Biomedical Imaging Methods I: Ultrasound and Computed Tomography

BME 4420/7450

Fall 2022

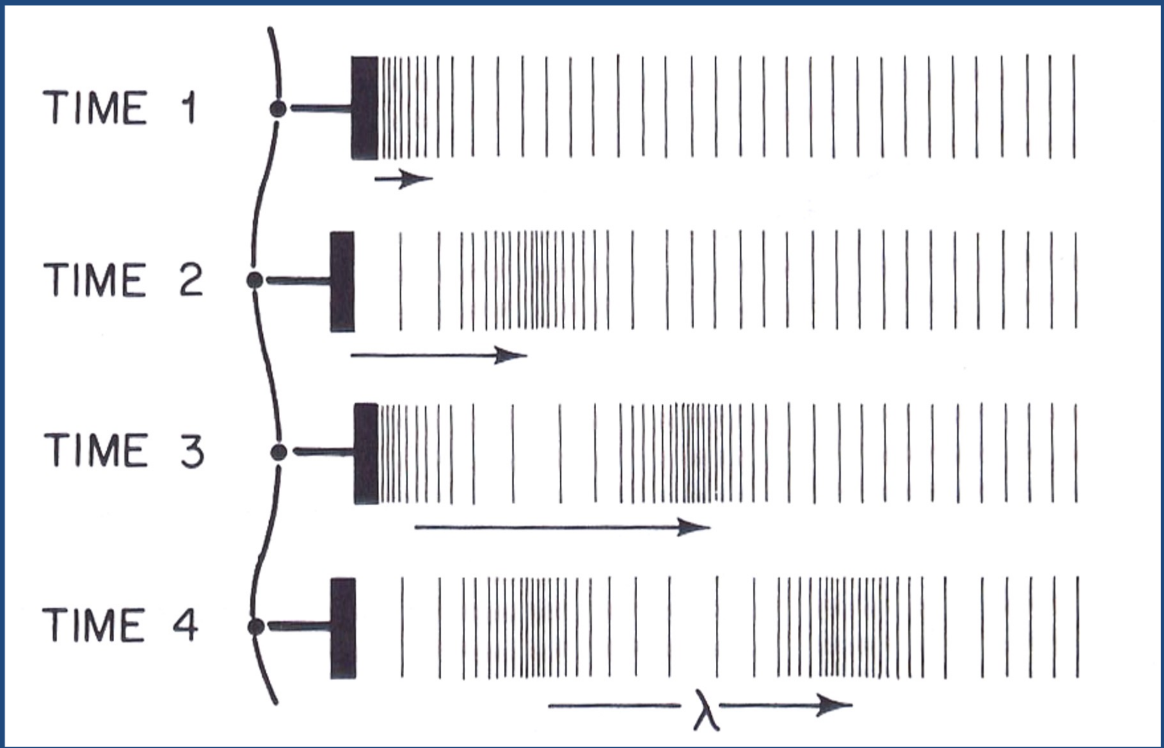
Biomedical Imaging Methods

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

Ultrasound in a nutshell

Generation of ultrasound pulses

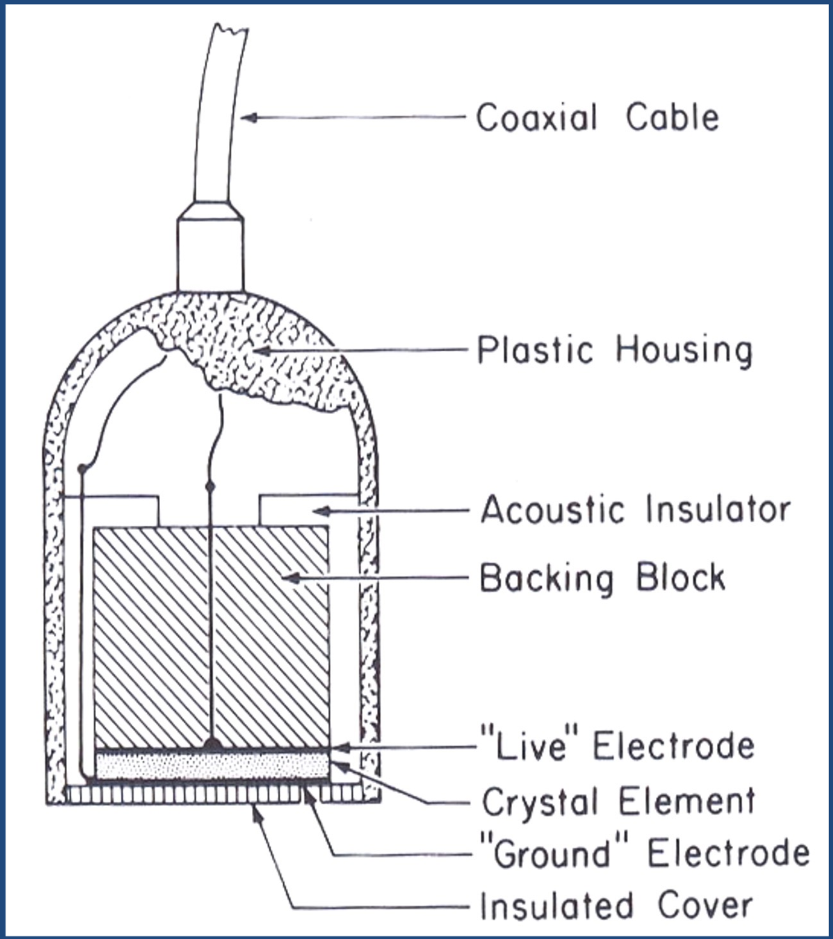
- Rapidly vibrating source radiates sound waves



Curry, 1990

Ultrasonic transducers

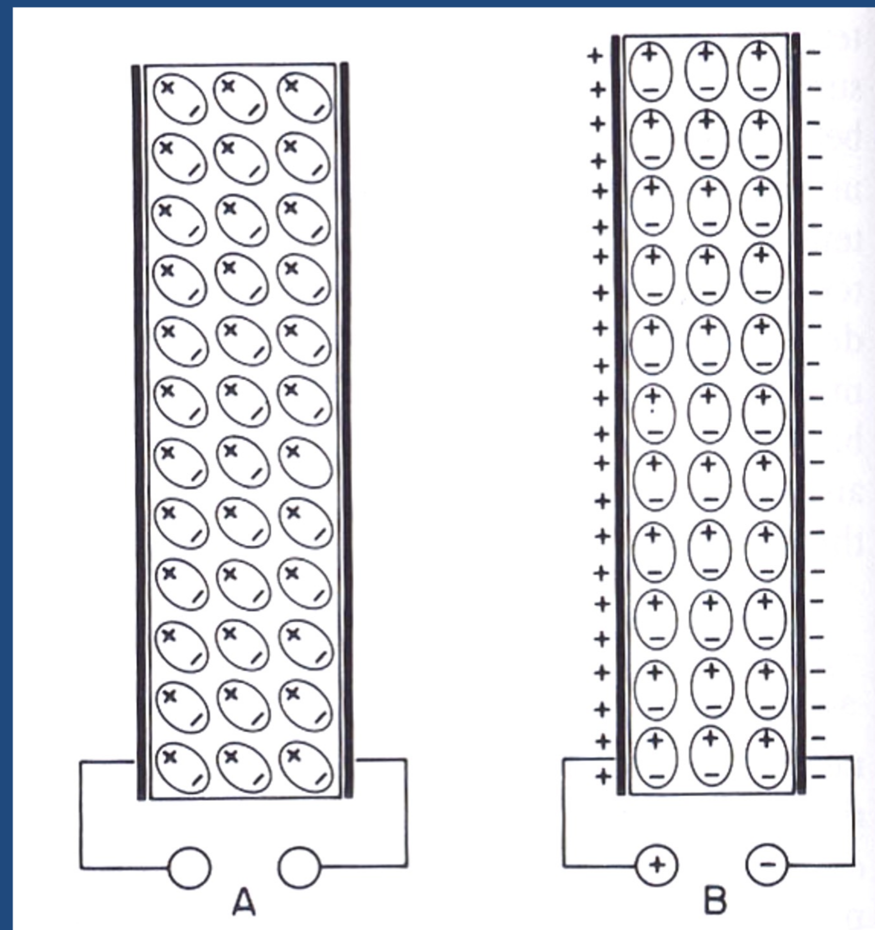
- Convert electric signals into acoustic energy
- Convert acoustic energy back to an electric signal
- Hand-held device



Curry, 1990

Piezoelectric crystal

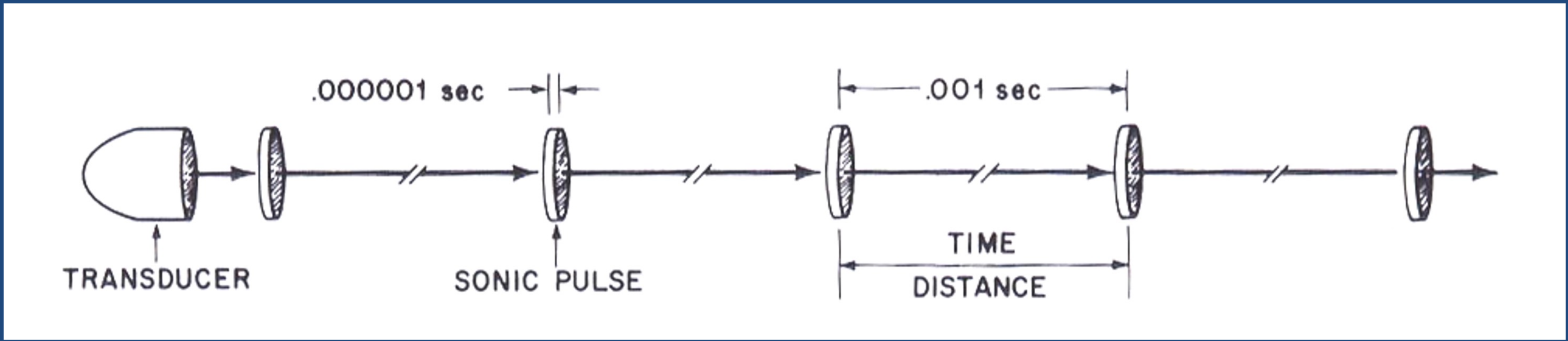
- Changes thickness when an electric field is applied
  - – Transmitter
- Produces an electric field when the crystal is strained
  - – Receiver



Curry, 1990

Measure depth of tissue boundaries

- Transmit a train of short pulses
- Measure time to receive reflected pulses
- For known velocity, time delay -> depth



Curry, 1990

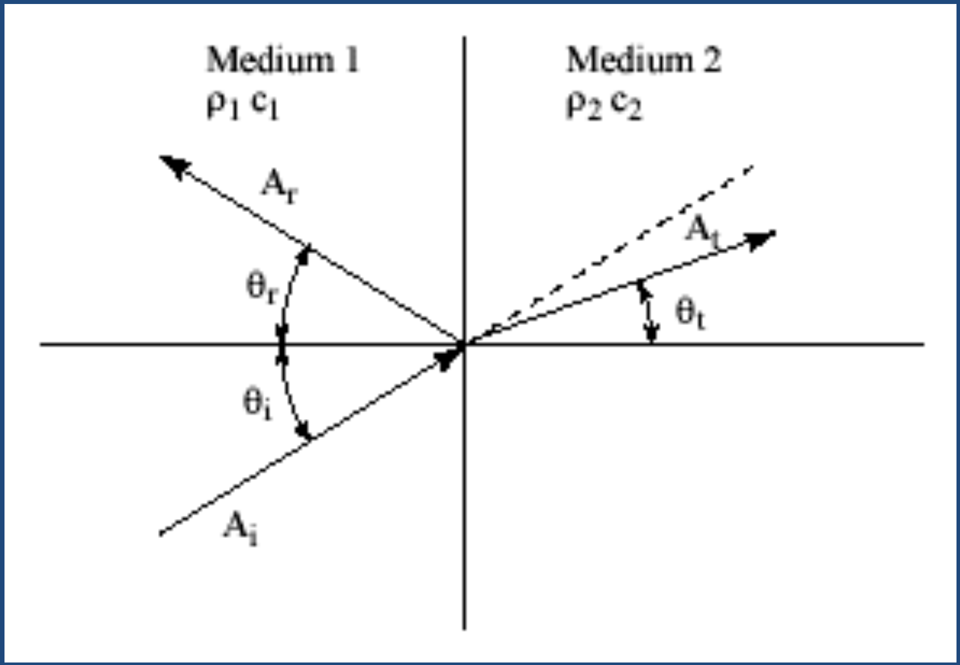
Reflection and refraction

- The amplitude of the reflected wave is determined by the acoustic impedance

$$Z = \rho c$$

$$R = \frac{A_r}{A_i} = \frac{Z_2 \cos\theta_i - Z_1 cos\theta_t}{Z_2 \cos\theta_i + Z_1 cos\theta_t}$$

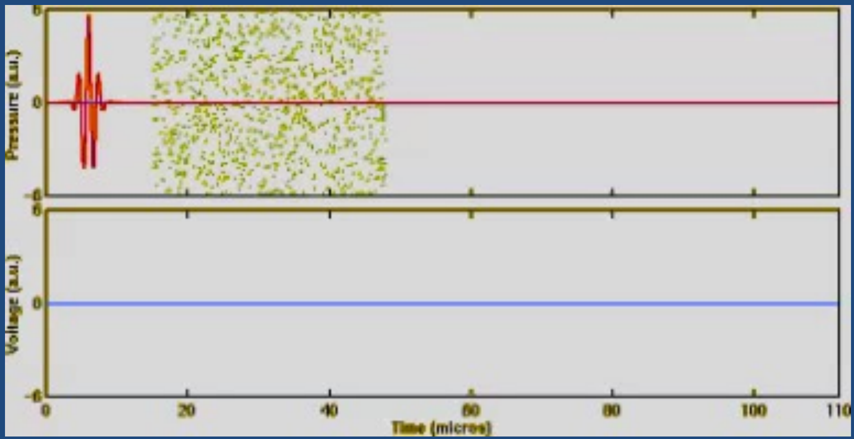
$$T = \frac{A_t}{A_i} = \frac{2\rho_1 c_2 \cos\theta_i}{Z_2 \cos\theta_i + Z_1 cos\theta_t}$$



Curry, 1990

Spatial information from ultrasound: A (amplitude) mode

- Amplitude of reflected wave is displayed as a function of time
- Allows 1D depth measurements



Suetens, 2002

Attenuation

- Loss of acoustic energy as the ultrasonic wave propagates through tissue
- Viscous damping
  - Acoustic energy -> heat
- Exponential decay with penetration depth (x)

$$A(x) = A_0 \exp(-\alpha f x)$$

- Example: for liver,

α = 0.5 dB/(cm MHz) (switching units!)

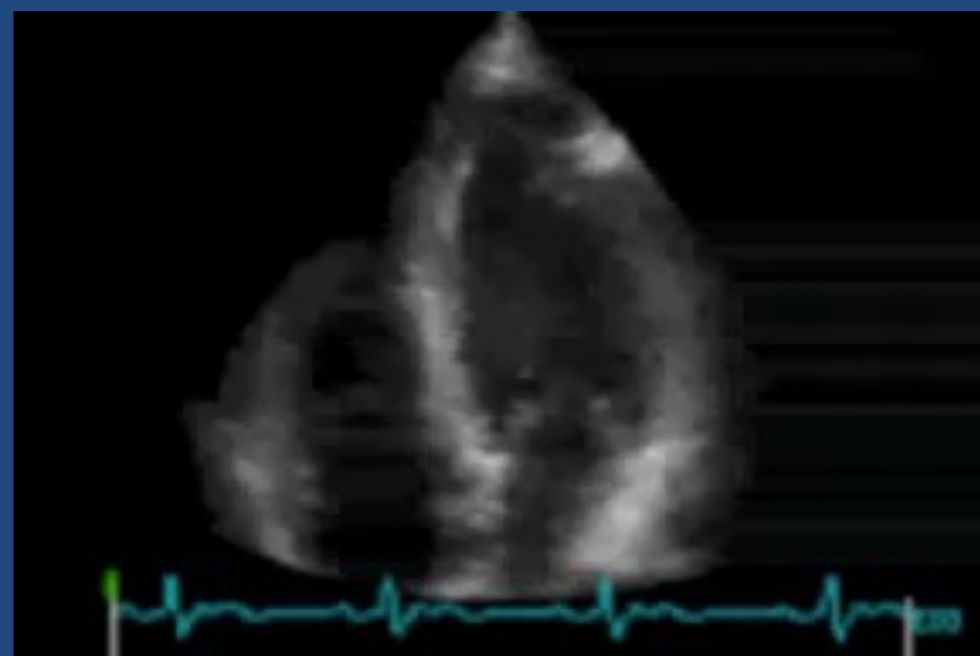
At f = 2 MHz, x = 6 cm

$A(x) / A_0 = 0.5$ (power is 25%)

B (brightness) mode imaging

- 2D image of a slice of tissue

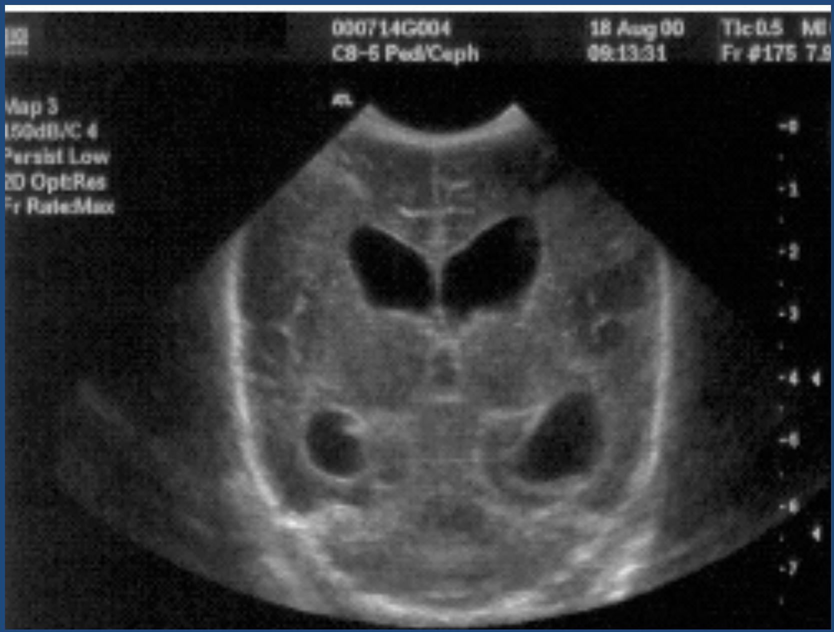
B mode image of a fetus



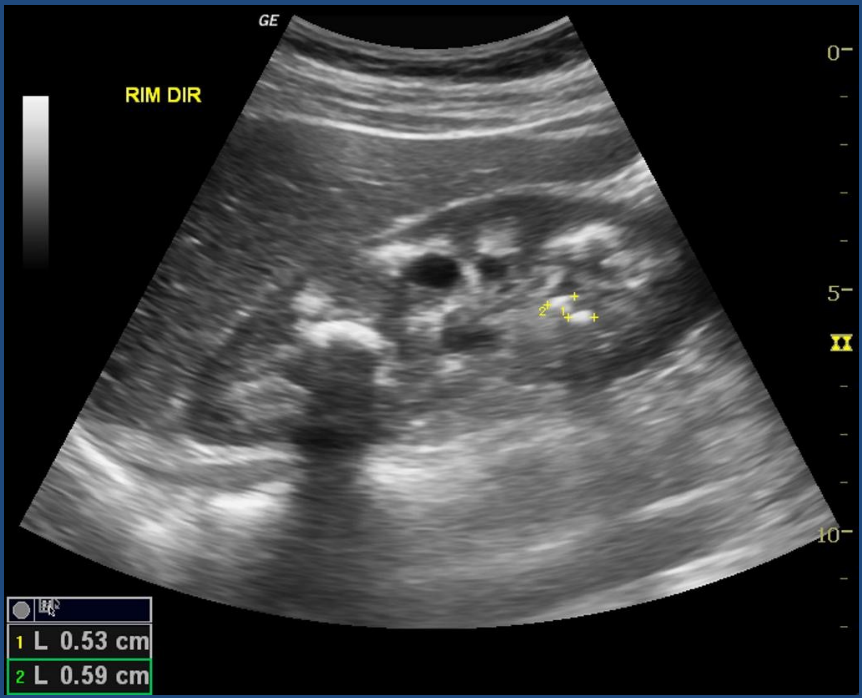
Four chamber view of the heart

Advantages and limitations of ultrasound

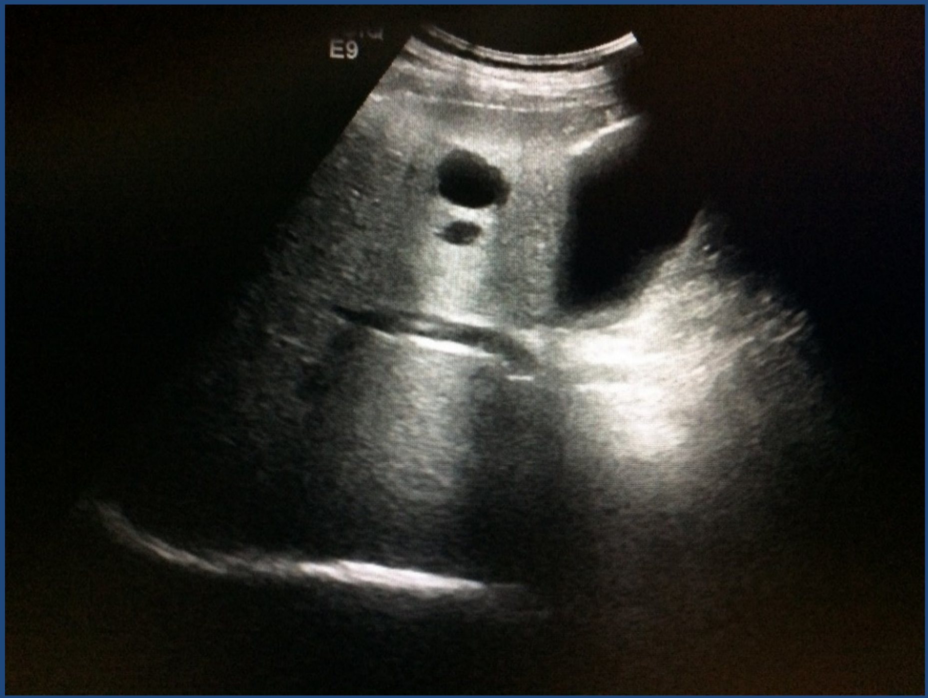
- Pros
  - Time resolution
  - Safety
  - Portable
  - Inexpensive
- Cons
  - Lateral spatial resolution
  - Strong reflections
  - Attenuation



What caused these artifacts?



Case courtesy of Dr Bruno Di Muzio, Radiopaedia.org



Case courtesy of Dr Ian Bickle, Radiopaedia.org

In-class exercise:
What caused this artifact?

Case courtesy of Dr Ayush Goel, Radiopaedia.org

Computed Tomography

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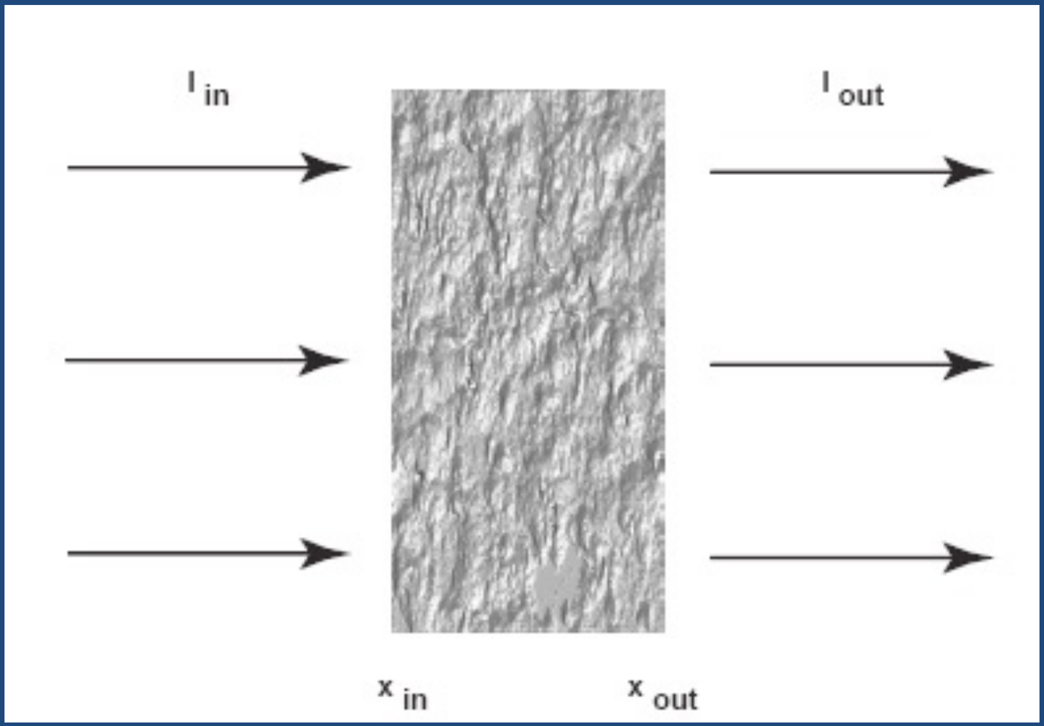
Attenuation of X-rays

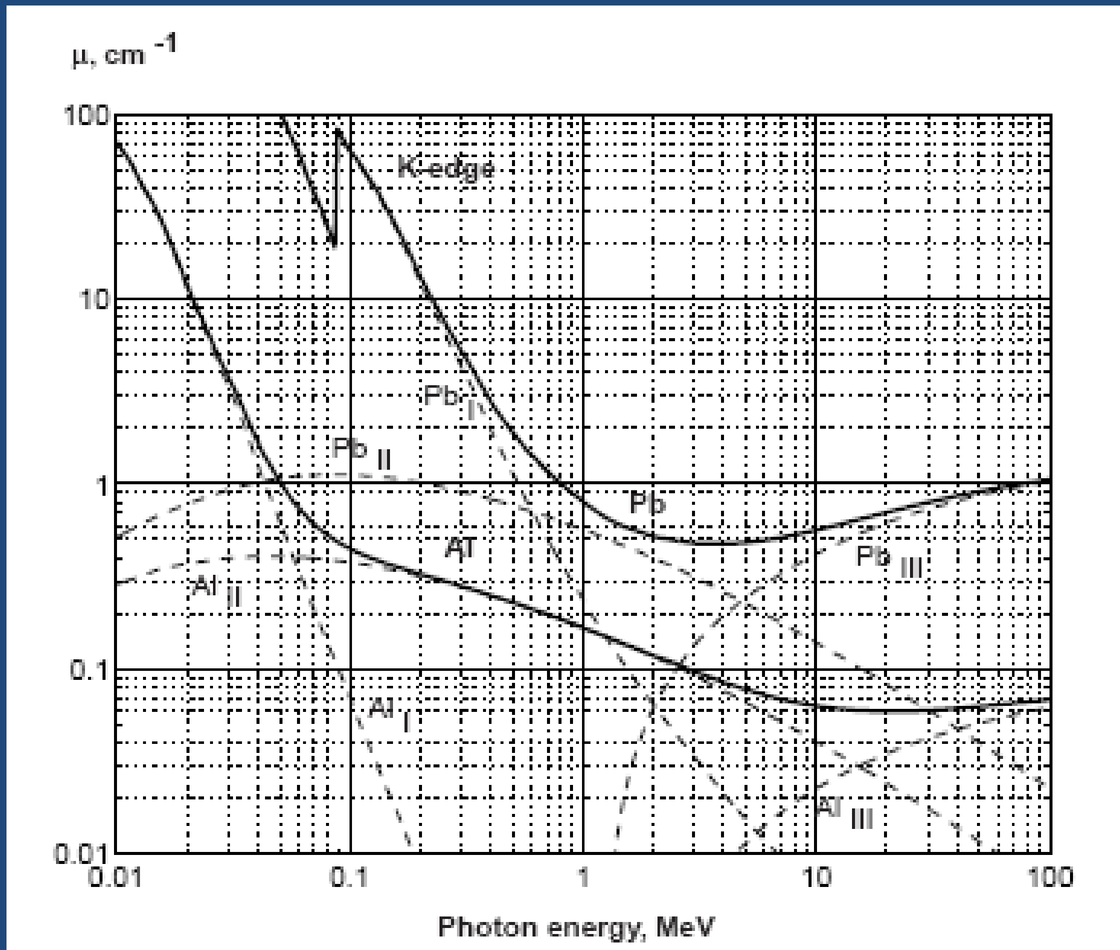
- Measured as an attenuation coefficient, μ



Suetens, 2002

$$I_{out} = I_{in} \cdot e^{-\mu(x_{out} - x_{in})}$$

Attenuation of X-rays in lead (Pb) and aluminum (Al)



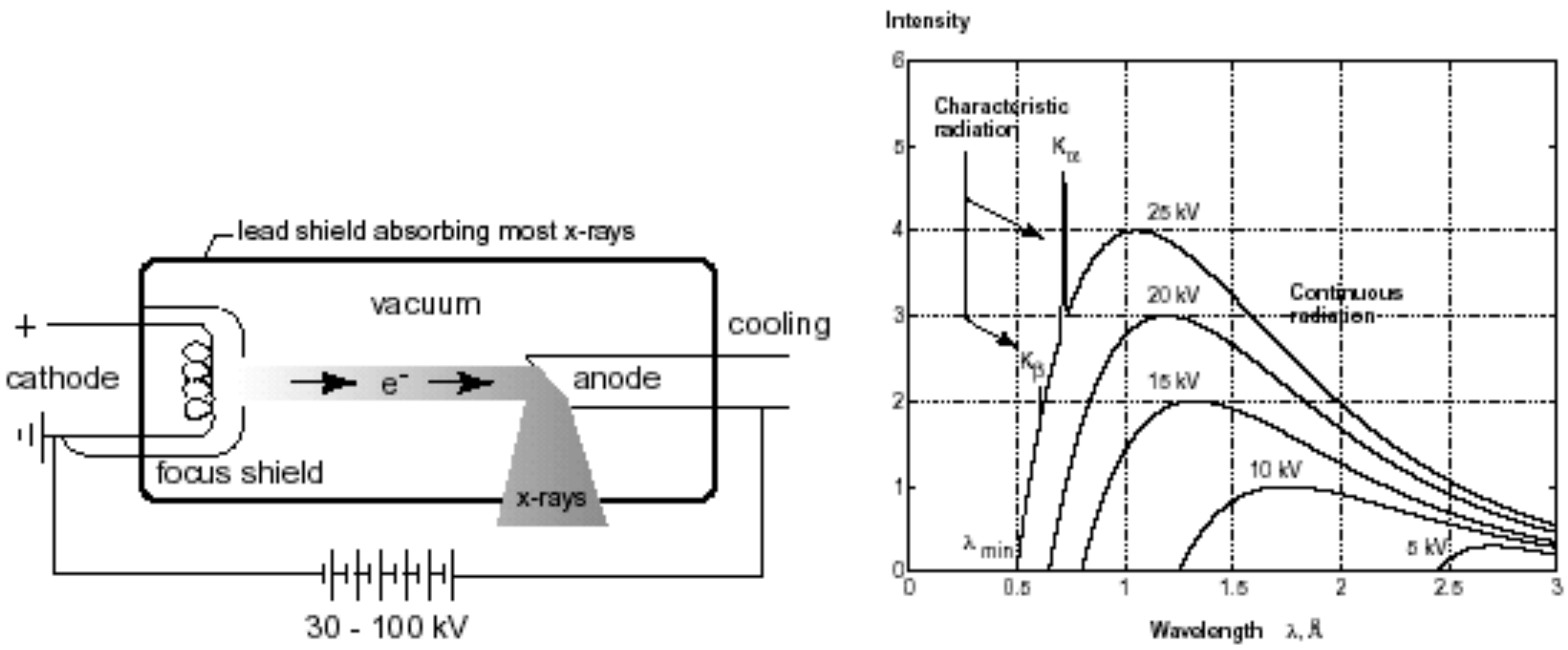
Suetens, 2002

I: Photoelectric absorption

II: Compton scattering

III: Pair production

X-ray production

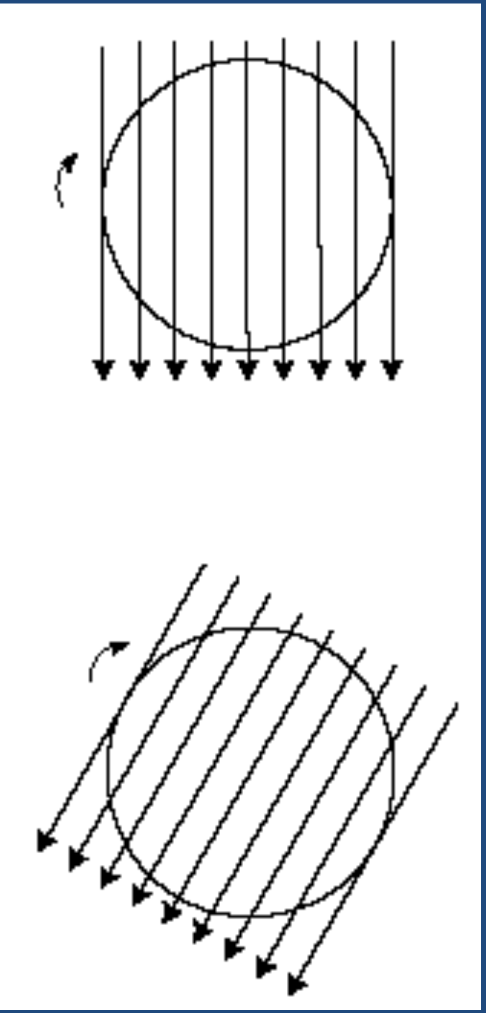


(a) (b)

Suetens, 2002

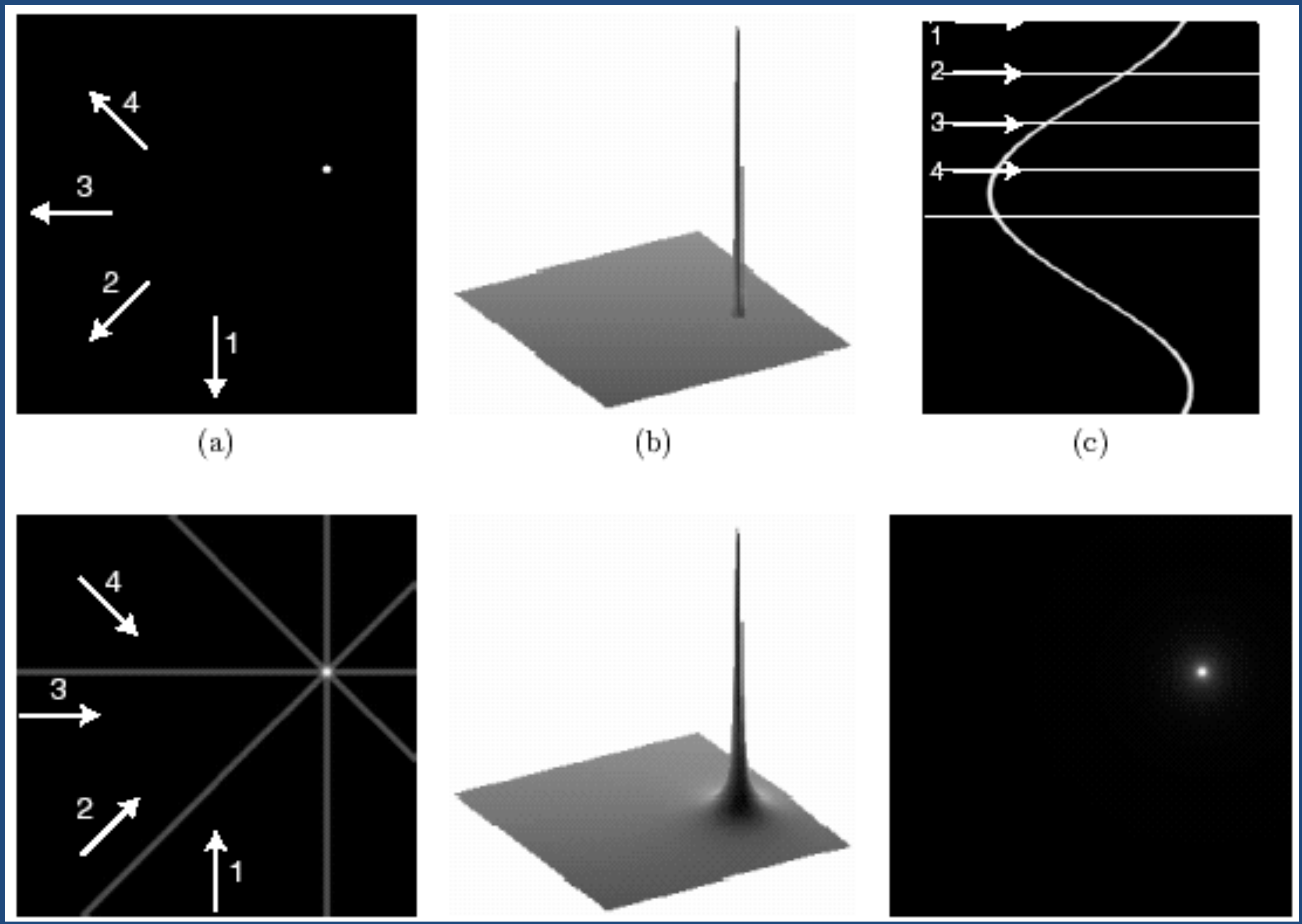
Image formation from projections

- At given incidence angle, θ
- Measure transmitted X-ray intensity at each point across the beam
- Increment angle and repeat



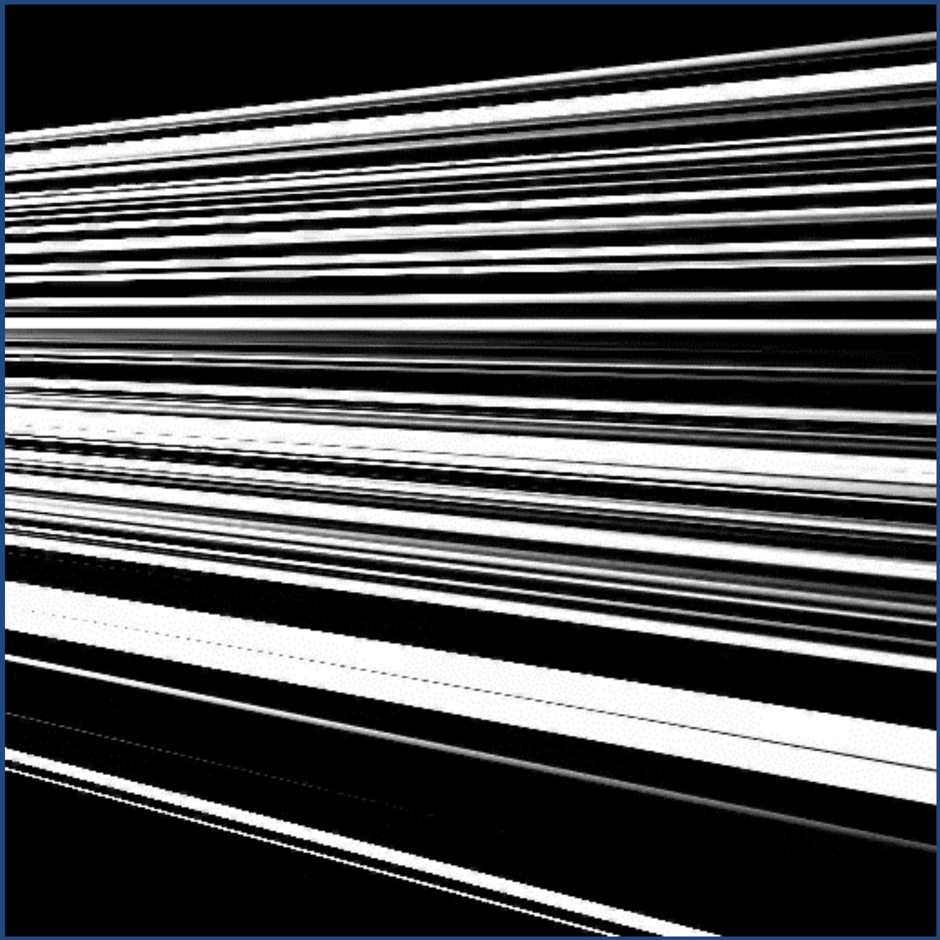
Suetens, 2002

Backprojection



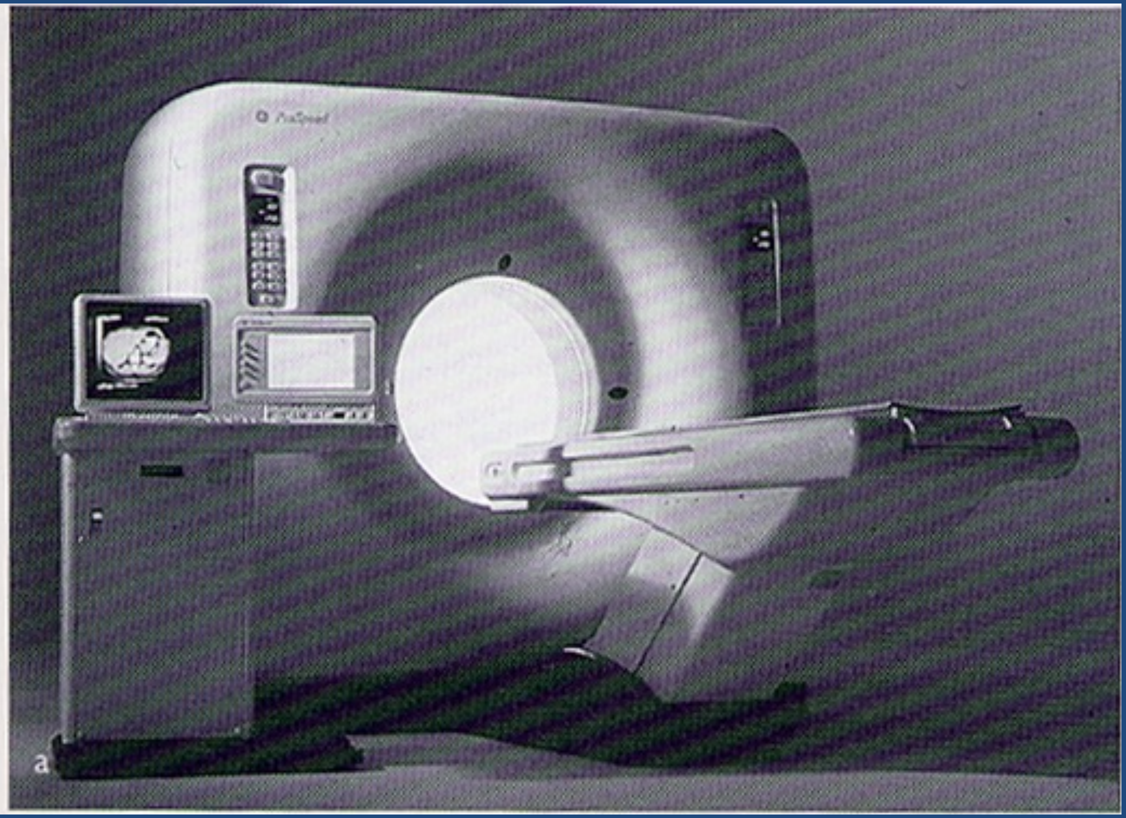
Suetens, 2002

Example of backprojection



Suetens, 2002

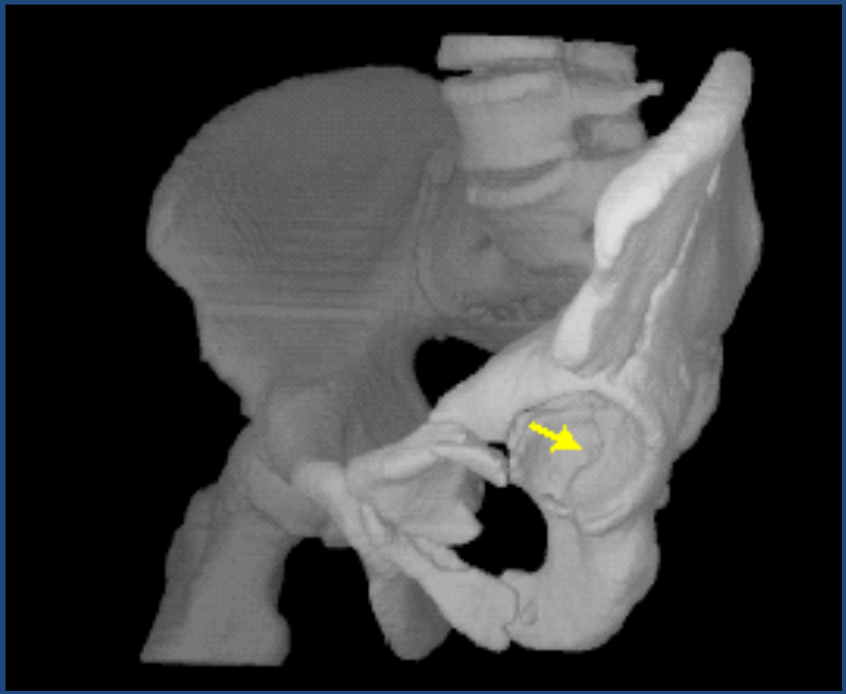
X-ray CT scanner



Wolbarst, 1999

Advantages and disadvantages

- Pros
  - High sensitivity to bone structure
  - Can track contrast agents
  - Fast scanning
- Cons
  - Ionizing radiation
  - Low soft-tissue contrast



Suetens, 2002

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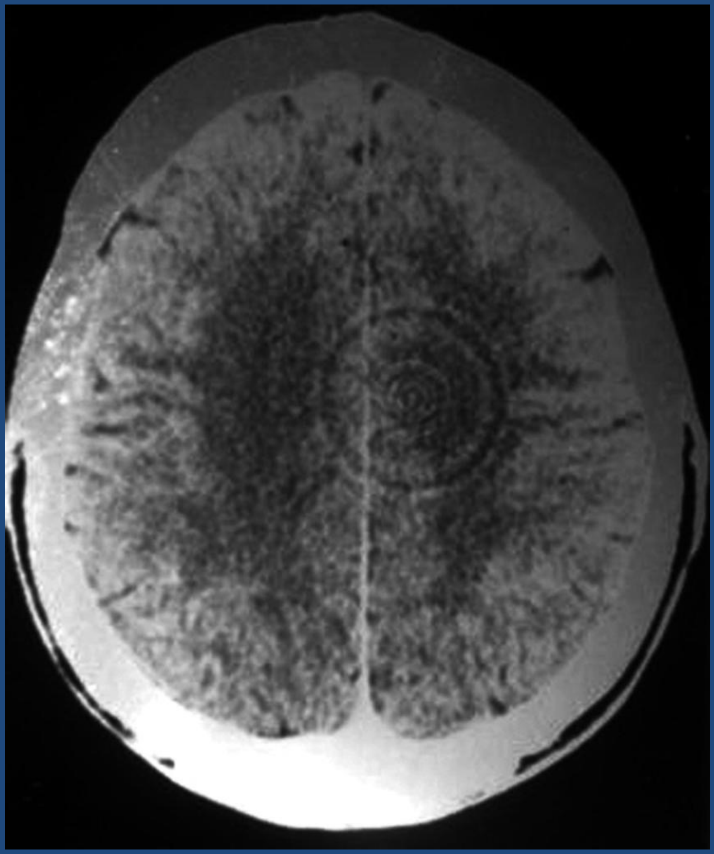
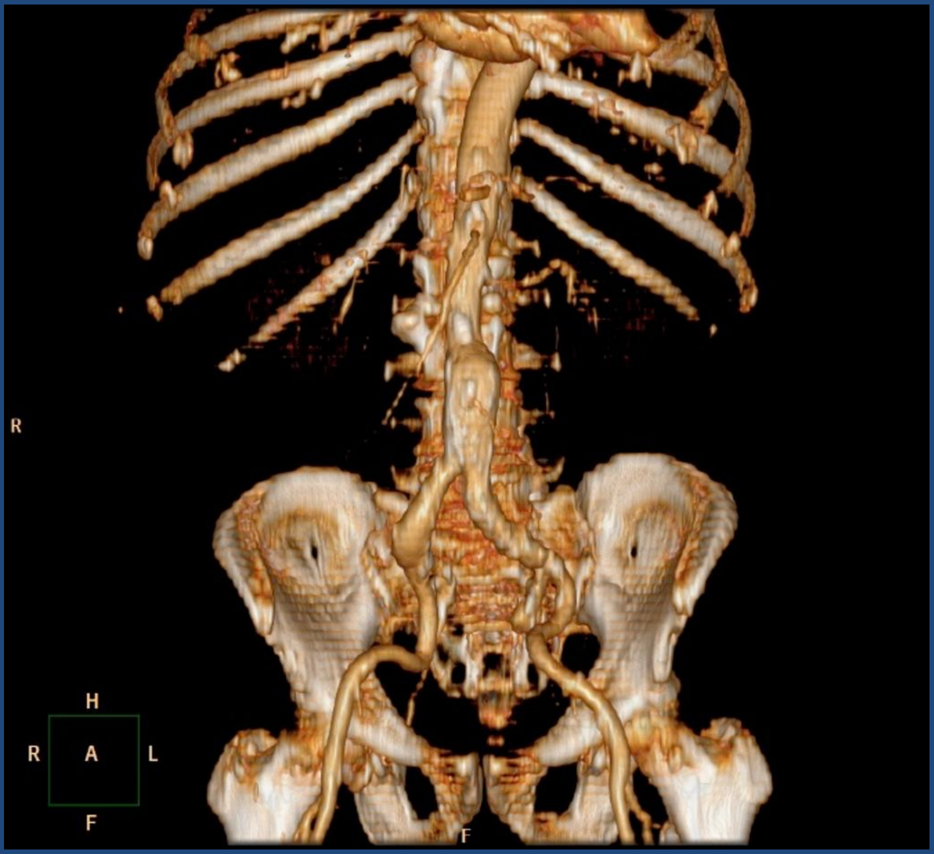


Case courtesy of Dr Laughlin Dawes , Radiopaedia.org



Case courtesy of Dr David Cuete, Radiopaedia.org

Sources

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- P Suetens, Fundamentals of Medical Imaging (Cambridge University Press, 2009).
- AB Wolbarst, Looking Within: How X-Ray, CT, MRI, Ultrasound, and other Medical Images Are Created, and How They Help Physicians Save Lives (Univ. California Press, 1999).
- Radiopaedia.org
- Cartoonstock.com