CAP 5516
Medical Image Computing
(Spring 2022)

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Lecture 4: Introduction to Medical Image Computing (2)

Image credit: https://www.syberscribe.com.au/blog/the-ins-and-outs-of-medical-imaging/

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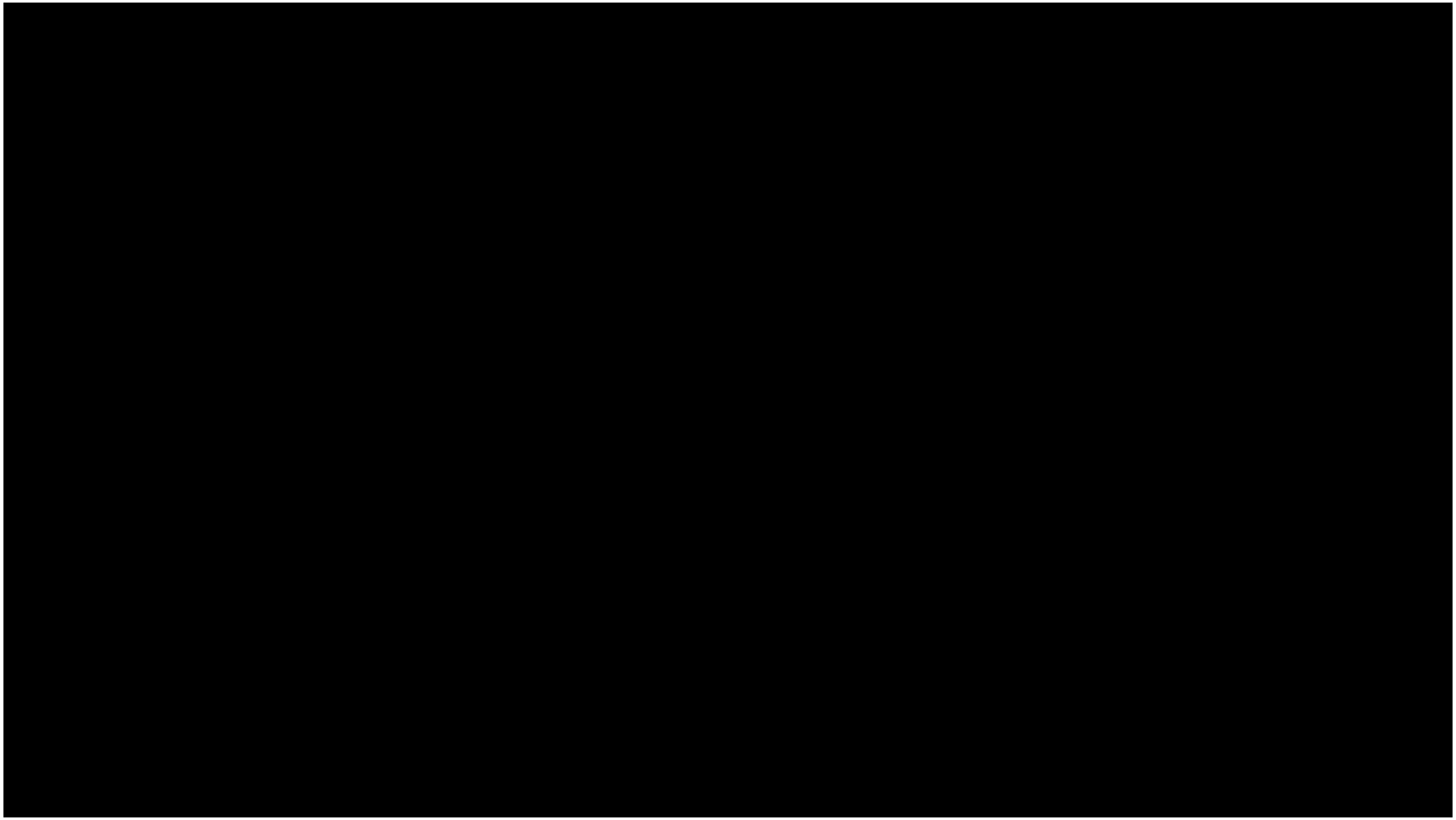
Magnetic Resonance Imaging (MRI)

- Magnetic Resonance Imaging (MRI) is a medical imaging procedure for making images of the internal structures of the body.
- MRI scanners use strong magnetic fields and radio waves (radiofrequency energy) to make images.

Source: https://assets.aboutkidshealth.ca/akhassets/BT_Neuro_MRI2_MEDIMG-PHO_EN.jpg?RenditionID=10

Magnetic Resonance Imaging (MRI)



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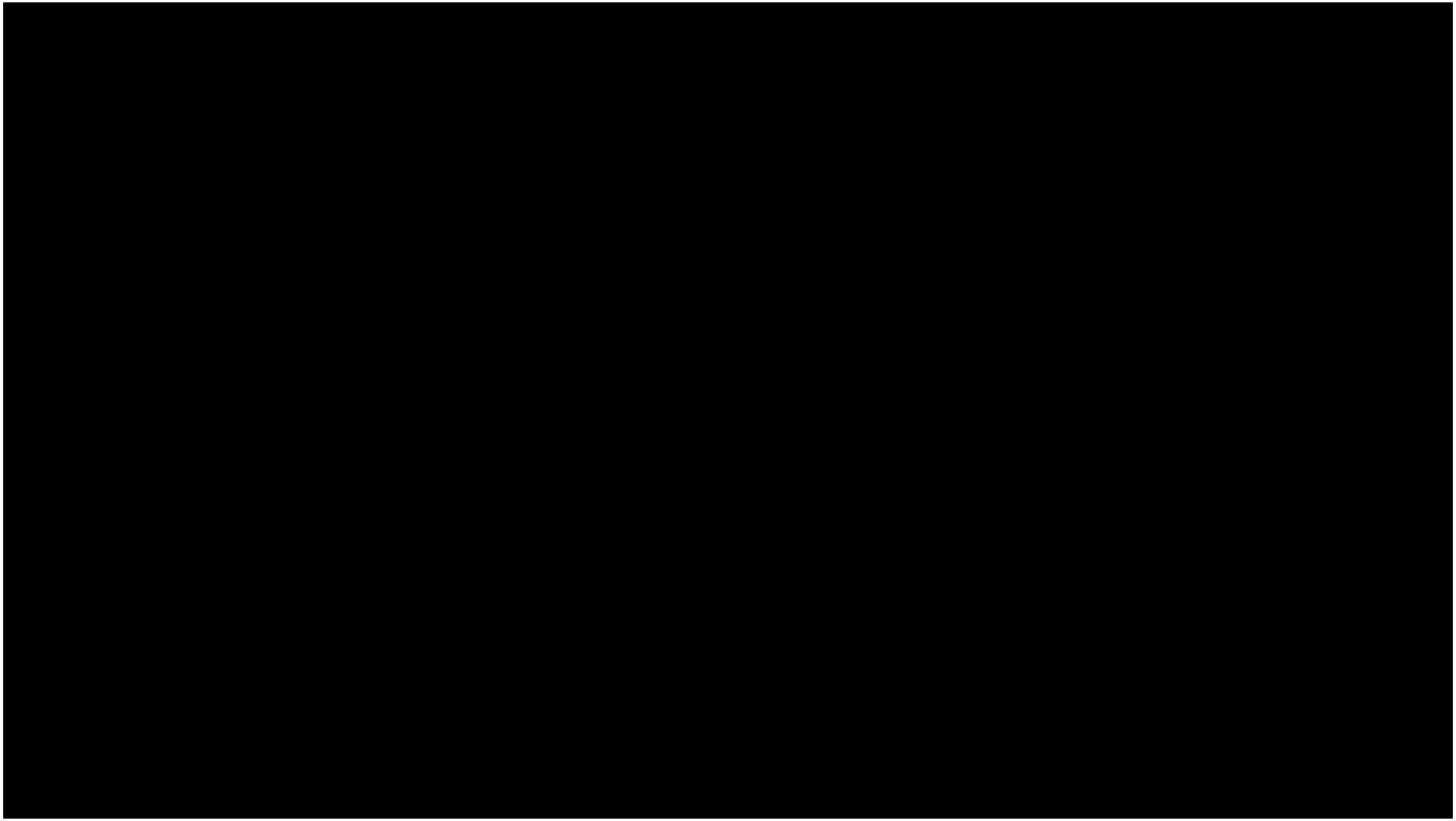
Magnetic Resonance Imaging (MRI)



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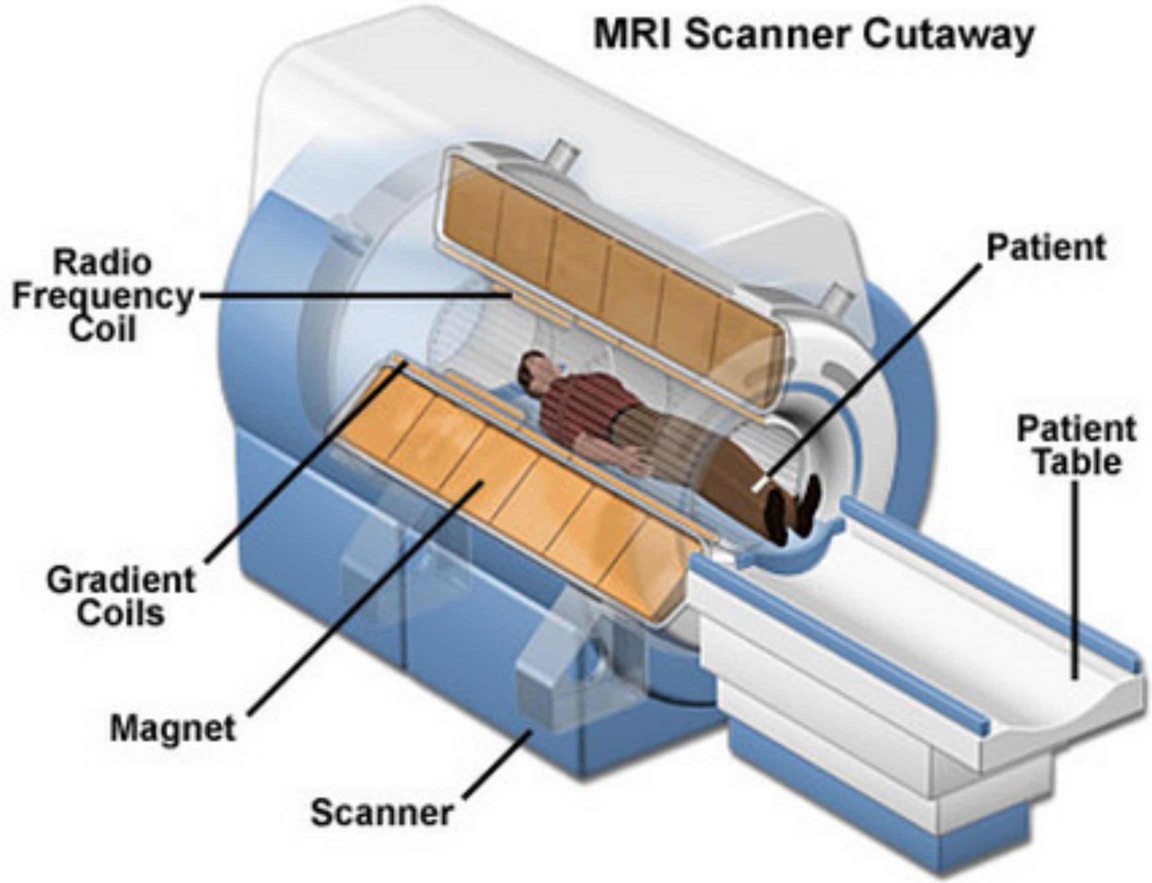
MRI System Components and Functions



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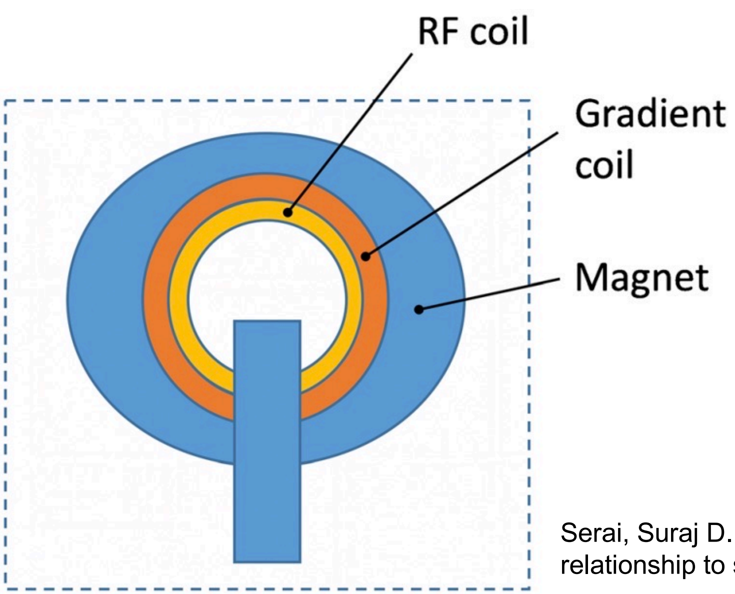
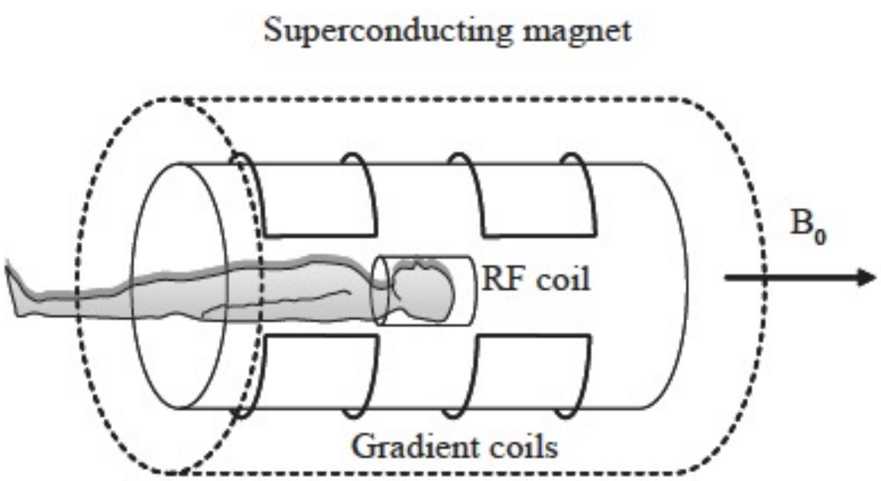


Serai, Suraj D., et al. "Components of a magnetic resonance imaging system and their relationship to safety and image quality." Pediatric radiology 51.5 (2021): 716-723.

MRI System Components and Functions

- The **magnet** is the largest and most expensive component of the MRI scanner
- The strength of the magnet is measured in [teslas (T)](). Clinical magnets generally have a field strength in the range 0.1–3.0 T, with research systems available up to 9.4 T for human use and 21 T for animal systems. The Earth's magnetic field is only 0.5 gauss. (1 tesla = 10,000 gauss)

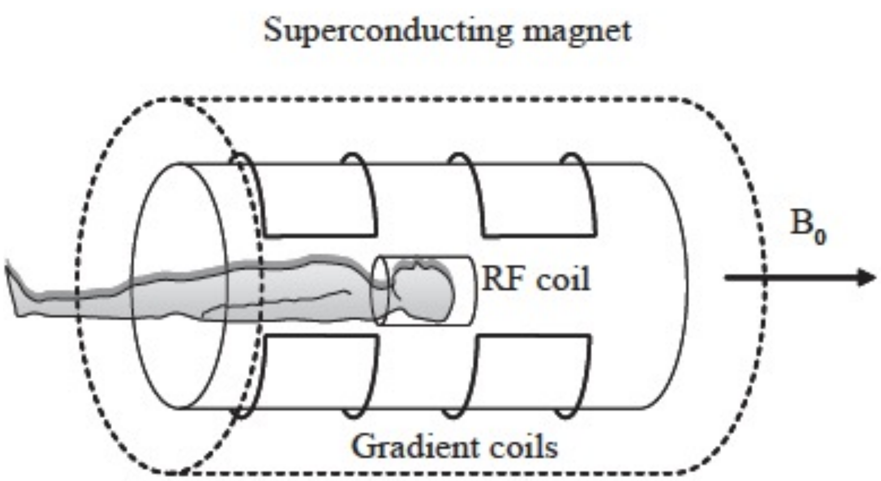


- Most clinical magnets are [superconducting]() magnets, which require [liquid helium]() to keep them very cold (temperatures below 10 Kelvin (−263 °C))

MRI System Components and Functions

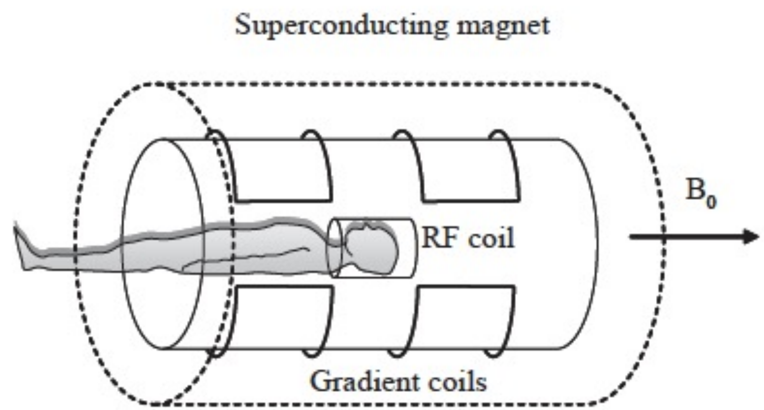
- A higher magnetic field strength increases longitudinal magnetization because more protons align along the main axis of the magnetic field, increasing the signal-to-noise ratio (SNR).

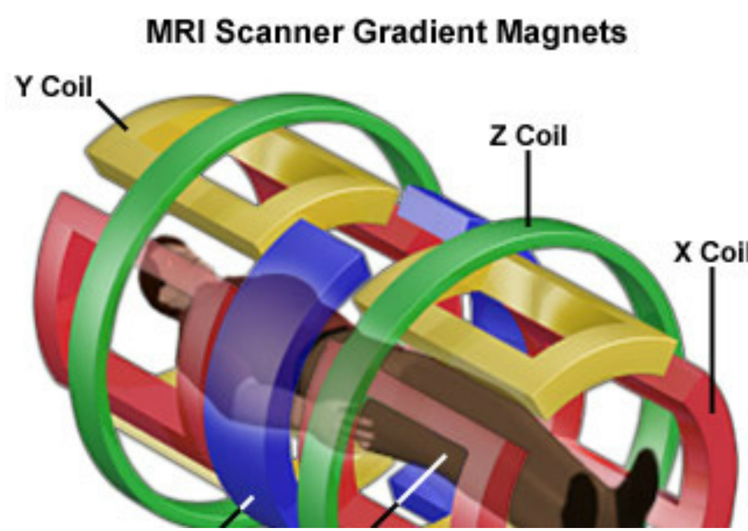
- The improved SNR can be used to generate images with improved spatial resolution.



MRI System Components and Functions

- **Gradient coils** are used to spatially encode the positions of protons by varying the magnetic field linearly across the imaging volume.
- There are *three* different gradient coils that are inside the MRI machine and are located within the main magnet.
- Each one of these produce three different magnetic fields that are each less strong than the main field.
- The gradient coils create a variable field (x, y, z) that can be increased or decreased to allow specific and different parts of the body to be scanned by altering and adjusting the main magnetic field.

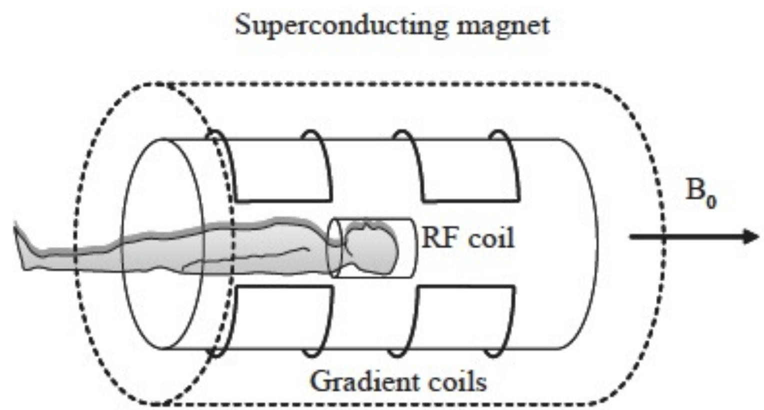


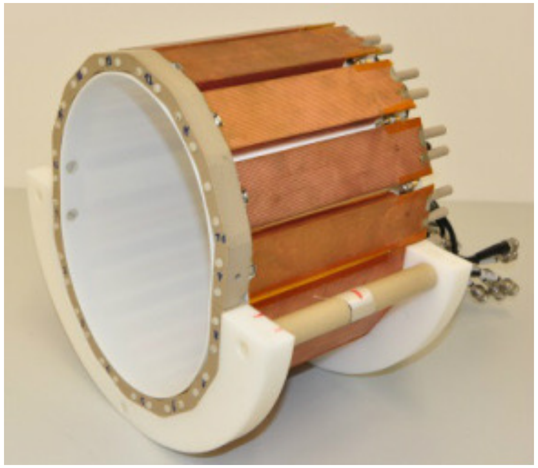


https://snc2dmri.weebly.com/components--functions.html

MRI System Components and Functions

- **Radiofrequency (RF) coils** are used to send RF pulses and receive the signal back from the patient's body.
- There are different coils located inside the MRI scanner to transmit waves into different body parts.

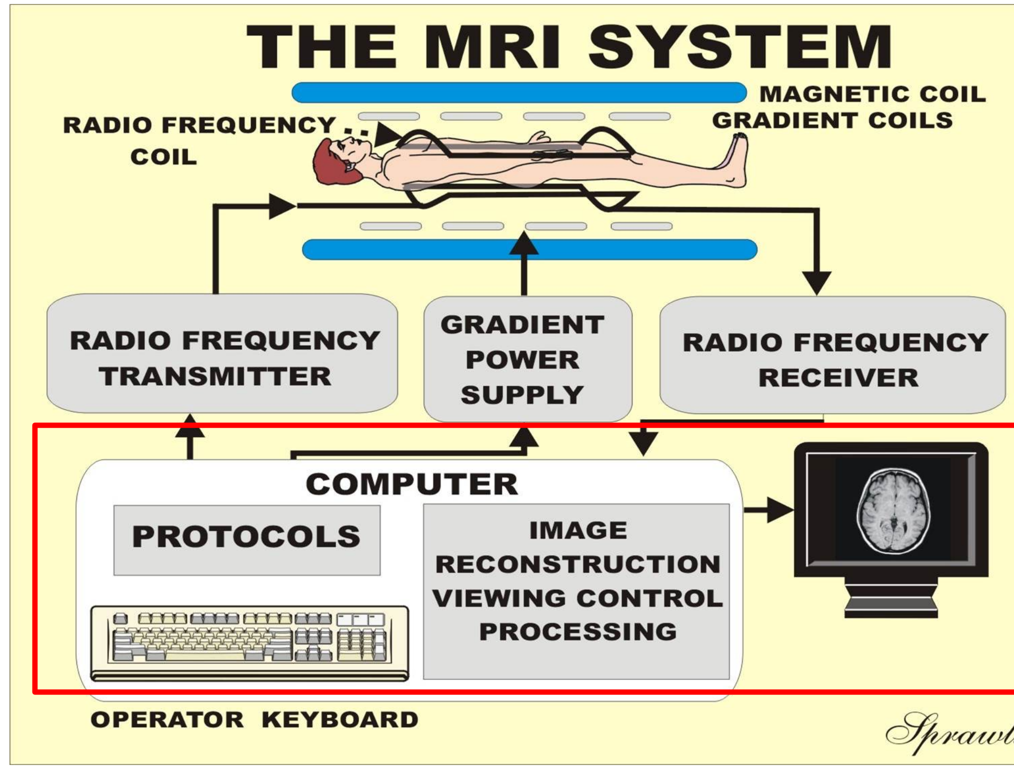




https://snc2dmri.weebly.com/components--functions.html

MRI System Components and Functions

- The multiple **computer systems** embedded in an MRI scanner have a range of functions
  - control the RF and gradient pulses
  - collect the data
  - process and display the generated image



http://www.sprawls.org/mripmt/MRI02/index.html

- More details about the basic physics for magnetic resonance imaging

  - Serai, Suraj D., et al. "Components of a magnetic resonance imaging system and their relationship to safety and image quality." *Pediatric radiology* 51.5 (2021): 716-723.
  - Currie, S., Hoggard, N., Craven, I. J., Hadjivassiliou, M., & Wilkinson, I. D. (2013). Understanding MRI: basic MR physics for physicians. *Postgraduate medical journal*, *89*(1050), 209-223.
  - Chavhan, Govind B. *MRI made easy*. JP Medical Ltd, 2013. Free online: https://rads.web.unc.edu/wp-content/uploads/sites/12234/2018/05/Phy-MRI-Made-Easy.pdf
  - Sprawls, Perry. Magnetic resonance imaging: principles, methods, and techniques. Madison, Wisconsin: Medical Physics Publishing, 2000. Online: http://www.sprawls.org/mripmt/index.html

MRI Sequences

- By varying the sequence of RF pulses applied & collected, different types of images are created
- The most common MRI sequences are T1-weighted and T2-weighted scans
- What are T1 and T2?

MRI Sequences

- By varying the sequence of RF pulses applied & collected, different types of images are created.

- **Repetition Time (TR)** is the amount of time between successive pulse sequences applied to the same slice.

- **Time to Echo (TE)** is the time between the delivery of the RF pulse and the receipt of the echo signal.

MRI Sequences

- Tissue can be characterized by two different relaxation times – T1 and T2.
- T1 (longitudinal relaxation time) is the time constant which determines the rate at which excited protons return to equilibrium. <u>It is a measure of the time taken for spinning protons to realign with the external magnetic field</u>.
- T2 (transverse relaxation time) is the time constant which determines the rate at which excited protons reach equilibrium or go out of phase with each other. It is a measure of the time taken for spinning protons to lose phase coherence among the nuclei spinning perpendicular to the main field.

MRI Sequences

- **T1-weighted images** are produced by using short TE and TR times. The contrast and brightness of the image are predominately determined by T1 properties of tissue.
- Conversely, **T2-weighted images** are produced by using longer TE and TR times. In these images, the contrast and brightness are predominately determined by the T2 properties of tissue.
- A third commonly used sequence is the **Fluid Attenuated Inversion Recovery (Flair)**. The Flair sequence is similar to a T2-weighted image except that the TE and TR times are very long.

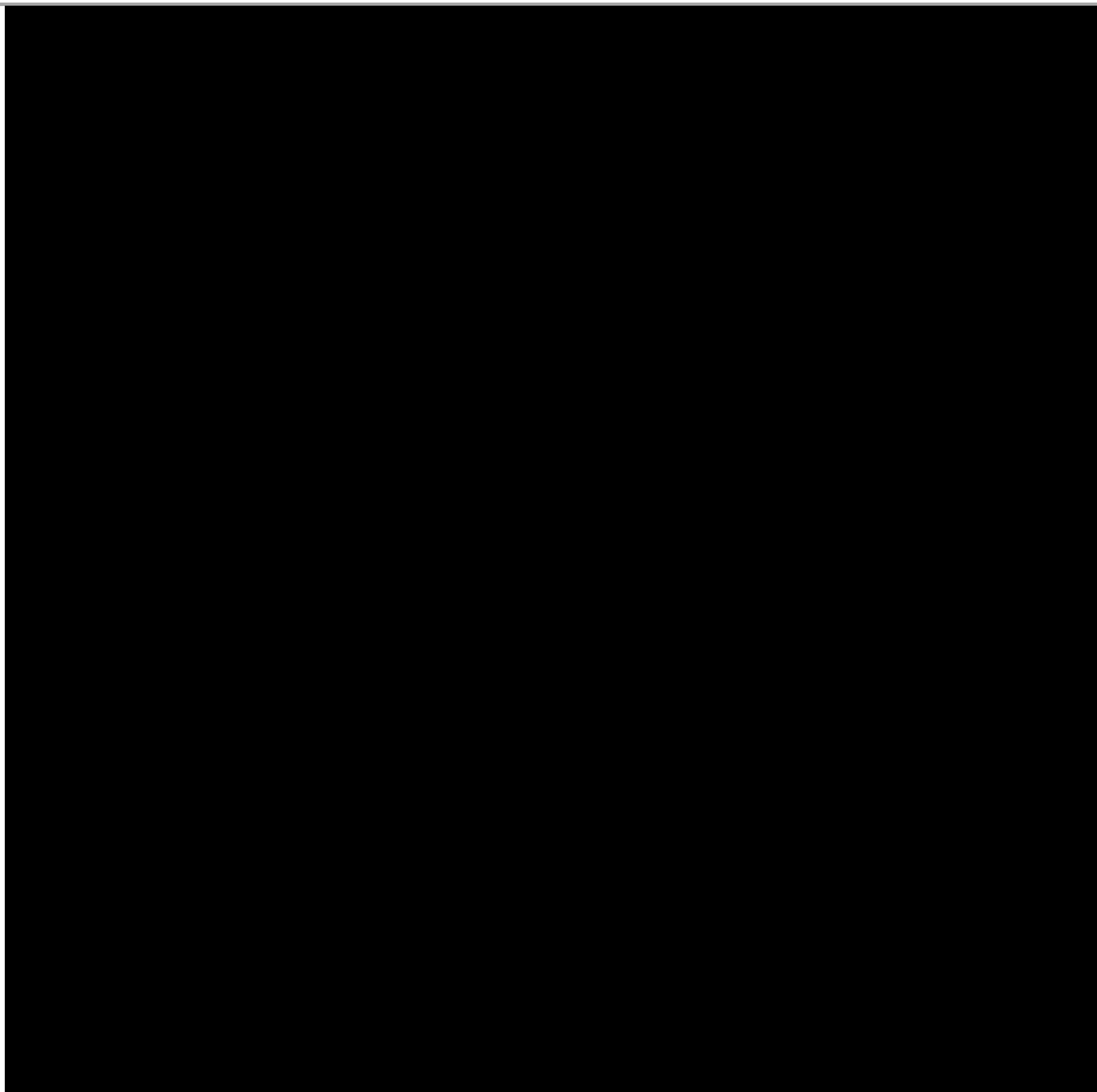
MRI Sequences

	TR (msec)	TE (msec)
T1-Weighted (short TR and TE)	500	14
T2-Weighted (long TR and TE)	4000	90
Flair (very long TR and TE	9000	114

Most common MRI Sequences and their Approximate TR and TE times.

https://case.edu/med/neurology/NR/MRI%20Basics.htm#:~:text=The%20most%20common%20MRI%20sequences,longer%20TE%20and%20TR%20times.

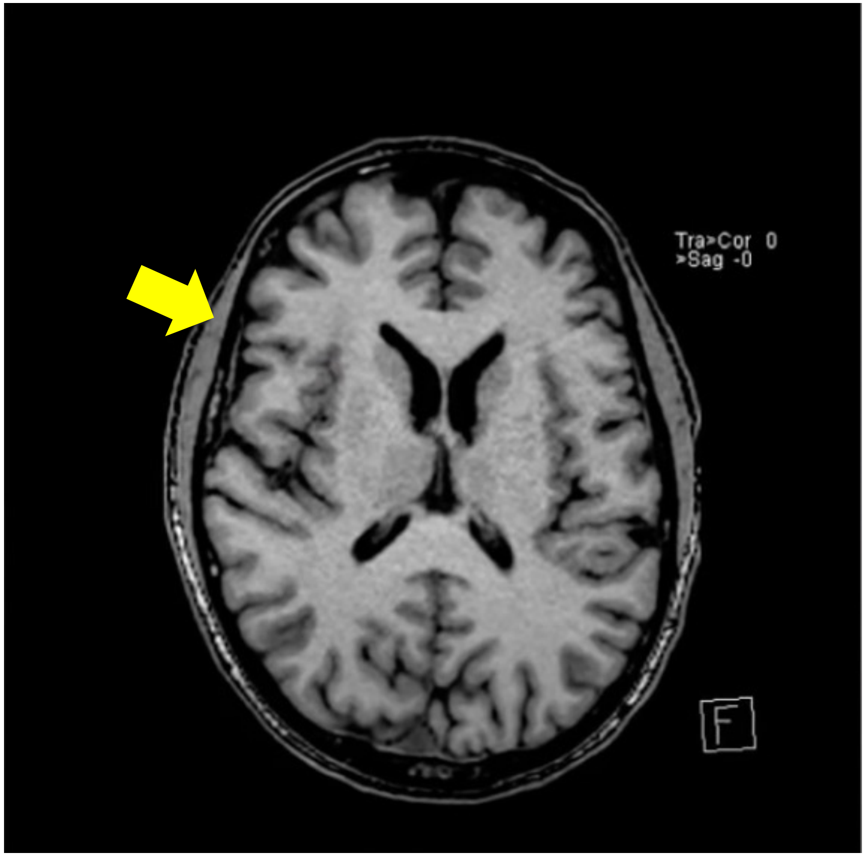
MRI Sequences



Source:
https://www.youtube.com/watch?v=Ue4gzUzIGNo

MRI Sequences (T1-Weighted Image)

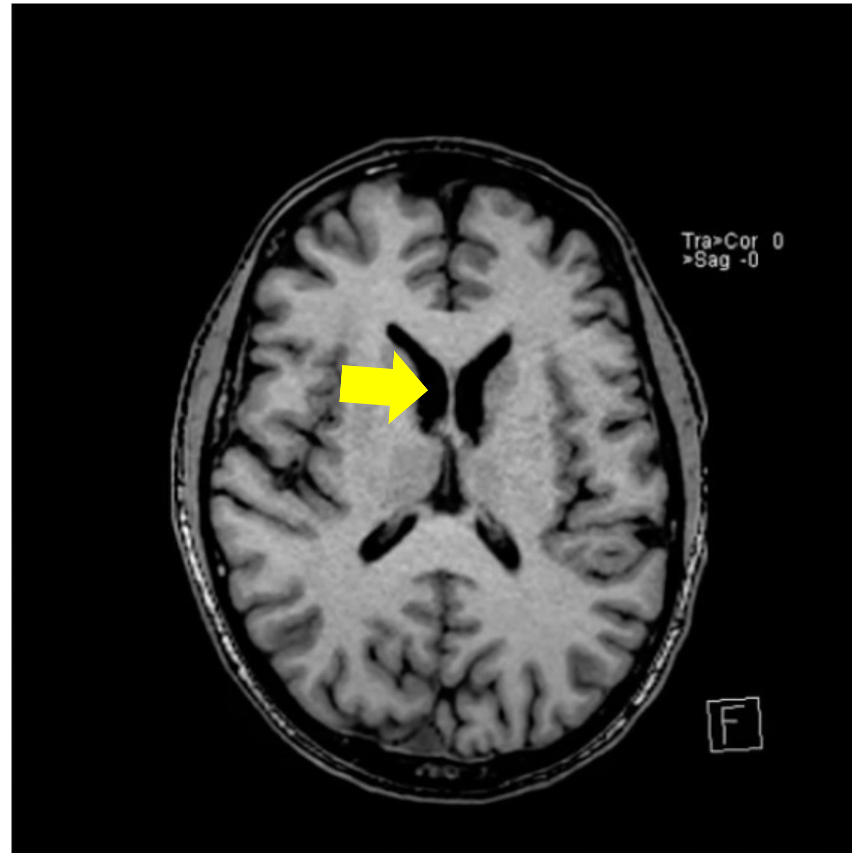
- Fat: Bright



Credit: Dr. David Nascene

MRI Sequences (T1-Weighted Image)

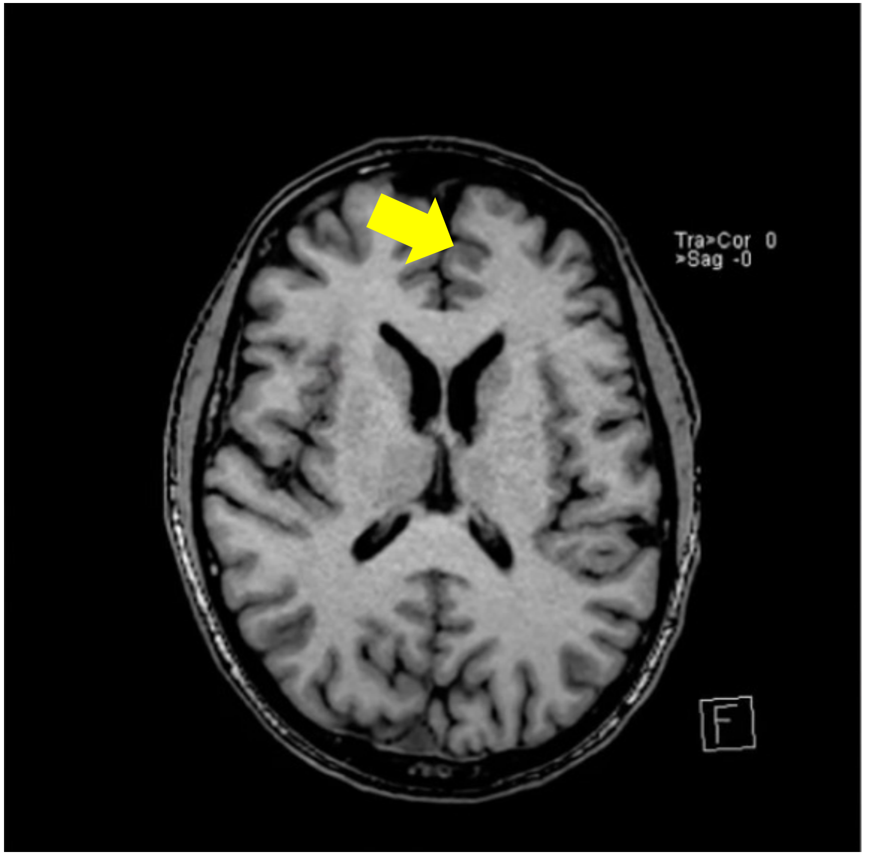
- Fat: Bright
- Fluid: Dark
  cerebrospinal fluid (CSF)



Credit: Dr. David Nascene

MRI Sequences (T1-Weighted Image)

- Fat: Bright
- Fluid: Dark
  cerebrospinal fluid (CSF)
- Gray matter is gray



Credit: Dr. David Nascene

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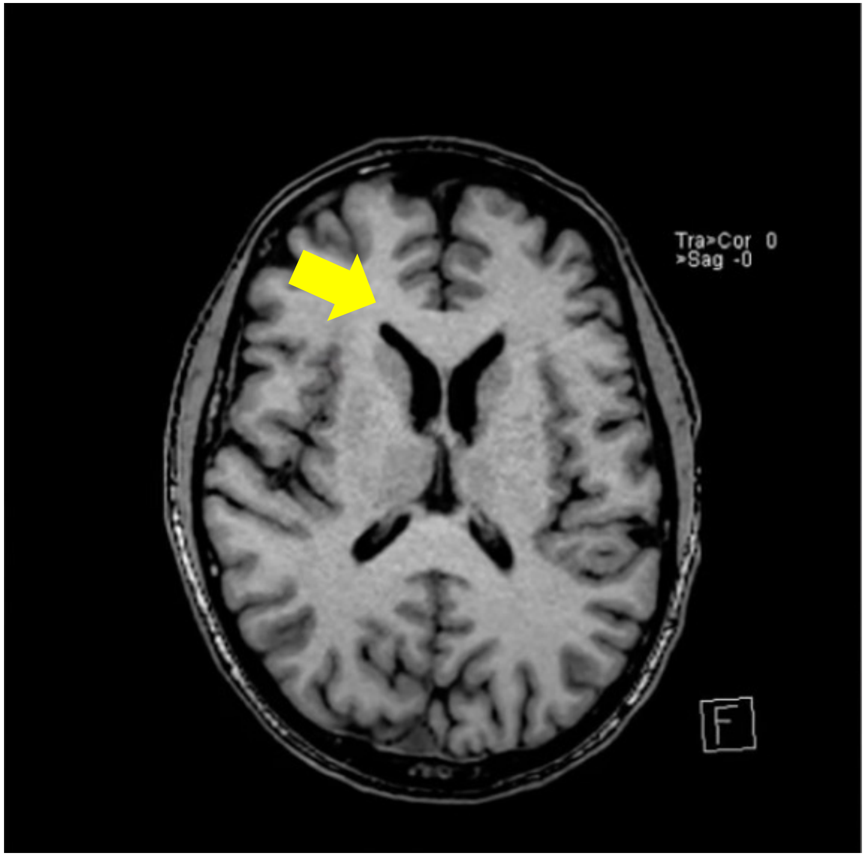
MRI Sequences (T1-Weighted Image)

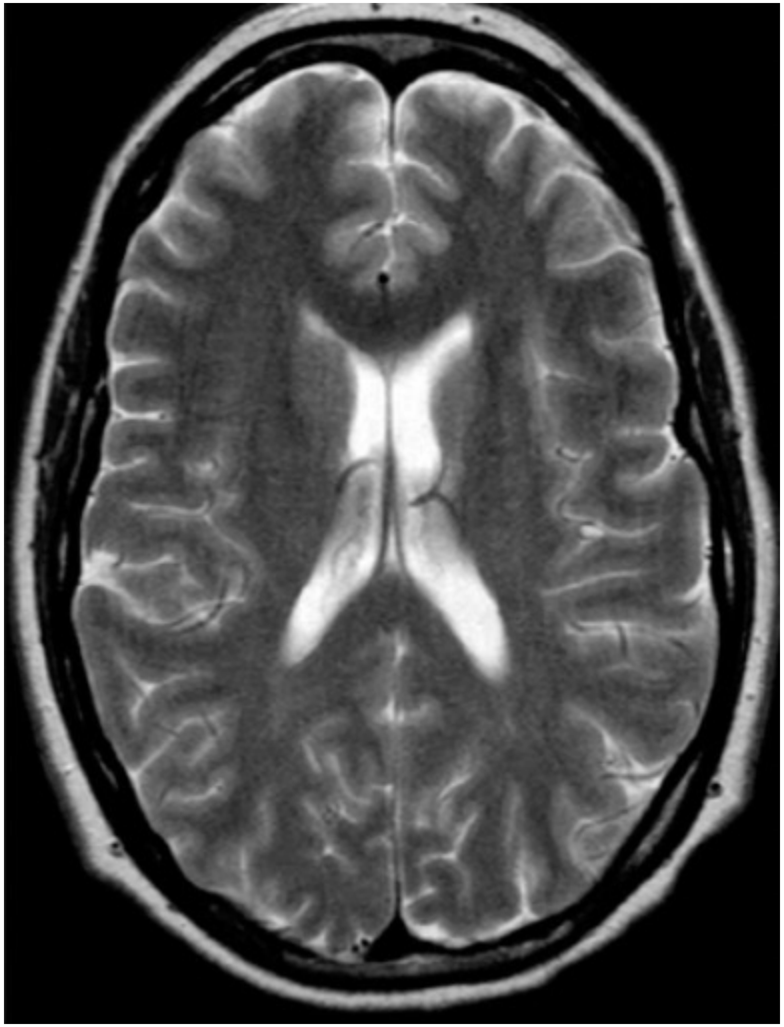
- Fat: Bright
- Fluid: Dark
  cerebrospinal fluid (CSF)
- Gray matter is gray
- White matter is white



Credit: Dr. David Nascene

MRI Sequences (T2-Weighted Image)

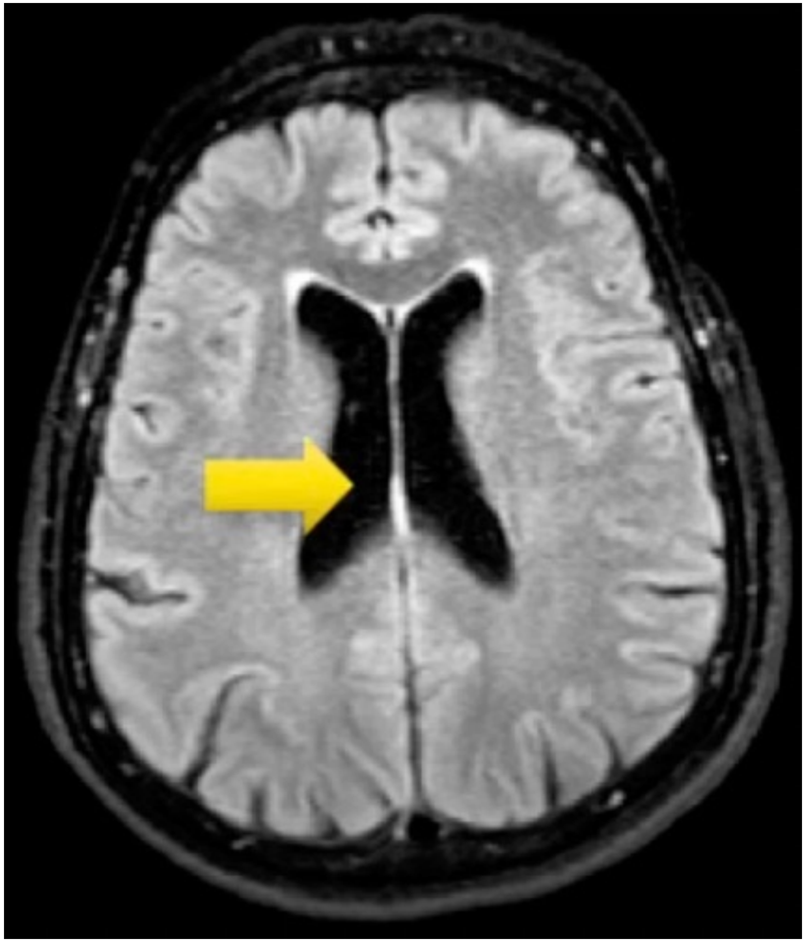
- Fat: Bright
- Fluid/CSF: Bright
- Gray matter: Bright
- White matter: Dark
- Good for detecting areas of **pathology**
  - Though FLAIR is more sensitive



Credit: Dr. David Nascene

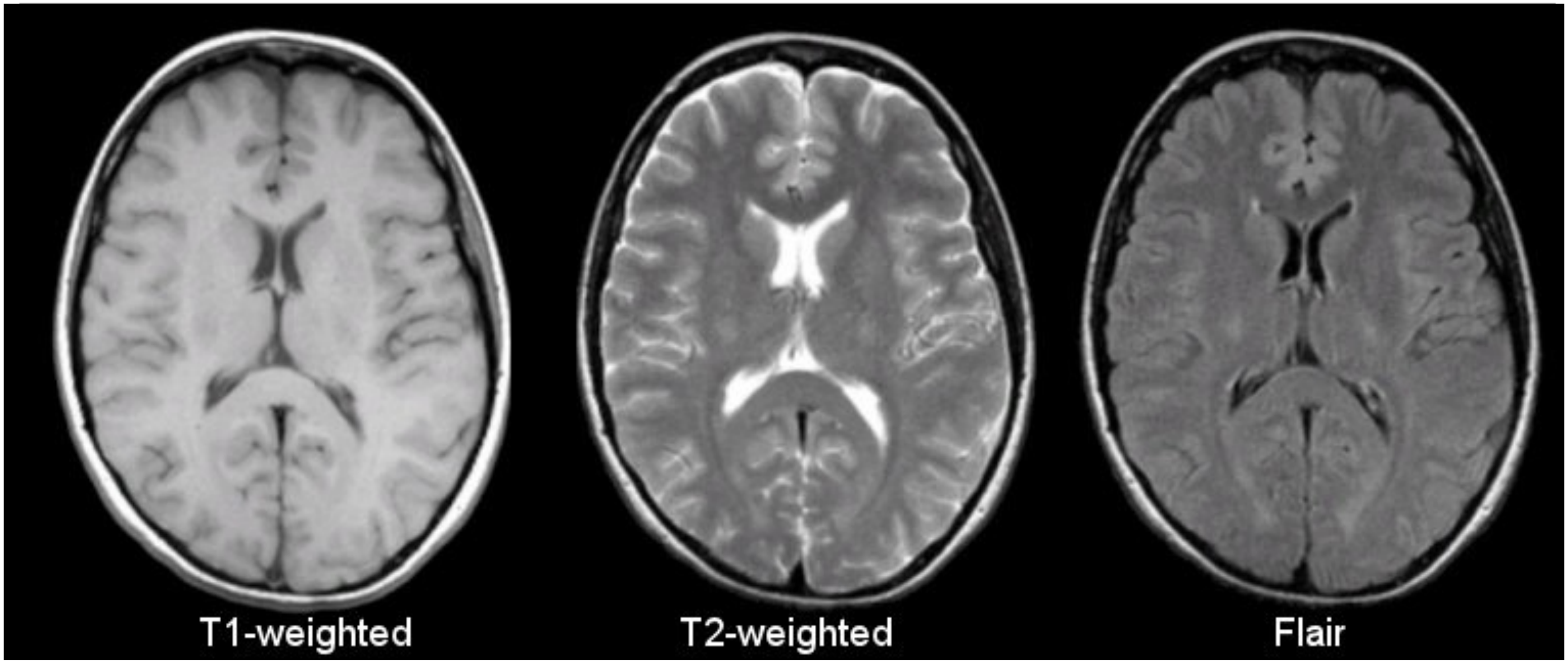
MRI Sequences (FLAIR)

- FLuid Attenuated Inversion Recovery (FLAIR)
- Akin to T2-W with signal from free water (e.g. CSF) suppressed
- Most pathology exhibits bright signal on FLAIR



Credit: Dr. David Nascene

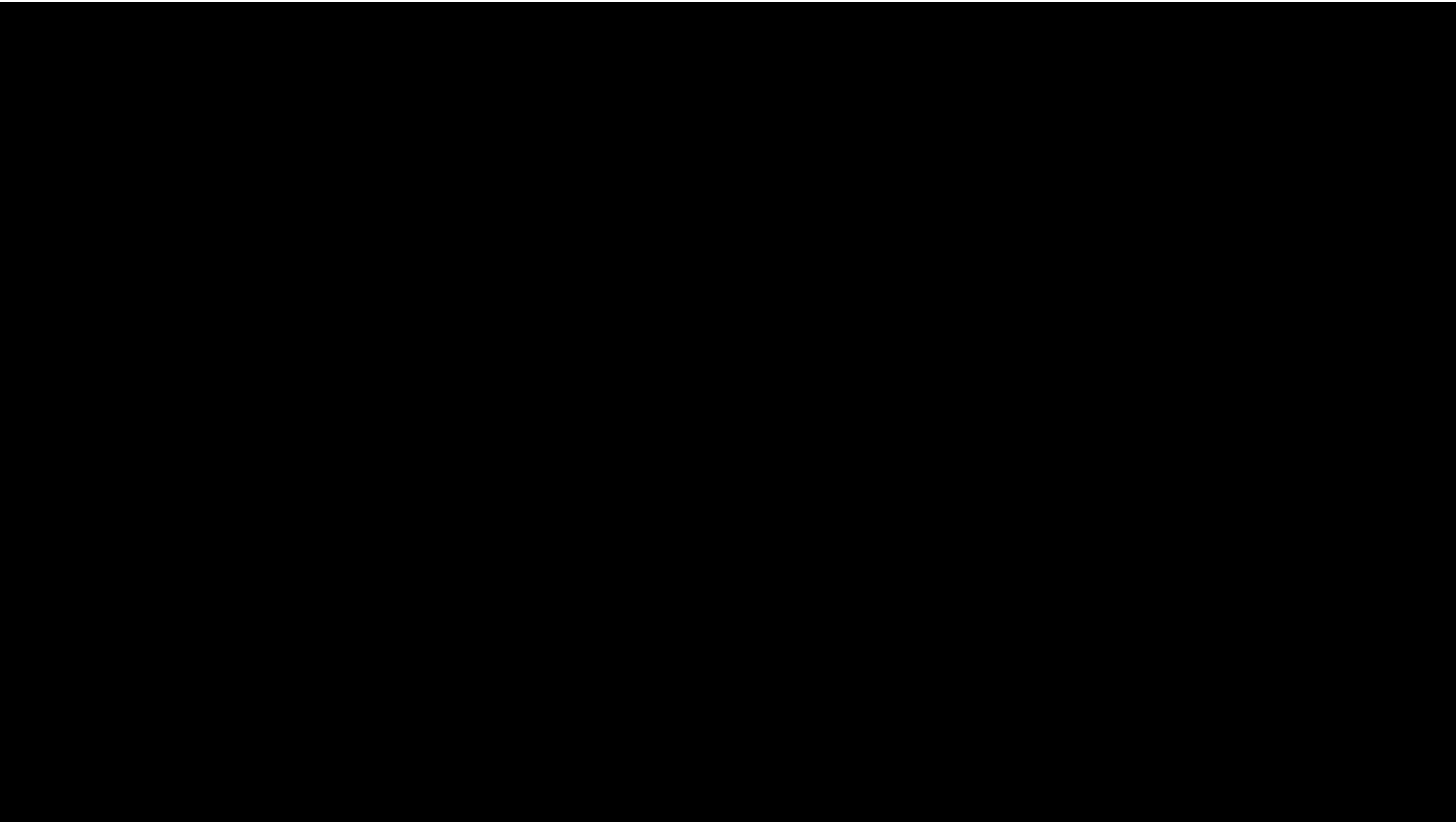
MRI Sequences (Comparison)



Tissue	T1-Weighted	T2-Weighted	Flair
CSF	Dark	Bright	Dark
White Matter	Light	Dark Gray	Dark Gray
Cortex	Gray	Light Gray	Light Gray
Fat (within bone marrow)	Bright	Light	Light
Inflammation (infection, demyelination)	Dark	Bright	Bright

https://case.edu/med/neurology/NR/MRI%20Basics.htm#:~:text=The%20most%20common%20MRI%20sequences,longer%20TE%20and%20TR%20times.

MRI Machine



Source: https://www.youtube.com/watch?v=OBUeEfq6jEQ&t=1711s

MRI is considered ideally suited for soft tissue problems

*** MRI is to soft tissue as x-ray is to dense tissue (bone)***

- Diagnosing multiple sclerosis (MS)
- Diagnosing brain tumours
- Diagnosing spinal infections
- Visualizing torn ligaments in the wrist, knee and ankle
- Visualizing shoulder injuries
- Evaluating bone tumours, and herniated discs in the spine
- Diagnosing strokes in their earliest stages

Magnetic Resonance Imaging (MRI)

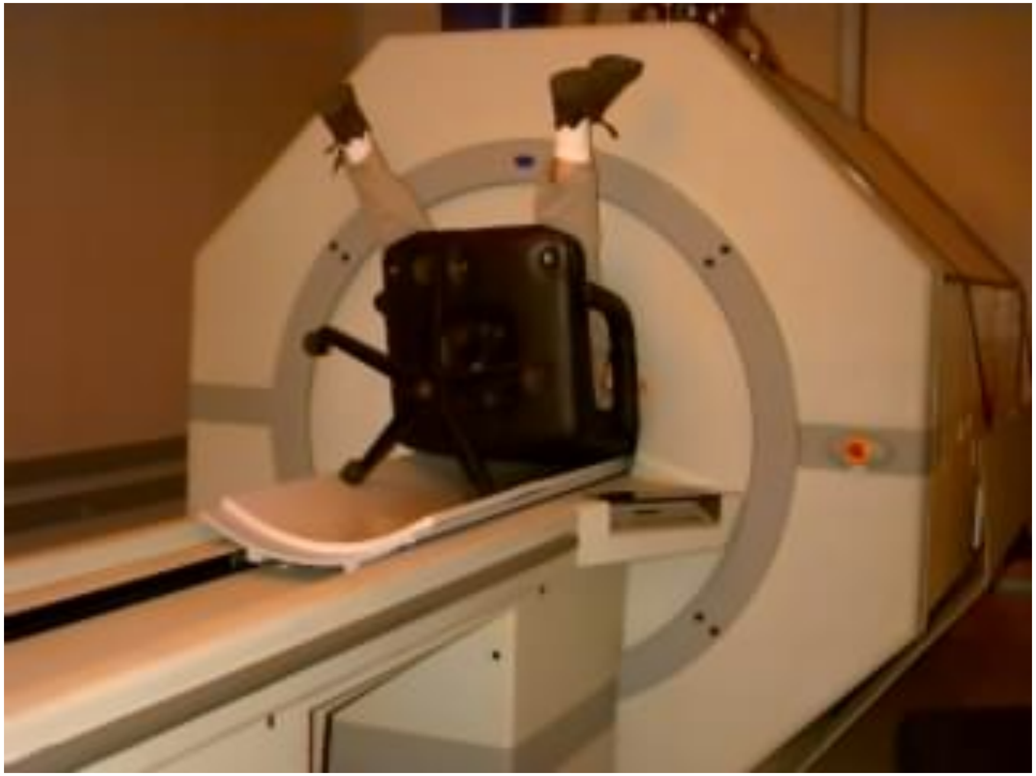
- CT is more widely used than MRI.
- **<u>MRI does not have ionizing-radiation.</u>**
- MRI has excellent soft tissue contrast, while CT is preferred for lung and bone imaging.
- CT is fast (few seconds), while MRI is slow (sparse MRI ~5-10 mins, abdomen or brain may take 30-40 mins).

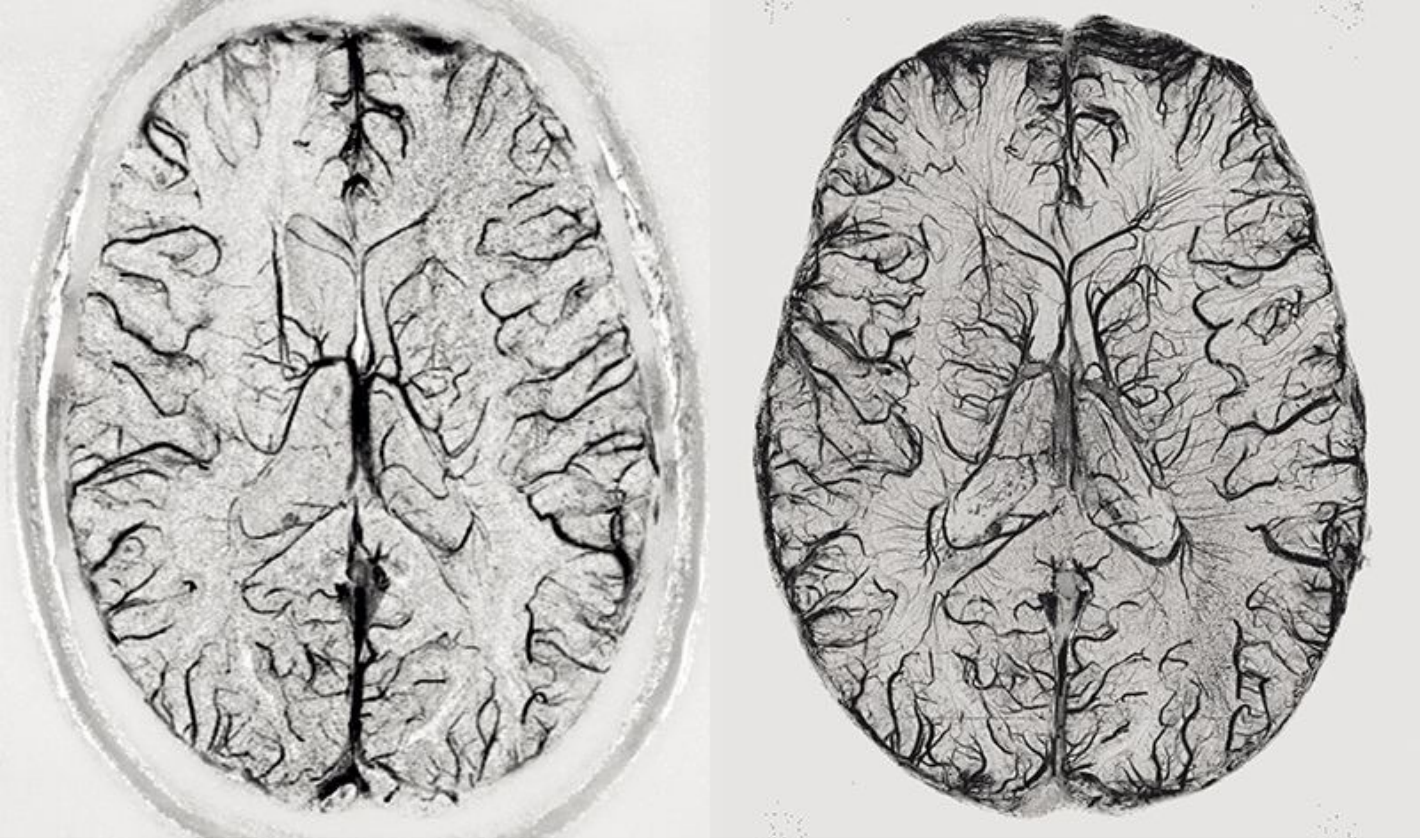
Contraindications to MRI

- Implanted devices and other metallic devices
  - Pacemakers and other implanted electronic devices
  - Aneurysm clips and other magnetizable materials
  - Cochlear implants
  - Some artificial heart valves
- Unstable patients (most resuscitation equipment cannot be brought into the scanning room)
- Pregnancy (relative contraindication due to unknown effects on the fetus)
- Other – severe agitation, or claustrophobia (may require anesthesia assistance)

Safety in MRI

- MRI room has a strong magnetic field at all times, and it is strictly **prohibited to bring magnetic objects into MRI room.**
- In general, in preparation for the MRI examination, you will be **required to wear earplugs or headphones to protect your hearing** because many scanning procedures produce loud noises.





The brain of a volunteer is imaged using a 3-T (left) and 9.4-T (right) magnetic resonance imaging machine.Credit: Rolf Pohmann/Max-Planck-Institute for Biological Cybernetics (https://www.nature.com/articles/d41586-018-07182-7)

Nobel Prizes for MRI

- 1944: Rabi
  Physics (Measured magnetic moment of nucleus)

- 1952: Felix Bloch and Edward Mills Purcell
  Physics (Basic science of NMR phenomenon)

- 1991: Richard Ernst
  Chemistry (High-resolution pulsed FT-NMR)

- 2002: Kurt Wüthrich
  Chemistry (3D molecular structure in solution by NMR)

- 2003: Paul Lauterbur & Peter Mansfield
  Physiology or Medicine (MRI technology)

Clinical Use: Example

Use MRI to detect herniated disc

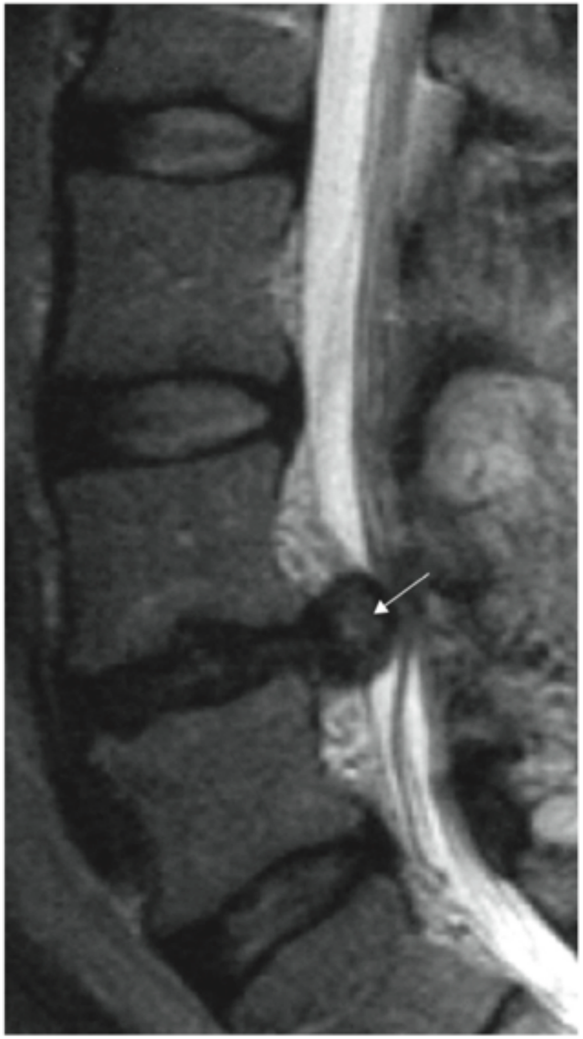
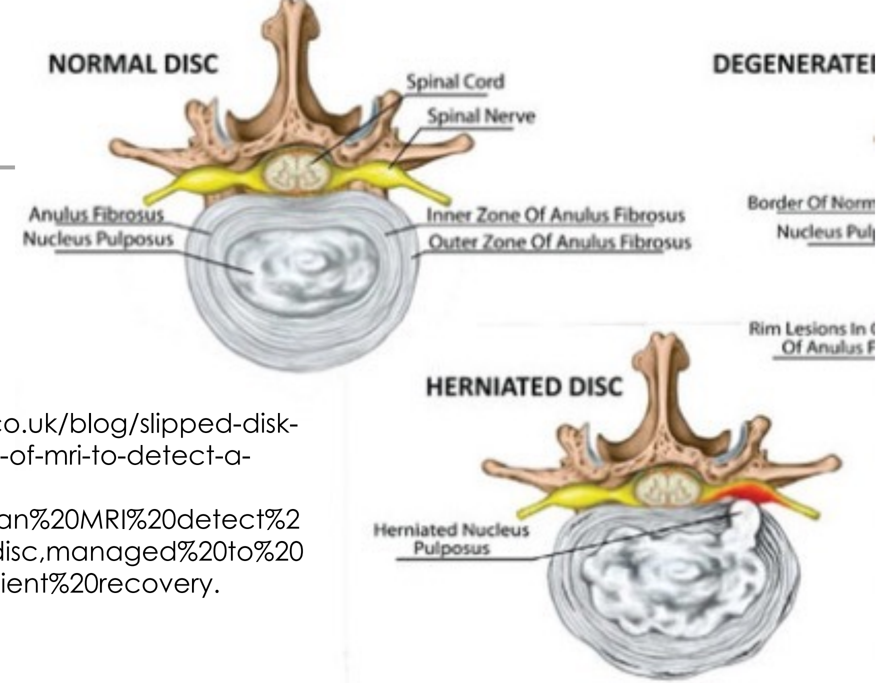
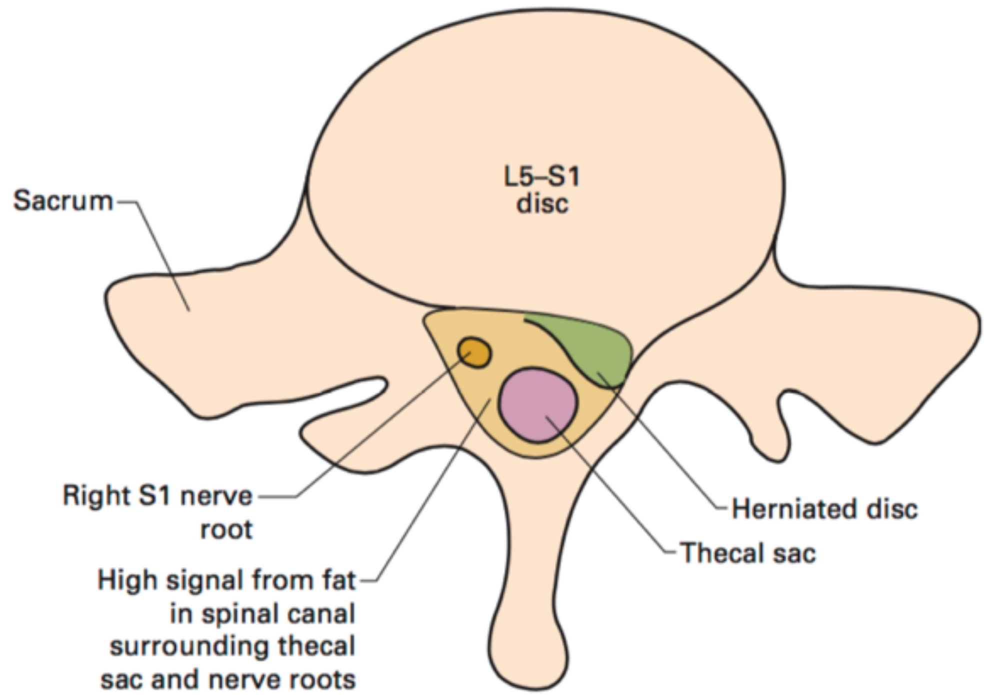


Image source: https://mriplus.co.uk/blog/slipped-disk-the-importance-of-mri-to-detect-a-herniated-disc/#:~:text=Can%20MRI%20detect%20herniated%20disc,managed%20to%20optimize%20patient%20recovery.





locate exactly the point on the spine that shows herniation

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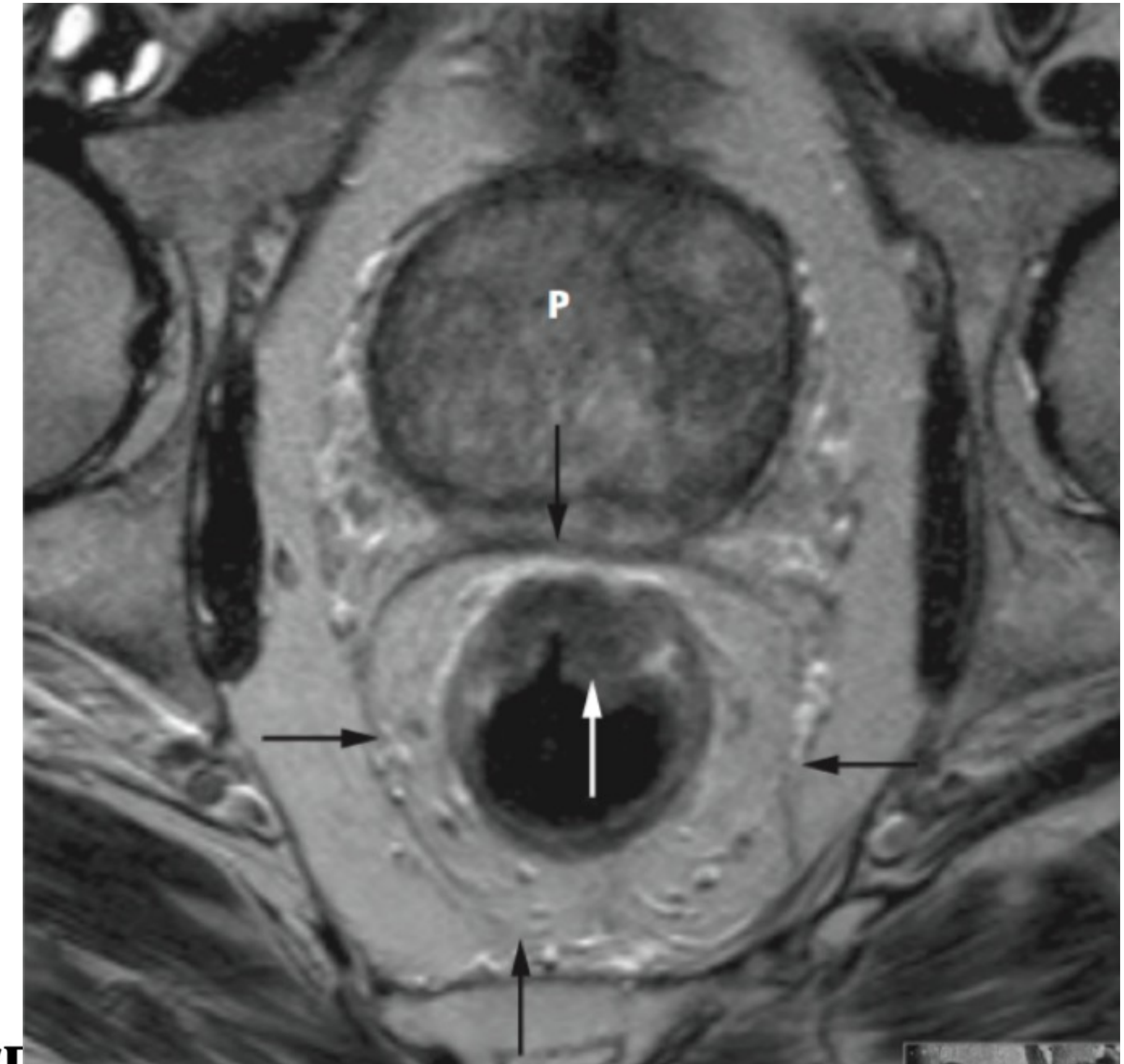
Clinical Use: Example

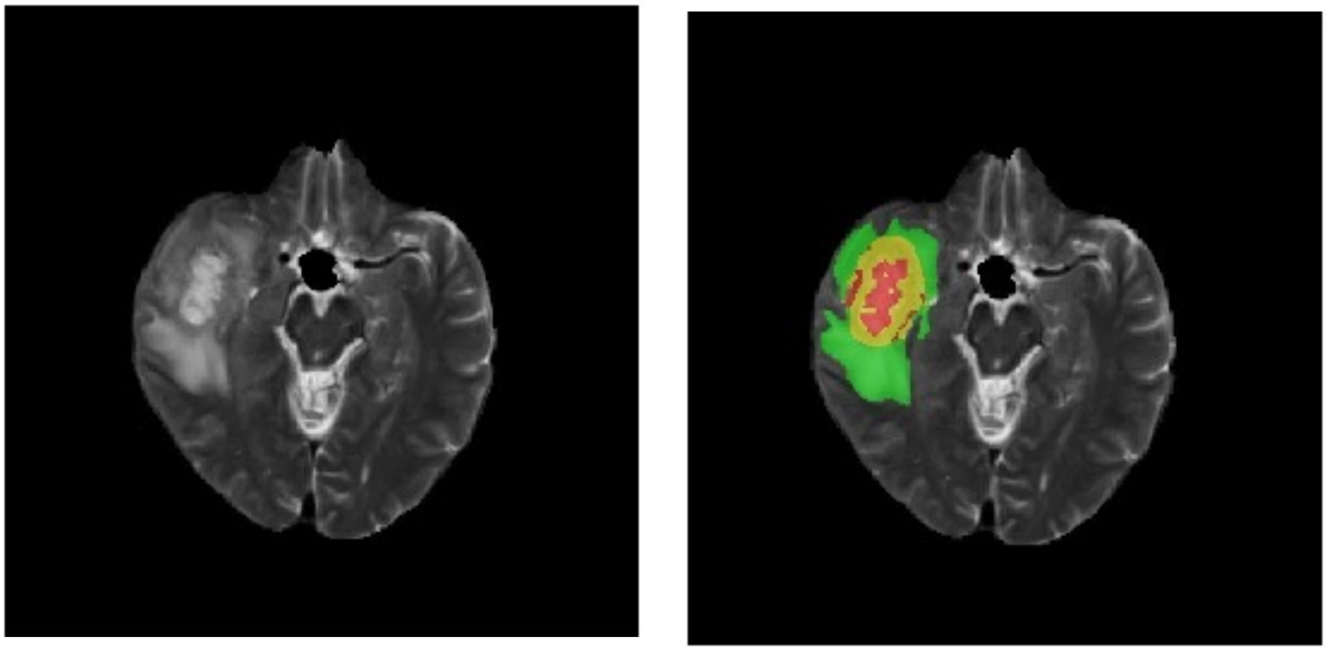
Myocardial Infarction Detection

Clinical Use: Example



rectal tumor

Clinical Use: Example



Brain Tumor

Brain tumor

Functional MRI (fMRI)

- Anatomical magnetic resonance imaging (MRI) provides excellent spatial resolution of head and brain anatomy.
- Functional MRI (fMRI) techniques provide an alternative measure of neural activation based on associated hemodynamic changes.
- These methodologies constrain and complement each other and can thereby improve our interpretation of functional neural organization.

Functional MRI (fMRI)

- Measures brain activity through oxygen concentration in the blood flow.
- Relies on the fact that cerebral blood flow and neuronal activation are coupled.
- When area of the brain is active (in use), blood flow to that area also increases.
- fMRI is being used in many studies to better understand how the healthy brain works, and in a growing number of studies it is being applied to understand how that normal function is disrupted in disease (e.g. Alzheimer's disease).

- Which part/location of the brain is activated when reading?
- Which part/location of the brain is activated when listening music?

Functional MRI (fMRI)

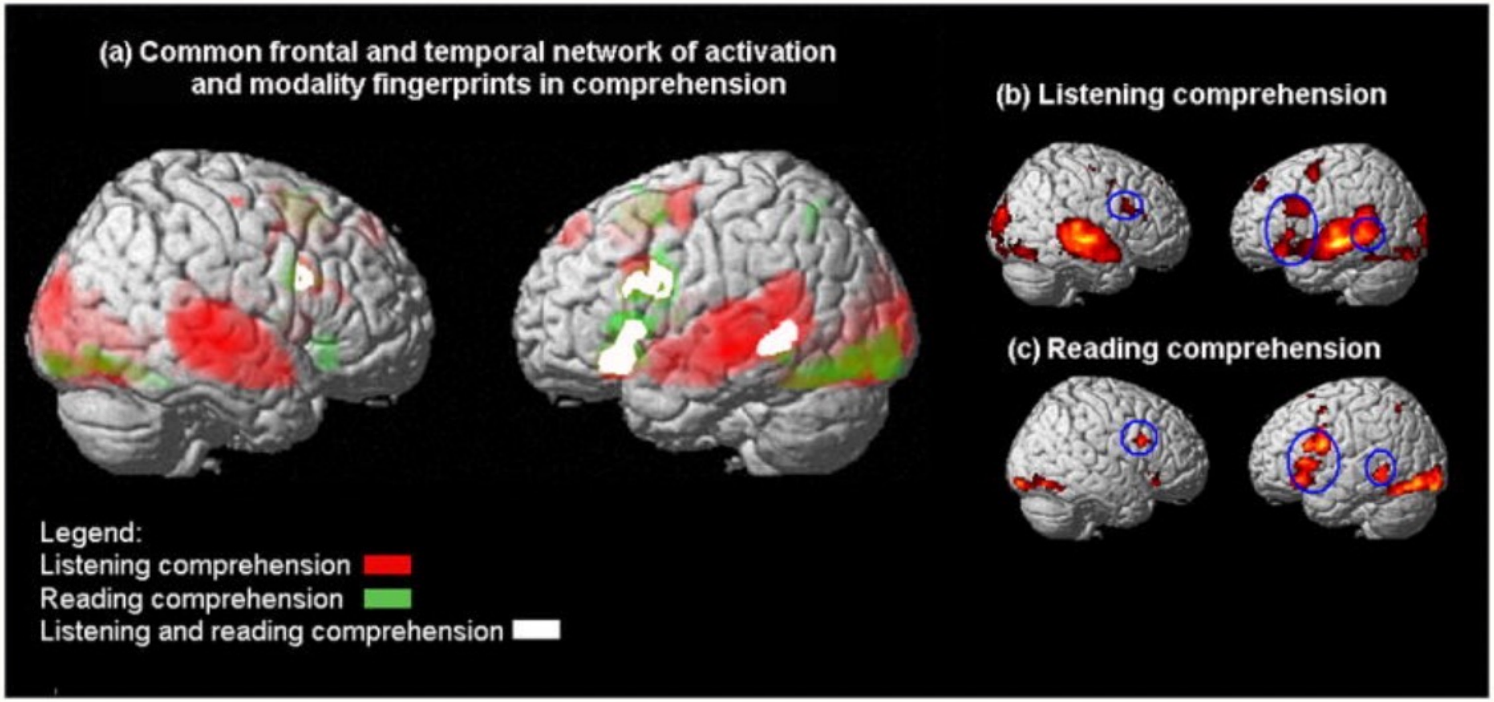
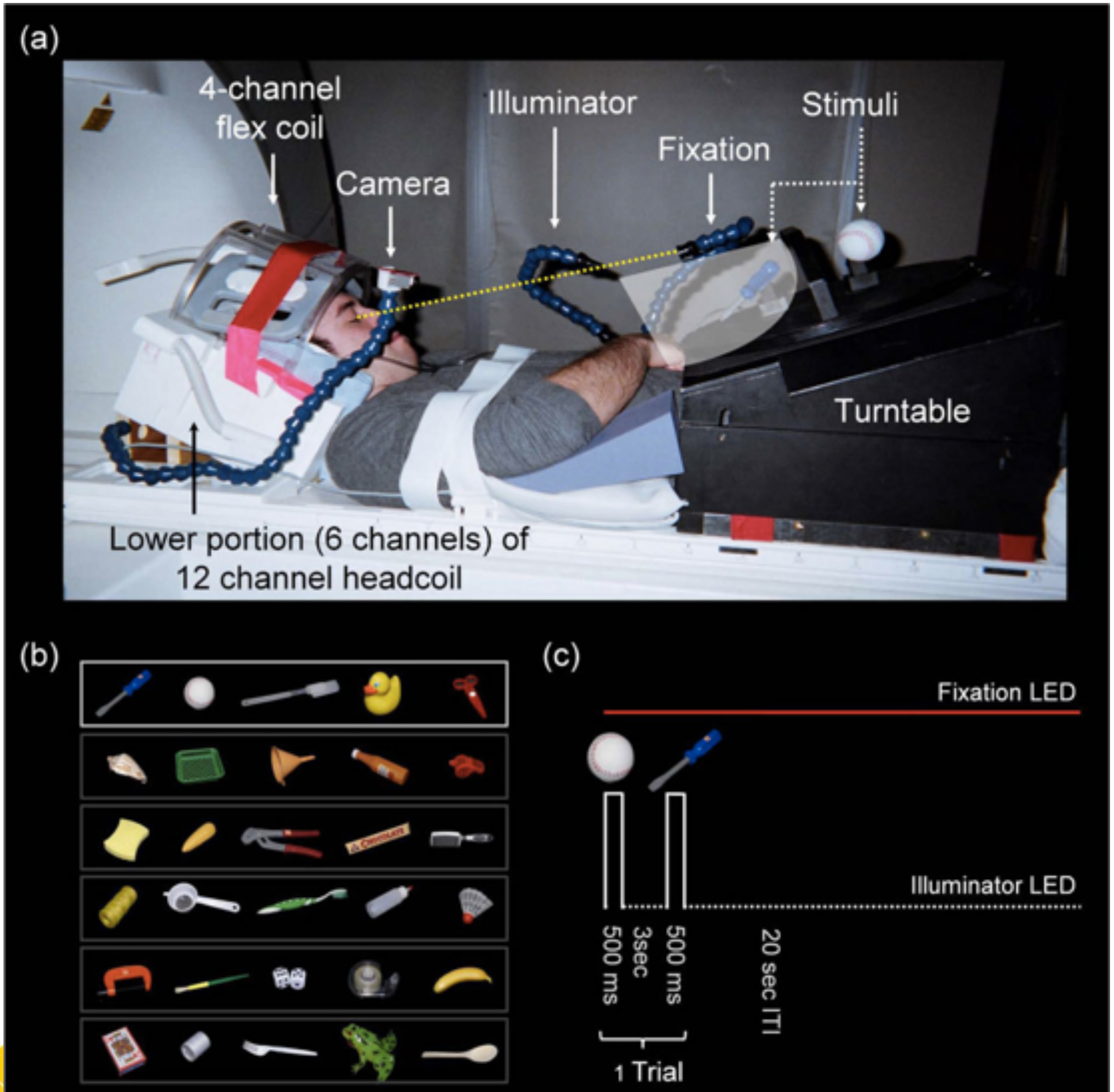


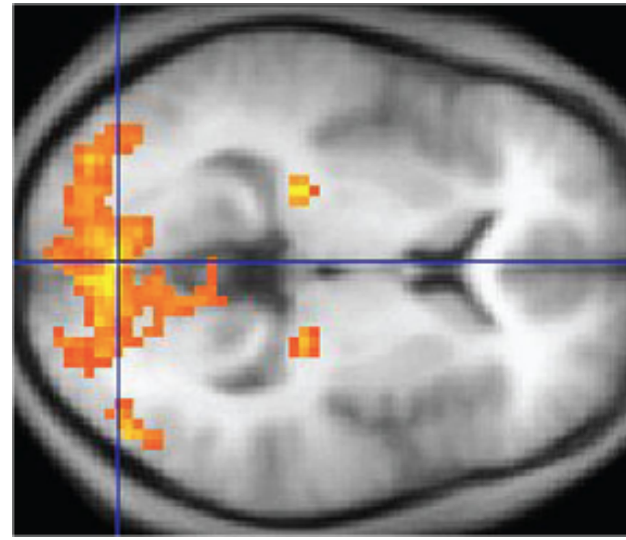
Figure 1

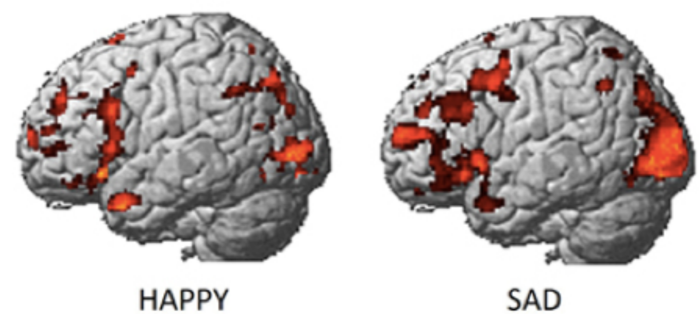
Cortical areas activated for listening and reading comprehension ($p < 0.001$, uncorrected; $T = 4.02$; extent threshold = 20 voxels; (a) illustrates the overlap of common subsets of cortical areas of activation for listening comprehension and/or reading comprehension contrasted with fixation (red = listening only; green = reading only; white = listening and reading), and shows the areas of activation (b) only in listening comprehension and (c) only in reading comprehension)

Buchweitz, Augusto, et al. "Brain activation for reading and listening comprehension: An fMRI study of modality effects and individual differences in language comprehension." Psychology & neuroscience 2.2 (2009): 111-123.

fMRI Settings







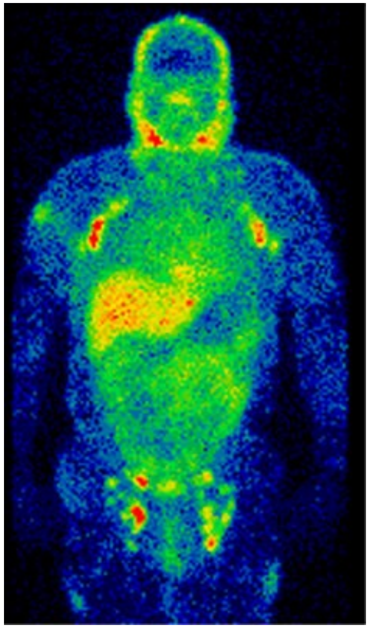
Active Regions

Nuclear Medicine Imaging – PET/SPECT

- Nuclear medicine is a medical specialty that uses radioactive tracers (radiopharmaceuticals) to assess bodily functions and to diagnose and treat disease. Specially designed cameras allow doctors to track the path of these radioactive tracers.
- Single Photon Emission Computed Tomography or SPECT and Positron Emission Tomography or PET scans are the two most common imaging modalities in nuclear medicine.
- **PET:** Positron Emission Tomography
- **SPECT:** Single Photon Emission Computed Tomography

Basics of SPECT Imaging

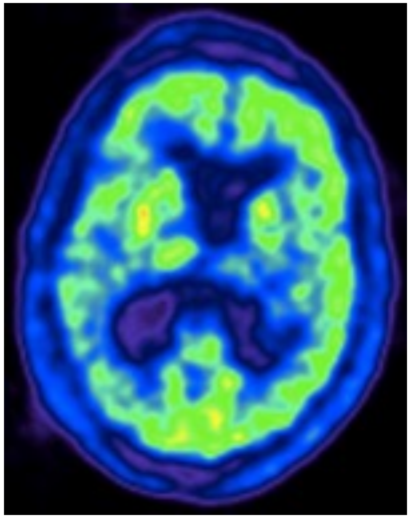
- SPECT imaging instruments provide three-dimensional (tomographic) images of the distribution of radioactive tracer molecules that have been introduced into the patient's body. The tracer is what allows doctors to see how blood flows to tissues and organs.
- SPECT imagers have gamma camera detectors that can detect the gamma ray emissions from the tracers that have been injected into the patient.
- Gamma rays are a form of light that moves at a different wavelength than visible light. The cameras are mounted on a rotating gantry that allows the detectors to be moved in a tight circle around a patient who is lying motionless on a pallet.
- The tracer is radioactive, which means your body is exposed to radiation. This exposure is limited, however, because the radioactive chemicals have short half-lives. They breakdown quickly and are removed from the body through the kidneys.



https://www.nibib.nih.gov/science-education/science-topics/nuclear-medicine

Basics of PET Imaging

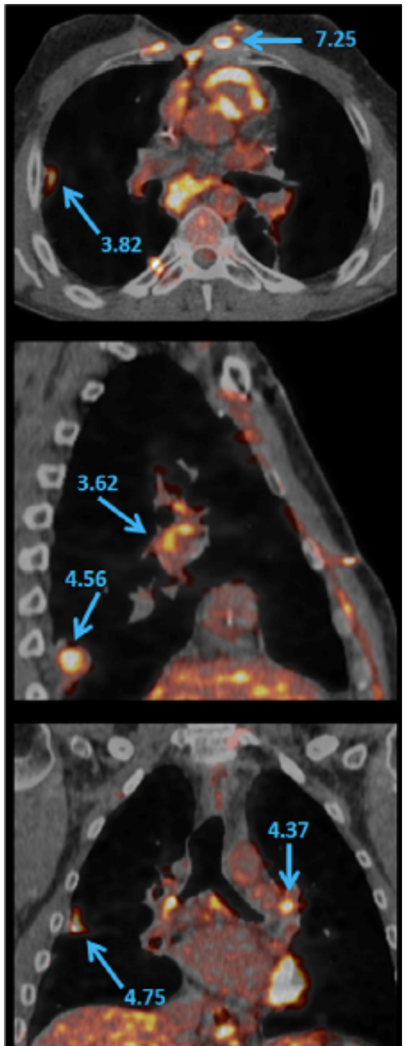
- The main difference between SPECT and PET scans is the type of radiotracers used.
- While SPECT scans measure gamma rays, the decay of the radiotracers used with PET scans produce small particles called positrons.
- A positron is a particle with roughly the same mass as an electron but oppositely charged. These react with electrons in the body and when these two particles combine they annihilate each other.
- This annihilation produces a small amount of energy in the form of two photons that shoot off in opposite directions.
- The detectors in the PET scanner measure these photons and use this information to create images of internal organs.

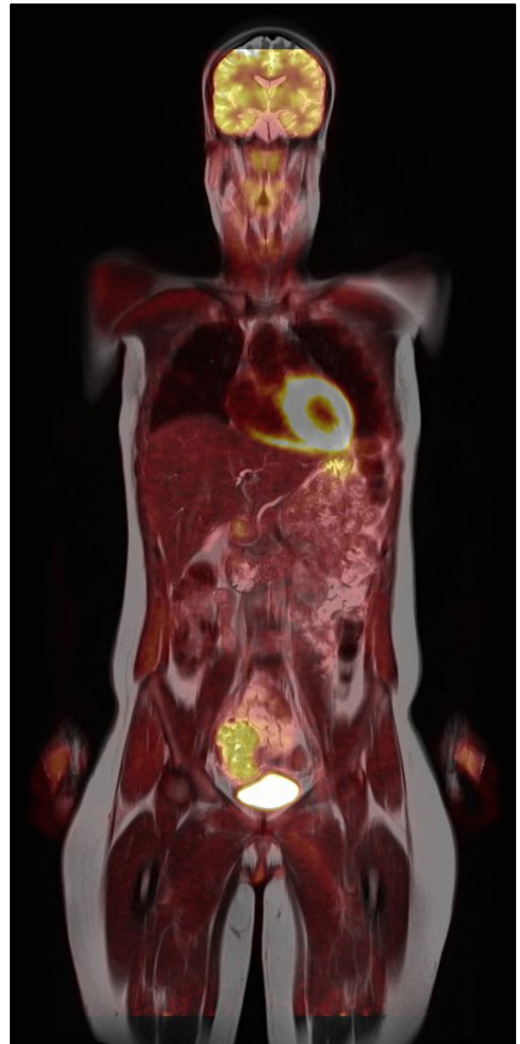


https://www.nibib.nih.gov/science-education/science-topics/nuclear-medicine

PET/CT and MRI/PET (Hybrid Imaging)

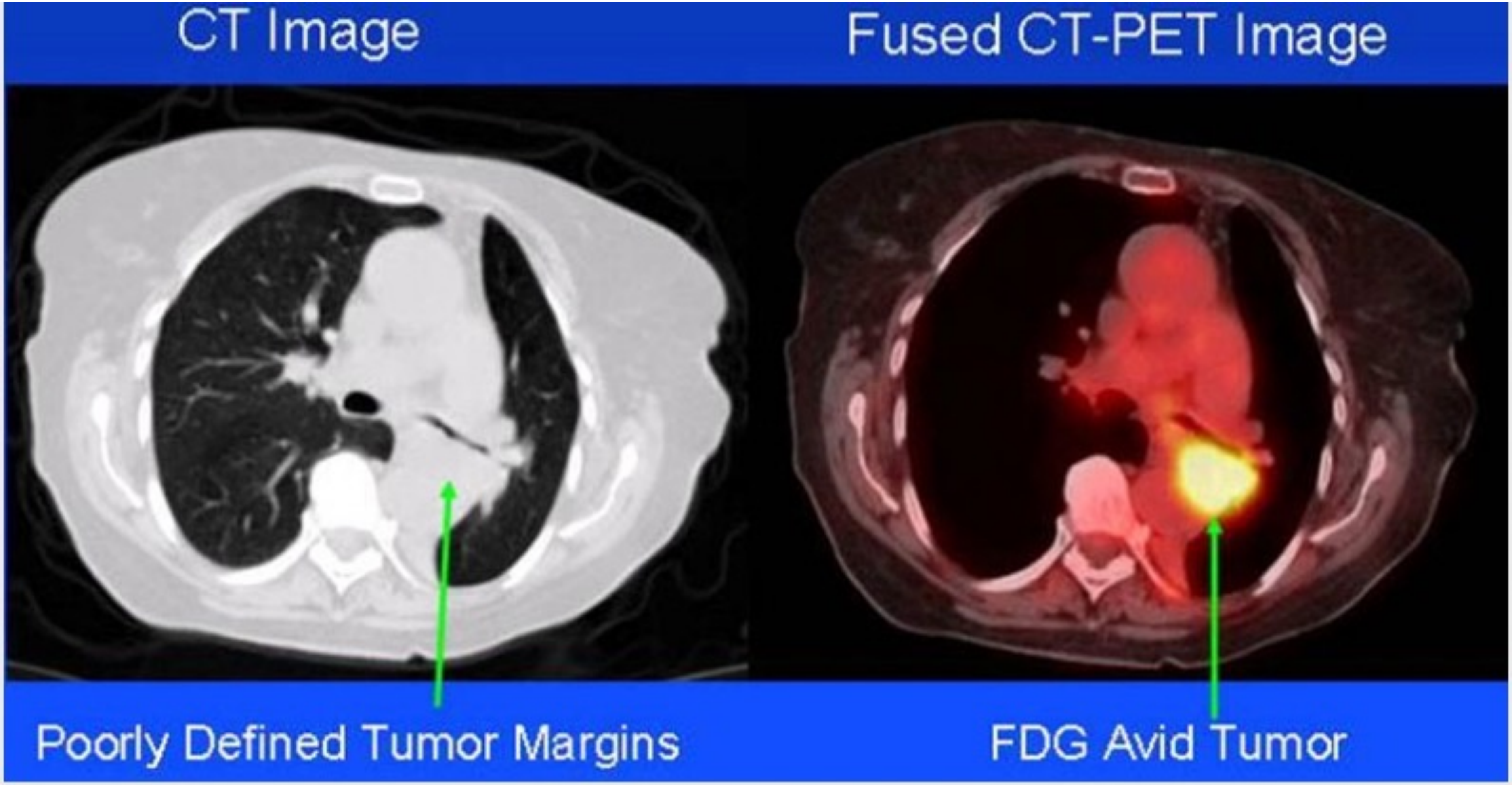
PET/CT





MRI/PET

Clinical Use of PET: Example



Fused CT-PET scans more clearly show tumors and are therefore often used to diagnose and monitor the growth of cancerous tumors.

https://www.nibib.nih.gov/science-education/science-topics/nuclear-medicine#:~:text=The%20main%20difference%20between%20SPECT,an%20electron%20but%20oppositely%20charged.

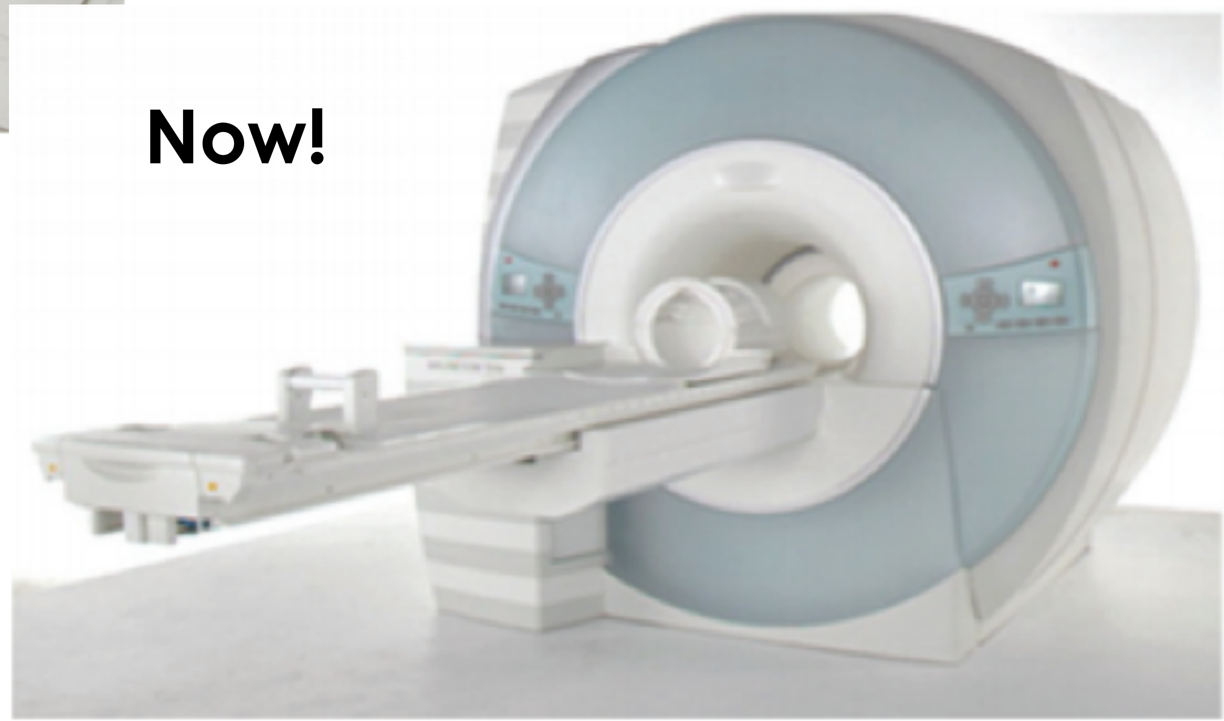
- John Sunderland, MD, shares a presentation on "What is Nuclear Medicine and Molecular Imaging?" at the SNMMI 2019 Patient Education Day. Topics include diagnostic applications, therapeutic applications, and radiation safety considerations.

Video of the presentation:
https://www.youtube.com/watch?v=I2OVu-JSU2Y&t=2379s

Serial and Simultaneous MRI/PET

Past

Now!



Free Software for Medical Image Analysis

- ImageJ (and/or FIJI)
- ITK-Snap
- SimpleITK
- MITK
- FreeSurfer
- SLICER
- OsiriX
- Mango: https://ric.uthscsa.edu/mango/
- An extensive list of software: www.idoimaging.com

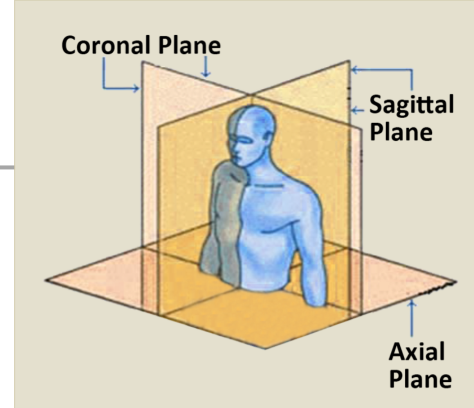
Medical Image Formats

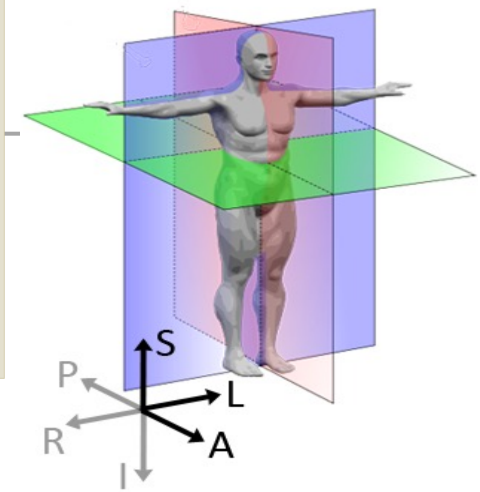
- Dicom
- Nifti
- Analyze (img/hdr)
- Raw data
- …

Nifti is a file format created at the beginning of 2000s by a committee based at the National Institutes of Health with the intent to create a format for neuroimaging maintaining the advantages of the Analyze format, but solving the weaknesses.

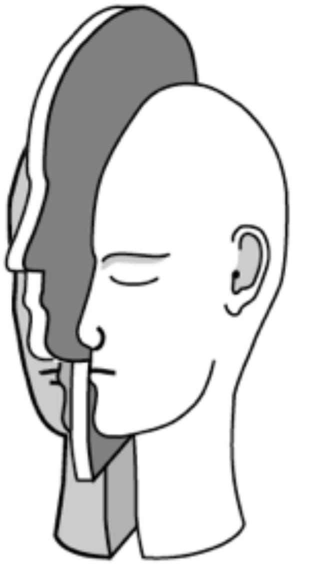
- Demo of using ITK-Snap

3D View Terminology





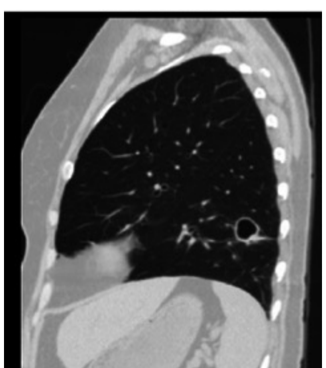
Anatomical space
R: right
L: left
A: anterior
P: posterior
I: inferior
S: superior



A Sagittal

B Coronal

C Axial



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- Some slides are adapted from Dr. Ulas Bagci's course materials