Magnetic Resonance Imaging

http://www.gehealthcare.com/euen/oncology/images/breast-health/onc_breast_pulmo_500.jpg

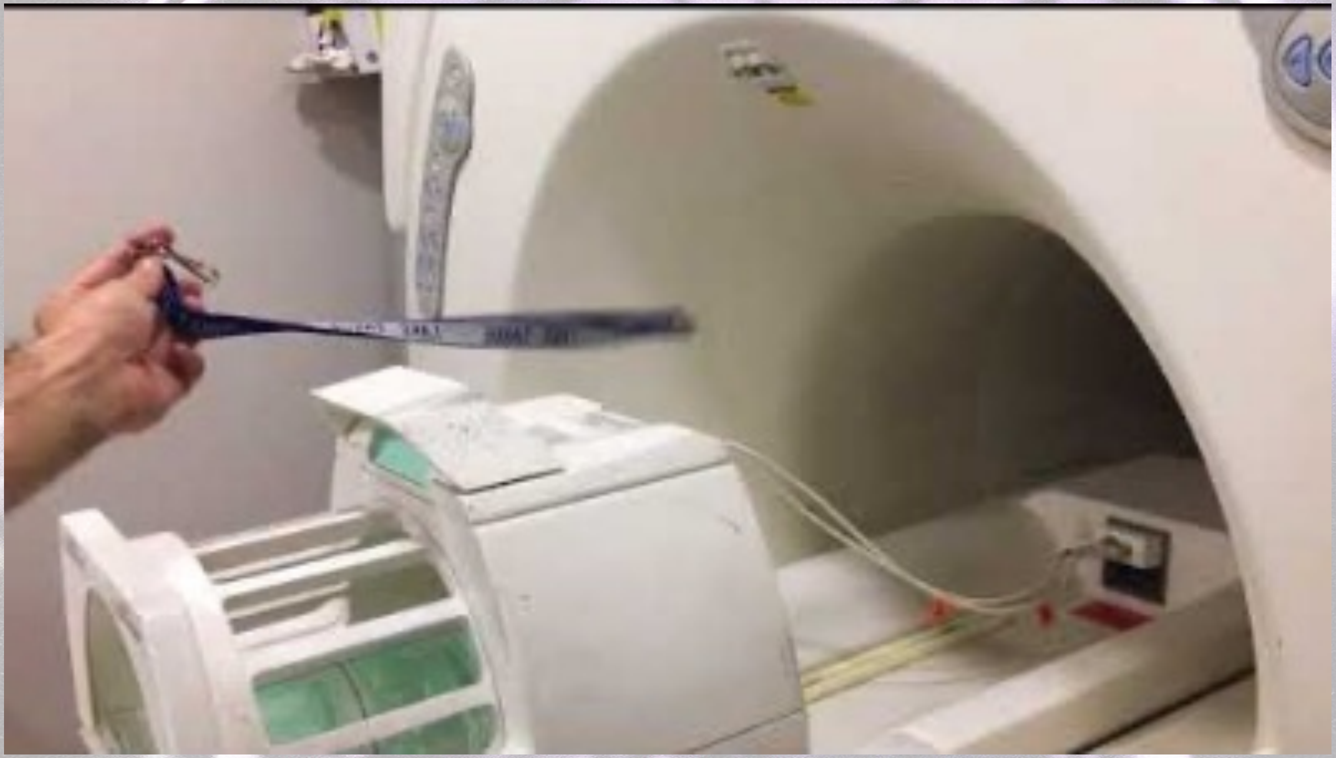
http://www.gehealthcare.com/euen/oncology/images/breast-health/onc_breast_wholemri.jpg

http://www.gehealthcare.com/euen/oncology/images/breast-health/onc_breast_bonemetasta_500.jpg

Background Image: http://www.ruf.rice.edu/~pomeran/images/brainmri.jpg

Producing a MRI Signal

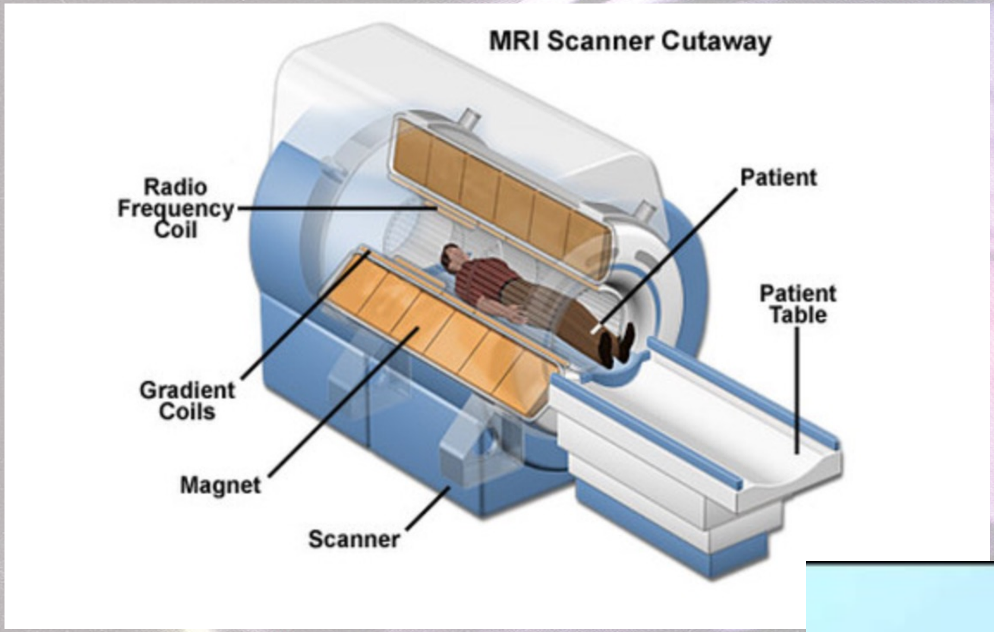
- The Magnetic Field



https://www.youtube.com/watch?v=ug3e9W5H0jI

Producing a MRI Signal

- The MRI Scanner



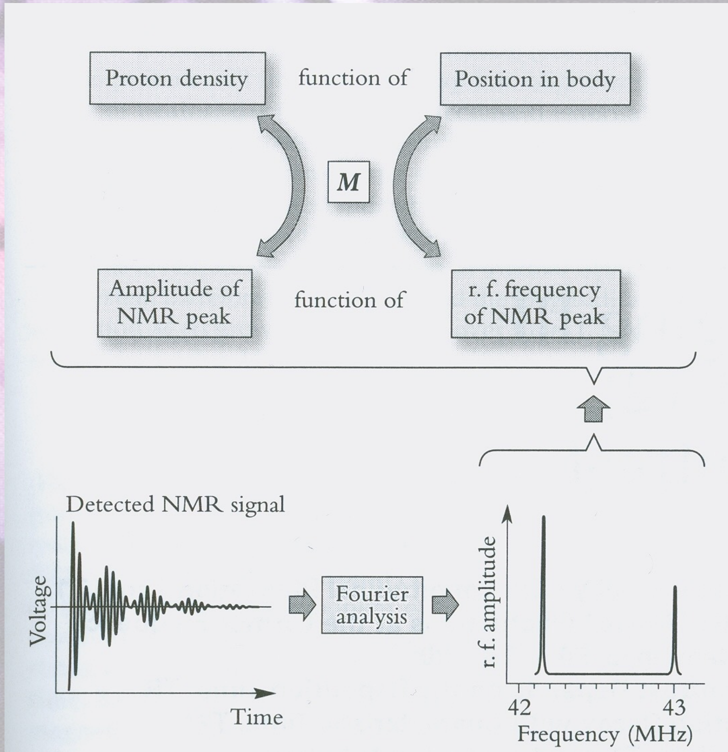
https://snc2dmri.weebly.com/components--functions.html

https://www.youtube.com/watch?v=kmfmGhI8l9E

Magnetic Resonance Imaging

- Image formation & reconstruction

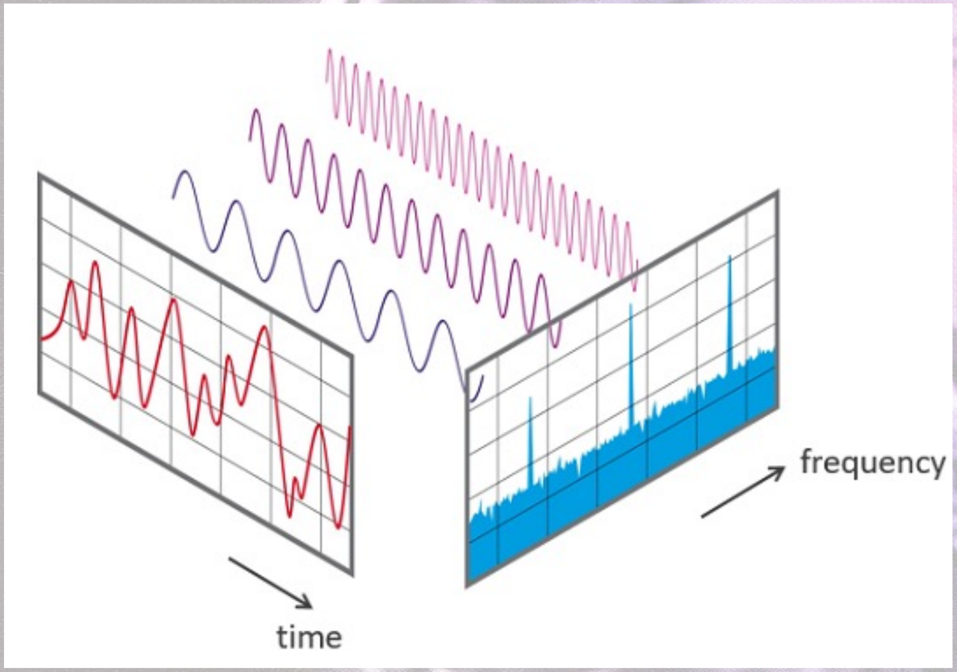
- The RF signals from the detector coils give information about the magnetization vector in the transverse plane as a function of time.
- We scan over a section of tissue and compare the signals received in the detector coils and “actually” calculate the magnetization.
- The value of the magnetization gives us a measure of T_1 as well as spatial information about the proton density and magnetic field environments of the nuclei.
- The differences in T_1 times provide contrast.



Physics of Radiology, Anthony Wolbarst

Magnetic Resonance Imaging

- Image formation & reconstruction



https://math.stackexchange.com/questions/4186037/when-why-to-use-a-fourier-transformation

- The signals are mixtures of many frequency photons.
- The signals are "deconvoluted" and analyzed using Fourier analysis.
- Then they are reconstructed to form an image.
- This is a highly non-trivial process, but it works along the same lines as CT.

Magnetic Resonance Imaging

- Image formation & reconstruction

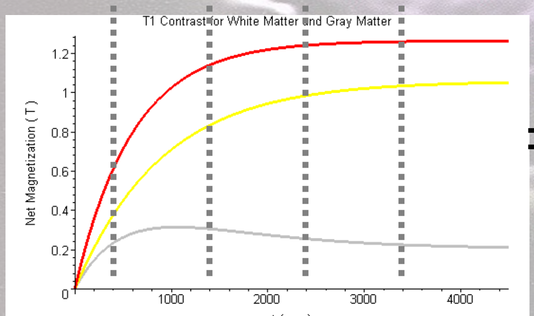
Integrate magnetization to get MRI signal intensity

- Select a z "slice" and form images of x-y plane variations where S is the intensity

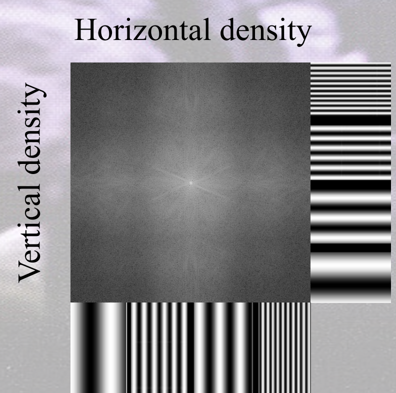
$$S(t) = \iint M_{xy}(x,y,t)e^{-i\omega t} = \iint M_{xy}(x,y,t)e^{-i\gamma\left[B_0\tau+\int_0^\tau B(x,y,z,t)dt\right]}$$

$$S(t) = \iint M_{xy}(x,y,t)e^{-i\gamma\left[B_0\tau+\int_0^\tau [xG_x(t)+yG_y(t)+zG_z(t)]dt\right]}$$

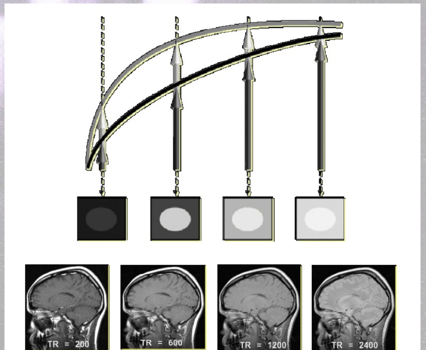
- Contrast is due to differences in magnetization intensities in space
    - *Image at several times*
    - *Scanner acquires k-Space weights (Fourier transforms of frequencies.)*
    - *Construct image and average slices from differences in* T_1 (or T_2).



⇒



⇒



The Brain

- The control system for the human body.

- Complex structure that is not easily visualized with surgical exploration.
  - Deep structures, brainstem, cranial nerves

- Subtle structures not easily visualized with the naked eye.

- Damage by exploration not easily repaired.

- The human brain and spinal cord are surrounded by cerebral spinal fluid. Normally, cerebral spinal fluid is produced primarily in the two lateral ventricles (small chambers in the brain). This fluid drains through the third and fourth ventricles and is circulated around the brain and spinal cord, and thus acts as a cushion for the brain.

- Protects the brain and spinal cord against impact from the bony surrounding structures. This protective function depends mainly on buoyancy, effectively making the weight of the brain 1/30th of its actual weight. CSF also ensures that there is an equal distribution of pressure on the nervous tissue.

- It allows variations in blood volume in the cranial cavity. If the blood pressure increases, CSF volume decreases, thus preventing a build-up of pressure.

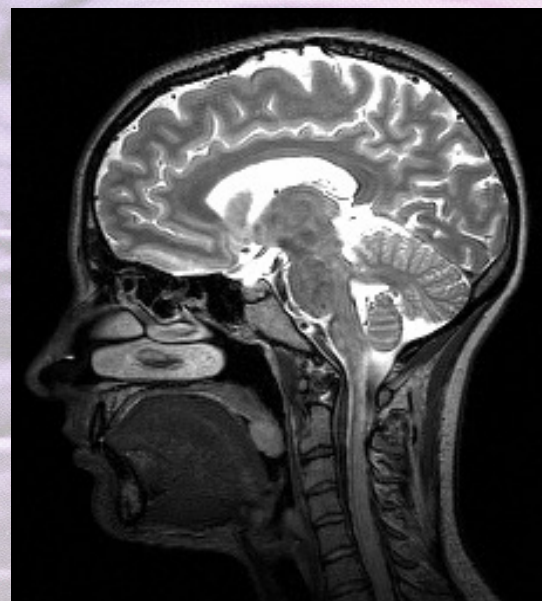
- It acts as a diffusion medium for neurotransmitters and neuroendocrine substances.

Magnetic Resonance Imaging

- Image Formation & Reconstruction Types

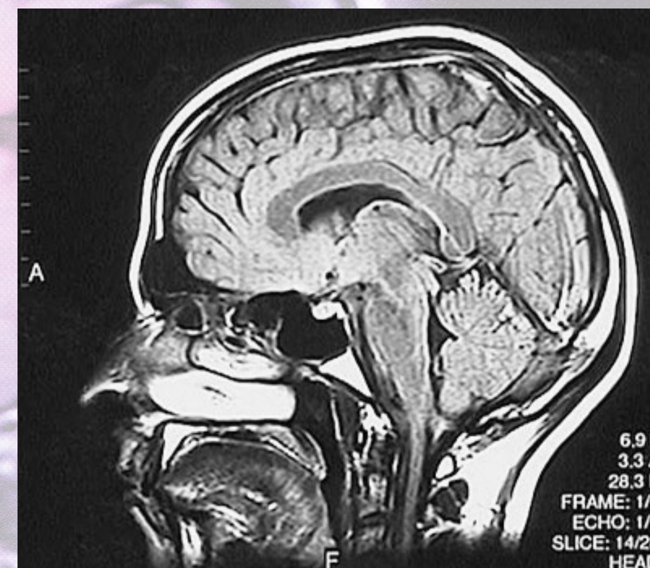
T_1 Weighted Image (T1WI)
(Gray Matter Gray – White Matter White)

T_2 Weighted Image (T2WI)
(White Matter Gray
Gray Matter White – CSF Contrast)



An Introduction to MRI Physics and Analysis Michael Jay Schillaci, PhD

FLAIR
White Matter Gray
T_2 minus CSF

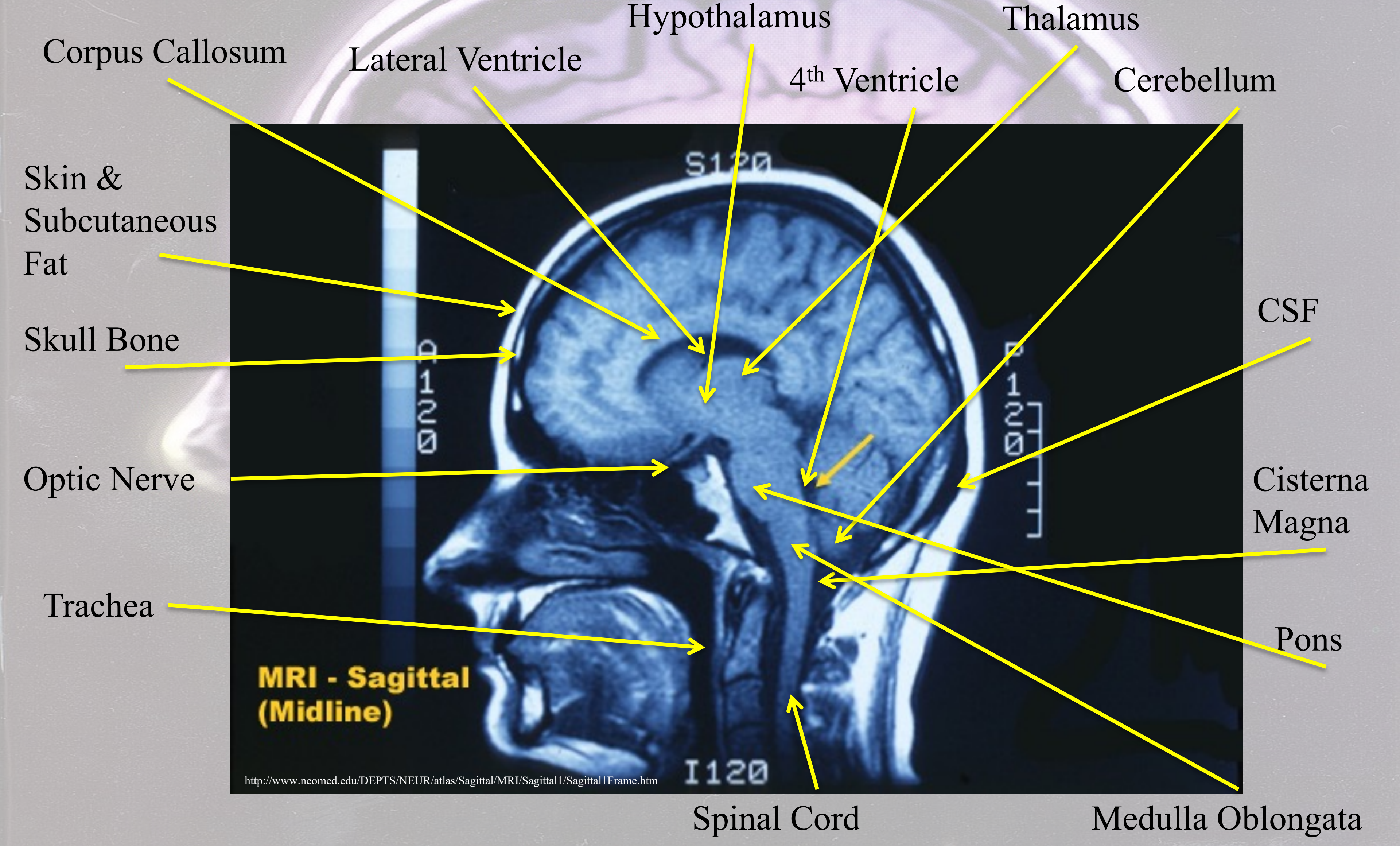


http://library.med.utah.edu/WebPath/HISTHTML/NEURANAT/MRIFS06.html

- T_2 scans are "almost" the photographic negative of T_1 scans. We make dark areas white and white areas dark to enhance fluid filled areas.

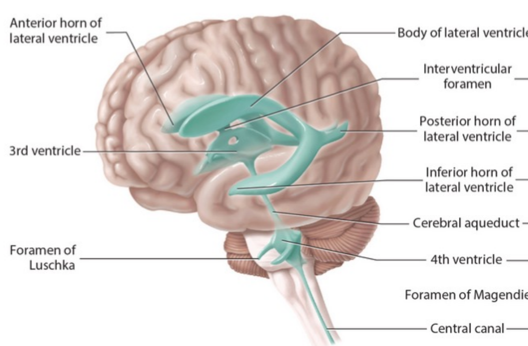
- FLAIR – Fluid Attenuated Image Recovery – T_2 image with CSF suppressed. Shows areas where fluid should not be. Visualizing periventricular pathology.

Imaging the Brain with MRI - Anatomy – T_1 weighted image



Imaging the Brain with MRI
- Anatomy of the Ventricular System

The Ventricular System and Cerebrospinal Fluid



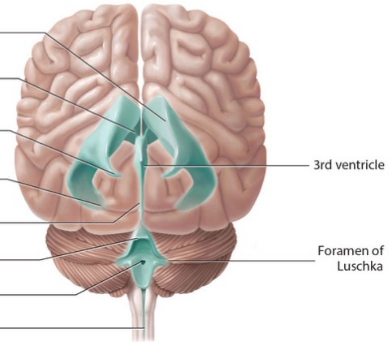
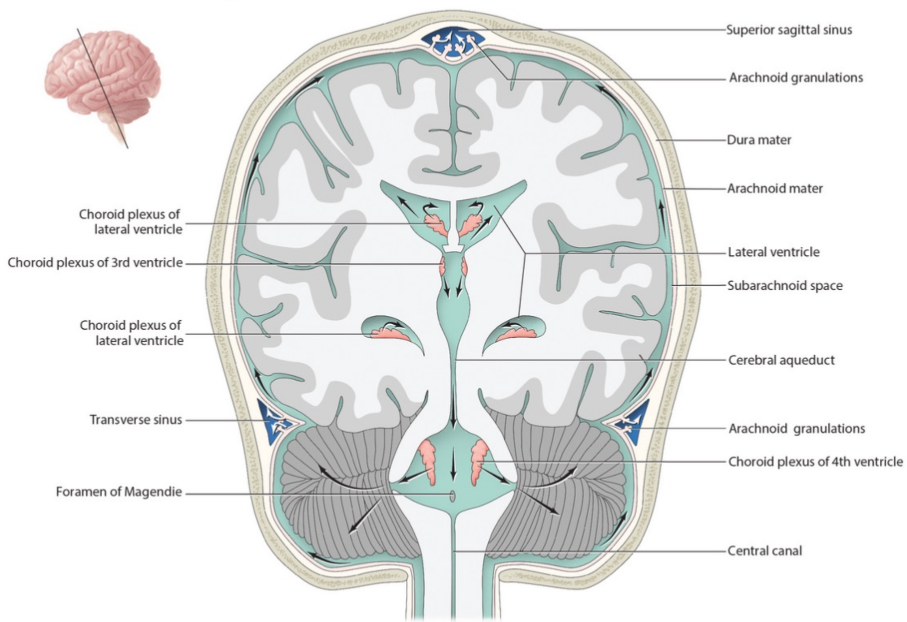
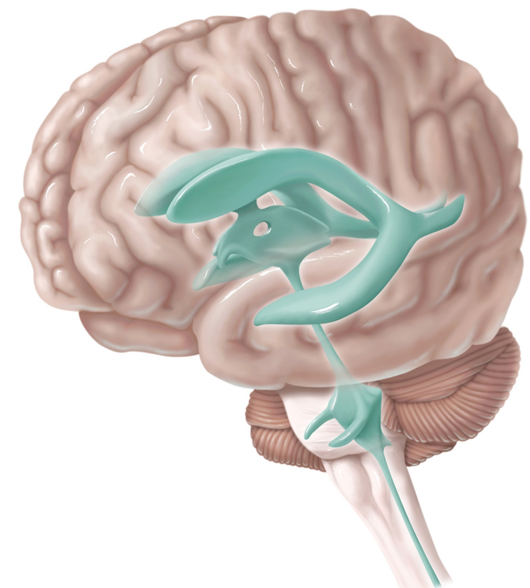


Figure 1a. Anterolateral view of the ventricles of the brain. Cerebrospinal fluid (CSF) is created by the choroid plexus, a complex system formed by invaginations of the vascular pia mater into each ventricle. CSF produced by the lateral ventricles travels to the third and fourth ventricles through the interventricular foramina and cerebral aqueduct.

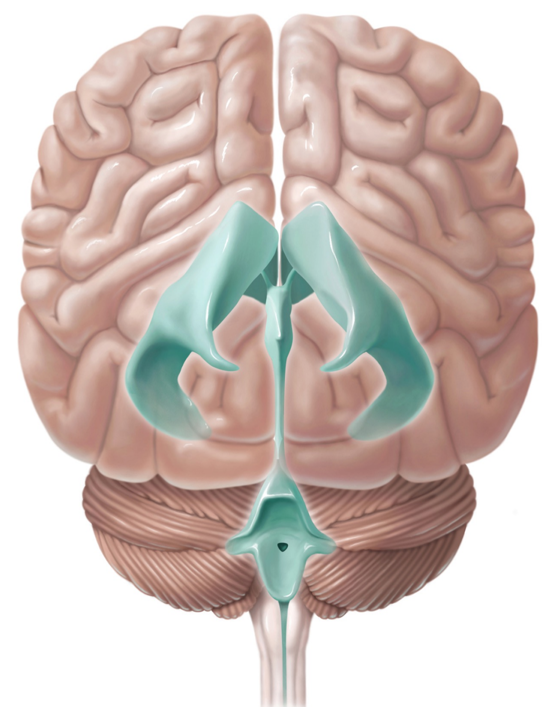
Figure 1b. Posterior view of the ventricles of the brain. From the fourth ventricle, CSF flows either out from the median Foramen of Magendie or the two lateral Foramina of Luschka into the subarachnoid space to surround the brain and spinal cord.



https://www.evelynlockhart.com/anatomic-brain-ventricles/

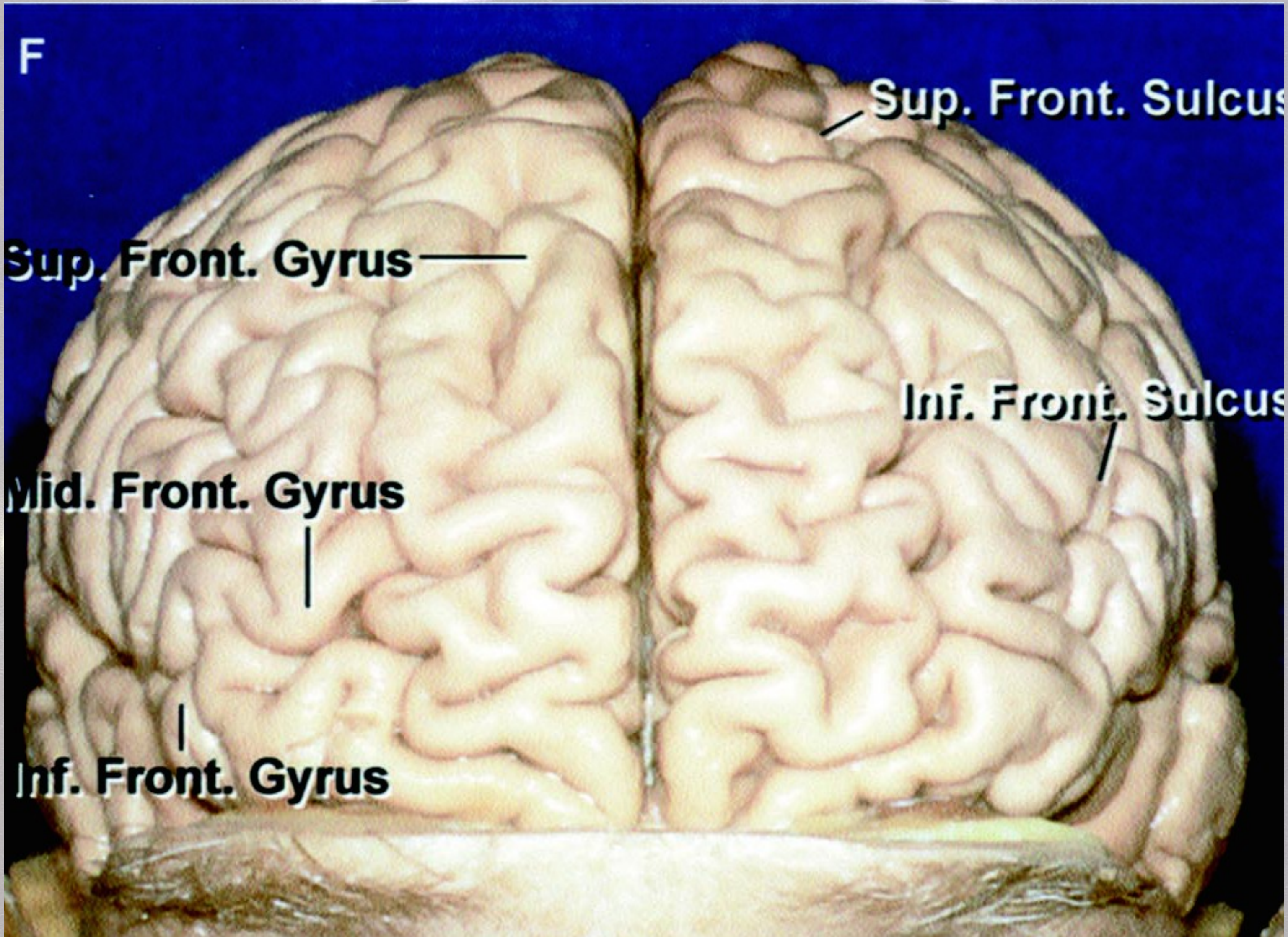


https://www.evelynlockhart.com/anatomic-brain-ventricles/



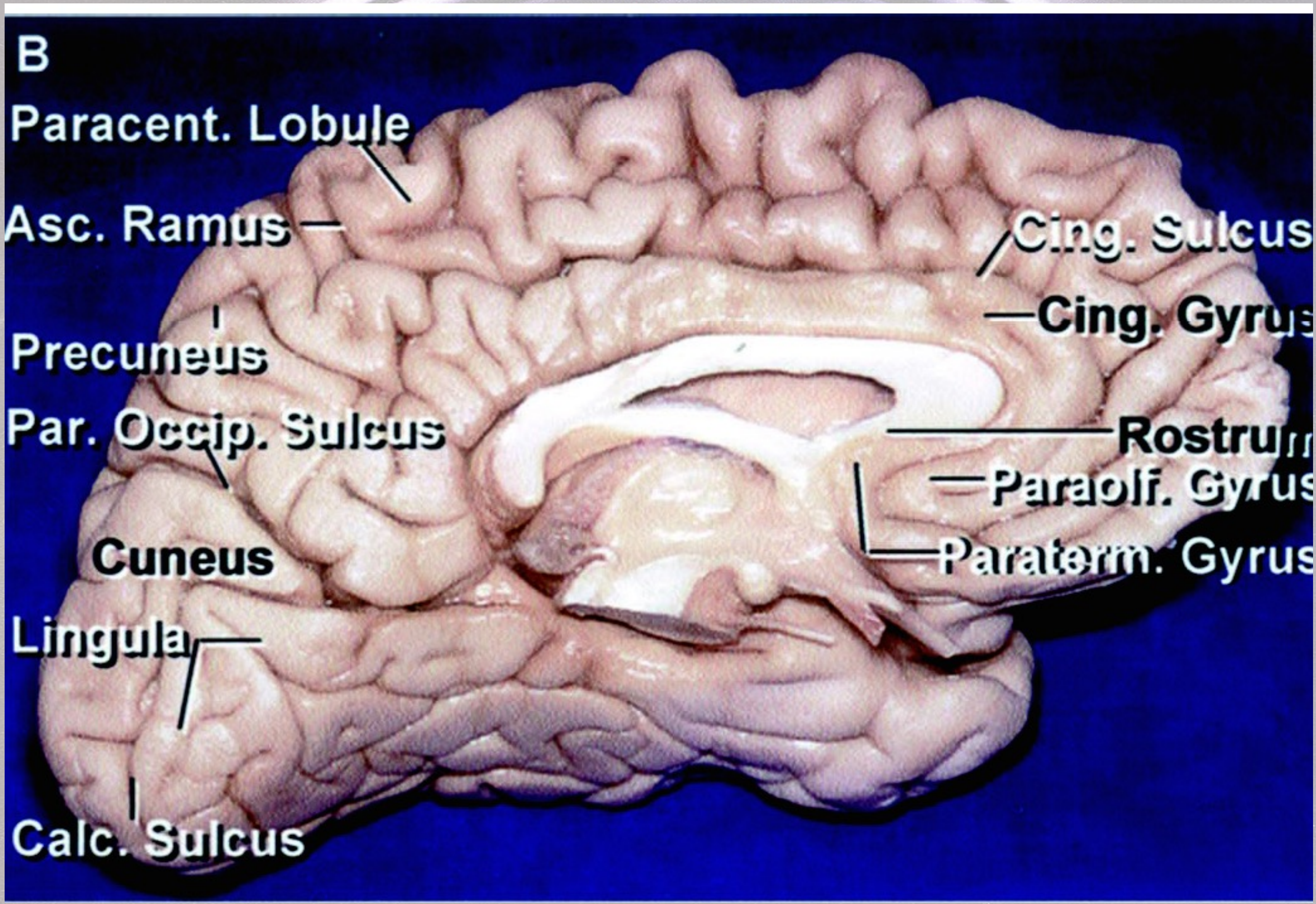
https://www.evelynlockhart.com/anatomic-brain-ventricles/

Imaging the Brain with MRI
- Anatomy



Alan L. Rhoton, Jr. MD, Dept. of Neurological Surgery, University of Florida, Courtesy of Dr. Allison Schachter MD, Union 2017

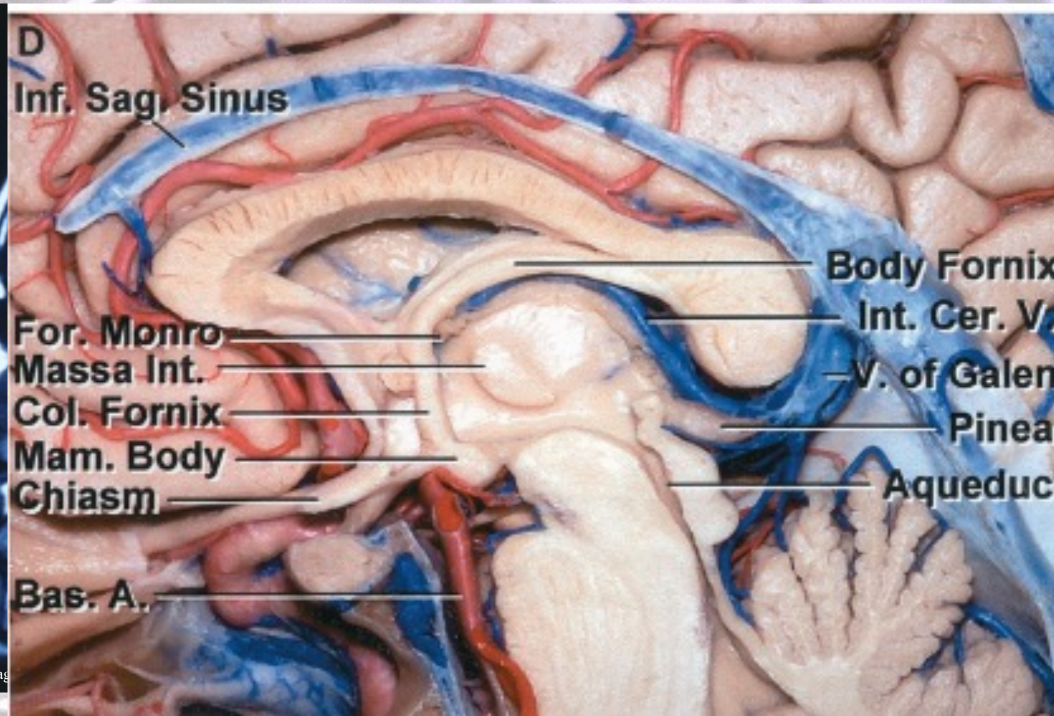
Imaging the Brain with MRI - Anatomy



Alan L. Rhoton, Jr. MD, Dept. of Neurological Surgery, University of Florida, Courtesy of Dr. Allison Schachter MD, Union 2017

Imaging the Brain with MRI - Anatomy

http://www.neomed.edu/DEPTS/NEUR/atlas/Sag

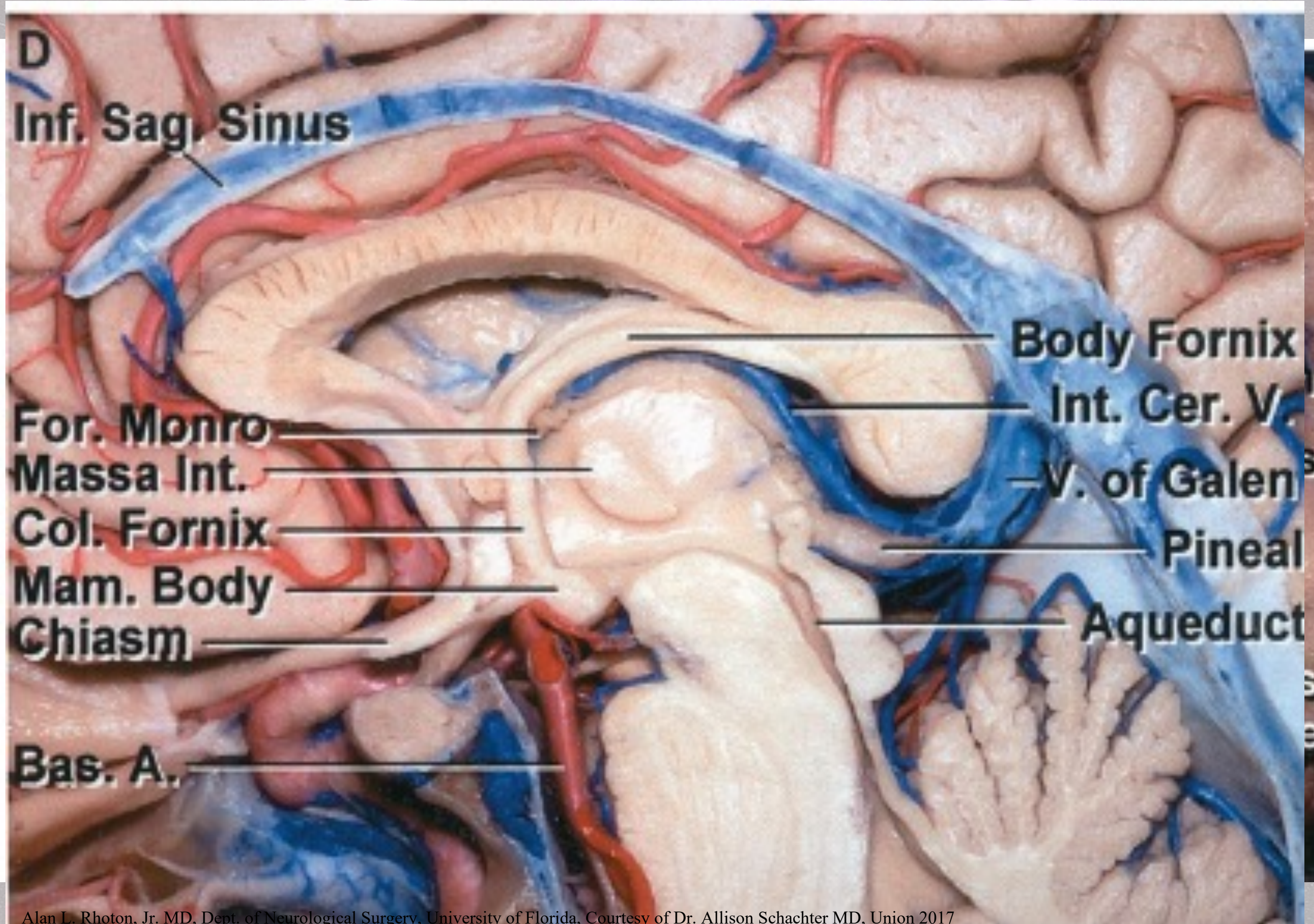


bjects/subject/193

Alan L. Rhoton, Jr. MD, Dept. of Neurological Surgery, University of Florida, Courtesy of Dr. Allison Schachter MD, Union 2017

- Cerebrospinal fluid produced in the fourth ventricle drains into the cisterna magna via the lateral apertures and median aperture.
- Cisterns are receptacles for holding liquid.

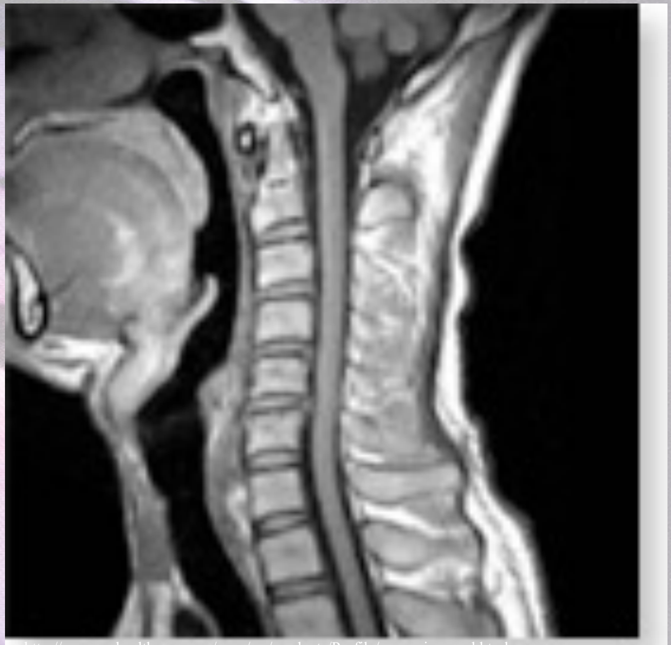
Imaging the Brain with MRI
- Anatomy



Alan L. Rhoton, Jr. MD, Dept. of Neurological Surgery, University of Florida, Courtesy of Dr. Allison Schachter MD, Union 2017

T1 weighted images

http://www.gehealthcare.com/usen/mr/products/Profile/neuro_img_gal.html

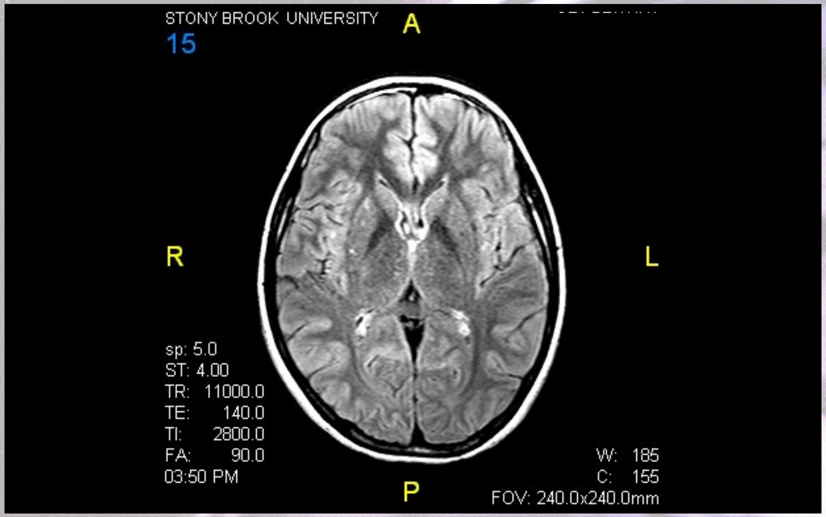


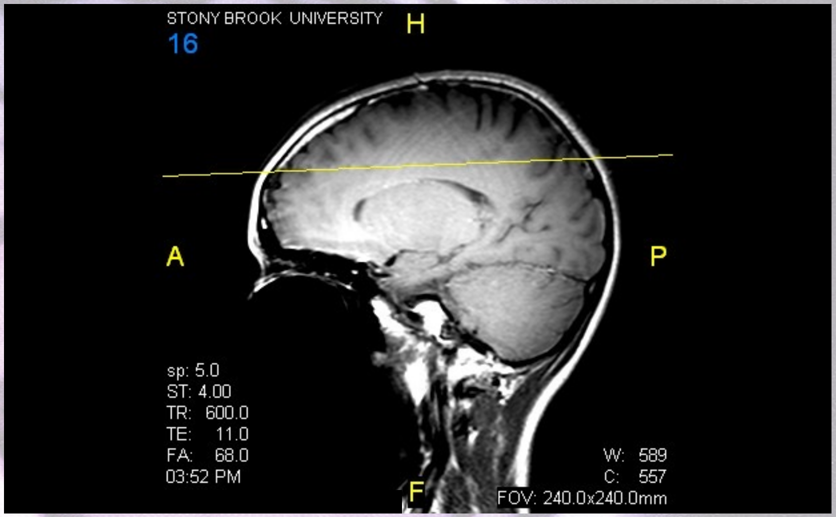
http://www.gehealthcare.com/usen/mr/products/Profile/neuro_img_gal.html

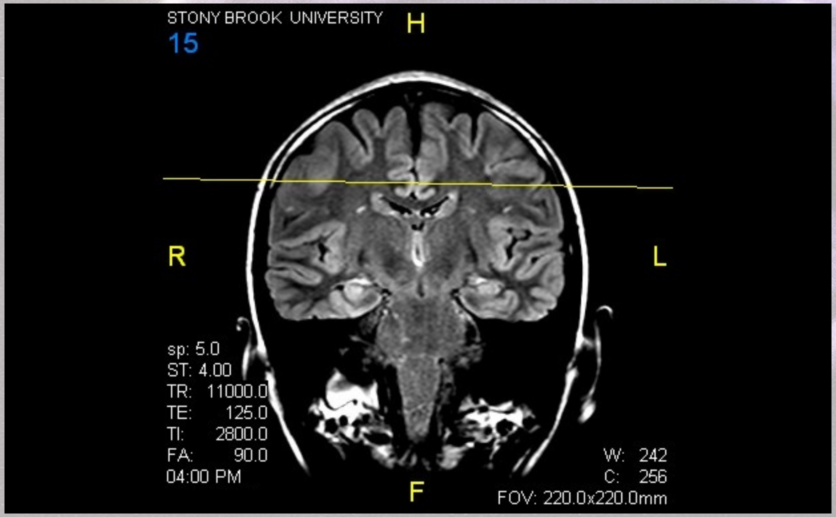
- Left image is a T1 weighted sagittal image of the human brain showing left hemisphere, lateral ventricles, cerebellum and sinus cavities.

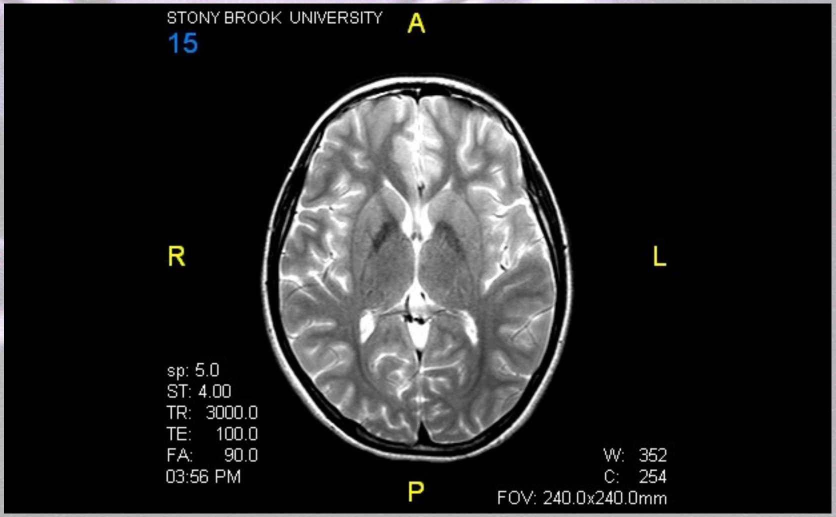
- The right image is also a sagittal image of the cervical spine. You can also clearly see the spinal cord and part of the cerebellum.

Imaging the Brain with MRI
- Anatomy of a Normal Brain





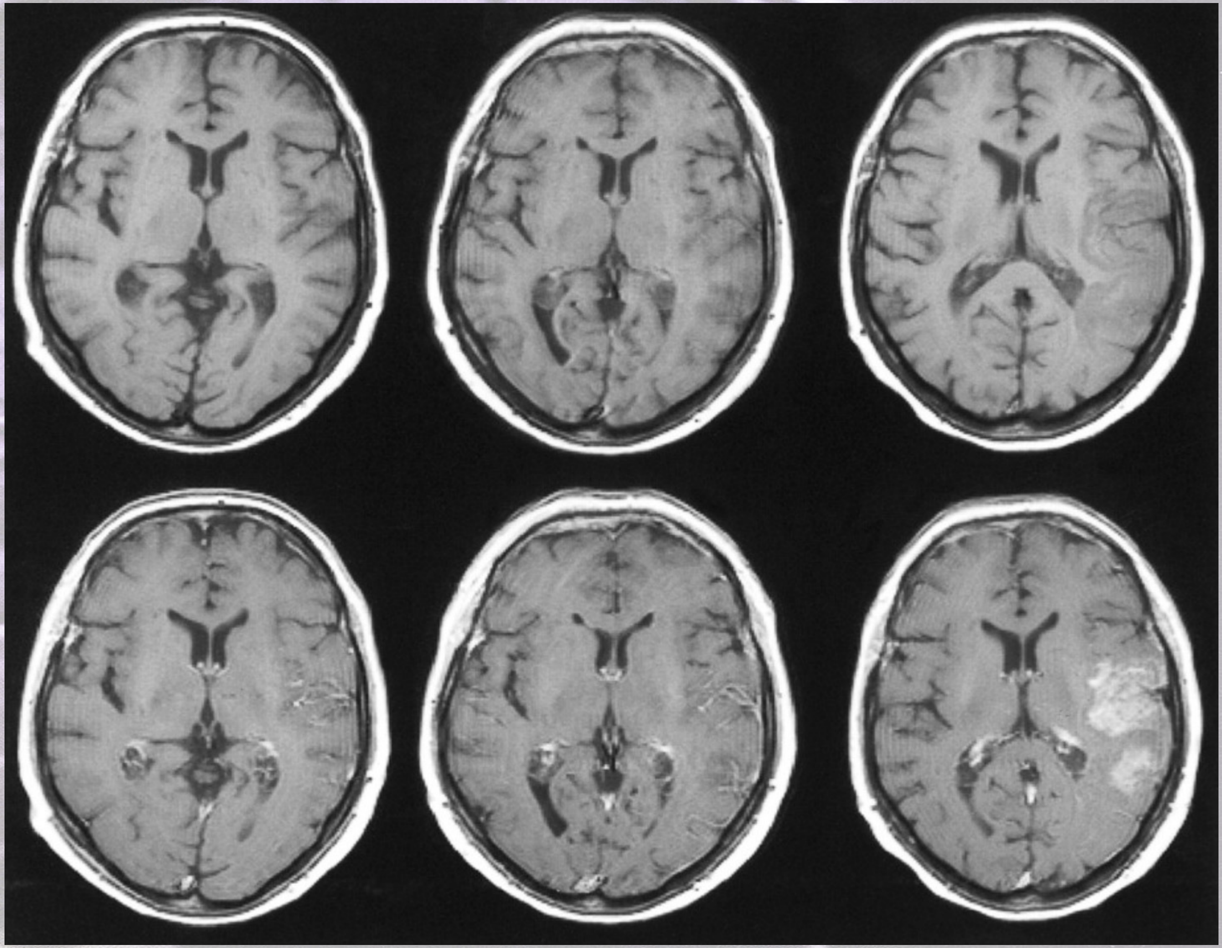




Images courtesy of Dr. William Moore, MD, NYU Langone Medical Center

Imaging the Brain with MRI - The Classics

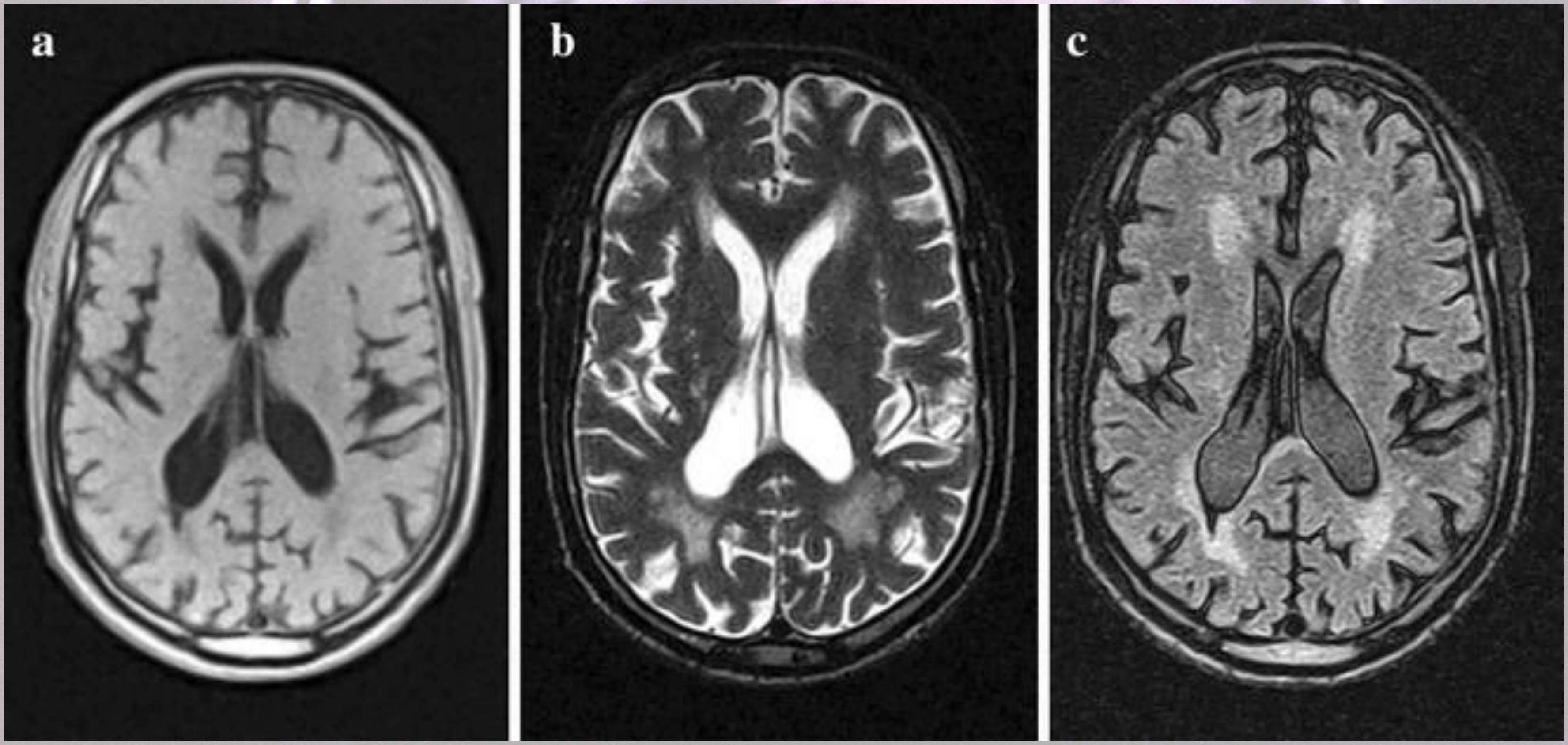
- Case Study: 75-year-old woman presents with dysphasia and weakness in the right arm.
- These are what kinds of MRI images?
- The first row was taken 8hrs after onset, the 2nd day after onset, and 1 week after onset.
- The second row is the same time frames with contrast.



Evolution of MR Contrast Enhancement Patterns during the First Week after Acute Ischemic Stroke, Jari O. Karonen, P. L. Kaarina Partanen, Ritva L. Vanninen, Pauli A. Vainio, and Hannu J. Aronen, AJNR Am J Neuroradiol 22:103–111, January 2001

Imaging the Brain with MRI
- Periventricular White Matter Hyperintensities

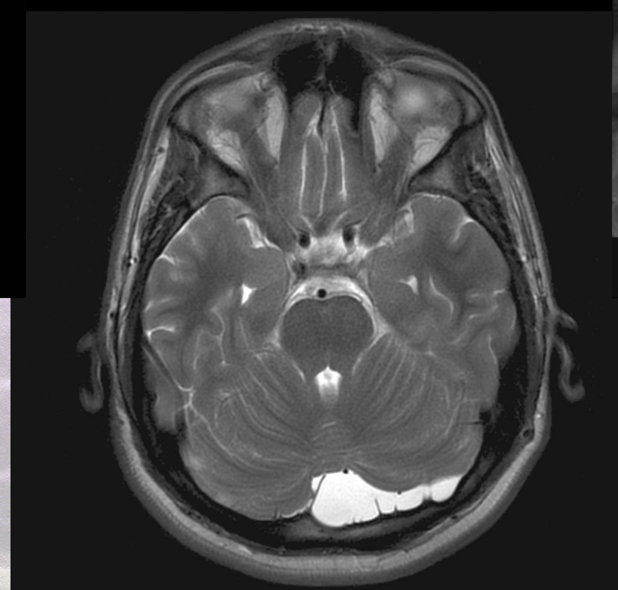
- 69-year-old male stroke survivor with PVMH.
- This condition is not well understood but it's associated with increased risk of another stroke and dementia.

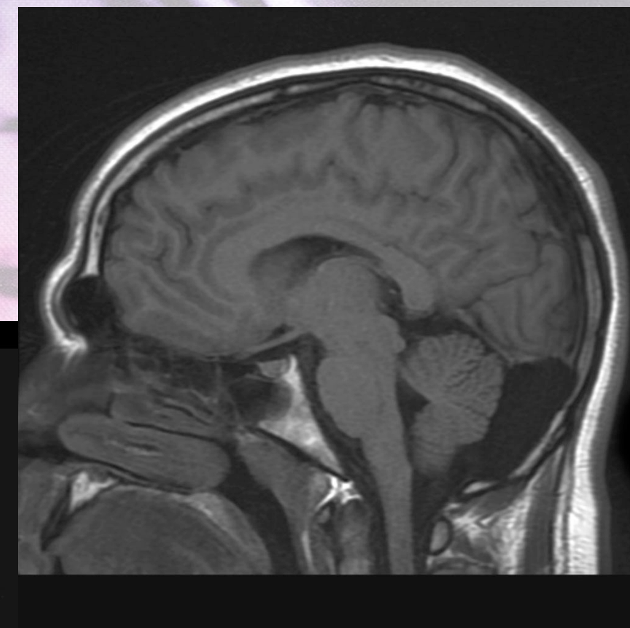


Akinyemi, Rufus & Firbank, Michael & Ogbole, Godwin & Allan, Louise & Owolabi, Mayowa & Akinyemi, Joshua & Yusuf, Bolutife & Ogunseyinde, Oluremi & Ogunniyi, Adesola & Kalaria, Raj. (2015). Medial temporal lobe atrophy, white matter hyperintensities and cognitive impairment among Nigerian African stroke survivors. BMC Research Notes. 8. 10.1186/s13104-015-1552-7.

Imaging the Brain with MRI - Mega-Cisterna Manga

Case courtesy of Frank Gaillard, Radiopaedia.org, rID: 9768

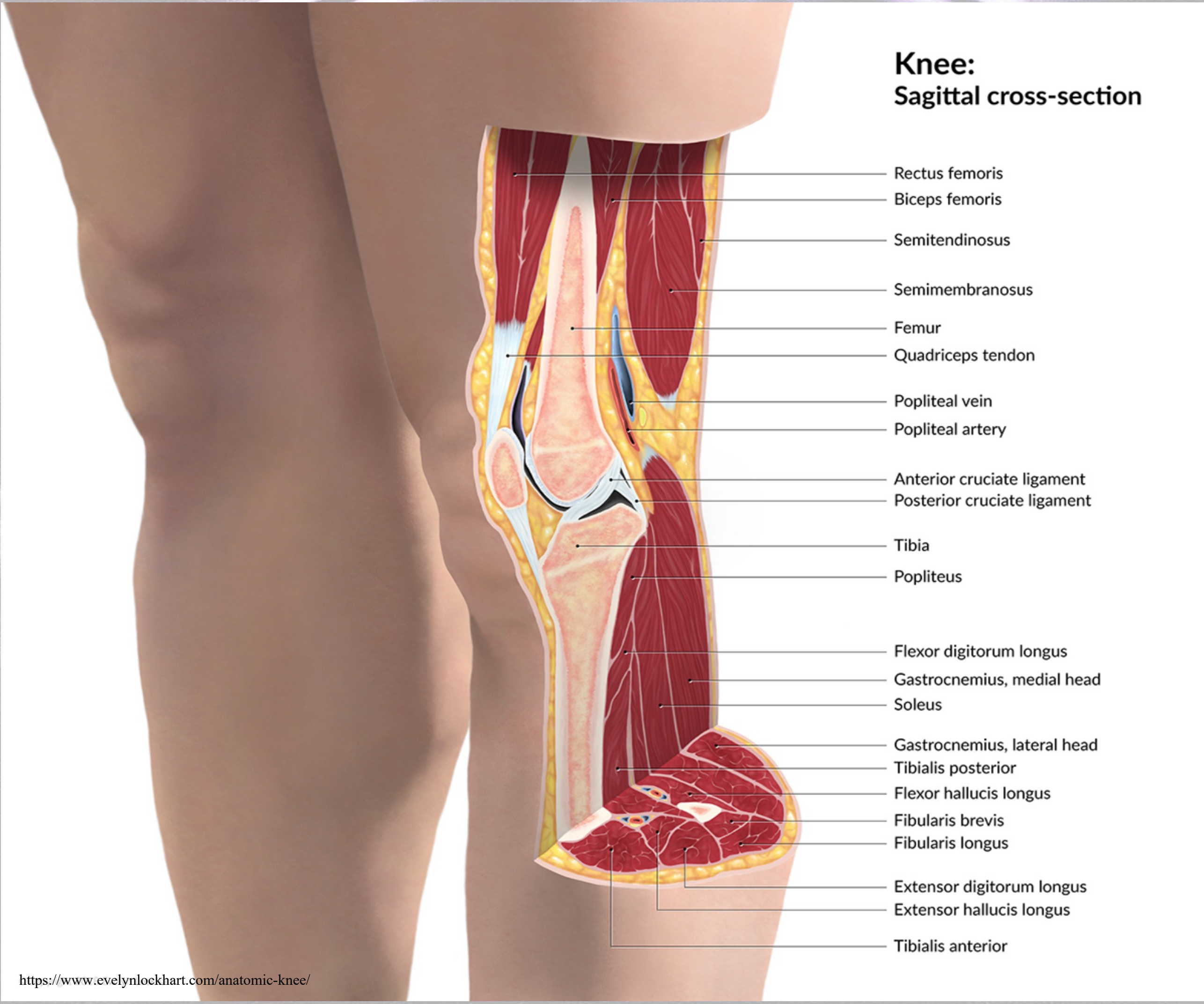




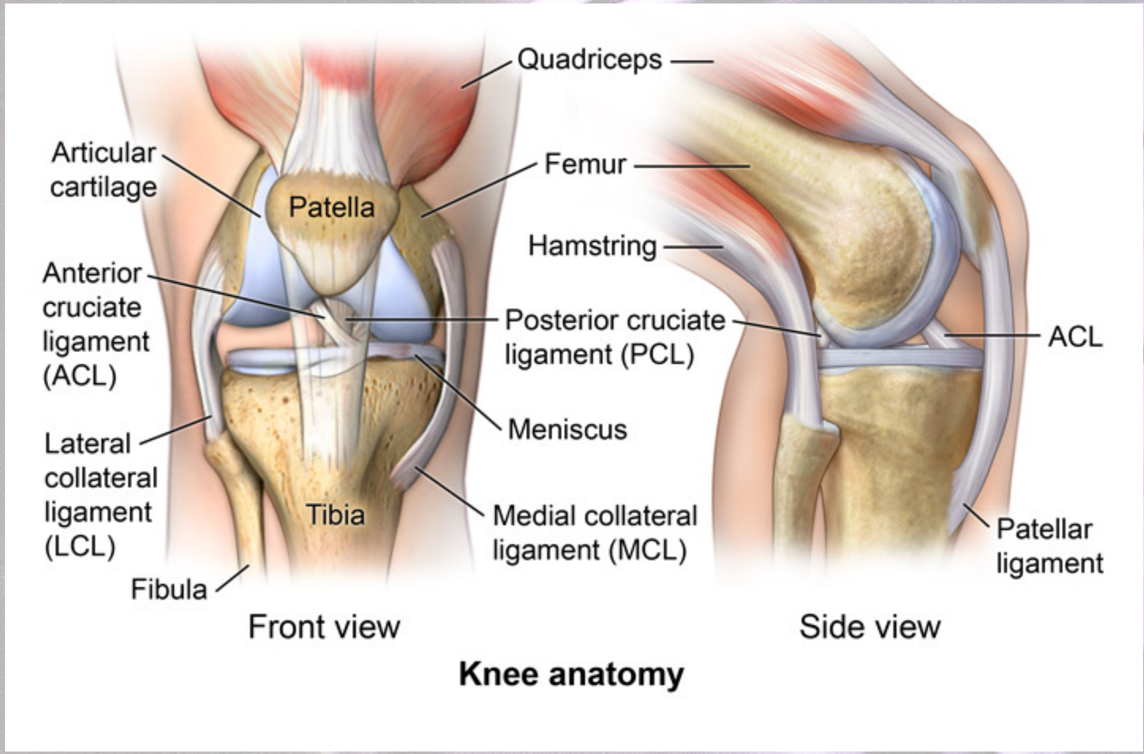
- Mega cisterna magna is an enlargement of the CSF-filled subarachnoid space in the inferior and posterior portions of the posterior cranial fossa.

- It is an incidental finding on neuroimaging, and no imaging follow up is necessary.

Imaging the Knee with MRI
- Anatomy of the Knee



Imaging the Knee with MRI
- Anatomy of the Knee



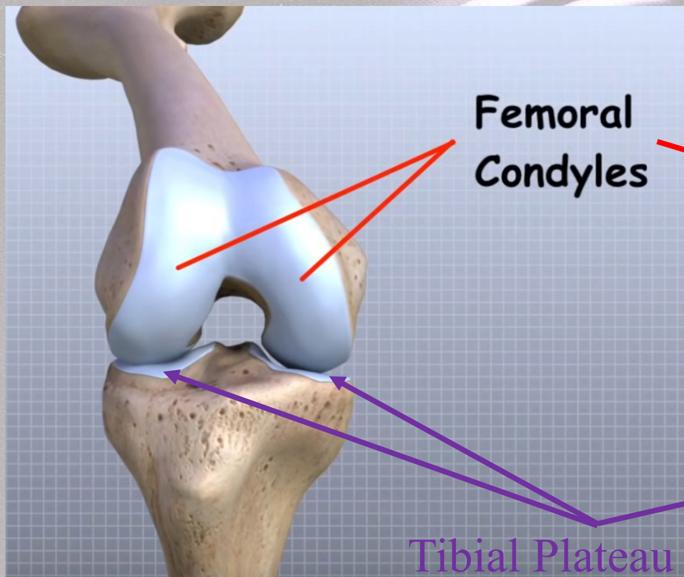
https://comportho.com/anatomy/anatomy-of-the-knee/

Anterior view of the right leg.

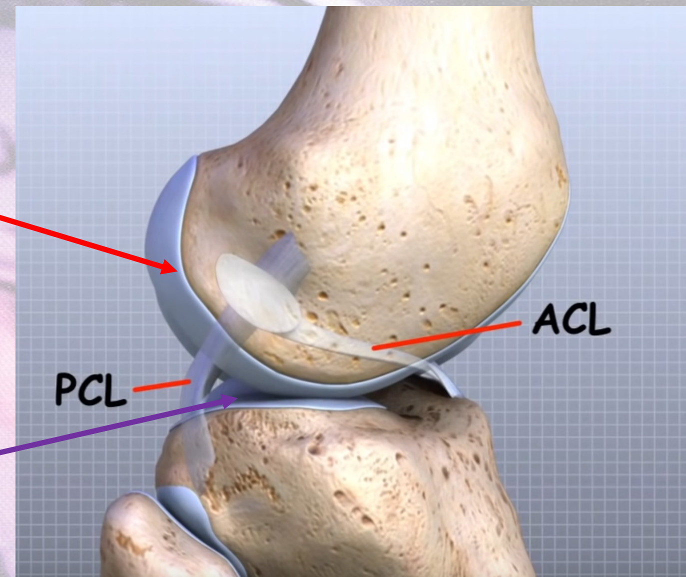
- Anterior Cruciate Ligament (ACL) is in the anterior-to-the-center of the knee joint. Its function is to prevent the forward sliding of the tibia on the femur.
- Posterior Cruciate Ligament (PCL) is in the posterior-to-the-center of the knee joint. Its function is to prevent the backward sliding of the tibia on the femur.

- Medial and Lateral Cruciate Ligaments (MCL & LCL) on the interior and exterior sides of the knee joint respectively and prevent the side-to-side sliding of the knee.
- The distal femur is covered in a cartilage like material (called the femoral condyles) to help reduce friction and help the sliding of the bones about the joint and end on rest the tibial plateau.

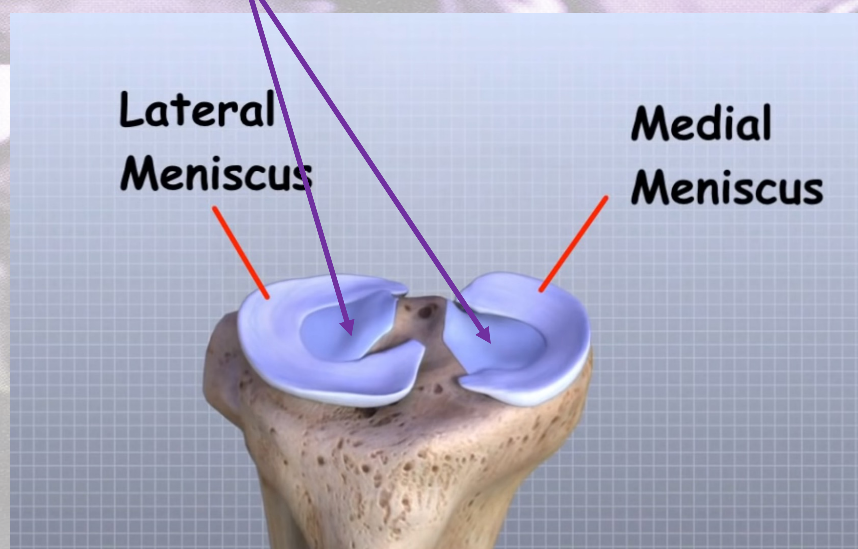
Imaging the Knee with MRI
- Anatomy of the Knee



https://www.youtube.com/watch?v=_q-Jxj5sT0g

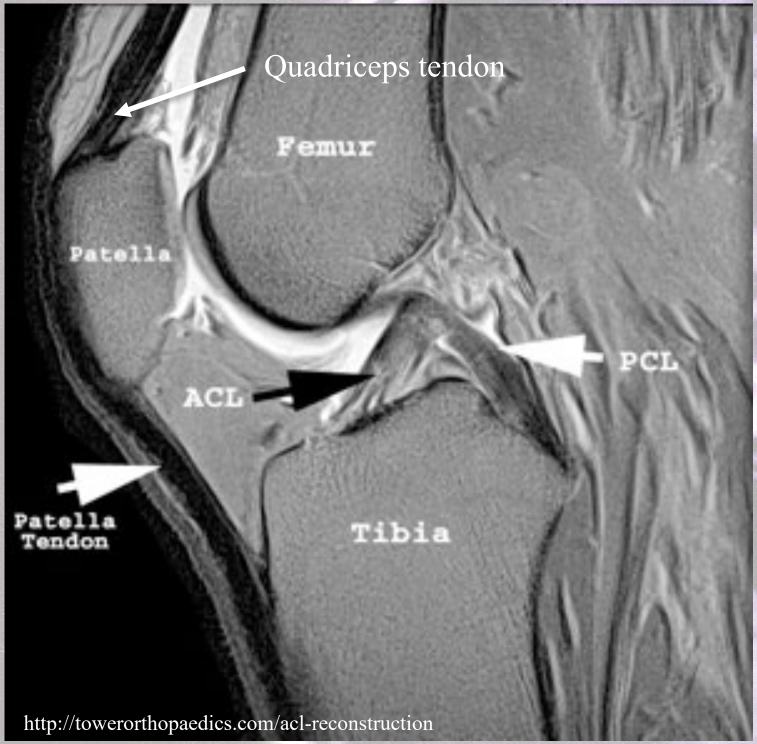


https://www.youtube.com/watch?v=_q-Jxj5sT0g



https://www.youtube.com/watch?v=_q-Jxj5sT0g

Imaging the Knee with MRI
- MRI of the Knee



Normal view of the ACL

Torn ACL – Striated fibrous tear

Imaging the Knee with MRI
- ACL Reconstruction

- Cost to image an ACL tear varies but averages about $2500.

- Most ACL tears cannot be sutured (stitched) back together. To surgically repair the ACL and restore knee stability, the ligament must be reconstructed. Your doctor will replace your torn ligament with a tissue graft. This graft acts as a scaffolding for a new ligament to grow on.

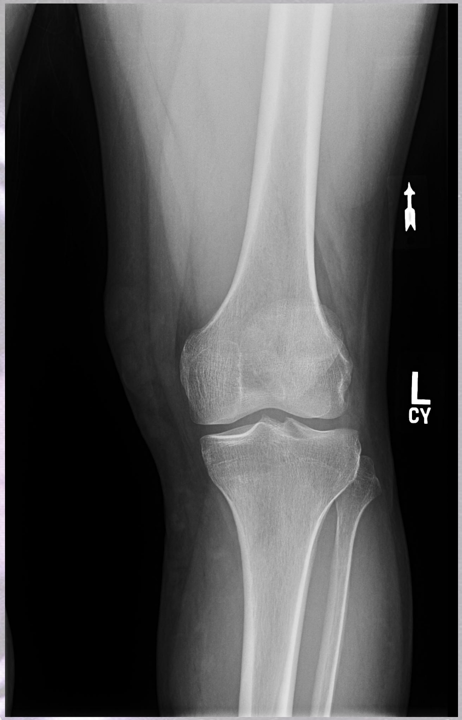
- Grafts can be obtained from several sources. Often, they are taken from the patellar tendon, which runs between the kneecap and the shinbone. Hamstring tendons at the back of the thigh are a common source of grafts. Sometimes a quadriceps tendon, which runs from the kneecap into the thigh, is used. Finally, cadaver grafts (allograft) can be used.

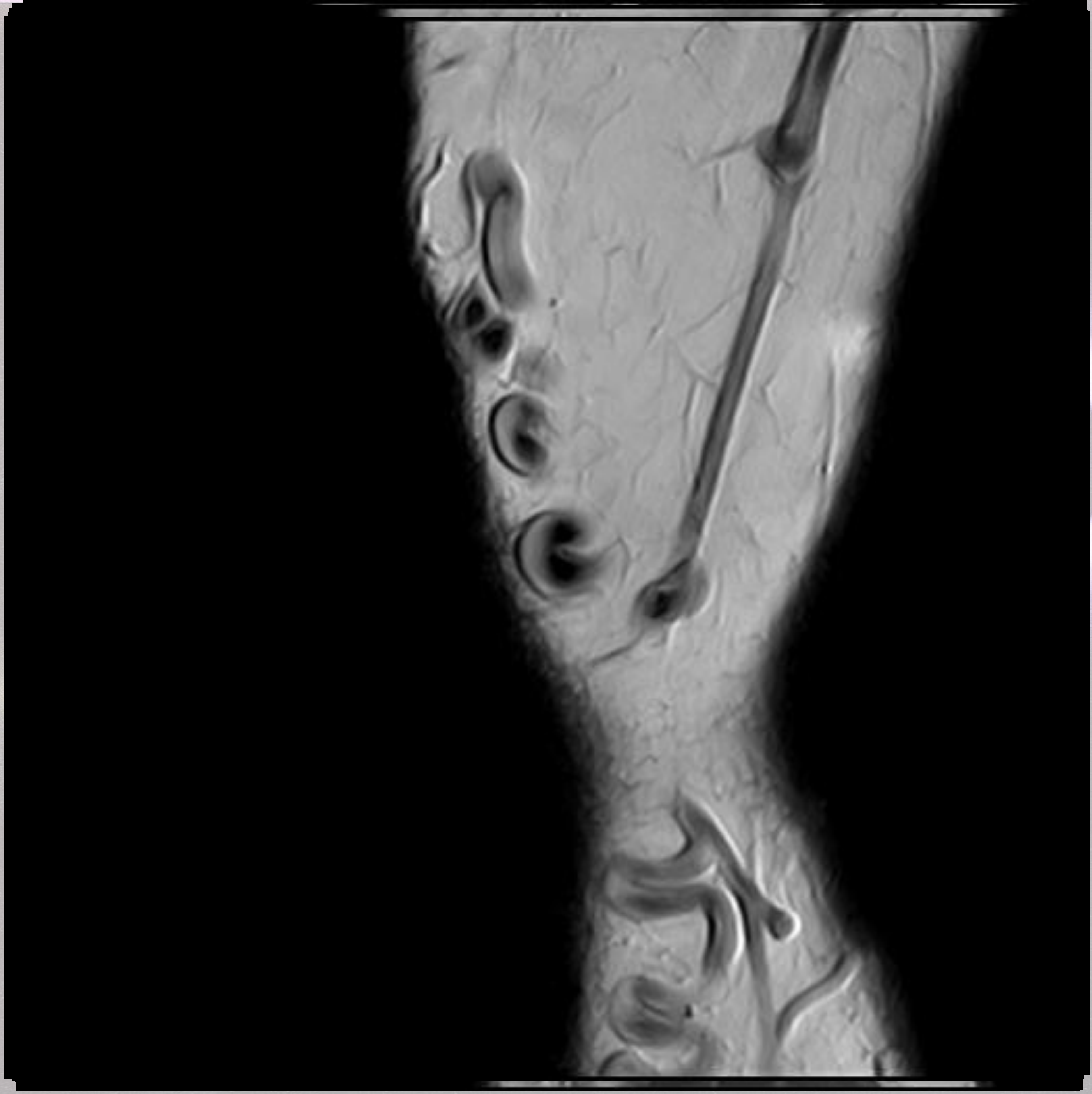
- Because the regrowth takes time, it may be six months or more before an athlete can return to sports after surgery.

Imaging the Knee with MRI - Meniscal Tears

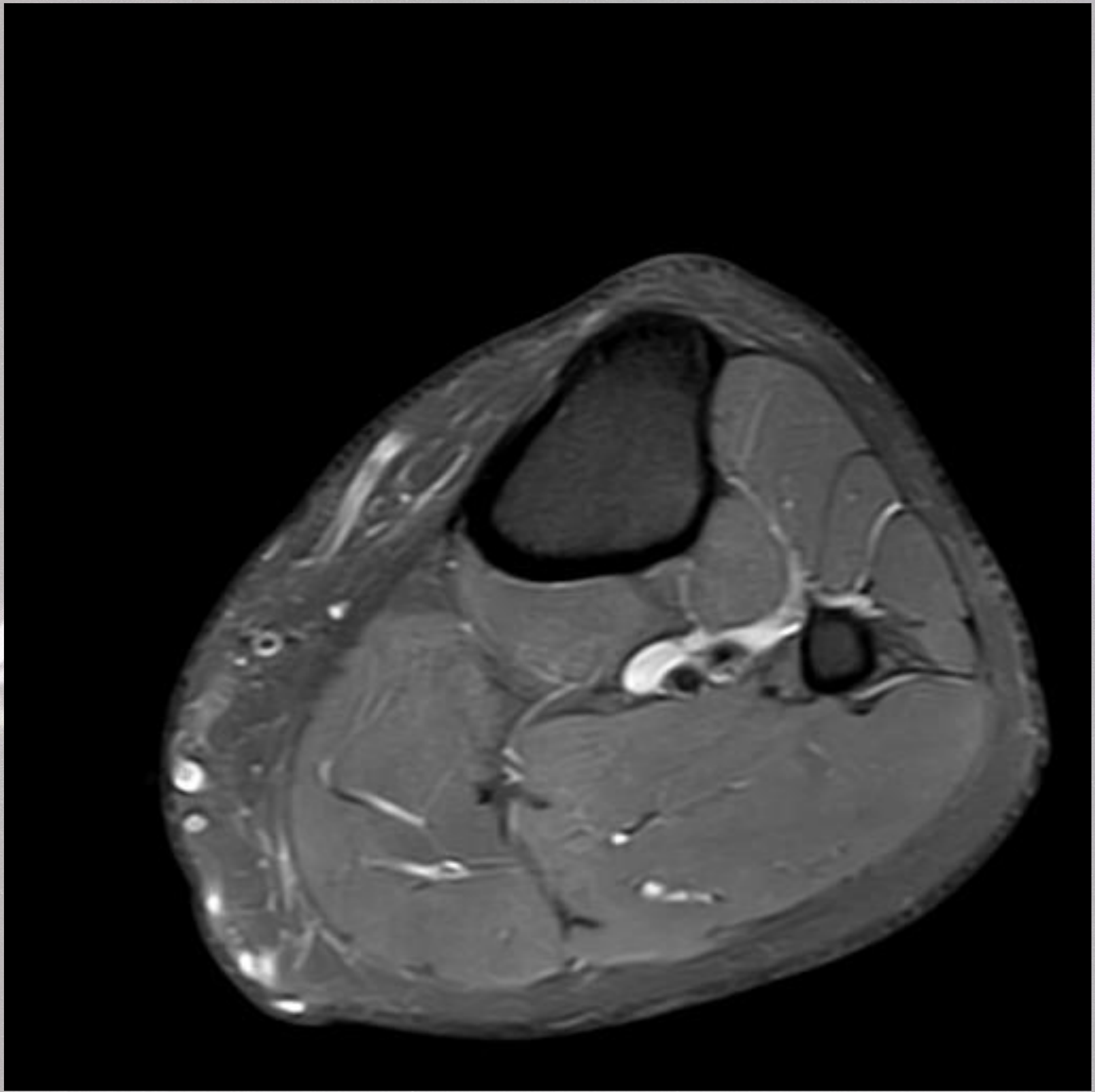
- The menisci — the medial meniscus and lateral meniscus - are crescent-shaped bands of thick, rubbery cartilage attached to the shinbone (tibia).
- They act as shock absorbers and stabilize the knee.
- The medial meniscus is on the inner side of the knee joint.
- The lateral meniscus is on the outside of the knee.

Images courtesy of Dr. Scott LaBrake, PhD





Images courtesy of Dr. Scott LaBrake, PhD



Images courtesy of Dr. Scott LaBrake, PhD

Magnetic Resonance Imaging

- Summary

- The MRI image reflects spatial distribution of T_1, T_2 or proton density within a slice of tissue.
- This involves the NMR signal from differing volume elements of protons caries information that allows for its localization within the body.
- The static magnetic field points along the patient's body, taken to be the z-axis and te transverse plane is a slice through the body, generally.
- Other slices, like coronal or sagittal are possible with good image resolution.
- Most commercial machines have resolutions on the order of a millimeter.
- The most critical and expensive component is the main magnet with fields in the 0.3 – 4T range.
- Cost of an average MRI machine varies. Low end $150k up to $3 million.
- The fields need to be stable and very uniform over the imaging region – not trivial.

Magnetic Resonance Imaging

- Summary

Complicating factors of MRI

- Implanted devices and other metallic devices.
- Pacemakers and other implanted electronic devices .
- Aneurysm clips and other magnetizable materials.
- Cochlear implants in the ear.
- Artificial heart valves.
- Intraocular metallic foreign bodies usually found by screening CT of the orbits if history suggests possible metallic foreign body in the eye.
- Unstable patients (most resuscitation equipment cannot be brought into the scanning room)
- Pregnancy (small and probably safe, but unknown effects on the fetus).
- Claustrophobia (may require anesthesia assistance)

Limitations of MRI

- Subject to motion artifact. Usually need to be restrained or immobilized.
- Inferior to CT in detecting acute hemorrhage.
- Inferior to CT in detection of bony injury.
- Requires prolonged acquisition time for many images compared to CT or US.