IMA101 – A Short Introduction To Medical Imaging Modalities

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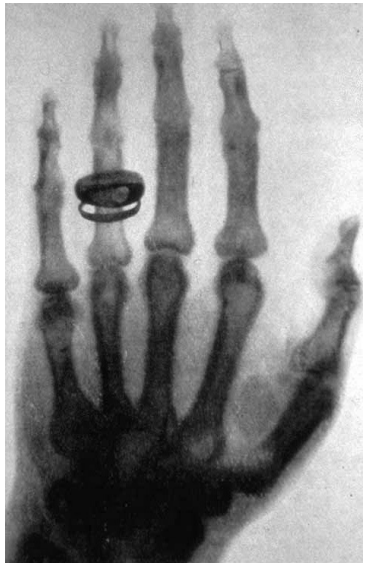
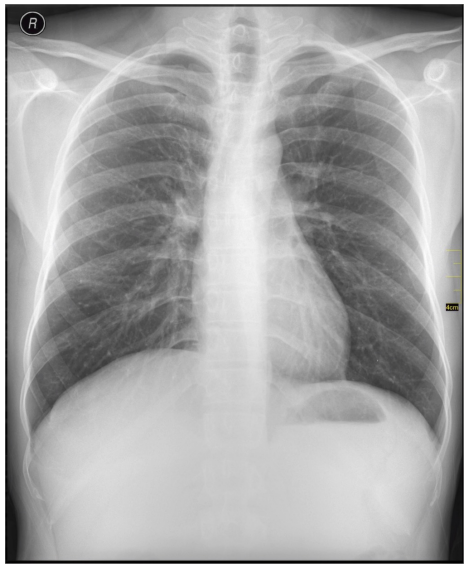
Conventional radiography or X-ray

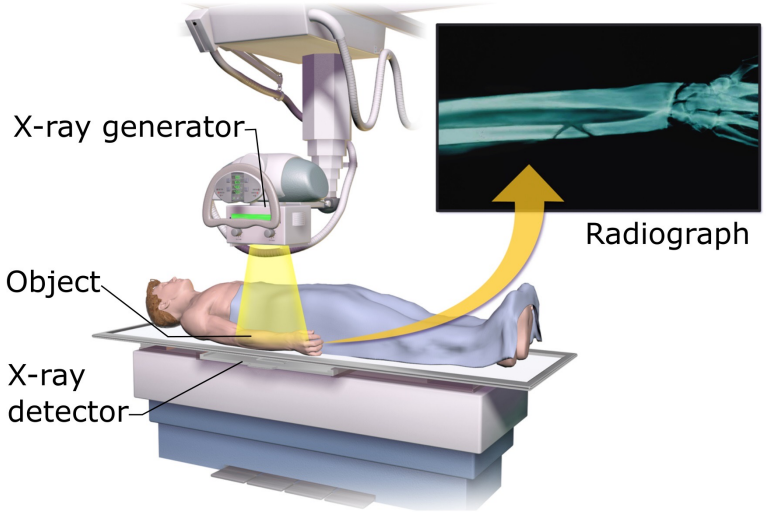
Source: Wikipedia



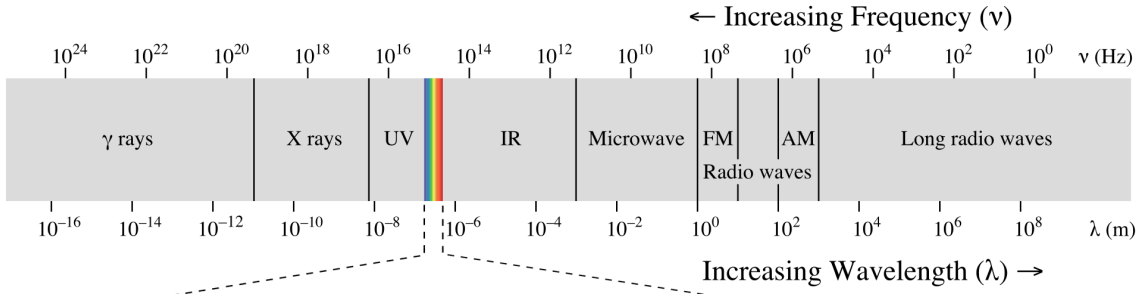
One of the 1st radiographs by Wilhelm Röntgen



Chest radiograph



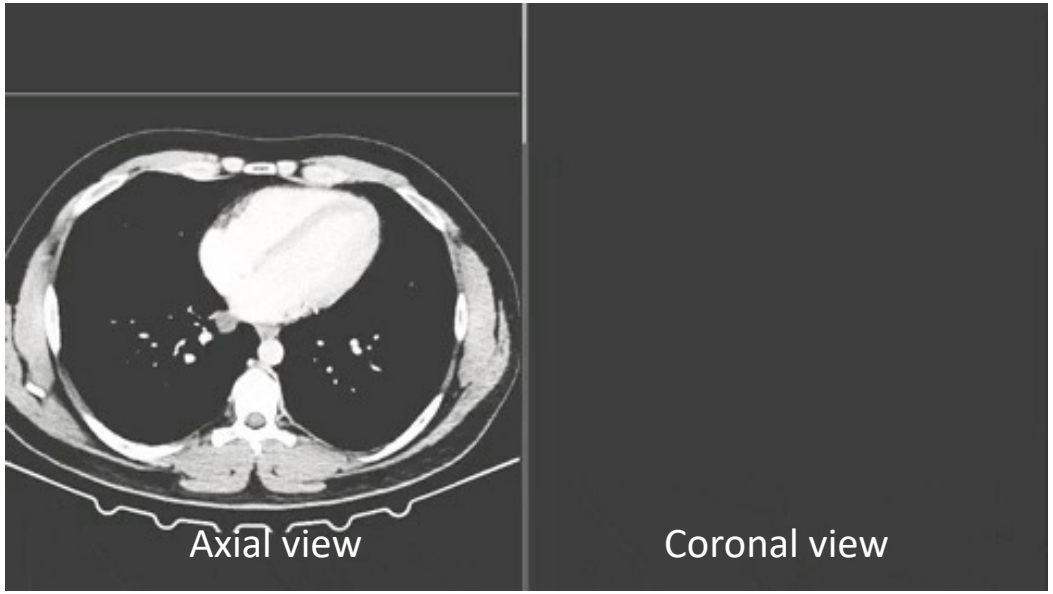
- Uses X-rays, a high-energy electromagnetic radiation
- Ionizing radiation, harmful to living tissue
- Wavelength: gamma-ray ≤ X-ray ≤ UVs



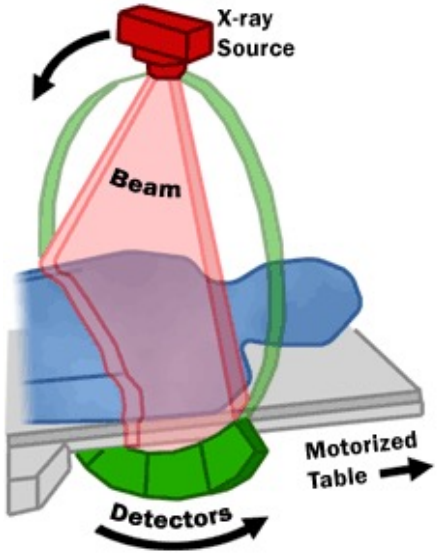
- 2D image (single projection)
- Primary beam attenuated when passing through the body
- Depends on density and structural composition of anatomy (e.g., bone more attenuated than air and soft tissue)

- Applications:
  - Bone fracture detection
  - Chest X-rays: pneumonia, heart failure, etc.
  - Mammograms: breast cancer
  - …

Computed Tomography or CT scan



Source: Wikipedia

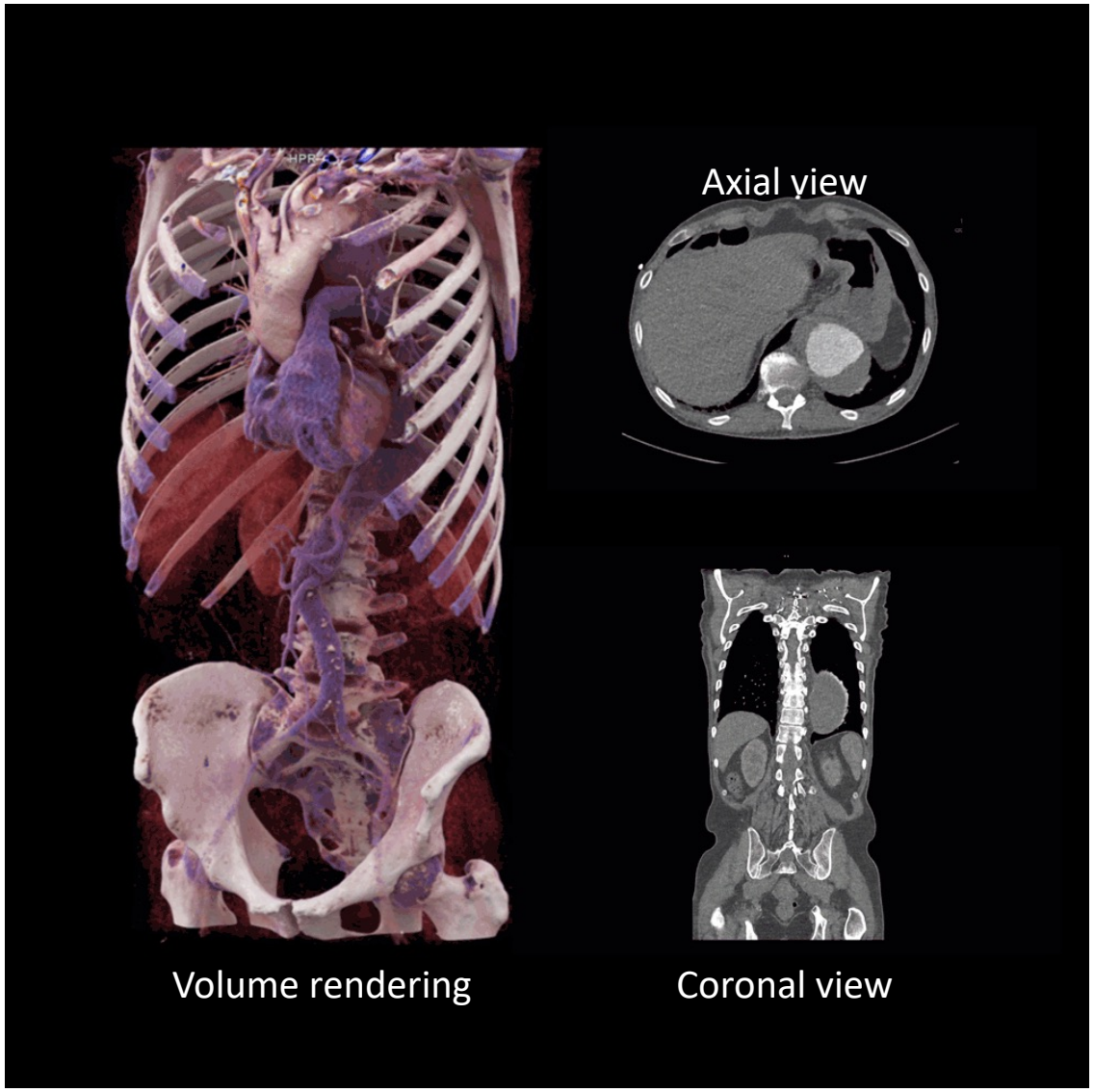


- Same principle as for X-rays but…
- … X-ray source is motorized & rotates around the body
- After a full rotation, signal processed to digitally form a 2D slice (cf. inverse Radon transform)
- 3D image constructed progressively as a stack of 2D slices, as the motorized bed is moved forward in the gantry
- Intensity signal measured in Hounsfield Units (HU): water $= 0\ HU$, air $= -1000\ HU$, dense bone $\sim 2000\ HU$

- View bone fractures, eroded joints
- View tumors or lesions (abdomen, lungs, head, bones…)
- Head scan: locate clots leading to stroke, hemorrhage
- Lungs: pulmonary embolism, excess fluid, emphysema…

- Contrast agents can be added to enhance the visibility of soft tissues or blood vessels
- e.g., CT angiography to examine the circulatory system, to look for possible obstructions

Computed Tomography or CT scan



Source: siemens-healthineers.com

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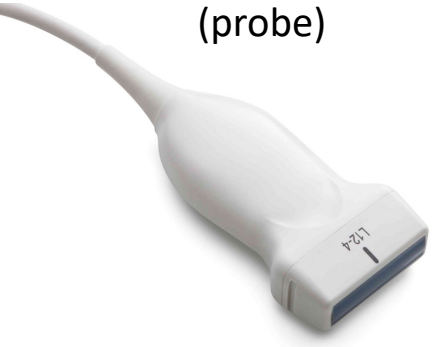
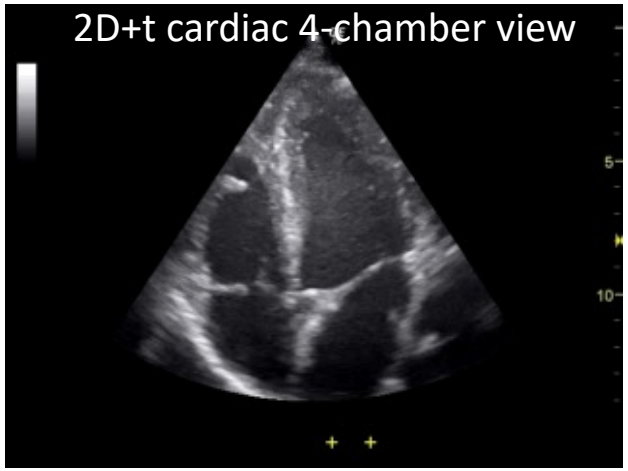
Ultrasound imaging or (ultra)sonography (US)

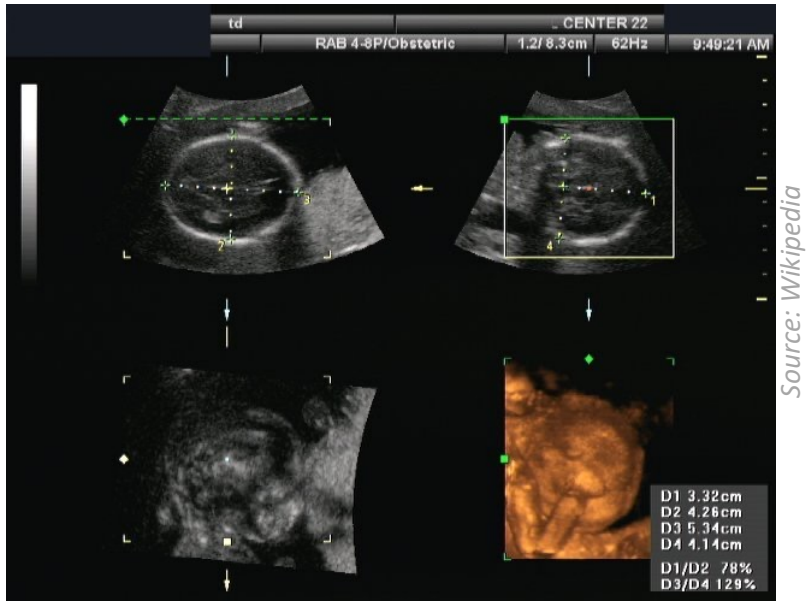
Ultrasound transducer (probe)





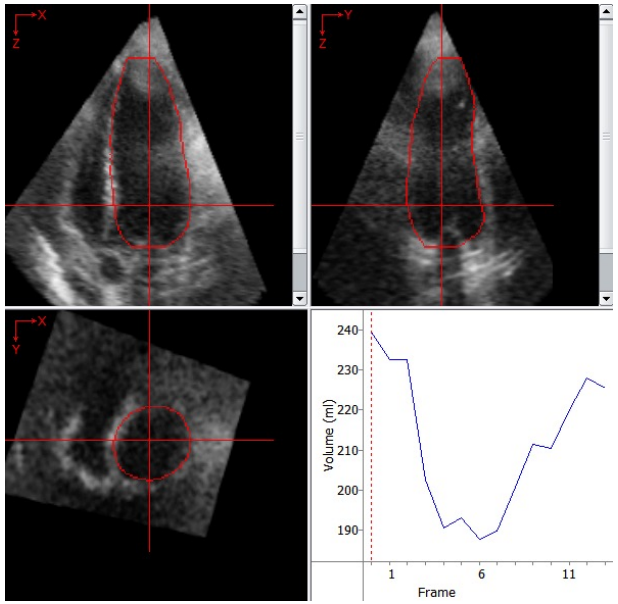
Source: Wikipedia

- Uses high-frequency sound waves
- Waves bounce off body tissue and make echoes
- The echoes are received by the transducer and transformed in a digital image
- Safe for health
- 2D or 3D



Source: Wikipedia

3D fetal imaging
(3 orthogonal views & volume reconstruction)

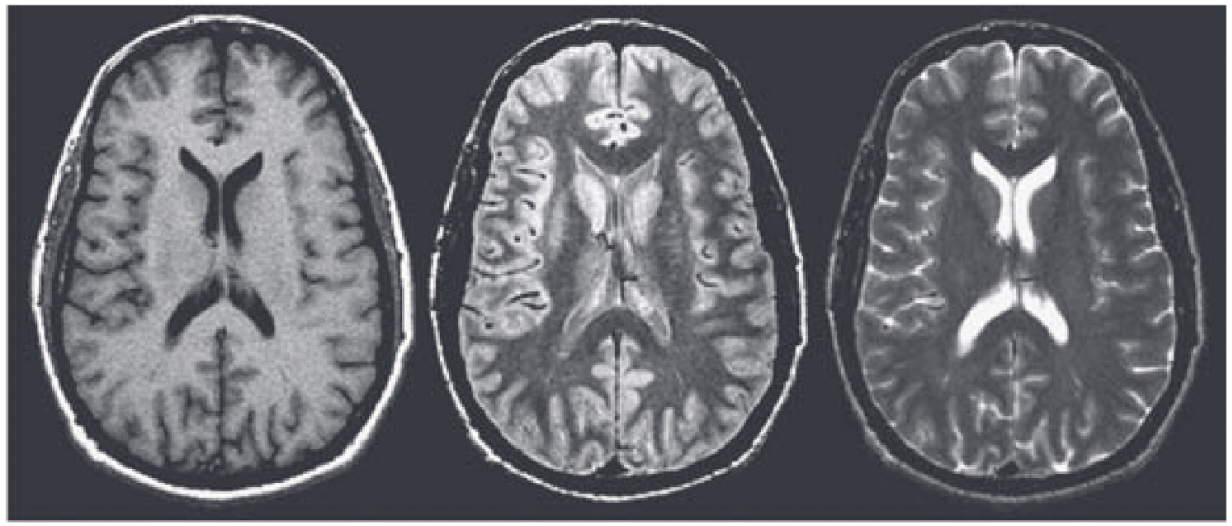


Source: iibi.uiowa.edu/cardiovascular-analysis

3D+t cardiac imaging
(overlayed left ventricle contour)

- Effective for imaging soft tissues
- Many applications for screening & diagnosis
  - Cardiology (echocardiography)
  - Prenatal ultrasound
  - Point-of-care ultrasound
  - Abdominal US (liver tumors…)
  - Hemodynamics (blood flow)
  - Urology (bladder…)

Magnetic Resonance Imaging (MRI)



Source: Buxton. Introduction to fMRI, 2009.

Source: philips.com

- Perfect to image soft tissues
- Safe except contraindications (metal implants, etc.)

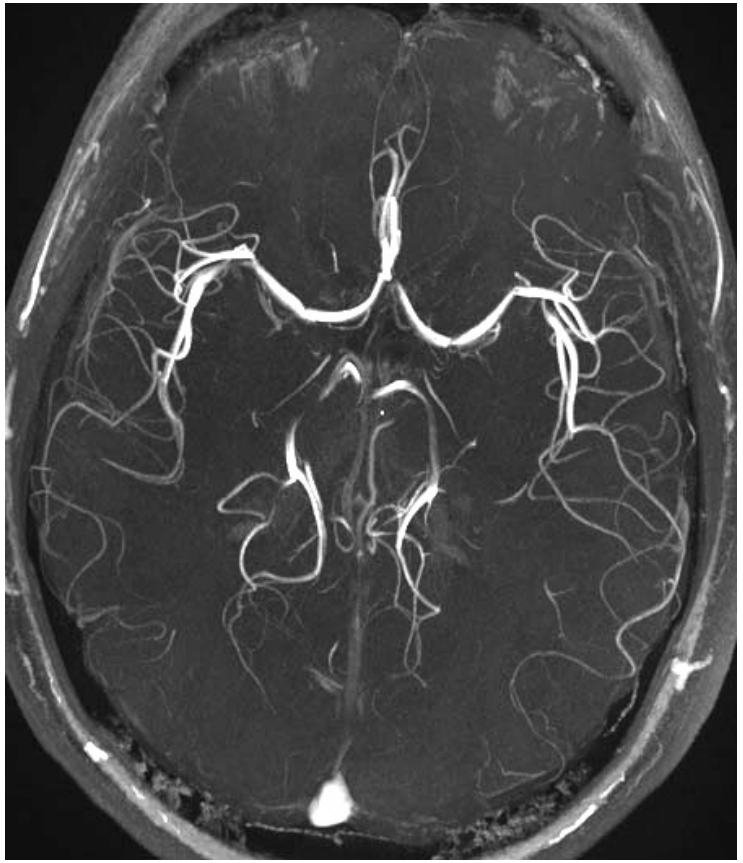
- Based on Nuclear Magnetic Resonance (NMR)
- Magnetization of hydrogen nuclei in an imaged sample

- $1.5T$, $3T$, up to $14T$ MRI depending on the strength of the large uniform magnetic field $\boldsymbol{B}_0$ applied to align the magnetic dipole moments of the H nuclei

- Many parameters resulting in many sequences with different appearances and contrast
  - Change repetition time TR and echo time TE (ms) to control the sensitivity of the signal to local tissue relaxation times T_1 and T_2 (depending on the proton density)
  - Flip angle
  - Acquisition plane ($3D$ as stack of $2D$)
  - …

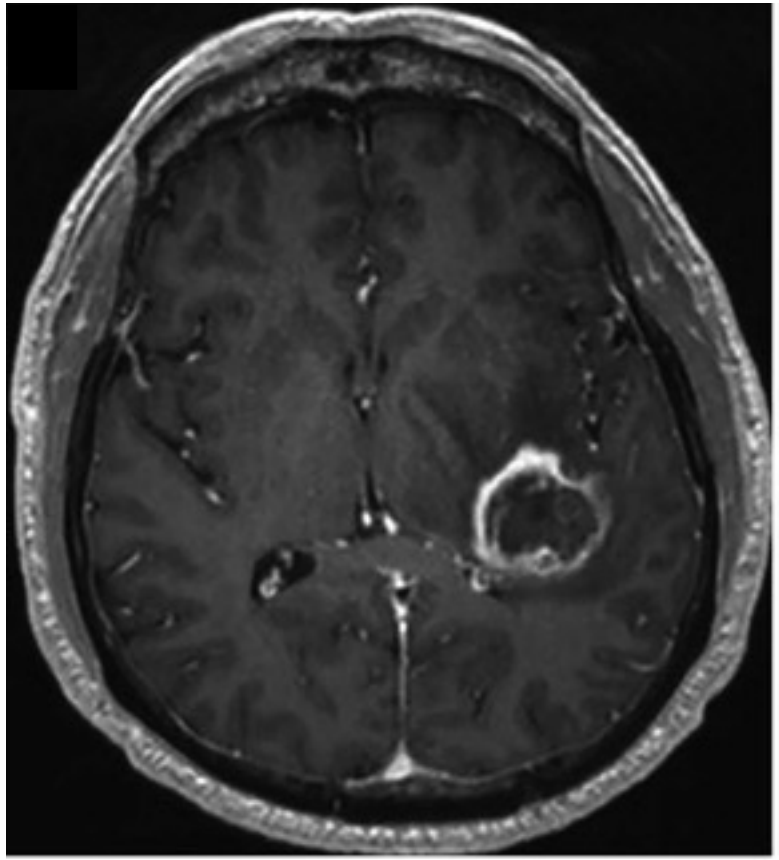
Magnetic Resonance Imaging (MRI)

MRI with contrast agent



Source: Wikipedia

Magnetic Resonance Angiography of the brain to image blood vessels (also common for neck, thoracic and abdominal aorta, renal arteries, legs)

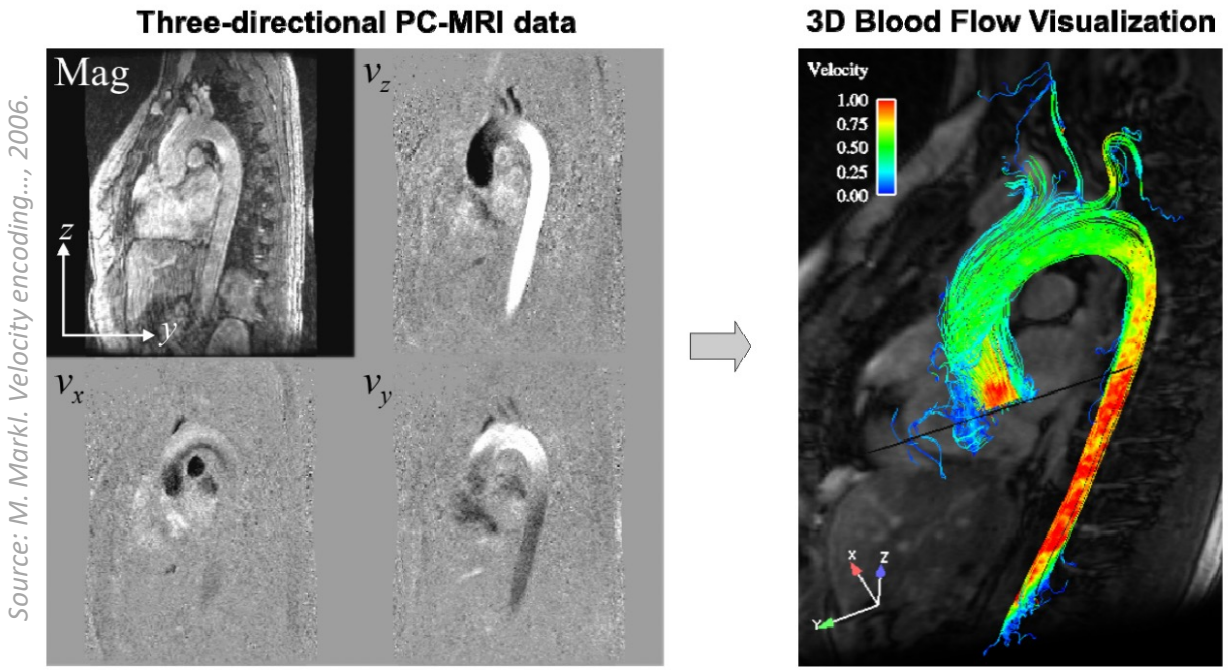


Source: Alvarez et al. J Neurosurg Case Lessons, 2021.

Gadolinium-enhanced T1-w MRI to image the glioblastoma (tumour)

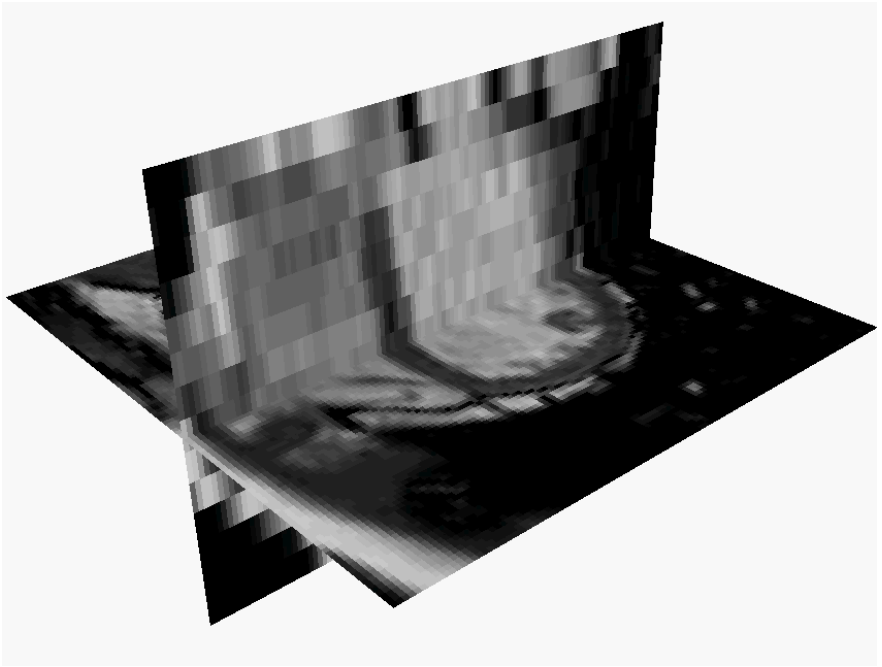
Magnetic Resonance Imaging (MRI)

MRI can reveal kinematics



Source: M. Markl. Velocity encoding..., 2006.

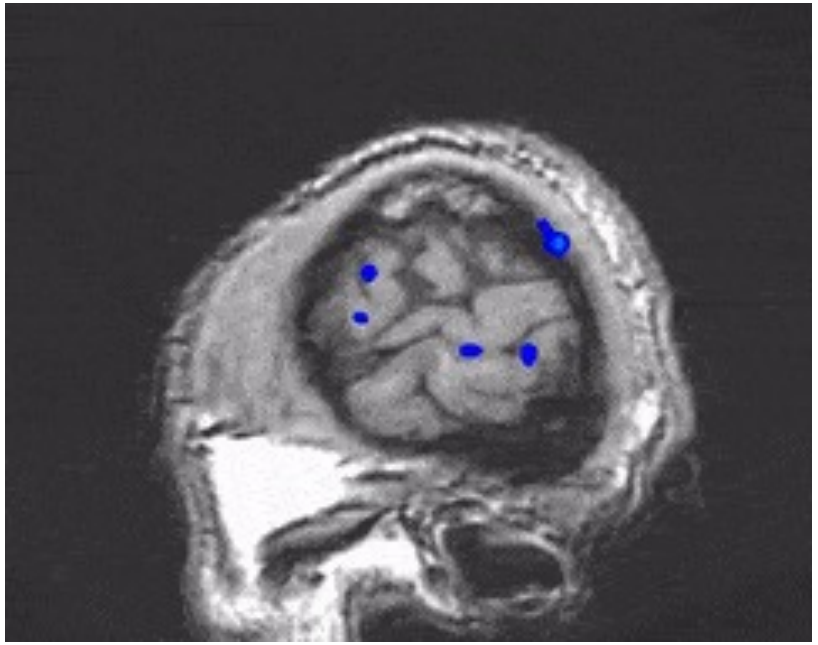
Phase-contrast MRI reveals the $3D$ blood flow in arteries
(e.g., shown here, heart and aorta in a sagittal slice)

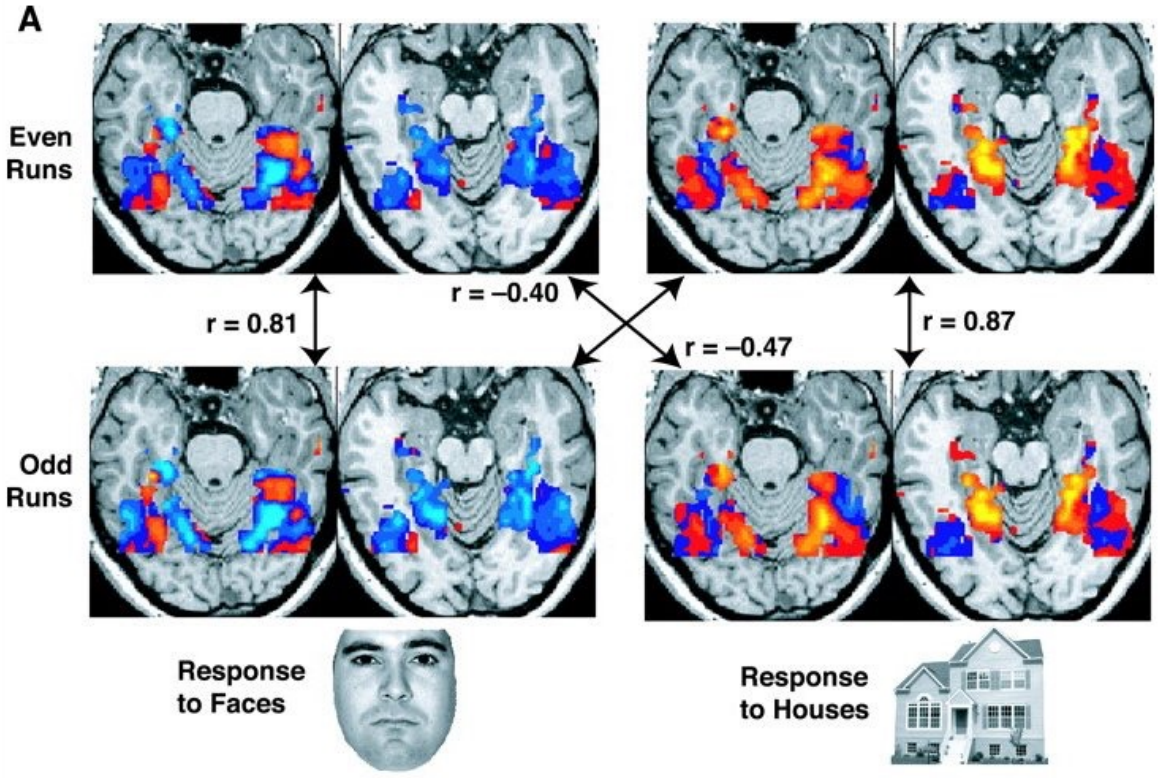


Cine MRI showing the beating heart
(left and right ventricles, 2 orthogonal planes shown)

Magnetic Resonance Imaging (MRI)

MRI can reveal functional information → **functional MRI**

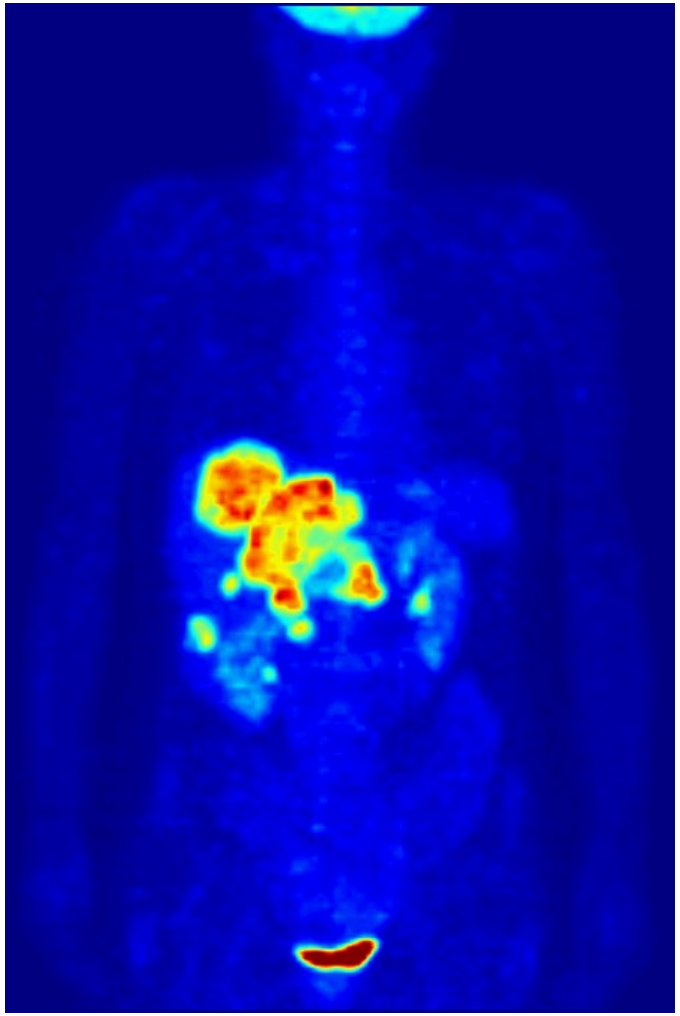




- Blood-oxygen-level dependent (BOLD) contrast
- fMRI measures brain activity via hemodynamic responses
  - Blood releases oxygen to active neurons at a greater rate than to inactive neurons
  - The difference between oxygenated and deoxygenated blood is measurable

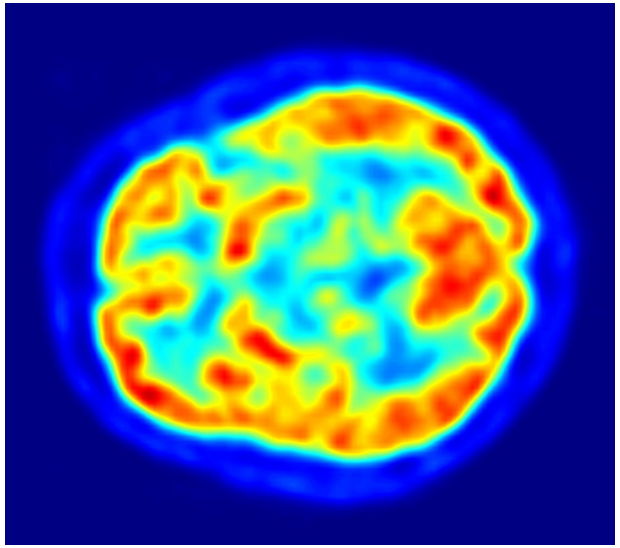
- Used in research
- Detect signal changes in response to different stimuli

Positron Emission Tomography (PET)



← Whole-body PET scan using a glucose-based radiotracer

↓ Brain PET scan



Source: Wikipedia

- Functional imaging technique
- Can be combined with CT and MRI to overlay an anatomical reference under the functional data (PET-CT, PET-MRI)
- Exposes to ionizing radiation

- A radioactive substance (radiotracer) is used to measure metabolic processes or physiological activity
  - The radiotracer undergoes positron emission decay in the tissue
  - Positrons are indirectly located as they annihilate with an electron

- Applications:
  - Oncology: detect tumours (glucose-based radiotracer)
  - Neuroimaging: measure the blood flow (oxygen-based radiotracer)
  - …