Biomedical Imaging & Analysis

Lecture 4, Part I. Fall 2014

Image Formation & Visualization (III):

Contrast Agents. Ultrasound.

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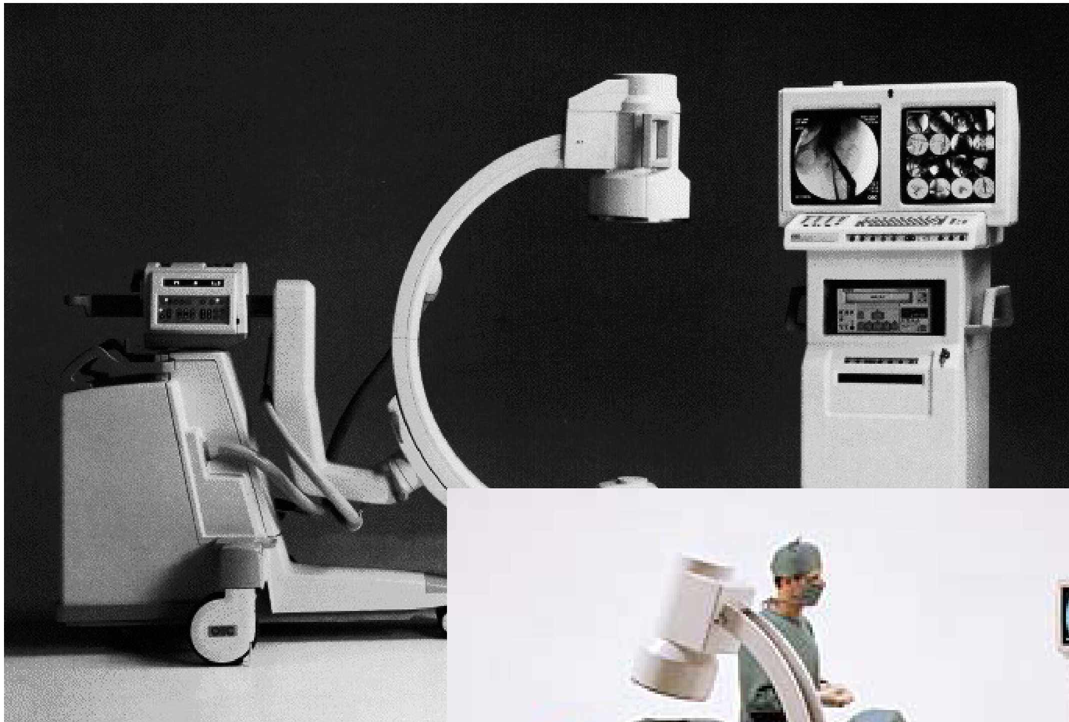
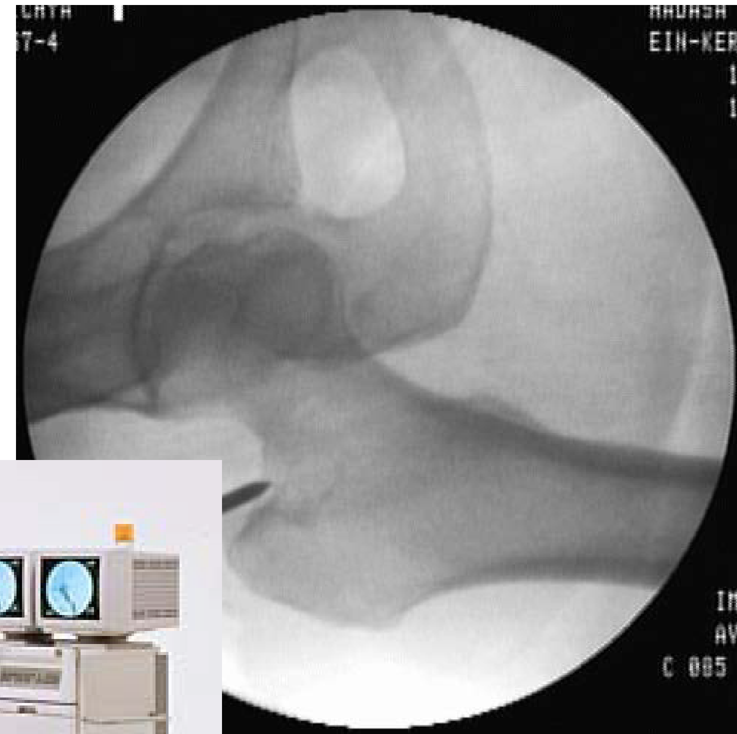
X-ray fluoroscopy

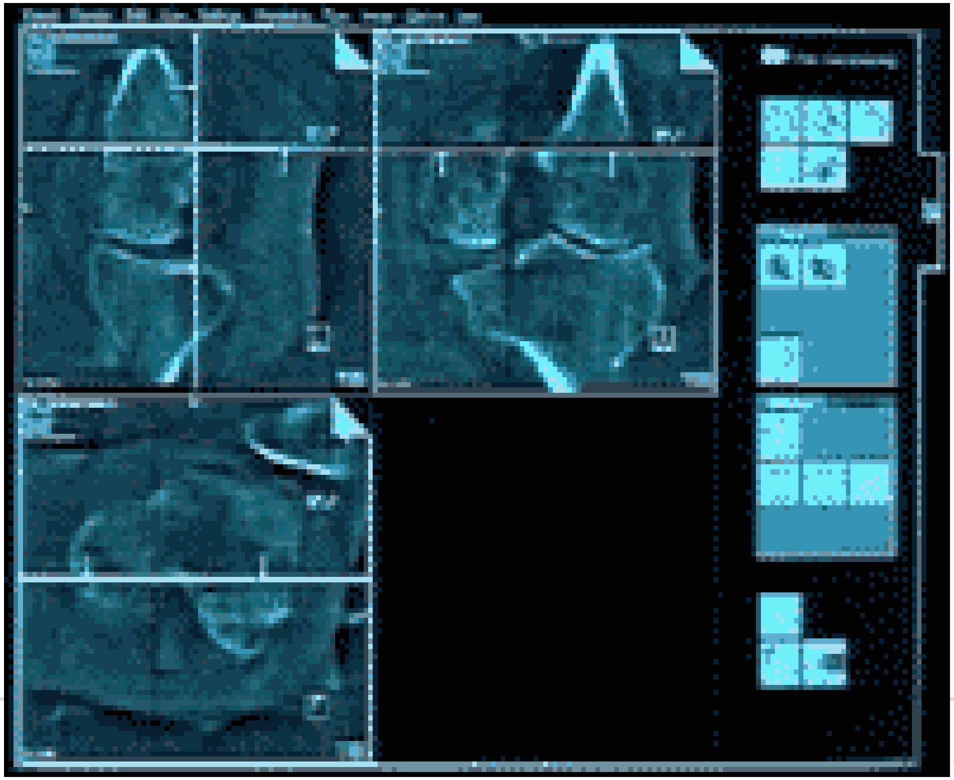




X-ray mammography

A_1528_1.LEFT_MLO A_1528_1.RIGHT_MLO

3D X-ray fluoroscopy (Iso3D C-arm)



X-ray imaging with **contrast agent**

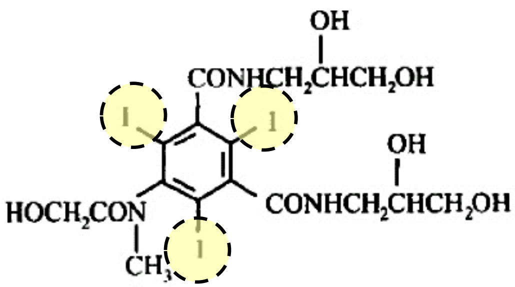
X-ray **contrast agents** ?

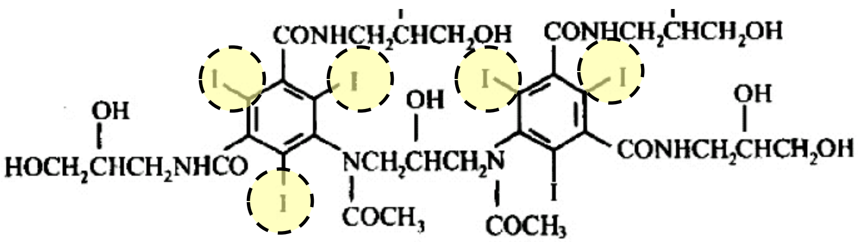
Exogenously administered substance (by infusion/ingestion)

modifying Z_{eff}

$\Rightarrow$ use high Z compounds

e.g., compounds with multiple iodine atoms, lanthanides etc.





Z_{eff} of (water+10 mmol/kg iodine) = ?

Iodine:

P_I = 10[mmol/kg]×127[mg/mmol] = 0.127%

Z_I = 53

A_I = 127

Calculation of Z_{eff}:

$$\lambda_i = \frac{P_i Z_i / A_i}{\sum_{\substack{\text{all tissue}\\ \text{components } j}} P_j Z_j / A_j}$$

Denominator of λ :

~ denominator λ of pure H_2O

$\rightarrow$ λ of H and O are as for water:

λ_H=0.2

λ_O=0.8

$$\lambda_I = \frac{0.127 \cdot 53/127}{55.6} = \frac{0.053}{55.6} = 9.5 \times 10^{-4}$$

$$Z_{eff}^{3.4} = \underbrace{0.2 \cdot 1^{3.4} + 0.8 \cdot 8^{3.4}}_{944} + \underbrace{9.5 \cdot 10^{-4} \cdot 53^{3.4}}_{690}$$

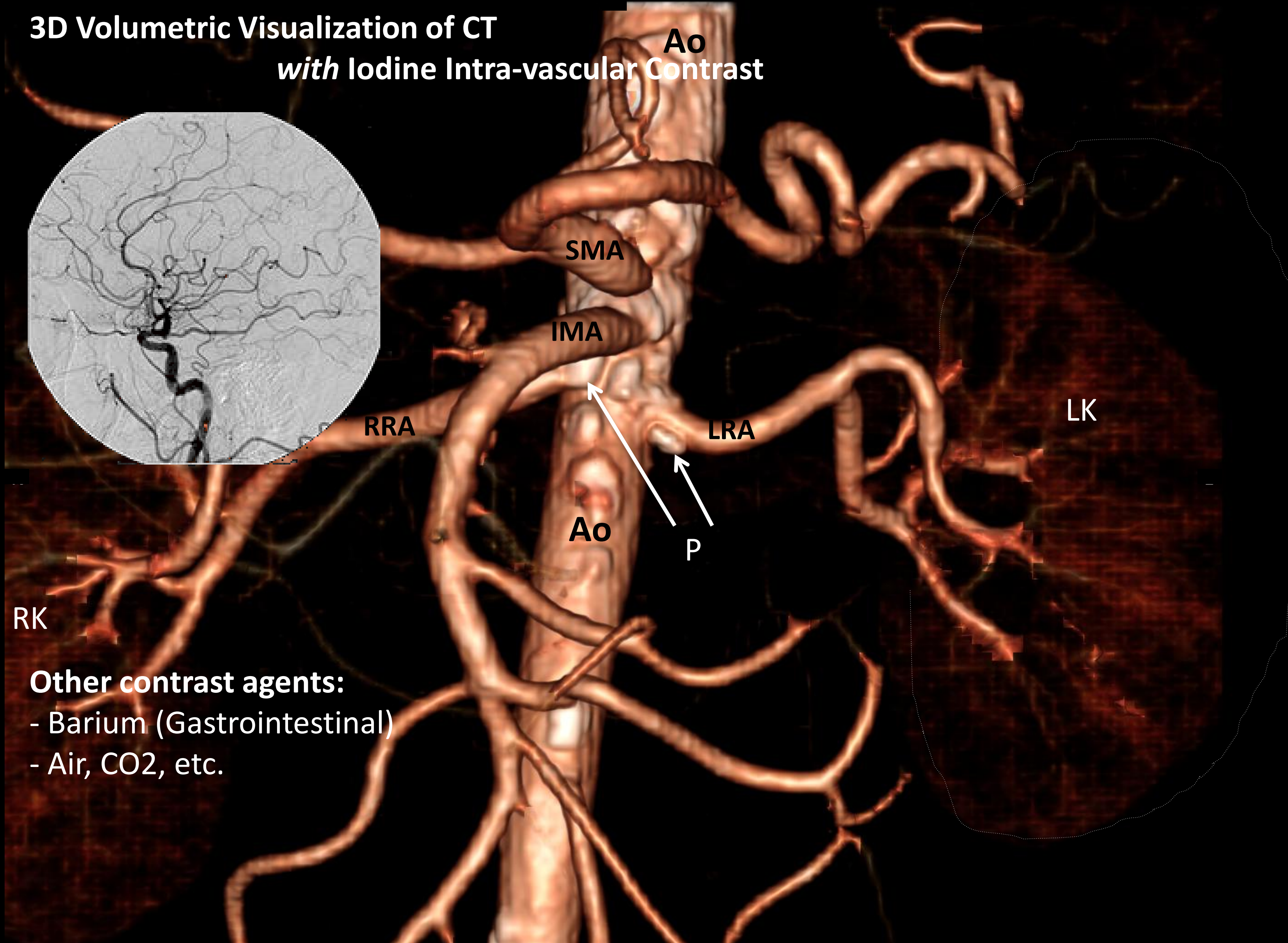
$$Z_{eff} = 8.8$$

$\mu_{PE} \propto Z_{eff}^{3.4}$

$\mu_{PE}(H_2O) \propto 944$

$\mu_{PE}(H_2O+I) \propto 1650$

3D Volumetric Visualization of CT *with* Iodine Intra-vascular Contrast



Other contrast agents:
- Barium (Gastrointestinal)
- Air, CO2, etc.

Wikipedia page: *http://en.wikipedia.org/wiki/Radiocontrast_agent*

X-Rays: CT

- 360 degrees of radiographs are taken and backprojected to form 2d image
  - These are stacked to form a full 3d volume (modern collection actually uses a helix pattern)
  - Filtered backprojection corrects for blurriness of simple recon
- Units are normalized to water LAC: HU = $(mu - mu_{water})/mu_{water} * 1000$
  - LACs depend on x-ray energy
- Be familiar with general ranges of HU for various tissues
- Windows and levels for CT give range of visible contrast
  - Bone window: W = 2500, L = 1000
  - Soft tissue window: W = 600, L = -100
- Contrast is already normalized: C = A - B
- Typical resolution: 1-2 mm x 1-2 mm in plane
- X-Ray dose is much higher than for radiograph (why?)

Radiographs: What's bright?

- Radiographs: Bright means less film exposure
  - More attenuation has occurred, either from going through more tissue, or higher Z material (bone, metal, etc)
- CT: Bright means high LAC
  - Cortical bone will always be bright, Iodine is bright because of high Z

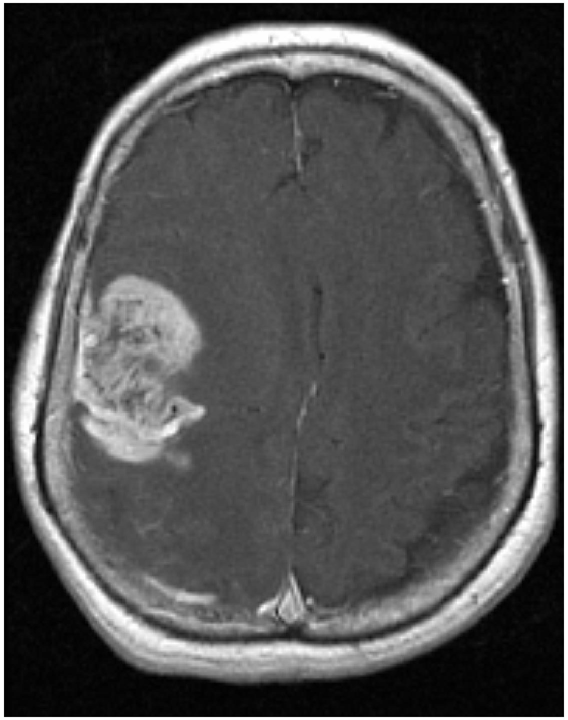
Radiographs: What's dark?

- Radiographs: Dark means more film exposure
  - Less attenuation has occurred, from going through mostly air
- CT: Dark means low LAC
  - Low density (low Z) materials will be darker, tissues are mostly similar to water, fat is slightly darker

CT tumor imaging with Contrast

In Healthy Brain, Blood Brain Barrier Prevents Large Molecules from Entering Brain.

trast



Contrast leaks into tumor because BBB is disrupted.

MRI **tissue specific contrast**: What's bright/dark?

- MRI: Brightness depends on contrast of scan induced by pulse sequence.
- More "rigid" materials generally have shorter T1 and T2 :
  - In proton density map, brightness is similar across many tissues (eg: white-matter of the brain is ~20% darker than most tissue.)
  - In T1 weighting, anything with short T1 will recover signal more quickly and will be brighter → more "rigid" things will be brighter → white matter brighter than gray matter.
  - In T2 weighting, anything with short T2 will decay more quickly and be darker → more "fluid" things will be brighter → Cerebro-spinal fluid is brightest, gray matter is brighter than white matter.
- Fat has a short T1 and T2.
- Cortical bone has T2 that's so short it always decays completely before we can make a measurement -> always dark.

Gadolinium Contrast - **MRI**

- Adding Gadolinium to the blood drastically reduces T1:

Gd^{3+} is toxic, so for *in vivo* use it's wrapped up in a kind of non-toxic jacket, called a chelate molecule, such as DTPA.

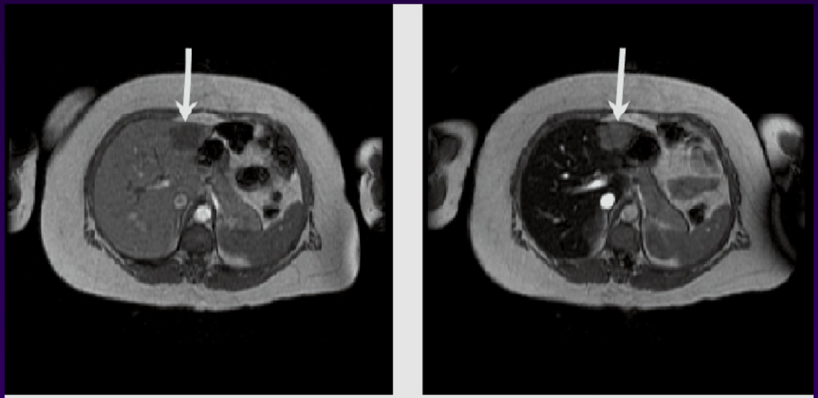
But Gd^{3+} has seven unpaired electrons, and the interaction of the electron spins with an external magnetic field (electron spin resonance) is equivalent to that of nuclear magnetic resonance.

g levels of Gd

MRI Contrast Agents

- Gadolinium (Gd)
  - Large paramagnetic susceptibility: 7 unpaired electrons (dipole)
  - Arterial, rapidly redistributes into extracellular fluid ($T_{½}$ = 11 min)
  - Shortens T1, so enhanced signal on post-contrast T1-w images
- SPIO (Super Paramagnetic Iron Oxide)
  - Reduces T2 → lower intensity on T2-w or T2*-w images
  - Liver/spleen imaging
  - Lower normal tissue signal → pathological tissue enhanced

Pre and Post-SPIO Contrast Images



igure 3.15 (a) Pre-SPIO and (b) post-SPIO T_2^*-weighted images of a metastatic liver tumour.

c.f. McRobbie, et al. MRI from Picture to Proton, 2nd ed., p. 44.

Pre and Post-Gd Contrast Images

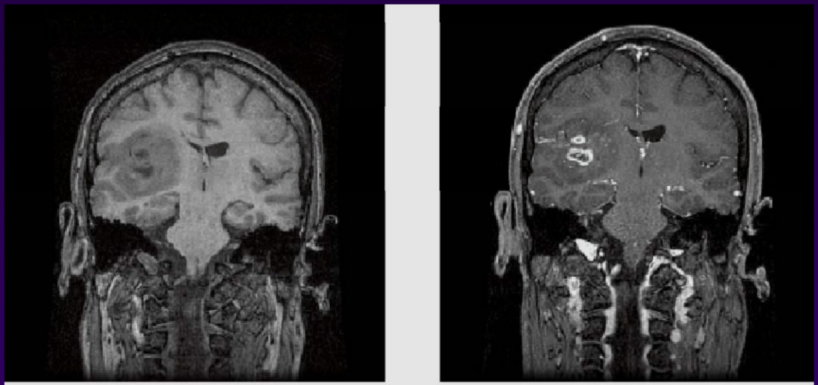


Figure 3.14 (a) Pre-Gd and (b) post-Gd SE T_1 images of a high-grade glioma.

c.f. McRobbie, et al. MRI from Picture to Proton, 2nd ed., p. 43.

MRI Contrast – Playing with T1, T2 relaxation, adjusting B_0, RF timings - TR, TE etc.

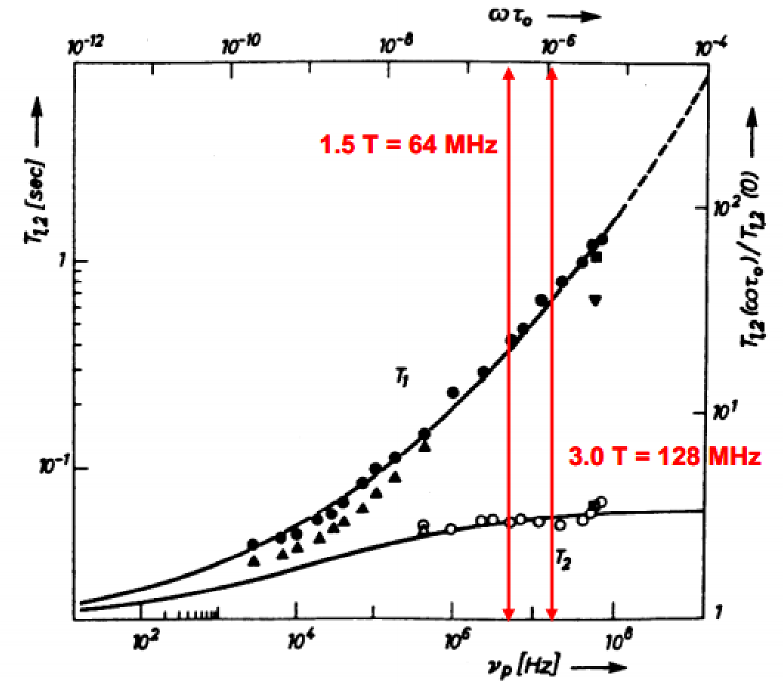


FIG. 2.5. Proton spin–lattice (T_1) and spin–spin (T_2) relaxation times in frog muscle as a function of frequency. (a) *Rana esculenta*: ●, T_1 at 25°C; ▲, T_1 at 0°C; ○, T_2 at 25°C; △, T_2 at 0°C. (b) *Rana pipiens*: ■, T_1 at 25°C; ▼, T_1 at 0°C; □, T_2 at 0 and 25°C. (c) Curves are theoretical fits to Eqs. (3a)–(3c) of Reference 41 with $\tau_0 = 1.1 \times 10^{-14}$ sec, $\alpha = 0.15$, and $T_1(0) = T_2(0) = 1.8 \times 10^{-2}$ sec. [From G. Held, F. Noack, V. Pollak, and B. Melton, *Z. Naturforsch*. **28c**, 59 (1973).]

c.f. Mansfield, et al. NMR Imaging in Biomedicine, 1982, p. 23

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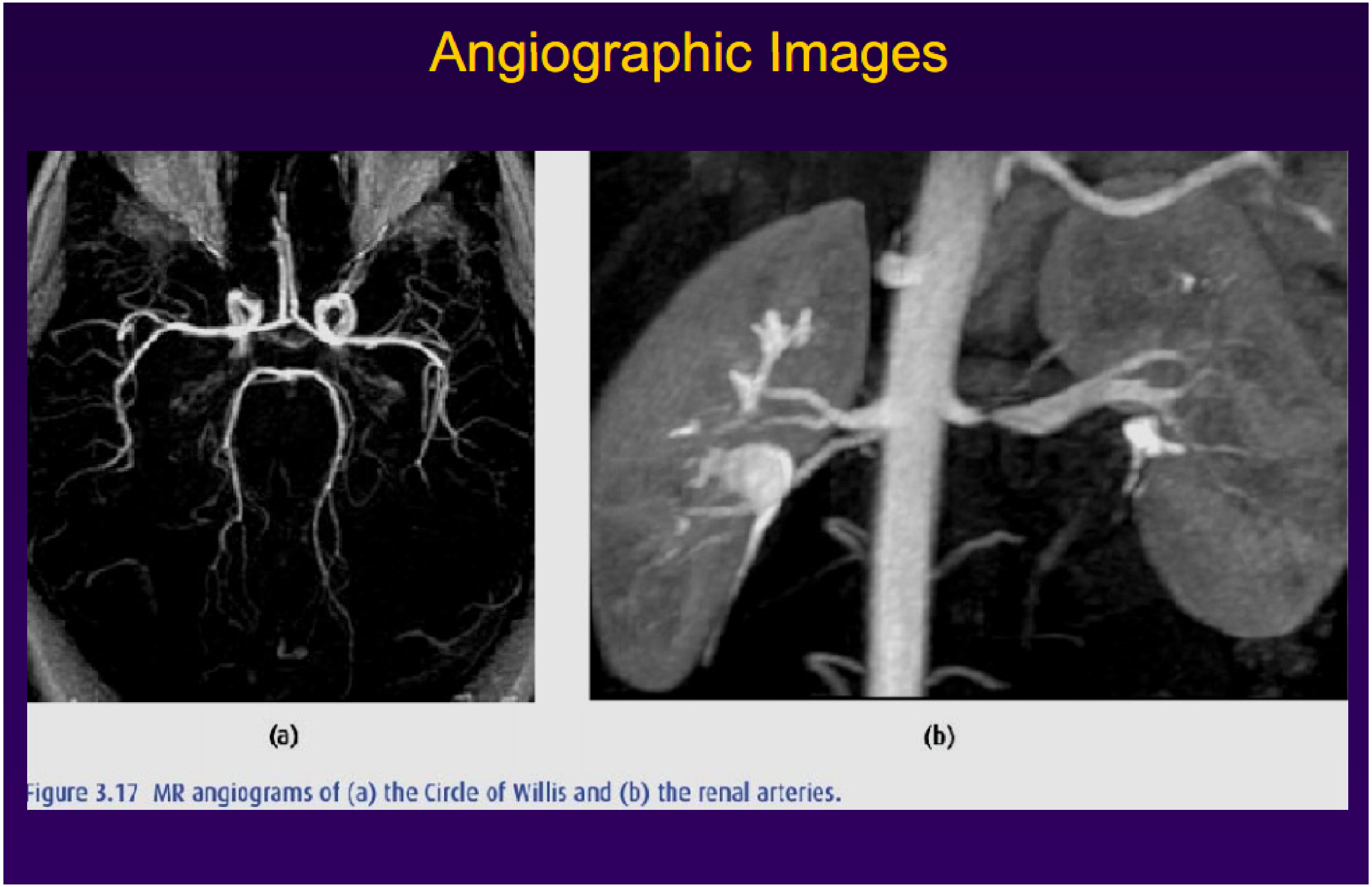


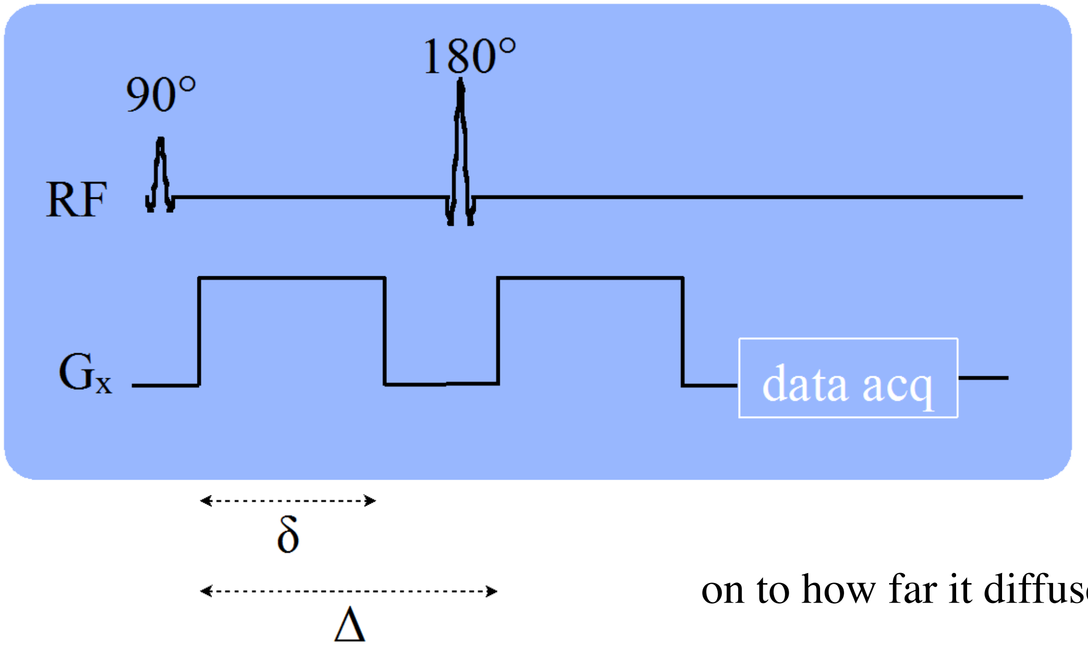
Figure 3.17 MR angiograms of (a) the Circle of Willis and (b) the renal arteries.

Angiography

- Iodine contrast for CT
- Gadolinium contrast for MRI
- MRI can also use time of flight as a means to accentuate non-contrast.

Diffusion Weight MRI Gradients

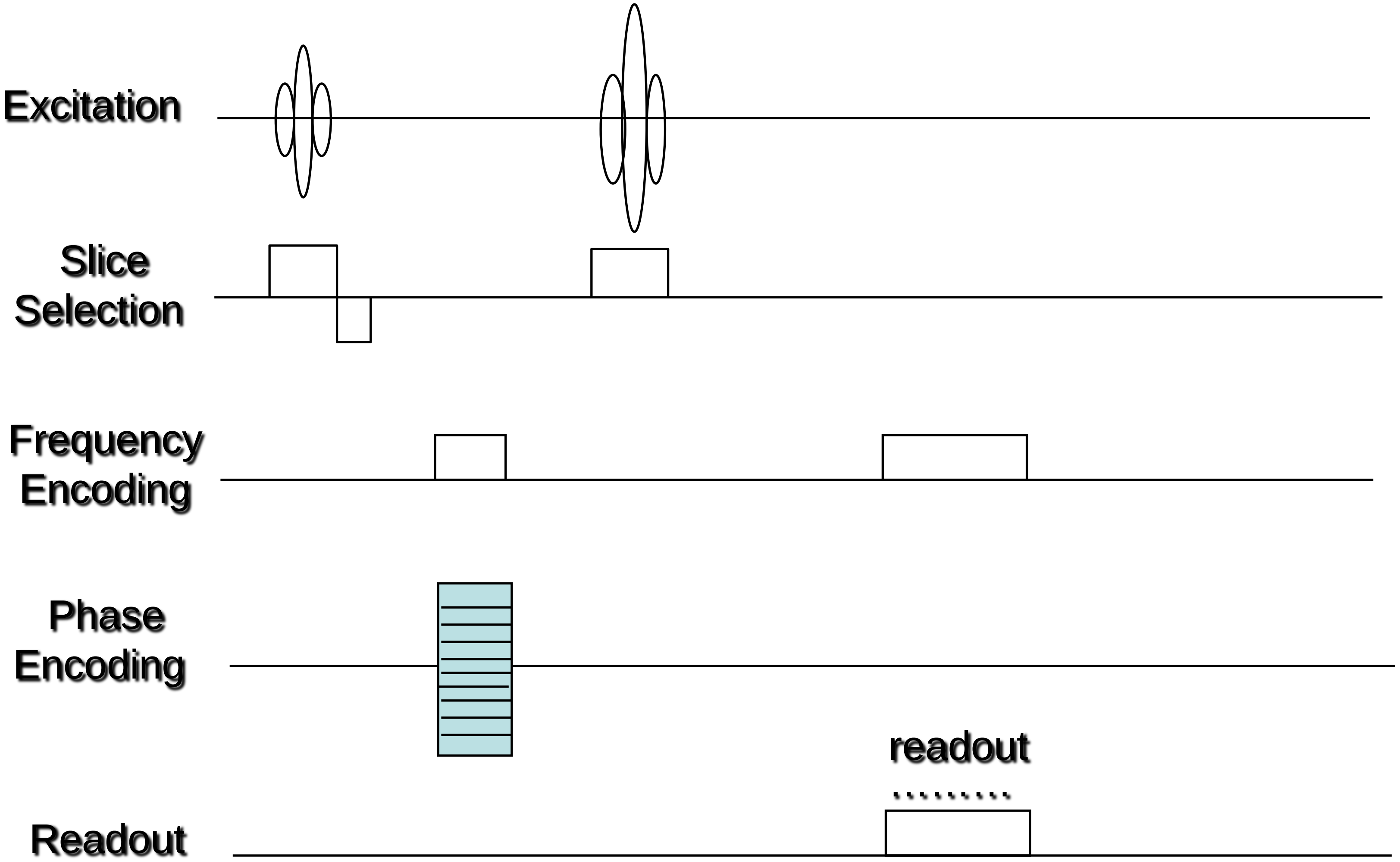
- Create an inhomogeneous magnetic field with big gradients



on to how far it diffuses and the applied gradients

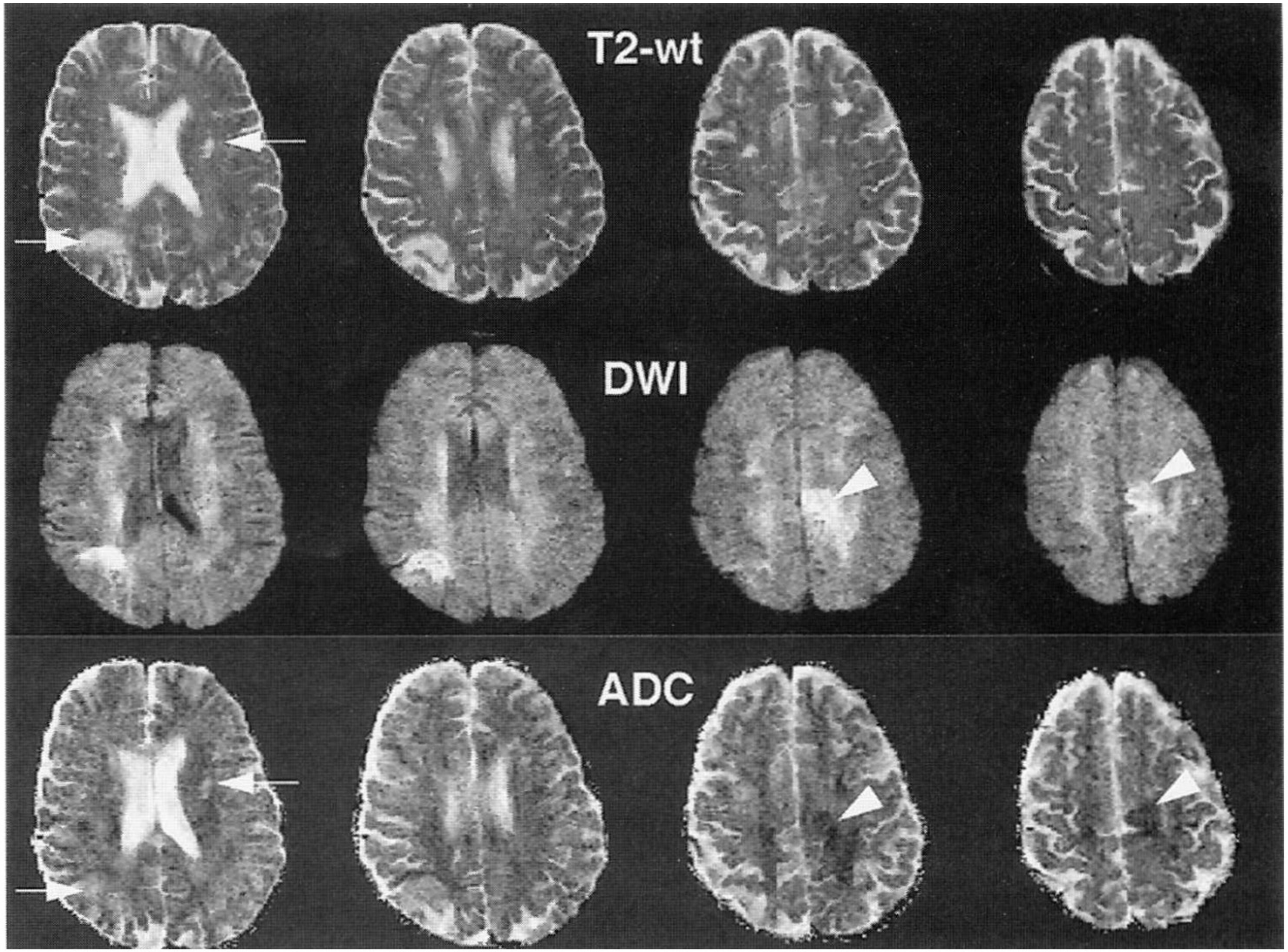
$$f = \gamma B$$

Recall Pulse Sequence: **Spin-echo MRI**



Diffusion Weighting Helps Visualize Stroke

old strokes necrosis

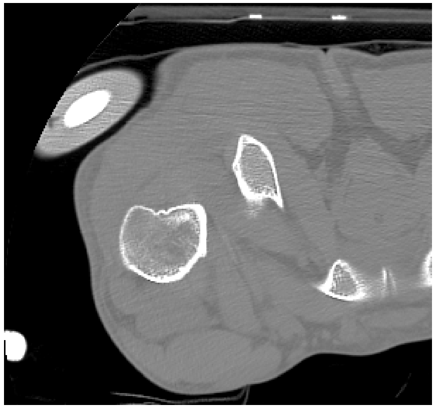


new stroke

Physics of imaging modalities

CT-Scanner

Density of
X-Ray
absorption

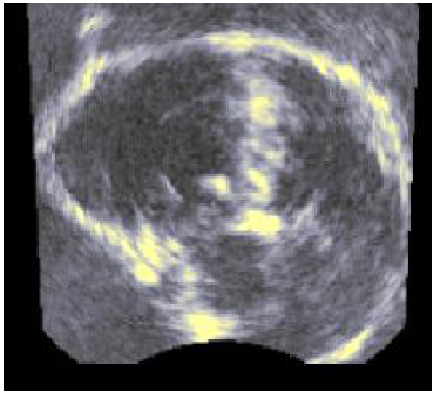


MRI

Density and
structure of
protons

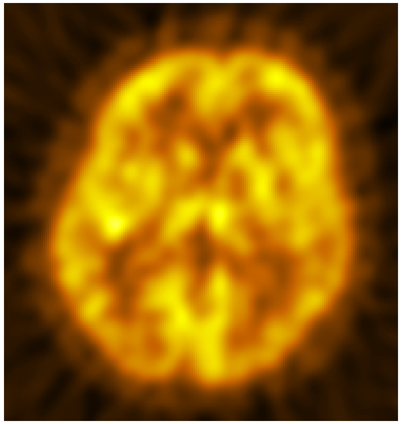
Ultrasound

Variations of
Acoustic
Impedance



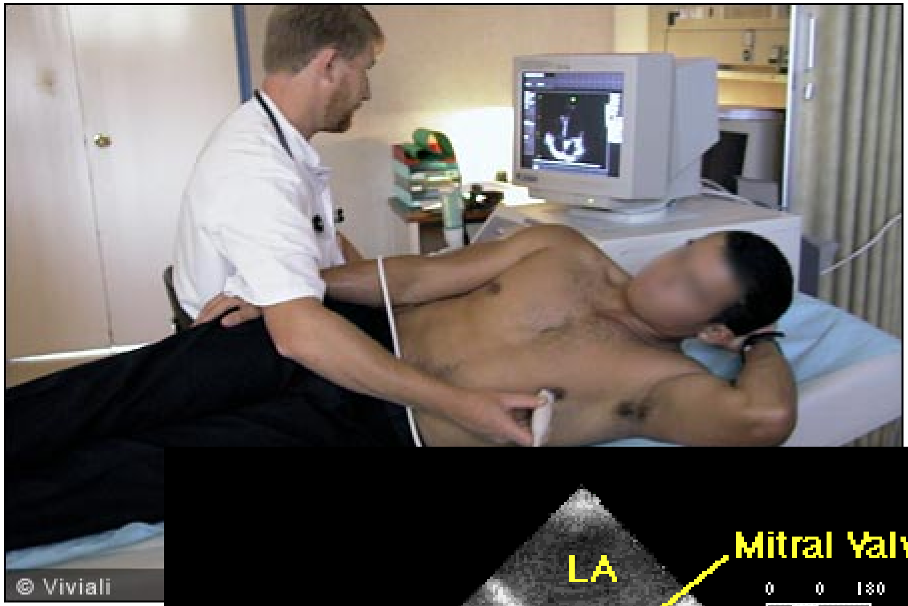
Scintigraphy

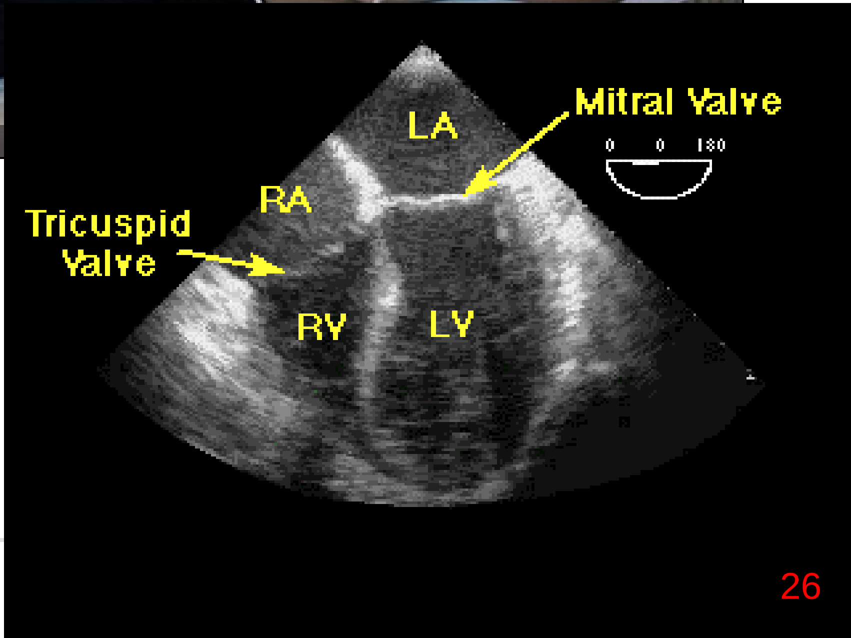
Density of
injected
isotopes



Ultrasound:

Physics meets Clinic (Part III)





Ultrasound:

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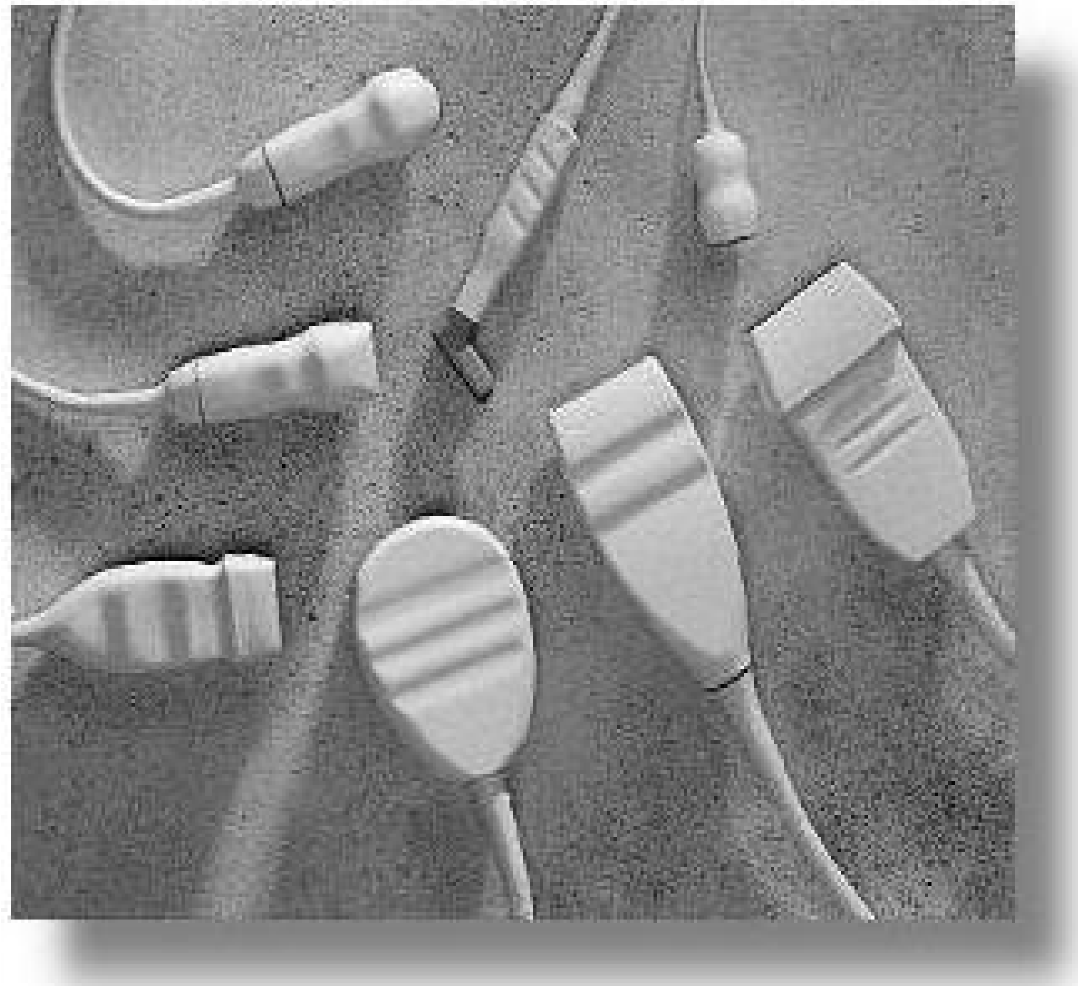


Ultrasound Basics

Ultrasound

- sound waves with frequencies above the normal human range of hearing.

Sounds in the range from 20-100kHz

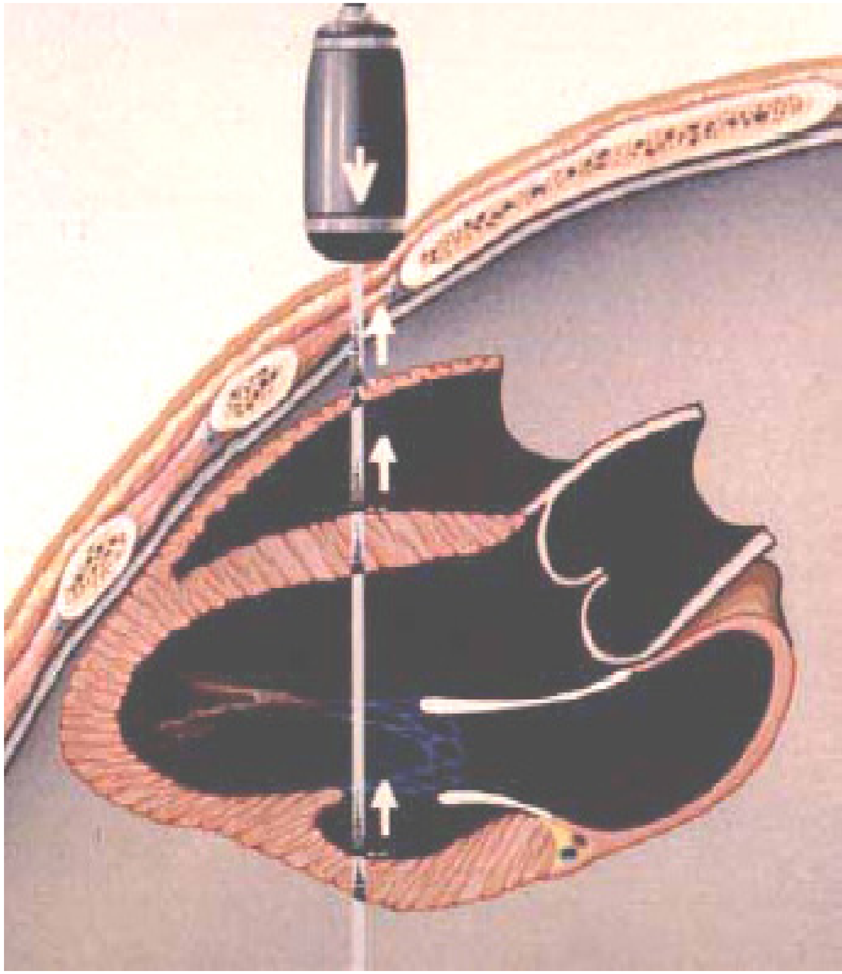
Infrasound

- sounds with frequencies below the normal human range of hearing.

Sounds in the 20-200 Hz range

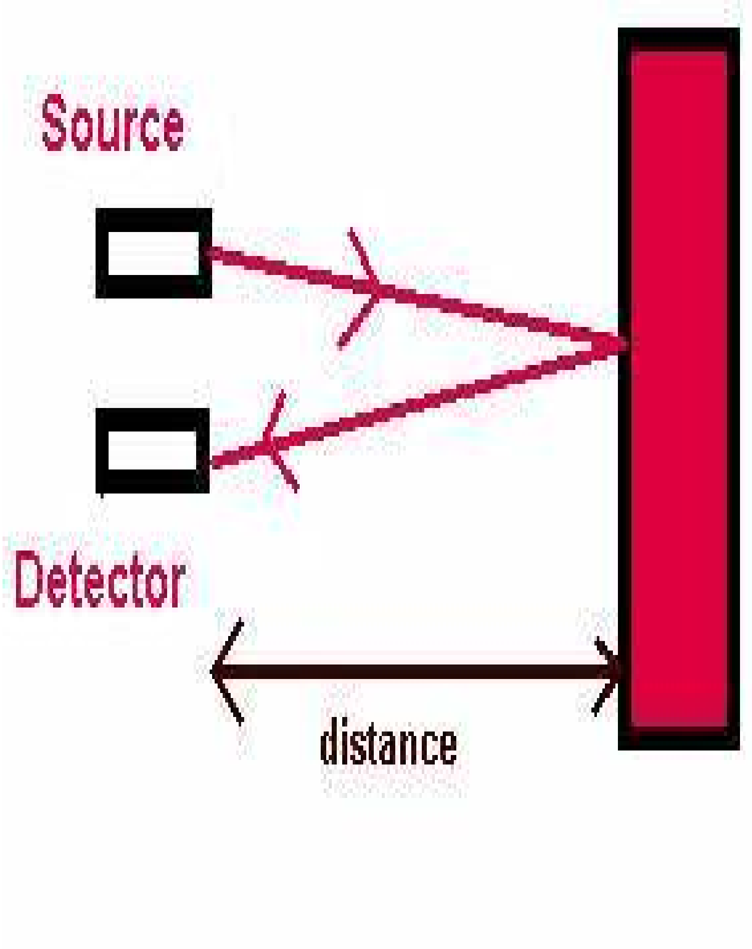
Ultrasound: **Principle**

- Probe sends high-frequency (1-10Mhz) sound waves into body
- Sound waves travel into tissue and get reflected by boundaries
- Reflected waves recorded by probe
- Time of flight gives spatial info of the boundaries
- Frequency of signal depends on a tradeoff: resolution v/s attenuation .



Basic Premise

- The principles of ultrasound are that a pressure wave (ultrasound) is transmitted into the body and the reflected wave is detected
- The time interval between transmission and reception give the distance to the reflector
- Sound is transmitted as a short pulse
- Time of return α distance of reflecting surface from probe
  - Spatial encoding



Ultrasound **Transducer**

- **Piezoelectric** – an alternating voltage across the crystal causes it to flex and contract, emitting sound.
- Piezoelectrics also generates alternating voltage in response to a returning sound wave.
- It emits sound waves and receives them.

US Transducer Coordinate System

- The spatial coordinate system used to describe the field and resolution of an ultrasound transducer array.