

Source: uhrad.com.

Medical Imaging

“Seeing Through the Human Body”

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History of medicine

- From humours...

Until 19th century western medicine was based on Galen's theory of humours, or principal fluids: black bile, yellow bile, phlegm (strange liquid related to tumors), and blood

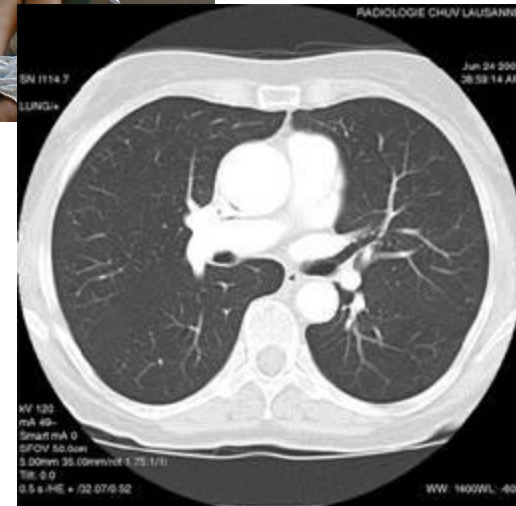


- ...to auscultation

Stethoscope: Laennec in 1816



- ... and imaging



XIXth century: first X-ray image (W.C. Röntgen)

1895: presentation at the Academy of Science



Röntgen's wife



Von Kolliker

History of Medical Imaging

X Ray

- **1895**: Discovery of X-ray by **Wilhelm Conrad Röntgen**, german physicist.
- **1972**: First scanner set up by **Allan Mc Cornack** et **Godfrey N. Hounsfield**, Nobel prize in 1979 for this work.

US

- **1915**: Ultrasound propagation principles for SONAR (SOund NAVigation Ranging).
- **1955**: First echography by **Inge Edler** (1911-2001), swedish cardiologist.

MRI

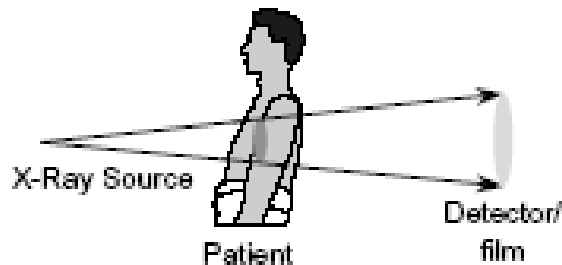
- **1945**: Discovery of nuclear resonance under a magnetic field by **Edward Purcell** and **Felix Bloch**, both nobel prize winners in 1952.
- **1973**: First MRI image on an animal by the american chemist **Paul Lauterbur**. P. Lauterbur and P. Mansfield won the Nobel Prize for Physiology or Medicine in 2003 for the development of MRI.
- **1980**: Spectroscopy by magnetic resonance.

Nuclear

- **1934**: Discovery of natural radioactivity by **Henri Becquerel**, **Pierre** et **Marie Curie**. Discovery of artificial radioactivity by **Irène** et **Frédéric Joliot-Curie**
- **1990**: Nuclear medicine development with scintigraphy and positron emission tomography.

Terminology

- **Transmission:** Photons passing through the body
- **Absorption:** Partial or total absorption of energy in the patient
- **Scatter:** Radiation diverted in a new direction



Source: Utrecht University, NL

- **Axial** - plane normal to a vector from head to toe.
- **Coronal** - plane normal to a vector from front to back
- **Sagittal** - plane normal to a vector from left to right.
- **Oblique** – otherwise.

Image types

- 2D:
 - Single slice.
 - Projection image.
- 3D:
 - Series of parallel slices with uniform spacing.
 - Series of slices with varying spacing and/or orientation.
 - Volumetric data set.

Imaging Support



**Films
(hard copy)**



**Digital Display
(soft copy)**

Imaging Modalities

- X-Ray:
 - Traditional
 - Computerized Tomography (CT)
- Ultrasound (US)
- Magnetic Resonance Imaging (MRI)
- Nuclear Imaging
- Optical imaging
- ...

Images are computed.

The image is not the reality!



X-rays



CT



Ultrasound



MRI

etc.

A lot of differences

- Physical principles (important to correctly interpret the images!)
- Irradiation
- Resolution
- 2D / 3D
- Slice / projection
- Temporal sequences
- Differentiation of tissues
- Anatomy / function or metabolism
- Instrumentation
- ...

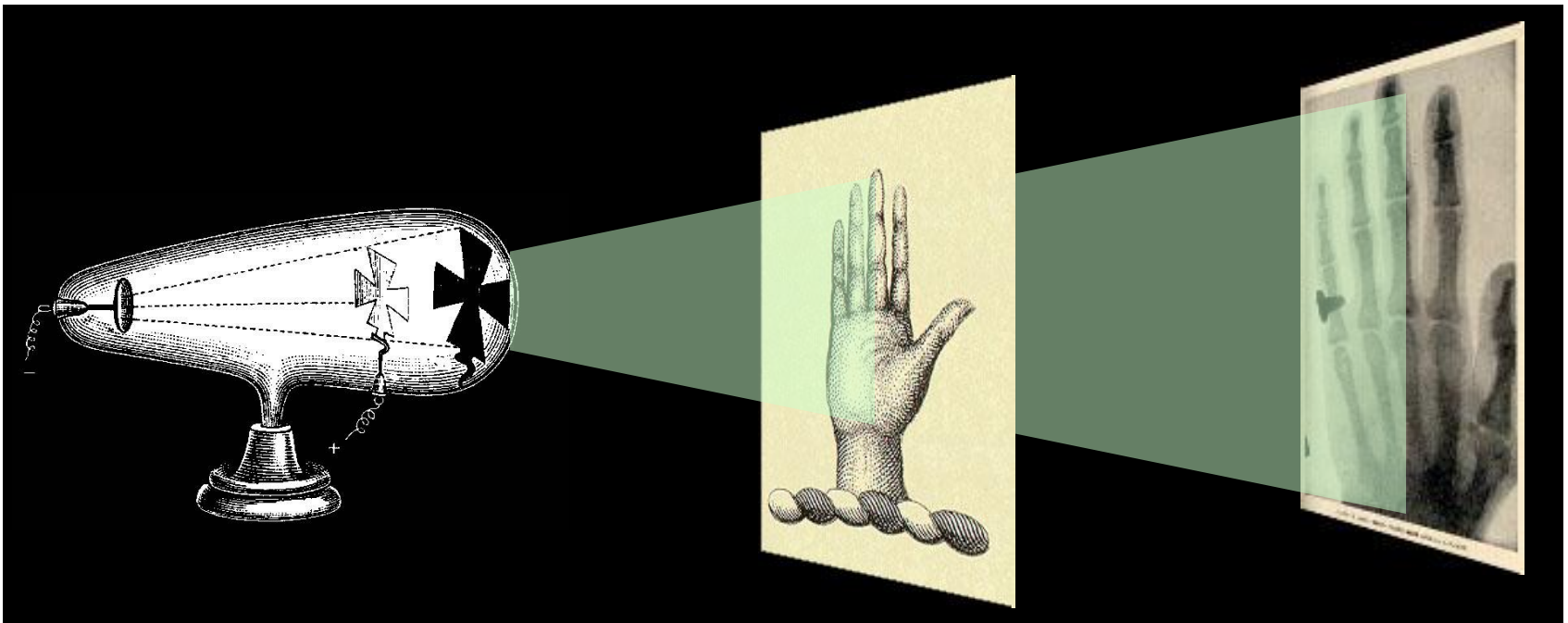
Research in image processing and understanding for medical applications

- Reconstruction
- Improve image quality
- Organ detection, classification, segmentation, recognition
- Pathology detection and recognition
- Quantitative measurements
- Modeling
- 3D visualization
- Registration and information fusion
- Functional analysis, neurosciences
- Aid to diagnosis, therapeutical or surgical planning
- Follow-up
- ...

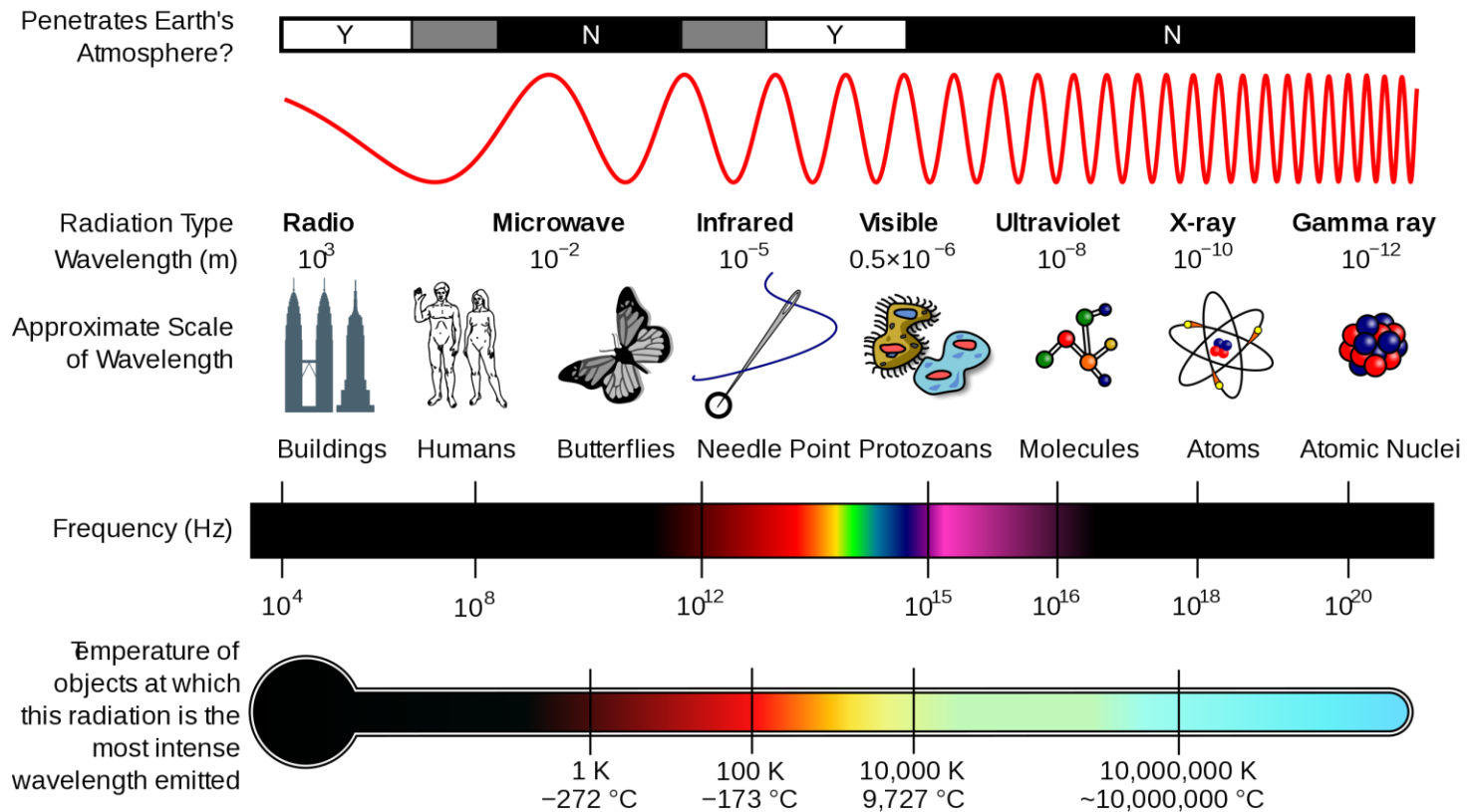
Complex and multi-disciplinary domain

- Physics
- Mathematics
- Computer science
- Biology
- Medicine, anatomy
- Neuroscience, psychology
- Clinical studies and research
- Strong interaction and communication needed among actors
- And the patient ...

Principle of X-ray imaging



Electromagnetic spectrum



Source: Wikipedia

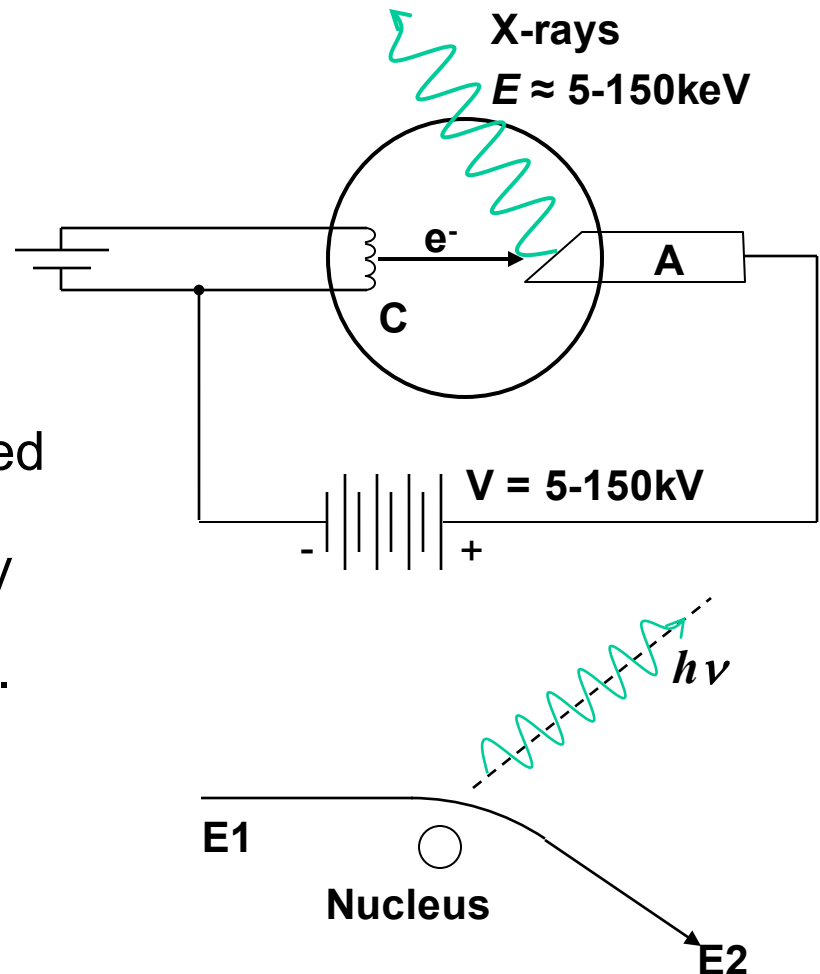
Conventional X-Ray



Conventional X-Ray

Physics Principles

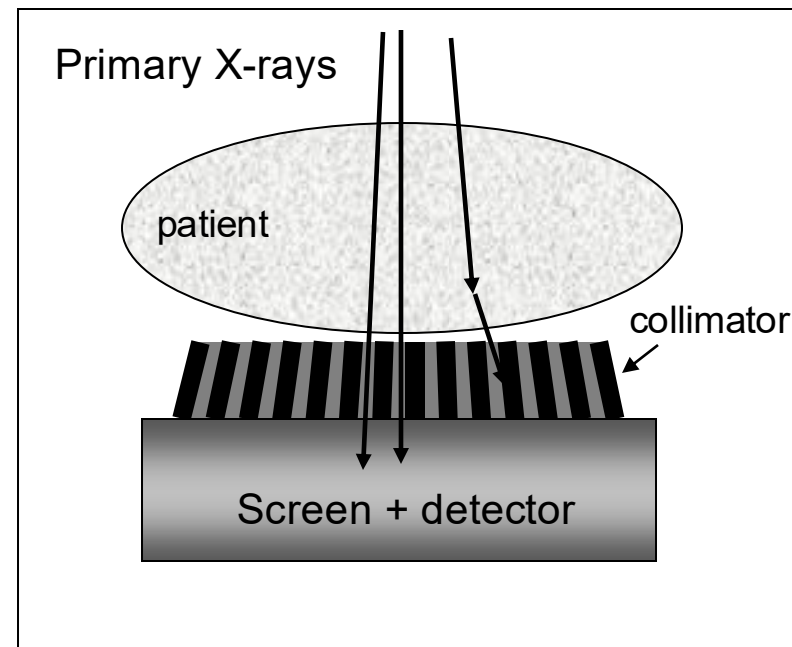
- Accelerating & decelerating electrons generate electromagnetic radiation
- Bombardment of a target material with a beam of fast electrons
- Electrons are emitted thermally from a heated cathode (C) and are accelerated toward the anode target (A) by the applied voltage potential V ($\sim kV$).
- Electromagnetic radiation is produced by the **quick deceleration** of the electrons when hitting the target (**Bremsstrahlung**).
 - $\sim 99\%$ of energy converted into heat.
 - Few generated X-ray photons with wavelength set by the amount of energy loss $E=h\nu=E_2-E_1$
 - For Tungsten: 59.3 KeV



Conventional X-Ray

Image Formation

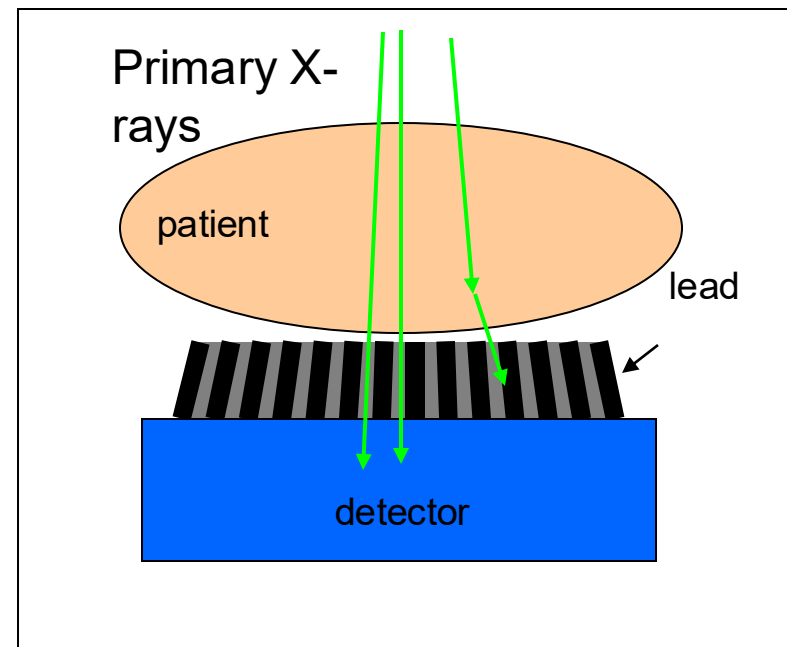
- X-ray beam goes through the patient
- Decrease in energy: depends on the absorption pattern inside the body (density + thickness)



Conventional X-Ray

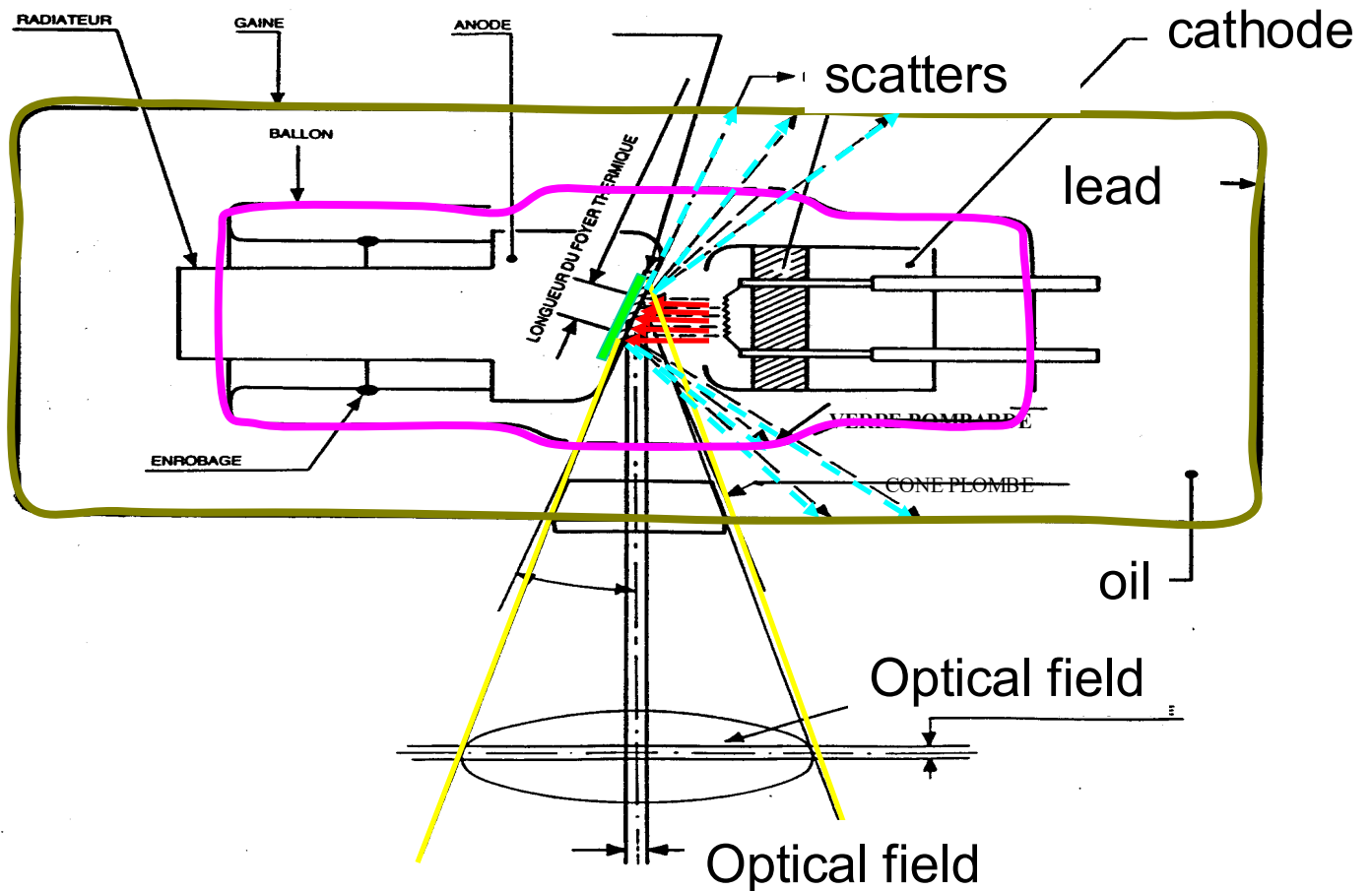
Image Capture

- Image captured on phosphor screen, with conversion to visible light.
- Recording on film (negative image)
- Display on video monitor (positive image)
- Numerical signal with CCD (charge couple device) camera

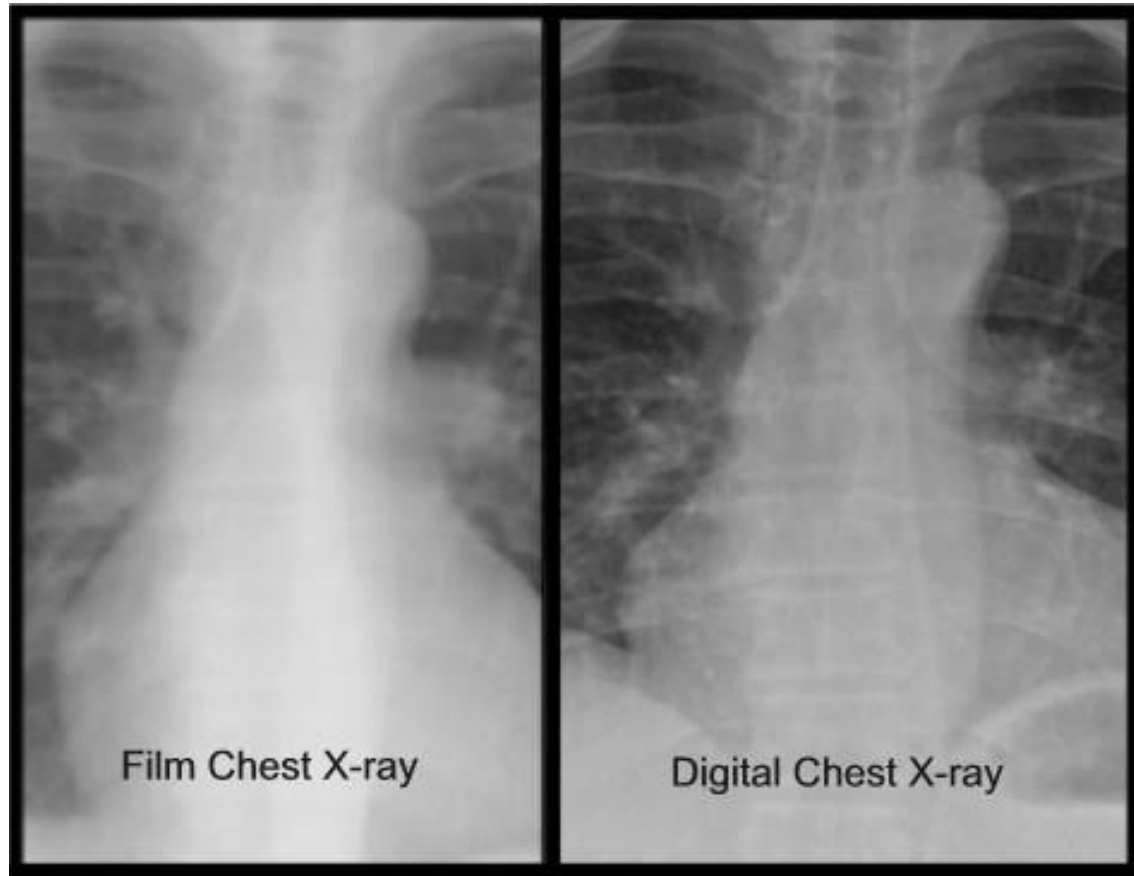


Conventional X-Ray

System Design



Conventional X-Ray



Conventional X-Ray

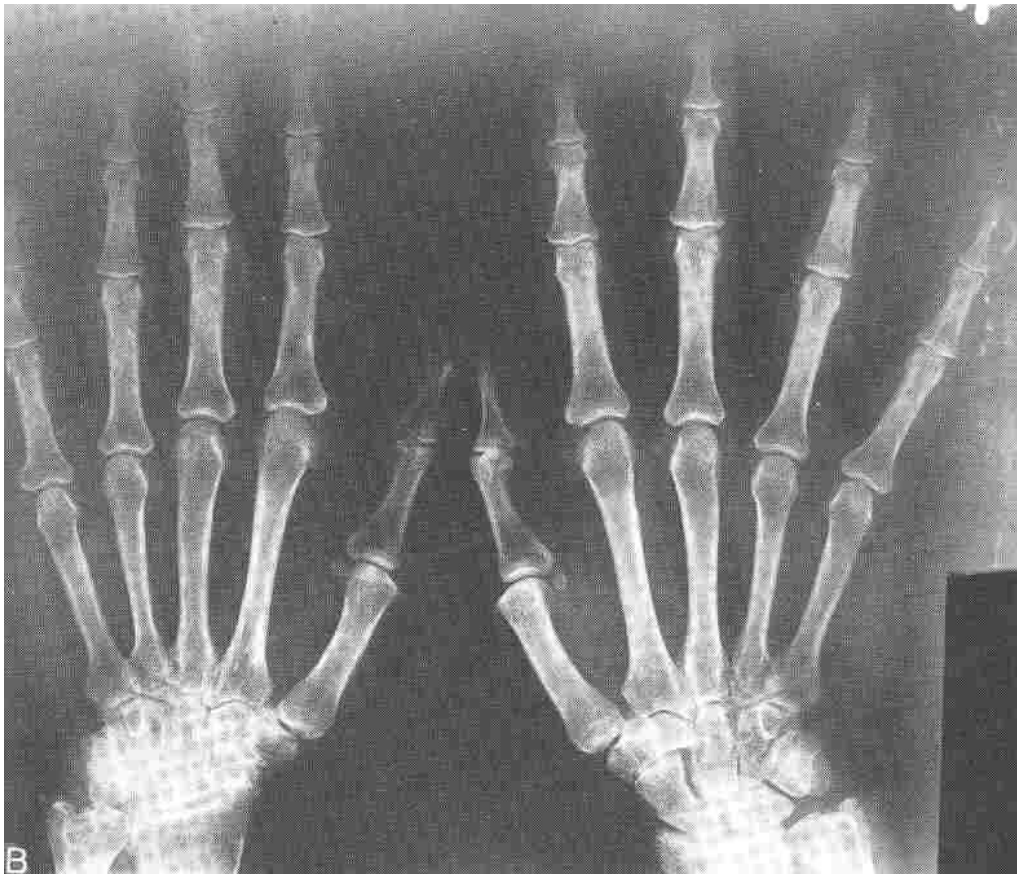
- **Advantages:**
 - Fast.
 - Inexpensive (relatively...).
- **Disadvantages:**
 - Ionizing radiations.
 - Projection images.
 - Poor blood vessel and soft-tissue contrasts.

Conventional X-Ray

- **Applications:**
 - Lungs, breasts.
 - Gastro-intestinal track.
 - Blood vessels (contrast agent).
 - Bones, joints.

Conventional X-Ray

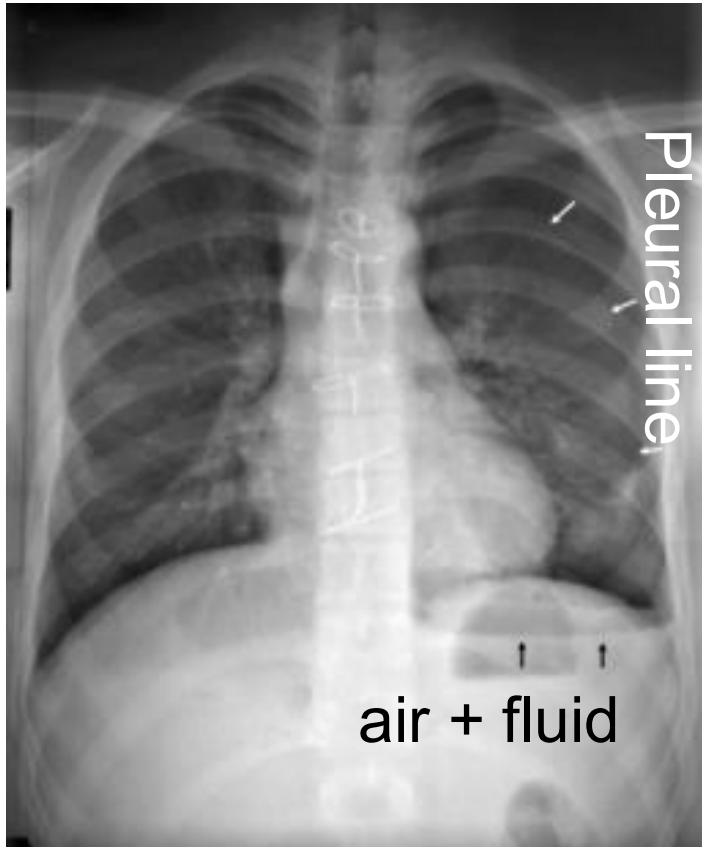
Examples: Bones



Conventional X-Ray

Examples: Lungs

Patient with hemo-pneumothorax



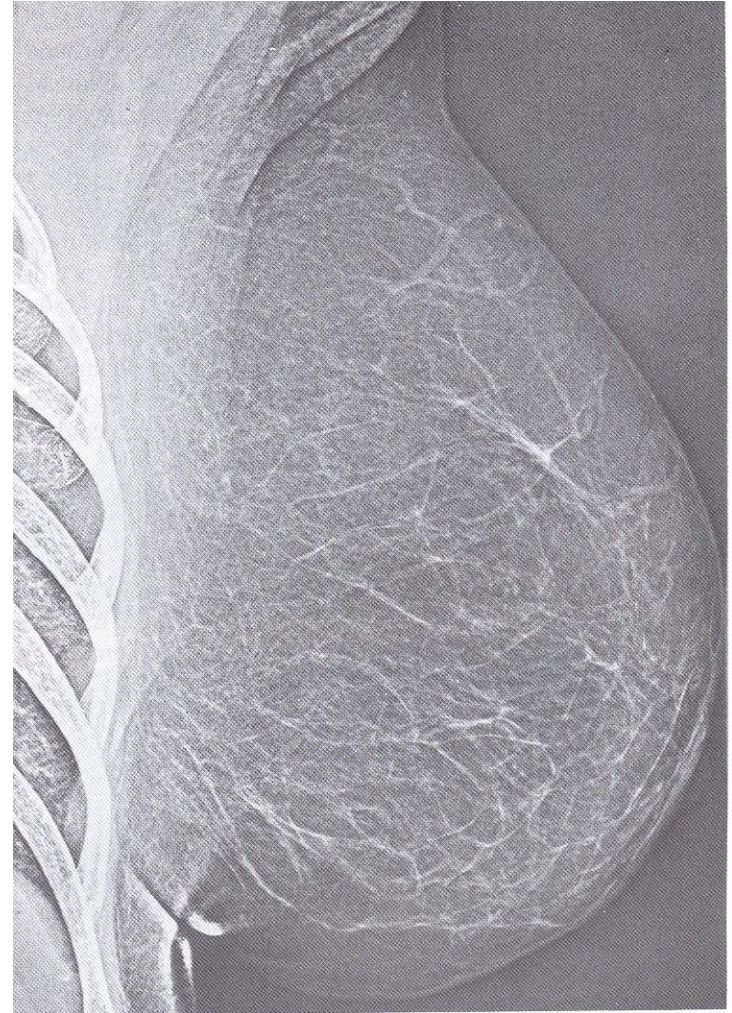
Patient with pacemaker



Conventional X-Ray

Examples: Mammography

- Low kV can be used (little attenuation) => sufficient photoelectric absorption to differentiate between normal tissue and pathology
- Dose must be limited.
- Breast must be compressed
 - To avoid motion.
 - To minimize focus/film distance.
 - To have equal tissue thickness.

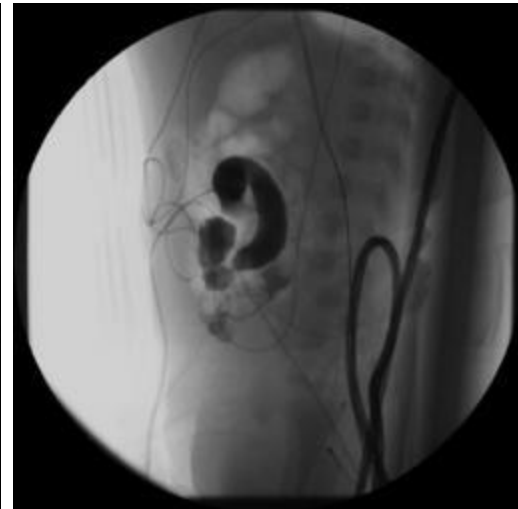


Conventional X-Ray

Examples: Fluoroscopy

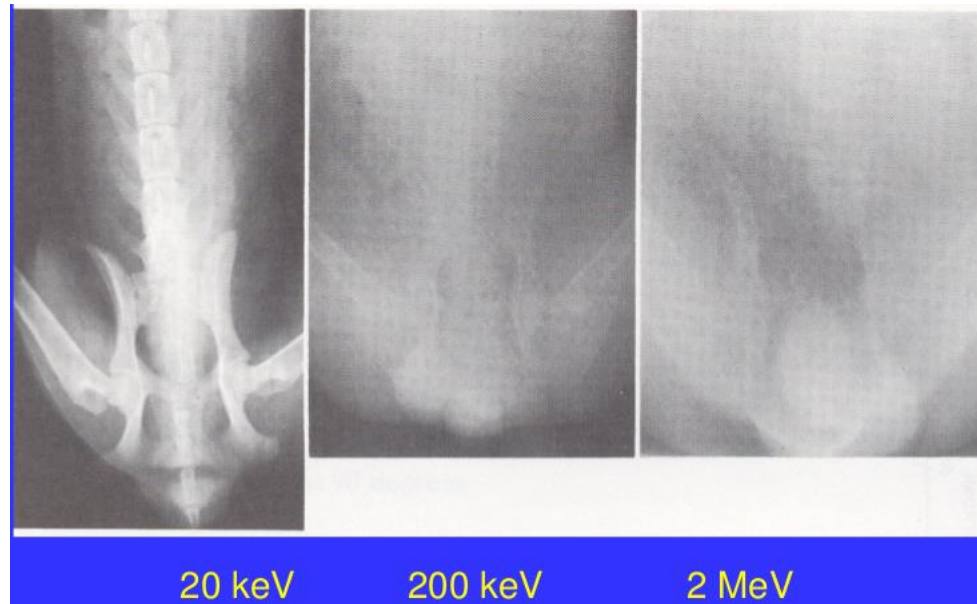
- Real-time X-ray imaging.
- Direct visualization on screen.
- Used for guidance of interventions (mainly vascular and orthopedic).

Ex: Fluoroscopic guidance with umbilical catheter injecting contrast agent in the small bowel.



Conventional X-Ray

Influence of energy



Less contrast when energy increases, and lower dose.



EOS Low Dose
115.62 μ Gy

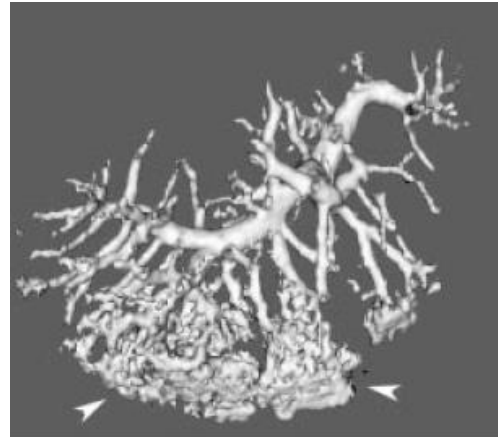
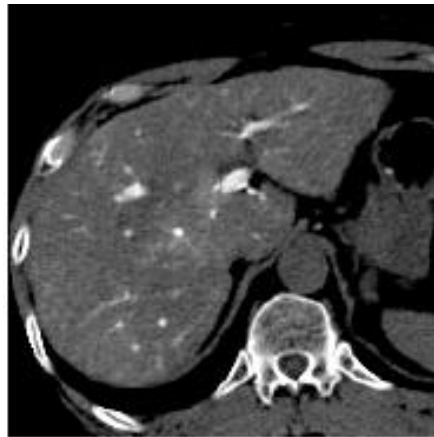


EOS Micro Dose
14.64 μ Gy



EOS preview
1.44 μ Gy

Computerized Tomography (CT)



CT

Physics Principles

- Same as X-ray.

Image Formation

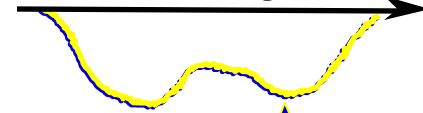
- Same as X-ray.

CT

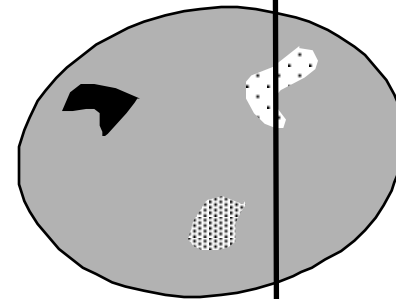
Image Capture

- Generation of a sliced view of body interior (“T”) (cf. tomos = slice in Greek).
- Computational intensive image reconstruction (“C”).

Measure = integral attenuation



$\mu(x,y)$?



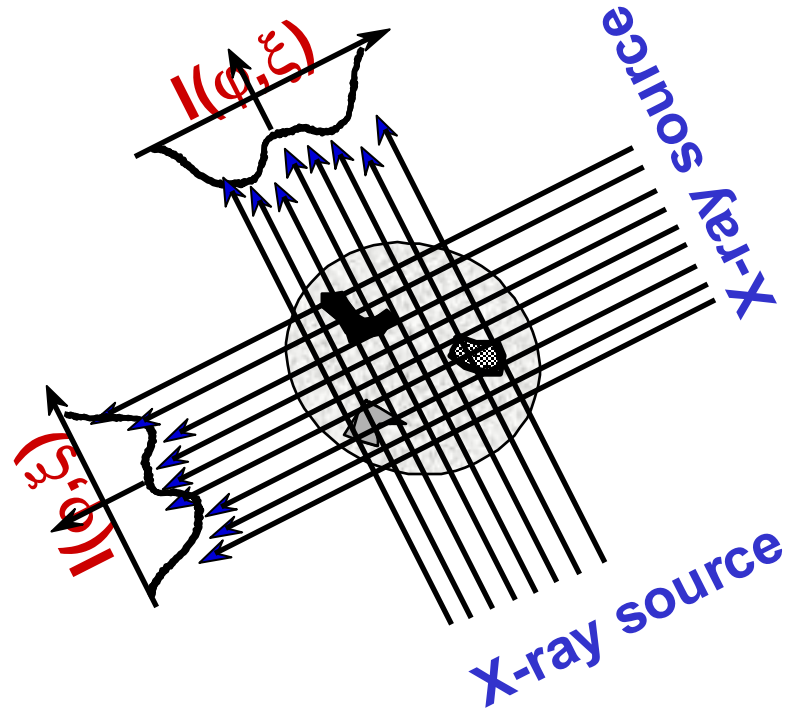
Patient's
body

X-ray source

CT

Image Capture

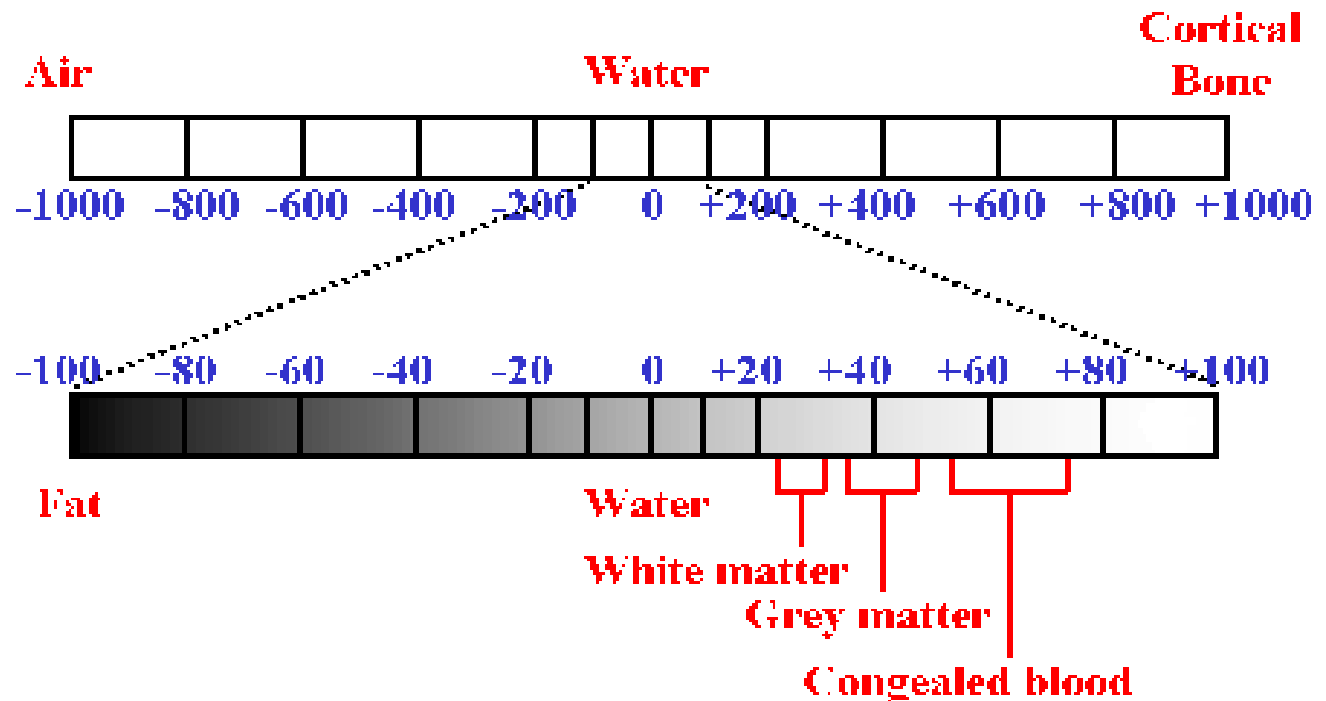
- Translation and rotation of integral measure of absorption.
- Reconstruction: see next lecture



CT

Image Capture: Hounsfield Units

- Relates the linear attenuation coefficient of a local region μ to the linear attenuation coefficient of water, μ_w at 70 keV ($=E_{\text{eff}}$).
- Based on measurements with the original EMI scanner invented by Hounsfield.



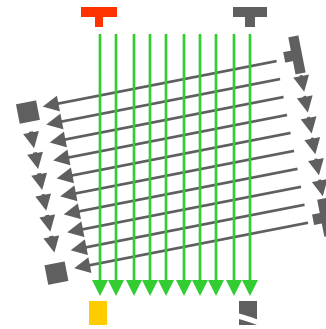
$$HU = 1000 \cdot \frac{\mu - \mu_w}{\mu_w}$$

- Assign calibrated values to gray scale of CT images -> allows for thresholding!

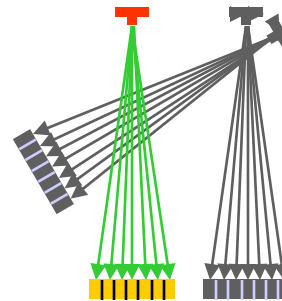
CT

System Design

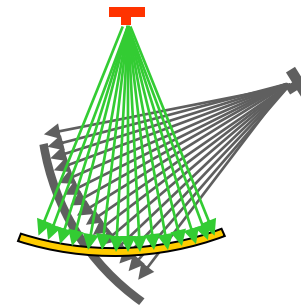
- **1st generation:** Original resolution: 80×80 pixels (ea. $3 \times 3 \text{ mm}^2$), 13mm slice thickness, 5min scan time, 20min reconstruction.
- **2nd generation:** reduced number of view angles \Rightarrow scan time ~ 30 s.
- **3rd generation:** scan time \sim seconds (reduced dose, motion artifacts). Reconstruction time \sim seconds.



Translation
& Rotation



Translation
& Rotation

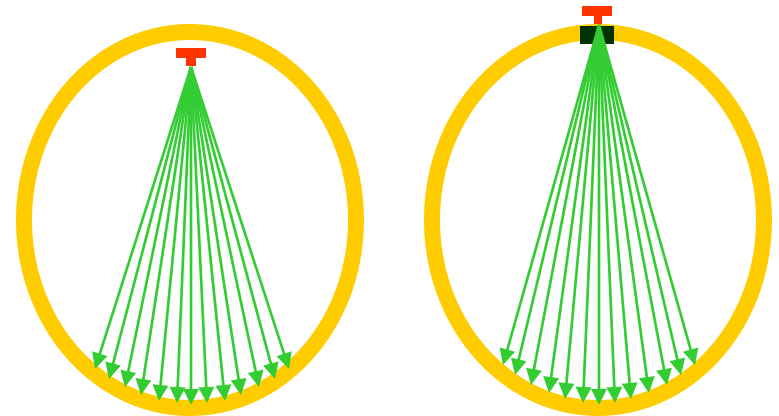


only
Rotation

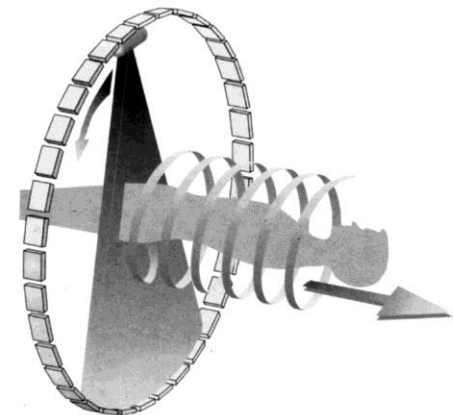
CT

System Design

- **4th generation:** scan time, reconstruction time ~sec.
- **Spiral:** Continuous linear motion of patient table during multiple scans. Increased coverage volume per rotation.



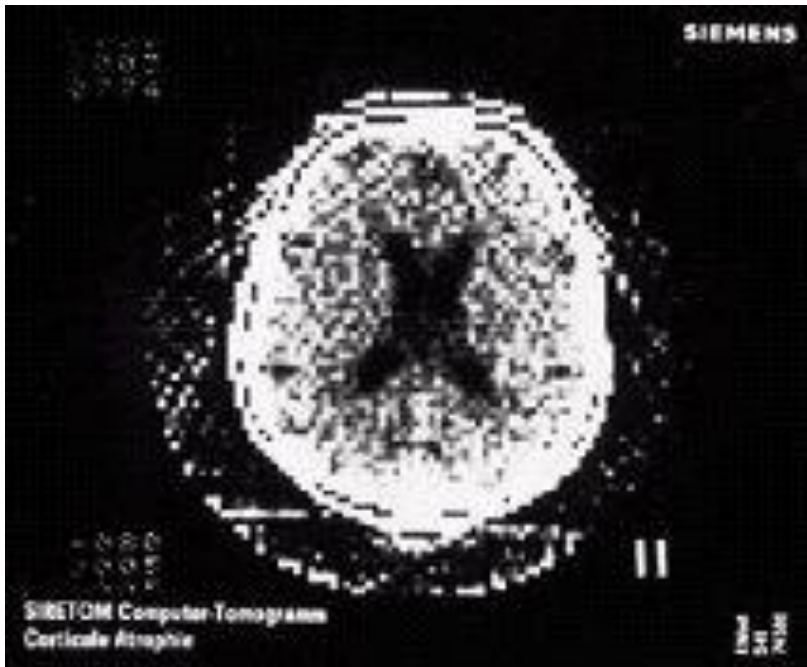
only Rotation of sources



CT

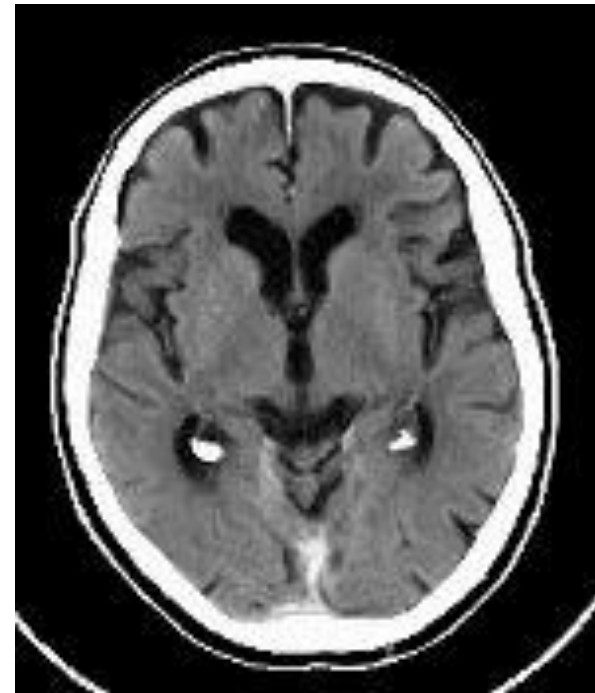
Example: Image quality

1975



128x128 pixels, 1-4 hours acquisition,
1-5 days computation

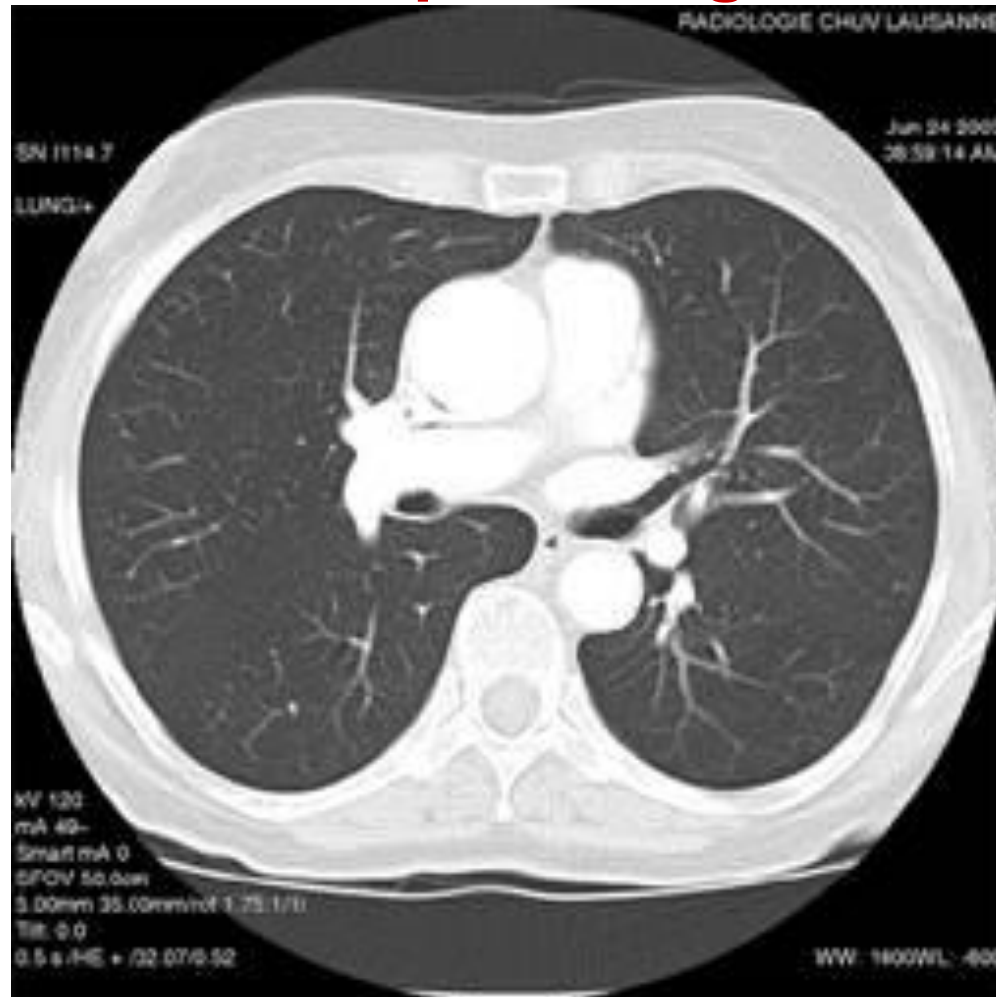
2000



512x512 pixels, 0.35 sec acquisition,
<1sec computation

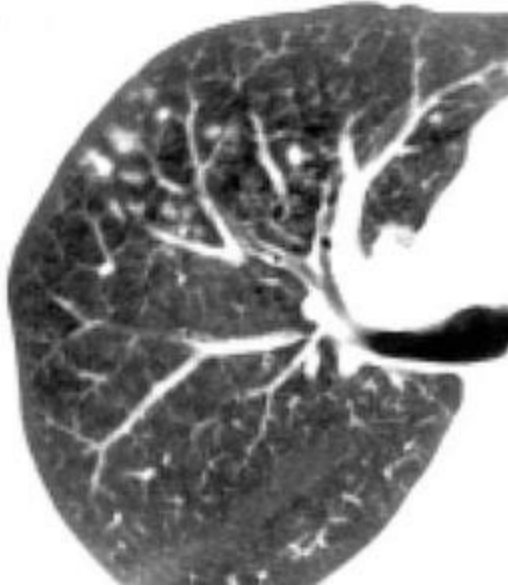
CT

Example: Lungs



CT

Example: Lungs

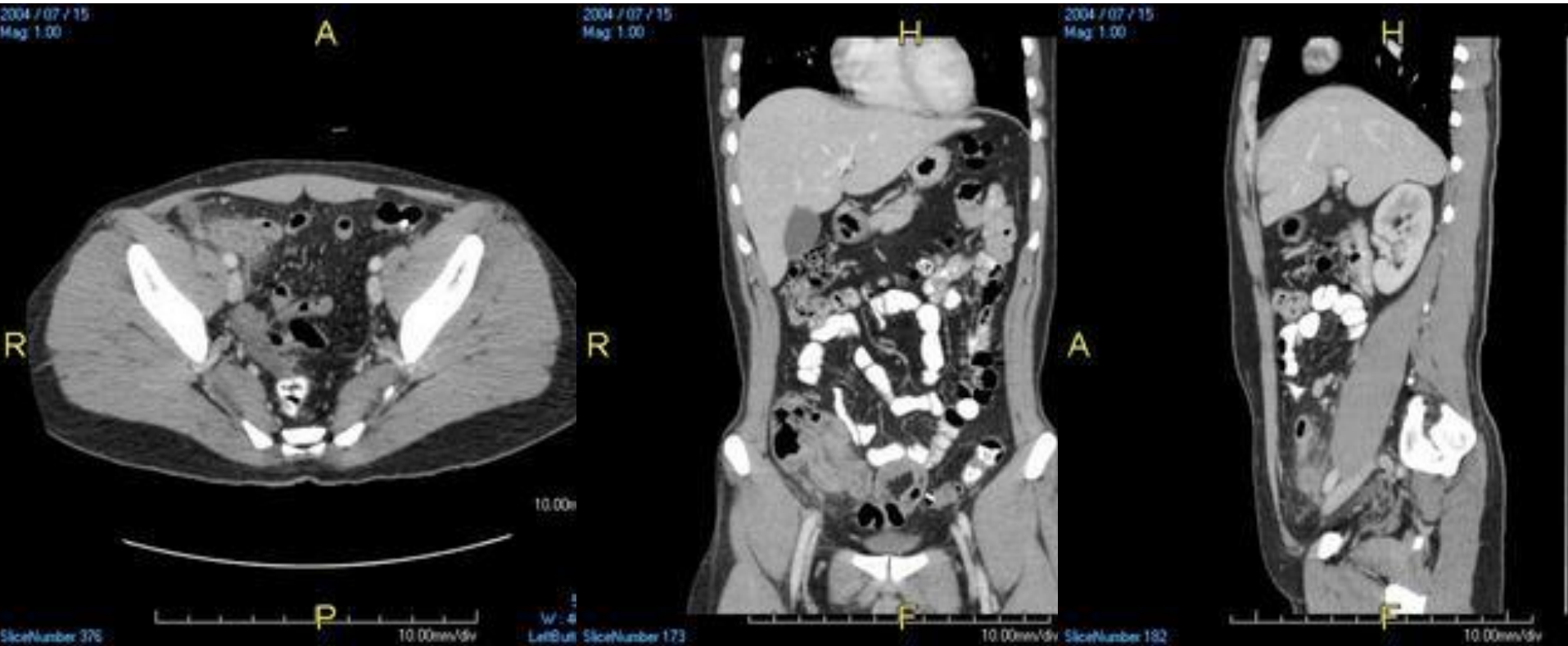


Ex: CT of right lung with active pulmonary tuberculosis: shows centrilobular lesions (nodules or branching linear structures 2-4 mm in diameter) in and around the small airways.

Source: www.mypacs.net

CT

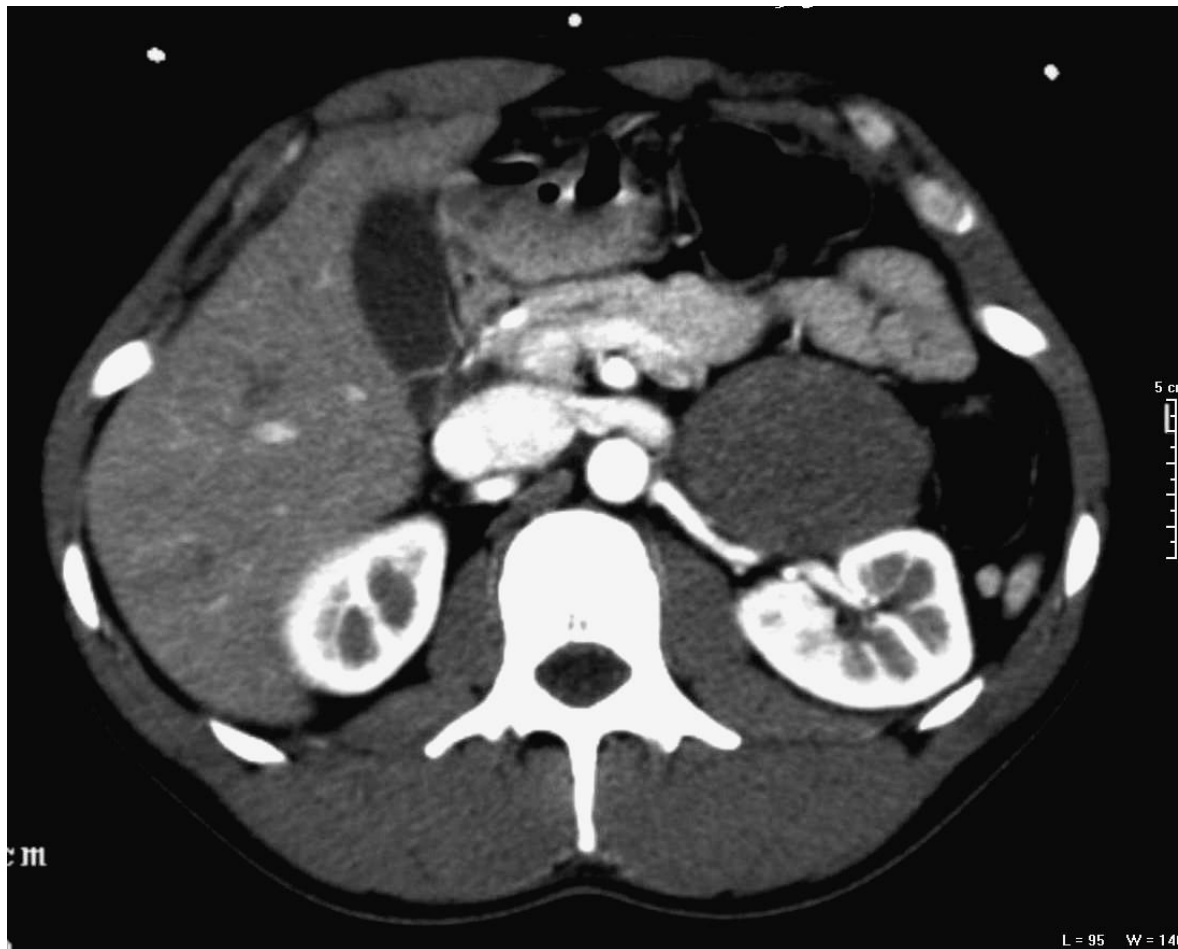
Examples: Abdomen



Diagnosis of appendicitis

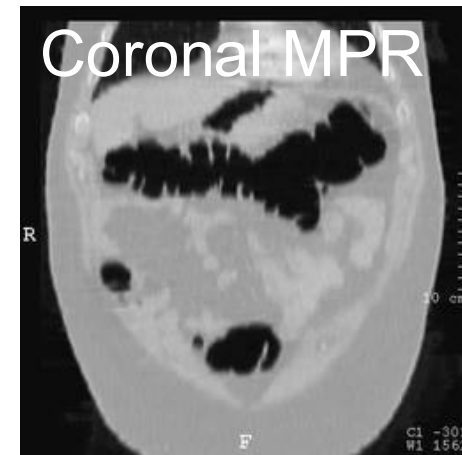
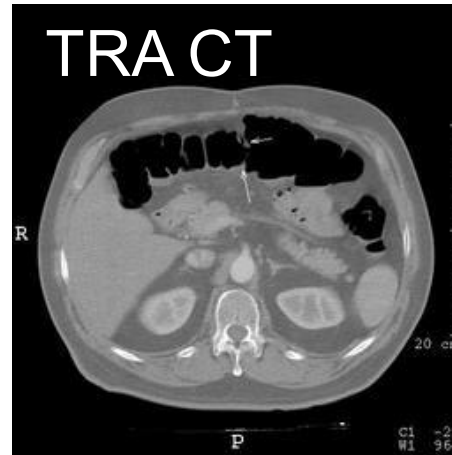
CT

Examples: Abdomen

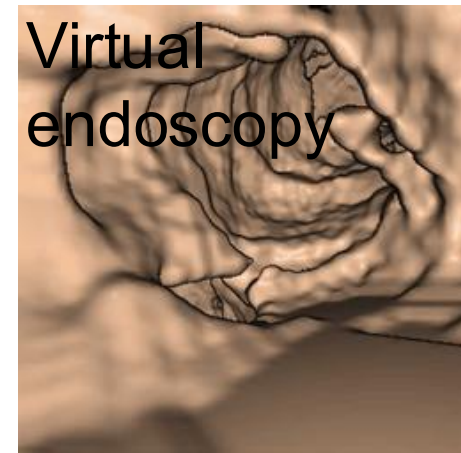
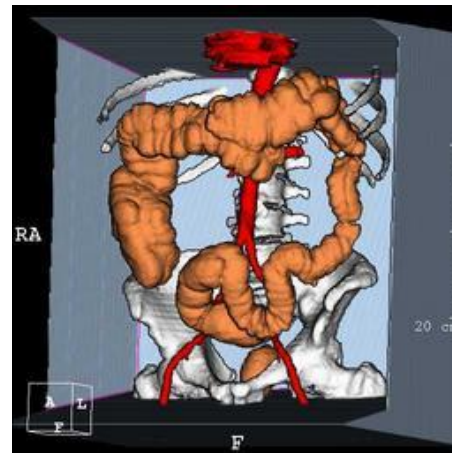
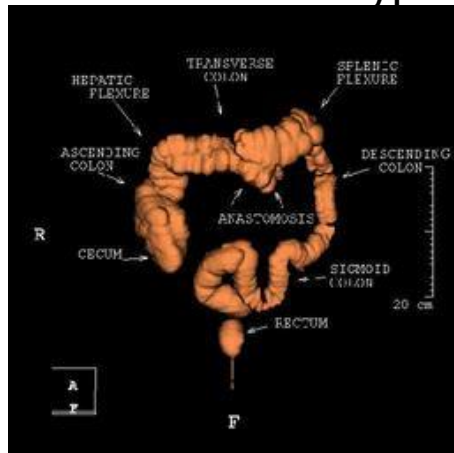


CT

Example: Abdomen



Source: www.mypacs.net



CT

Example: Blood vessels

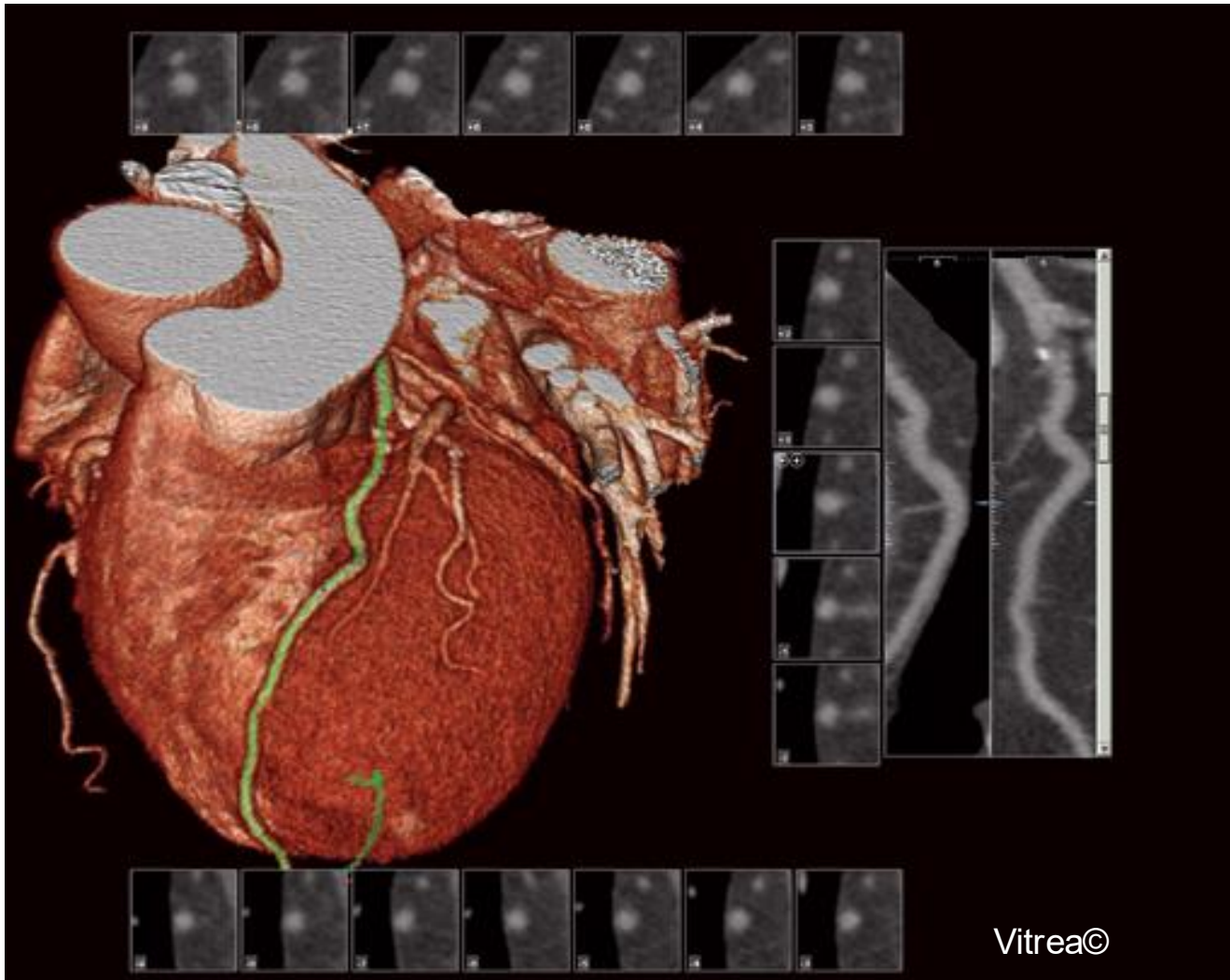


CT

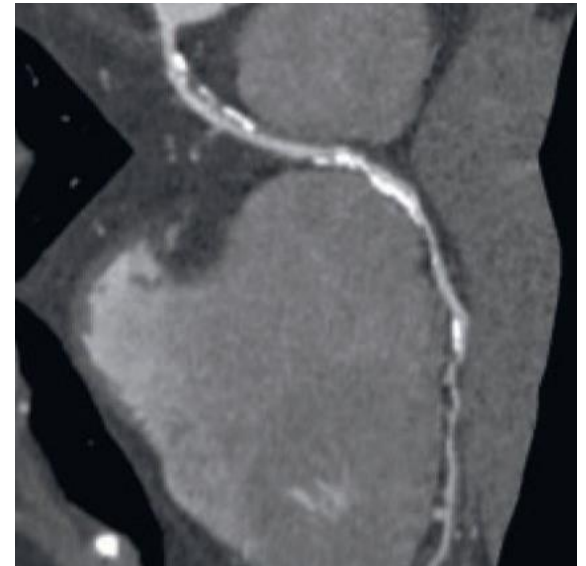
Example: Blood Vessels



CT

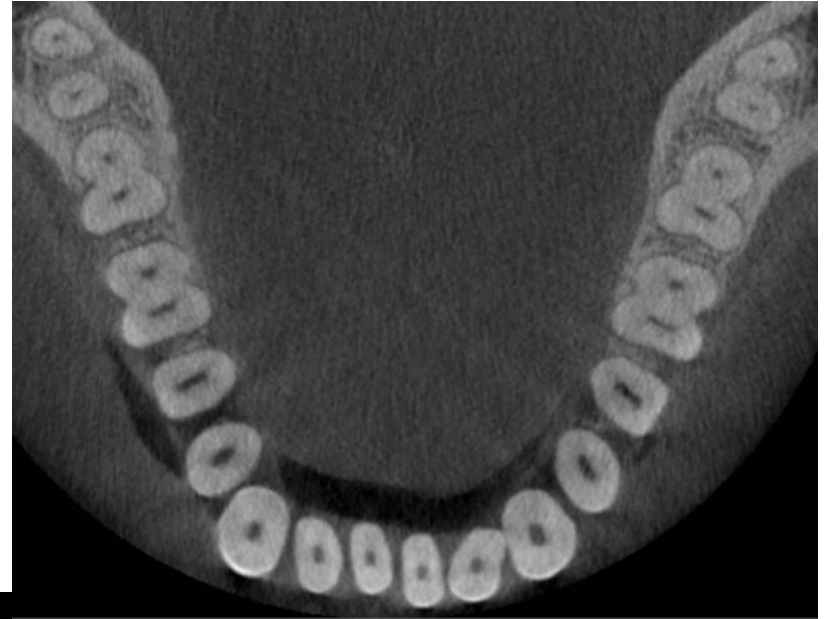
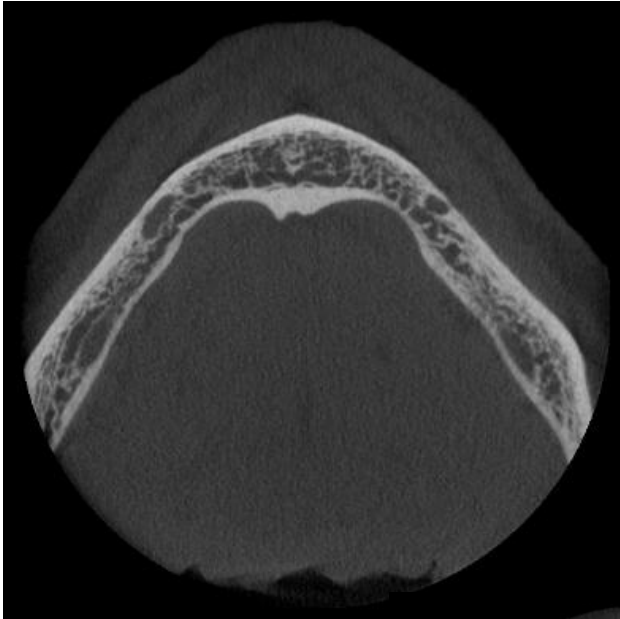


CT

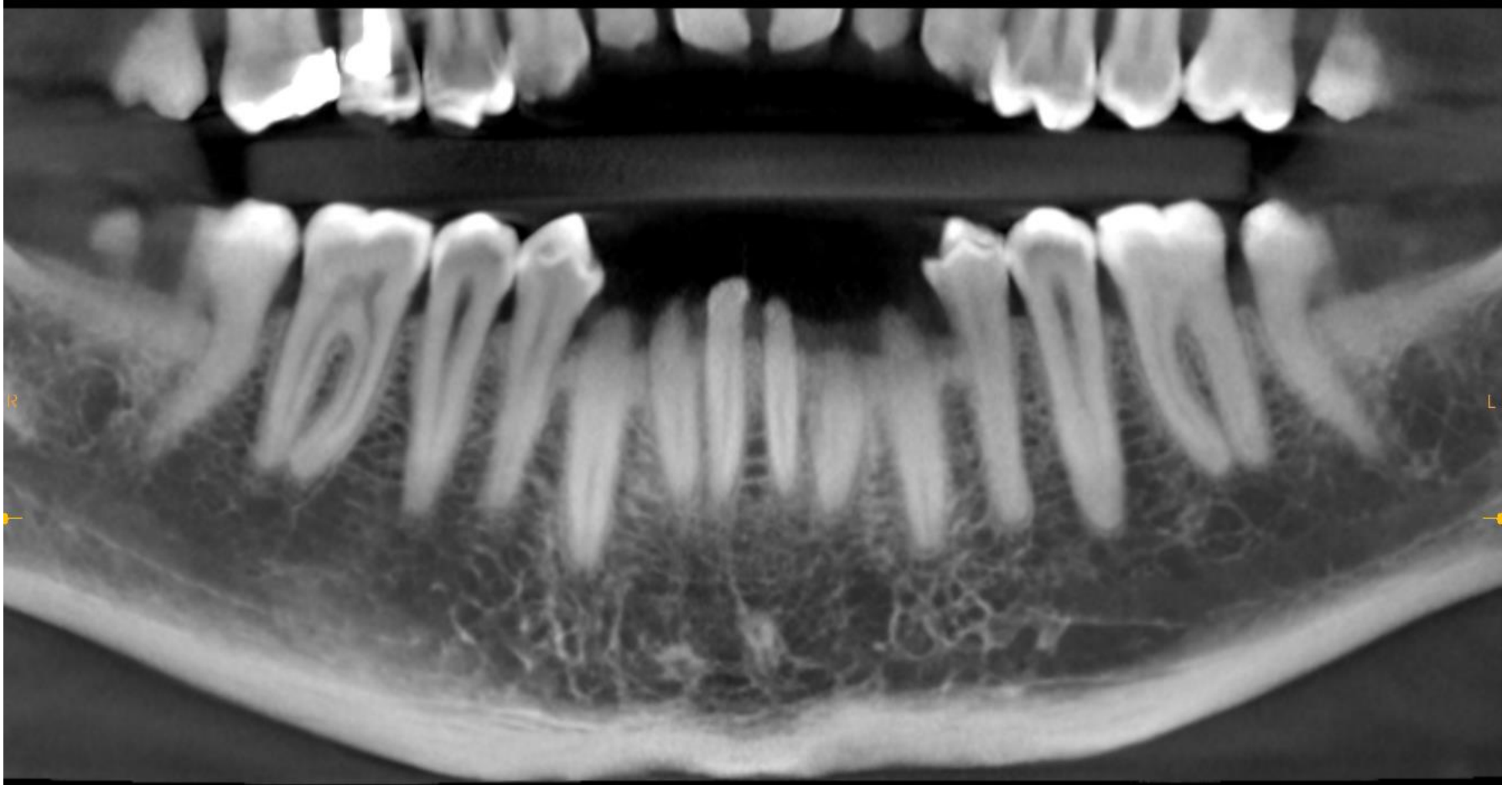


High resolution CT

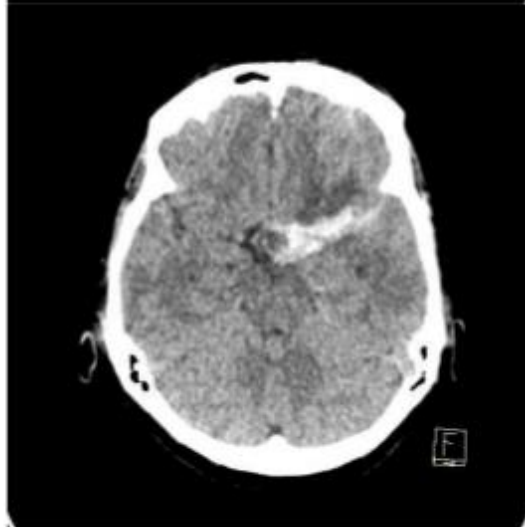
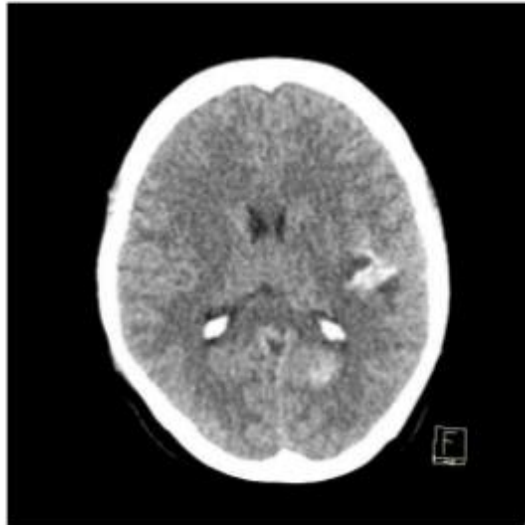
Cone Beam CT (CBCT)



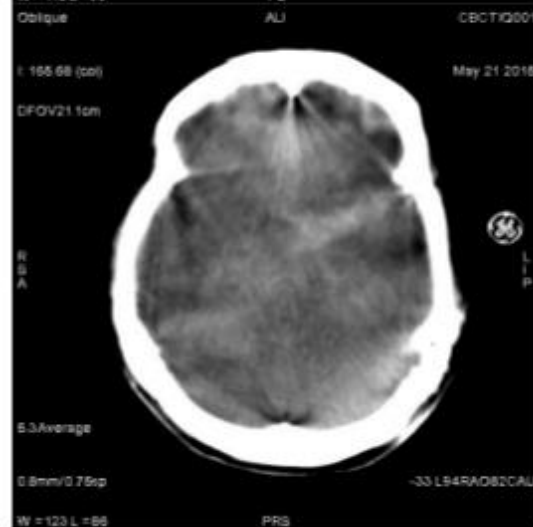
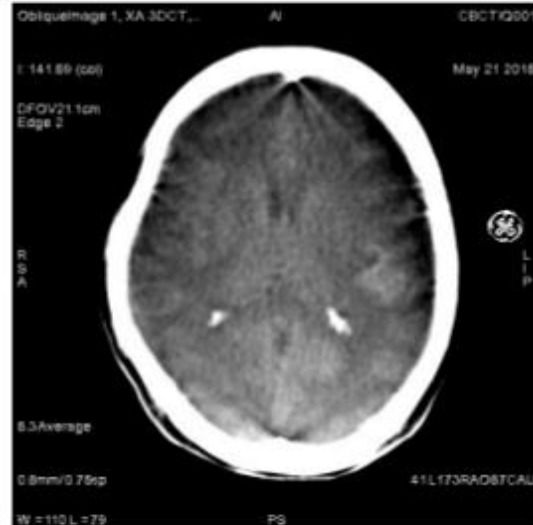
Cone Beam CT (CBCT)



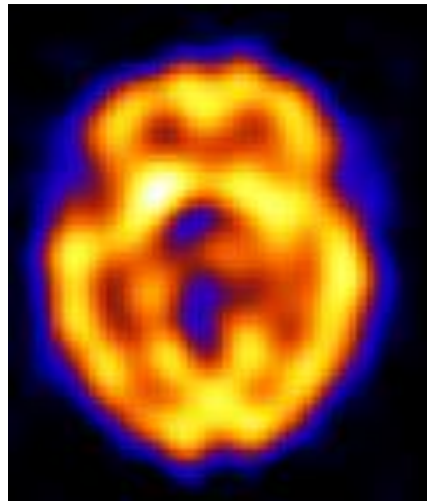
CT



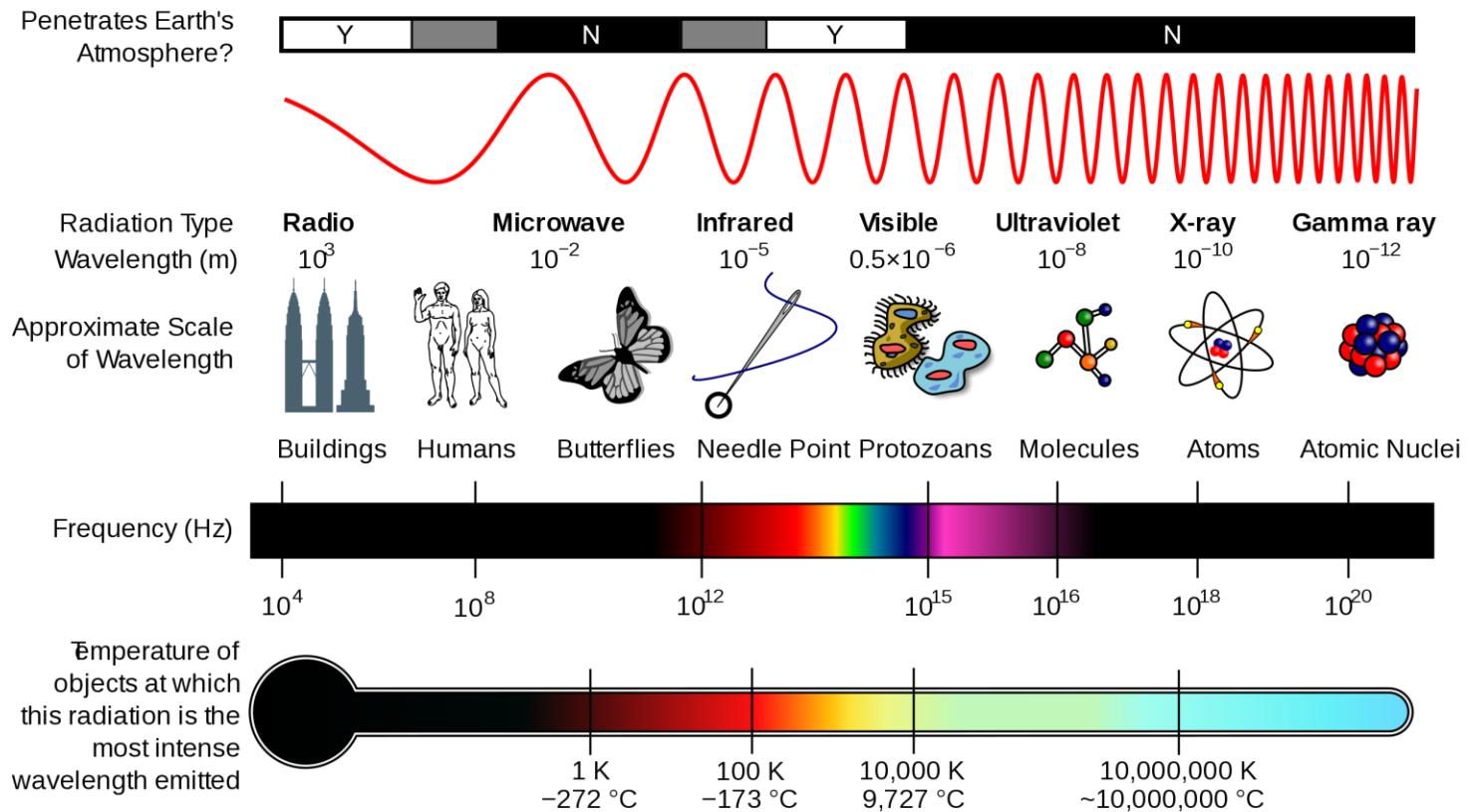
CBCT



Nuclear Imaging (SPECT, PET)



Electromagnetic spectrum



Source: Wikipedia

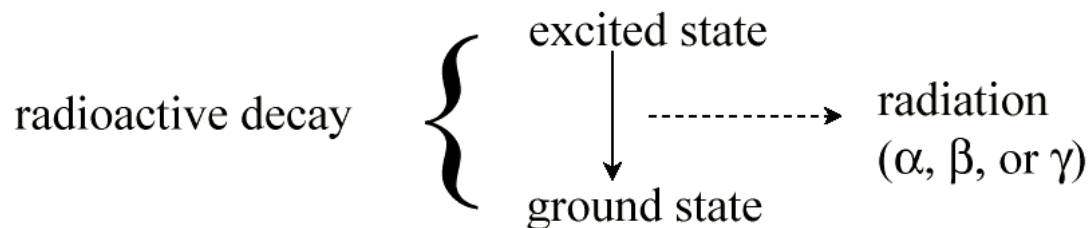
Nuclear Imaging

Physics Principle

Nuclear imaging is the use of **radioactive materials** for imaging **function** inside the body (different from therapeutic use)..

Stability of Atomic Nuclei

- *ground state*: most stable.
- *metastable state*: nucleus is unstable, has long lifetime before transforming to another state.
- *excited state*: nucleus very unstable, exists in this state for small time period before transforming.



Nuclear Imaging

Types of radiation

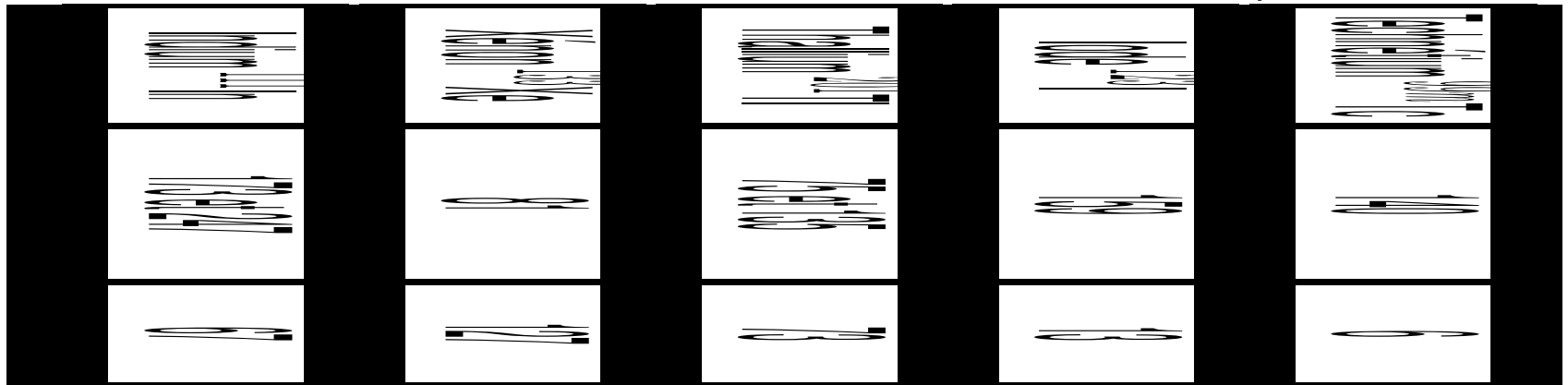
- α : Z and A decrease
- β : $Z \rightarrow Z - 1$ and A constant, proton \rightarrow neutron + positron
- γ : A and Z constant (example: Tc)

- Z = number of protons
- A = number of protons + neutrons

Nuclear Imaging

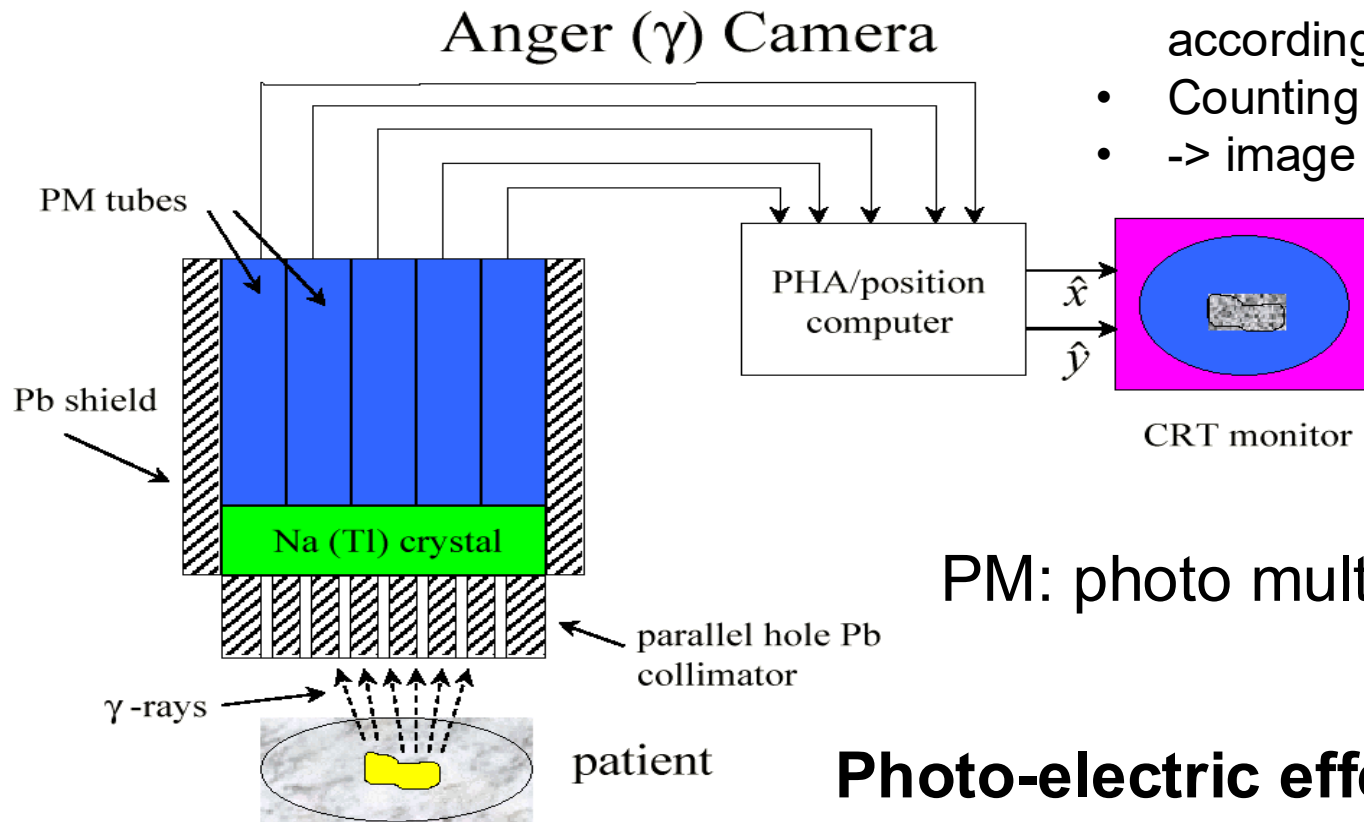
Energy (in keV)

Half-life (in hours)



Nuclear Imaging

System Design



- Energy-based selection
- Localization according to PM
- Counting
- -> image

PM: photo multiplier

Photo-electric effect

+ Compton (undesirable) 55

Nuclear Imaging

SPECT (single photon emission computerized tomography)

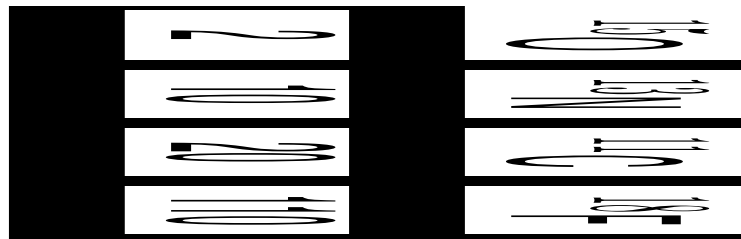
- Several projections
- Reconstruction (as for CT, see next lecture)
- Attenuation correction

Nuclear Imaging

PET (positron emission tomography)

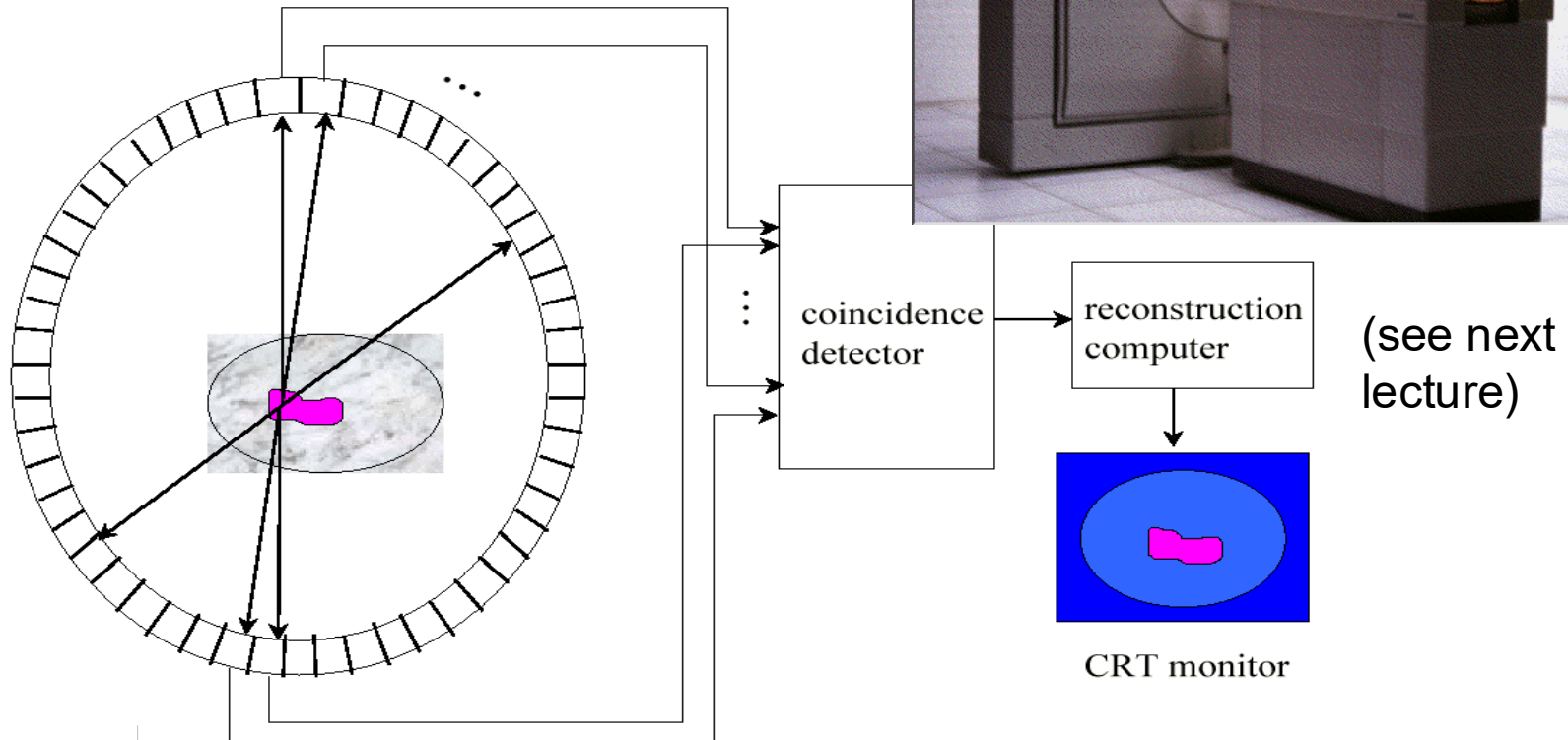
- In unstable nucleus, (more protons than neutrons) proton converts to neutron under emission of **positron**.
- Positron travels limited distance in tissue.
- Positron can combine with electron of nearby atom and emits two 511 keV X-ray photons (γ rays) that travel in opposite directions.

Half-life (in min)



Nuclear Imaging

Positron Ring Detector



Nuclear Imaging

- **Advantages**

- Functional imaging: metabolism, immunology, function, flux (not an anatomical imaging technique!).

- **Disadvantages**

- Poor spatial resolution (a few mm).
- High level of noise.
- Expensive hardware.
- Need of cyclotron.

Nuclear Imaging

Applications

- Heart
- Lungs
- Kidneys
- Bladder
- Gastro-intestinal Track
- Endocrine system (hormones)
- Immune system (white blood cells)
- Tumors (ex: FDG)

Nuclear Imaging

New developments

- Detection using semi-conductors
- Combined machines:
 - PET/CT
 - PET/MRI

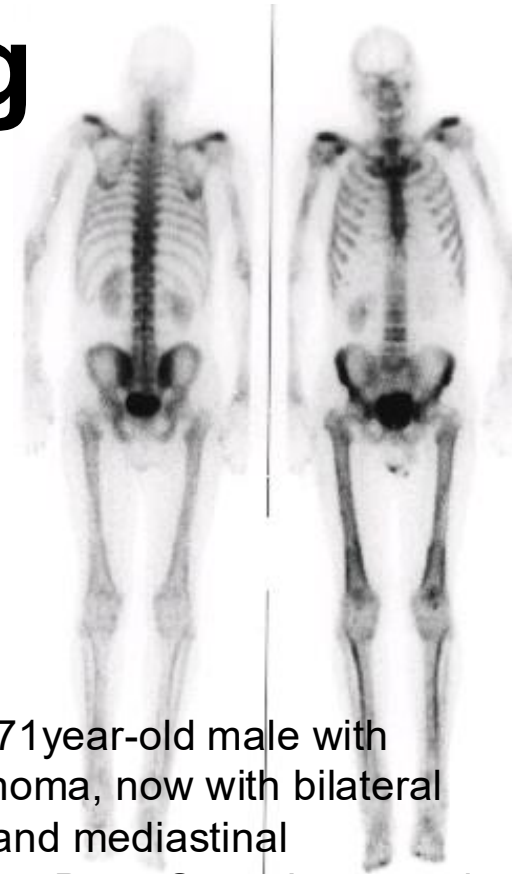
Nuclear Imaging

Whole Body



Figure 1. Whole-body gallium-67 scan showing lymphoma in the chest, the spleen, the abdomen, and the groin. The chest and spleen sites were known before the scan. The abdominal and groin uptakes were detected only by the scan.

Source: <http://www.nucmednet.com/galymph.htm>



Clinical History: A 71-year-old male with history of lung carcinoma, now with bilateral pulmonary nodules and mediastinal adenopathy. **Findings:** Bone Scan: Increased radiopharmaceutical uptake along cortical margins of the bilateral femurs and tibias. No evidence of bony metastases.

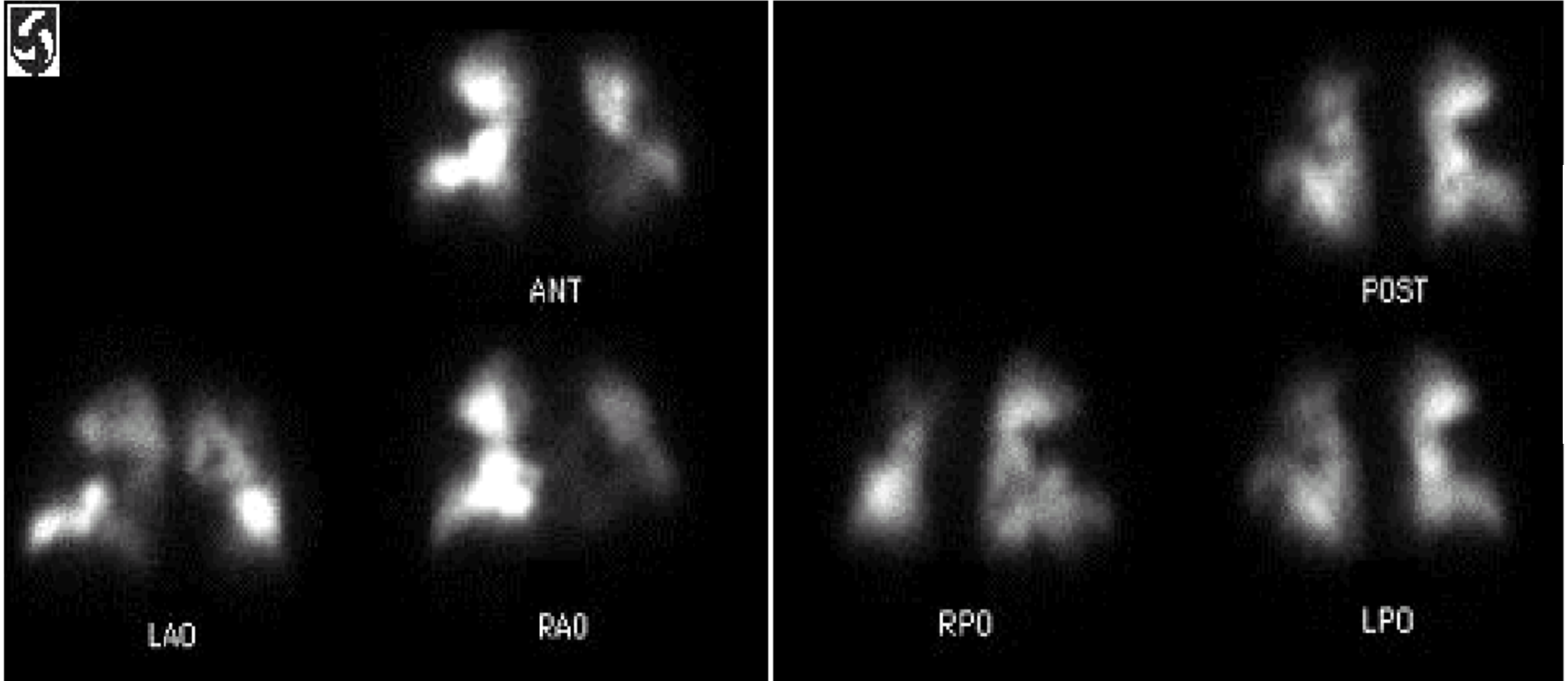
Diagnosis: Hypertrophic osteoarthropathy

<http://www.uhrad.com/spectarc.htm>

Nuclear Imaging

Example: Lung

SPECT scan for lung perfusion (pulmonary embolism)

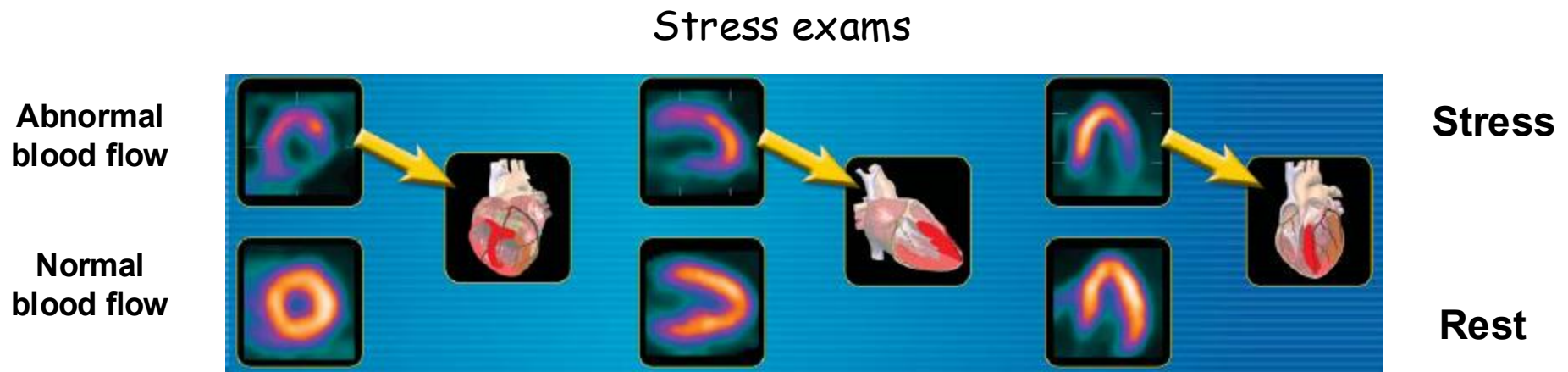


Source: Brigham & women's Hospital

Nuclear Imaging

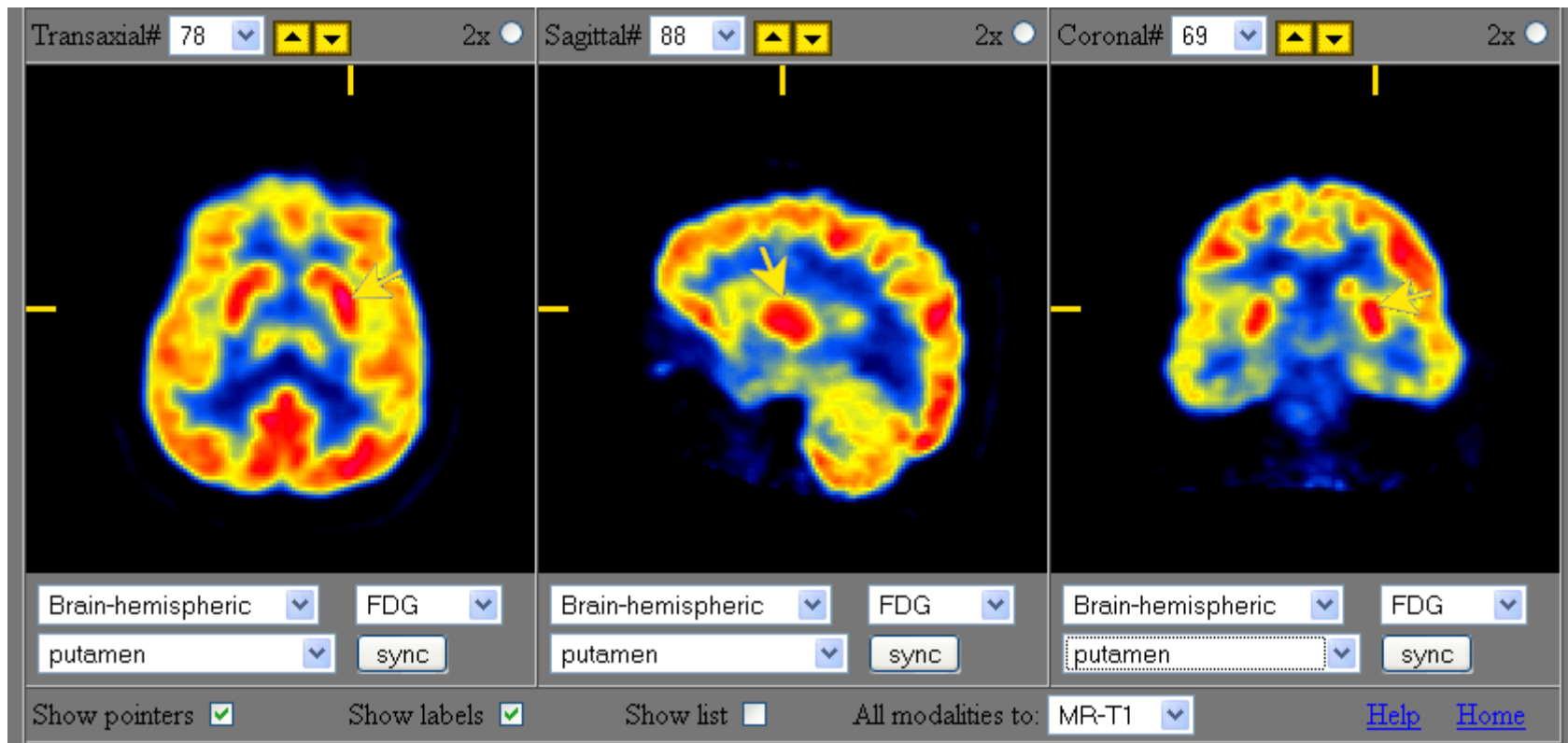
Example: Heart

- Perfusion Imaging



Nuclear Imaging

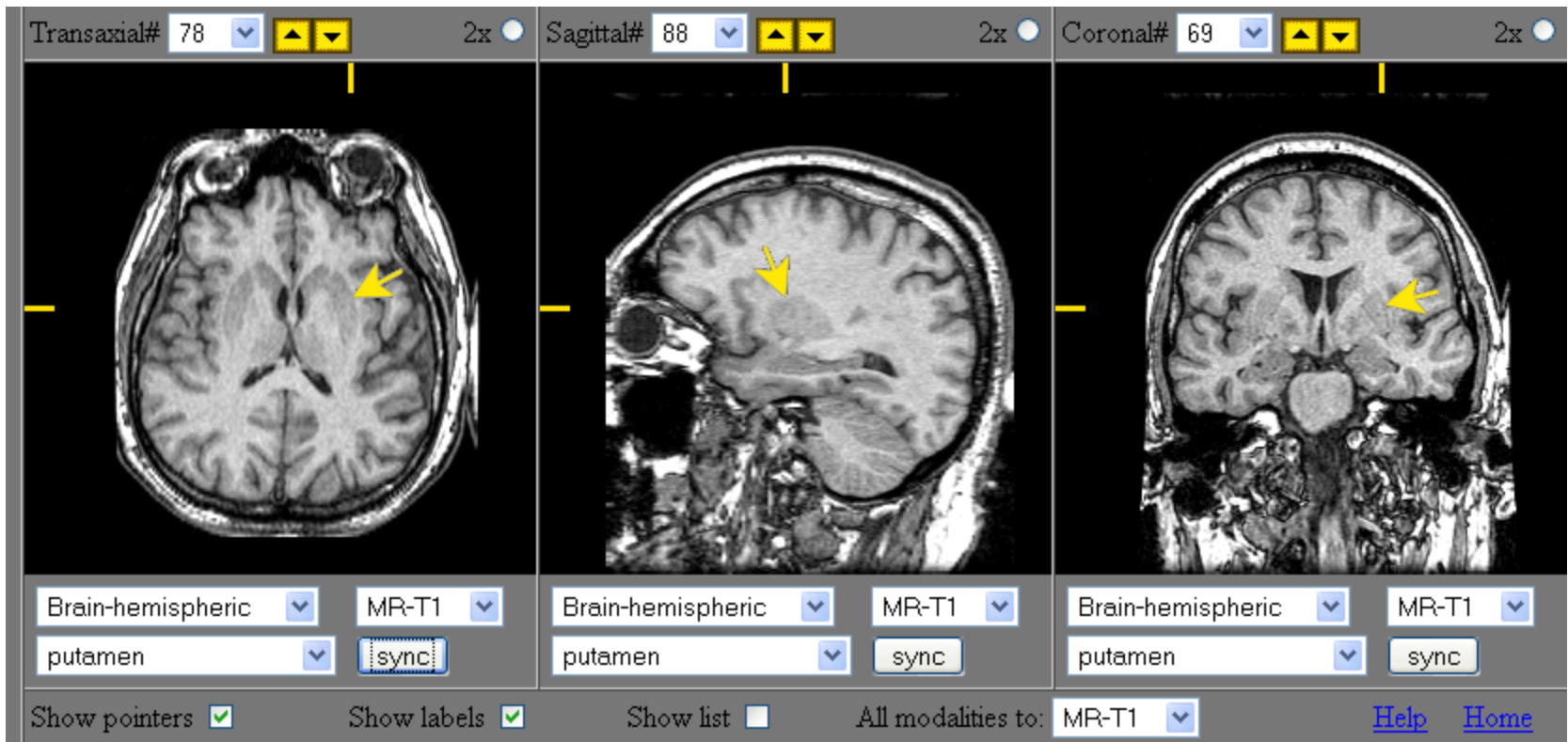
Example: Brain



Source: www.med.harvard.edu/AANLIB

Nuclear Imaging

Example: Brain

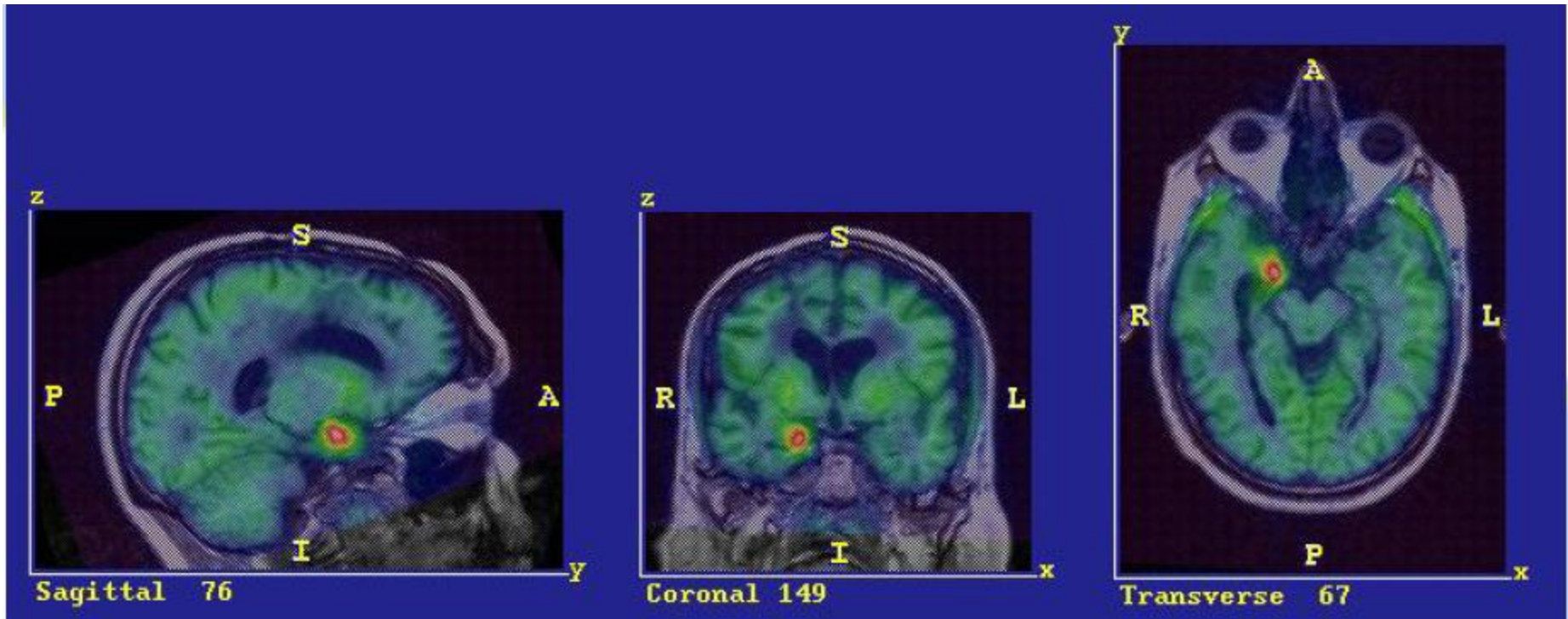


Source: www.med.harvard.edu/AANLIB

Nuclear Imaging

Example: Brain

PET with FDG tracer for diagnosis of brain tumor

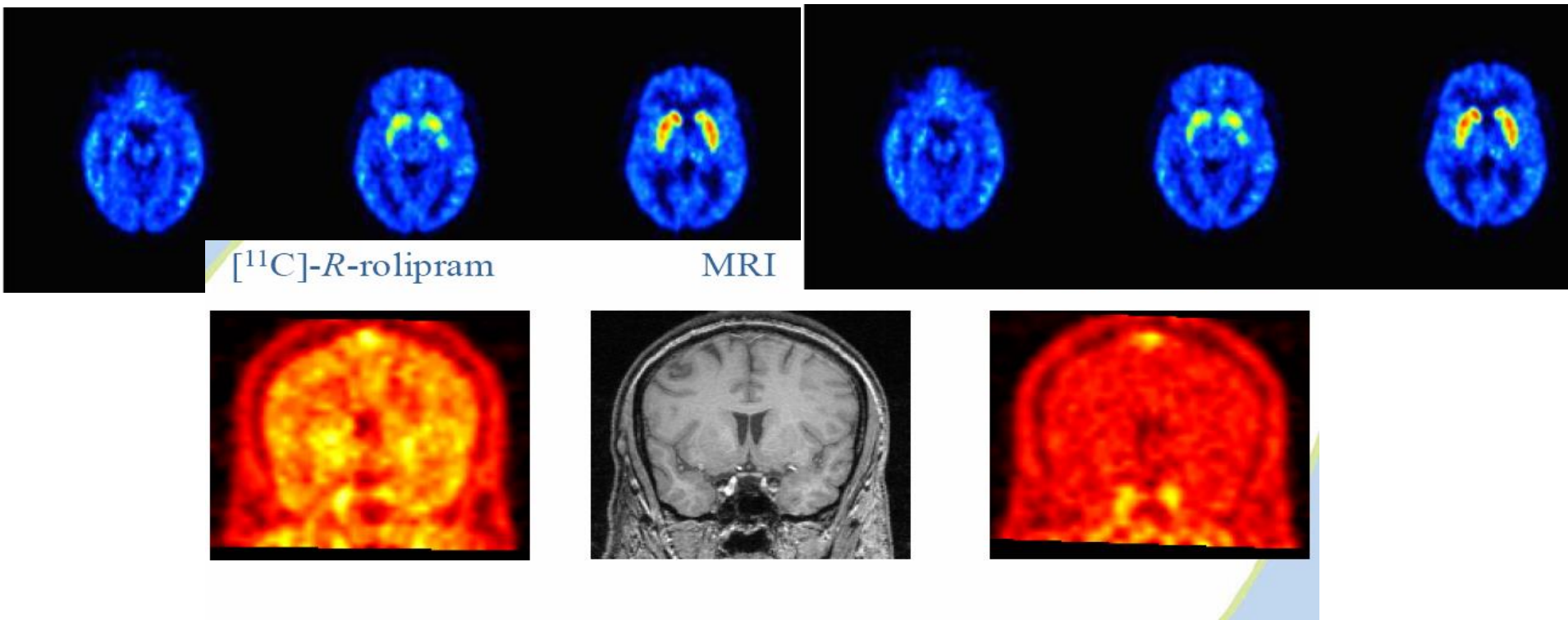


Source: V. Cunningham, GlaxoSmithKline.

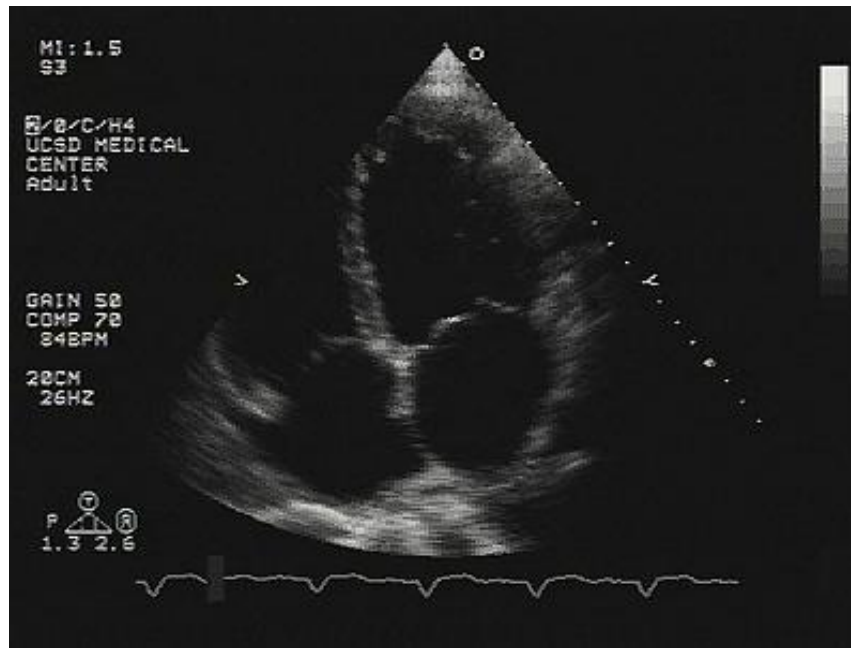
Nuclear Imaging

Example: Brain

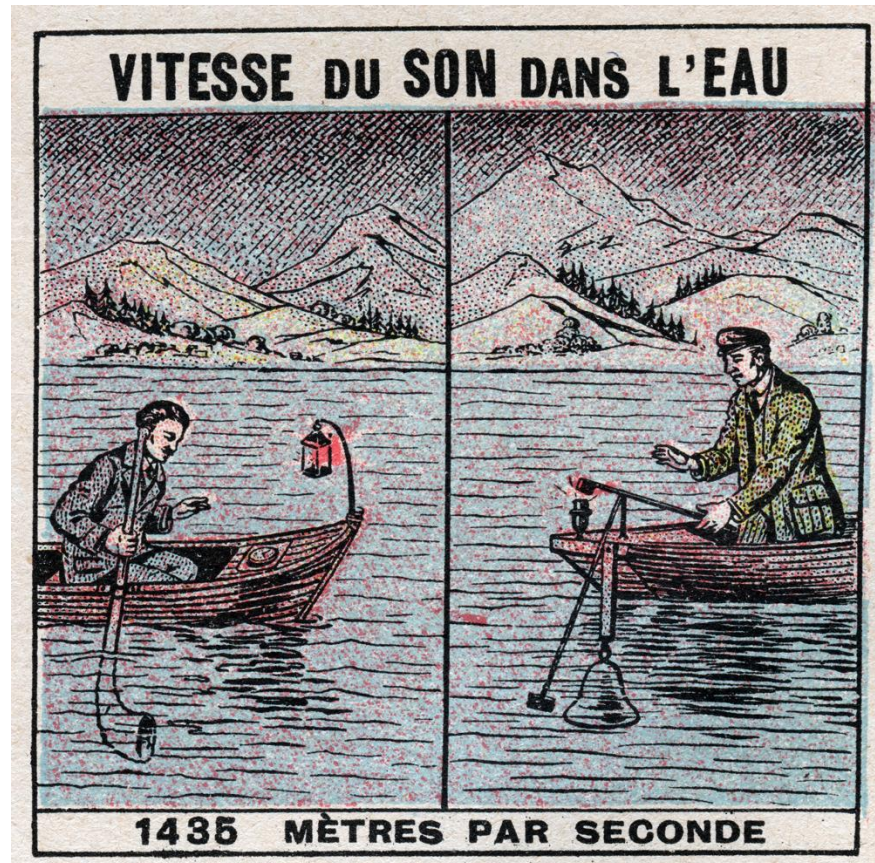
PET for in-vivo testing of new drugs



Ultrasound



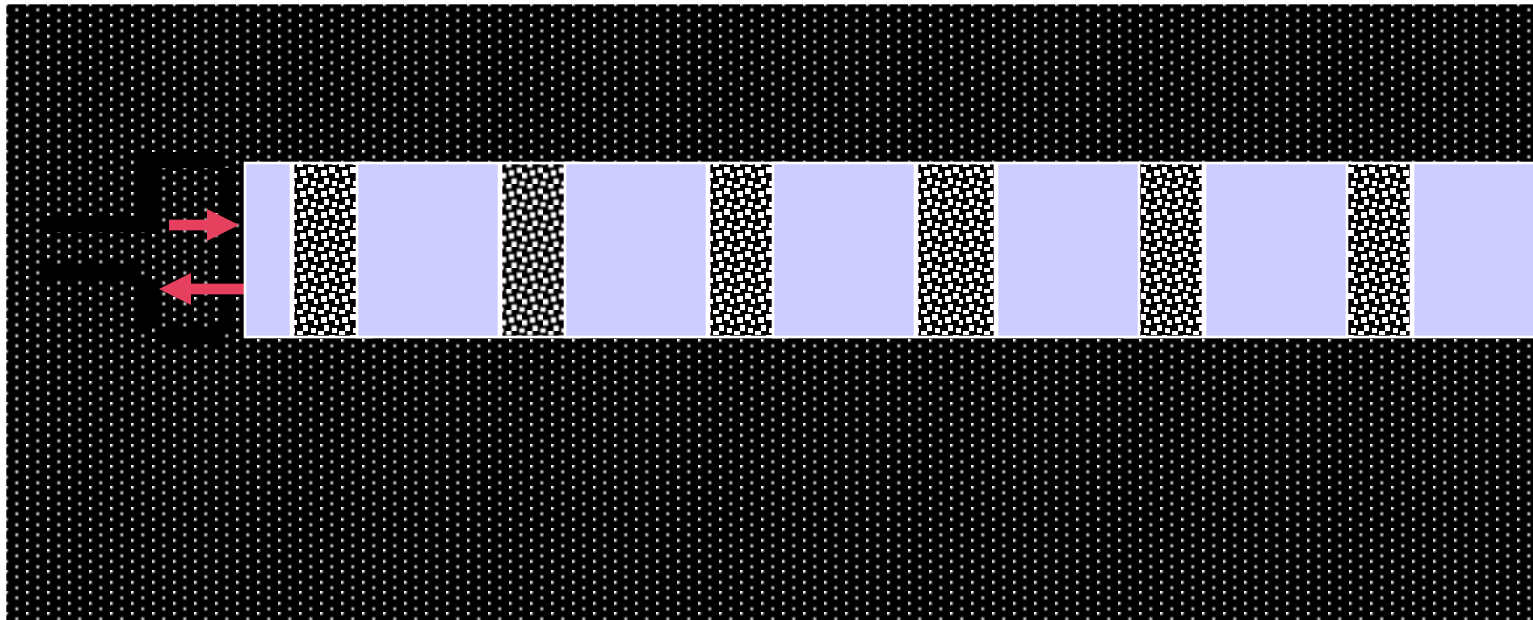
1841: Jean-Daniel Colladon and Charles Sturm discover that sound travels four times faster in water (1435 m/s) than in air (344 m/s at 20°C)



Ultrasound

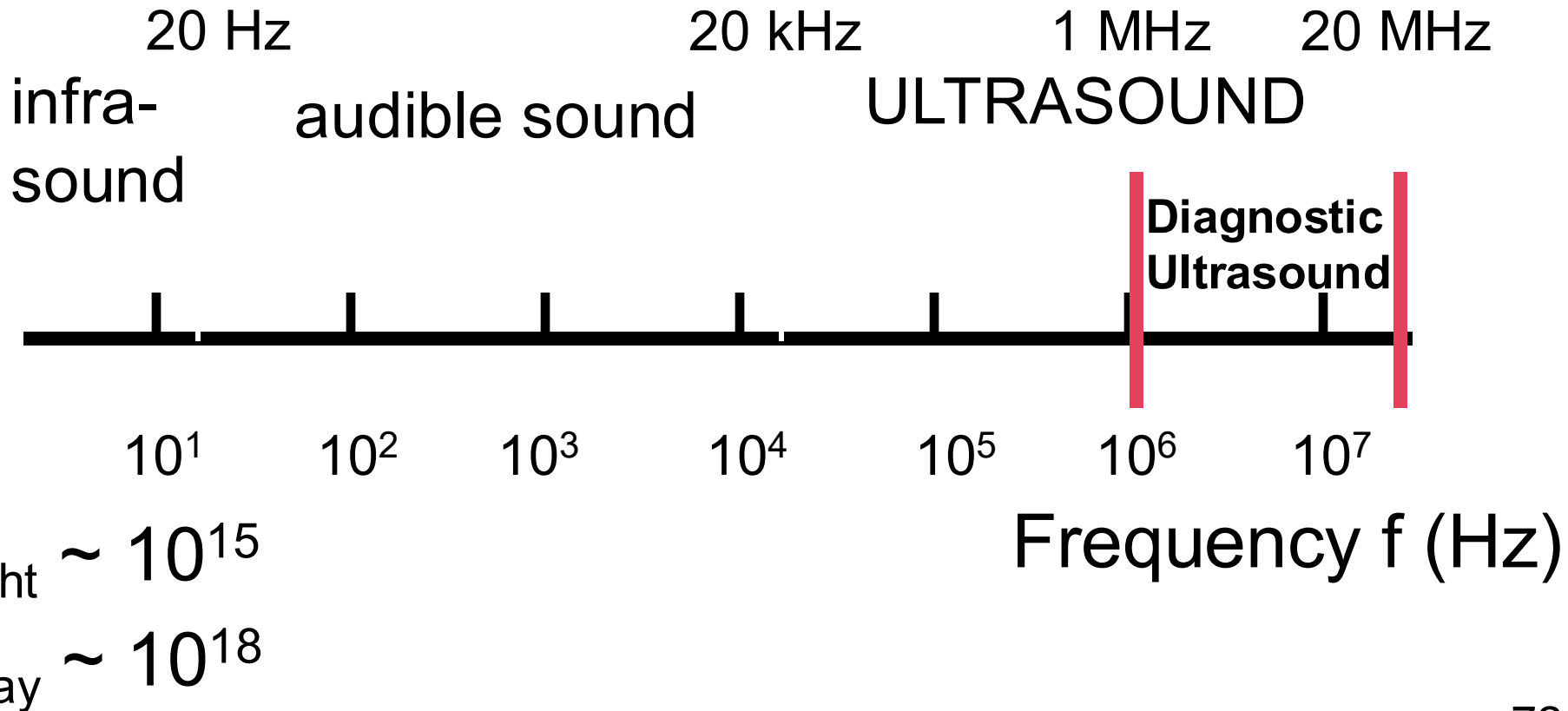
Physics Principle

- Traveling pressure waves through a medium.



Ultrasound

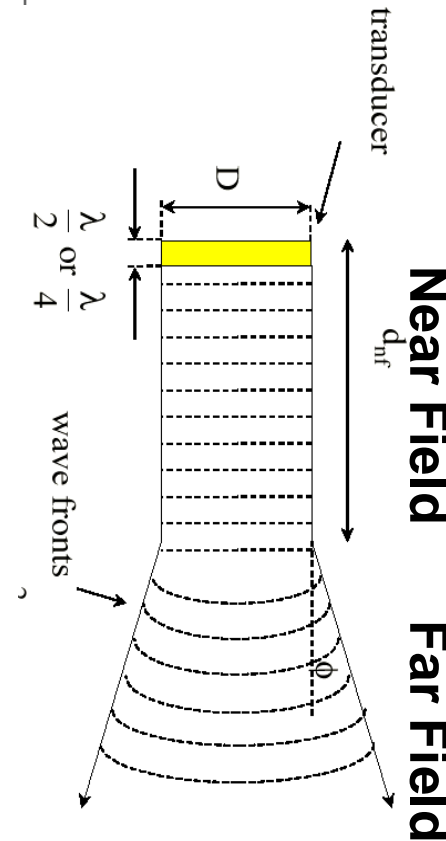
Physics Principle



Ultrasound

Image Formation

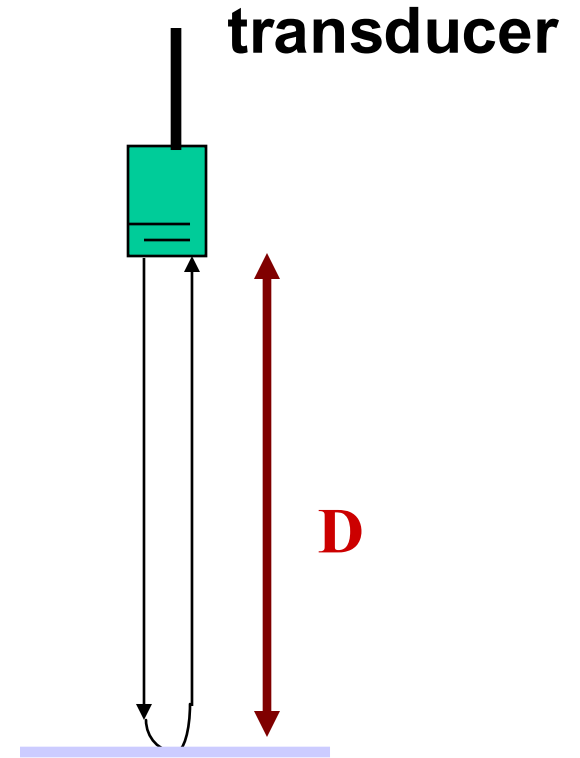
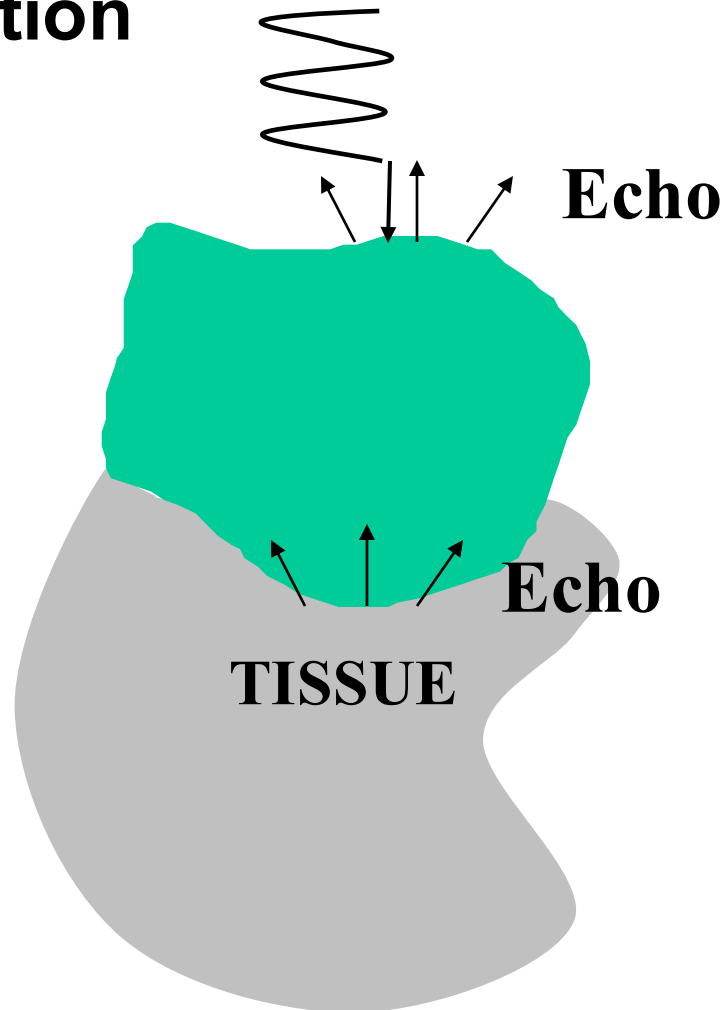
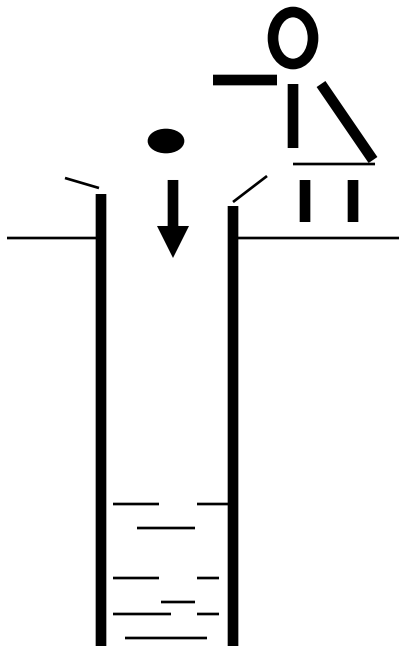
- Sound waves propagate through the body.
- At each interface, part is reflected, part is transmitted.
- Reflected waves are recorded back.



Ultrasound

Ultrasound Pulse

Image Formation

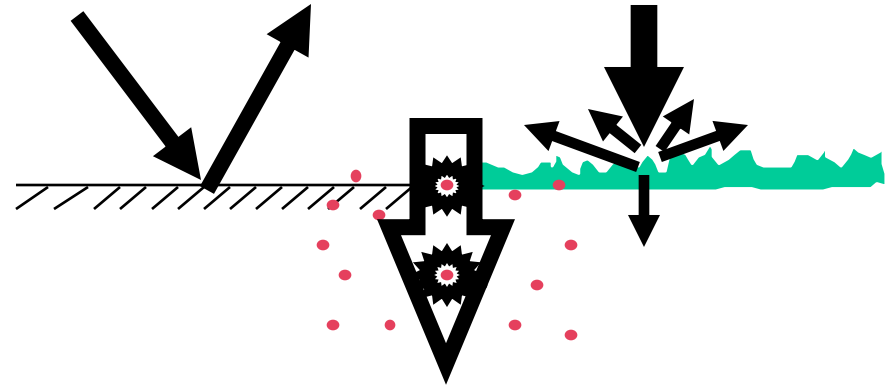


$$D = c \times \text{Time} / 2$$
$$c = 1.54 \text{ mm}/\mu\text{s}$$

Ultrasound

Image Capture

- **Recorded signals:**
 - Specular reflection, Diffuse scattering, Rayleigh scattering
- **Frame rate (FR)** = number of times per second a sweep of the ultrasound beam is performed.
 - The higher the frame rate, the better the temporal resolution.
 - Limited by:
 - Time delay from maximum depth.
 - Speed of sound.



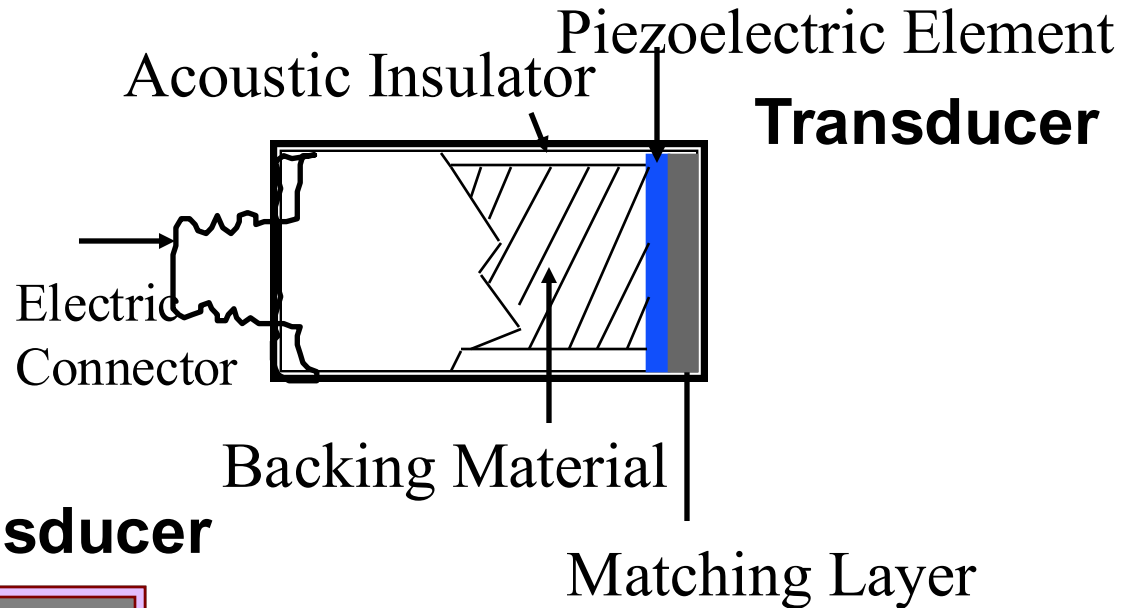
A transducer converts electrical energy into ultrasounds and vice-versa.

Piezoelectric transducers are based on the piezoelectric effect.

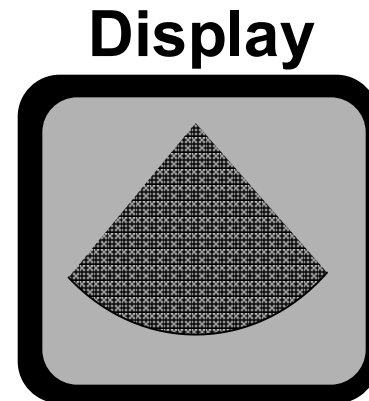
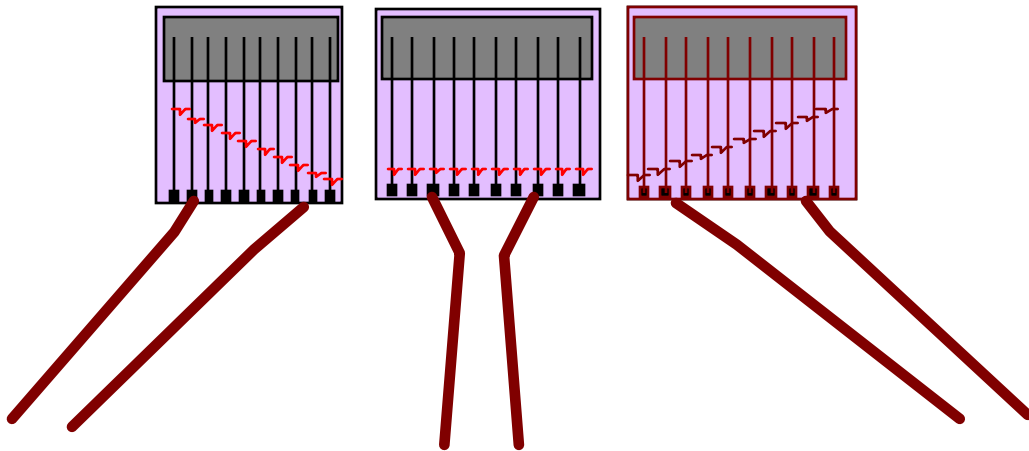


Ultrasound

System Design



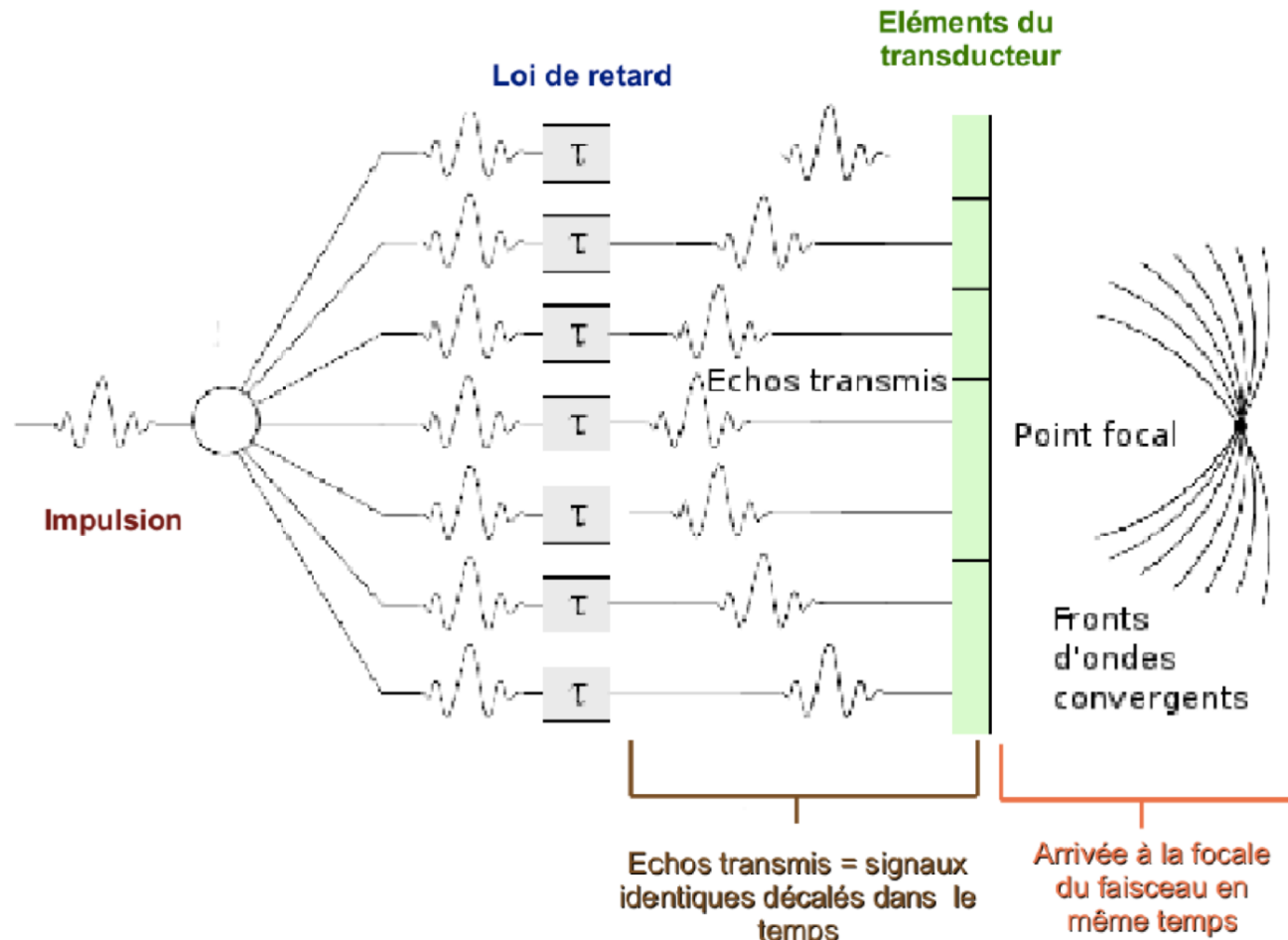
Phased array transducer



Phased array transducer: Emission

Focused waveform produced by delaying in a different way all elements

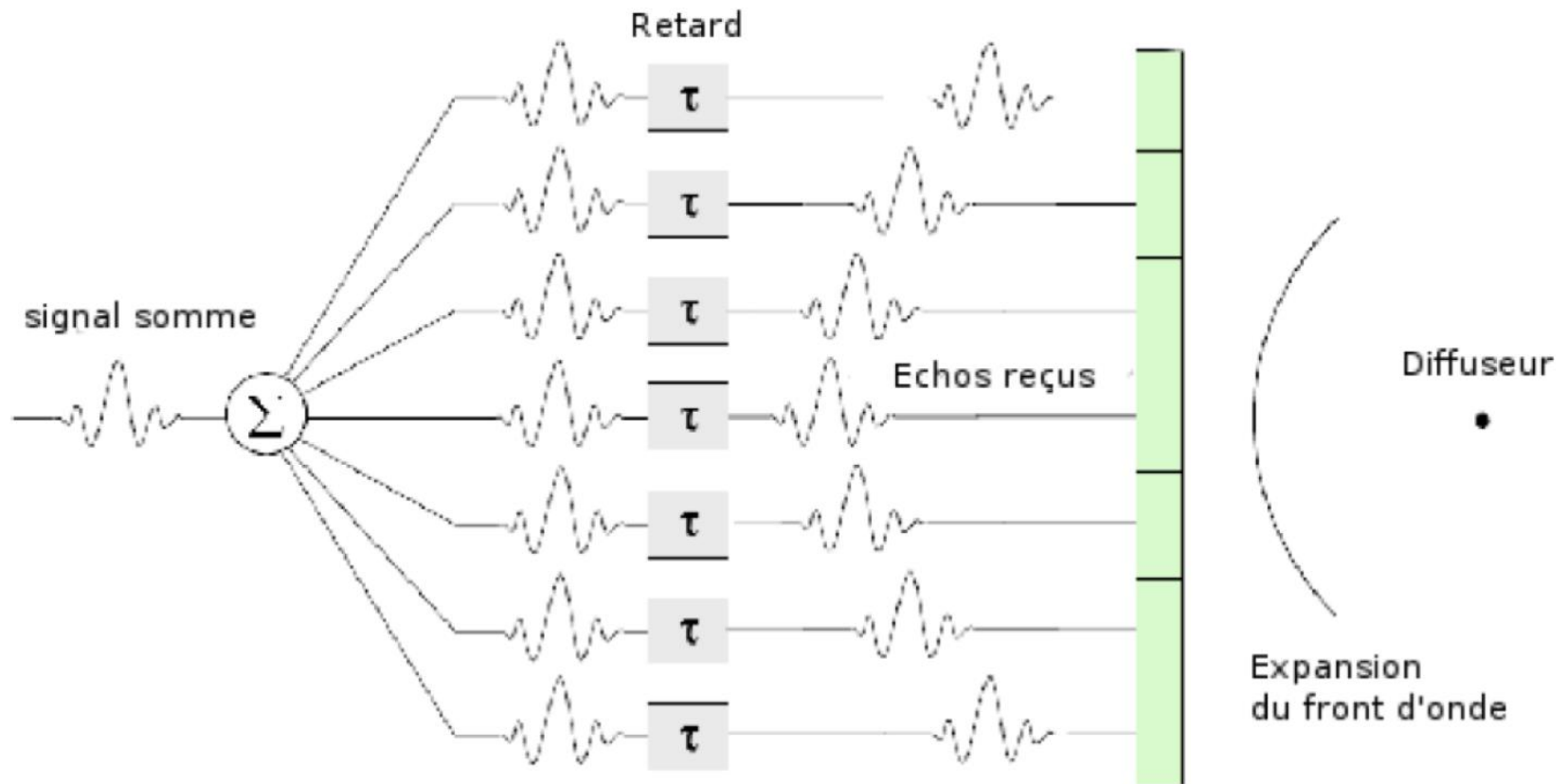
-> ultrasonic pulses arrive at the same point simultaneously



Phased array transducer: Reception

Received signals are delayed in order to be in phase and then summed together

-> produce acoustic signature of a precise point



Acoustic impedance of a medium:

$$Z = \rho c$$

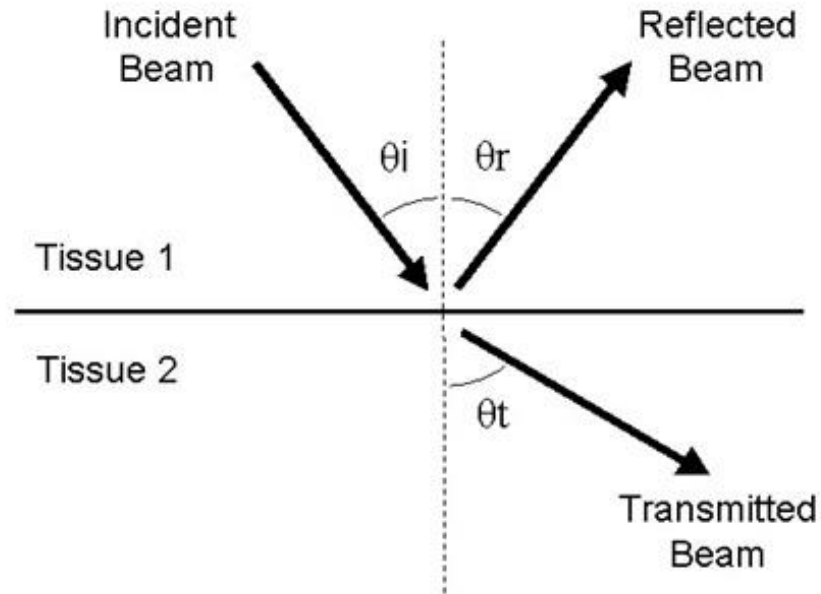
ρ = density

c = velocity

Interfaces are characterized by:

- Impedance values of the two mediums
- Shape of the mediums (curved or plane)
- Orientation with respect to the wave direction
- Roughness of the mediums
- Size of the mediums

When an ultrasonic wave encounters an interface it is reflected and refracted (or transmitted).



Refraction coefficient

Transmission coefficient

Importante of the relative impedances!

Absorption: Energy absorbed by the medium is converted to heat

-> intensity of the ultrasound wave decreases

It follows an exponential model: $I = I_0 \exp(-ax)$

$a = kf^2$ or kf (depending on tissues): absorption coefficient

x = distance from the source

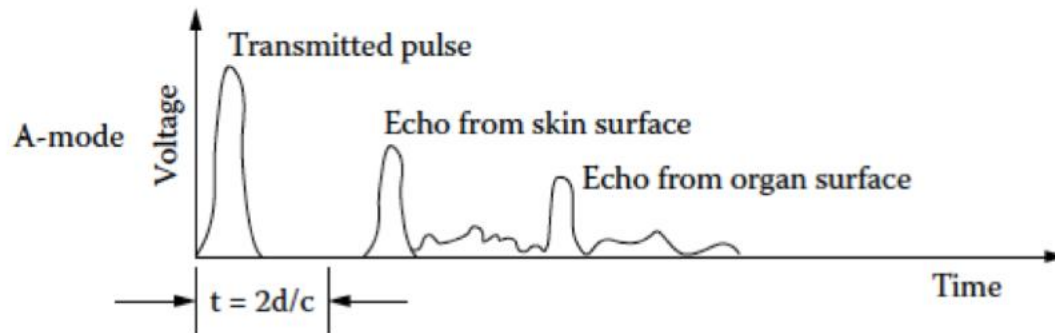
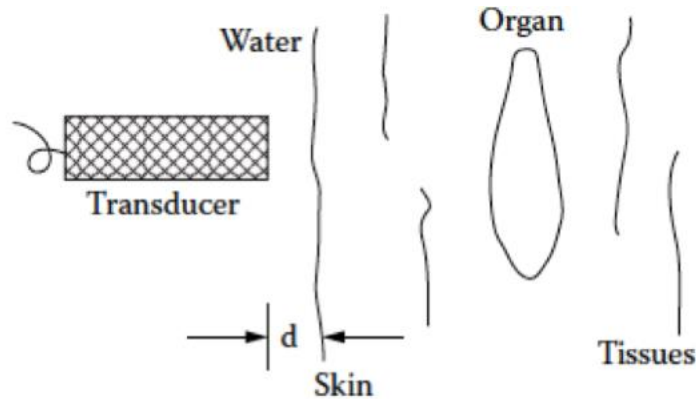
I_0 = initial intensity

Frequency of ultrasound determines the maximal depth: the greater f , the faster the ultrasound wave energy is absorbed.

Example:

- with $f = 10\text{MHz}$ (e.g. eye) the max depth is 2cm
- with $f = 2.5\text{MHz}$ the max depth is $> 15\text{cm}$

Ultrasound: brightness (B) mode imaging



(a)

B-mode

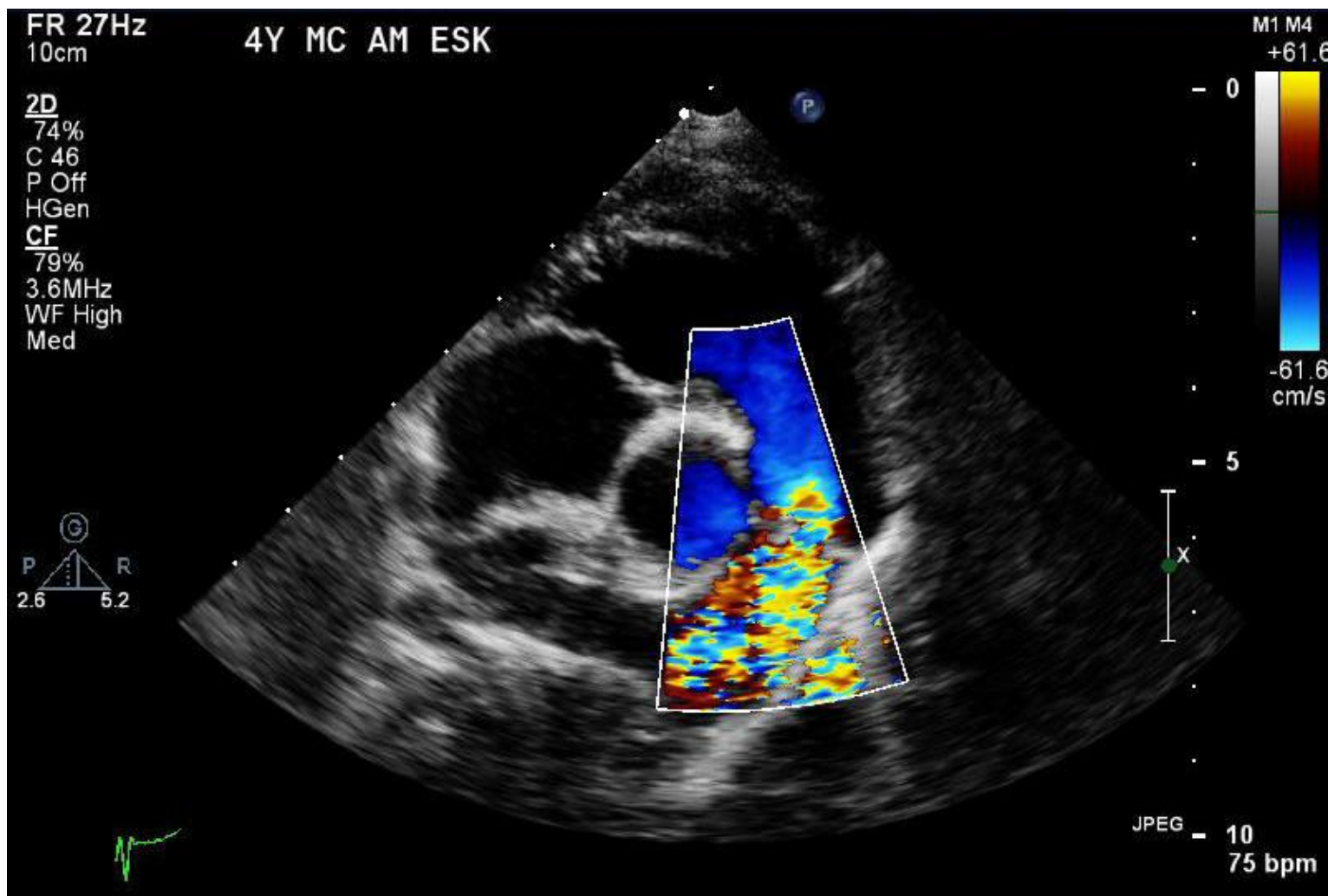




Ultrasound: Doppler imaging

Definition: An observer perceives a variation in frequency of a sound when the source of the sound and/or the observer are moving.

Used for measurement and imaging of blood flow (Doppler frequency is proportional to red cell velocity).



Source: Kienle et al., 1998

Ultrasound artifact: Acoustic shadowing

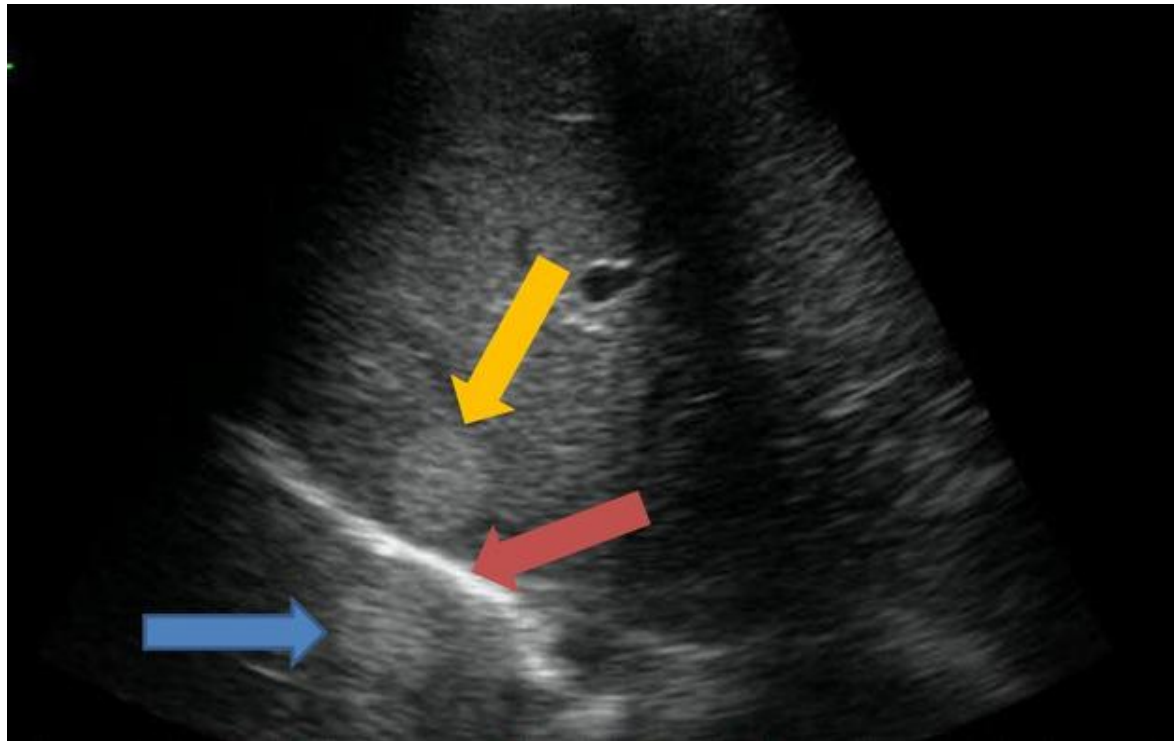
Signal void behind structures that strongly absorb or reflect US



Source:
Radiopedia

Ultrasound artifact: Mirror image

Echo from structure A finds another structure B and it is reflected back to structure A. Echo is then again reflected back to transducer -> Echo is judged to come from a deeper structure.



Source:
Radiopedia

Ultrasound

- **Advantages:**
 - Portable.
 - Inexpensive.
 - Good spatial resolution (<1mm).
 - High temporal resolution.
 - No ionizing radiation, safe.
- **Disadvantages:**
 - Poor image quality.
 - High level of noise.
 - Operator-dependent.

Ultrasound

Applications

- Obstetric
- Heart
- Gastro-intestinal track (liver, gall bladder, pancreas)
- Urinary track (bladder, kidneys)
- Genital organs (prostate, testicles, ovaries, uterus).
- Blood vessels (Doppler).

Ultrasound

Example: Fetus

- Establish number of fetus.
- Check position of placenta.
- Determine fetal age and development.
- Check for congenital defects.
- Check fetus position.



Fetus at 9 weeks



Ultrasound

Example: Obstetric

1961: First image of fetus



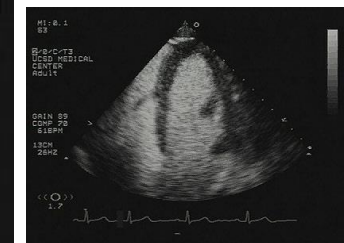
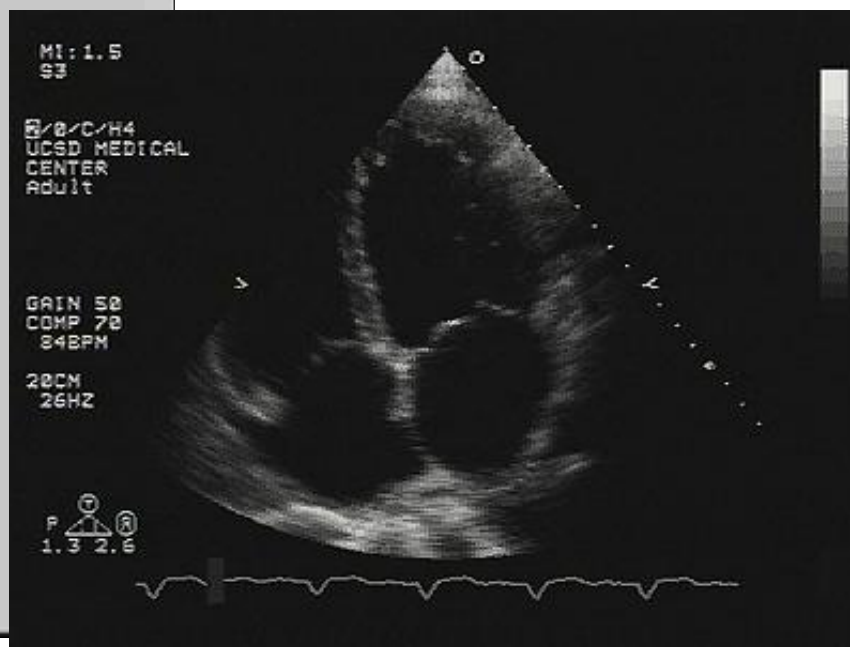
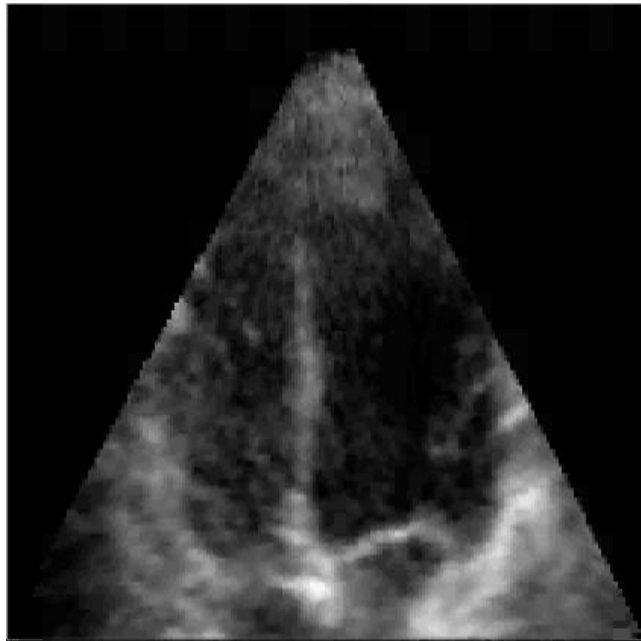
1990: First 3D visualization of fetus



Ultrasound

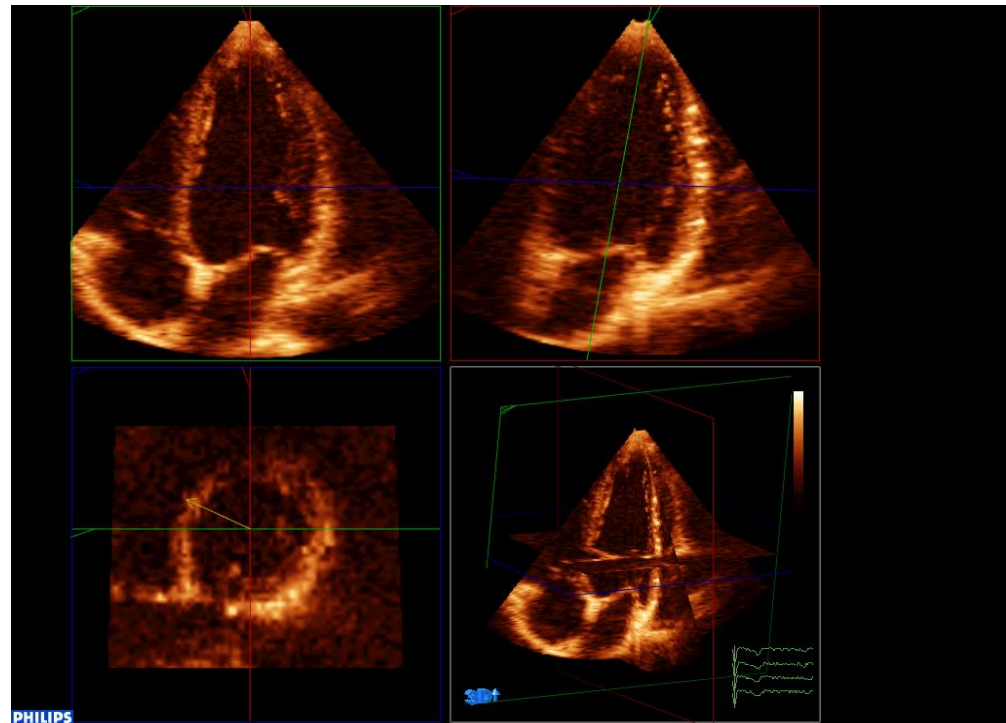
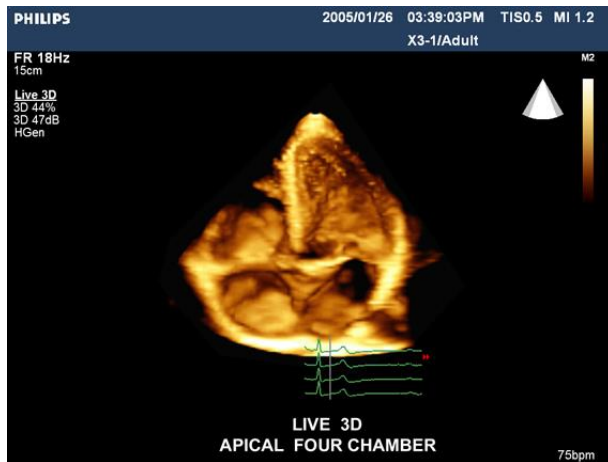
Example: Heart

- Valve diseases.
- Cardiac function (pumping efficiency).
- Blood clots in cardiac chamber.

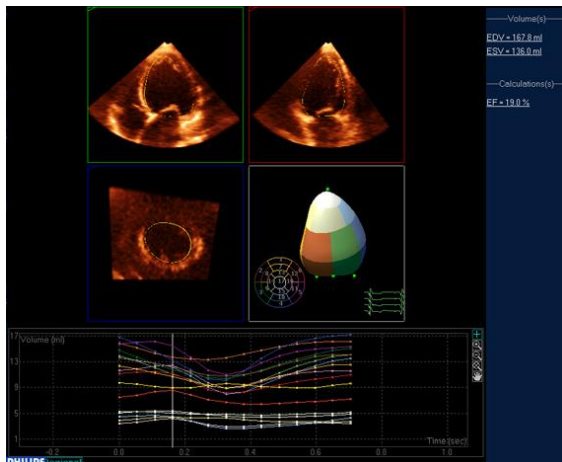


Ultrasound

Example: Heart



- Real-Time 3D Ultrasound

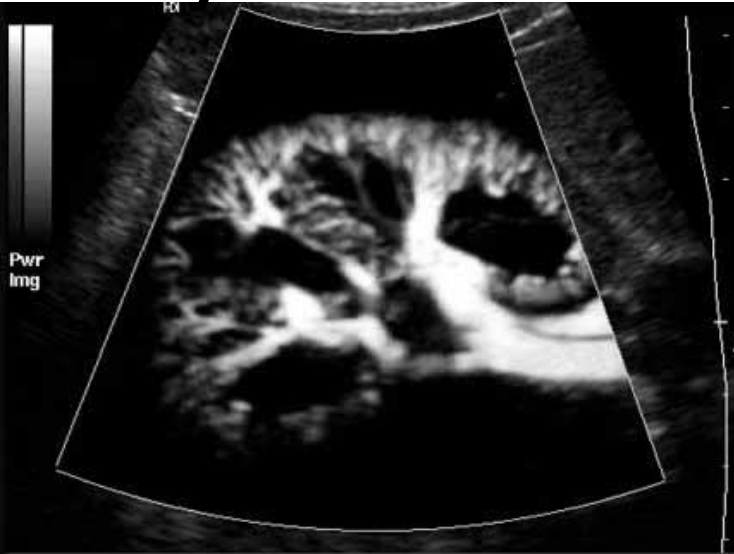


Ultrasound

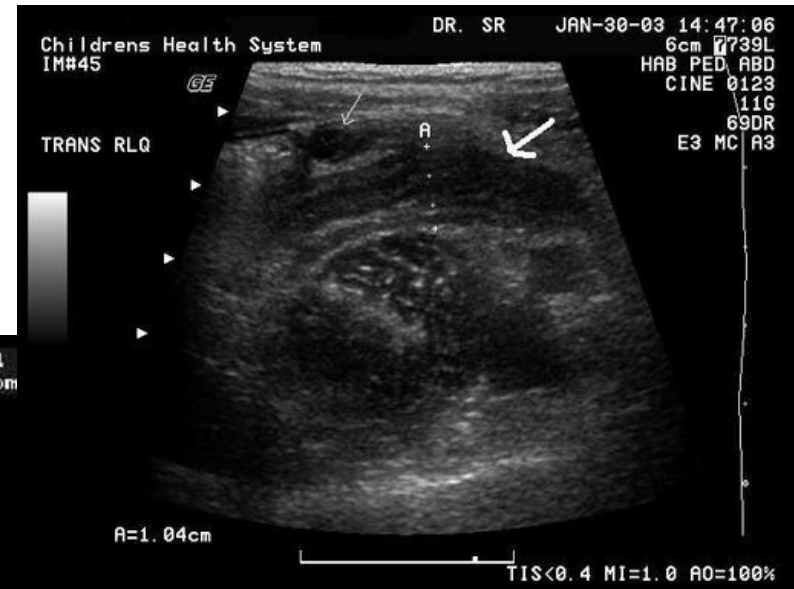
Examples: Abdomen

- Biopsy guidance.
- Diagnosis of abdominal pains, kidney stones, inflamed appendicitis.

kidney



liver

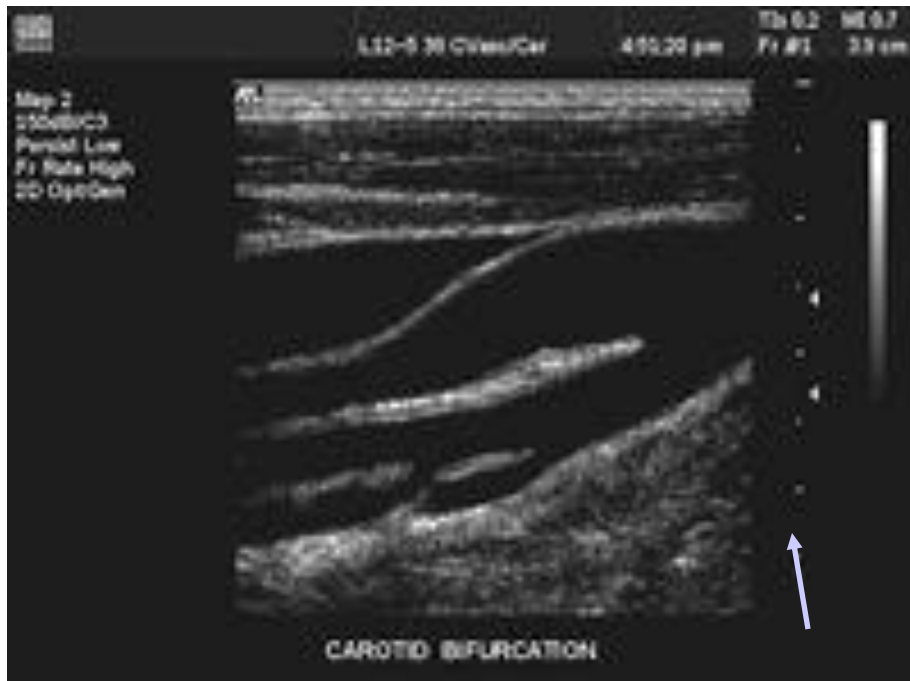


appendicitis

Ultrasound

Example: Blood vessels

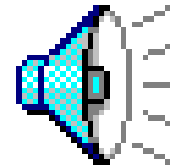
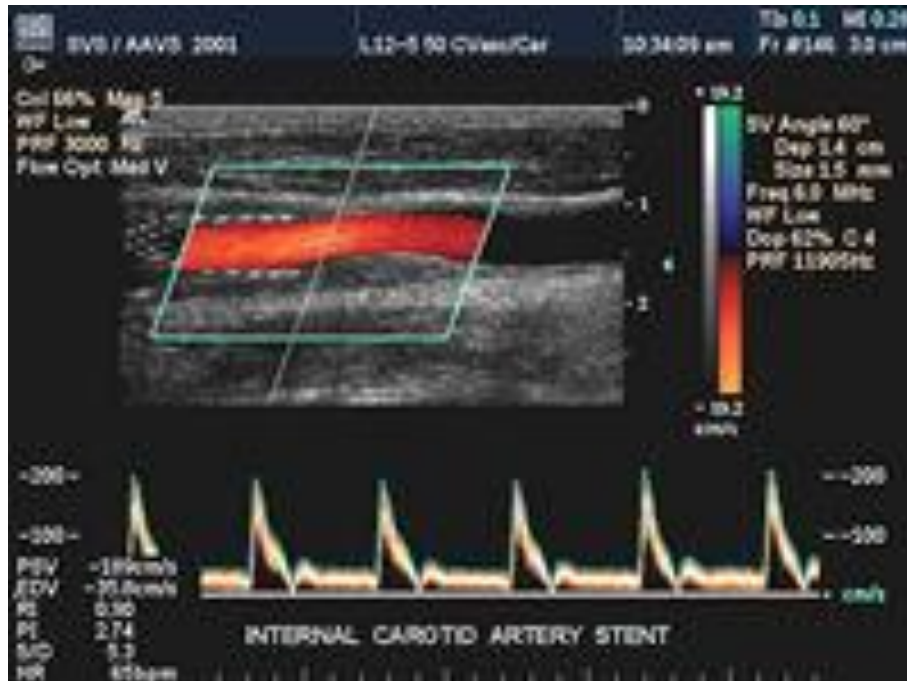
- Artery blockage from blood clots.
- Arteriosclerosis (plaques).
- Stent position



Ultrasound

Example: Blood vessels

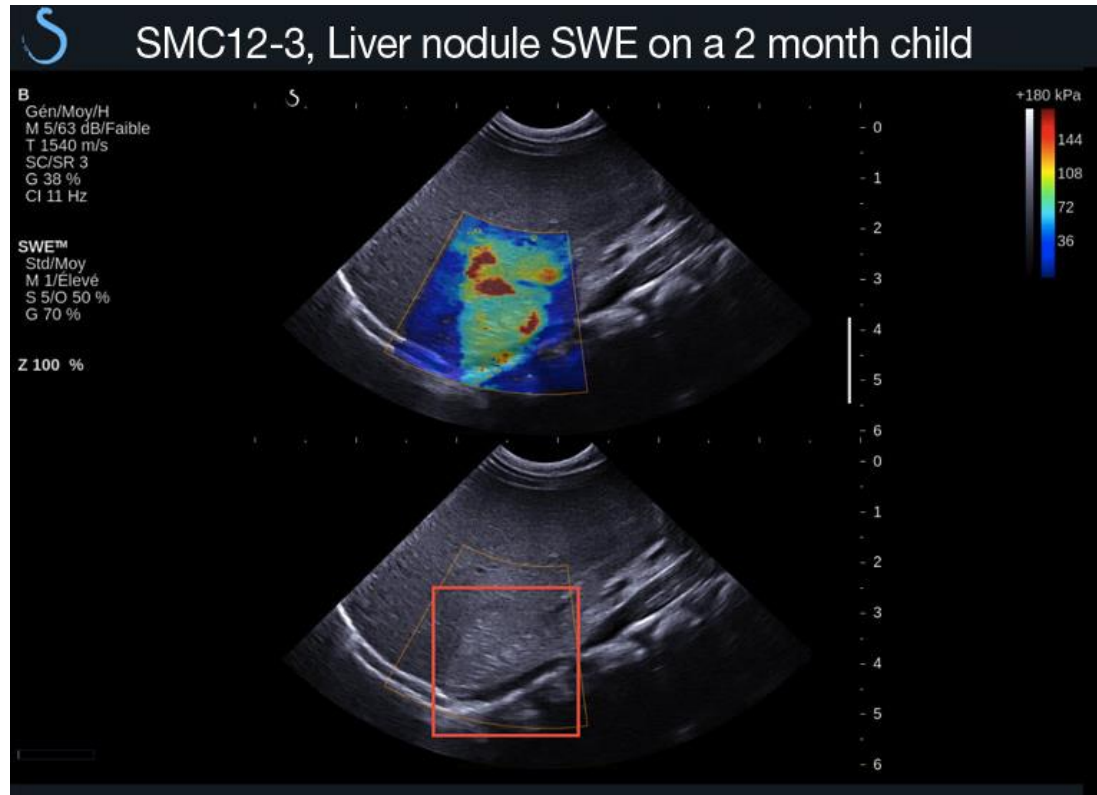
- Doppler



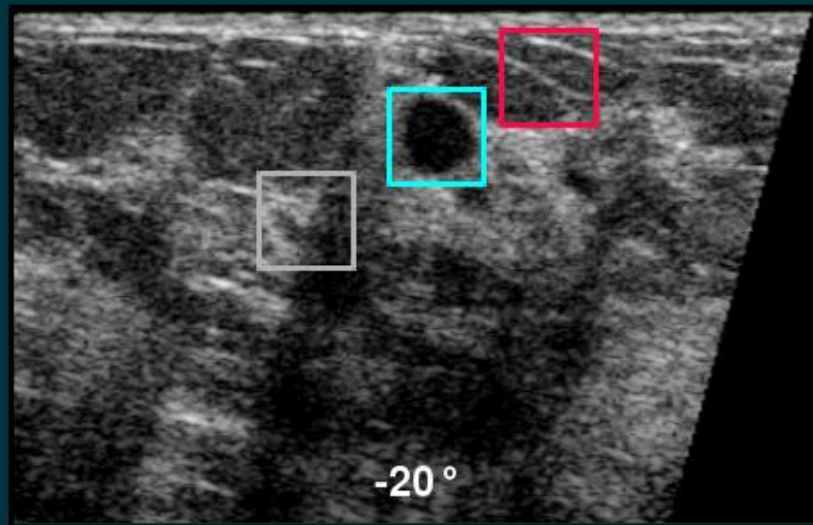
Ultrasound

Elastography

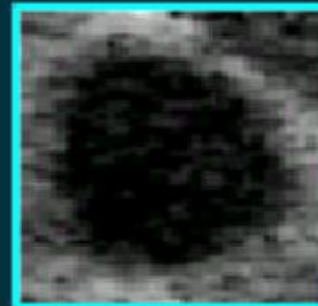
Exploits shear wave (orthogonal to vibration)



2D Spatial Compounding Example



Speckle

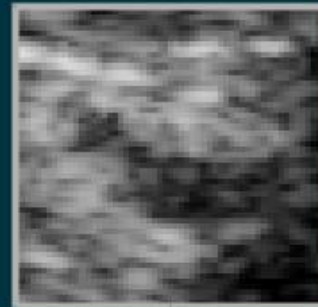
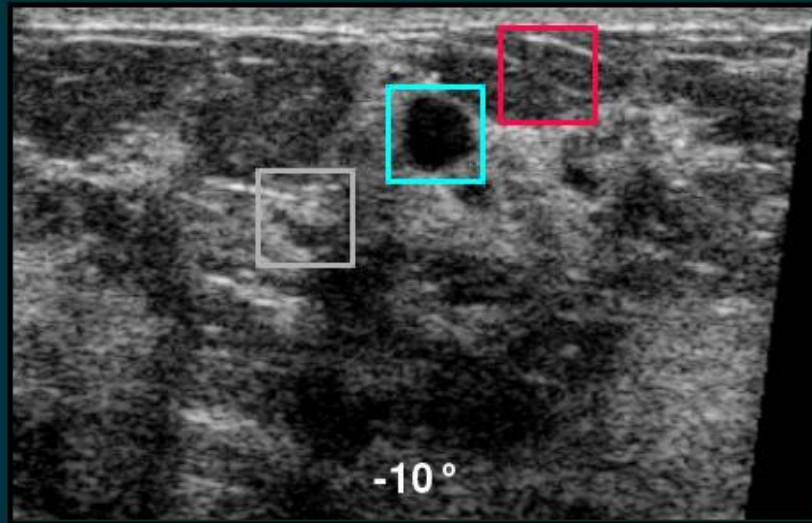


Clutter

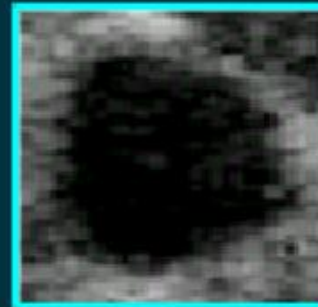


Specular reflectors

2D Spatial Compounding Example



Speckle

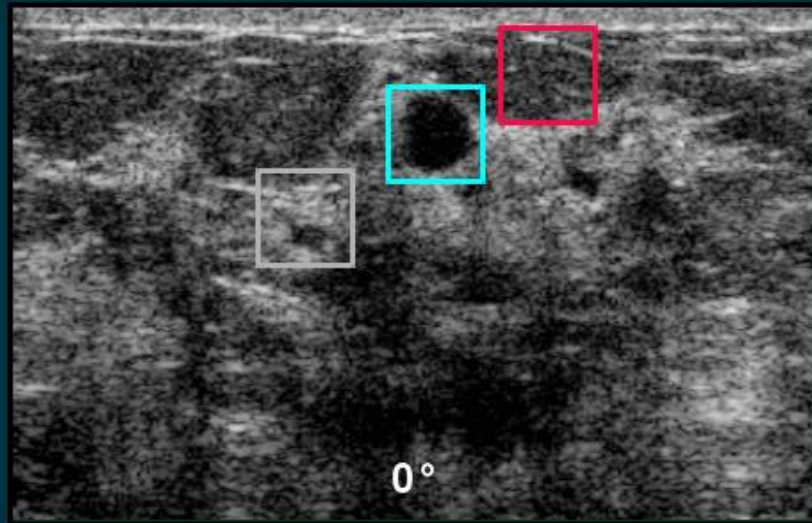


Clutter



Specular
reflectors

2D Spatial Compounding Example



Speckle



Clutter



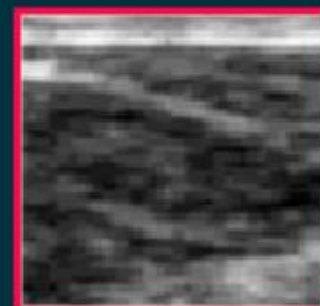
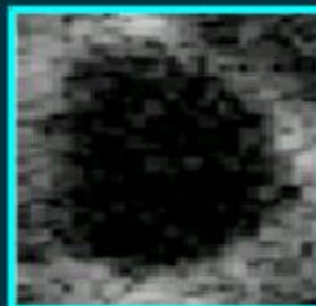
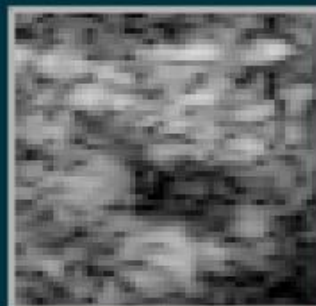
Specular reflectors

2D Spatial Compounding Example



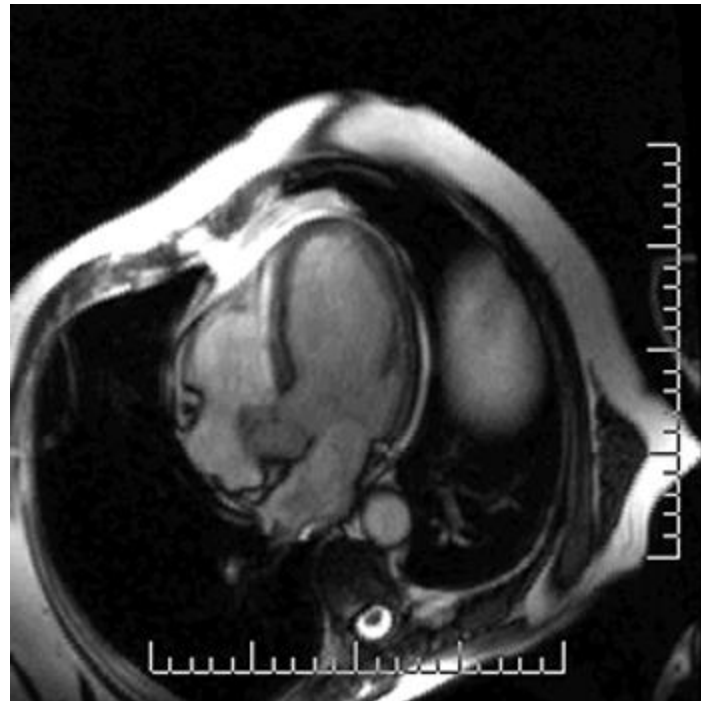
1 view

SonoCT



SonoCT

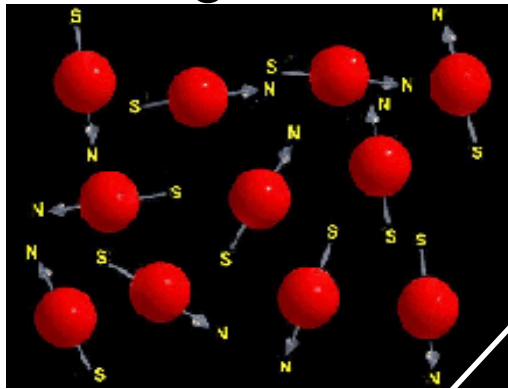
Magnetic Resonance Imaging (MRI)



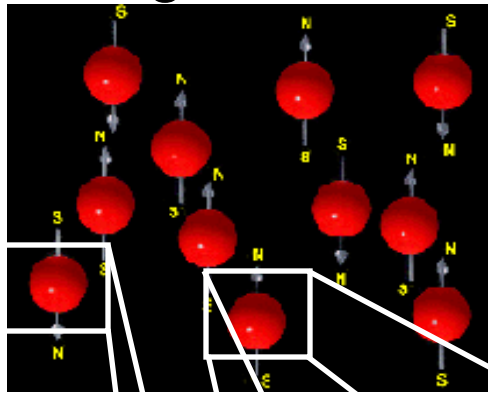
MRI

Physics Principle

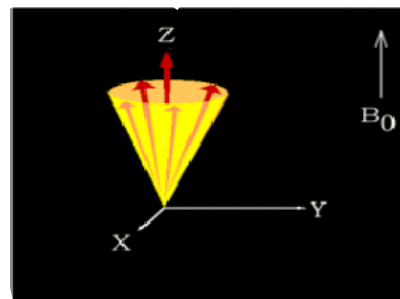
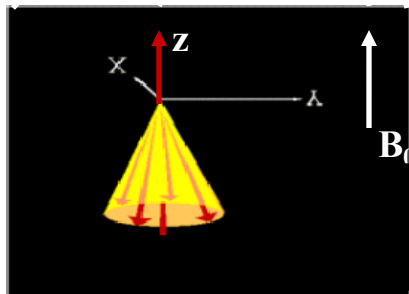
No magnetic field



Magnetic field

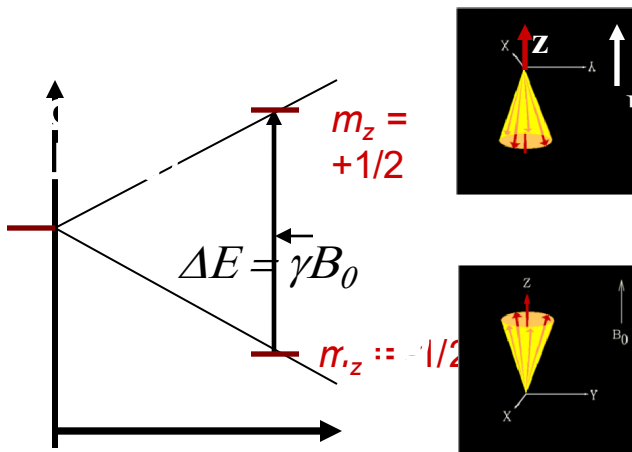


- Nuclei with magnetic dipoles (H).
- Magnetic field B_0 makes nuclei precess along its direction.
- The precession rate is the Larmor frequency.
- $f_L = \gamma B_0$ ($43 \times 1.5 = 64$ MHz for Hydrogen into a 1.5T magnet).



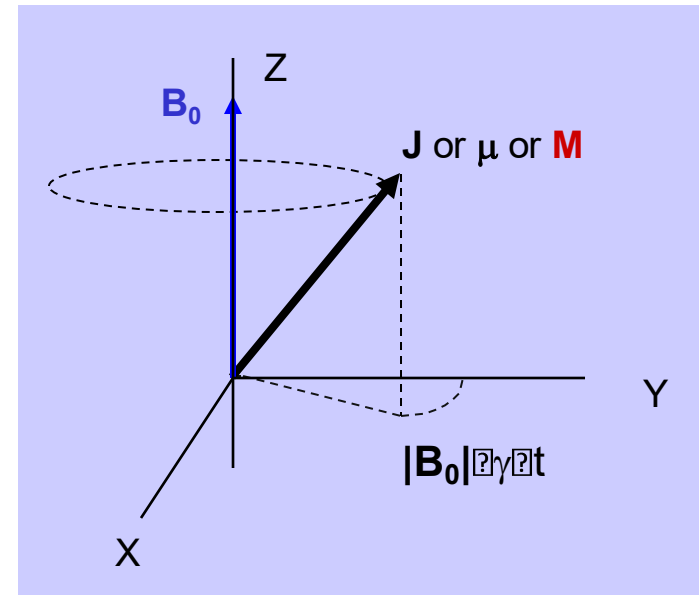
MRI

Image Formation



- For every 1,000,000 nuclei in upper state ($m_z = +1/2$) there are 1,000,007 nuclei in lower state ($m_z = -1/2$).
- This difference is enough to result in macroscopic **net magnetization of material**.

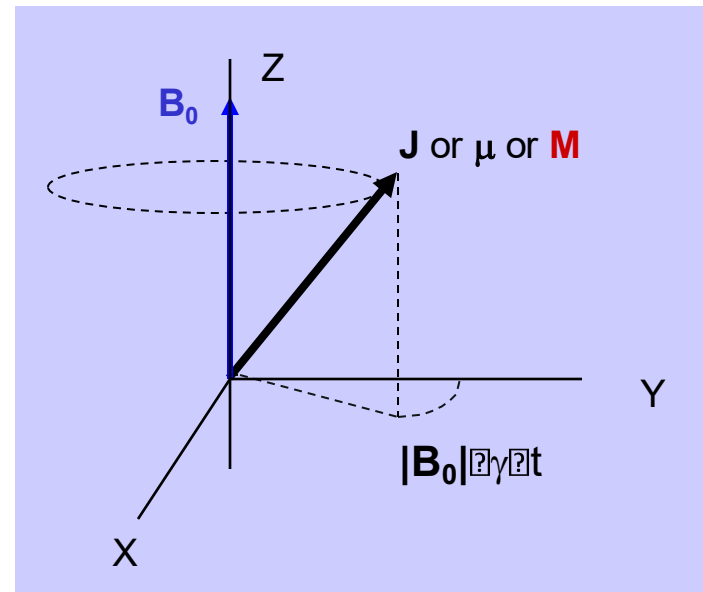
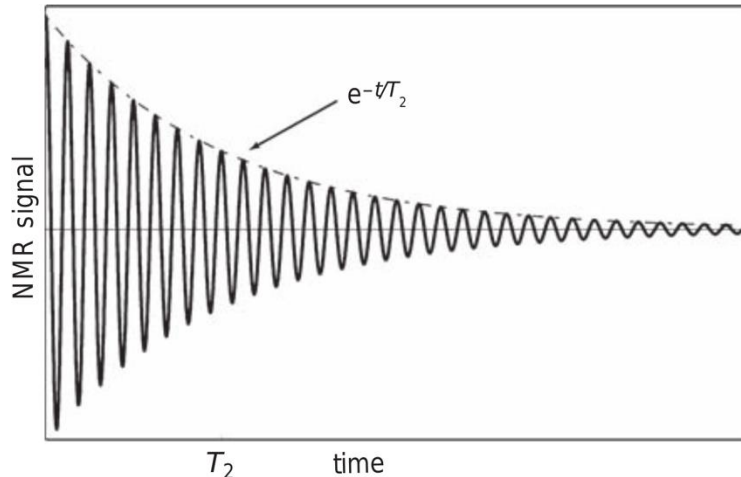
- Nuclei with magnetic dipole moment μ , and angular momentum \mathbf{S} .
- Net magnetization \mathbf{M} = density of μ .
- Tip \mathbf{M} away from $\mathbf{B}_0 \Rightarrow$ Precession at frequency γB_0 , producing a measurable **RF magnetic field**.



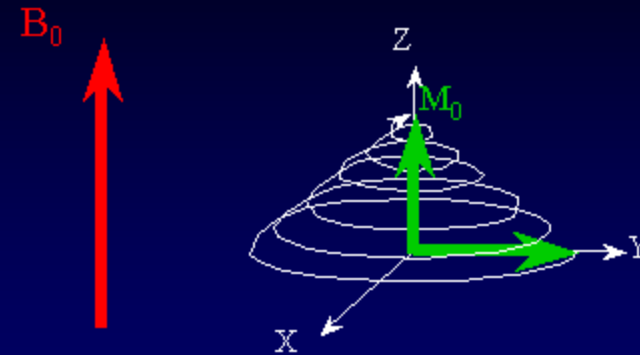
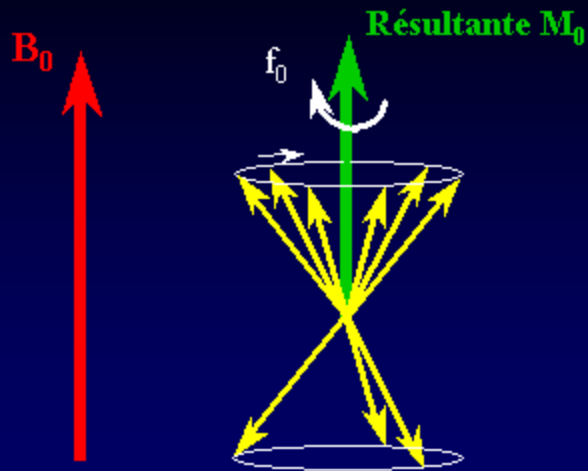
MRI

Image Capture

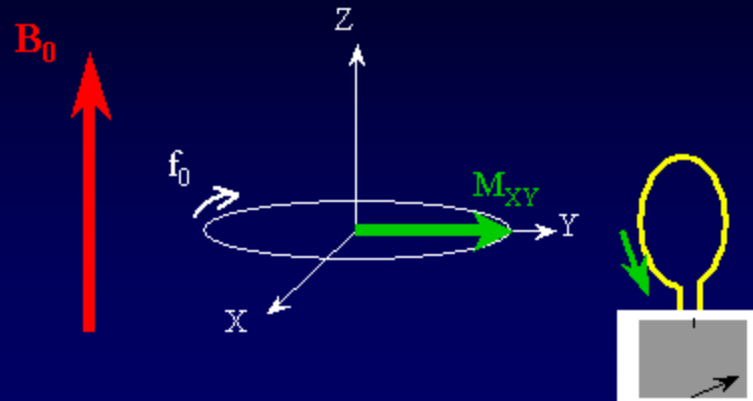
- As the magnetization precesses it creates its own RF magnetic field.
- This field is much smaller than the exciting RF field.
- It can be detected with a standard radio receiver (e.g. RF coils used to tip M away from B_0)
- The resulting signal from precession is called the **Free Induction Decay** or FID.



Retour de l'aimantation à son état d'équilibre:

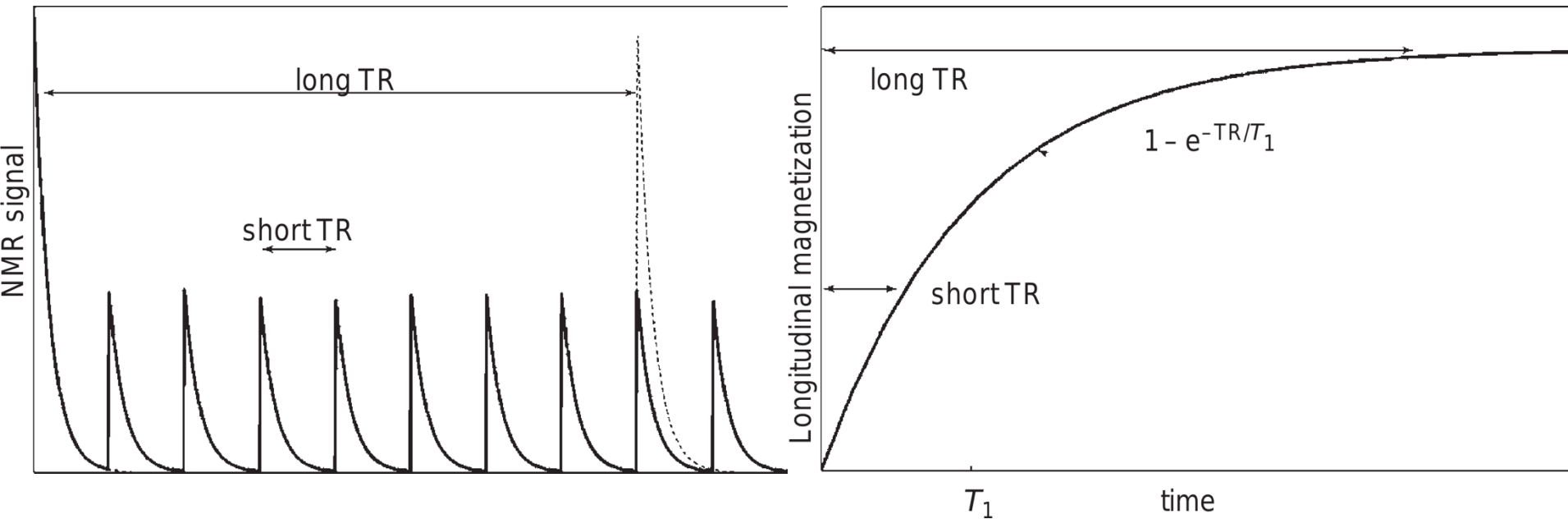


Enregistrement d'un courant dans la bobine de réception:



TR = repetition time (between consecutive RF pulses)

If the recovery of the first FID is not complete ($TR < T_1$), the next FID signal will be reduced.



TE = spin echo time

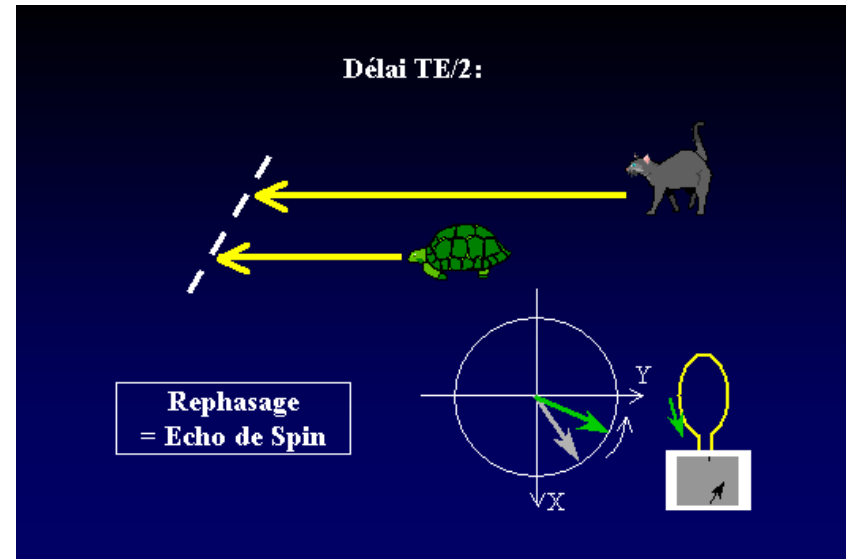
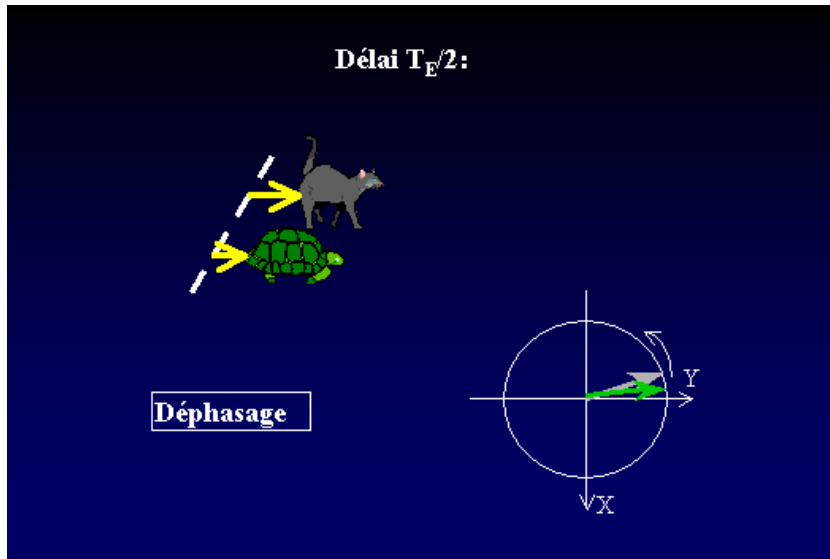
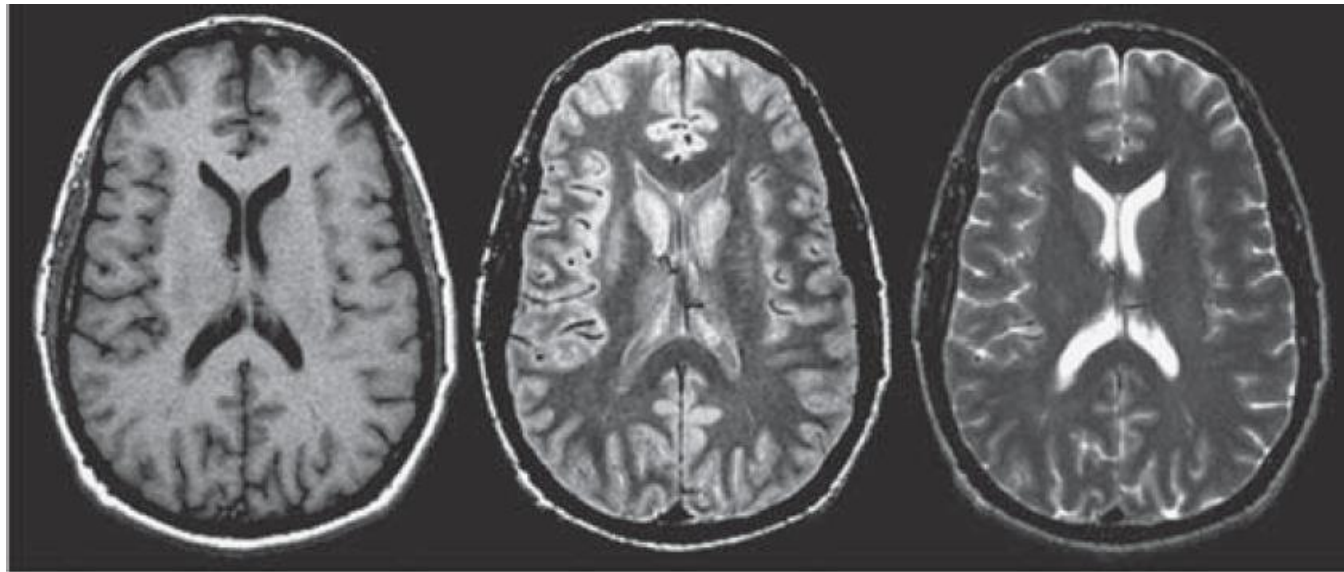


Image contrast:

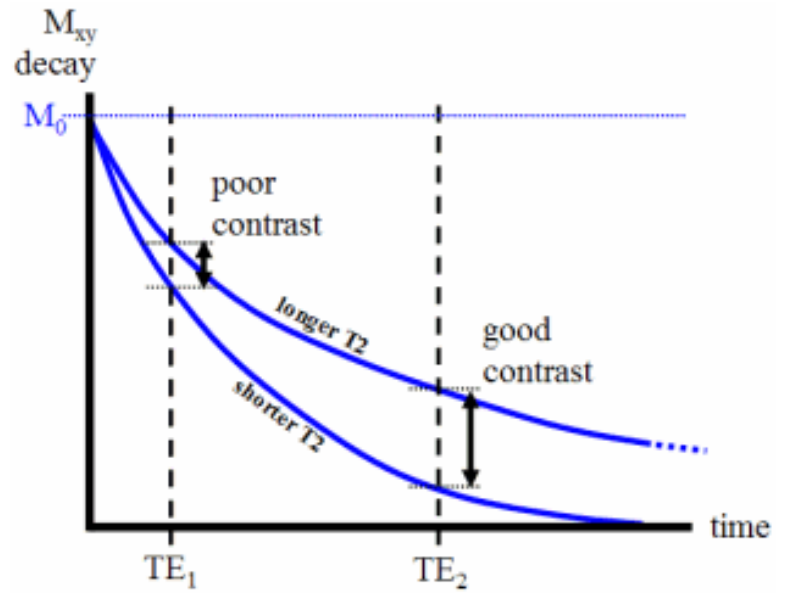
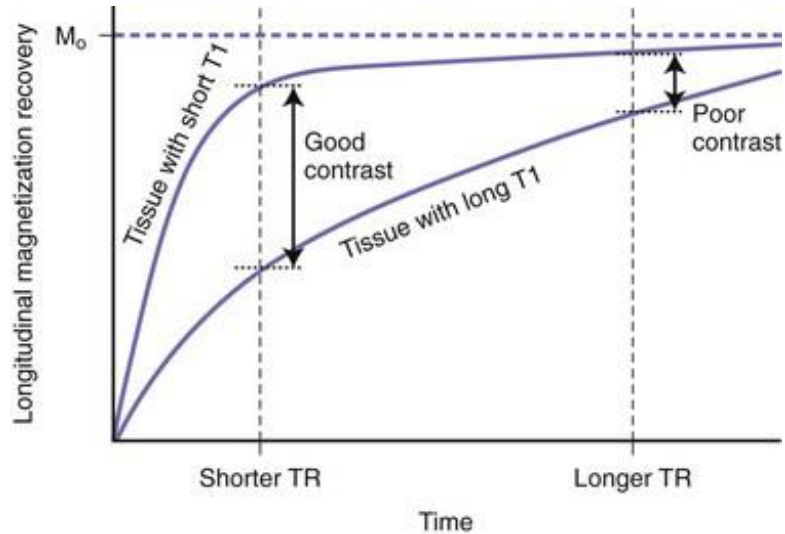


T_1 -weighted
(TR = 600, TE = 11)

Density-weighted
(TR = 3000, TE = 17)

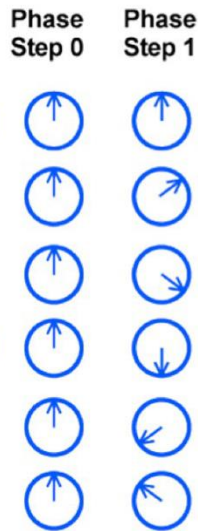
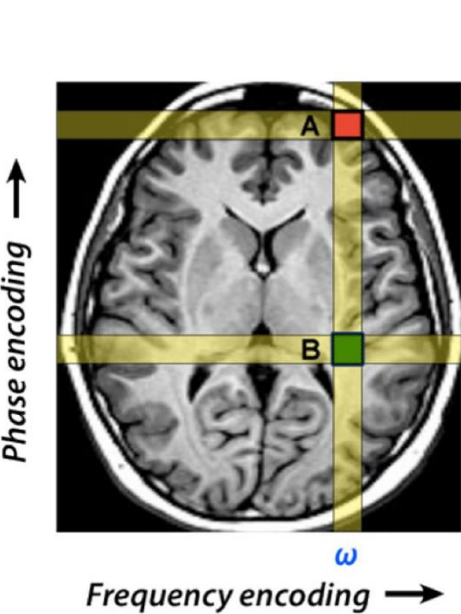
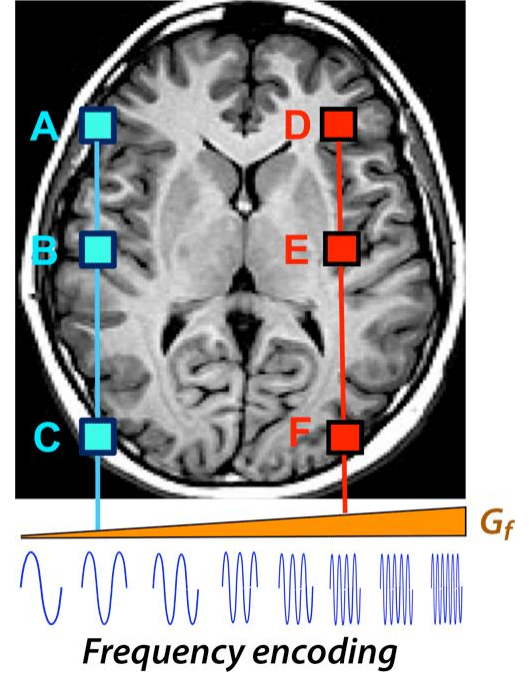
T_2 -weighted
(TR = 3800, TE = 102)

Image contrast:

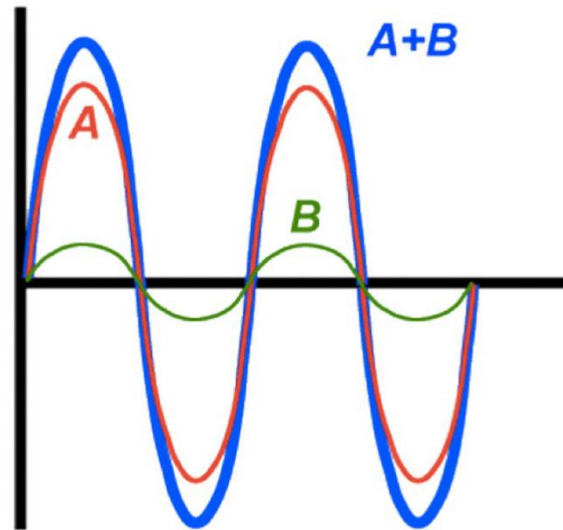


	Short TR	Long TR
Short TE	T1 	PD
Long TE	Poor contrast 	T2

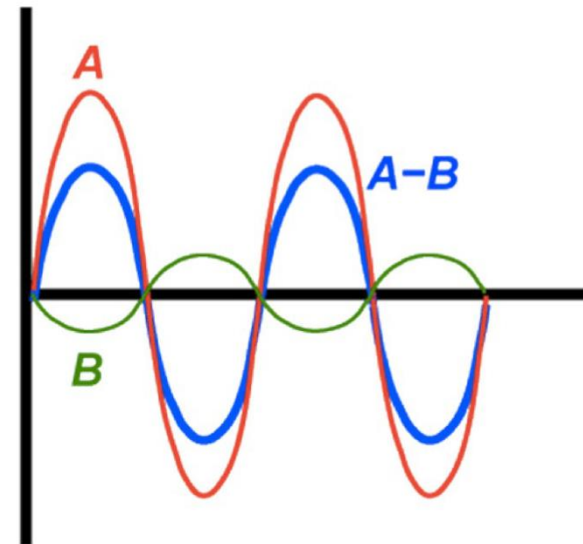
Spatial localization: using gradient field, frequency encoding and phase encoding



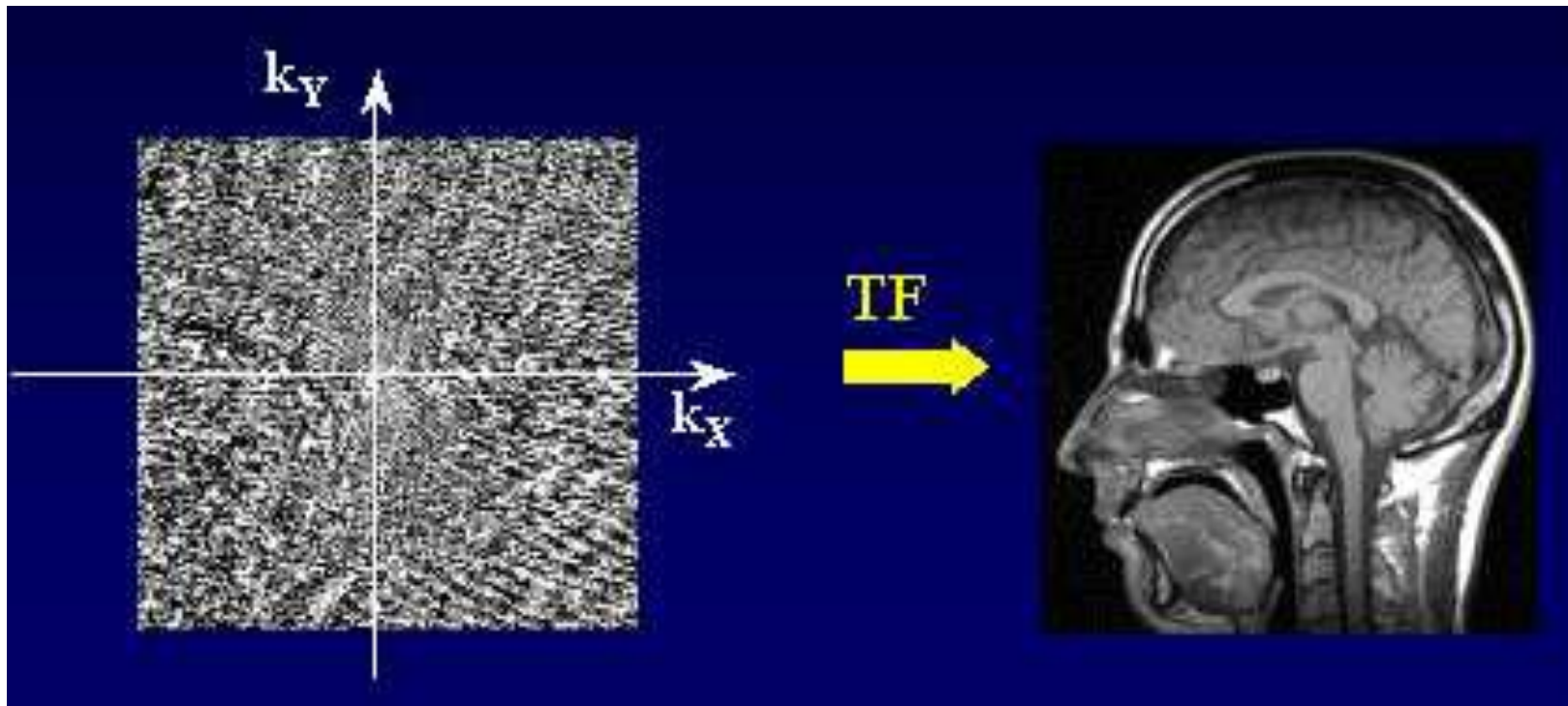
PE Step 0. A & B in phase



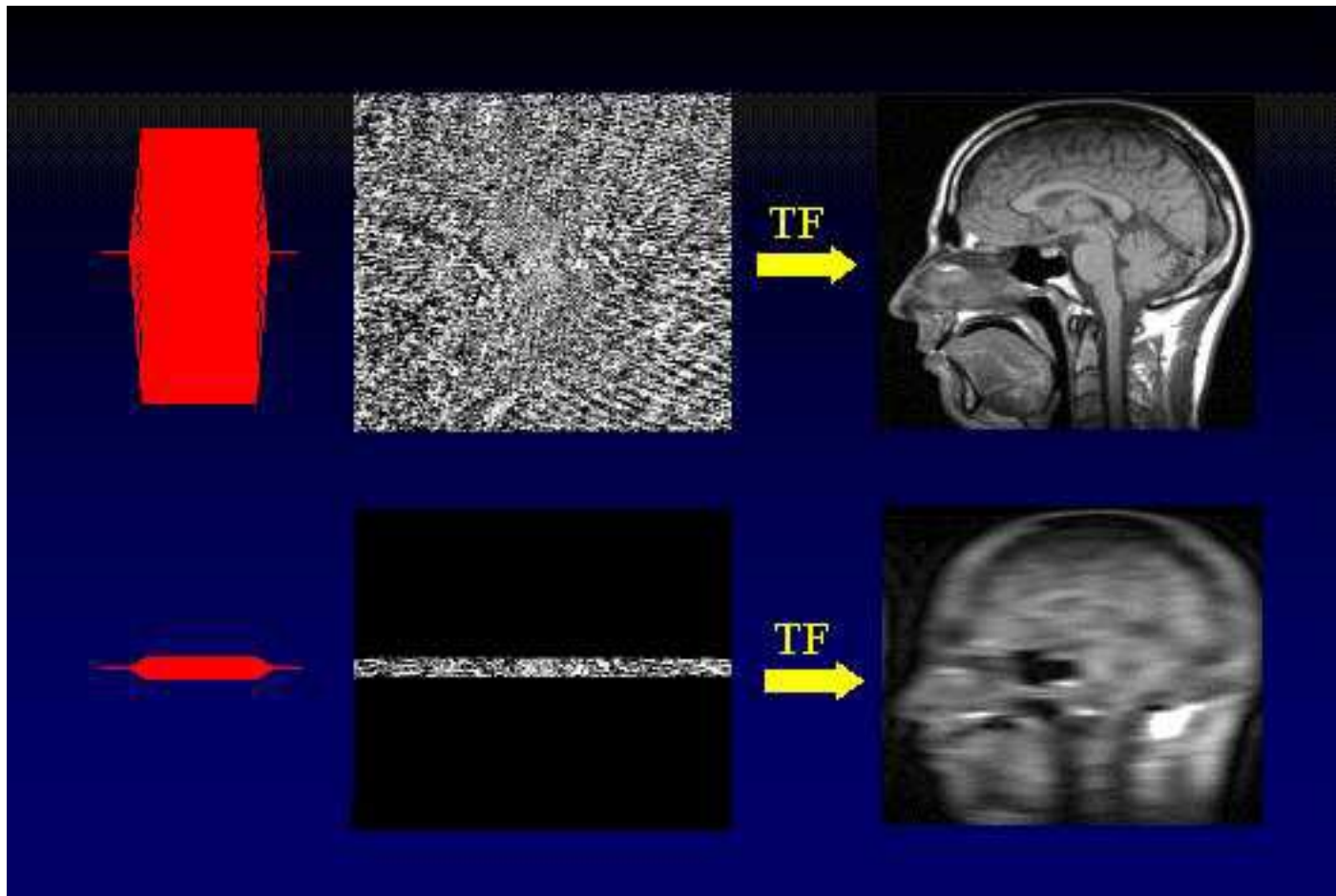
PE Step 1. B phase shifted 180°



signal = sum of the contributions from all the locations
= Fourier transform of the image (k-space)



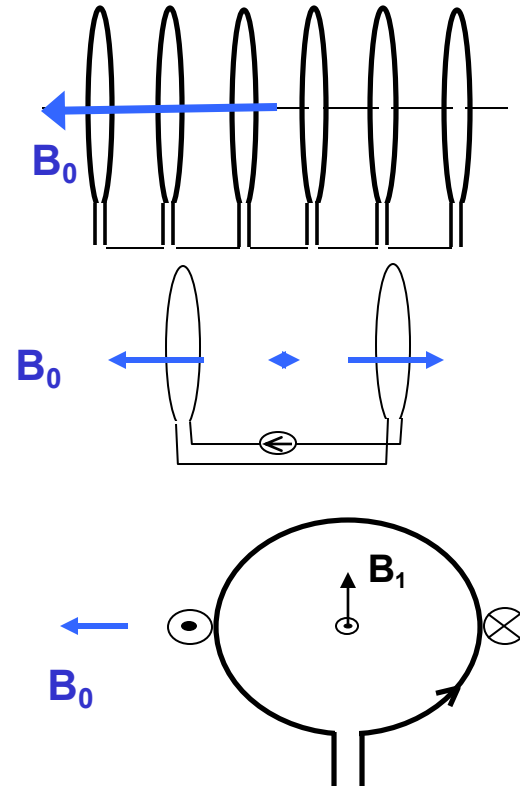
signal = sum of the contributions from all the locations
= Fourier transform of the image (k-space)



MRI

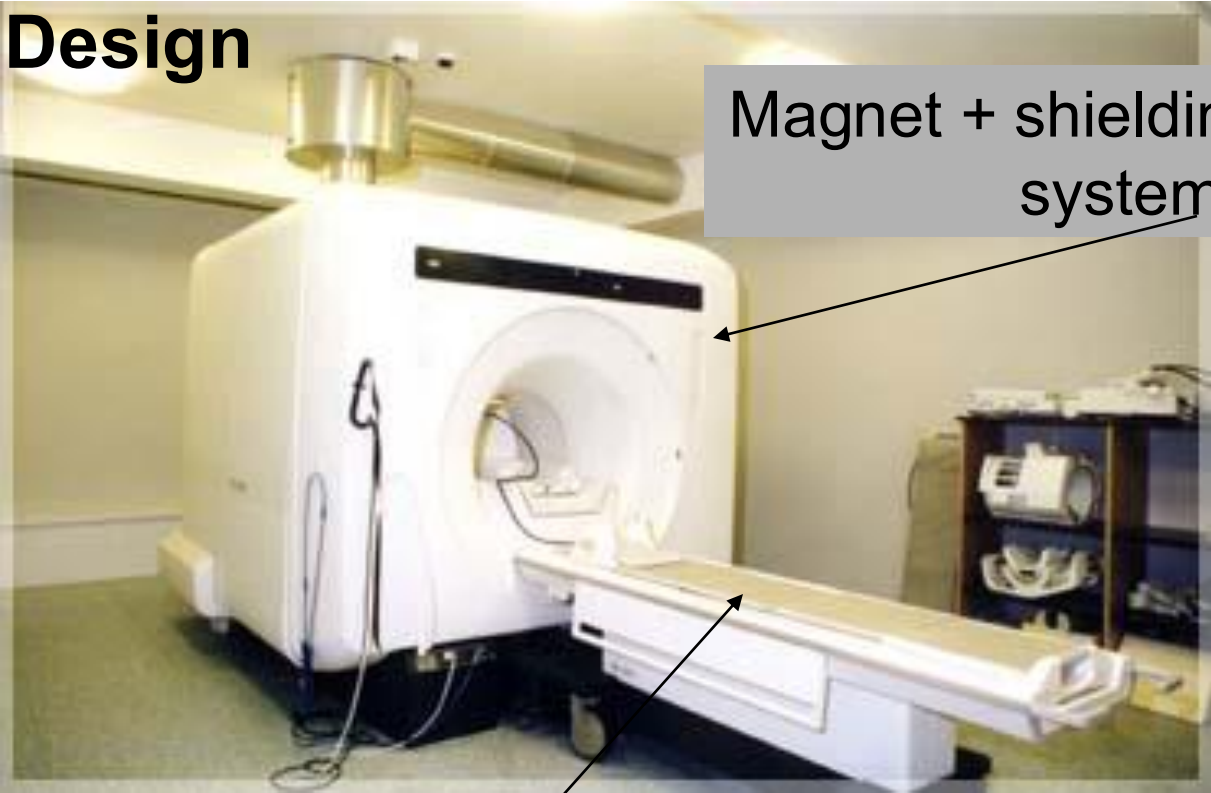
System Design

- **Main Magnet**
 - High, constant, Uniform Field, B_0 .
- **Gradient Coils**
 - Produce pulsed, linear gradients in this field: G_x , G_y , & G_z
 - spatial localization
- **RF coils**
 - Transmitter: B_1 Excites NMR signal to generate Free Induction Decay (FID).
 - Receiver: Senses FID.



MRI

System Design



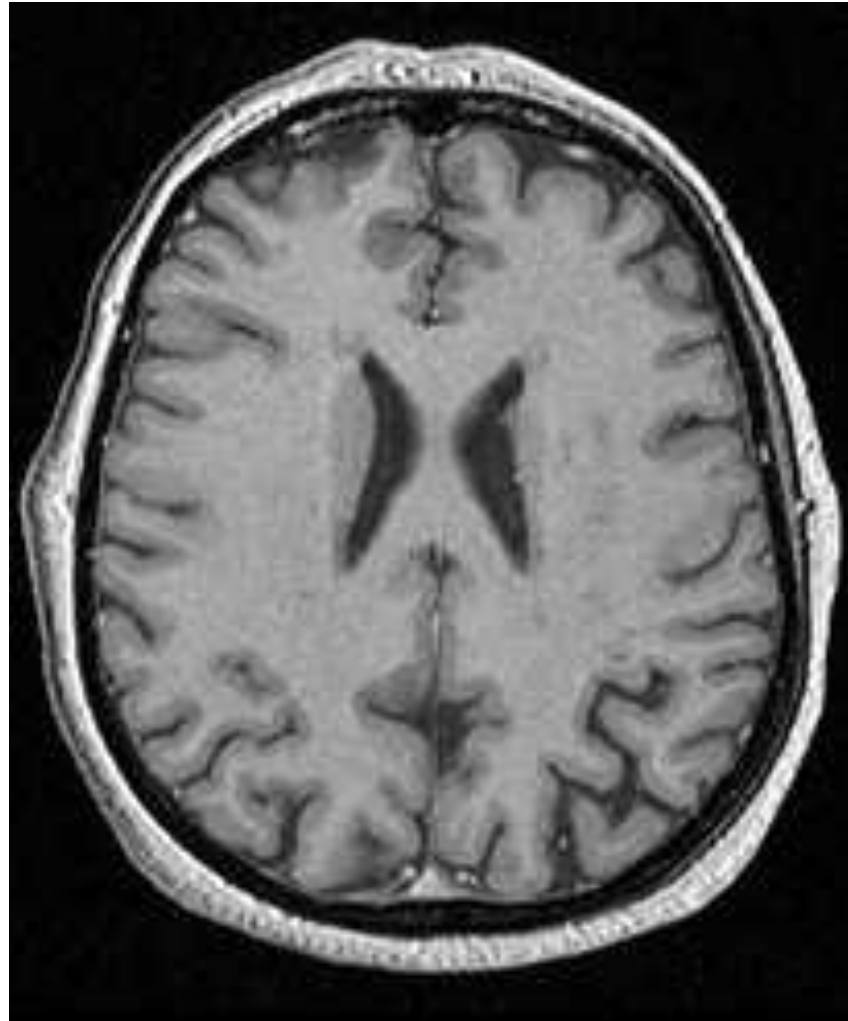
Magnet + shielding + cooling systems

gantry

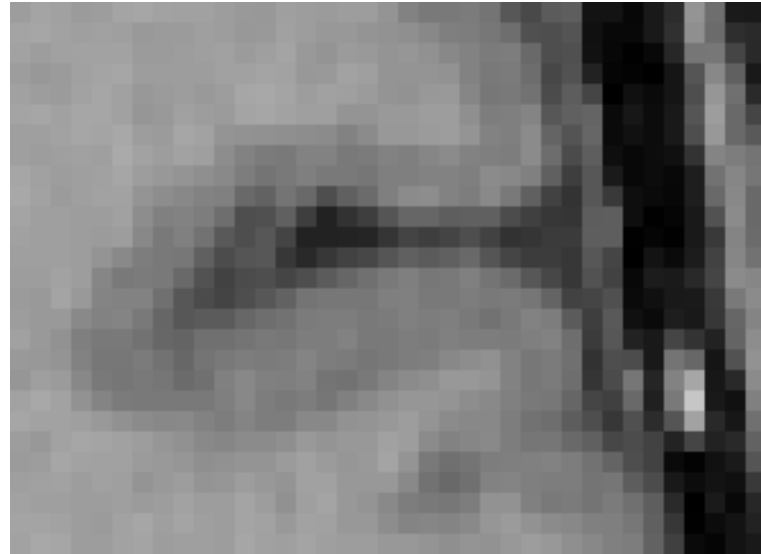
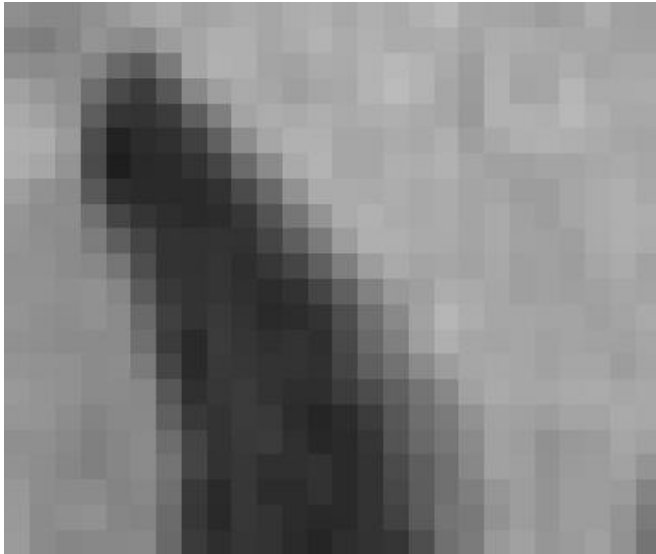
MRI

- **Advantages:**
 - High image quality.
 - Good spatial resolution (~1mm).
 - Almost all tissues.
 - Can provide information on both anatomy and function.
- **Disadvantages:**
 - Very expensive scanners.
 - Some patients cannot be imaged (pacemaker, claustrophobia).

Chemical shift:



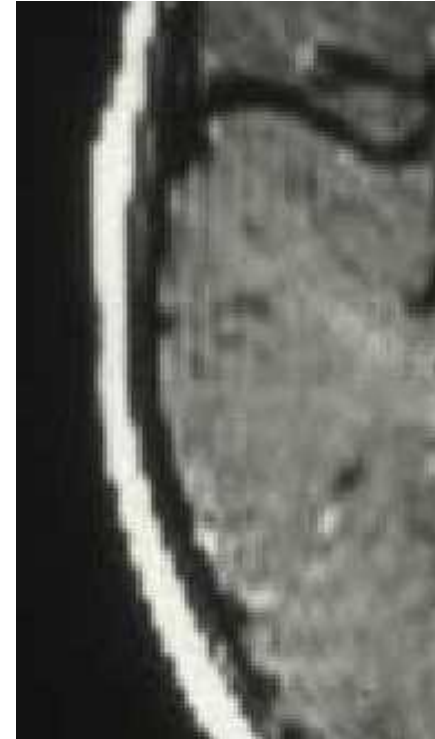
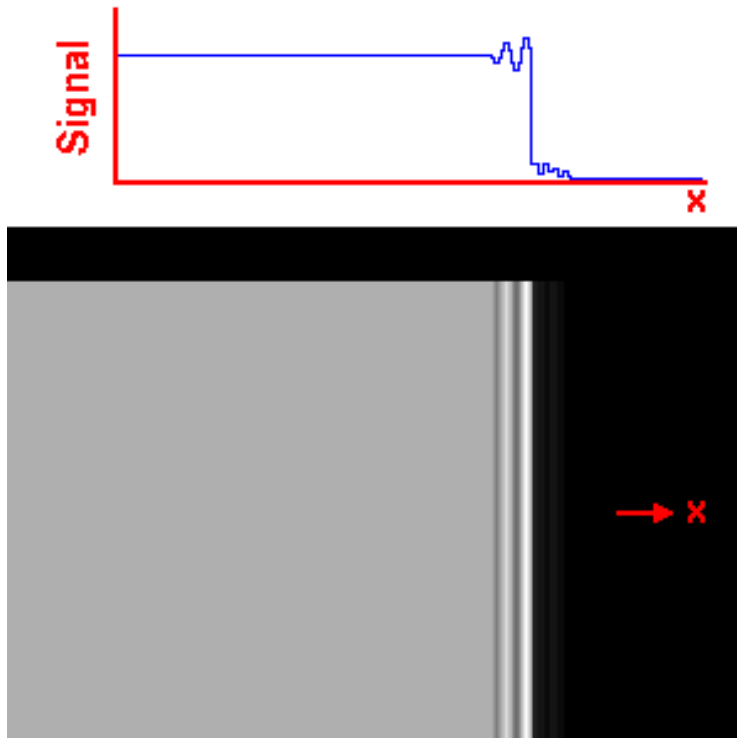
Partial volume effect:



Local antenna:



Gibbs effect:



Contrast agent: Gd-DTPA (paramagnetic) – Reduces T1



MRI

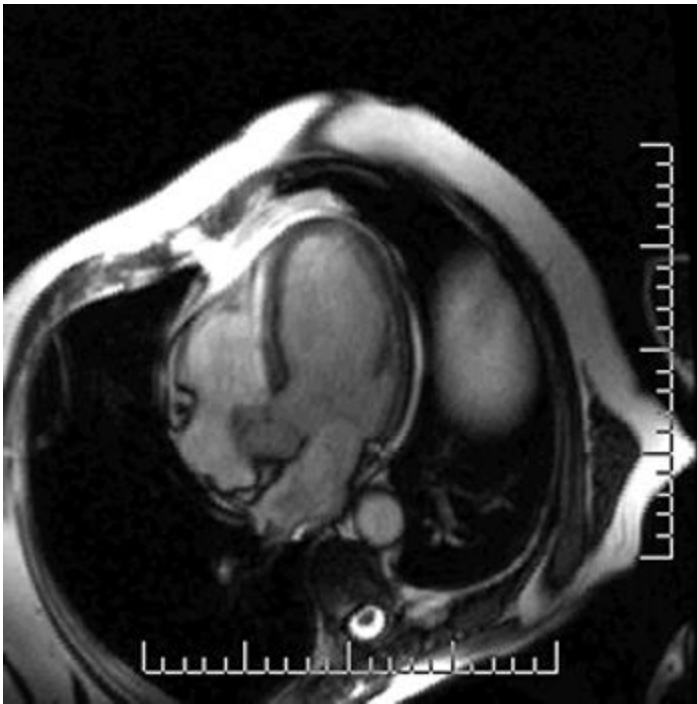
Applications

- Brain (Multiple sclerosis, Alzheimer's disease, epilepsy, tumors)
- Spine
- Muscles, tendons.
- Blood vessels: angiography (strokes, aneurism)
- Heart
- Soft tissues

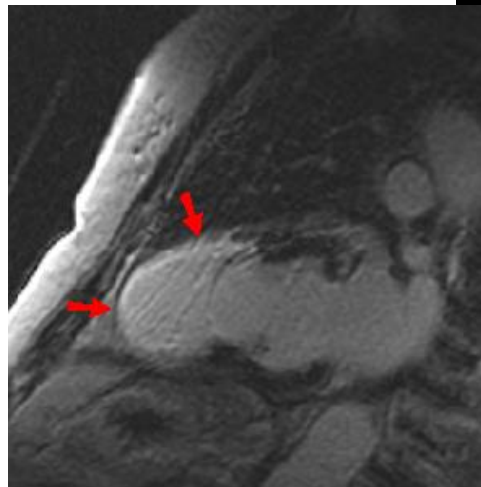
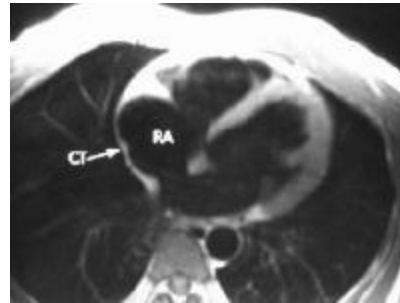
MRI

Example: Heart

- CINE MRI

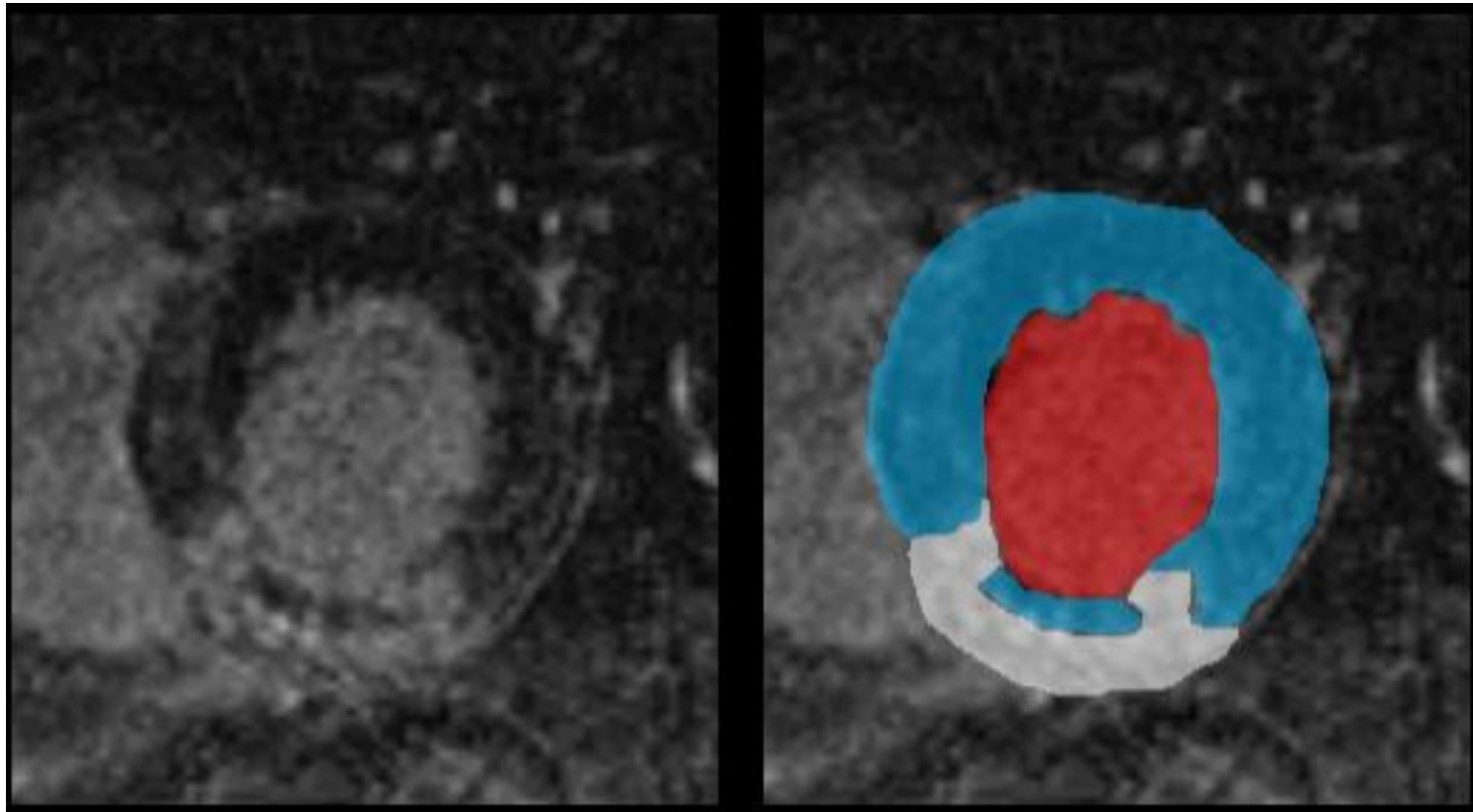


Courtesy of Robert R. Edelman



MRI

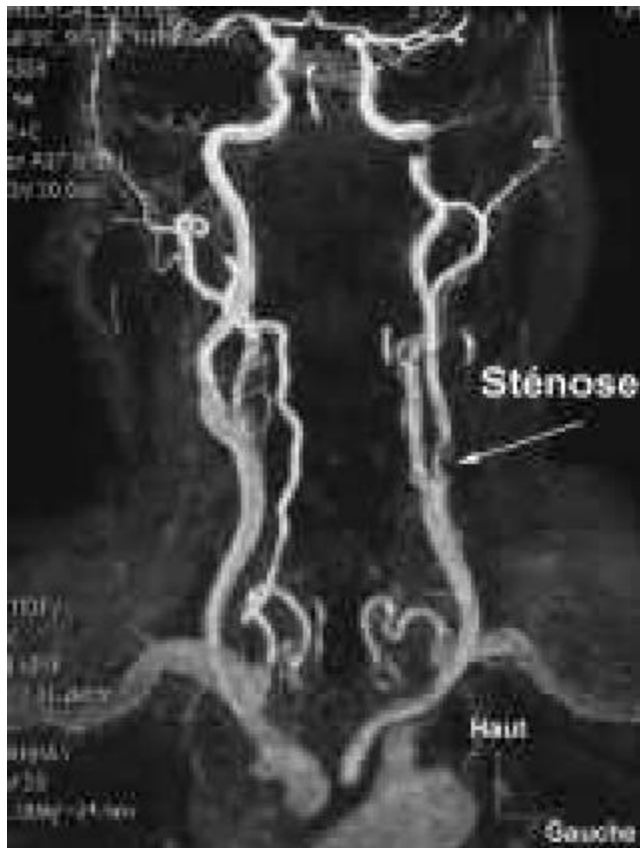
Example: Heart



MRI for myocardial perfusion

MRI

Example: Blood vessels



Magnetic Resonance Angiography

MRI

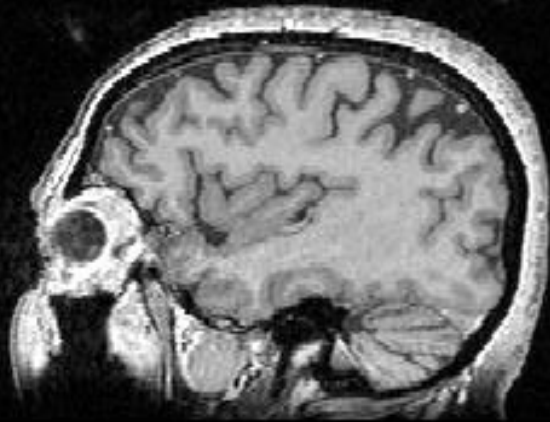
Example: Blood vessels



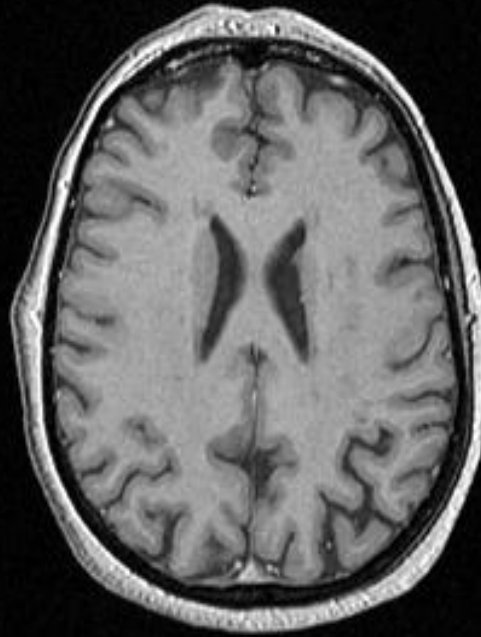
Aorta

MRI

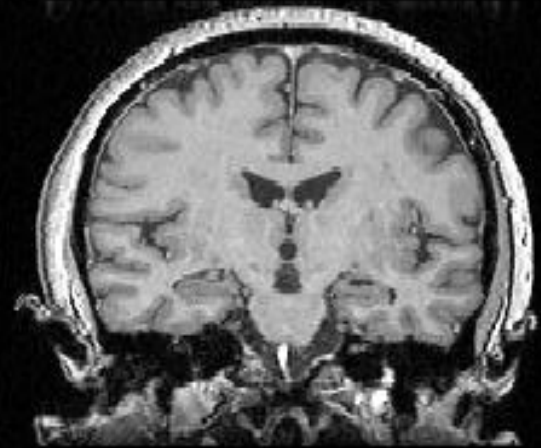
Example: Brain



SAGITTAL



AXIAL



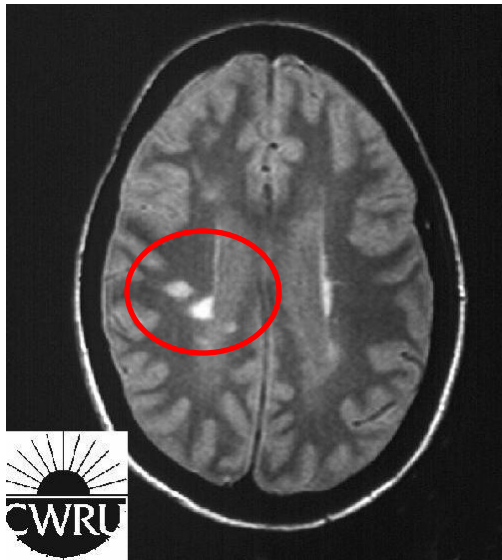
CORONAL

CEA SHFJ ORSAY / TELECOM PARIS

MRI

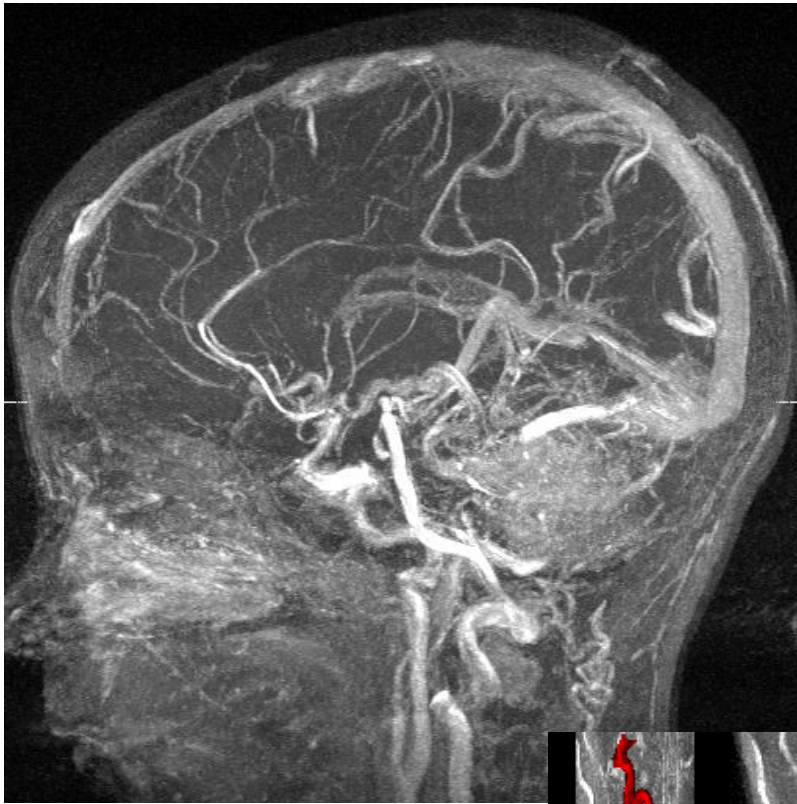
Example: Brain

- Diagnosis of Alzheimer's and Parkinson's disease.

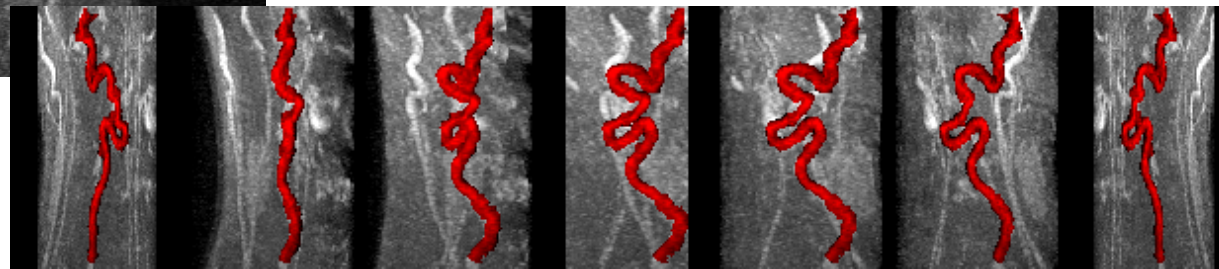


MRI

Example: Blood vessels

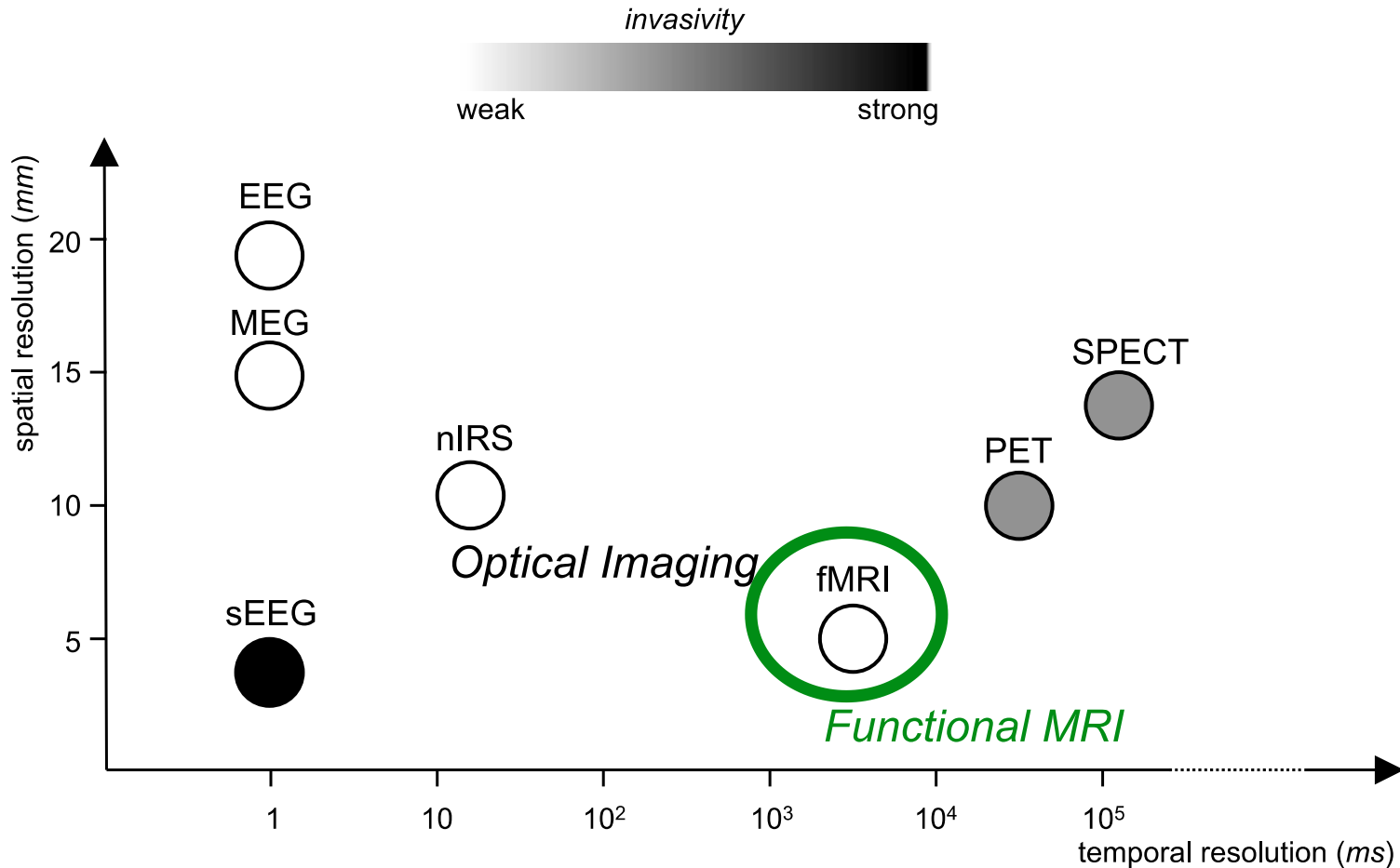


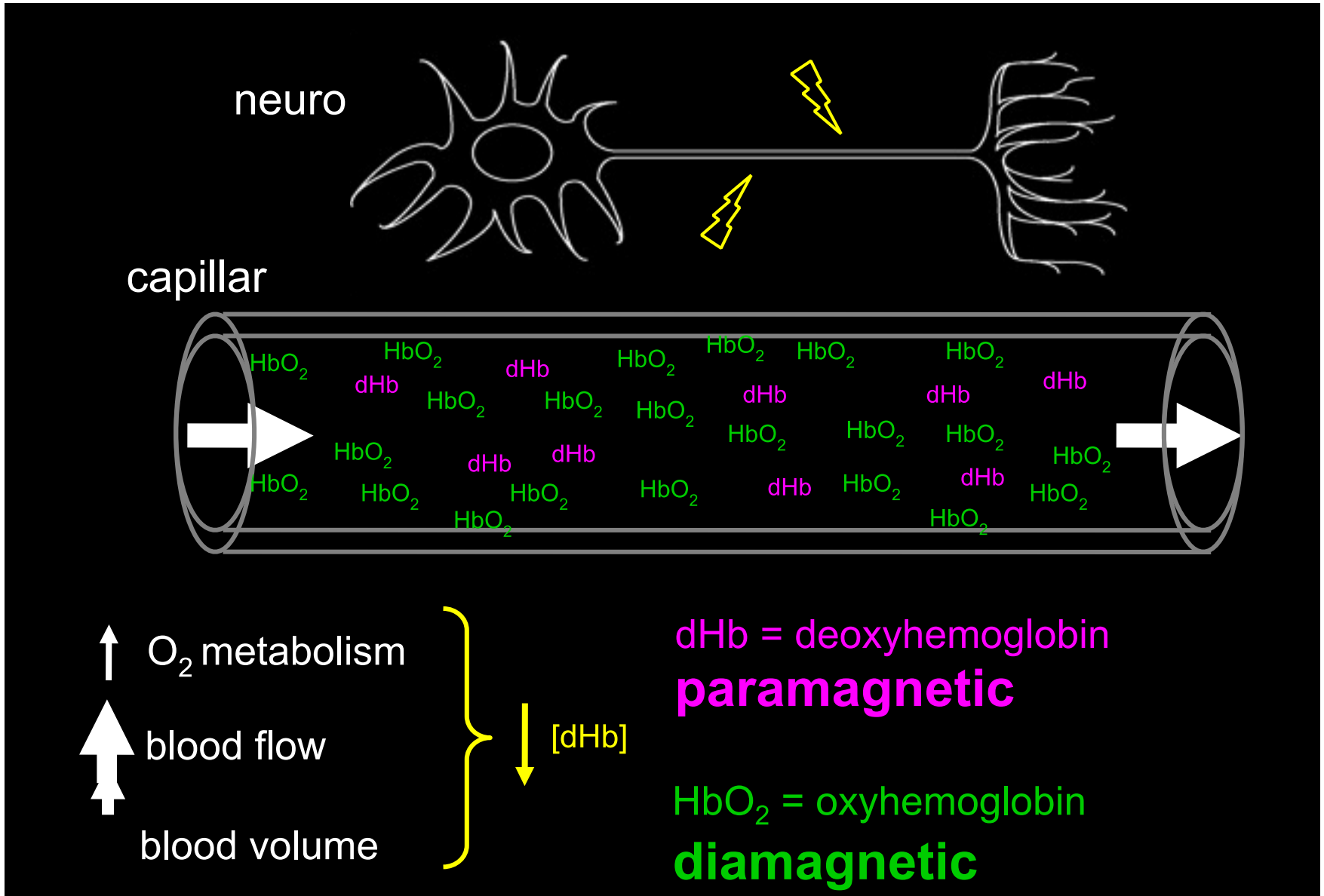
MR Angiography



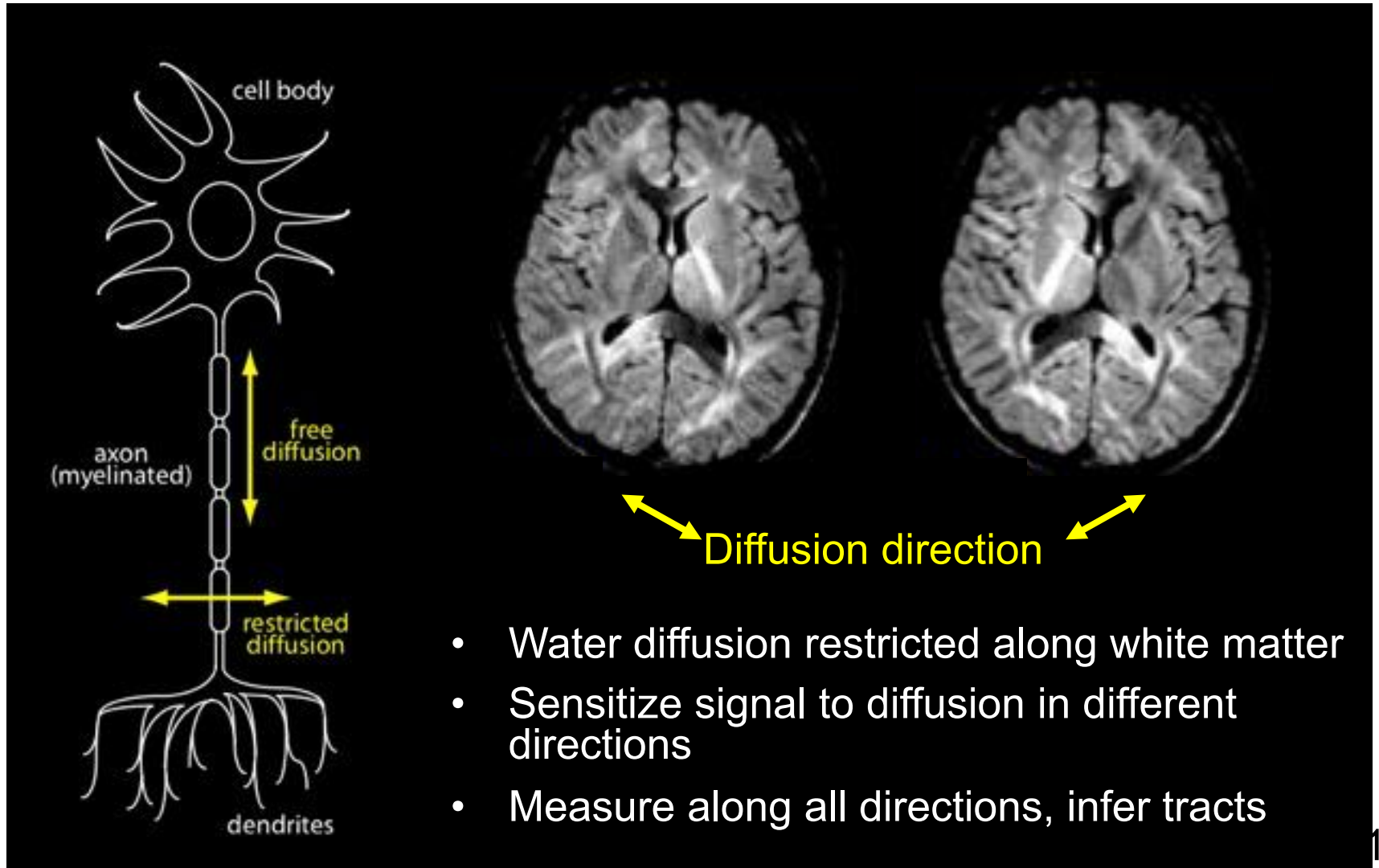
fMRI

Functional neuroimaging modalities





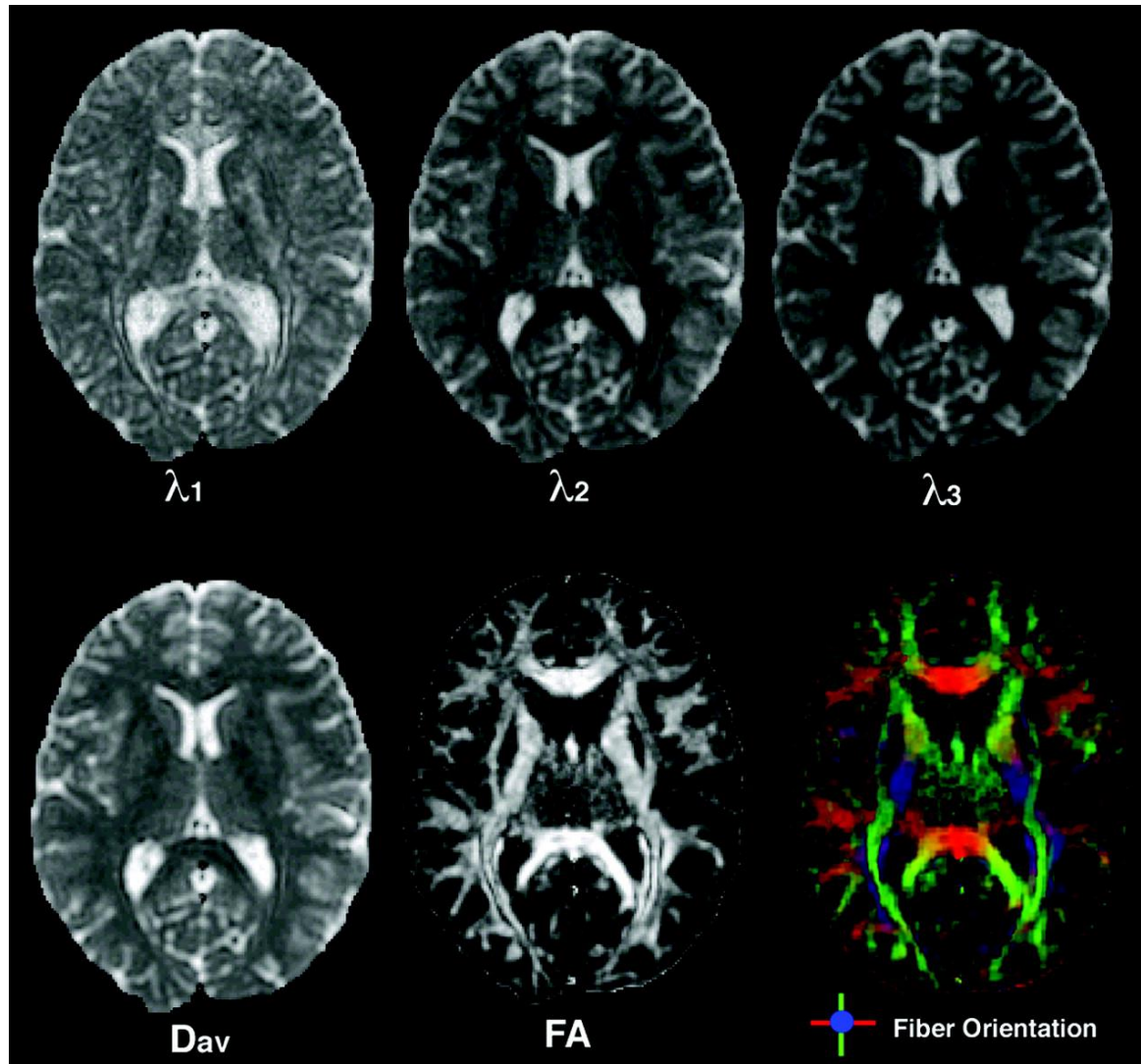
Diffusion MRI



The diagram on the left shows a neuron with a cell body at the top, an axon (myelinated) in the middle, and dendrites at the bottom. A vertical yellow double-headed arrow labeled 'free diffusion' is positioned along the axon, indicating unrestricted water molecule movement. A horizontal yellow double-headed arrow labeled 'restricted diffusion' is positioned across the axon, indicating that water molecule movement is hindered by the axonal membrane. To the right, two axial brain MRI slices show white matter tracts. Yellow double-headed arrows labeled 'Diffusion direction' point to these tracts, indicating the direction of the diffusion MRI signal.

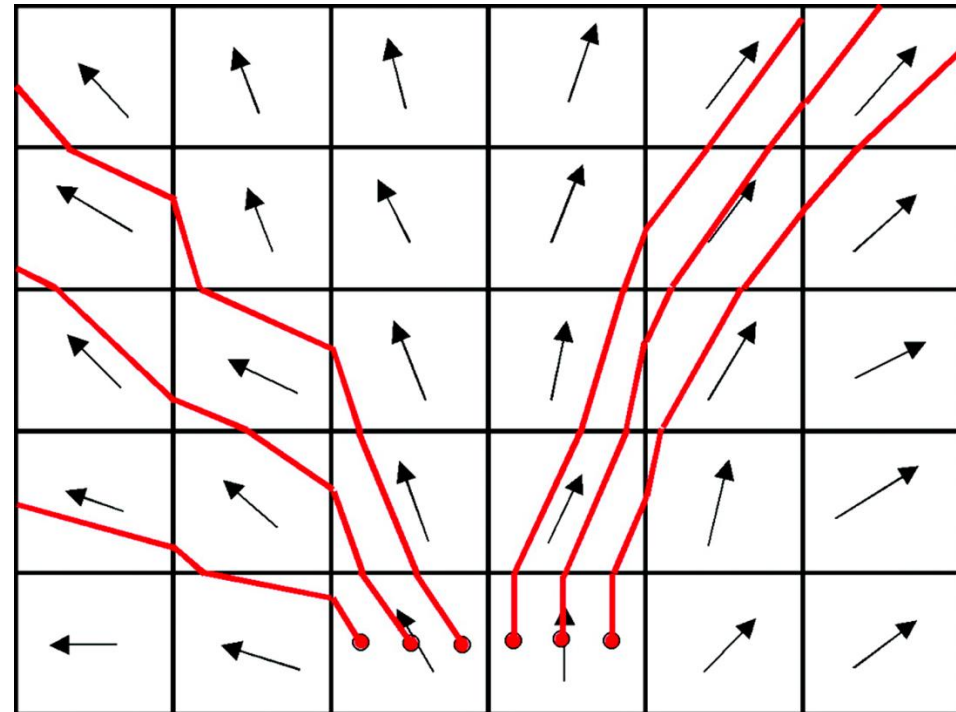
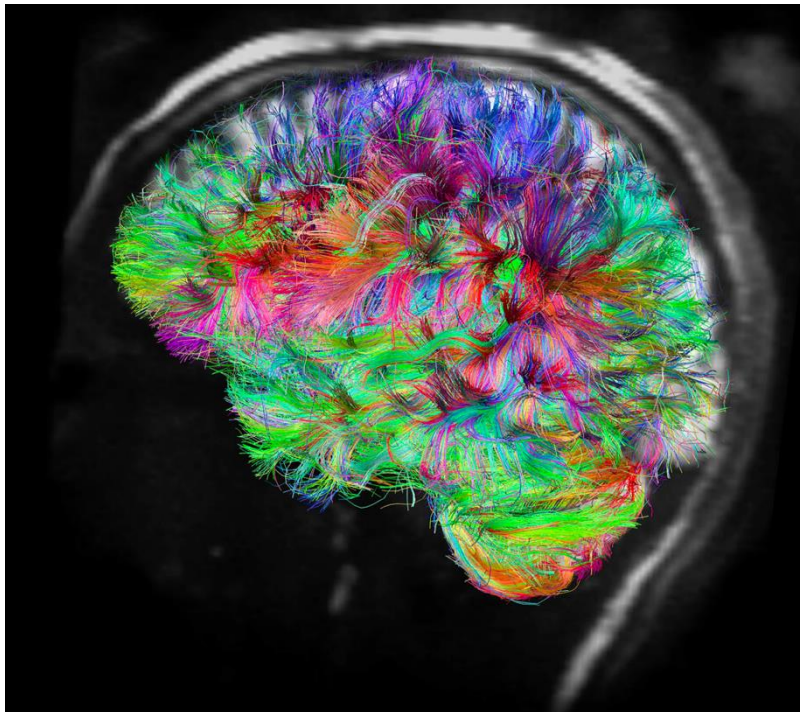
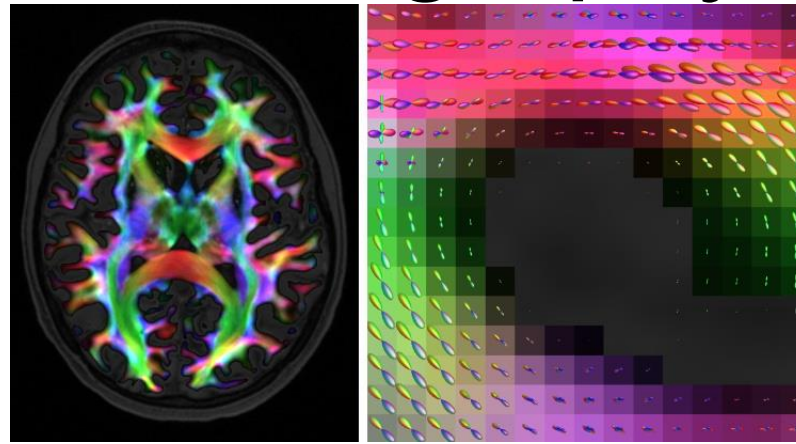
- Water diffusion restricted along white matter
- Sensitize signal to diffusion in different directions
- Measure along all directions, infer tracts

Diffusion MRI

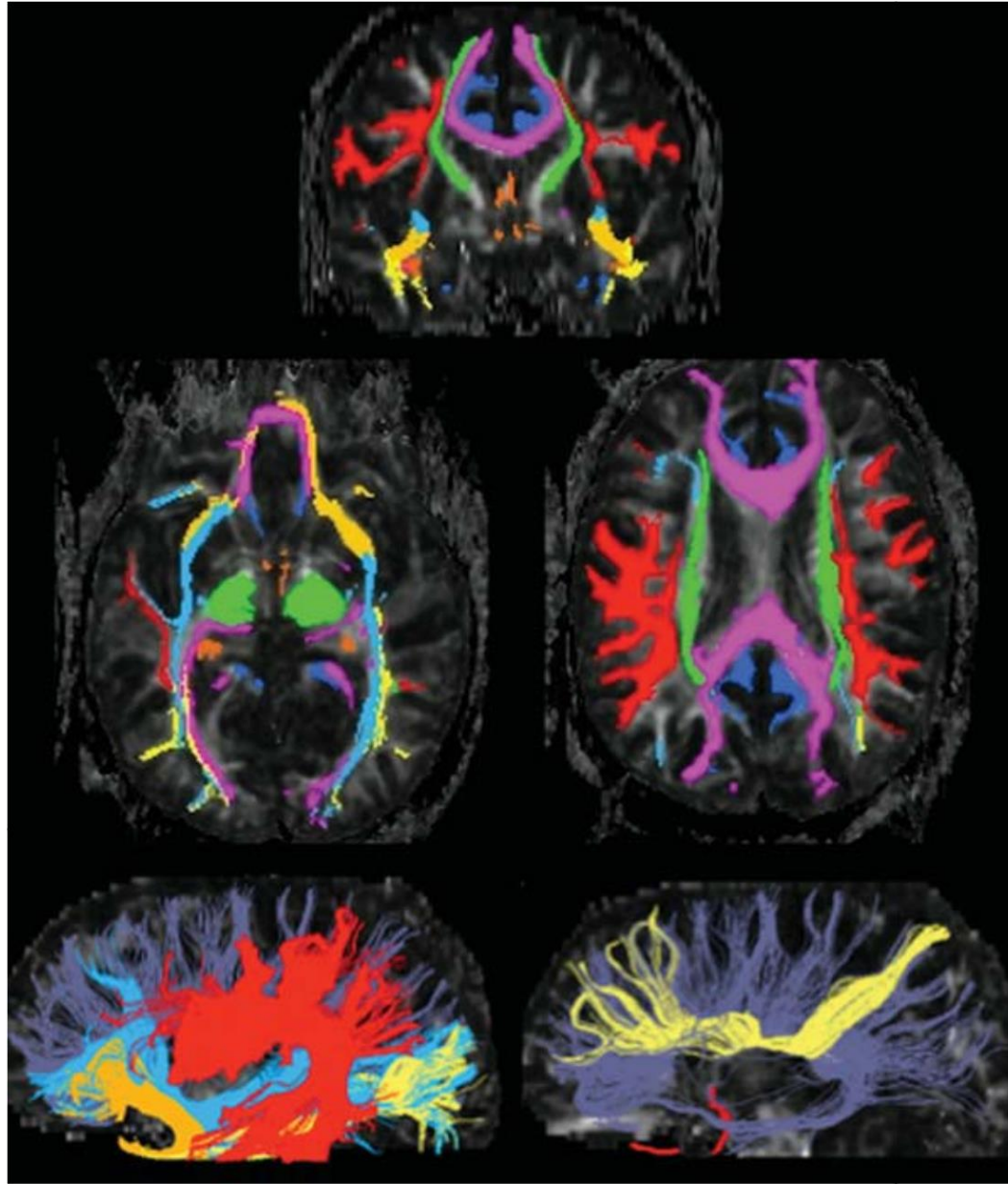


*P. Mukherjee
(2008)*

Tractography

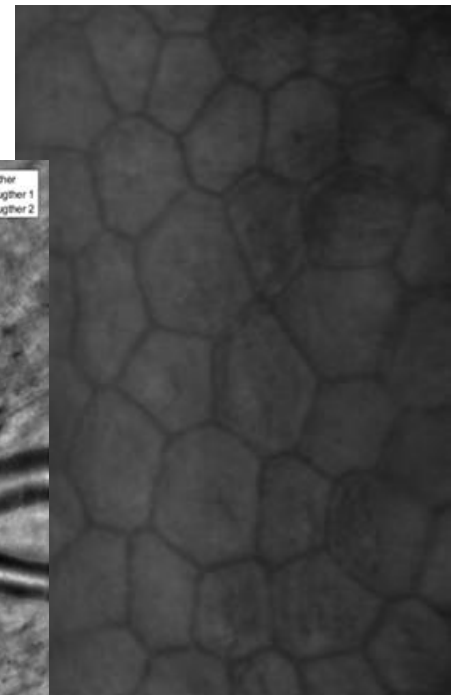
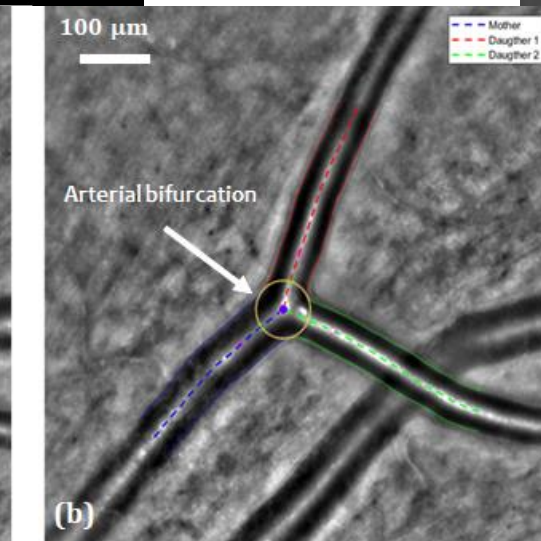
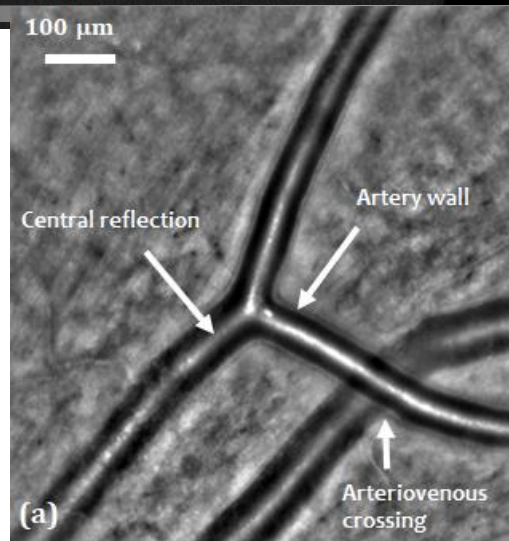
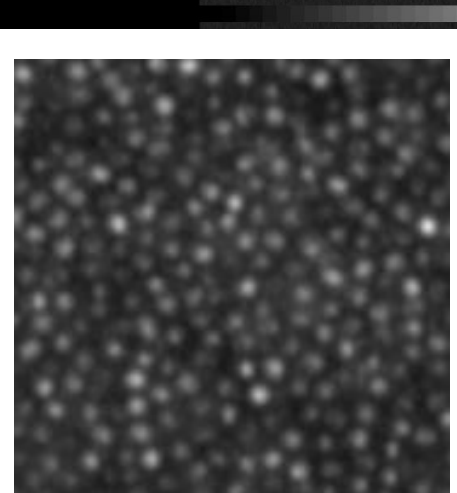
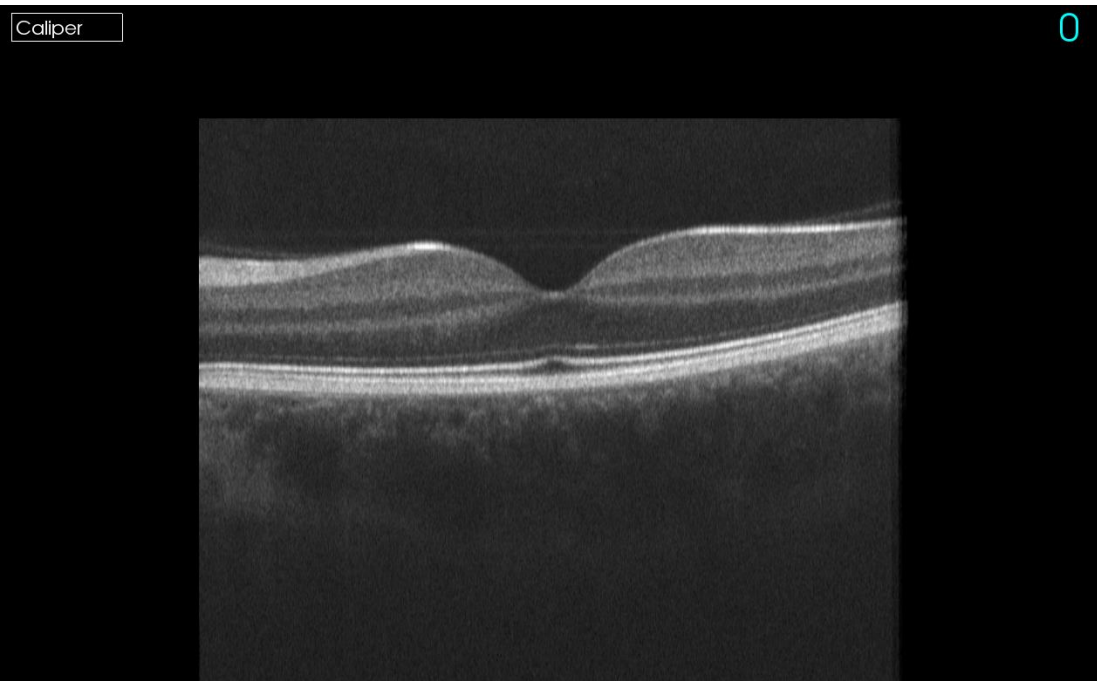


Tractography



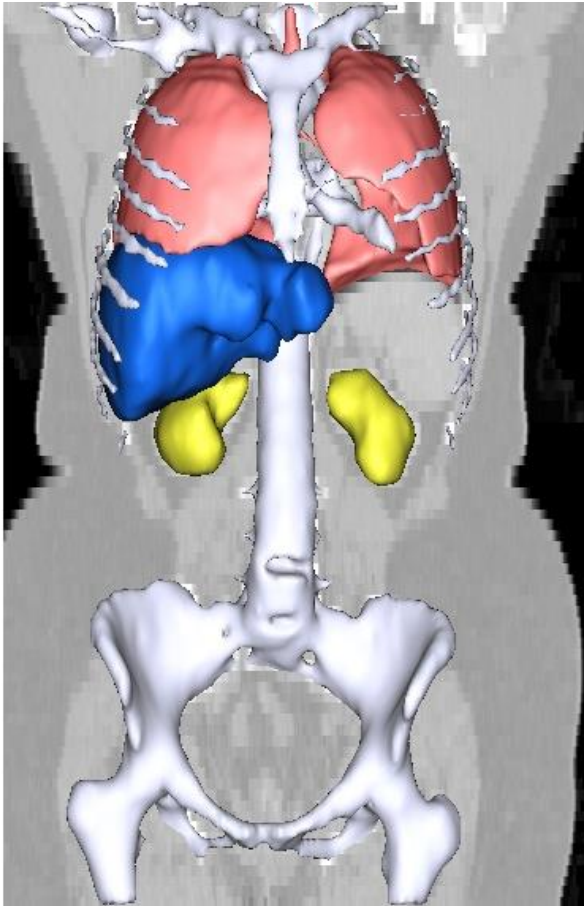
*D. K. Jones
(2010)*

Optical imaging

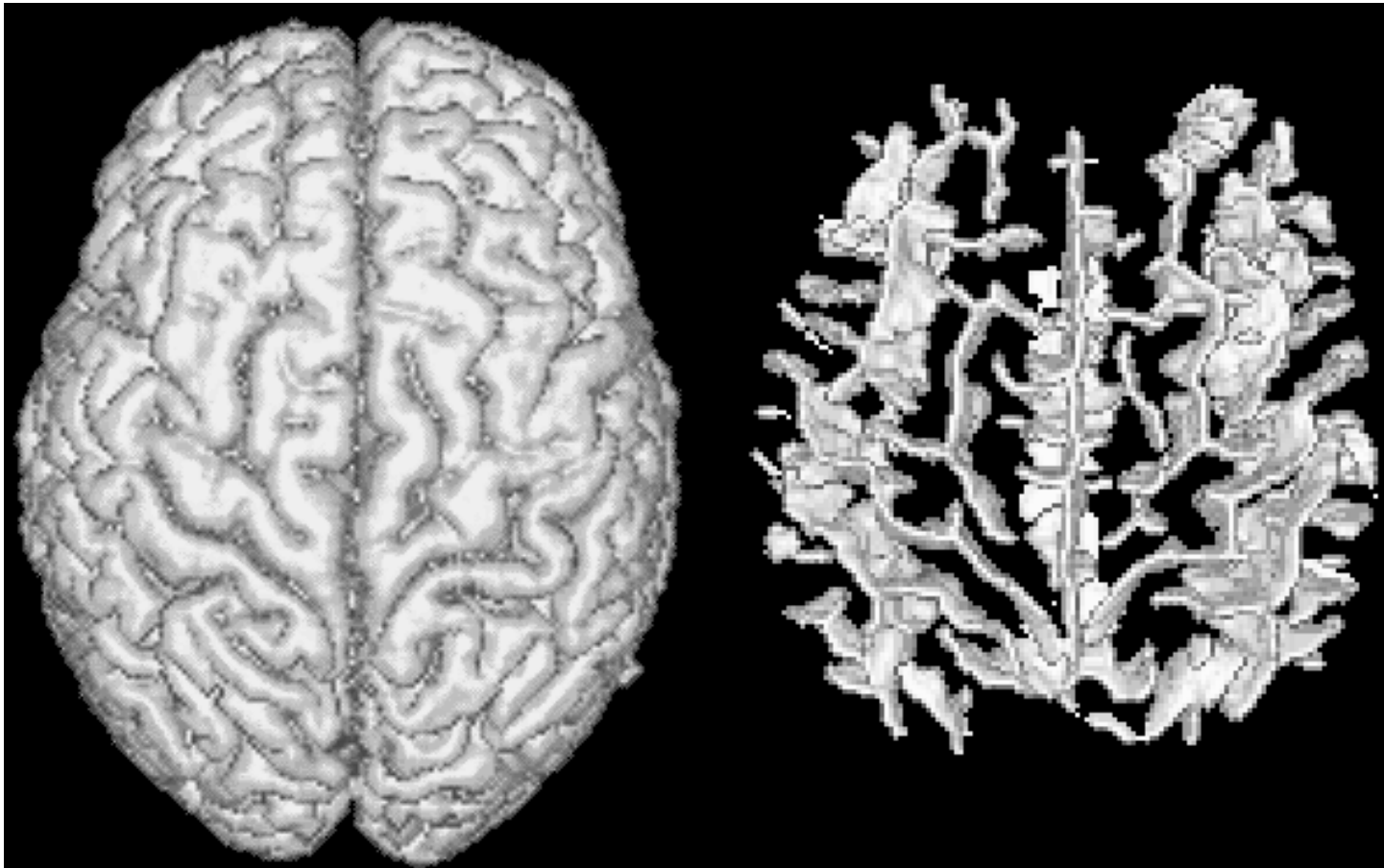


Research in Medical Imaging: a few examples

Registration of CT and PET abdomen images

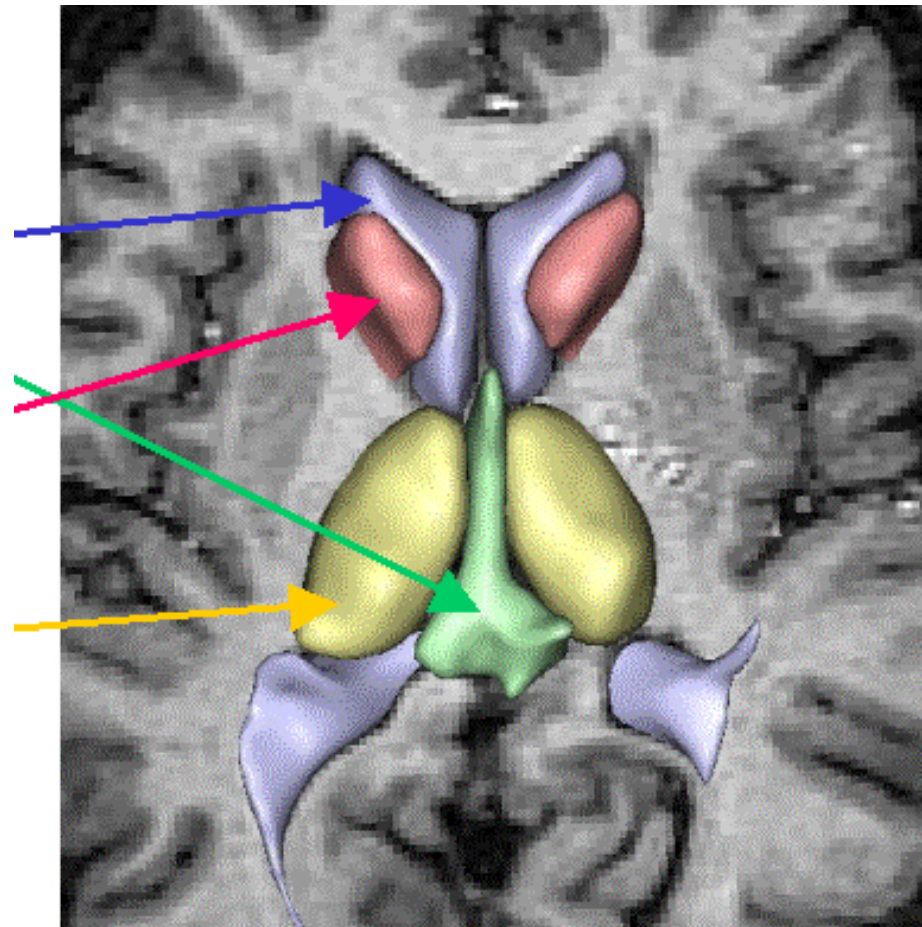


Segmentation of cortical brain structures

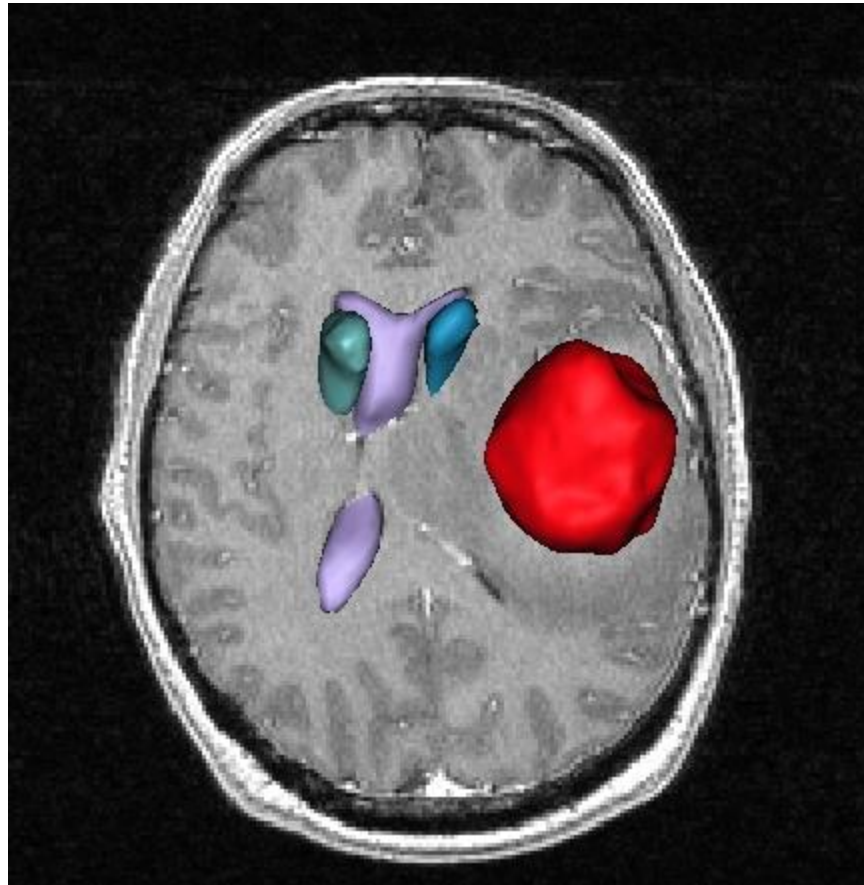


Segmentation of sub-cortical structures

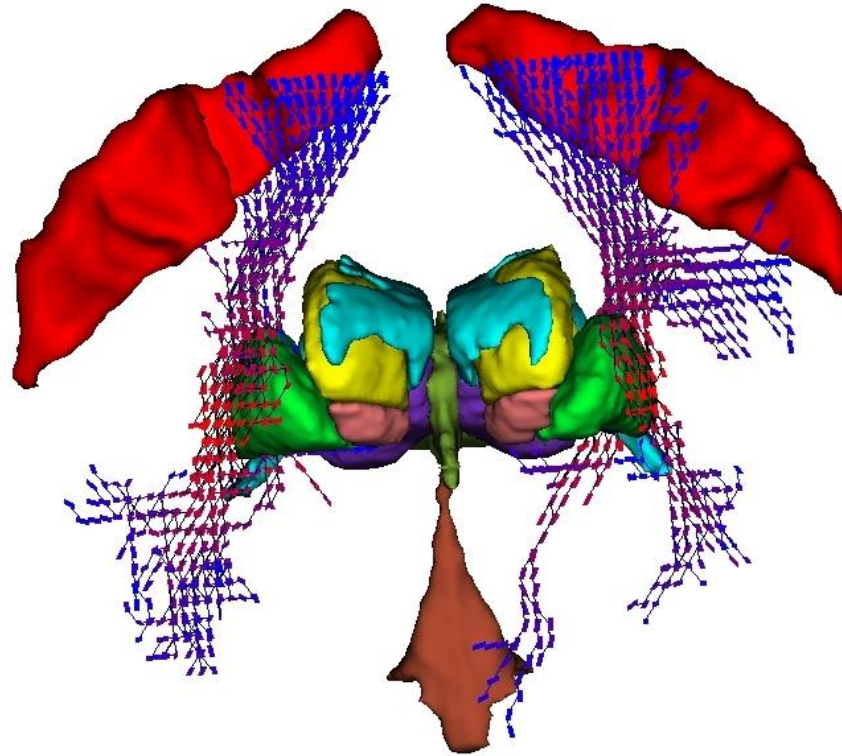
Lateral ventricles
Third ventricle
Caudate nucleus
Thalamus



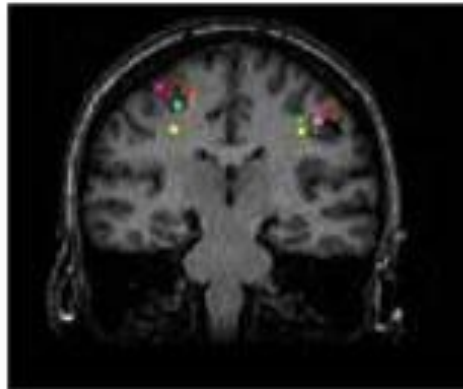
Segmentation of sub-cortical structures and tumors



Diffusion Tensor MRI for Brain White Matter Fibers



Functional Brain MRI

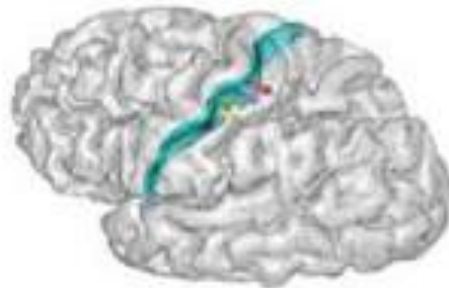


Distance entre doigt ~ 0.9 cm
Distance I - V ~ 1.5 cm

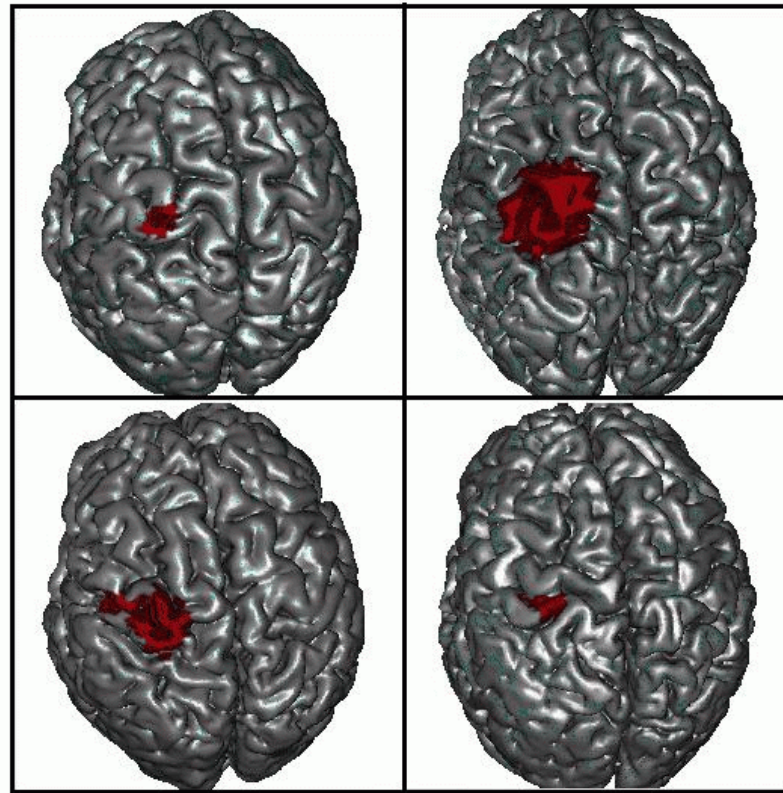


petit doigt
majeur
index
pouce

**Motor control of
fingers**

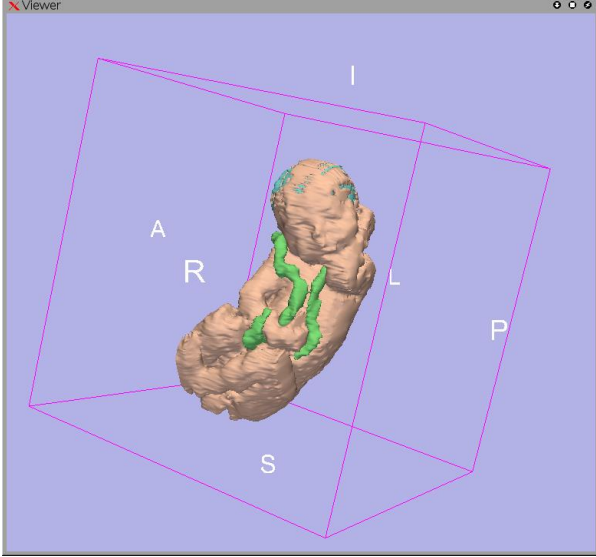
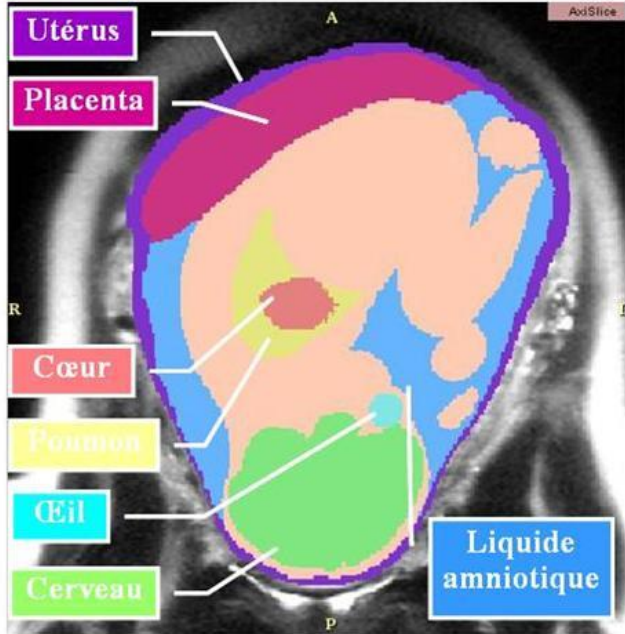


Functional MRI

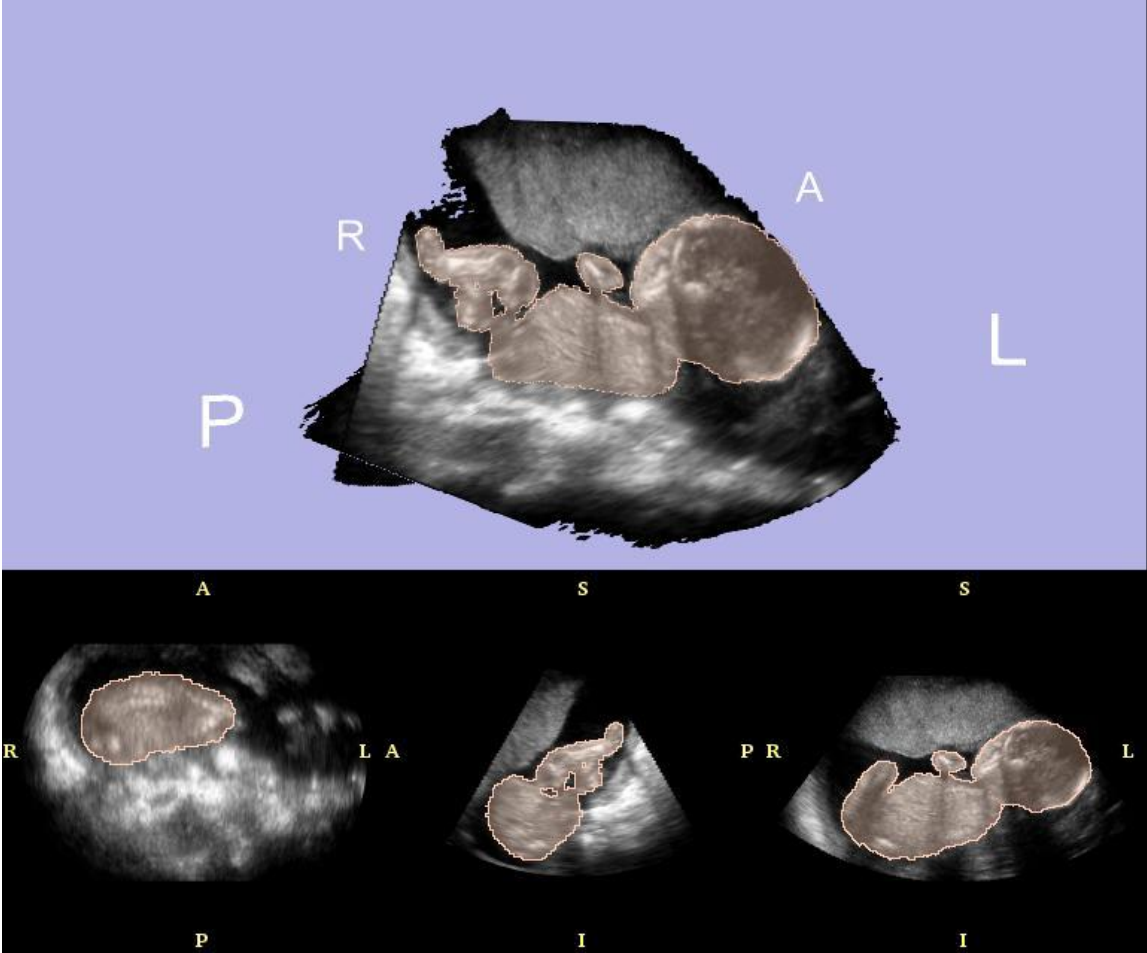


Motor control of right hand

Fetal Imaging

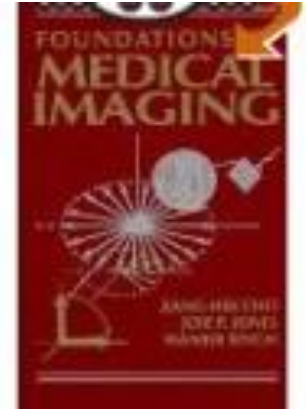


Fetal Imaging



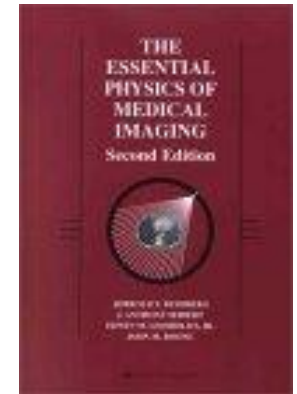
Books

• **Foundation of Medical Imaging**, Z.H. Cho, J.P. Jones, M. Singh, John Wiley & Sons, Inc., New York 1993, ISBN 0-471-54573-2.

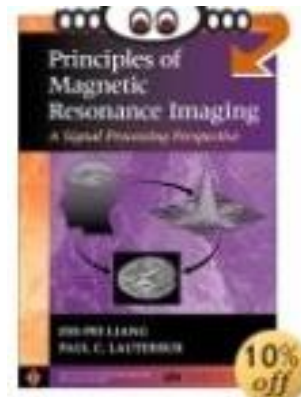


• **Principles of Medical Imaging**, K.K. Shung, M.B. Smith, B. Tsui, Academic Press, San Diego 1992, ISBN 0-12-640970-6.

• **The Essential Physics of Medical Imaging (2nd Edition)**, Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt Jr., John M. Boone, Lippincott Williams & Wilkins; 2nd edition, ISBN 0683301187.



• **Image Reconstruction in Radiology**, J.A. Parker, CRS Press, Boca Raton, FL 1990, ISBN 0-8493-0150-5/90.



• **Principles of Magnetic Resonance Imaging**, Zhi-Pei Liang, P.C. Lauterbur IEEE Press, New York, NY 2000, ISBN 0-7803-4723-4.