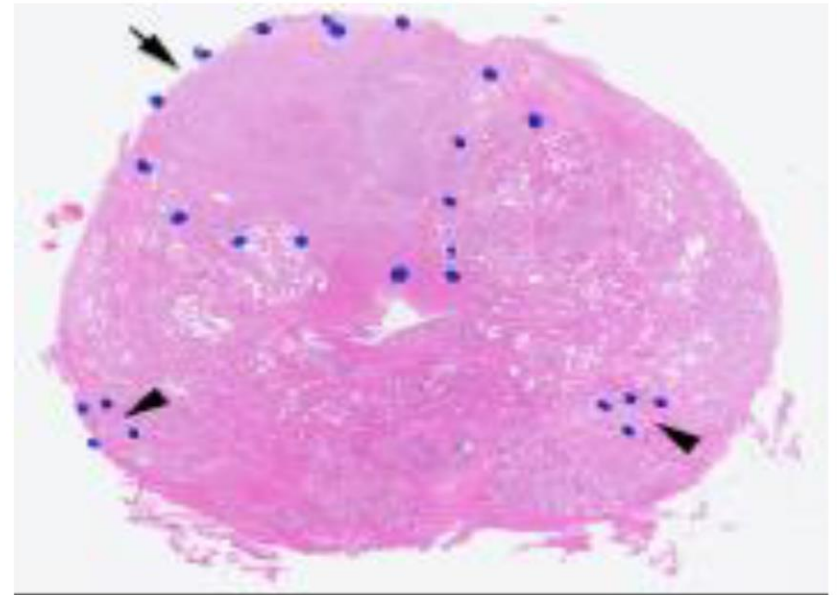
Non ionic iodinated contrast

Non ionic Iodinated Contrast



MRI

Magnetic Resonance Imaging



Prostate Cancer on MRI and Pathology

MRI Advantages

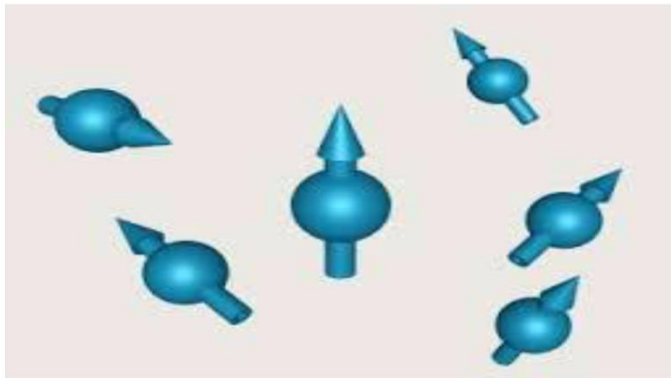
- No radiation
- Multiplanar
- Multiple contrast types:
 - T1 weighting, T2 weighting
 - Diffusion weighting
 - Contrast enhanced MRI
 - Spectroscopy

MRI Disadvantages

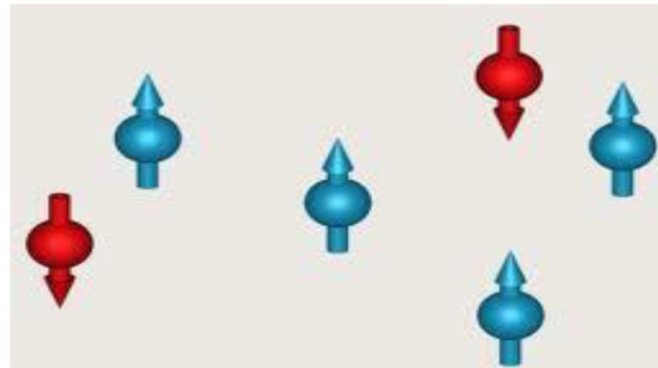
- Slower than CT
- More expensive
- Does not depict calcifications
- Safety issues
 - Metallic objects become projectiles
 - Incompatible with metallic implanted devices
 - Pacemakers
 - Cochlear implants

MRI physics

MRI Physics 101



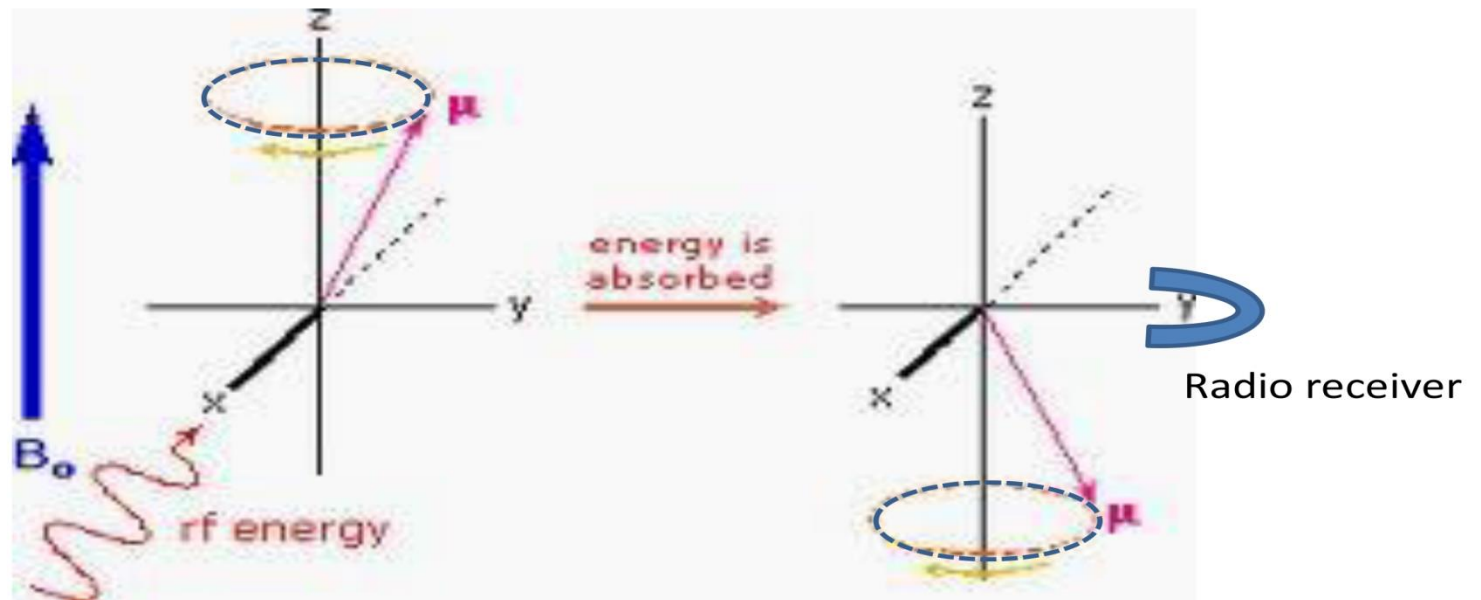
Protons in space: no field



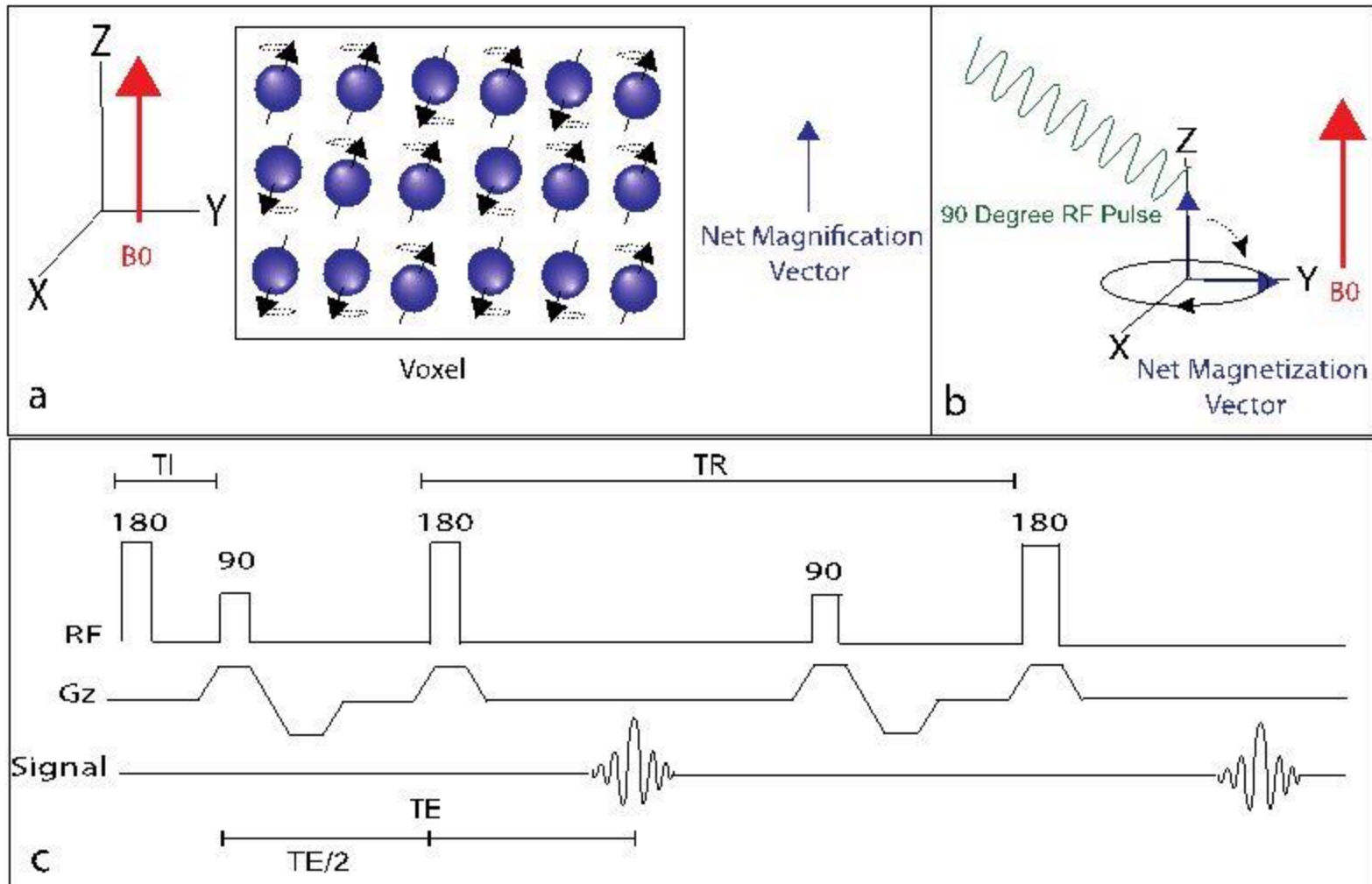
Protons in magnetic field

MR physics

MR Physics

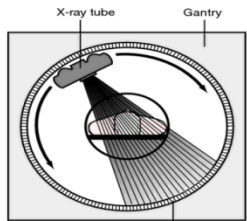


Summary

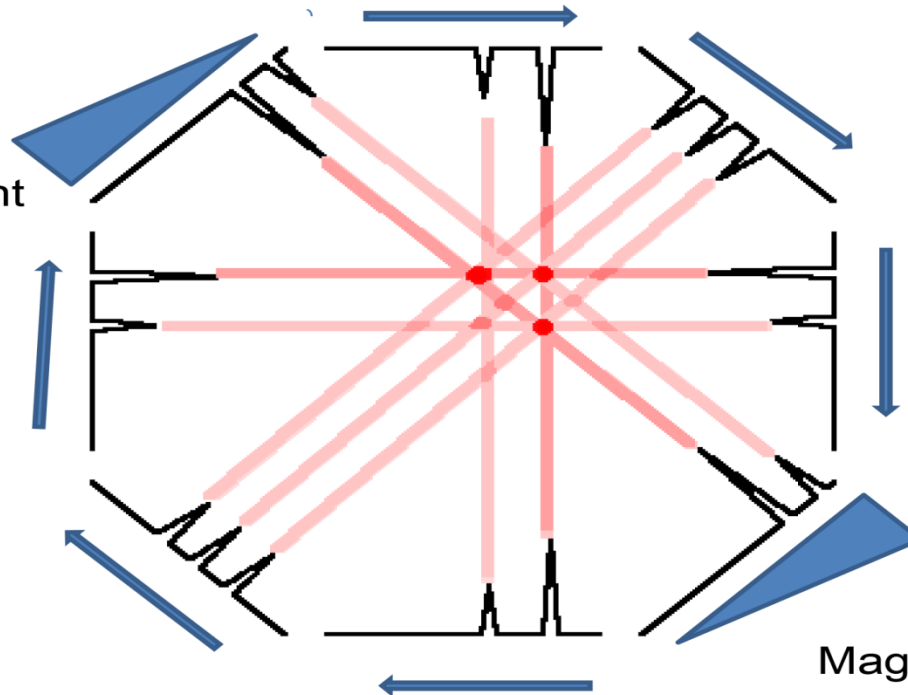


Creating a MR Image

Creating an MR Image:
No detectors! Just antennas (coils)

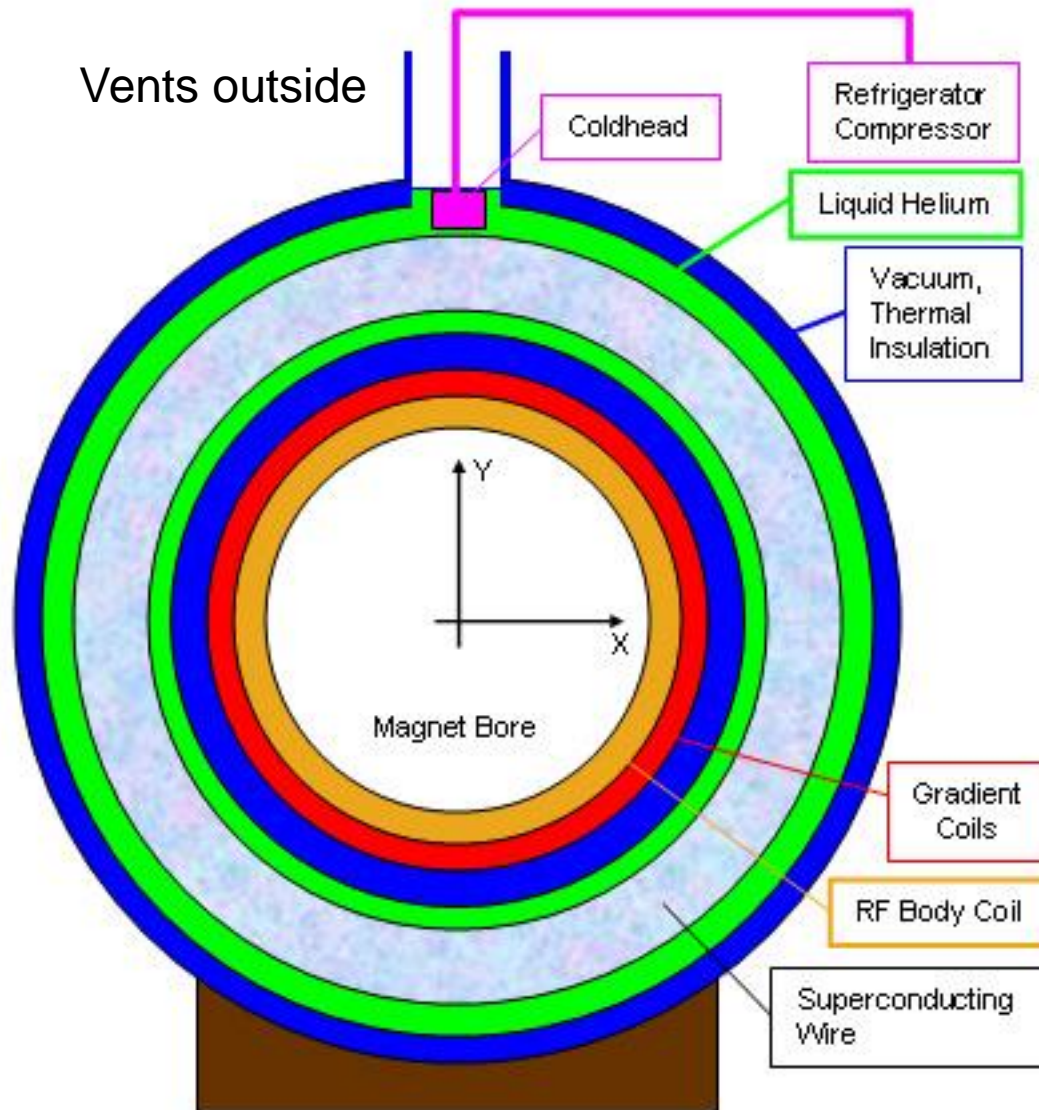


Magnetic Gradient

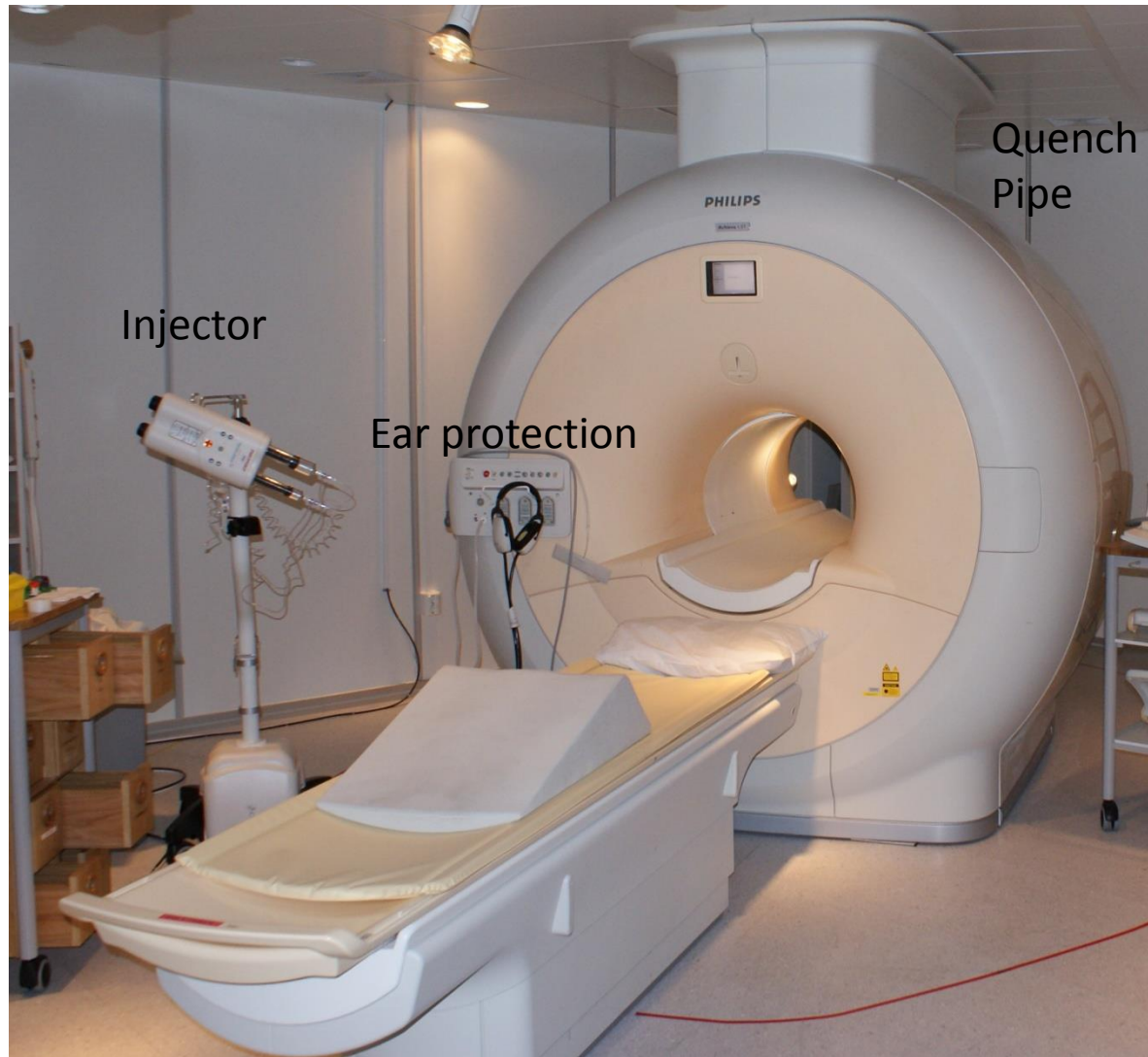


Magnetic Gradient

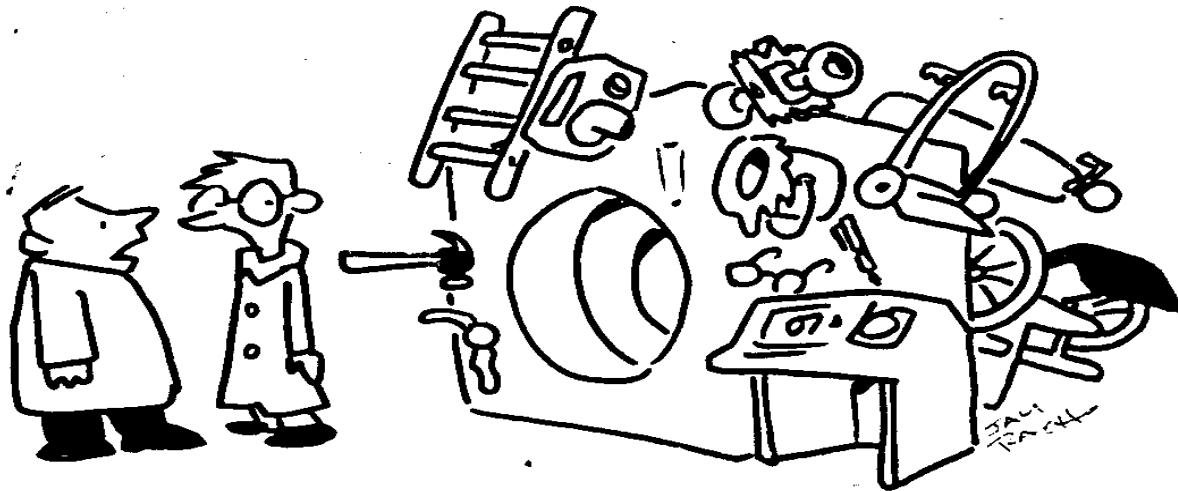
Anatomy of an MRI



Safety issues in MRI



The Importance of MR Safety

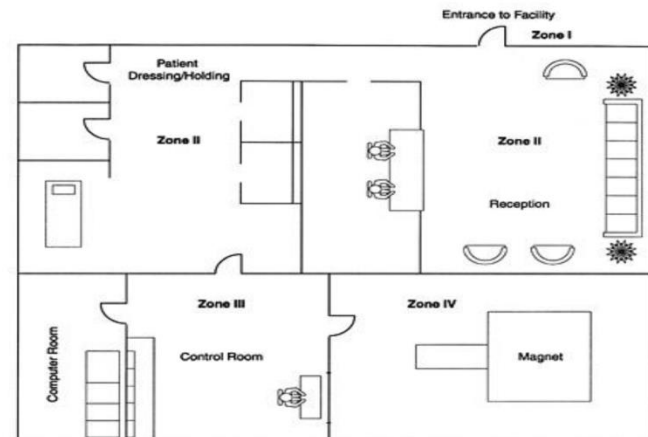


“Maybe it is time for us to review the magnet safety instructions.”

MRI Safety

MRI SAFETY

- MRI scanners are extremely powerful
- Objects that are attracted by the MRI magnetic field can reach 60 miles per hour.
- A sharp or heavy object can be deadly to anyone standing in its path.
- Metal objects used everyday (scissors, oxygen tanks, infusion pumps, etc) become projectiles
- This can cause potential injury to patients or hospital staff.
- MRI departments are divided into Zones for Safety



MRI Safety

MRI SAFETY



Oxygen tank

O2 Tank, “Missile”



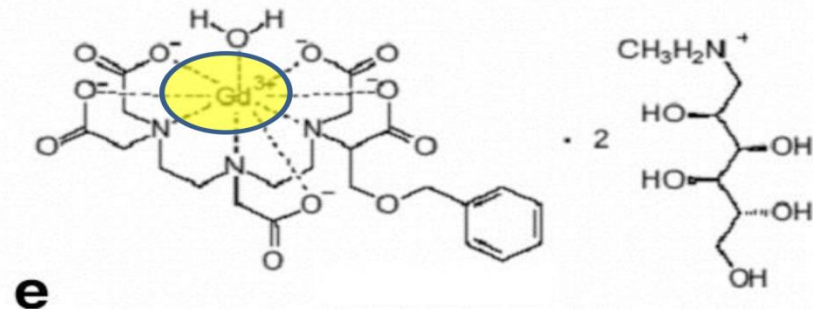
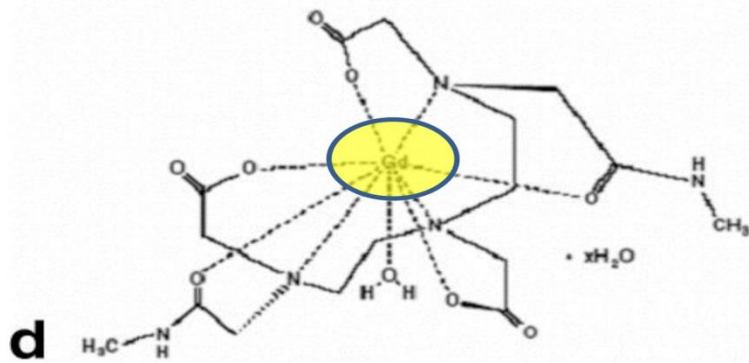
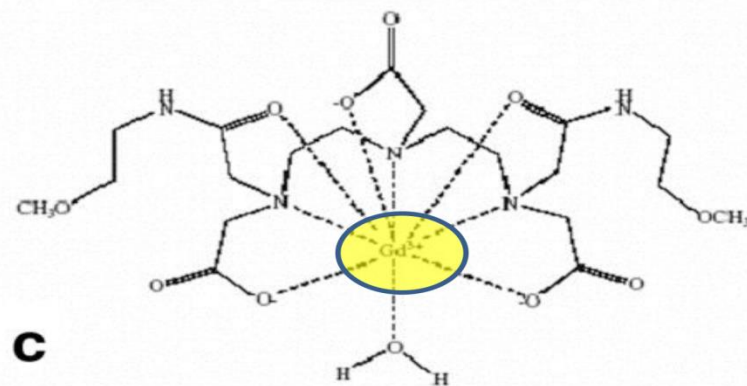
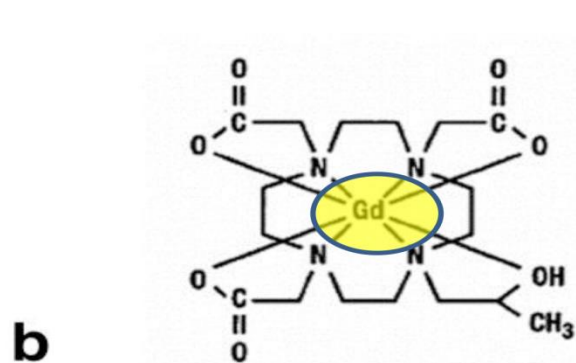
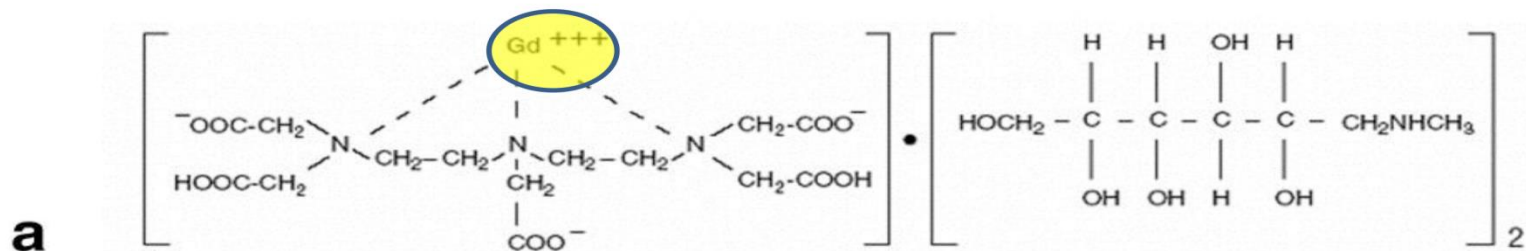
An Oxygen tank can become an Airborne torpedo in an MRI



Value of Contrast Media



Gd reagents



GD reagents

GD Reagents

| Extracellular Gd-CM | Type | Thermodynamic stability constant | Conditional Stability | Amount of excess chelate (mg ml ⁻¹) | Kinetic stability (dissociation half-life at pH 1.0) |
|---|------------------|----------------------------------|-----------------------|---|--|
| Gadoversetamide, Gd-DTPA-BMEA (OptiMark, Tyco, St. Louis, MO) | Non-ionic linear | 16.6 | 15 | 28.4 | Not available |
| Gadodiamide, Gd-DTPA-BMA (Omniscan, GE, Waukesha, WI) | Non-ionic linear | 16.9 | 14.9 | 12 | 35 s |
| Gadobutrol, Gd-BT-DO3A (Gadovist, Schering, Berlin, Germany) | Non-ionic cyclic | 21.8 | Not available | Not available | 5 min |
| Gadoteridol, Gd-HP-DO3A (Prohance, Bracco, Italy) | Non-ionic cyclic | 23.8 | 17.1 | 0.23 | 3 h |
| Gadopentetate Gd-DTPA (Magnavist, Schering, Berlin, Germany) | Ionic linear | 22.1 | 18.1 | 0.4 | 10 min |
| Gadobenate, Gd-BOPTA, (Multihance, Bracco, Italy) | Ionic linear | 22.6 | 18.4 | None | Not available |
| Gadoterate, Gd-DOTA (Dotarem, Guerbet, France) | Ionic cyclic | 25.8 | 18.8 | None | > 1 month |

Nephrogenic systemic sclerosis

Examples: nephrogenic systemic sclerosis



Mechanism

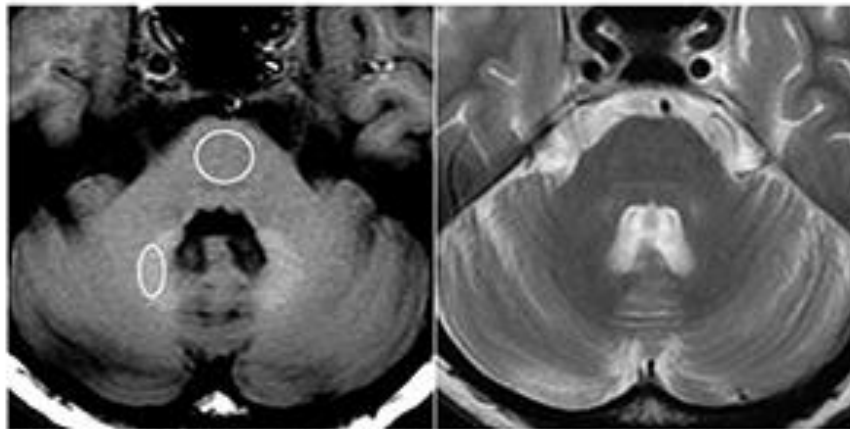
- Gadolinium is highly toxic
- Patients with normal renal function excrete Gd-chelates within 24-48h
- Patients with abnormal renal function may take weeks to excrete the agent
- Dissociation of Gd from the chelate could deposit in soft tissues (documented)
 - Hugh et al. Tissue Gd conc .14-24 ng/mL
- Fibrosis is an inflammatory response to toxic Gd ion.

Risk Factors

- Renal failure:
 - Dialysis
 - Chronic renal failure (GFR <30cc/min)
- Dose
 - Double, triple (vs. half dose)
- Contrast agent
 - Omniscan>Optimark>Magnevist>Prohance>
- Alternative imaging?
 - Non con MRI
 - CT, US, PET

Residual Gadolinium

Residual Gadolinium!



| Substance (d/C) | Type | Thermodynamic stability constant | Chemical stability | Amount of release (mg kg ⁻¹) | Renal stability (excretion half-life at pH 7.4) |
|--|------------------|----------------------------------|--------------------|--|---|
| Gadobutrolamide, Gd-DTPA-BMEA, Cypritol, Tyn, St. Louis, MO | Non toxic linear | 15.5 | 15 | 28.8 | Not available |
| Gadobutrolamide, Gd-DTPA-BMEA, Cinconex, GE, Waukesha, WI | Non toxic linear | 14.5 | 14.5 | 12 | 30 h |
| Gadoterate, Gd-BT-DO3A (Gadovist, Schering, Berlin, Germany) | Non toxic cyclic | 21.8 | Not available | Not available | 3 min |
| Gadoterate, Gd-BT-DO3A (Proscan, Bracco, Italy) | Non toxic cyclic | 21.8 | 17.7 | 8.23 | 3 h |
| Gadoterate, Gd-DTPA (Magnevist, Schering, Berlin, Germany) | Toxic linear | 22.1 | 16.1 | 8.8 | 10 min |
| Gadoterate, Gd-BT-DO3A (Multacontrast, Bracco, Italy) | Toxic linear | 21.4 | 16.8 | None | Not available |
| Gadoterate, Gd-DOTA (Dotarem, Guerbet, France) | Toxic cyclic | 25.8 | 16.8 | None | > 10 months |

Ultrasound



US advantages

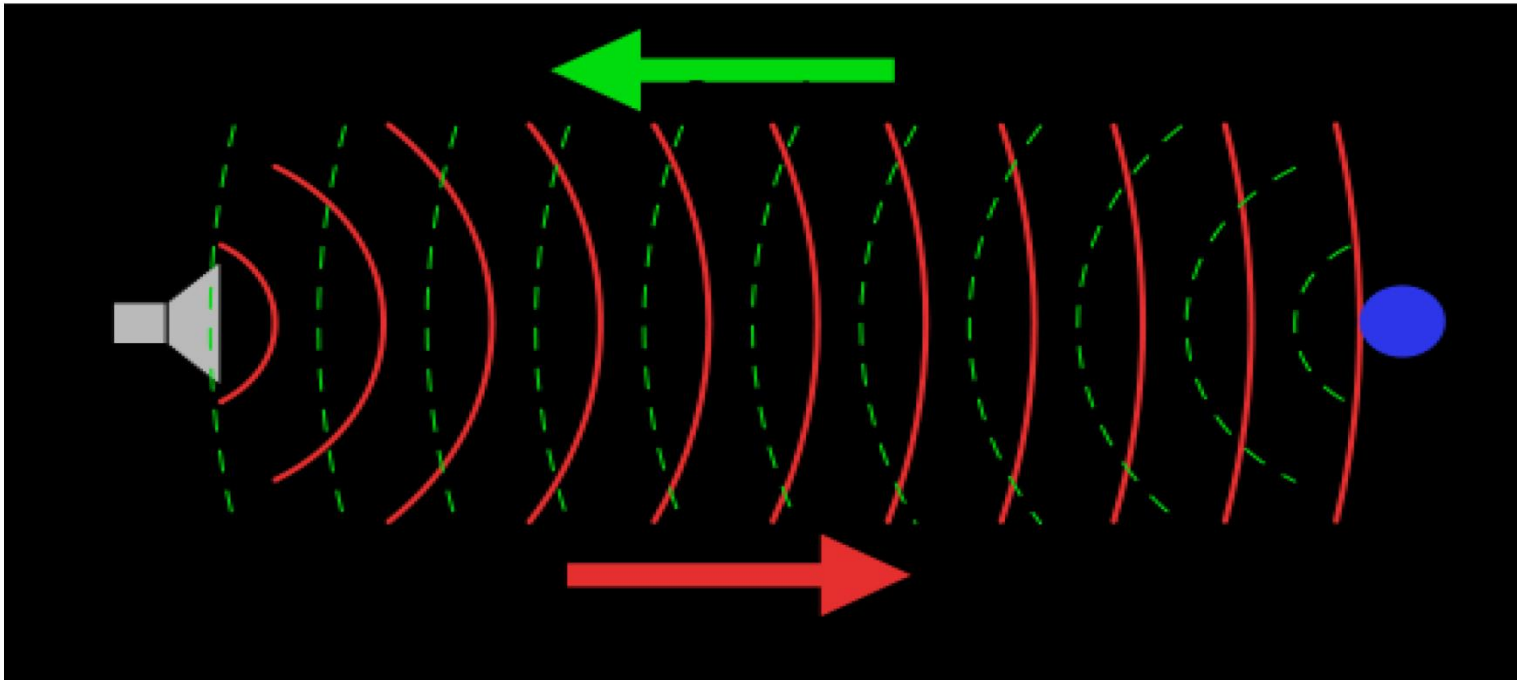
- No radiation
- Real time
- Inexpensive
- Quick, little prep
- No injection

US disadvantages

- Operator dependent
- What you see is all there is
- Difficult to quantify
- Limited access (lungs, brain, bone etc.)

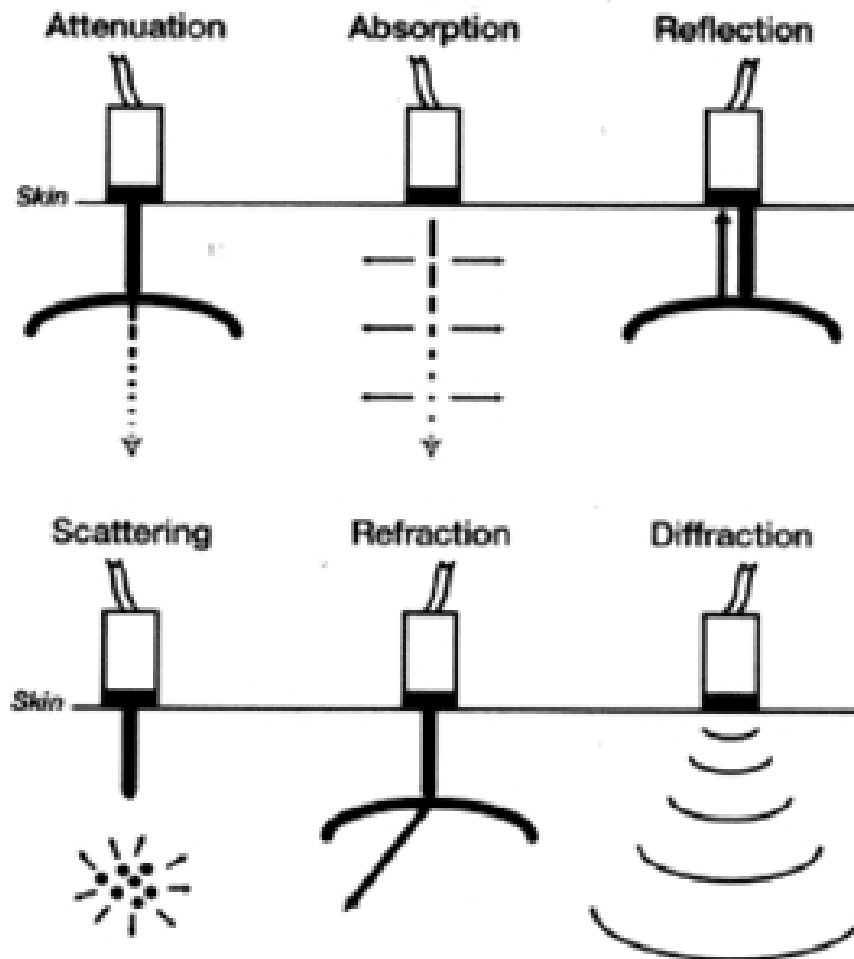
Ultrasound basics

US basics



Imaging dependent on the speed of sound
In tissue

Fate of sound waves in body

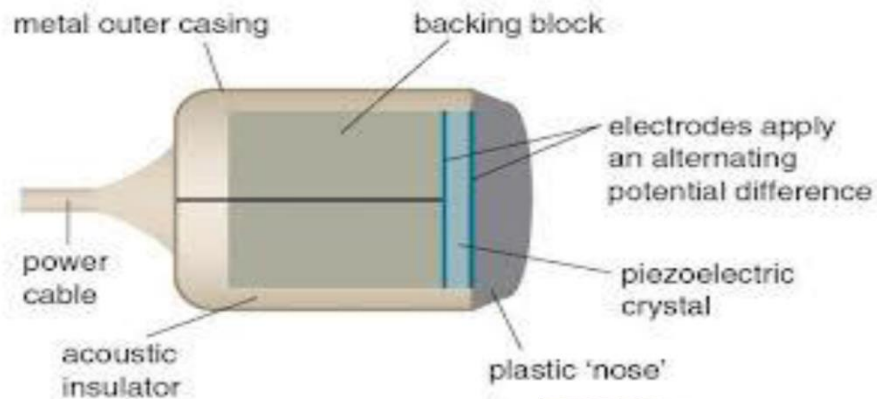


Liver metastases



Ultrasound probes

US Probes



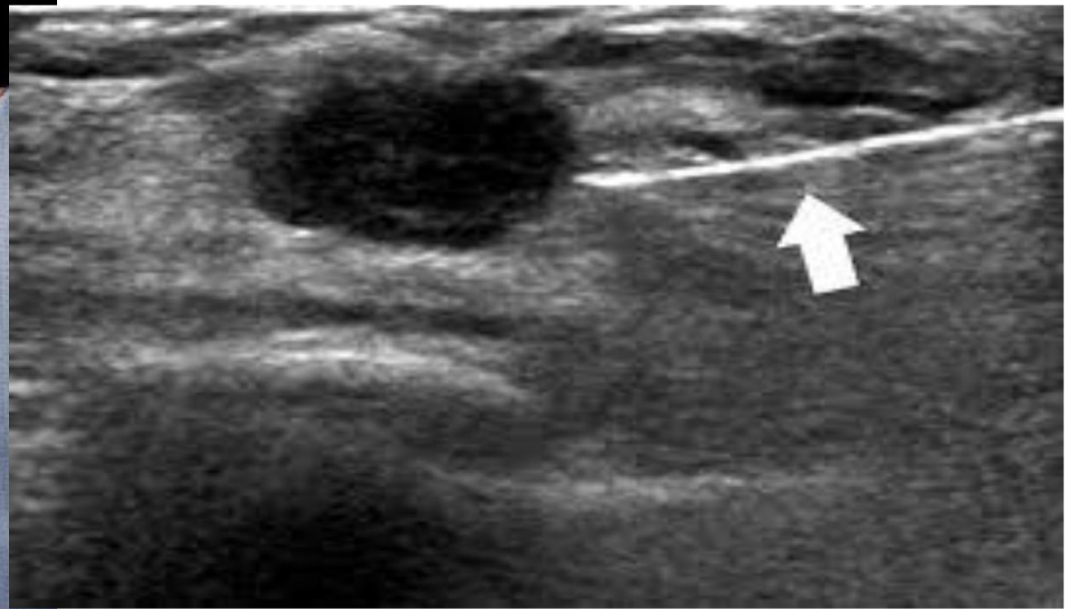
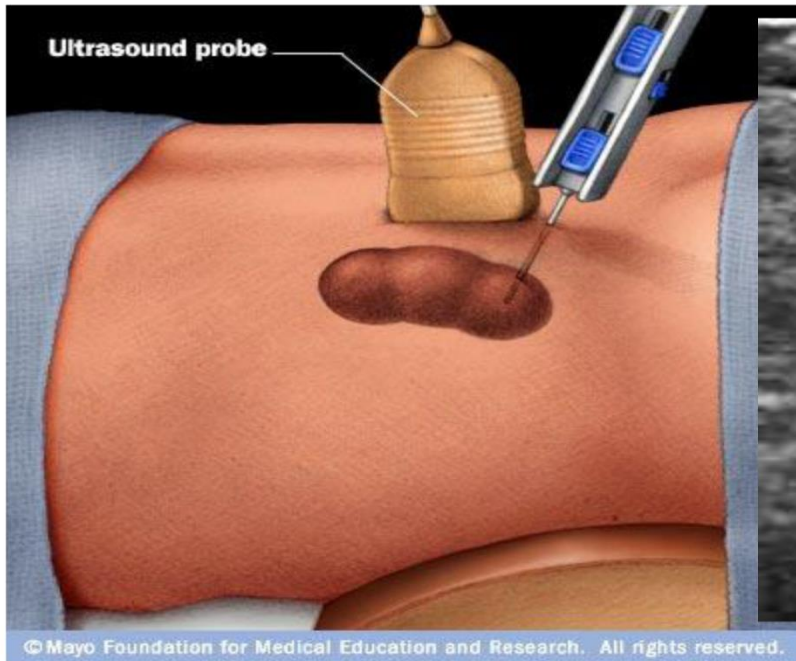
Ultrasound devices

Evolution of US devices



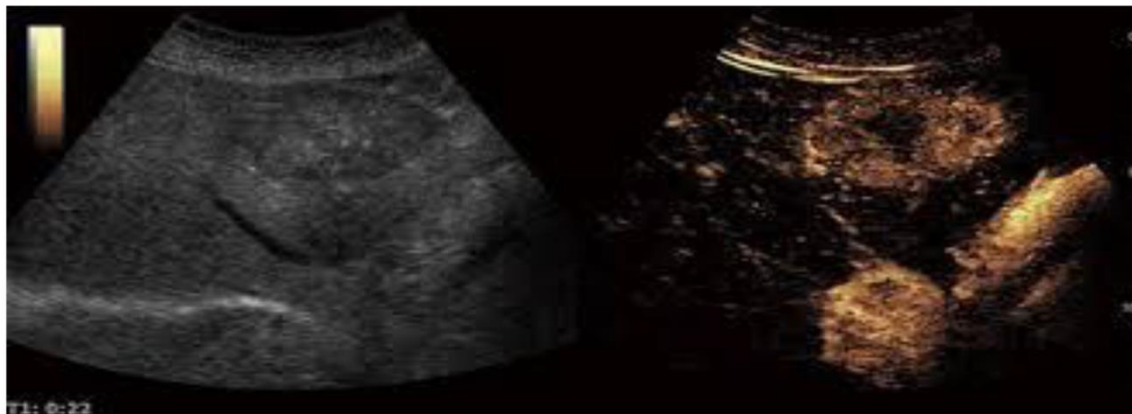
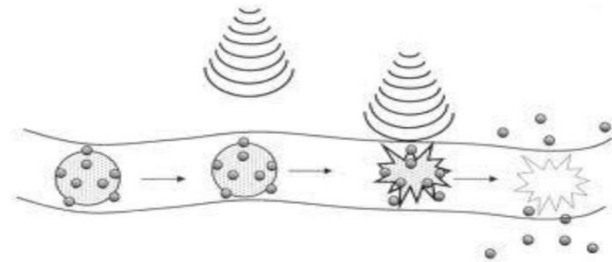
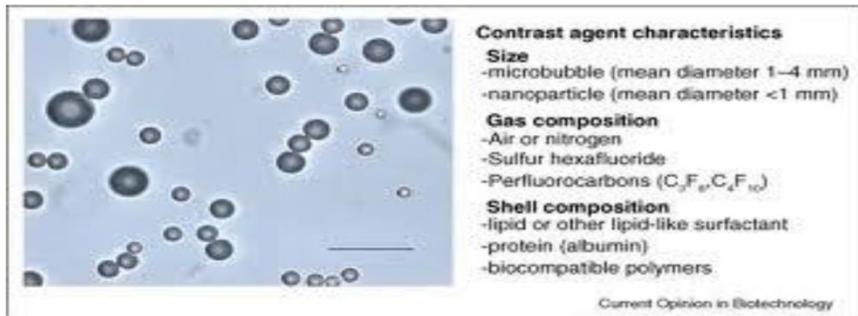
Ultrasound guided biopsy

US guided biopsy-real time



Ultrasound

US Microbubble contrast

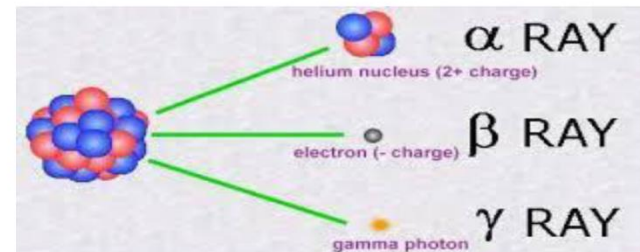


SPECT

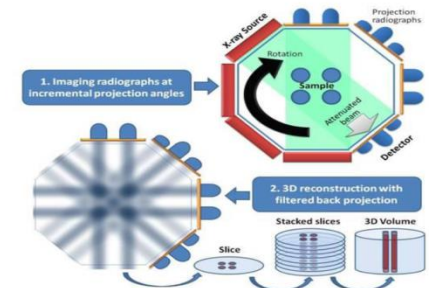
Single Photon Emission Computed Tomography-SPECT

- Single Photon Emission

+



- Computed Tomography

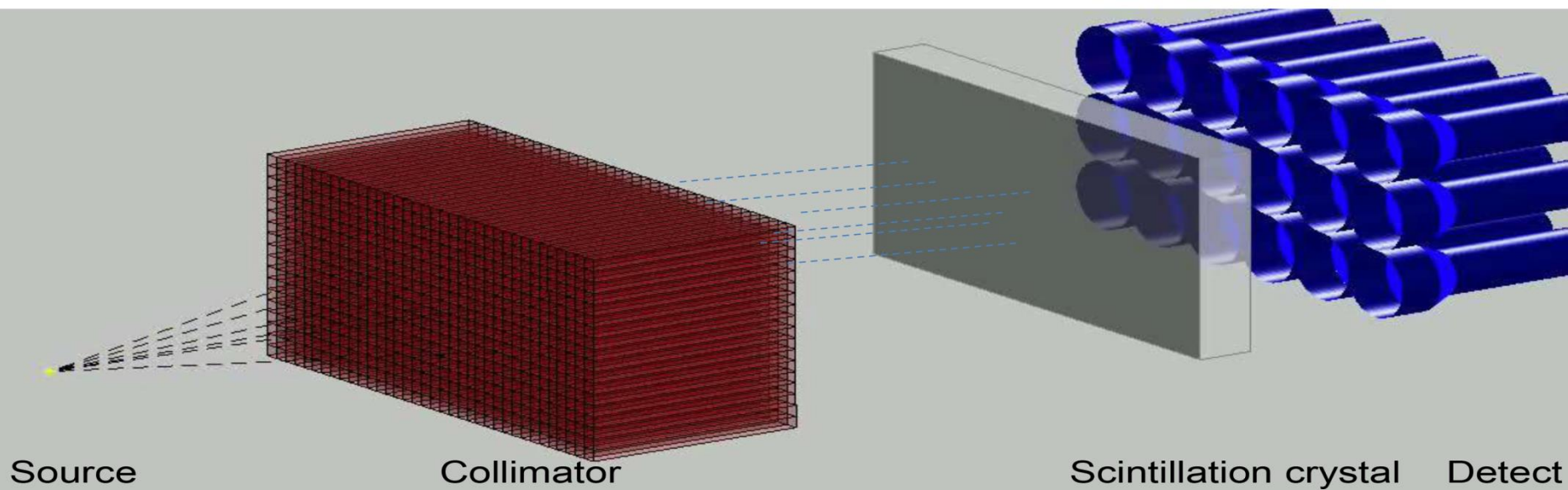


SPECT Advantages/Disadvantages

- Relatively inexpensive
- Broad experience
- Disadvantages
 - Radiation exposure
 - Preparation of imaging agent
 - Nuclear Regulatory
 - Scanning is slow, low resolution

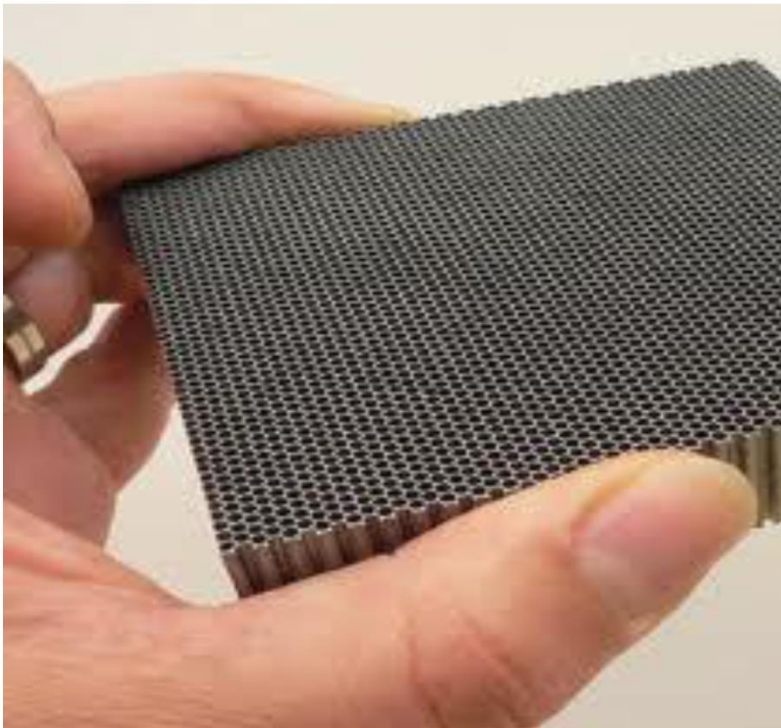
SPECT detectors

SPECT detectors



Collimation

Collimation cont'd

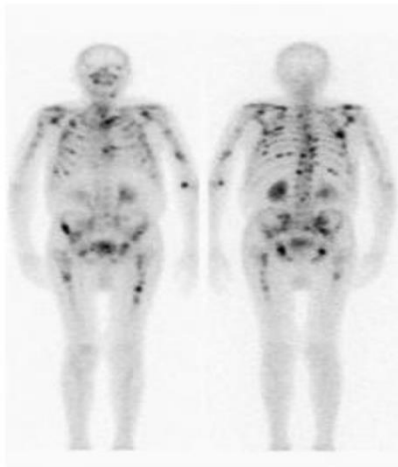


Collimation reduces the sensitivity and resolution of SPECT by rejecting the majority of events

SPECT imaging

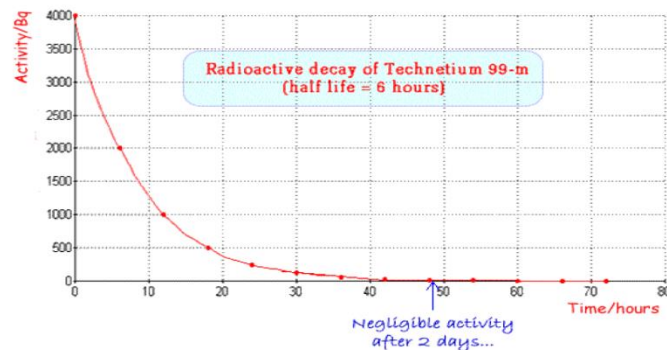
SPECT Imaging

- Requires conjugation of a radioactive isotope to a compound of interest which is injected into the patient:



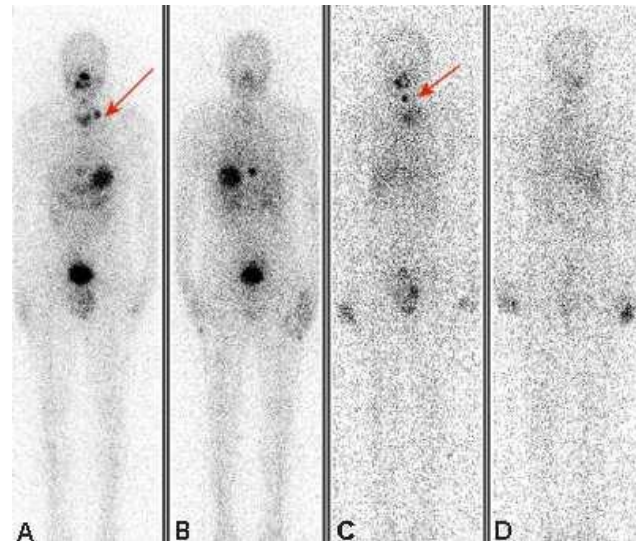
The bone scan:

^{99m}Tc Technetium-methyl diphosphonate



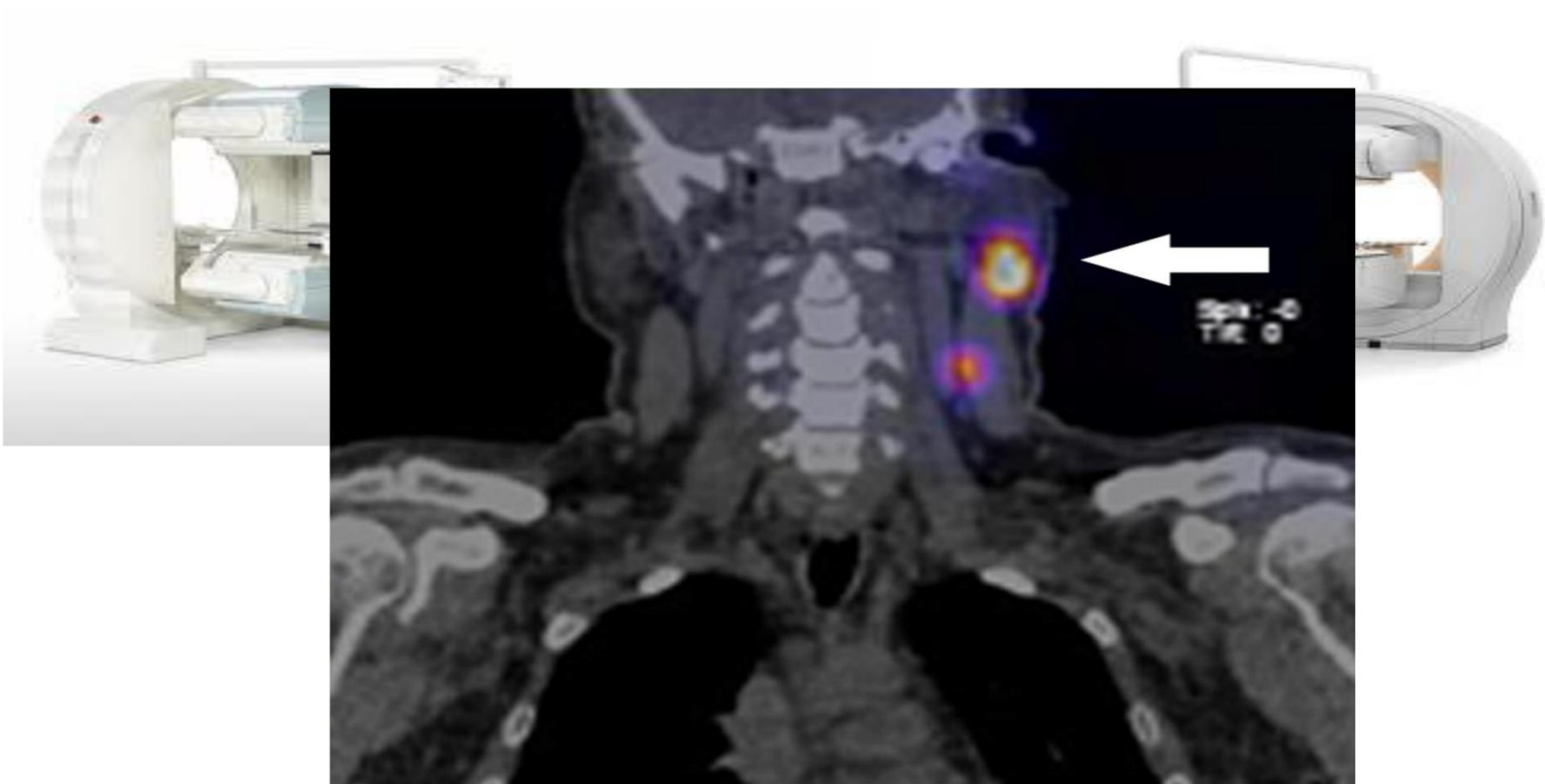
SPECT agents for cancer

- ^{99m}Tc MDP Bone Scan
- ^{99m}Tc Pertechnetate (thyroid, salivary gland)
- ^{201}Tl Chloride (parathyroid)
- ^{111}In oxine (WBC labelling)
- ^{131}I Iodine (thyroid)

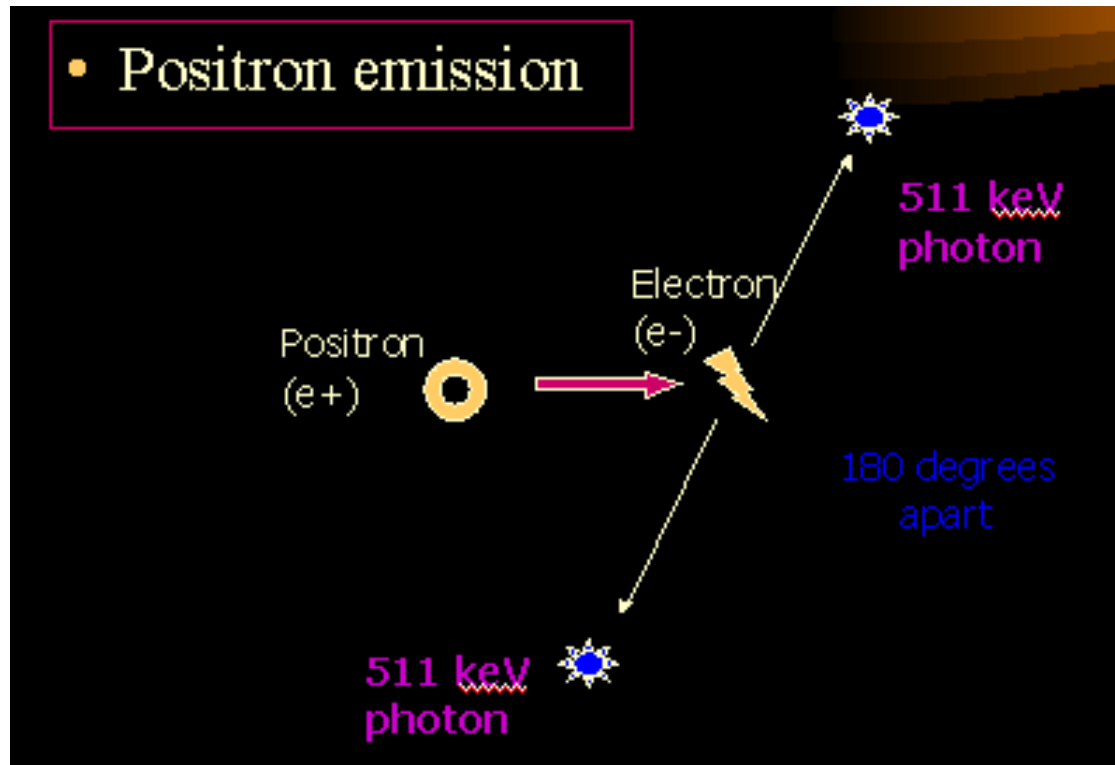


Hybrid Imaging

Hybrid Imaging



Positron Emission Tomography

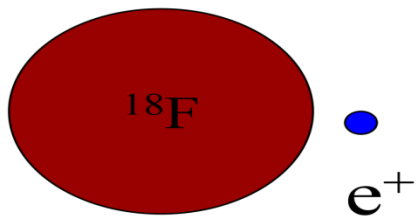


PET:Advantages and Disadvantages

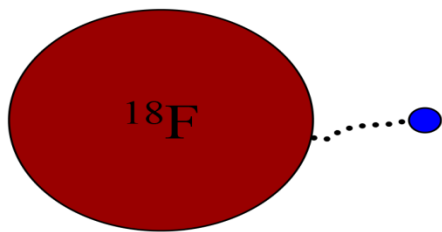
- Highly sensitive
- Metabolic information
- Better spatial resolution than SPECT
- Combined with CT
- ---
- Expense
- Regulatory
- Short half life

PET

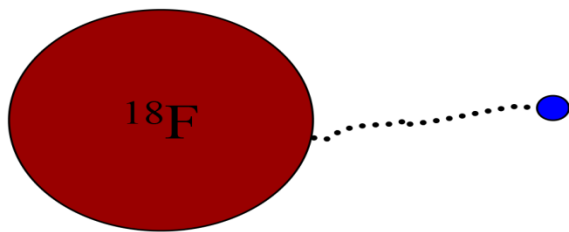
Positron Emission Tomography



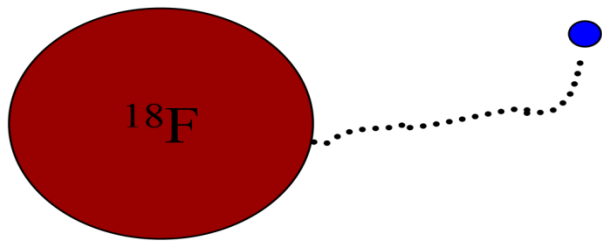
Positron travel



Positron travel



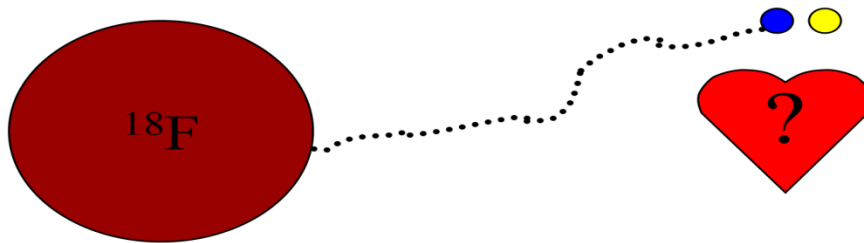
Positron travel



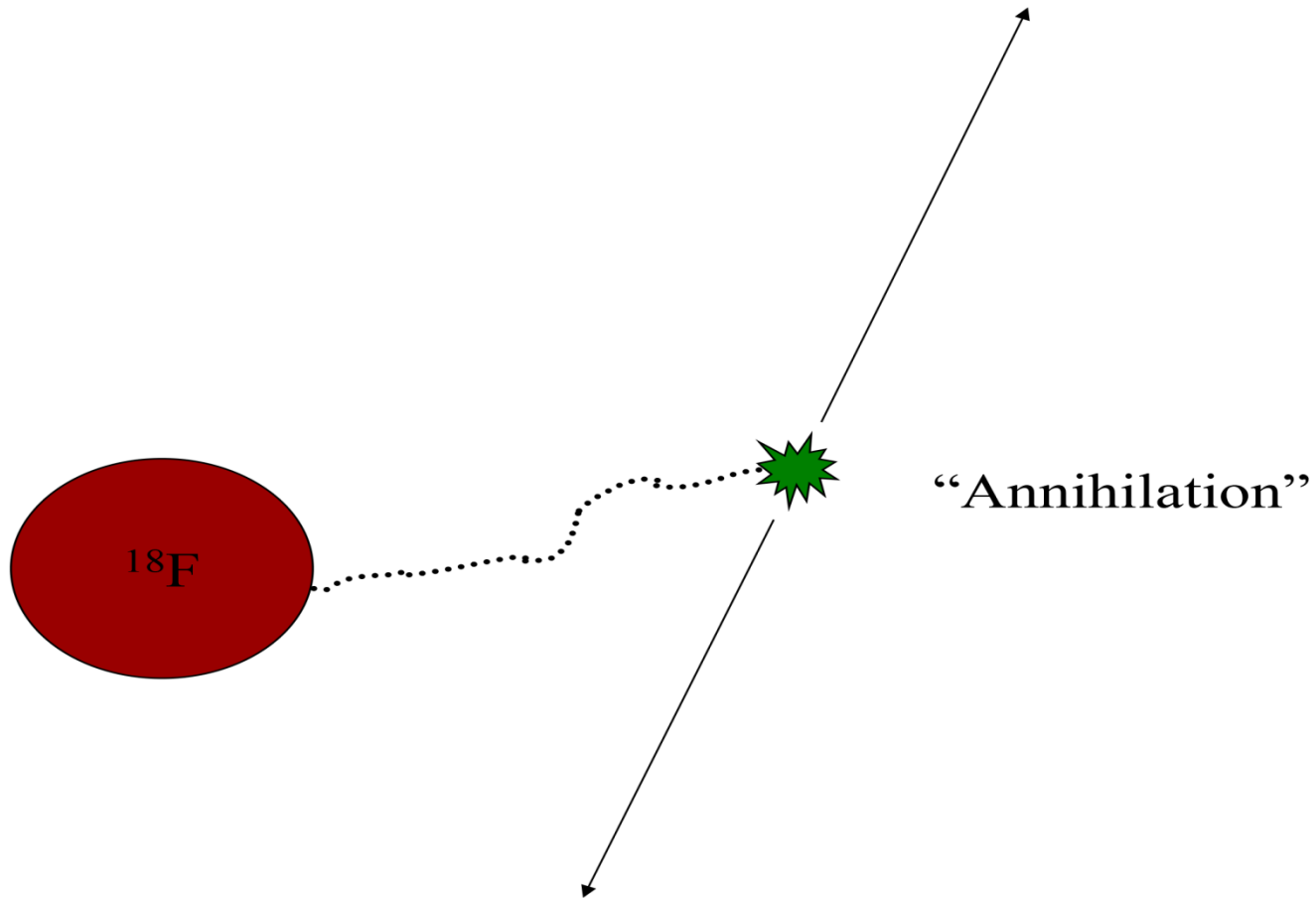
Positron travel



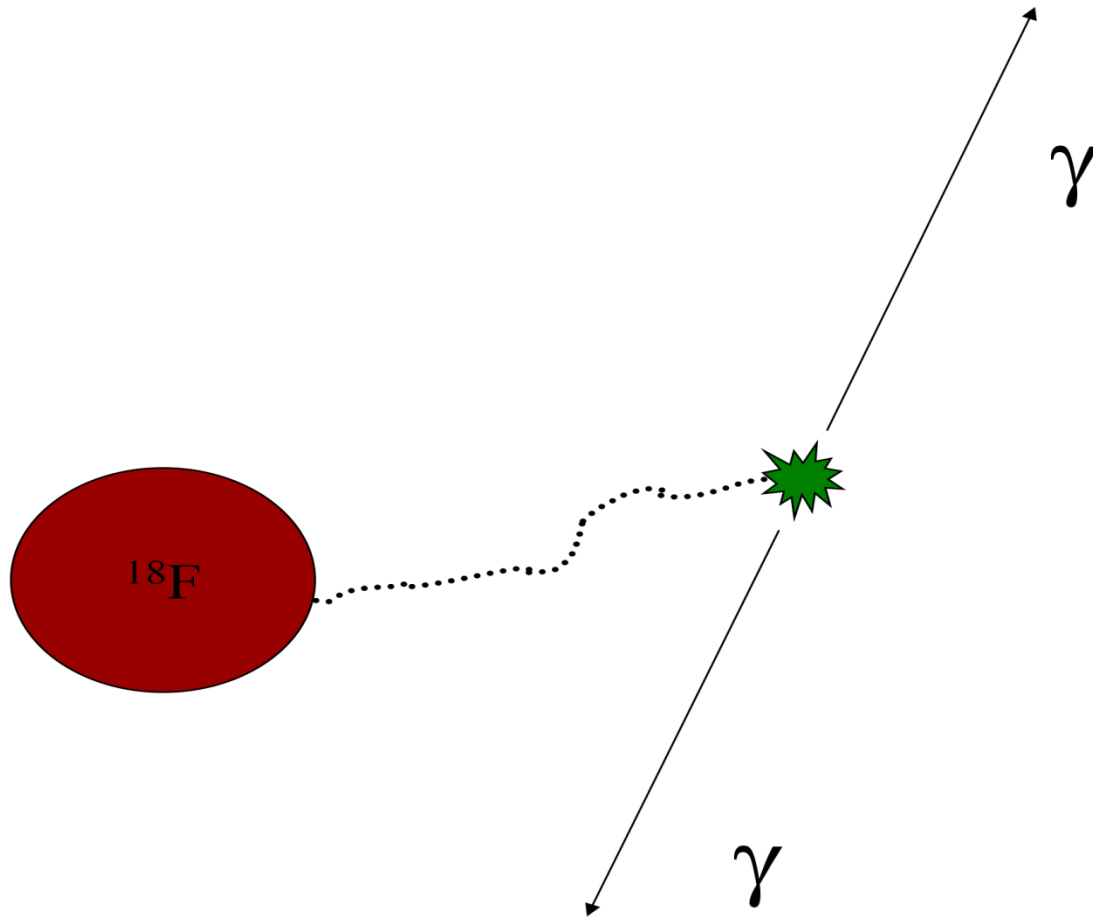
Positron and Electron



Annihilation

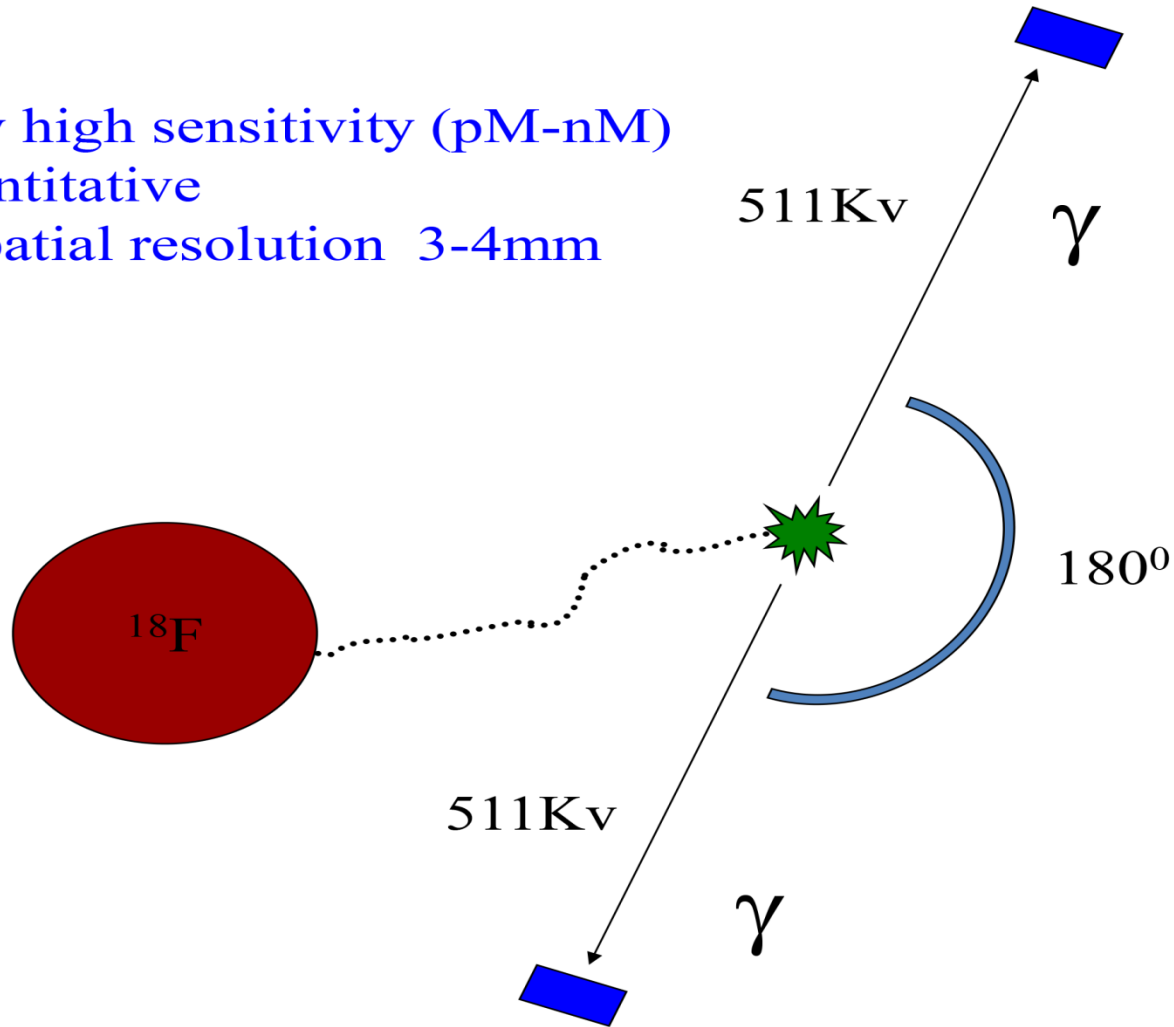


Gamma rays



Gamma ray orientation

Very high sensitivity (pM-nM)
Quantitative
 \pm Spatial resolution 3-4mm



F-18 Deoxyglucose

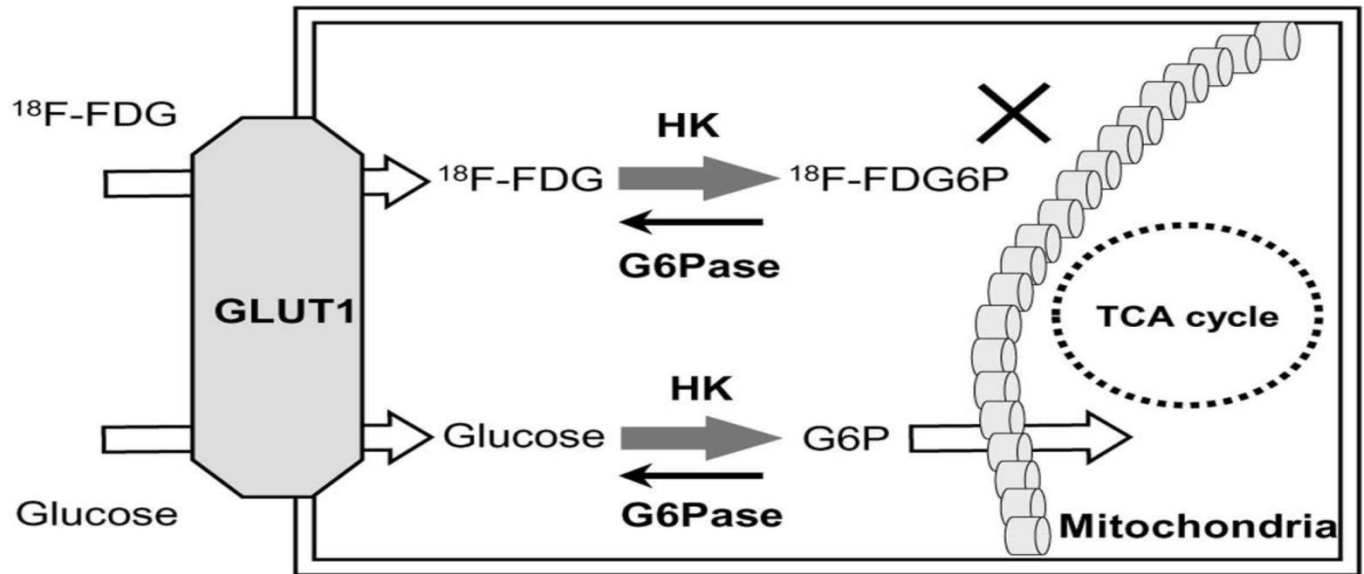
F-18 Deoxyglucose



Otto Warburg

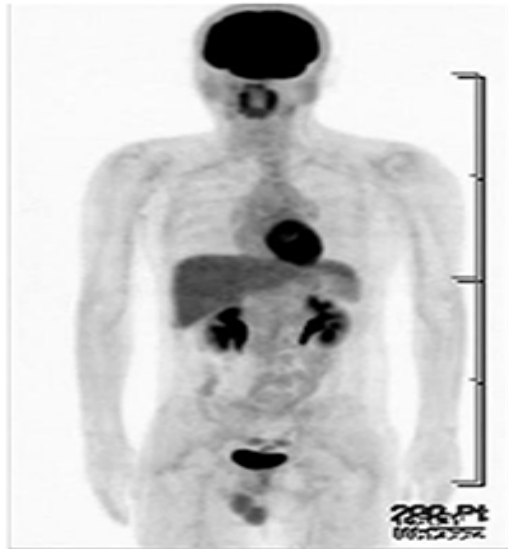


Lou Sokoloff

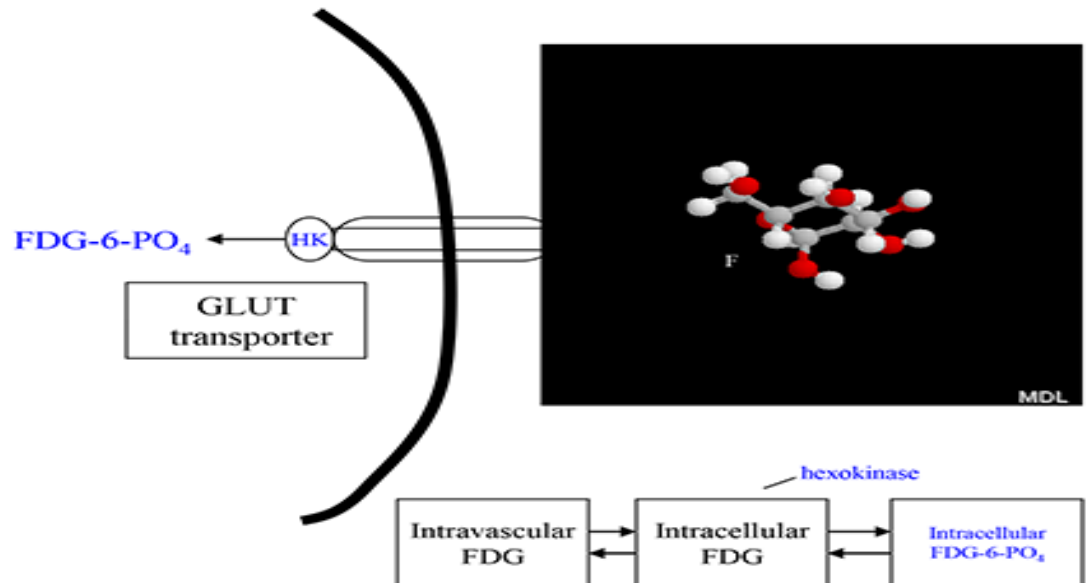


^{18}F FDG PET Imaging

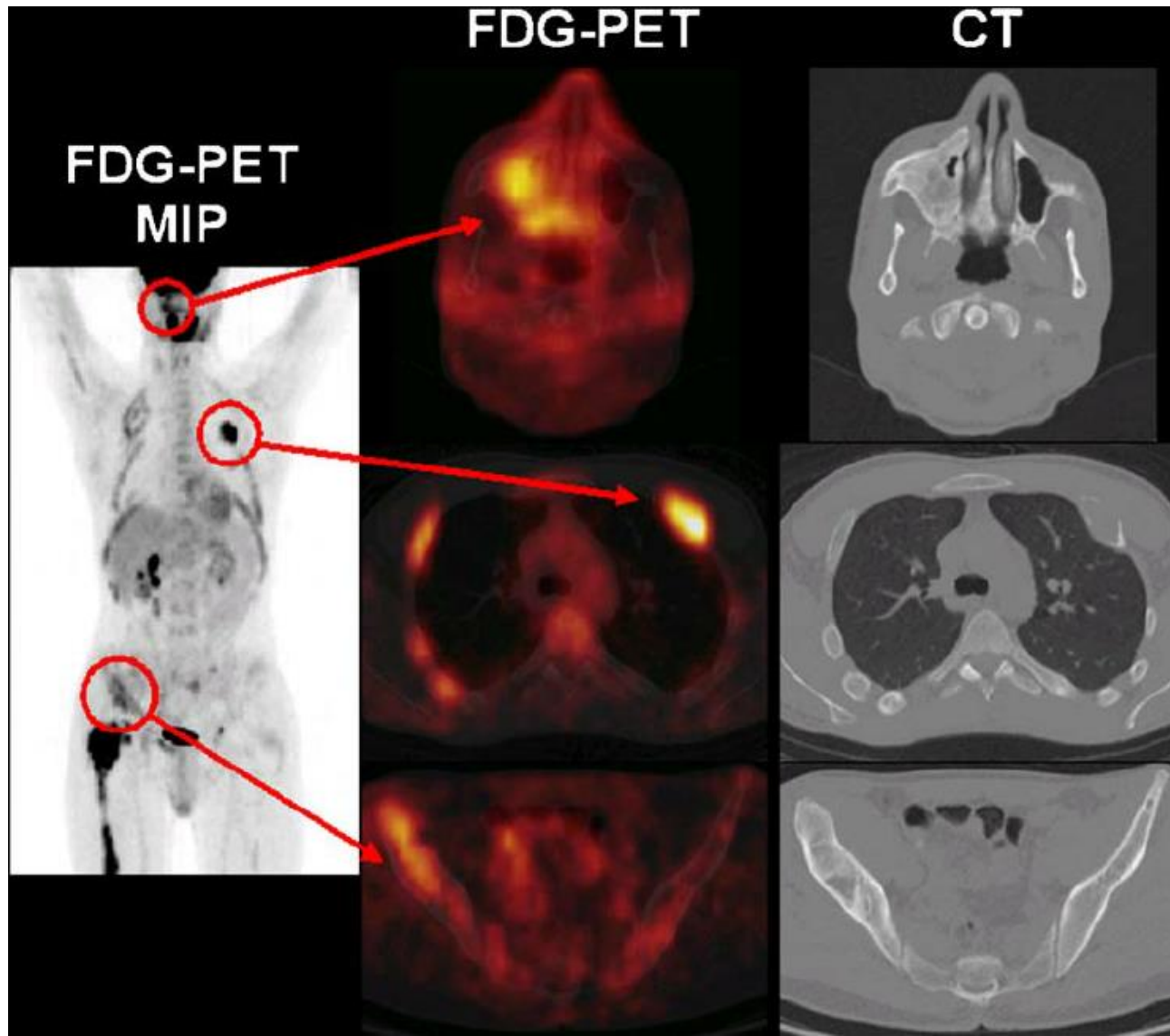
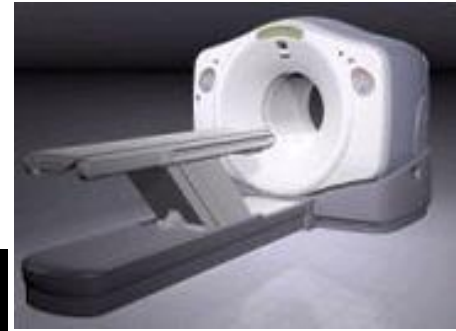
^{18}F FDG PET Imaging



E PET MIP

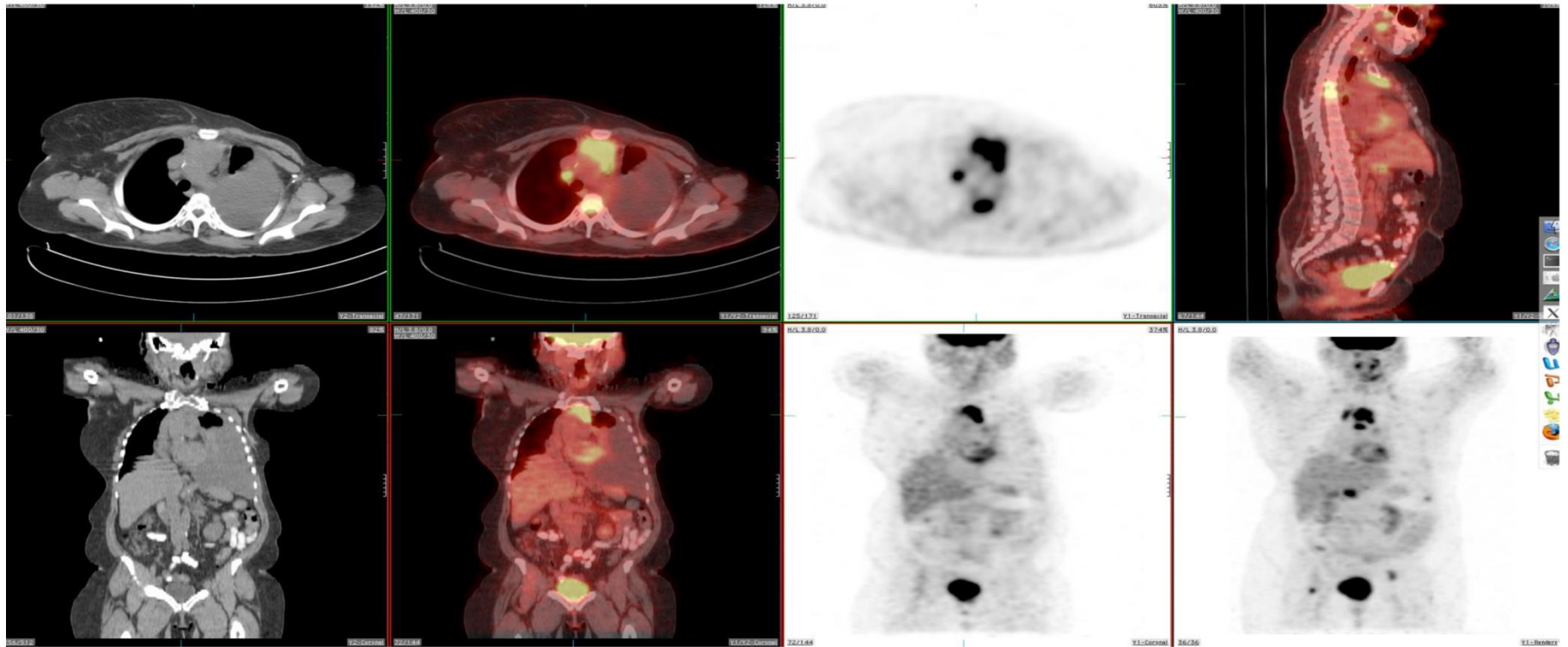


PET-CT scanners



Metastatic Breast Cancer

Mediastinal and spine metastases (breast)



Metastatic Breast Cancer

Notable PET Agents

- Sodium Fluoride: Bone target
- Fluorothymidine: Cellular Proliferation
- Fluoroestadiol: Estrogen receptor
- Fluorocholine: Membrane Turnover
- Fluoromiso: Hypoxia
- Florbetaben: Amyloid (Alzheimers)
- Zirconium Herceptin: labeled antibody
- Zirconium Oxine: Cell labeling

Image Correction



**Non-attenuation
corrected**



**Attenuation
corrected**

PET Imaging

- Positron emission tomography (PET) has the advantages of :
 - High energy photon imaging
 - High Sensitivity, Moderate Specificity
 - The ability to correct for attenuation
 - No need for collimation
 - Resolution is still limited

Summary

Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|--------------|------------|------------------|---------------|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

Cancer Imaging

Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|--------------|------------|------------------|---------------|
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| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

Cancer Imaging

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| PET | SPECT | CT | PET |

Cancer Imaging

Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|--------------|------------|------------------|---------------|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

General Guidelines

- Overall “workhorse” for oncology: CT
- Specialty cancers: brain, liver, prostate: MRI
- Problem solving (e.g cyst vs. solid): US
- Bone mets: SPECT
- Metabolic activity: PET

Imaging of cancer

Imaging of cancer



Imaging of Cancer: