Imaging in Radiotherapy

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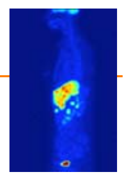
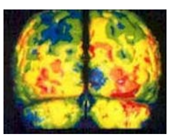
X-rays

CT



PET

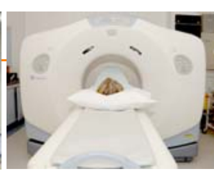


SPECT

7T MRI Image

3D/4D Fetal Imaging

X-rays



CT

PET

SPECT

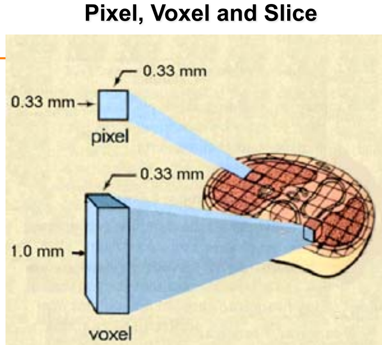
MRI

Ultrasound

What is an image?

Zoom In

Pixel, Voxel and Slice



The whole CT images are made of a huge number of tiny voxels

What is an image?

- A square matrix with a pixel value for each pixel
- Each pixel has some kind of meaning
- All pixels together give a whole picture

Parameter	Symbol	Typical values
Rows	*N*	256,512,525,625,1024,1035
Columns	*M*	256,512,768,1024,1320
Gray Levels	*L*	2^n ---- 2,64,256,1024,4096,16384

Some concepts

- Resolution, r (cm/pixel)
- Dimension, d (pixels)
- Thickness, t (cm)

$$L(cm) = r \times d$$

Example: 256x256, 1.8 mm/pixel, L=256*1.8=46.08 cm

When the image is down-sampled to 128x128, resolution will be 46.08/128=3.6 mm/pixel.

Method	Property Imaged	Best Resolution
X-ray	Anatomy	<0.1 mm
CT	Anatomy	1 mm
MR	Anatomy + Function	1 mm
SPECT	Function	3 mm
PET	Function	3 mm
Ultrasound	Anatomy	1 mm

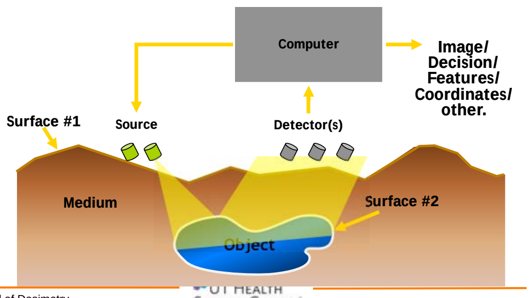
Sample Question

- Using a FOV of 30cm and reconstruction matrix of 512, the spatial resolution is 0.586mm/pixel. What is the spatial resolution if the FOV is changed to 36cm?
  - **A.** 0.4mm/pixel
  - **B.** 0.5mm/pixel
  - **C.** 0.7mm/pixel
  - **D.** 0.9mm/pixel

First,
300mm/512 = 0.586mm/pixel

Now,
360mm/512 = 0.7mm/pixel

How the image is generated



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Basic Physics

$$I = I_0 e^{-\mu x}$$

Where "u" ,linear attenuation coefficient, is a function of density, atomic number, and photon energy.

X is the thickness photon travels.

Therefore, the intensity "I" is a function of original intensity I_0, u, and x.

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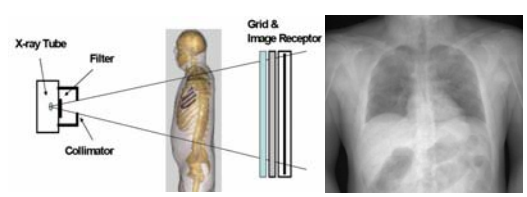
X-ray image



Source: x-ray tube
Detector: film
Physics: attenuation
Factors affecting attenuation: Thickness, density, atomic number, kilo-voltage

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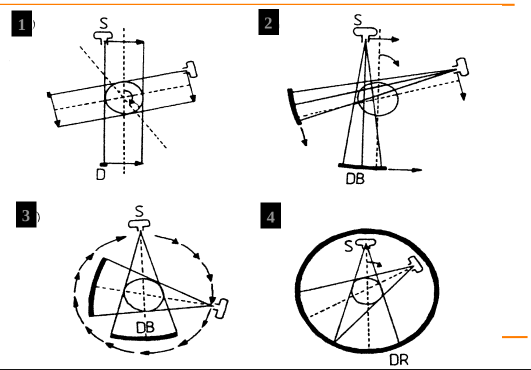
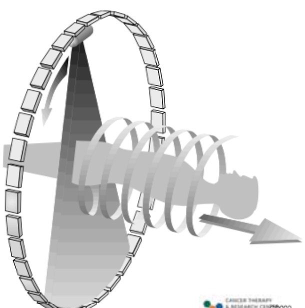
CT Scanner (1st – 4th generation)

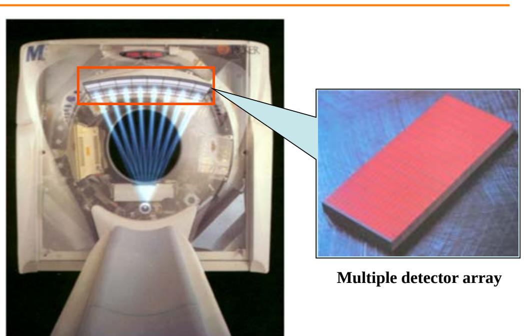


CT Scanner (6th generation)



In spiral, the table advances at a constant speed through the gantry while the x-ray tube rotates continuously around the patient.

CT Scanner (7th generation)



Multiple detector array

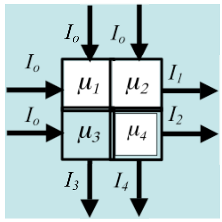
CT image reconstruction

$$M_1 = \ln\left(\frac{I_o}{I_1}\right) = (\mu_1 + \mu_2)x$$

$$M2 = \ln\left(\frac{I_o}{I_2}\right) = (\mu_3 + \mu_4)x$$

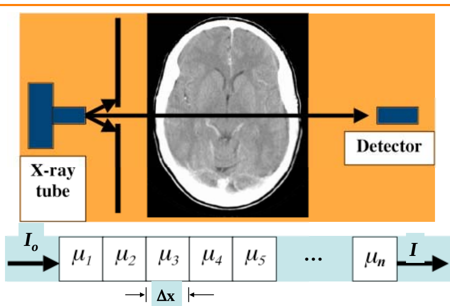
$$M_3 = \ln\left(\frac{I_o}{I_3}\right) = (\mu_1 + \mu_3)x$$

$$M_4 = \ln\left(\frac{I_o}{I_4}\right) = (\mu_3 + \mu_4)x$$



Thus we have 4 equations, 4 unknowns, problem solved.

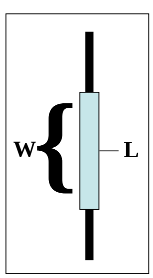
CT process

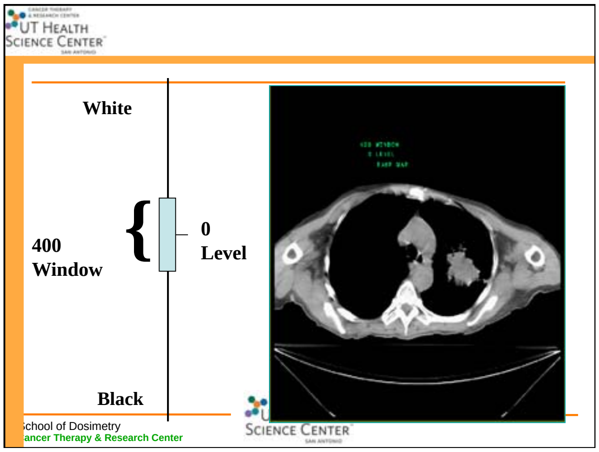


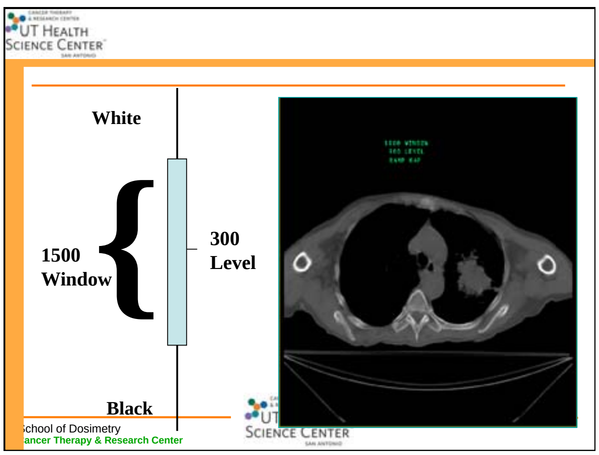
The process has to rotate to get enough equations to solve μ!

CT Window/Level

- **Window Width - the range of**
  - **gray shades in the image.**
- **Window Level - the middle HU**
  - **of the window.**
- **Window adjustments are set in accordance with the structures to be viewed.**







CT Number Definition

$$CT = \frac{\mu - \mu_{water}}{\mu_{water}} \bullet 1000$$

- A measure of the attenuation of the material in each individual voxel
- CT numbers range from approximately -1000 to +1000
- HU of water is 0, HU of air is -1000

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CT number

tissue	approximate CT number	μ (cm^{-1}) at 125 kVp
dense bone	1000	0.46
muscle	50	
white matter	45	0.187
grey matter	40	0.184
blood	20	0.182
CSF	15	0.181
water	0	0.180
fat	-100	0.162
lungs	-200	
air	-1000	0.0003

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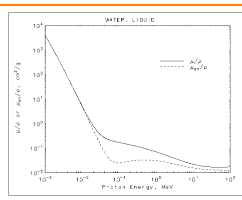
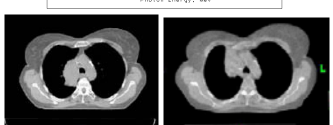
kVCT vs. MVCT

- μ function of photon energy
  - Varies more at lower energies (<100kV)
- kVCT ~40kV
- MVCT ~ 800kV
- kVCT
  - Better soft tissue delineation and contrast
  - Same resolution





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Sample Question

- The fundamental measurement made by CT scanner is:
  - **A.** Sorting of CT numbers
  - **B.** Determination of gray scale
  - **C.** Pixel density
  - **D.** Relative x-ray attenuation
  - E. Voxel atomic number

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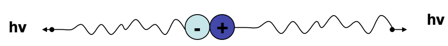
PET – Basic Physics

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta + {}^{0}_{0}v$$

Parent, Daughter, Positron, Neutrino

Positron + Electron = Two 511 keV photons 180 degrees directions



Annihilation reaction

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Commonly used isotopes

Radionuclide	half - life	tracer	application
Fluorine-18	110 mins	FDG, Fluoride ion, Fluoro - mizonidazole	Oncology neurology cardiology
Carbon-11	20 mins	Methionine, flumazenil, raclopride	Oncology Epilepsy Mov't disorders
Nitrogen-13	10 mins	ammonia	Myocardial perfusion
Oxygen-15	2 mins	Carbon dioxide, water	Brain activation studies

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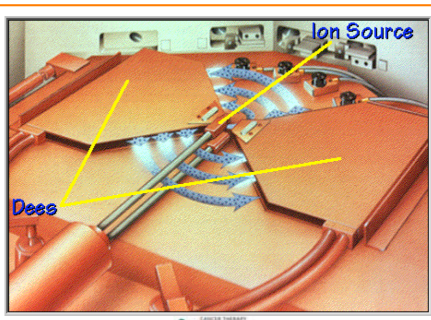
Positron Imaging



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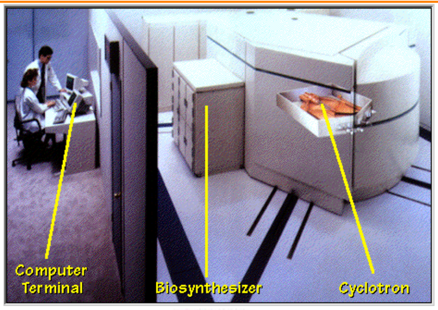
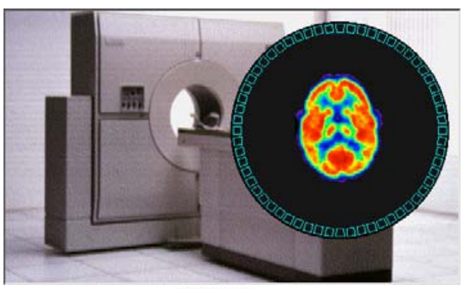
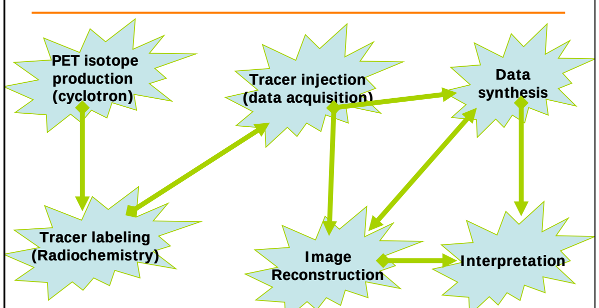
Positron Imaging



Positron Imaging

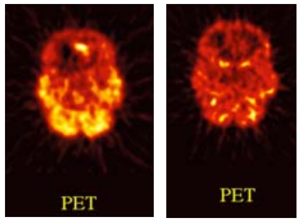


PET – Basic Process

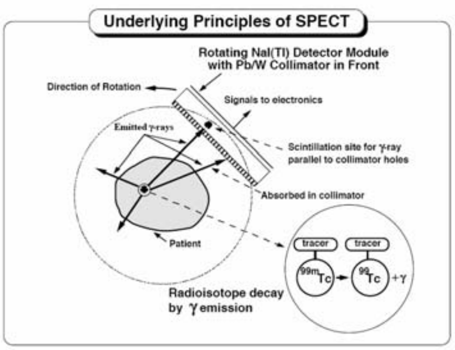


Why PET imaging?

- Provides physiological information
- Pre-RT
  - Assess tumor size
  - Assess tumor location
    - Locate metastases
  - Assess tumor physiological make up
    - Metabolism
    - Hypoxia
- Post-RT
  - Assess treatment response



Nuclear Medicine Tomographic Imaging:
single photon emission computed tomography (SPECT)

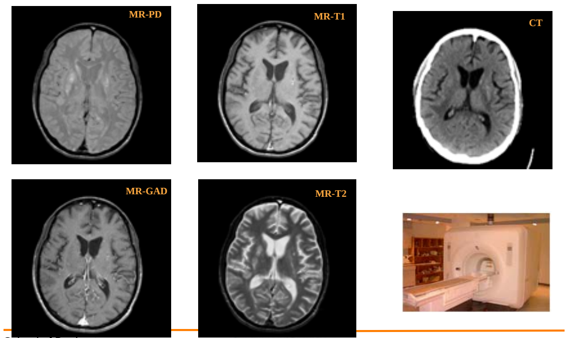


Summary

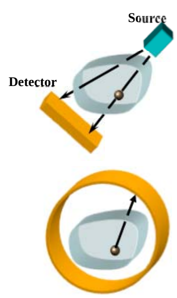
So far we have discussed: x-ray, CT, PET, SPECT. All of those imaging modalities involving radiation either from external source or internal source.

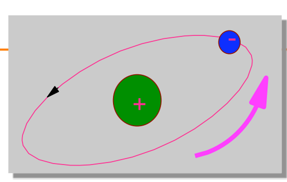
Next we will discuss MRI, ultrasound which are not using ionizing radiation

Magnetic Resonance Imaging



- X-ray
  - Source/detector geometry
  - Projective and computed tomography
- Magnetic Resonance
  - Source of signal from within body
  - 2D and 3D imaging

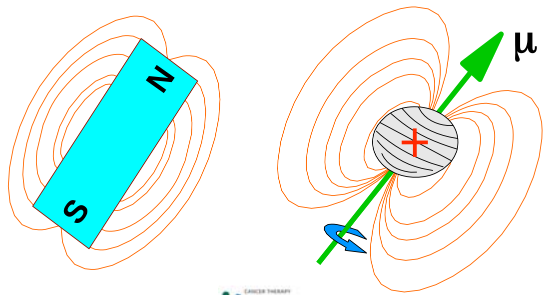




At the atomic level magnetism arises from three sources:

- Electronic Orbital Momentum
- Electron Spin
- Nuclear Spin → Proton Spin, Neutron Spin

Spinning nuclei generate magnetic fields



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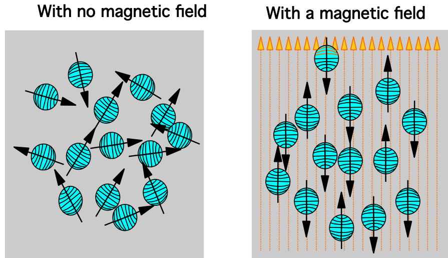
Nuclei Interact with a Magnetic Field

With no magnetic field | With a magnetic field



Nuclei in random orientations | Nuclei align to the applied field

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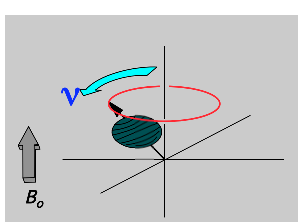
Individual Nuclei Process about the Applied Field



The precession frequency is given by the Larmor Equation:

$$\nu = \frac{\gamma}{2\pi} B_o$$

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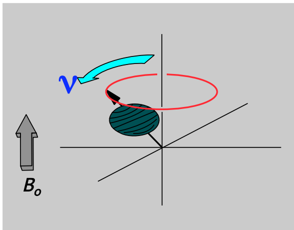
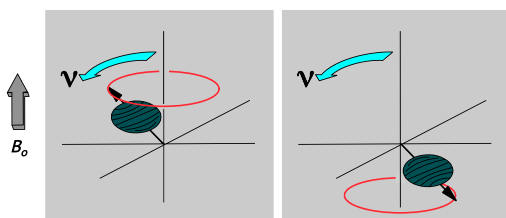
Individual Nuclei Process about the Applied Field



Note: Unlike a gyroscope, the angle of precession is quantized.

Some nuclei align with the magnetic field and some align against it

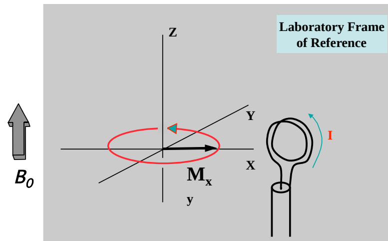


$M_I = +1/2$ $M_I = -1/2$

Resonance

- If you apply energy of the correct frequency to any system you get absorption
  - The opera singer and the glass trick!!
- If you apply energy of the correct frequency to nuclei they resonate and absorb
  - *i.e.*... some jump from the lower "ground" state to a higher of "excited" state
- The resonance frequency is called the Larmor frequency

Energy emission: a classical physics view



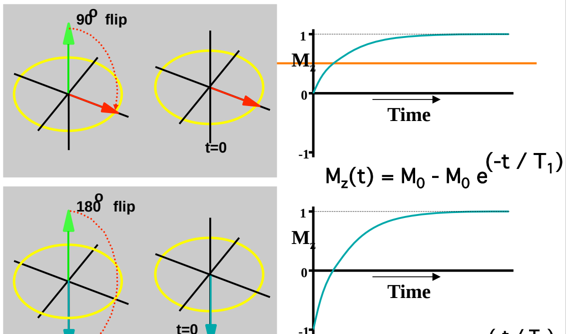
Rotating transverse magnetization induces currents in a pick-up coil

Why the Proton is used for Imaging

- The proton has the highest gyromagnetic ratio of all the natural nuclei
  - Therefore the strongest signal
- Protons are present all over the body
  - Water, Fats (lipids)
- There are a lot of protons
  - Each cubic mm of water has about 2 x10^{22} protons
  - *i.e.* 20,000,000,000,000,000,000,000

Relaxation

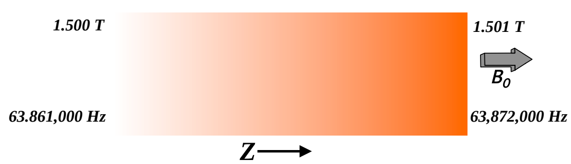
- After RF excitation, magnetization returns to equilibrium
  - This is called RELAXATION
- Different tissues relax at different rates
- Liquid like tissues, e.g. CSF, relax slowly
  - “Soft” materials like fat relax quicker
  - “Hard” materials like bone relax too fast to be seen
  - In general pathological tissue relaxes slower that normal tissue
- Relaxation is described in terms of two relaxation times:
  - T_1 is also called “Spin-lattice” or “Longitudinal” relaxation
  - T_2 is also called “Spin-spin” or “Transverse” relaxation



$$M_z(t) = M_0 - M_0\, e^{(-t / T_1)}$$

$$M_z(t) = M_0 - 2M_0\, e^{(-t / T_1)}$$

A Field Gradient Makes the Larmor Frequency Depend upon Position



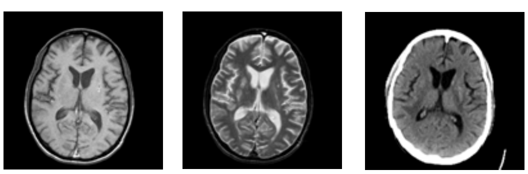
Gradient in Z

$$B(z) = B_o + G_Z * z$$

$$\nu = \frac{\gamma B}{2\pi}$$

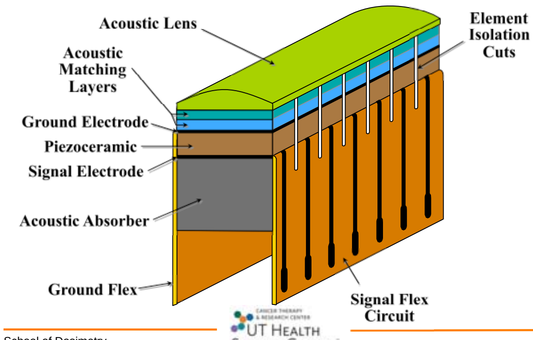
Sample Question

- Indicate which is a T2-weighted MR image



A B C

Ultrasound Transducer Structure



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Linear

Convex

Intraoperative

Vaginal / Rectal

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Physics of Ultrasound

$$v = \lambda f$$

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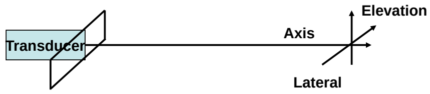
Resolution Determination

Axial Resolution: Spatial Pulse Length (SPL)/2
Lateral Resolution: diameter/2
Elevation Resolution: 1.5D with 5~7 rows



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DICOM

- Digital Imaging and Communications in Medicine (DICOM) is a standard for handling, storing, printing, and transmitting information in medical imaging
- DICOM enables the integration of scanners, servers, workstations, printers, and network hardware from multiple manufacturers into a picture archiving and communication system (PACS)
- Standardizes all image formats
  - CT, MR, NM, US, DR, Film
- In Radiation Oncology, similar format for plans
  - DICOM RT

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PACS

- Picture archiving and communications systems (PACS)
- Computers or networks dedicated to the storage, retrieval, distribution and presentation of images
- PACS has two main uses:
  - **Hard copy replacement**:
    - Replaces hard-copy of managing medical images, such as film archives,
    - Provides a growing cost and space advantage over film archives
    - Instant access to prior images at the same institution
    - Able to manipulate data
  - **Remote access**
    - Provides capabilities of off-site viewing and reporting (distance education, telediagnosis).
    - Enables practitioners in different physical locations to access the same information simultaneously for teleradiology

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Questions?

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