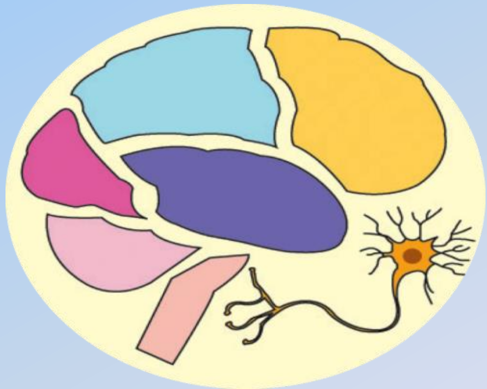
INTRODUCTION TO NEUROIMAGING OF MRI/CT

January 25, 2019



Javier Chapa Dávila, MD

Neurologist – Neurophysiologist - Epileptologist - Neuroimager

ASN 42ND ANNUAL MEETING
JANUARY 24-26, 2019
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DISCLOSURES

- Financial Disclosure
  - Nothing to disclose
  - Author didn't received monetary compensation for the following work/presentation
- Unlabeled/Unapproved Uses Disclosure
  - Nothing to disclose
- Some of the slides have been adapted from teaching materials used at the University of Oklahoma Health Sciences Center

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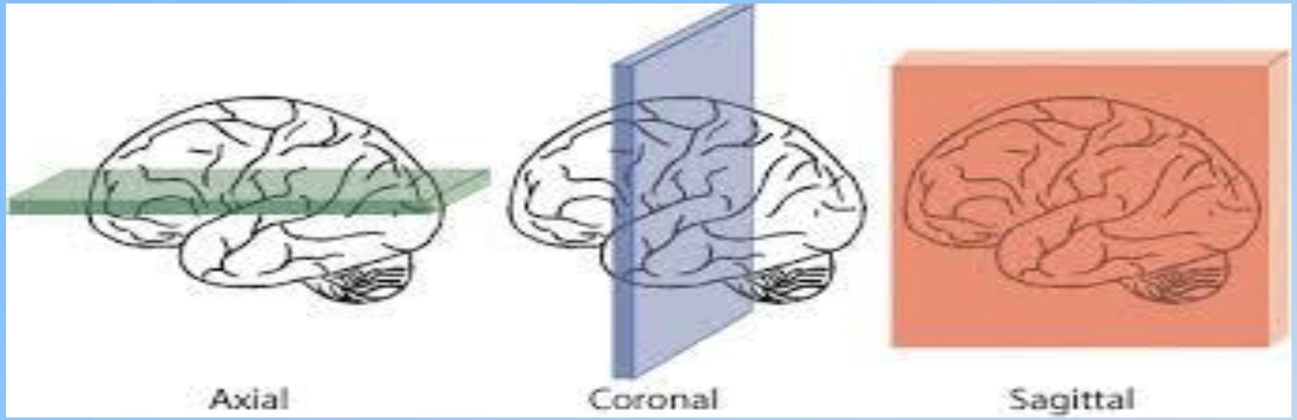
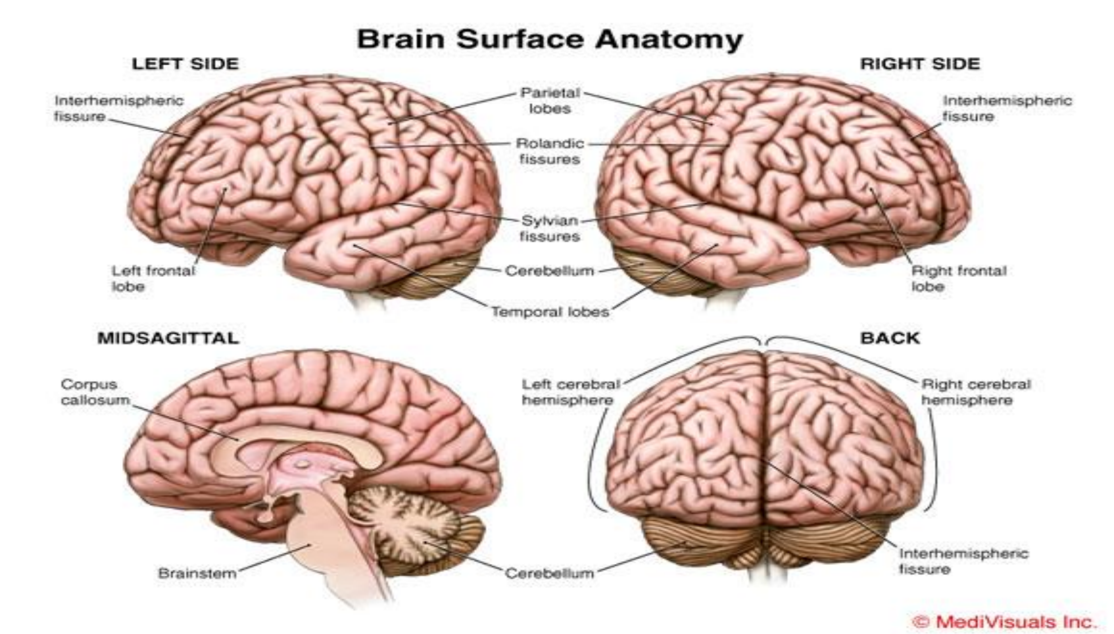
Objectives

- Understand basic neuroimaging of MRI/CT
- Discuss functional and nuclear studies

Axial, Coronal and Sagittal Planes





Neuroimaging techniques

- Anatomical
  - X-ray
  - CT, CTA
  - MRI, MRA
  - DTI
- Functional
  - MRS - Spectroscopy
  - PET (nuclear study)
  - SPECT (nuclear study)
  - fMRI

X-ray – plain films

- X-ray beam serves as source of photon energy and the recipient (film or digital receiver) is the “detector”
- As the density atomic number and electrons per gram of a tissue increase, the degree of attenuation of an x-ray bean increase
- Metal > bone >> air/soft tissue

Pneumoencephalography

- Removal of CSF by LP and injection of air follow by X-ray
- Initially described in 1918 [1]
- Low resolution
- High morbidity, including:
  - Meningeal irritation, 6 hrs:
    - Headache
    - Nausea
    - Emesis
  - Elevation in BP

1: AJNR 2012

CT

- Originally known as computed axial tomography (CAT or CT scan) and body section rentenography.

- The word "*tomography*" is derived from the Greek *tomos* (slice) and *graphein* (to write).

- CT produces a volume of data which can be manipulated, through a process known as *windowing*, in order to demonstrate various structures based on their ability to attenuate the X-ray beam.

CT BASICS

- CT uses x-rays
- Provides axial brain view
- CT scan is a density (attenuation) based study- measures density of the tissue being studied
- **Pros**: fast, quickly accessible, cost-effective, less claustrophobia limitations.
  - Good for bone/fracture (trauma), calcifications, fresh hemorrhage imaging (SAH), paranasal sinus anatomy, immediate post-operative evaluation.
- **Cons**: radiation exposure, fair tissue imaging cannot detect blood flow, iodinated contrast, brainstem, poor posterior fossa imaging (artifact)

CT History

- Electric Musical Industries (EMI) introduce the CT scanner under the work of Sir Godfrey Hounsfield between 1972-1973.
- EMI was the same company that use the Beatles for distributing their music on the Apple label.
- There is a common believe that the sells from the Beatles allowed the EMI company to develop the CT

J Comput Assist Tomogr. 2012 Mar-Apr;36(2):161-4. doi: 10.1097/RCT.0b013e318249416f.

Do we really need to thank the Beatles for the financing of the development of the computed tomography scanner?

Maizlin ZV[1], Vos PM.

Author information

Abstract

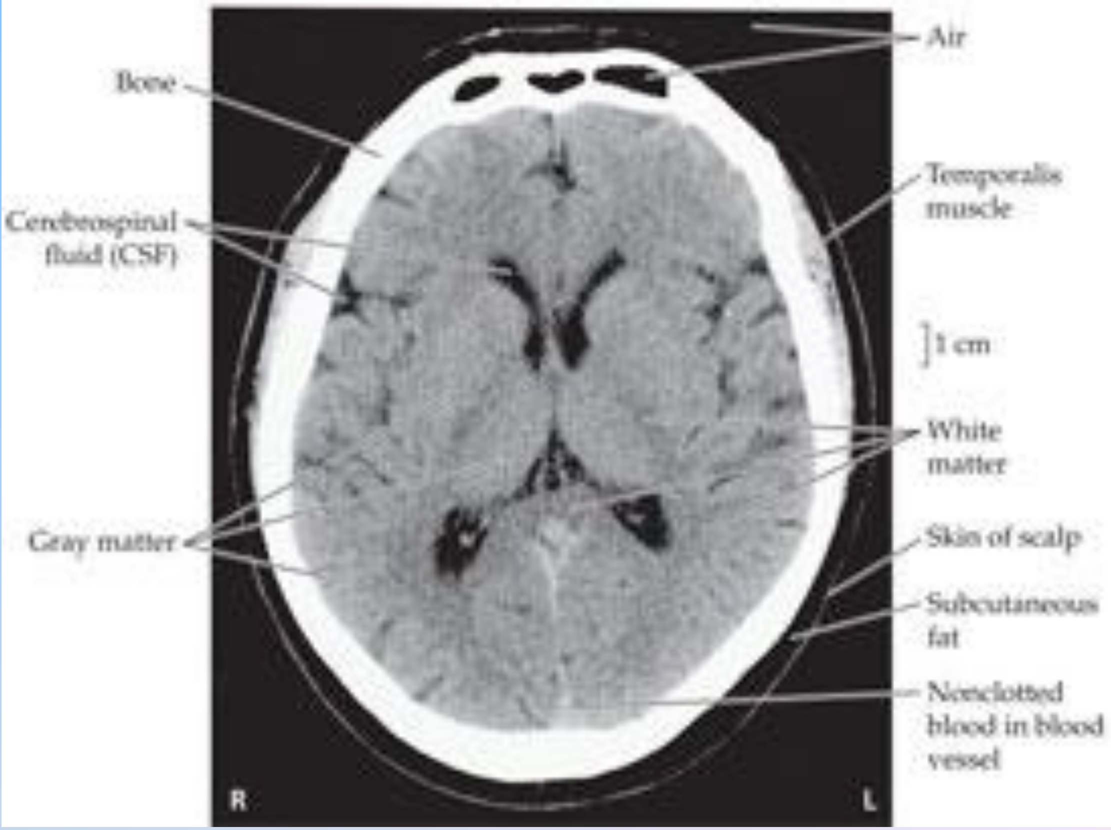
It is commonly believed that the revenues from the selling of the Beatles' records by Electric and Musical Industries (EMI) allowed the company to develop the computed tomography (CT) scanner. Some went to define this as the Beatles' gift to medicine. However, significant controversies and discrepancies arise from analysis of this statement, making its correctness doubtful. The details of financing required for the CT development and the part of EMI in financial input have never been publicly announced. This work analyzes the financial contributions to the CT development and investigates if the revenues received from the sales of the Beatles' records were used for the creation of the CT scanner. Timeline of the development of the EMI CT scanner and the financial inputs of EMI and British Department of Health and Social Security (DHSS) were assessed. Without salary expenses to Godfrey Hounsfield and his team, the development of the CT scanner cost EMI approximately £100,000. The British DHSS's expenses were £606,000. Hence, the financial contribution of DHSS into the development of the CT scanner was significantly bigger than that of EMI. Accordingly, British tax payers and officials of British DHSS are to be thanked for the CT scanner. The Beatles' input into the world's culture is valuable and does not require decoration by nonexistent connection to the development of CT. A positive aspect to this misconception is that it keeps in public memory the name of the company that developed the CT scanner.

CT BASICS-density

- Black

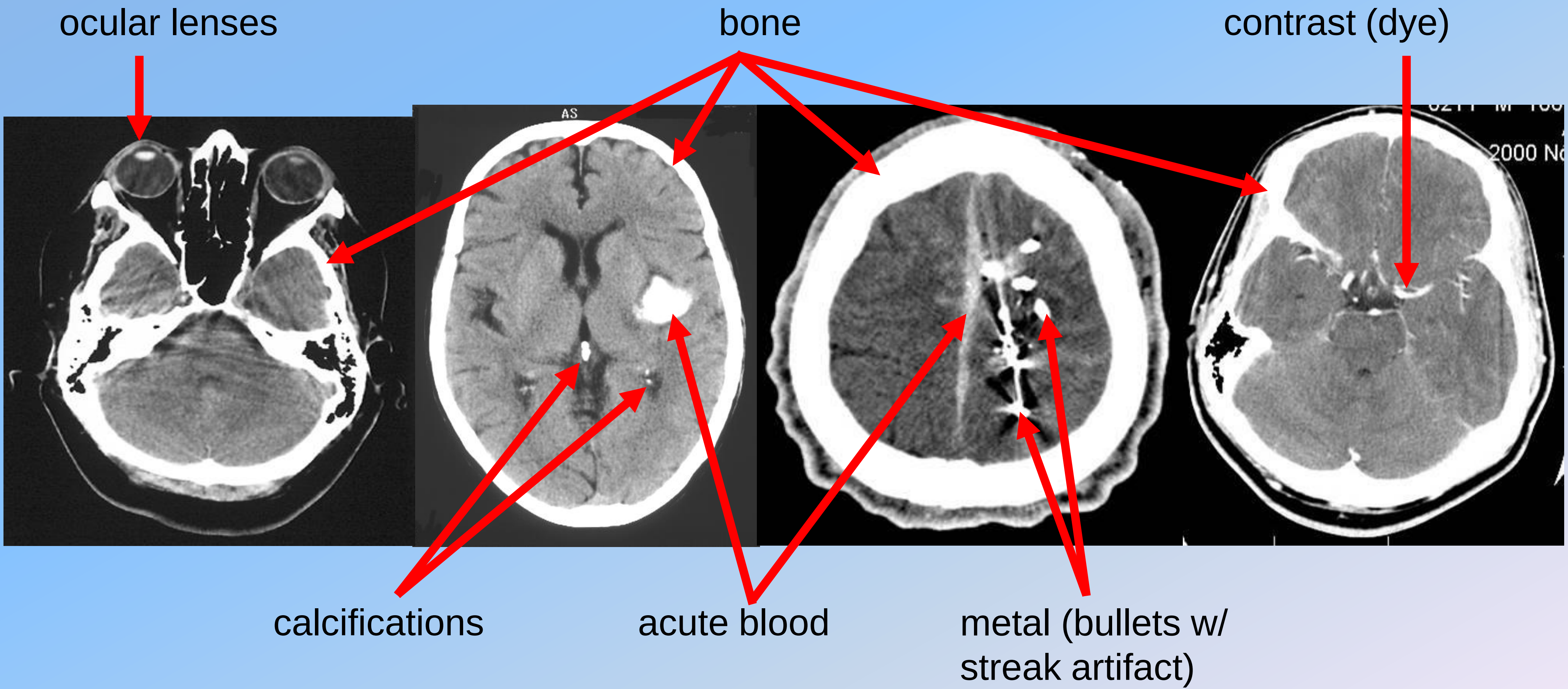
Structure/ Tissue	Hounsfield units
Air	-1000 to -600
Fat	-100 to -60
Water	0
CSF	+8 to 18
White matter	+30 to 41
Gray matter	+37 to 41
Acute blood	+50 to 100
Calcification	+140 to 200
Bone	+600 to 2000

White



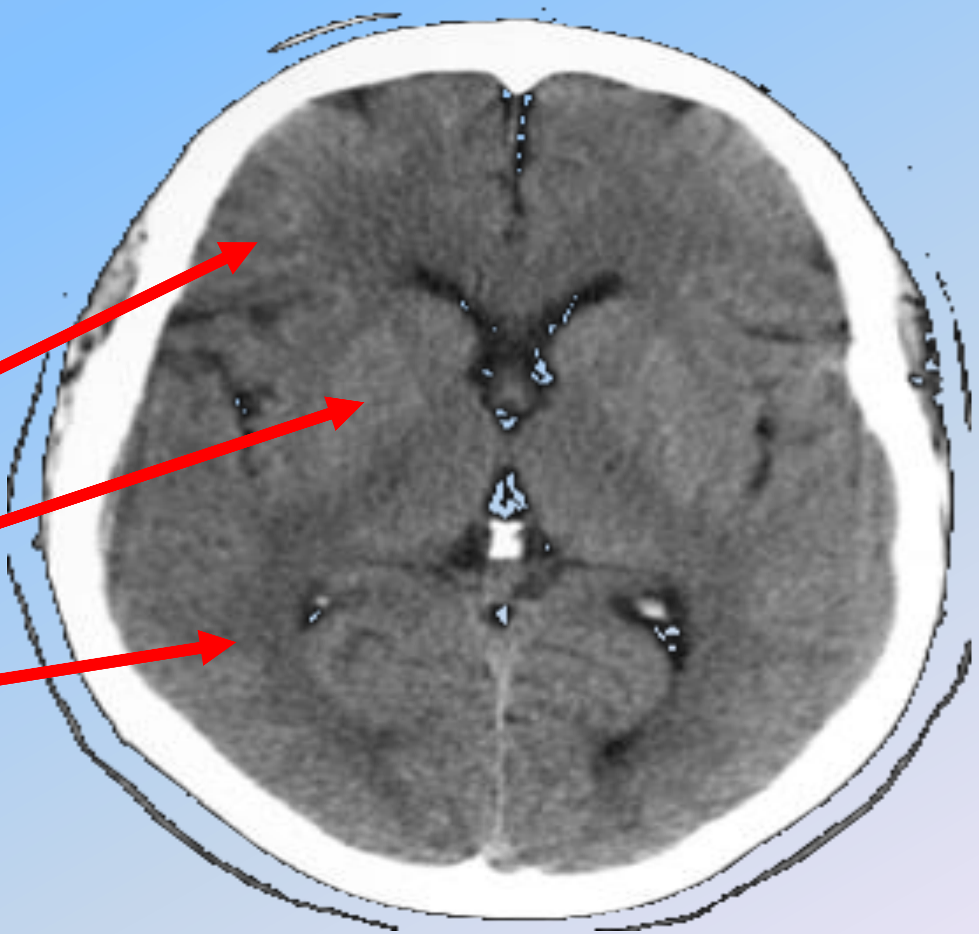
Hyperdense/Hyperattenuation things on CT

- Bone, calcium, acute hemorrhage & contrast



Isodense things on CT - Brain parenchyma

- *Brain parenchyma is light gray*
- *White matter is darker than gray matter*



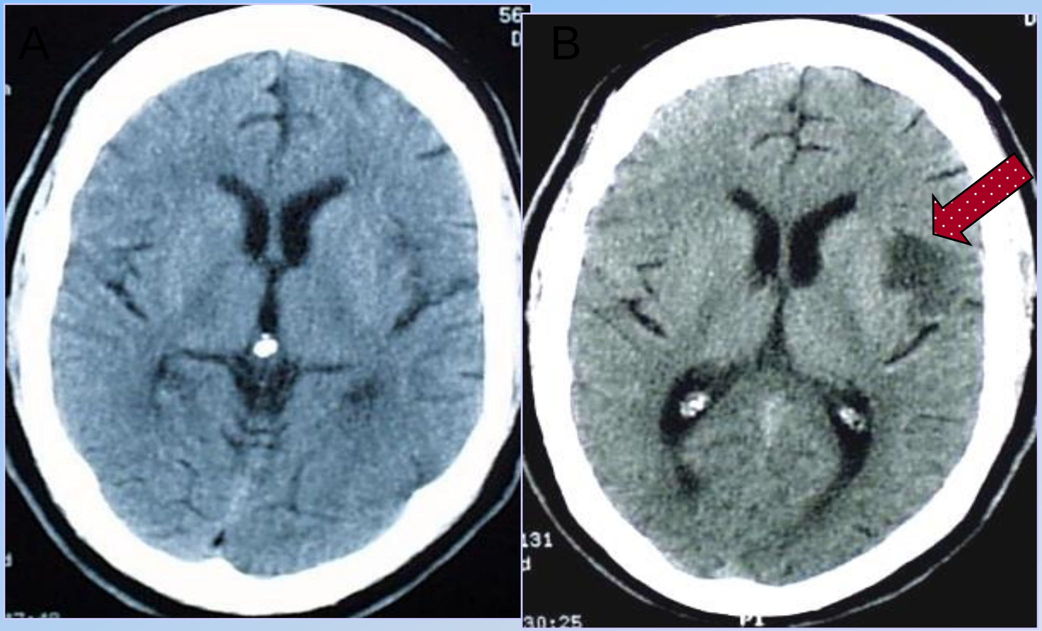
Why gray matter is more hyperdense than white matter?

NONCONTRAST CT BRAIN: ACUTE ISCHEMIC STROKE

A. In 1st few hours to day, CT usually normal (though may show blurring of gray-white junction & sulcal effacement)

B. By day 2, CT shows dark area with mass effect (compression of surrounding structures)

- Window widths (WW) – gray-scale display
- Window level (WL) – center point about which range is displayed
  - Small WW and WL help differentiate soft-tissue differences



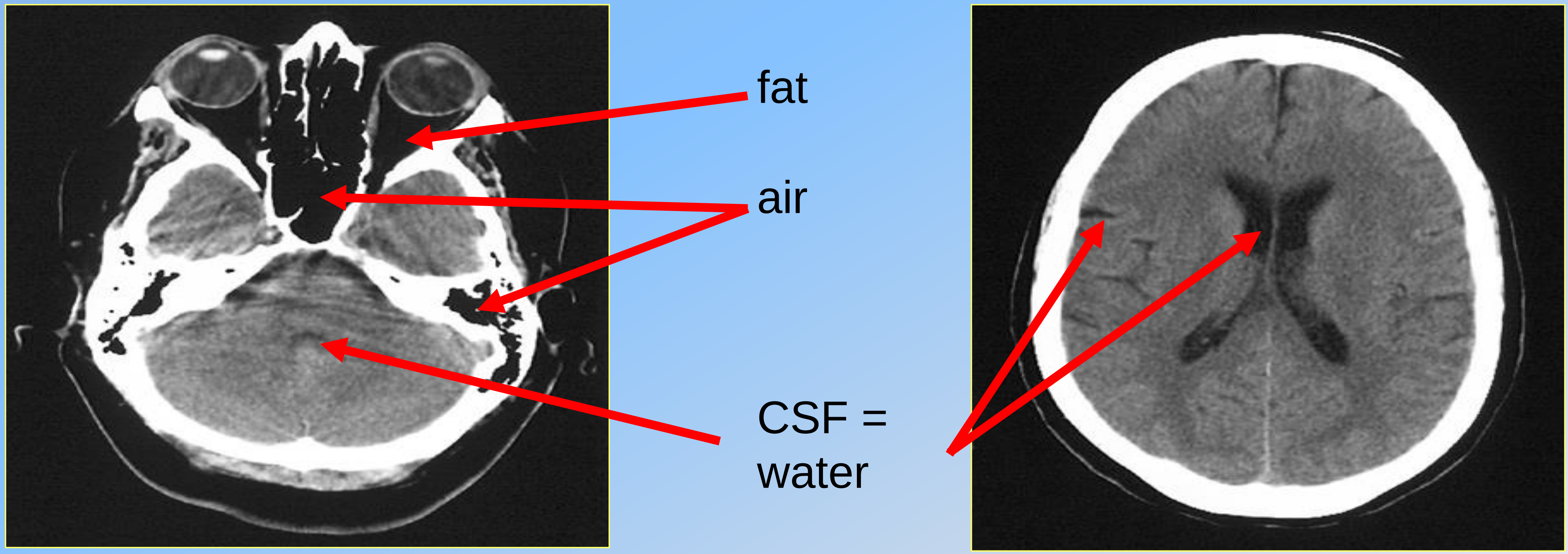
Day 1
Acute infarction

Day 3
Subacute infarction

For better gray white matter differences adjust CT windows to C40 and W40.

Hypodense things on CT scan

- CSF is very dark, sulci, cisterns & ventricles
- Air , nasal cavity, sinuses, mastoid air cells



BRAIN CTA principles

- Contrast is used to further evaluate cerebral vasculature (aneurysms, injury-dissection, vascular malformations, blockages-atherosclerosis)
- Use of iodinated contrast injected rapidly through a vein and images are obtained as the contrast bolus travels through the intracranial vessels
- CAUTION!! Patient allergic to sea food are allergic to CT contrast

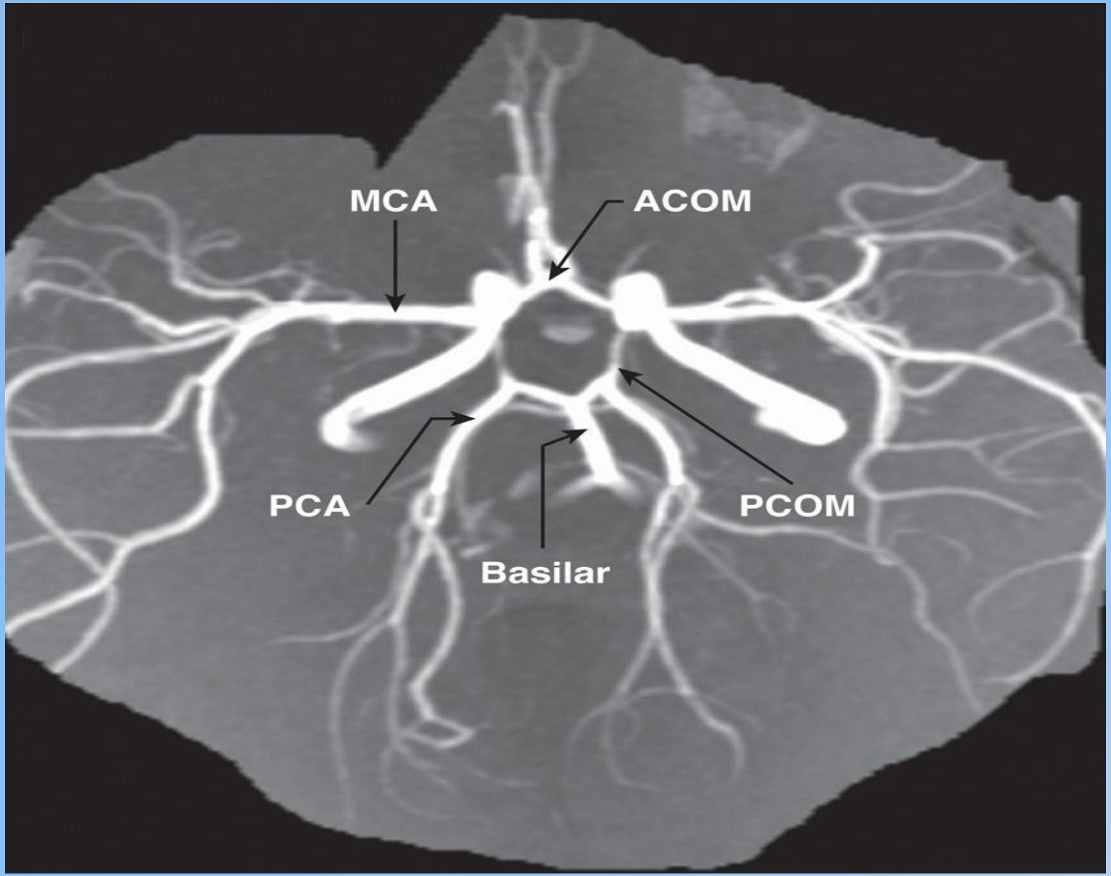
CTA

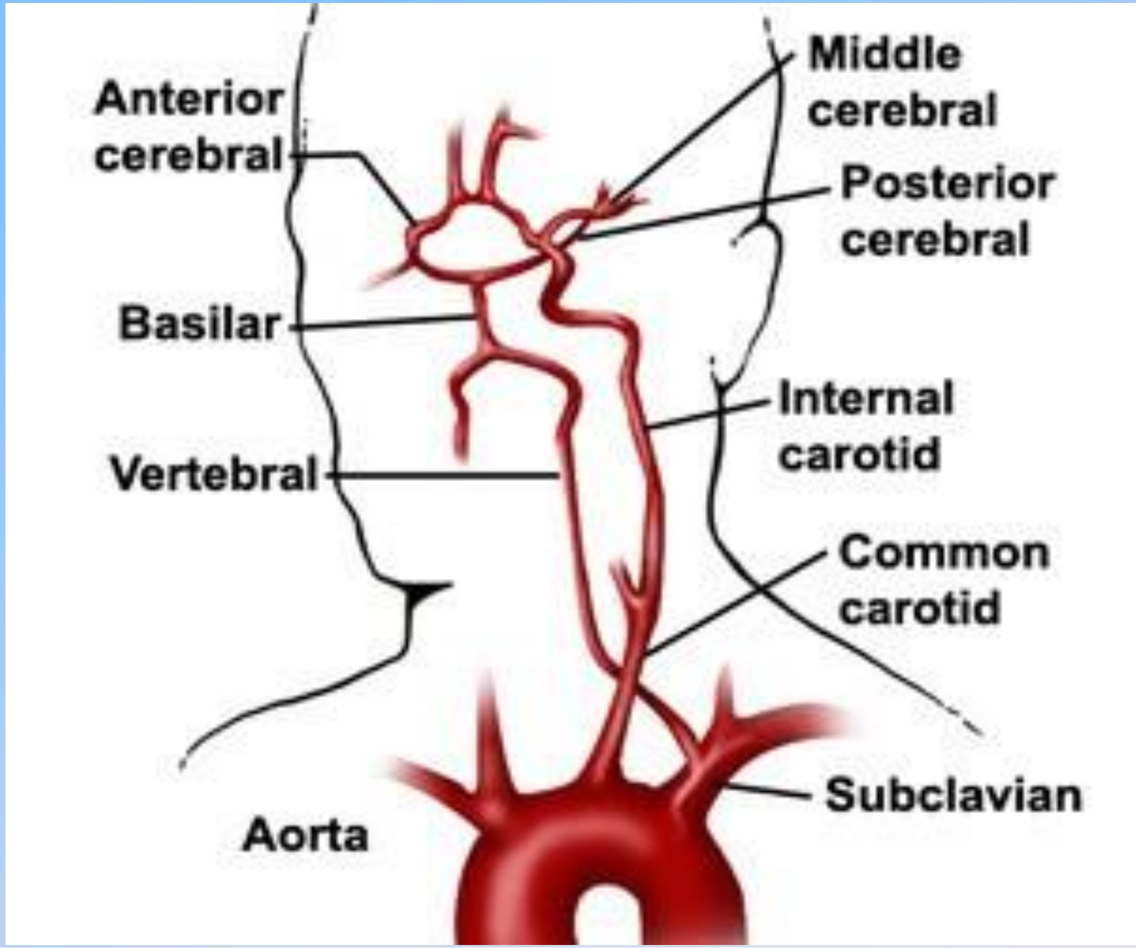
- X-ray based study with IV injection of dye to look at vessels
- Advantages
  - Rapid, easily available for detecting intracranial occlusions and vessel visualization.
  - Less invasive vs catheter based angiogram
  - Coagulopathy not a major factor as no need for arterial access

CTA

- Disadvantages
  - Radiation
  - Risk for contrast induced nephropathy (presence of renal insufficiency, diabetes or prediabetes)
- Contraindications
  - Pregnant women (may shield if absolutely needed)
  - Iodine contrast allergies

CTA


MCA
ACOM
PCA
PCOM
Basilar


Anterior cerebral
Middle cerebral
Posterior cerebral
Basilar
Internal carotid
Vertebral
Common carotid
Subclavian
Aorta

CT VS MRI

CT

Air	Dark
Fat	Dark
Water	Dark
Brain tissue	gray
Bone, cortical brain tissue,	Bright

MRI

	MR-T1	MR-T2
Air	Dark	Dark
Fat	Bright	Bright
water	Dark	Bright
Brain tissue	GM – gray WM - white	GM – white WM - gray
Bone , cortical brain tissue	Dark	Dark

DENSITY AND ATTENUATION

INTENSITY

Rincón – Puerto Rico

- Invented the MRI in 9/1971
- Conducted his research in the development of MRI at State University of NY at Stony Brook
- American chemist that wins the "Nobel Prize in Physiology or Medicine" in 2003

MRI history – Paul C. Lauterbur

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MRI is…

- Magnetic Resonance Imaging
- Also called NMR (nuclear magnetic resonance)
  - Negative connotation of “nuclear” word, then MRI name was adopted
- Based on the magnetic properties of protons, i.e. hydrogen atoms
- Applicable to other atomic nuclei too (sodium, phosphorous, etc.) but there is much more hydrogen in humans than any of these others

Magnet

- Protons spin in a magnetic field (2.5kHz, 150,000 rpms, in the Earth's field)
- The stronger the magnet, the stronger the signal and the faster the rotation
- Magnet field strength is measured in Tesla(T) or Gauss(G) (1T = 10,000G)
- Earth's field = 0.6 Gauss
- 1.5T magnet is 30x stronger than the earth magnetic field

MRI basics

- MRI uses a magnet and radio-wave pulses to create cross-sectional pictures between external magnetic fields and tissues within the patient
- MRI is an intensity based study vs CT scan which is density (hyperintense vs hyperdense lesion, respectively)
  - **Hyperintense = increased signal = white**
  - **Hypointense = decreased signal = black**
    - **In CT we talk about density or attenuation**

MRI - advantages

- Provides multiple brain views easily without moving the patient, including axial, sagittal, and coronal
- Quick detection of ischemic changes w/in minutes (diffusion-weighted MRI sequence)
- MRI is more sensitive for parenchymal lesions, including infarcts & older blood
- Superior visualization of posterior fossa (esp. brainstem) and inferior temporal lobes

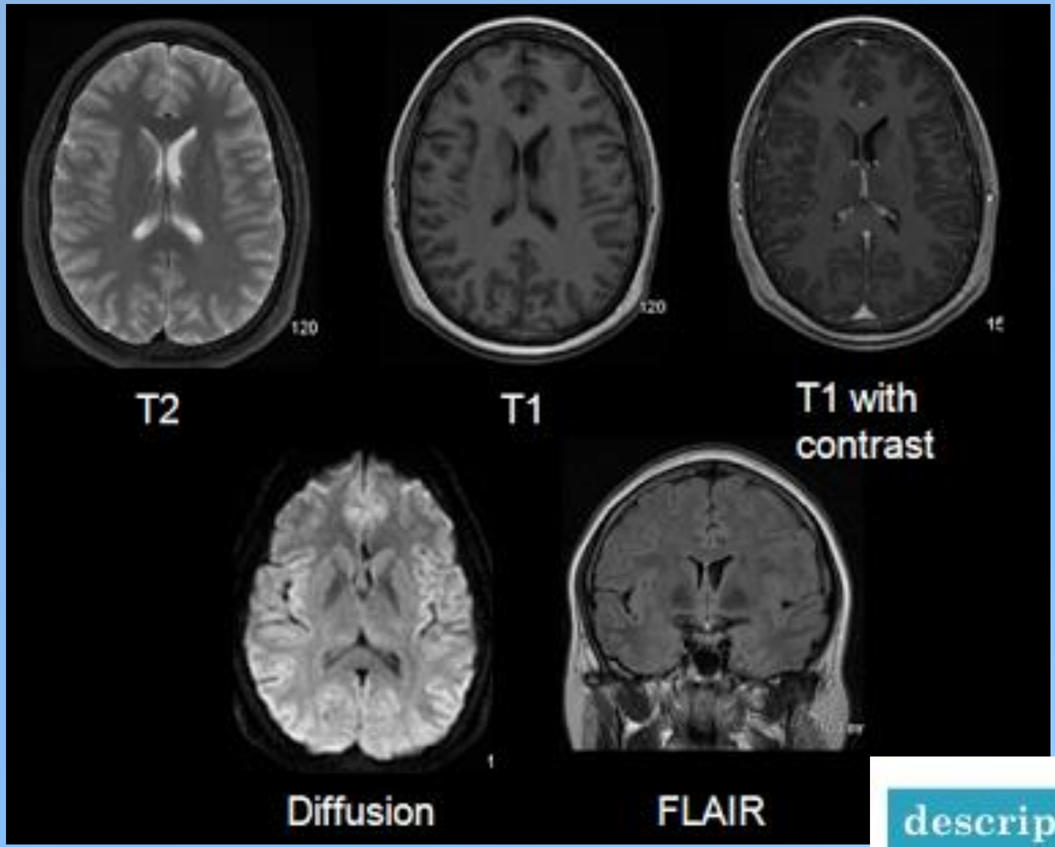
MRI -disadvantages

- Claustrophobia limitations – option open MRI (less sensitivity)
- Difficult for the very young to be still for imaging may require sedation
- Weight limitations
- Critical patients on multiple infusions
- Slower, less accessible
- Fair bone imaging
- Presence of metallic objects (pacemaker, prosthetic heart valves, aneurysm clips, TENS units, hearing aids/cochlear implants)

MRI sequences

- T1
- T2
- FLAIR – fluid attenuation inversion recovery
- GRE – gradient echo
- SWI – susceptibility weight imaging
- DWI – diffusion weight imaging
- ADC – apparent diffusion coefficient
- STIR – short tau inversion recovery
- FIESTA – Fast imaging employing steady state acquisition
- MP-RAGE – Magnetization Prepared Rapid Gradient Echo Imaging

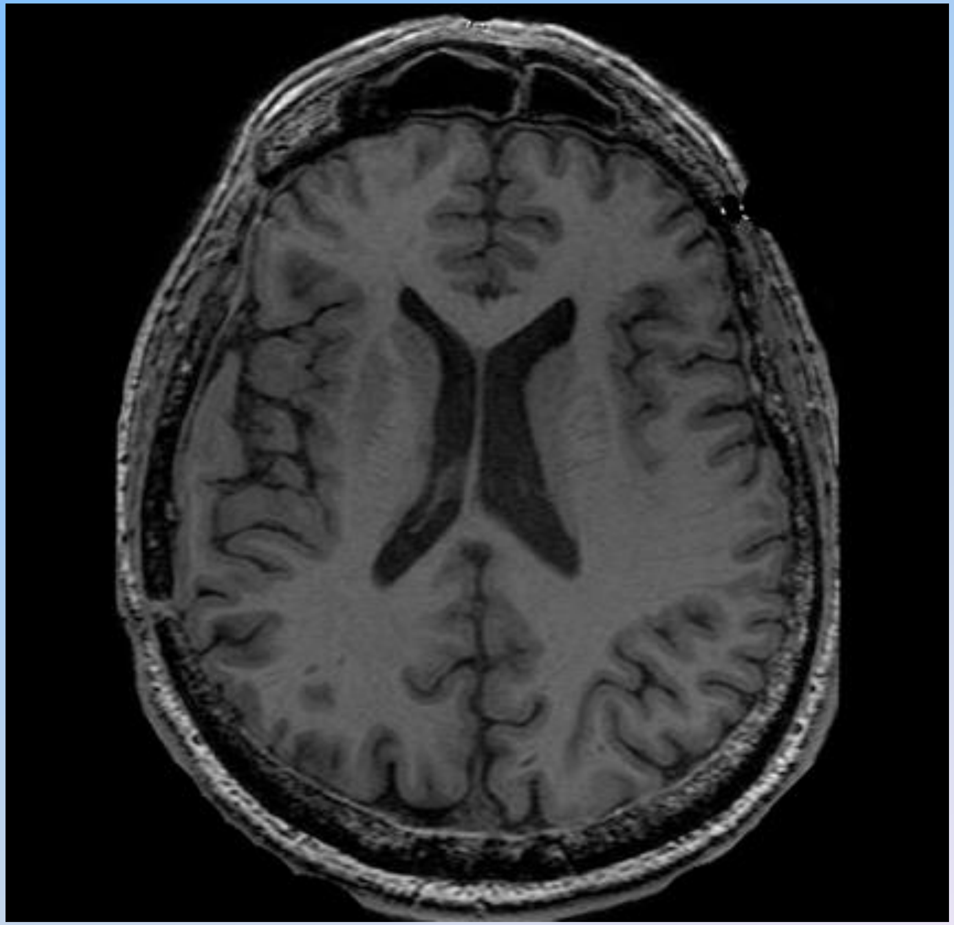
MRI Sequences

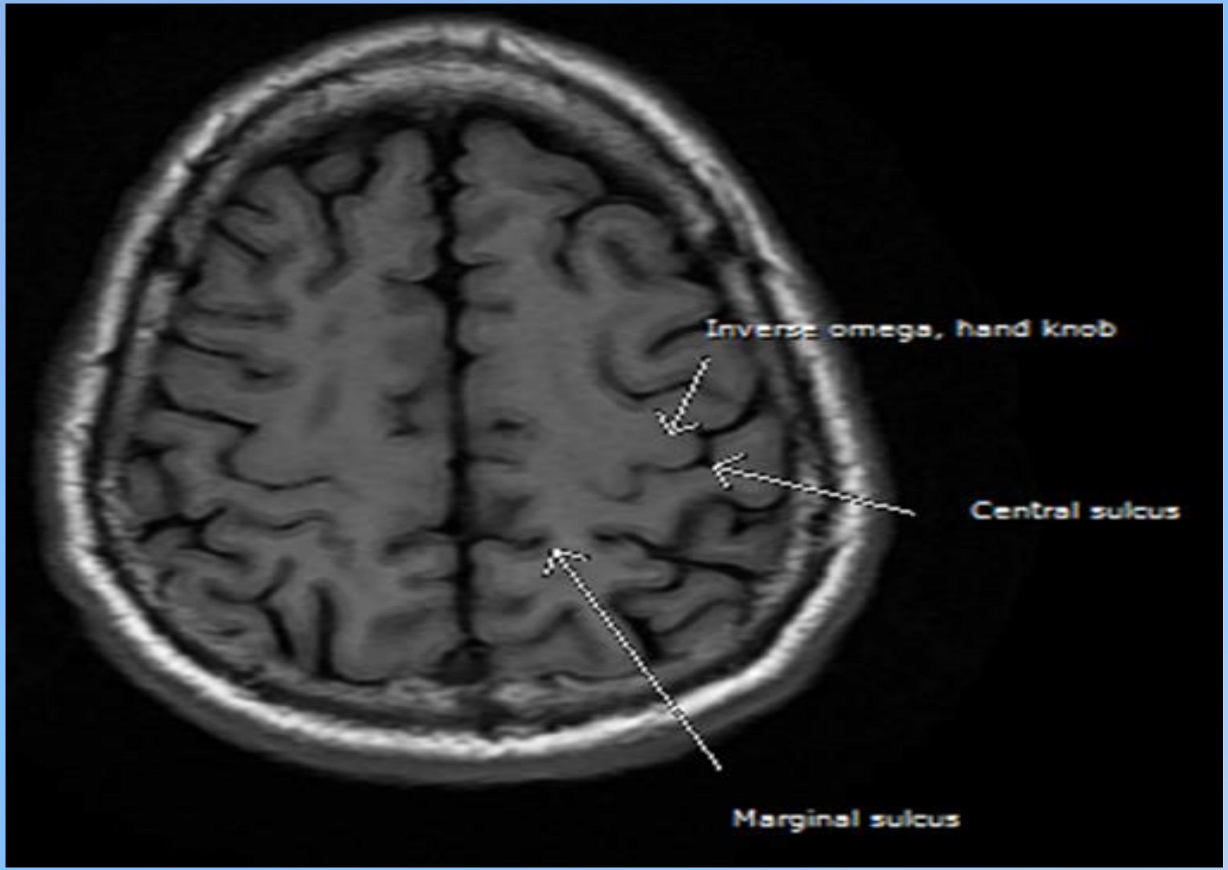


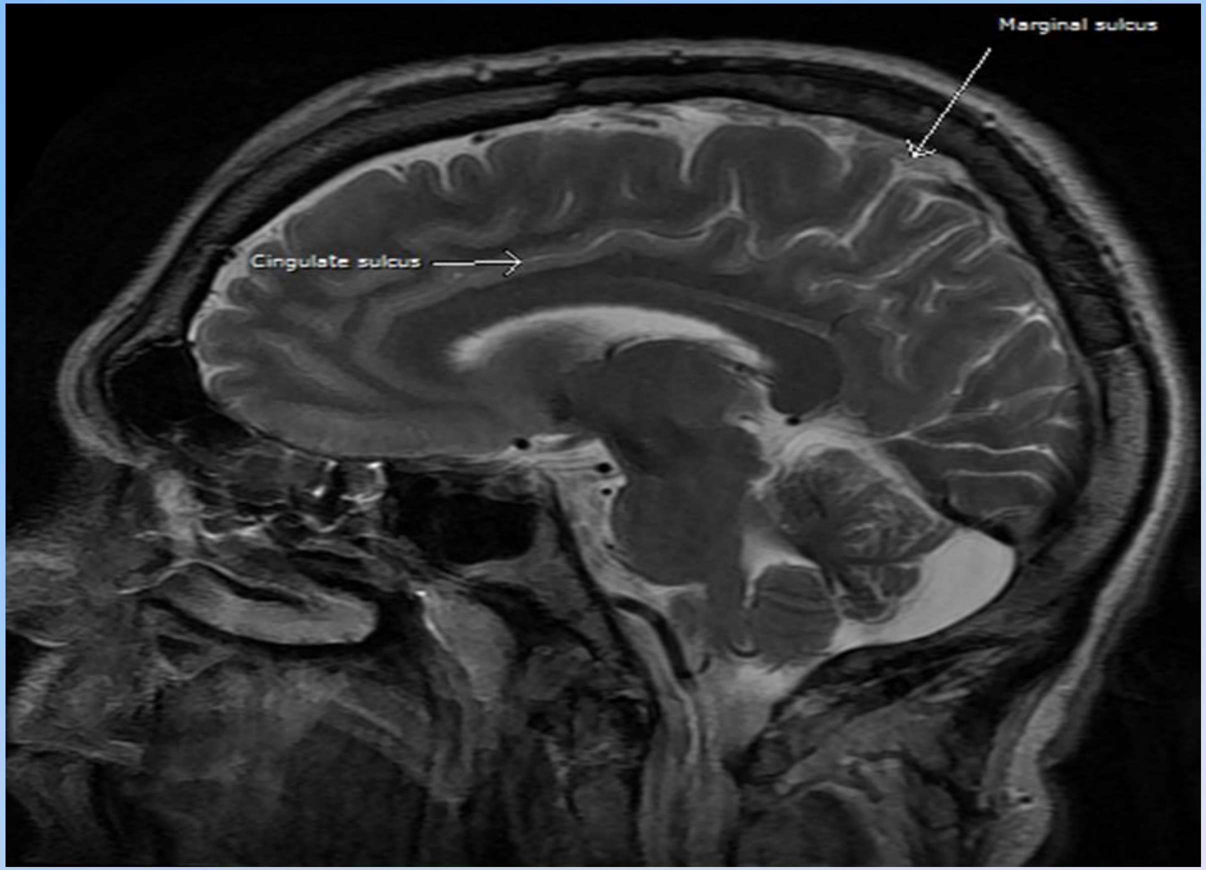
description	T1	T2	FLAIR	DWI	ADC
White matter	high	low	intermediate	low	low
Grey matter	intermediate	intermediate	high	intermediate	intermediate
CSF	low	high	low	low	high

T1-Good for anatomy evaluation

- Dark-CSF, edema, water, acute infarction, gliosis
- Bright- fat, metals,
- Lesions poorly seen without IV contrast (gadolinium)
- Best used for pre- & post-gadolinium comparisons
- Ca++ & bone black

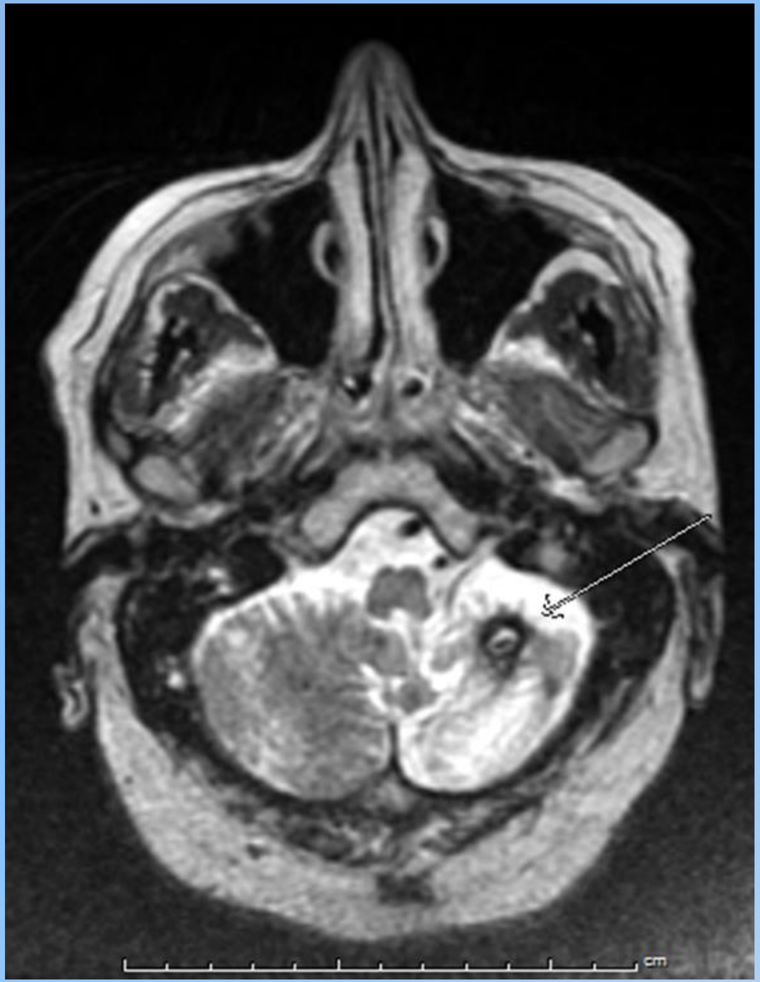


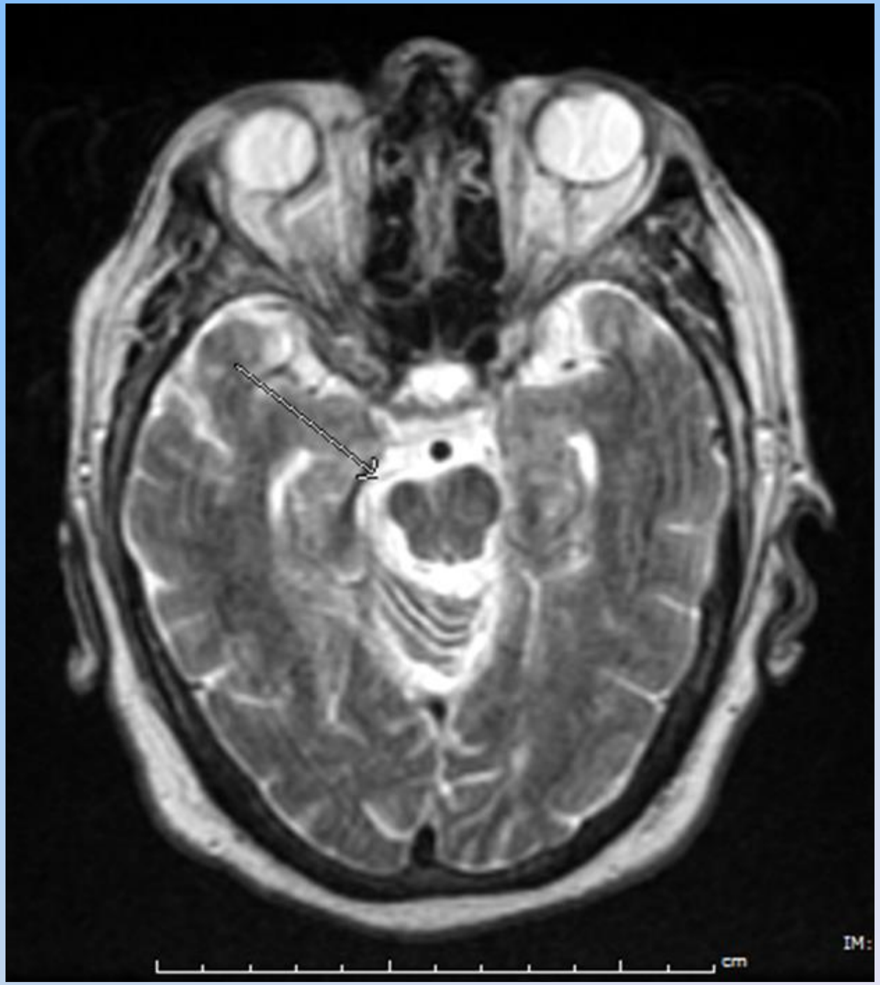




Central sulcus localization

63 y/o Man with AVM s/p gamma knife in left cerebellum.

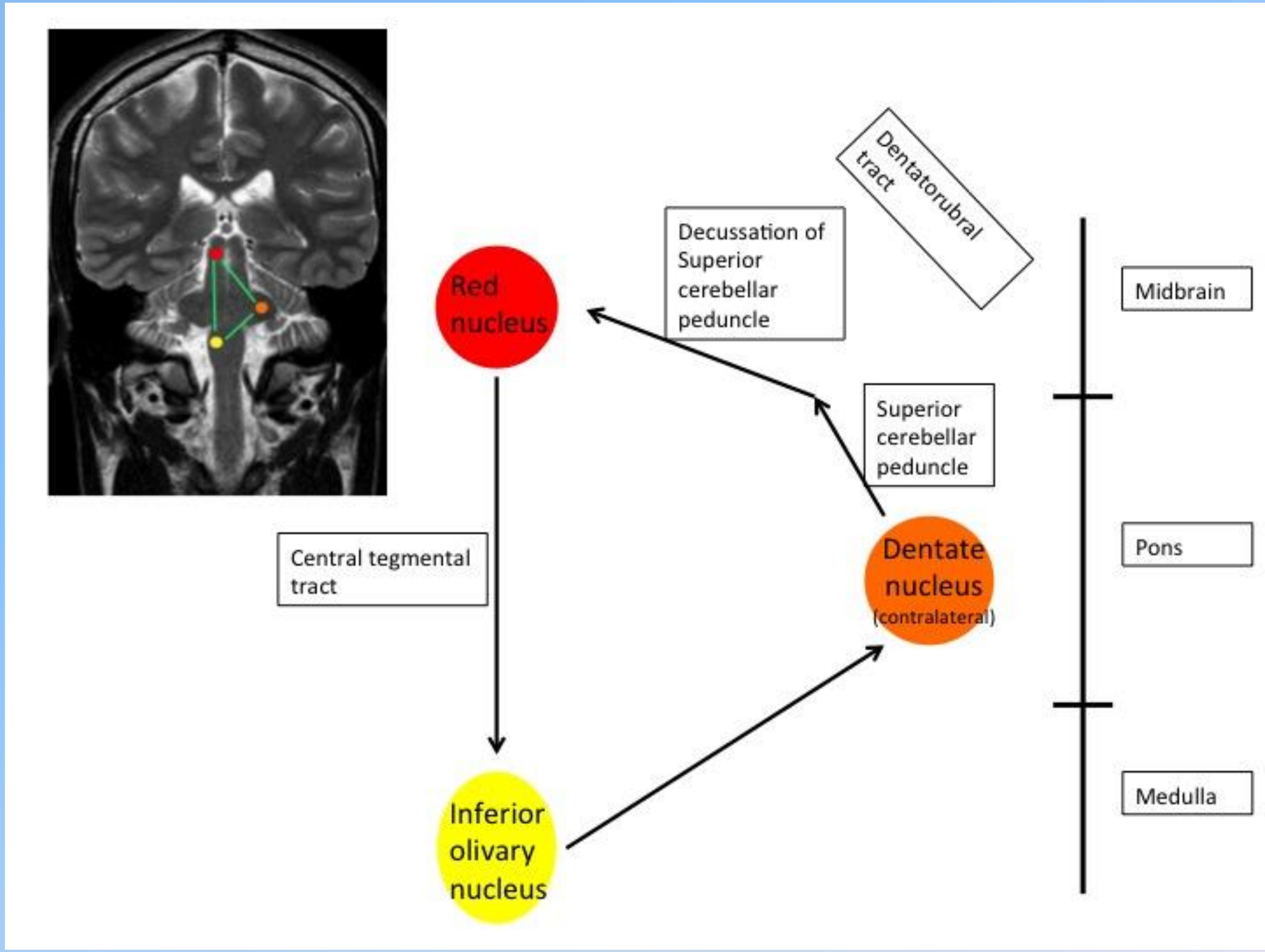




Neuroanatomy question

There is any relation between the two abnormalities???

Guillain Mollarte triangle – palatal myoclonus

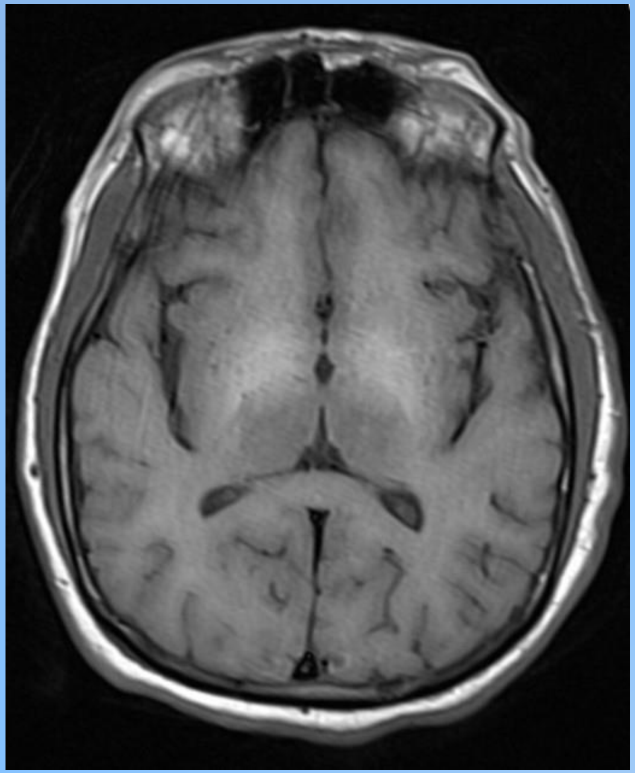


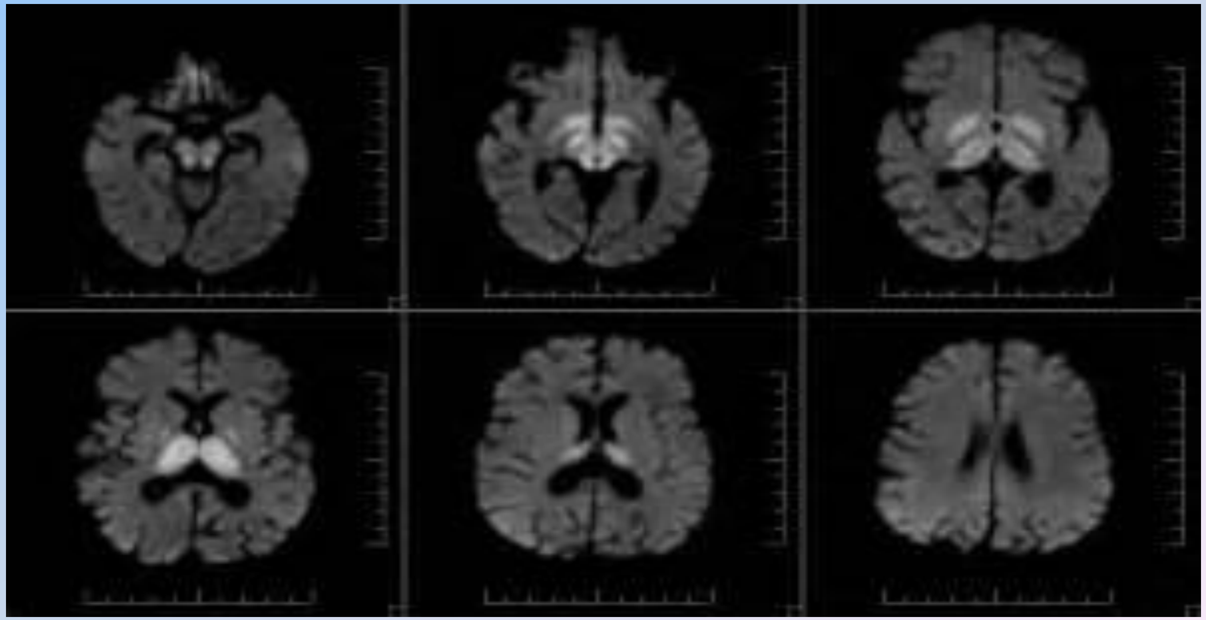
T1 Hyperintensity – Diff Dx

- Fat (Lipoma, dermoid)
- Manganese
- Melanin
- Subacute blood
  - (Methemoglobin intra or extracelular)
- High Proteins structure
  - (colloid cyst, craniopharyngioma, laminar necrosis)
- Iron
- Copper
- Gadolinium
- Calcium - Low grade of mineralization
- Slow flow blood

AED effects

- **Valproic acid**
  - Hyperammonemic encephalopathy (manganese)
    - T1 hyperintense basal ganglia
  - Pseudoatrophy
    - Widened sulci that reverse after withdrawal AED





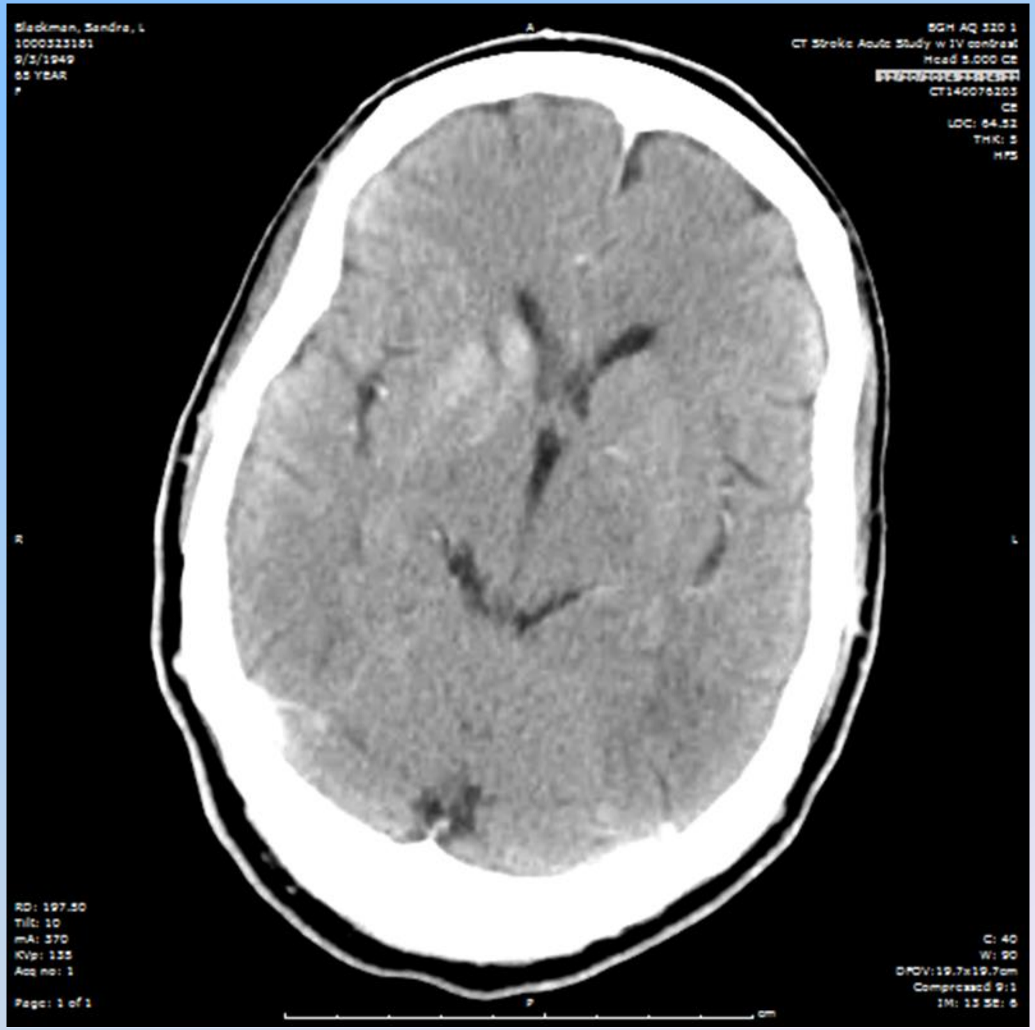
Vigabatrin

Bilateral symmetric lesions in thalami, midbrain, GP and dentate in asymptomatic patients

History

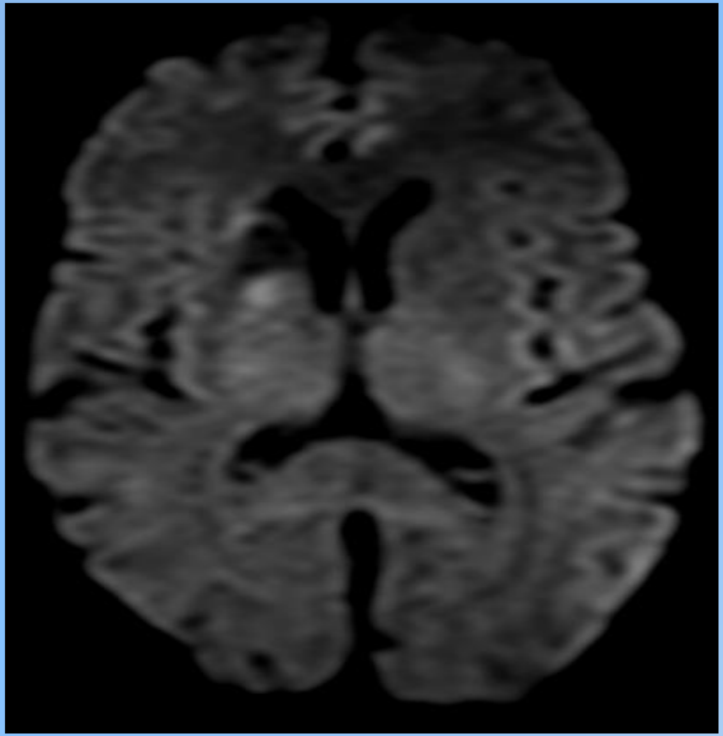
- 65 y/o woman with acute left arm hemiballismus.

- Blood glucose levels 300-400 mg/dL

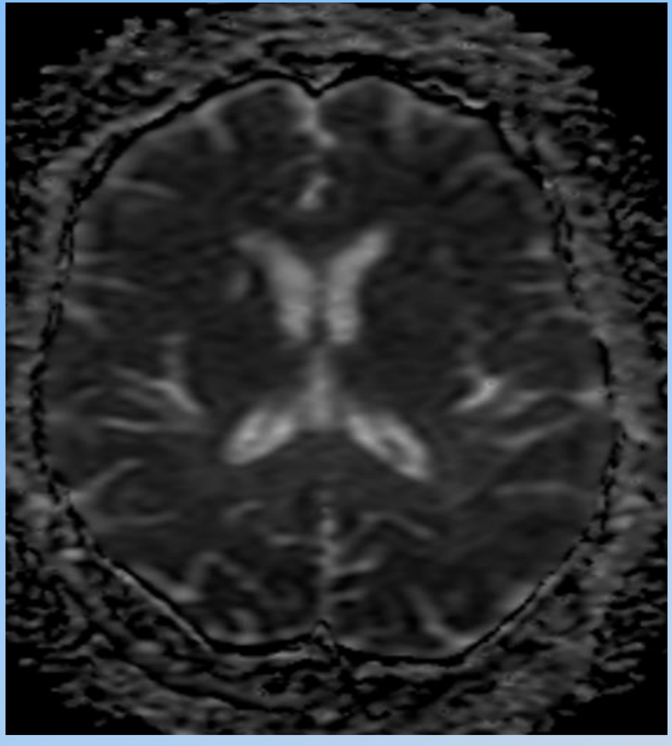


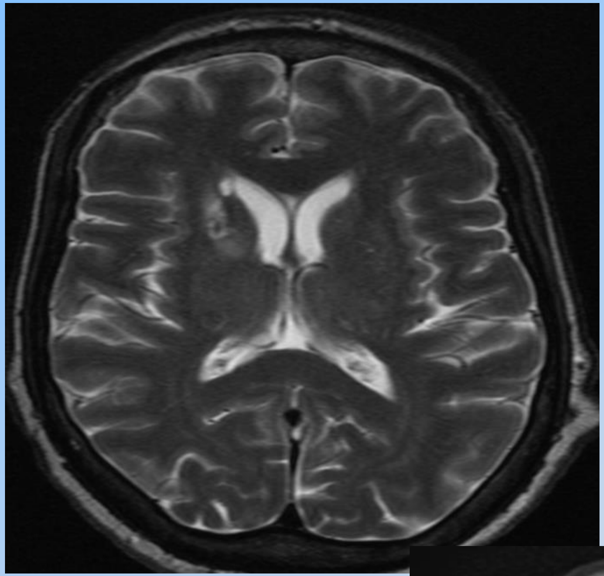
No restricted diffusion– rule out infarct

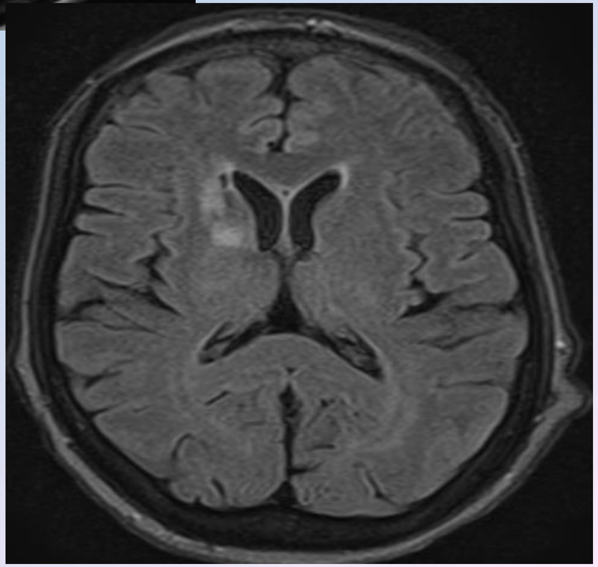
DWI



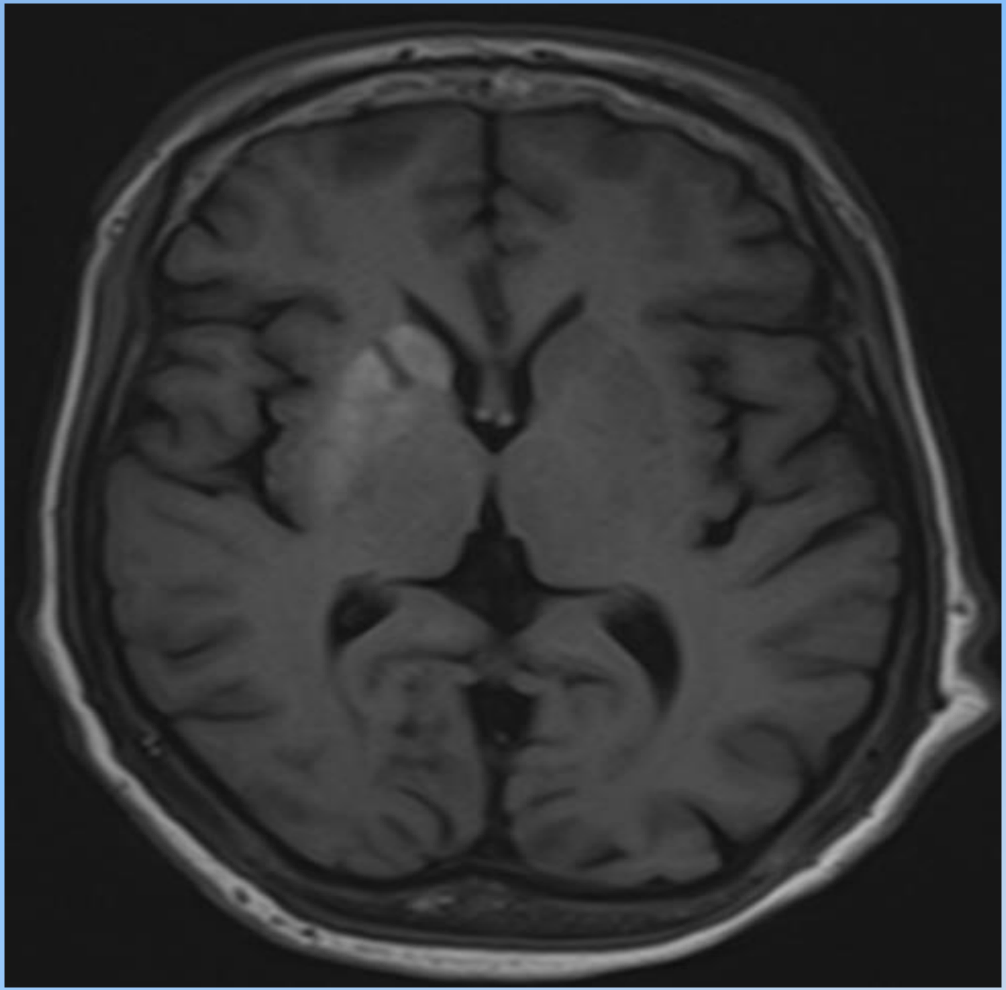
ADC

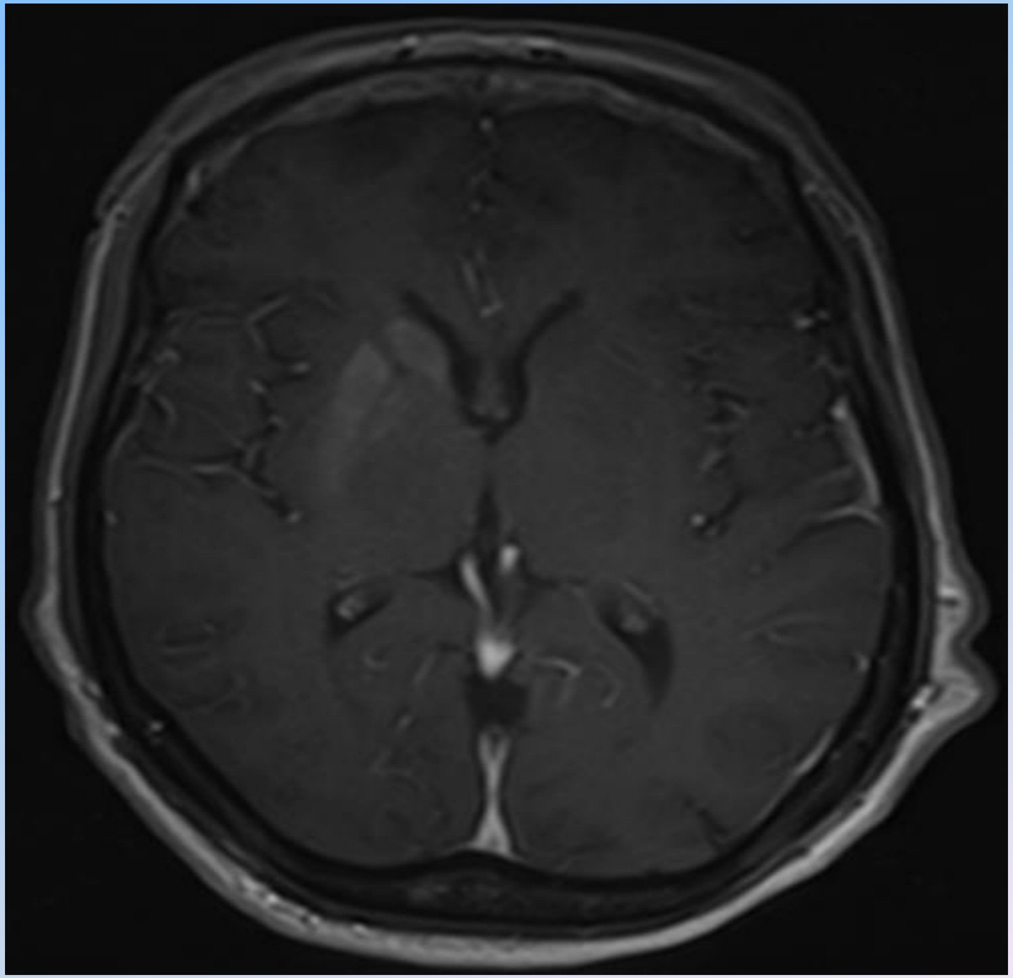






T1 w/o gado – Hyperintensity in T1 is 2ry to proteins in the cytoplasm of astrocytes



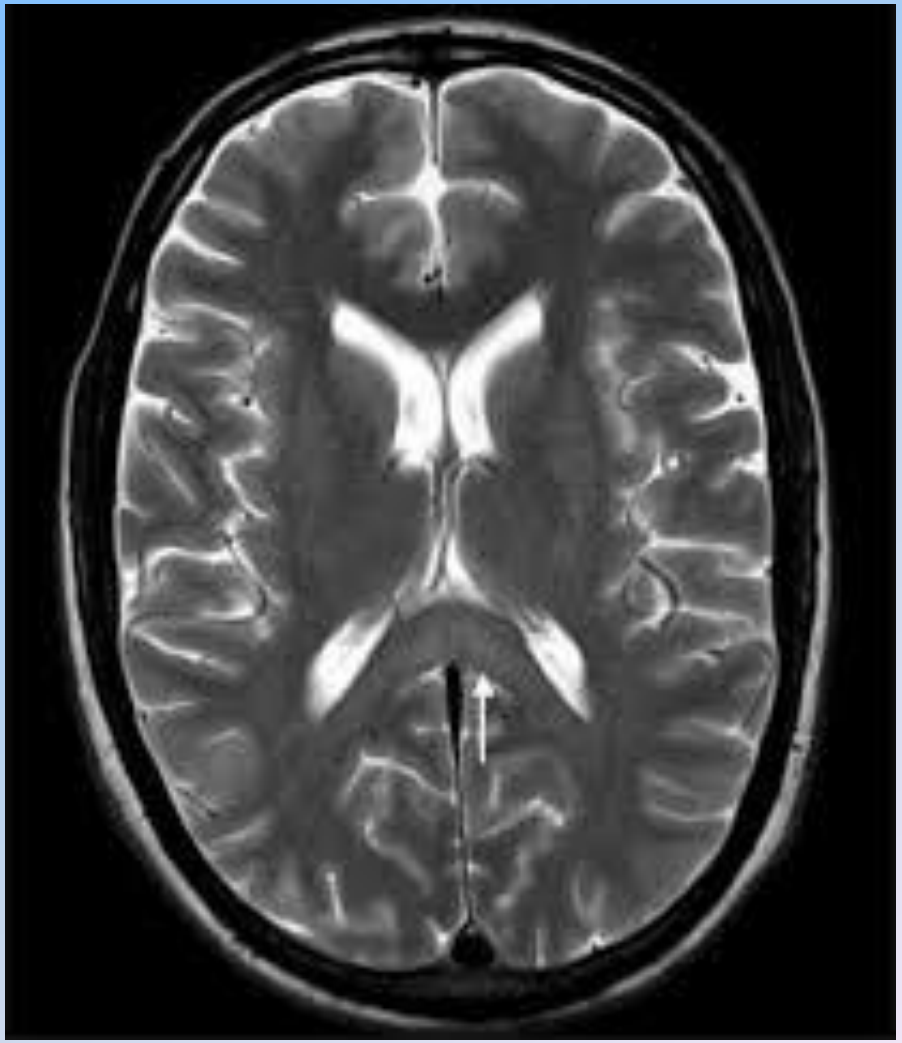


Dx Non-ketotic hyperglycemia

- 2nd most common cause of hemichorea/hemiballismus after CVA
- Unilateral BN (caudate and putamen) hyperdensity and T1 hyperintensity almost pathognomonic
  - Rarely present bilateral T1 hyperintensity
  - contralateral to patient's symptoms.
  - NO abnormalities in SWI (R/O mineralization or blood)
  - T2/FLAIR slighlty hypo-isointense
  - Mild restricted diffusion
  - No enhancement
- Hemiballismus improved with insulin administration and glucose normalization
- Diff dx of T1 hyperintensity
  - Manganese, Wilson, hypoparathyroidism, Fahr's, Lupus, Chronic Liver

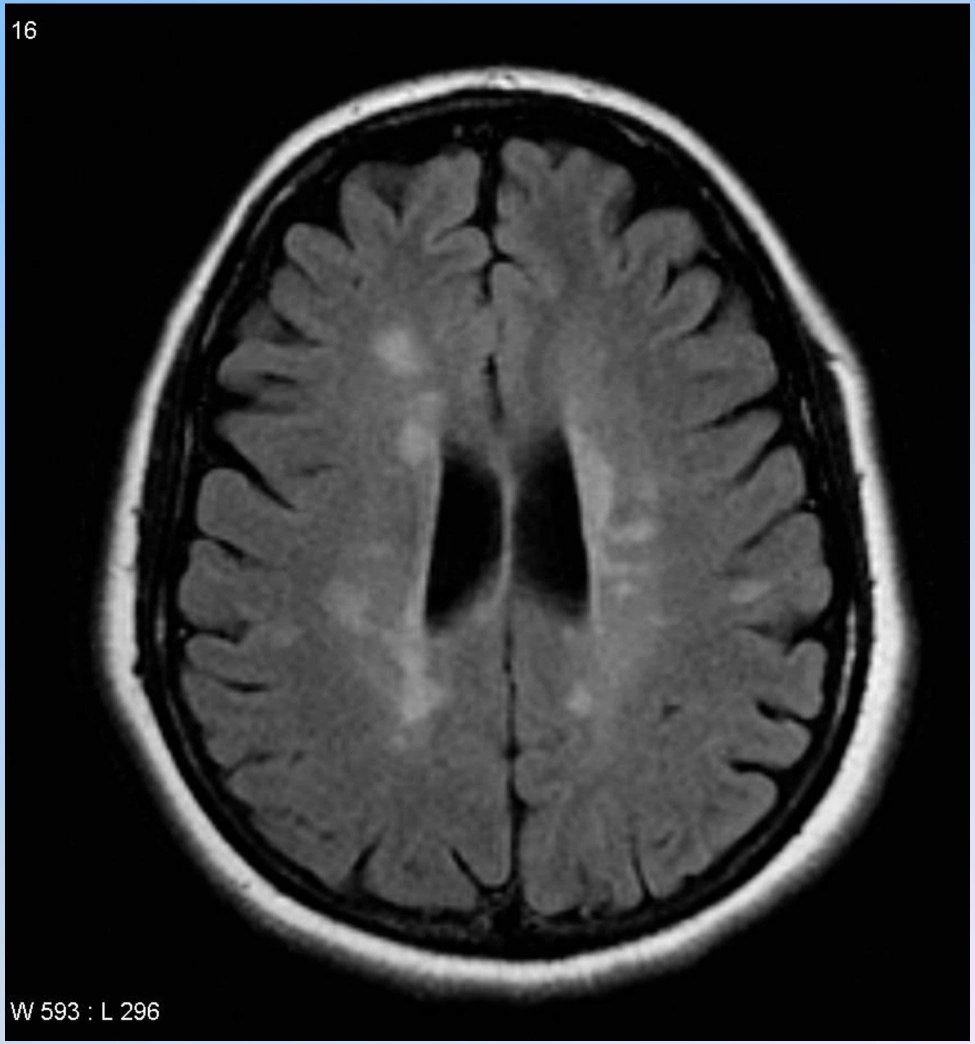
T2-good for pathology

- CSF is white
- Lesions are white
  - Edema
  - Water
  - Acute infarction
  - Gliosis
- Lesions <u>very well</u> seen, but…
  - May be difficult to distinguish lesion and CSF
  - Does not visualize very new infarctions



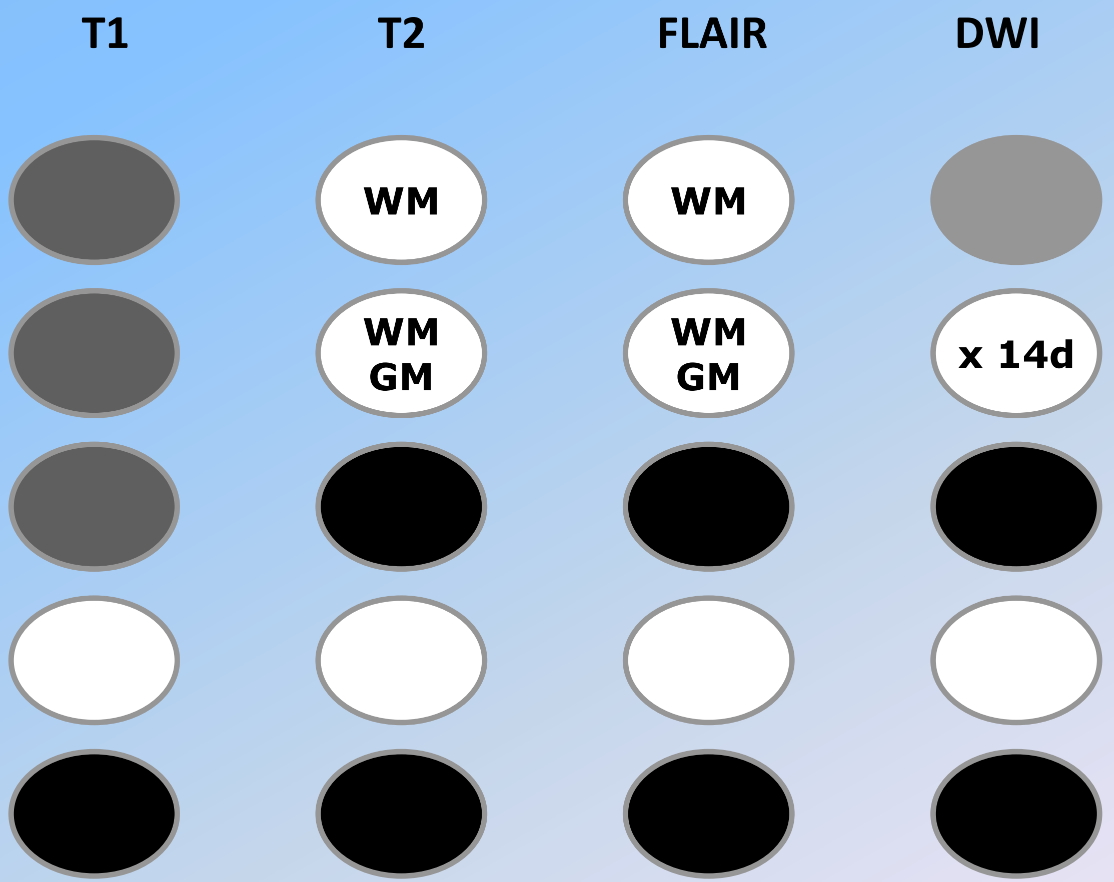
FLAIR *(Fluid-attenuated inversion recovery)- basically like T2 but CSF is dark*

- T2-weighted image with standing water turned black, therefore:
  - CSF & old lacunes black
- Lesions are white
  - Edema
  - Acute infarction
  - Gliosis



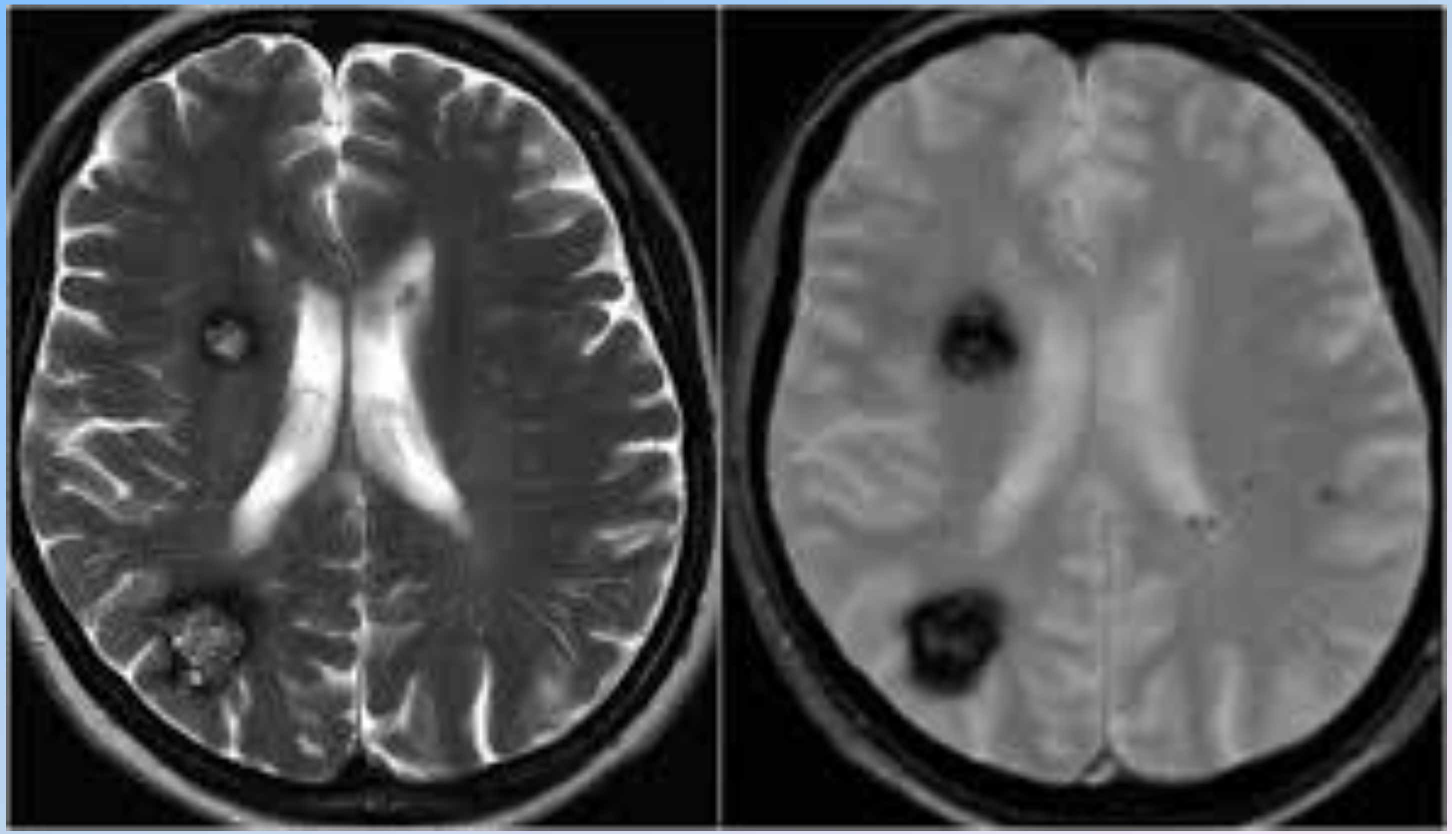
VISUALIZING PARENCYMAL EDEMA & BLOOD ON DIFFERENT MRI SEQUENCES

- VASOGENIC EDEMA
- CYTOTOXIC EDEMA
- ACUTE HEME *(deoxyHb)*
- SUBACUTE HEME *(metHb)*
- CHRONIC HEME *(hemosiderin)*



GRE-Gradient Echo and SWI

- Good for looking at brain tissue
  - Blood
  - Mineralization
    - Iron, Ca^{2+}, Manganese
- Appears hypointense
- Evaluate susceptibility artifact
- SWI is 7 x stronger than GRE



Appearance of intracerebral hemorrhage on non-contrast CT and MRI by stages

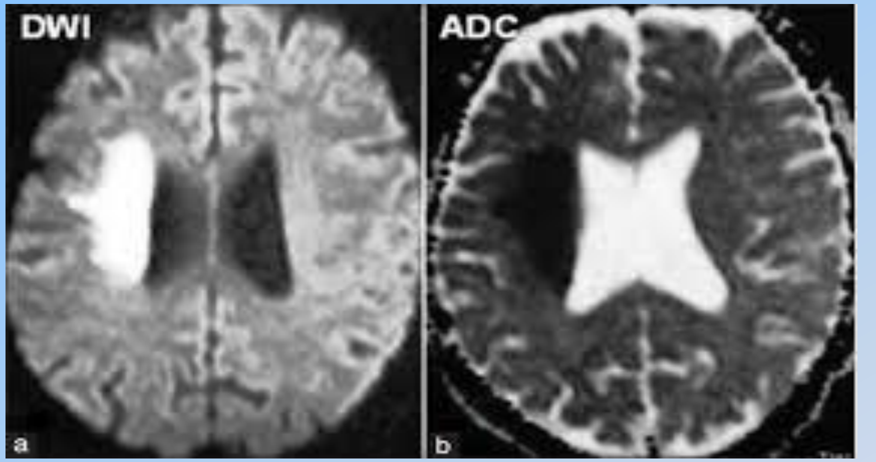
Table 2. Appearance of Intracerebral Hemorrhage on Noncontrast CT (NCCT) and MR by Stage[9]

	Phase of Blood	NCCT	T1-Weighted MR	T2-Weighted MR	T2*-Weighted MR
Hyperacute	Oxyhemoglobin	Smooth, hyperdense	Hypointense or isointense	Hyperintense	Marked hypointensity
Acute (12–48 h)	Deoxyhemoglobin	Hyperdense with fluid levels	Isointensity or slight hypointensity with thin hyperintense rim in the periphery	Hypointense with hyperintense perilesional rim	Marked hypointensity
Early subacute (72 h)	Methemoglobin intracellular	Hypodense region of edema with mass effect	Hyperintensity	Hypointensity	Hypointensity
Late subacute (3–20 d)	Methemoglobin extracellular	Less intense with ring-like profile	Hyperintensity	Hyperintensity	Hypointensity
Chronic (9 wk)	Hemosiderin and ferritin	Isodense or modest confined hypodensity	Hypointensity	Hypointensity	Hyperintense or isointense core surrounded by hypointense rim

Downloaded from http://stroke.ahajournals.org/ by guest on July 27, 2015

Care w DWI to interpret bleed – restricted or increased diffusion could be seen with bleed

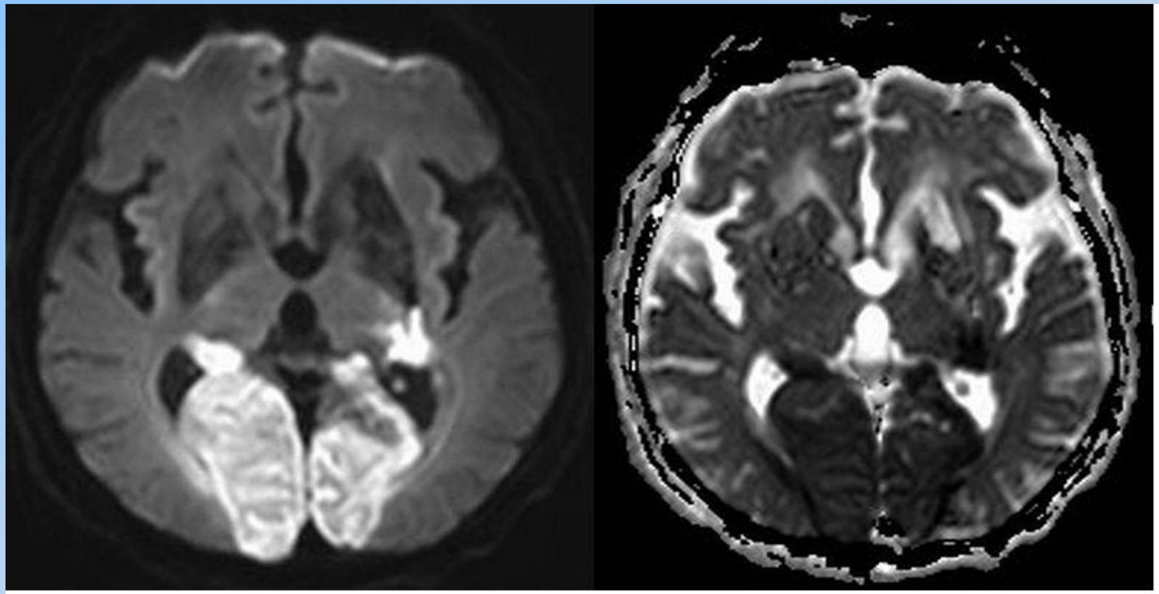
DWI- diffusion weighted imaging



- Dark-CSF
- Bright-cytotoxic edema, necrosis, abscess
- Ischemic lesions
  - New infarctions are white 30 min to few weeks
  - Old lesions not seen
- Compare to T2 or FLAIR to distinguish new & old lesions
- Compare to ADC to ensure infarction is real
  - *DWI may show lesions due to other conditions such as seizure or "T2-shine-through" phenomenon*

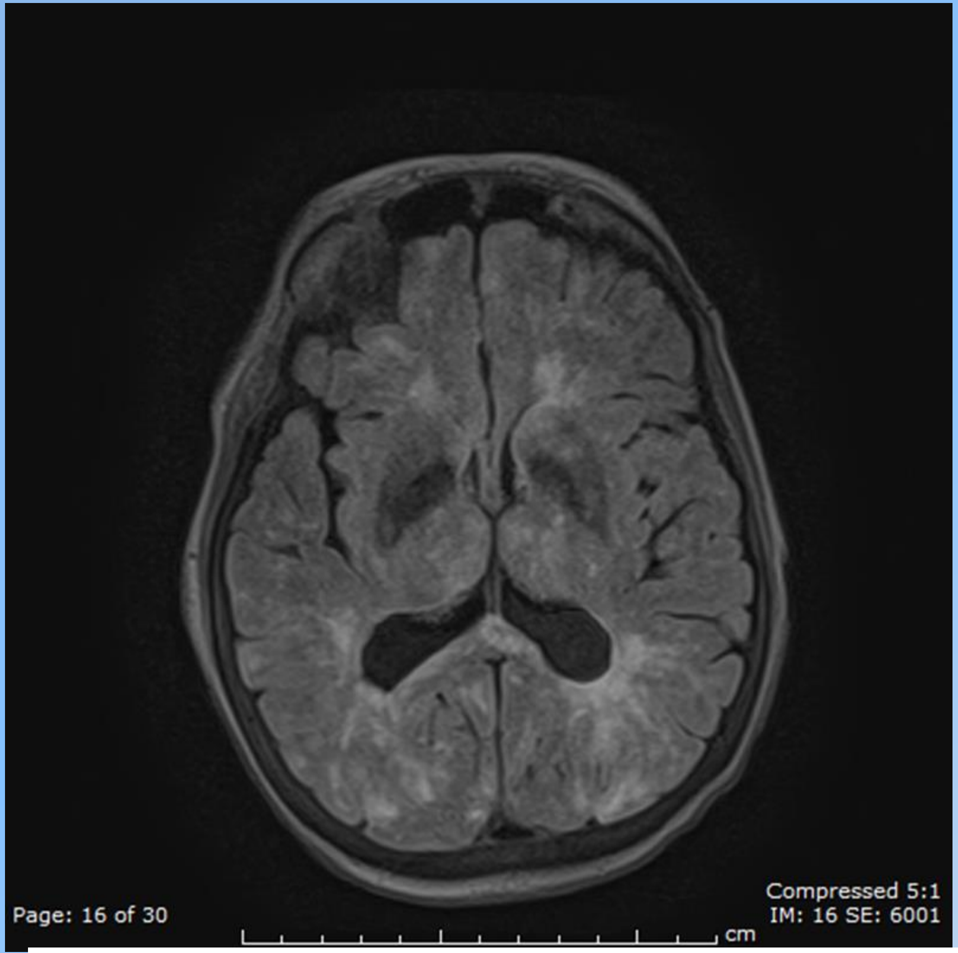
ADC-Apparent diffusion coefficient

- Bright-CSF, gliosis
- Dark-Infarcts
  - New infarctions are black, confirm that white DWI lesion is truly infarction
- Hemorrhage may also be black, so must compare to other MR images



(a) DWI (b) ADC

68 woman with recent hip surgery



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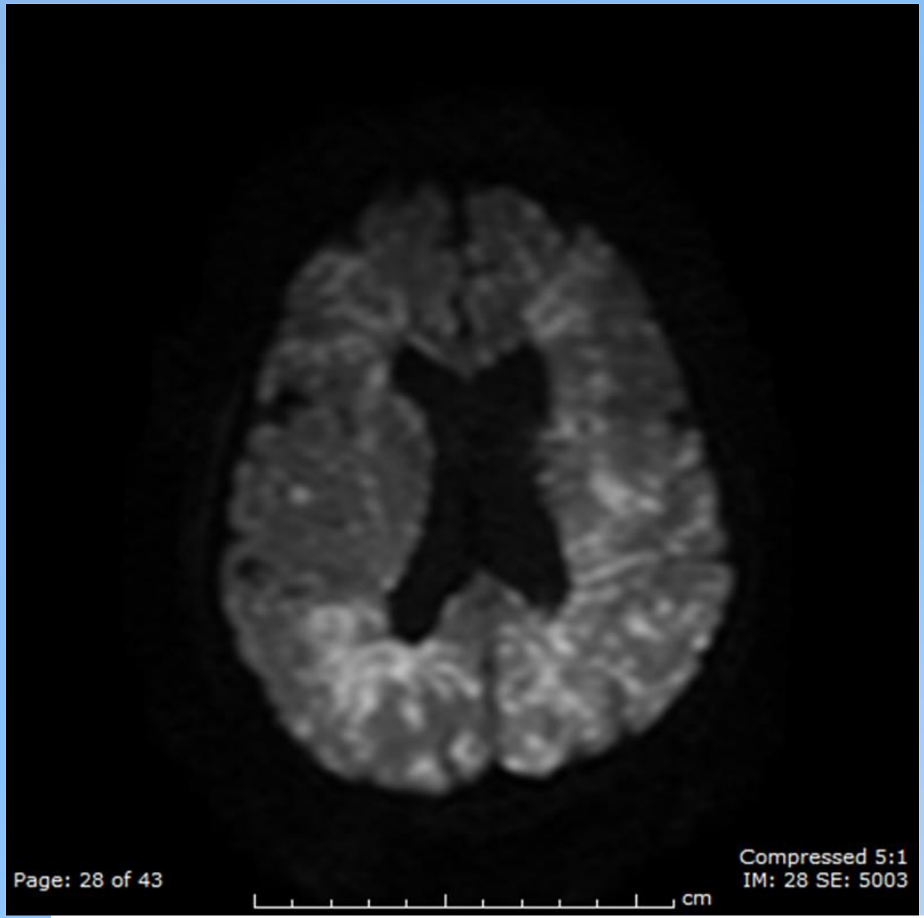
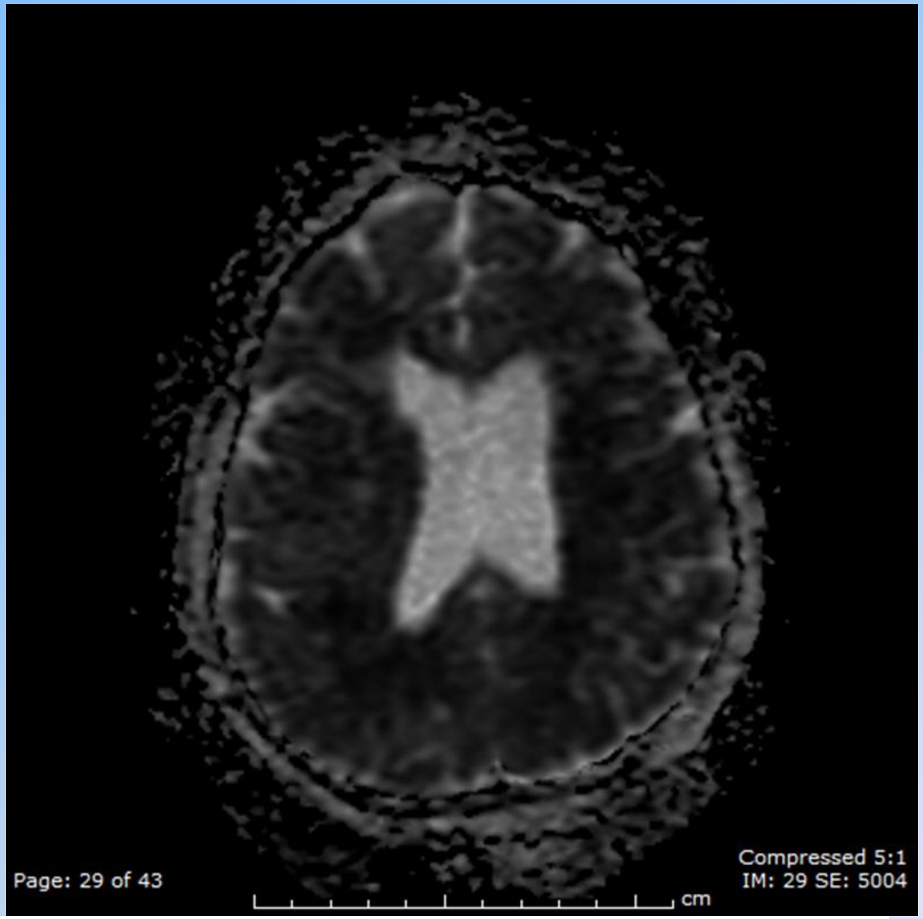
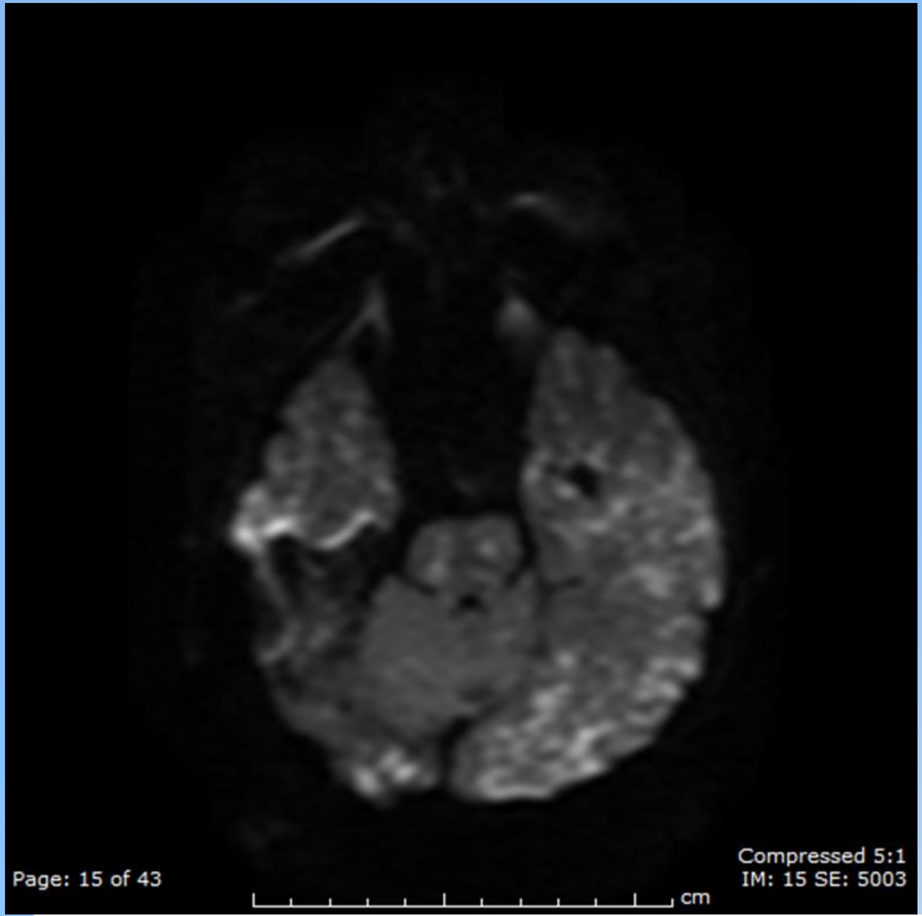
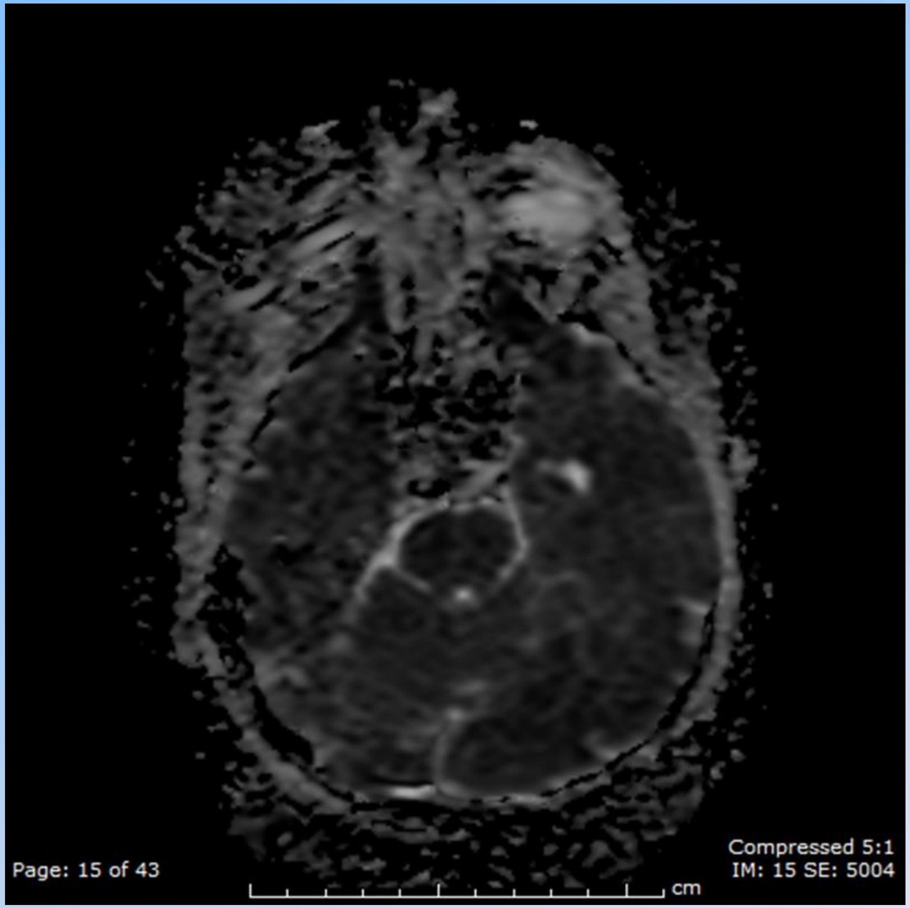




68 woman with recent hip surgery





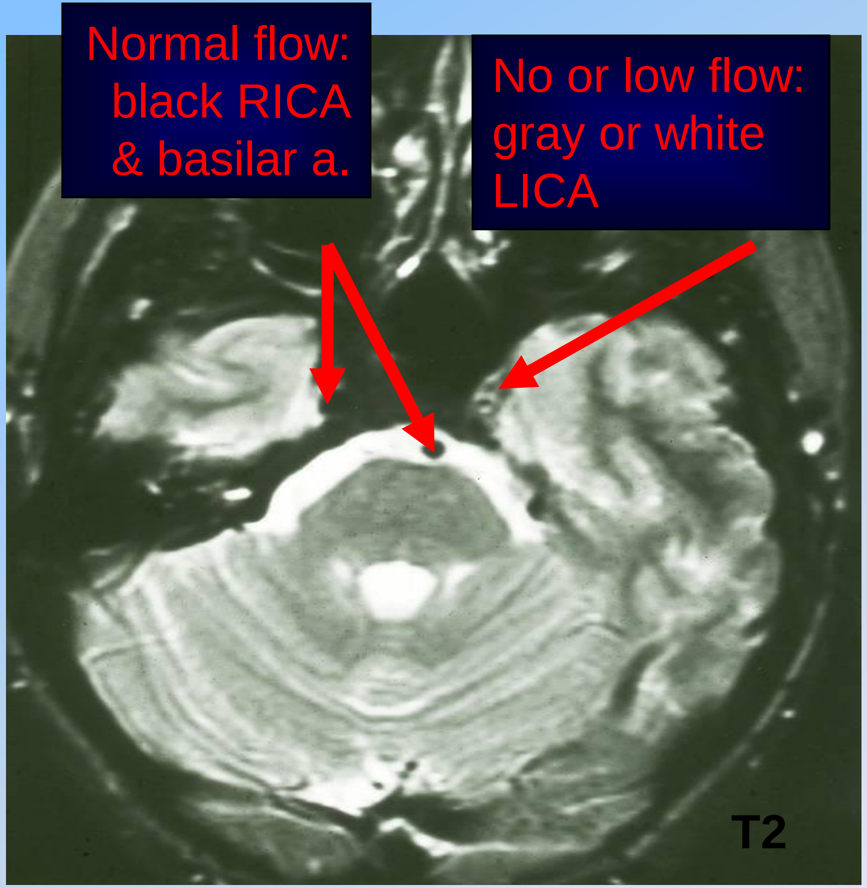
Not only I-CVA has restricted diffusion

Differential diagnosis of lesions that restrict in DWI/ADC

- Acute-subacute ischemic infarct (<10 d)
- Status epilepticus
- Brain abscess
- Epidermoid cyst
- Acute demyelination (MS)
- High cellular tumor: PNET, PCNS lymphoma, meningioma, (GBM????)
- Canavans disease
- Jakob Creutzfeld disease
- Herpes encephalitis
- Severe hypoglycemia
- Cortical spreading depression (migraine)
- Anoxic brain Injury
- Osmotic demyelination (pons)
- Trauma/bleed (affect DWI signal)

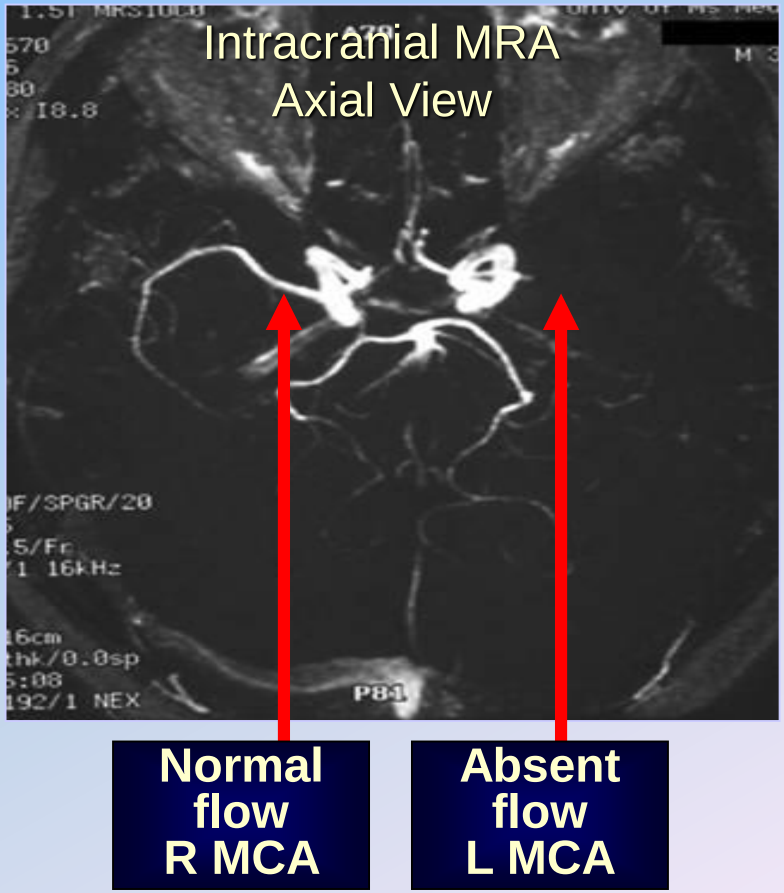
BLOOD FLOW ON MRI

- Spin Echo (SE): T1, T2, FLAIR
  - Normal vessels are black ("flow-void phenomenon")
- Gradient Recall Echo (GRE = GRASS)
  - Normal flow white, no or low flow black
  - GRE images used for magnetic resonance angiography (MRA)



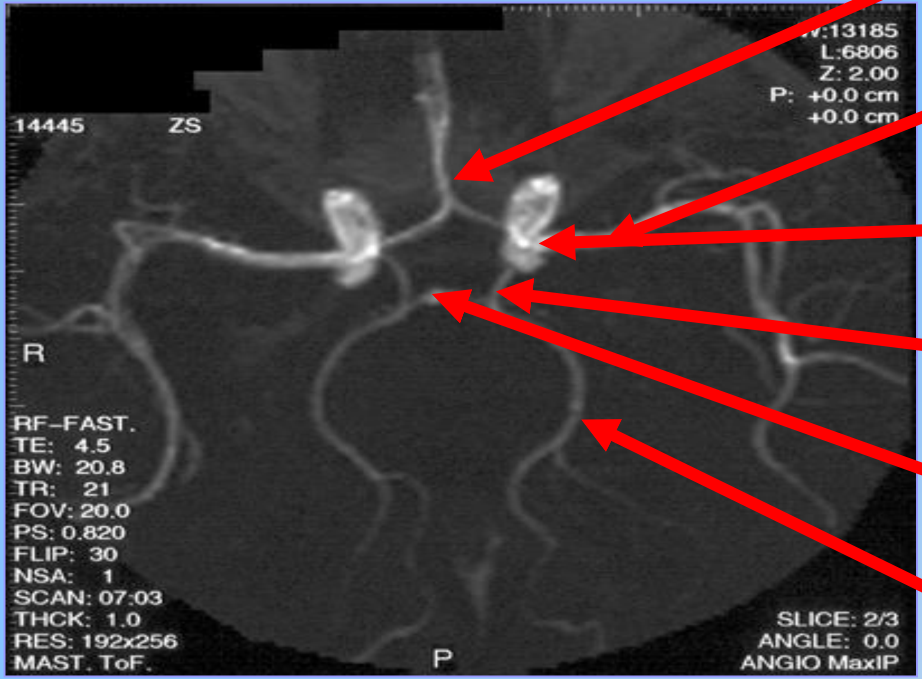
MR ANGIOGRAPHY (MRA) basic

- MRI w/ software change (GR technology)
- Can’t differentiate low flow vs. occlusion
- Can specify veins vs. arteries, anterior circulation vs. posterior circulation
- Normal flow is white
- No or low flow is black
- No need contrast



INTRACRANIAL MRA ANATOMY

Axial view



ACA

MCA

ICA

PCommA

BA

PCA

VA

Coronal view

MR with contrast

- Gadolinium useful for evaluation of
  - Tumors
  - Infection
  - Abscess
  - Demyelination disease processes
  - Infarct

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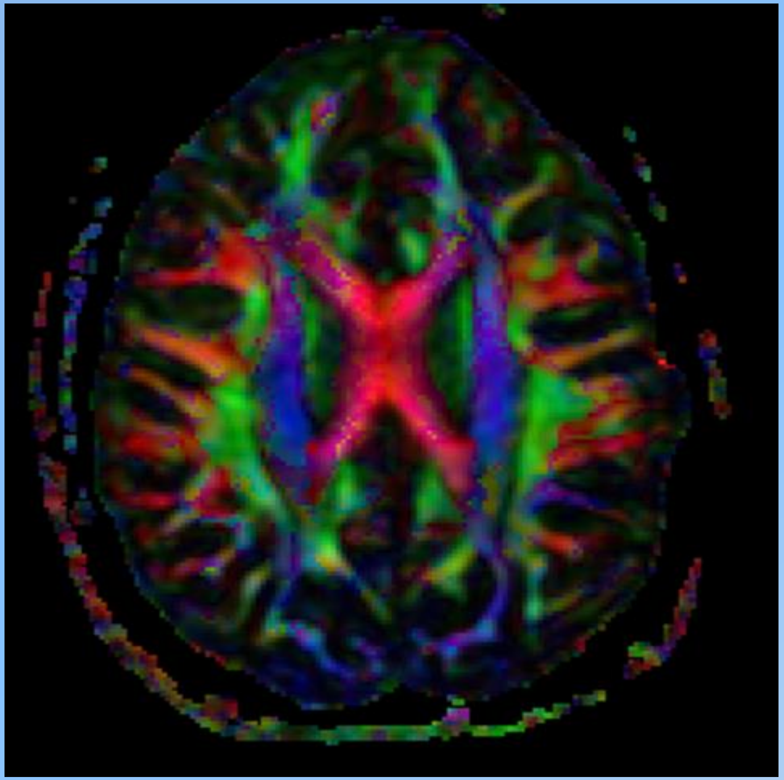
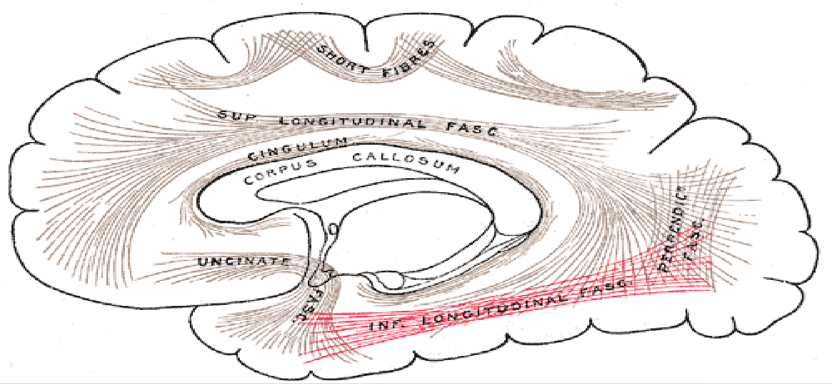
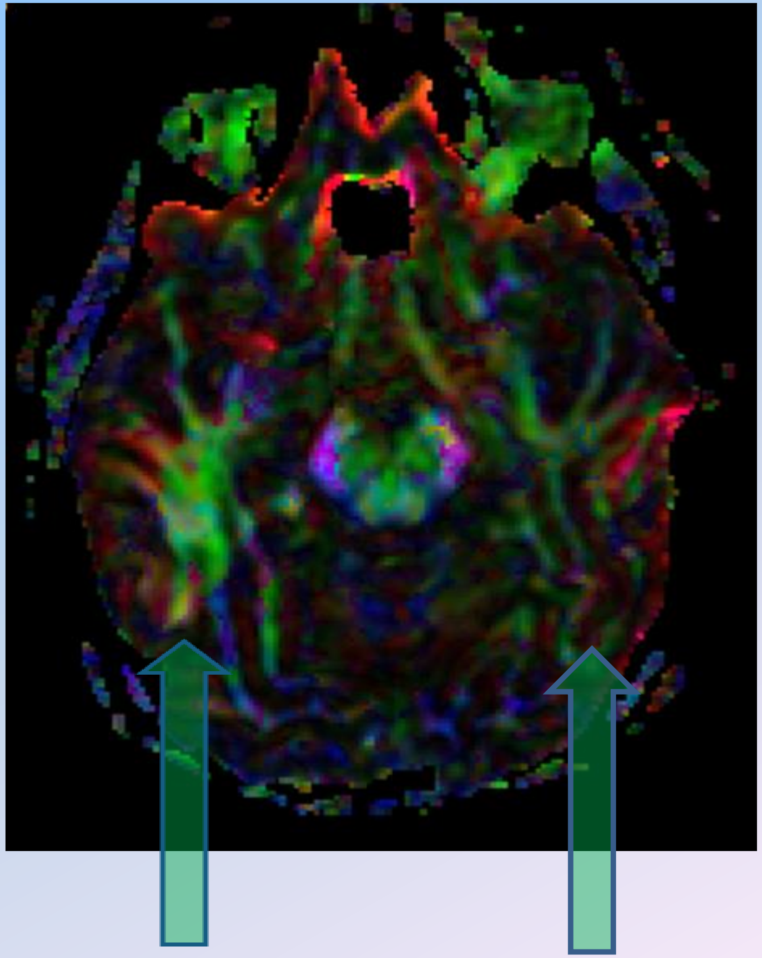
Diffusion Tensor Imaging (DTI)

- Technique that measures anisotropic diffusion and obtains directional information.
  - Anisotropy = molecules does not move the same in all directions
  - Isotropy = molecules move the same in all directions
- Molecules are more likely to diffuse in the direction of axons rather than perpendicular to it.
- Requires image acquisition in at least 6 planes rather than the 3 planes in DWI.
- Tractography = anatomical study that delineate the fibers connection using the technique of DTI.

18 F with (L) MTS s/p amygdalohippocampectomy





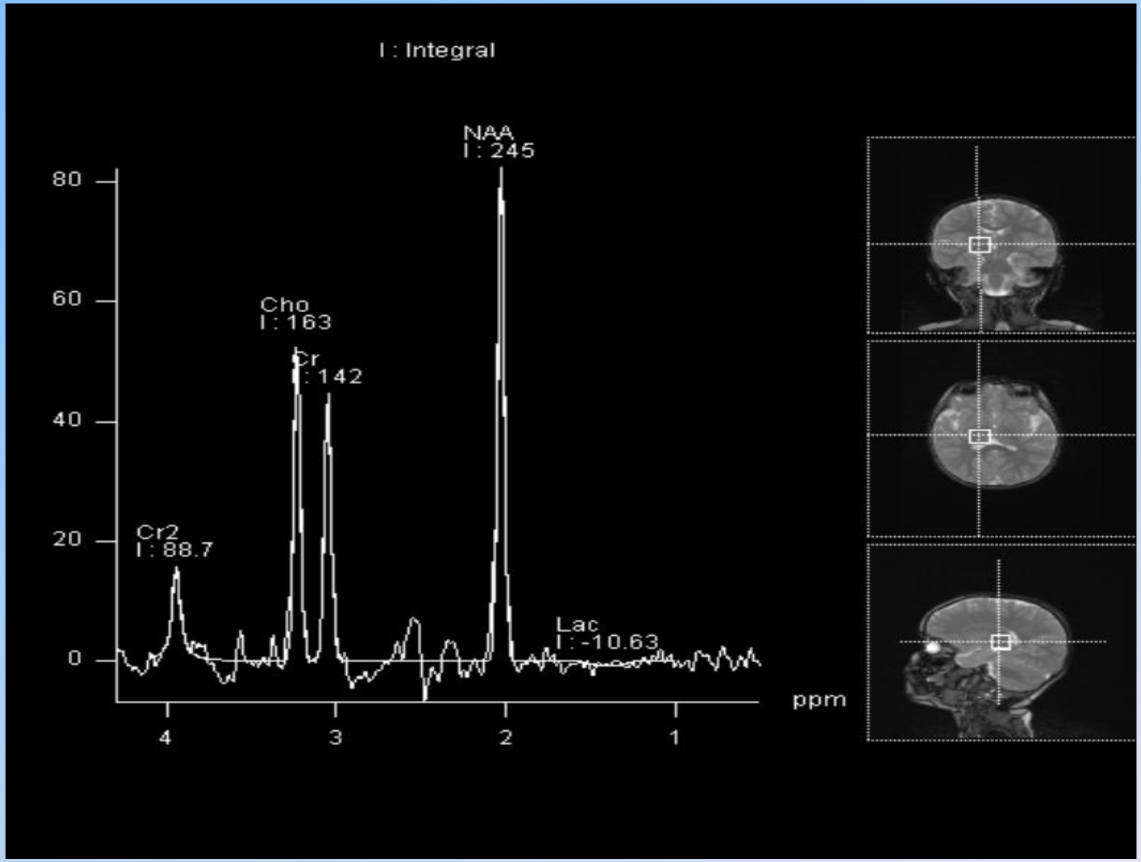


Blue: rostro-caudal tracts
Red: commisural tracts
Green: AP tracts

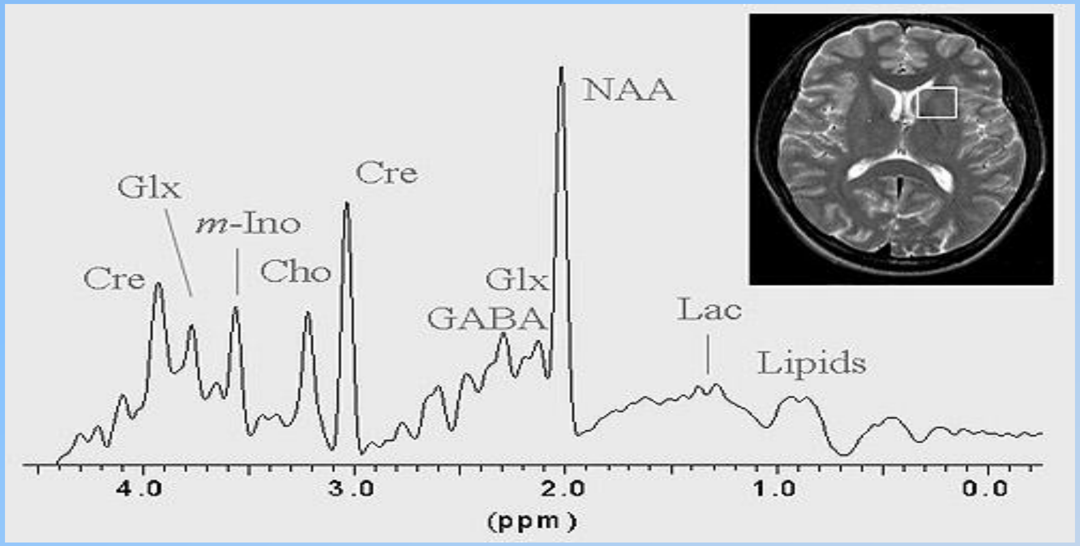
MRS - Spectroscopy

Hunter's angle = 45°

- Measures molecular composition within a voxel
- NAA – neuronal integrity
- Choline – membrane turnover
- Creatine – energy metabolism
- Myoinositol – glial composition
- Lactate – appears in inflammation, infarct



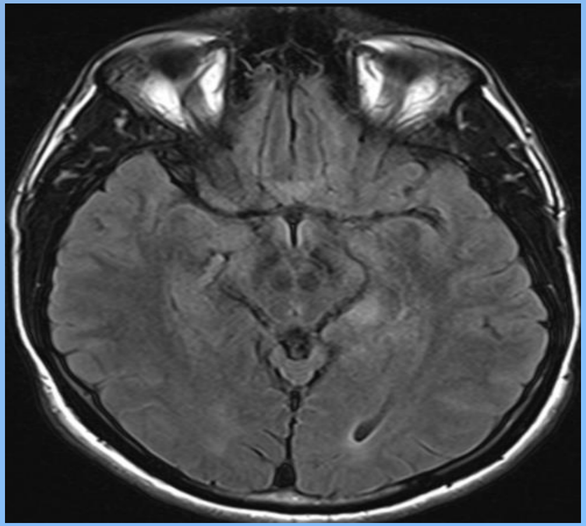
MRS in MTS

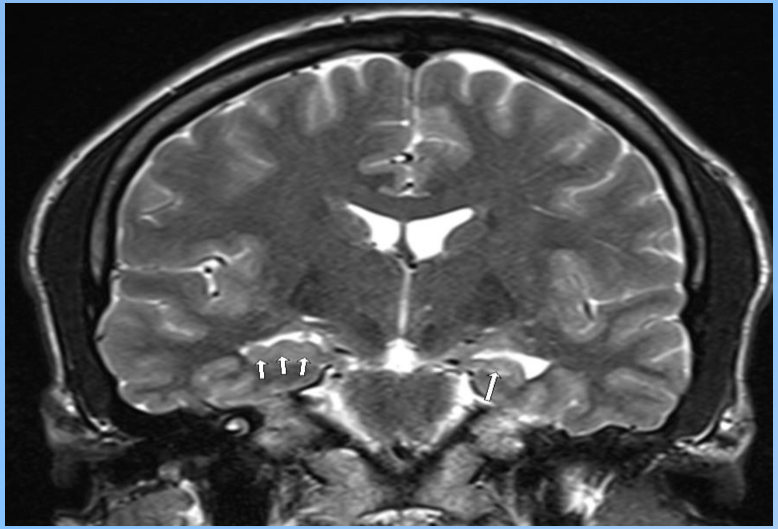


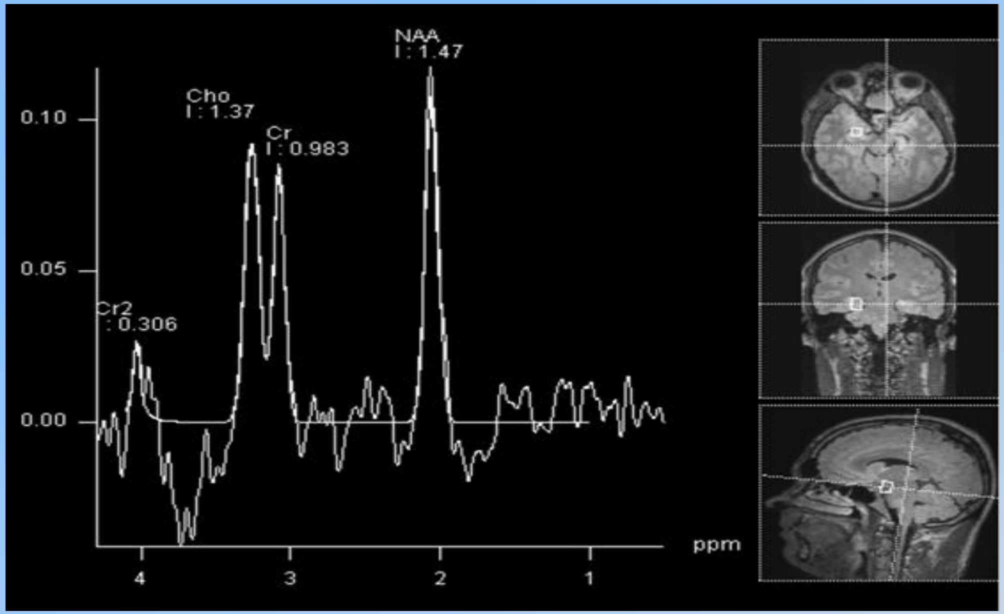
Normal MRS

- In MTS due to gliosis and neuronal loss there is decrease of NAA peak and sometimes elevations of Cr and/or Cho peaks.
- Unilateral MRS changes have a predictive value of 82% for good surgical outcome.
- Decrease NAA peak in contralateral hippocampus might be reversible after ATL.

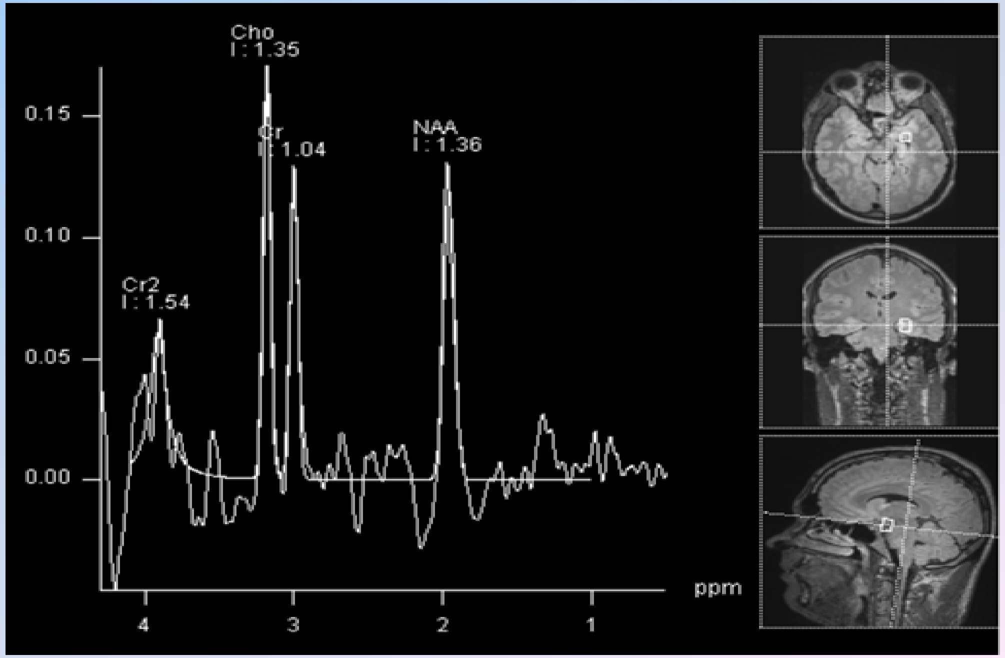
(L) MTS in 22 M with seizures - MRS

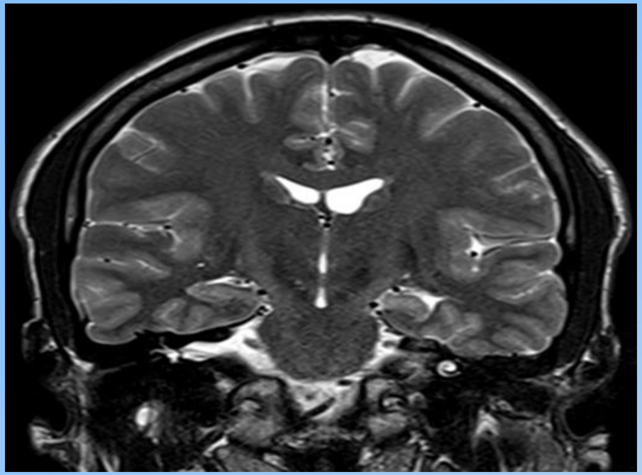


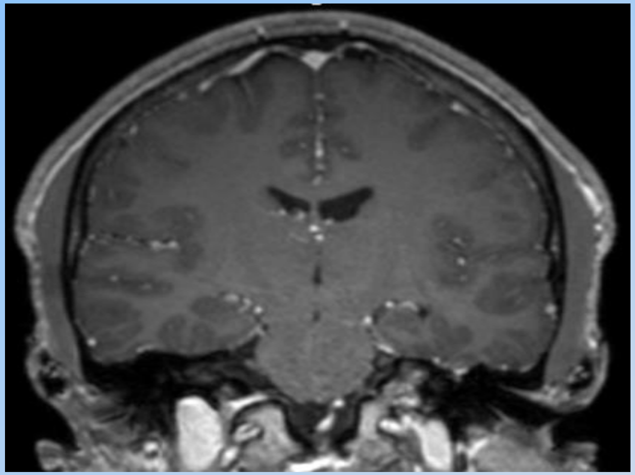




Right and Left hippocampus

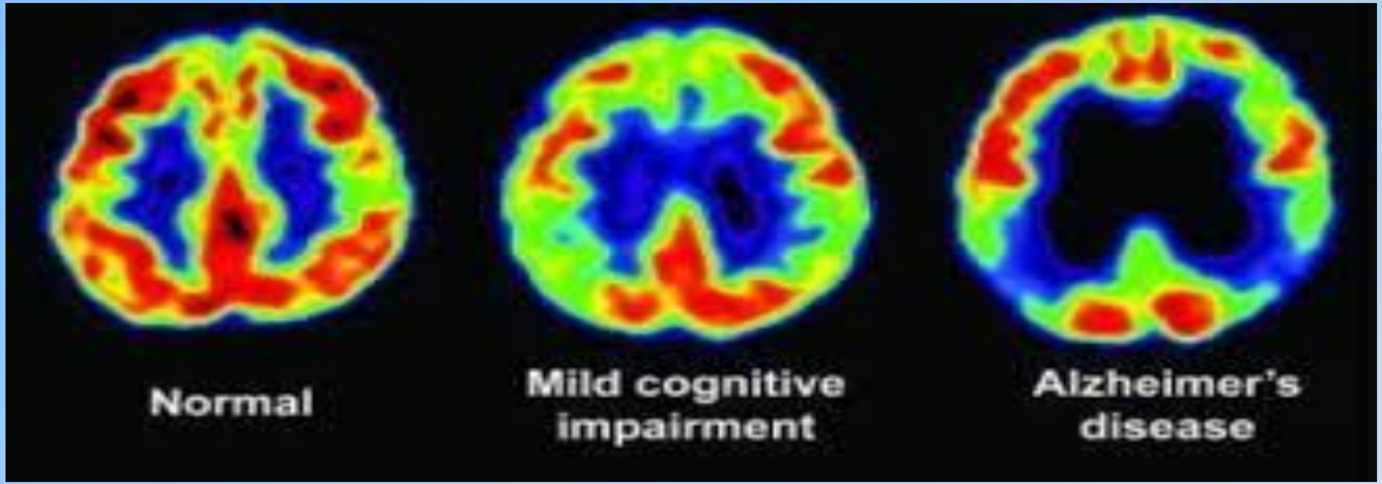




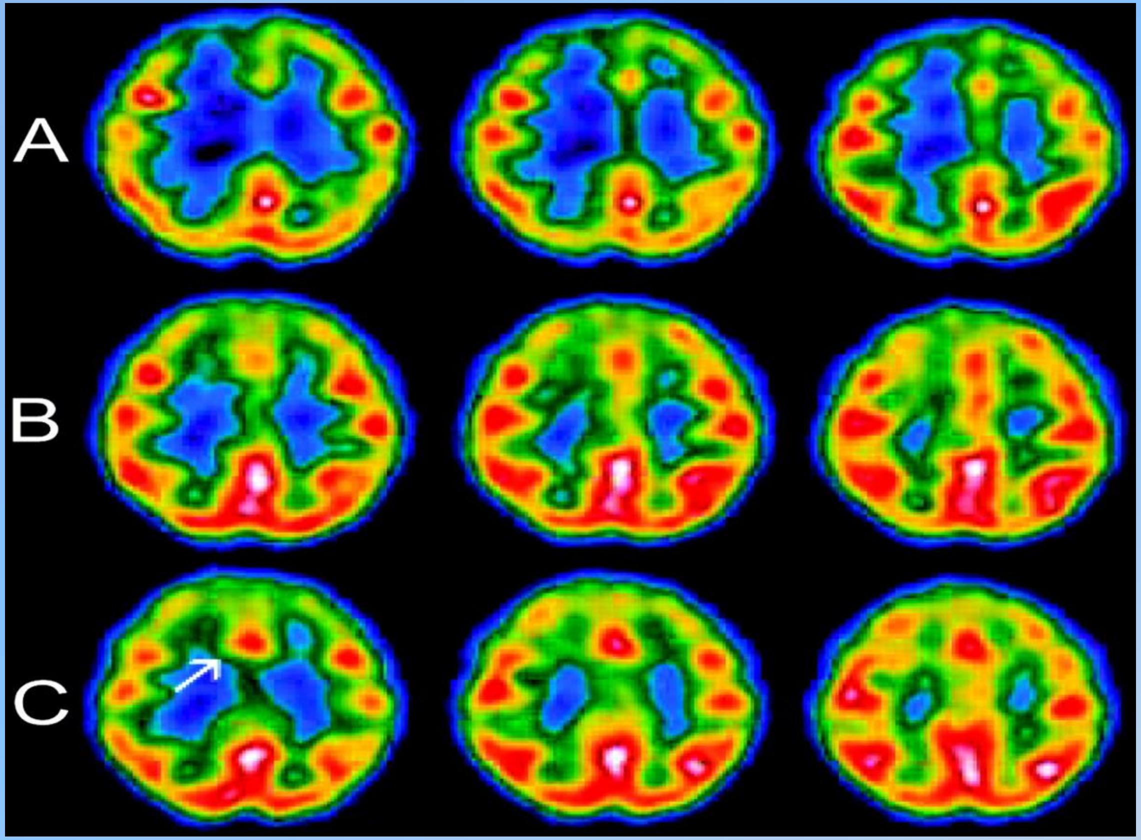


PET

- Measures metabolic activity
- Could use different tracers
- Most common
  - ^{18}FDG – fluorine 18-deoxyglucose



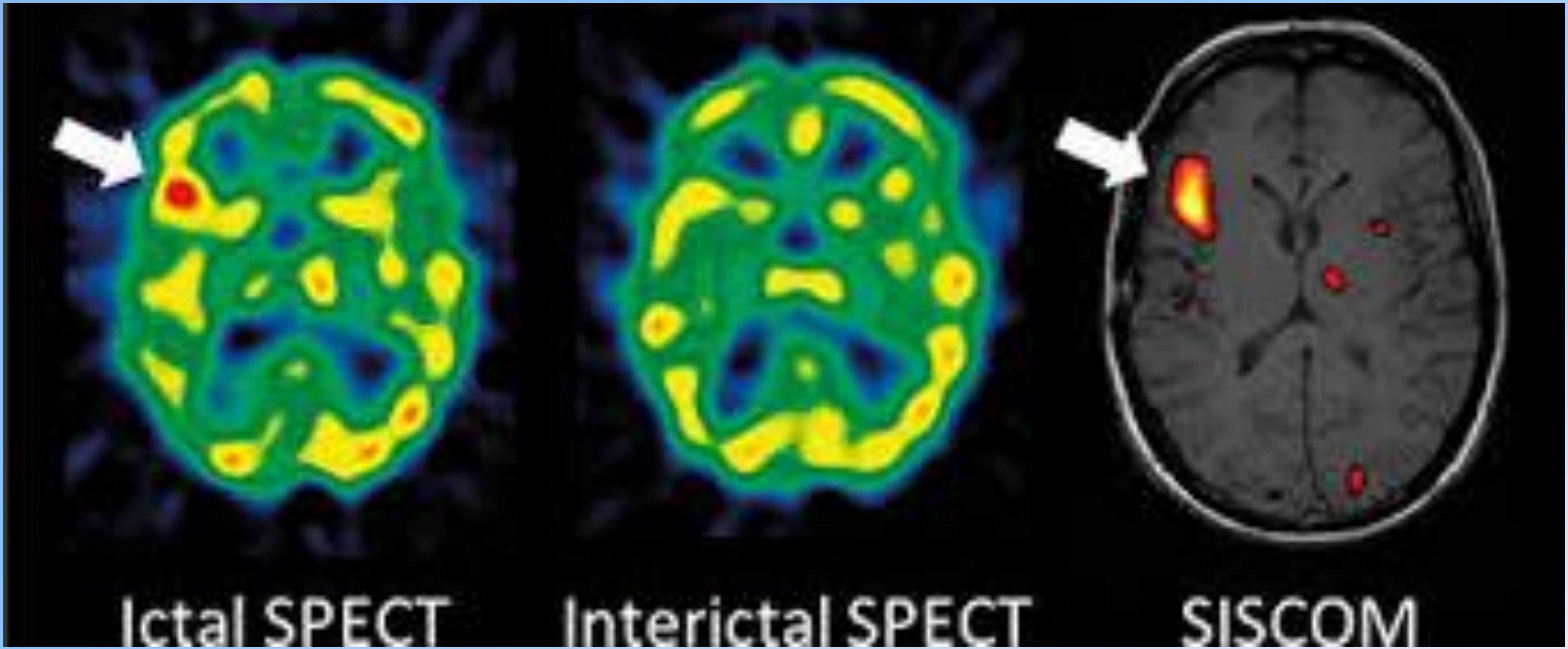
SPECT



- Measures perfusion instead of metabolism
- Use technetium -99m or iodine-123-labeled agents

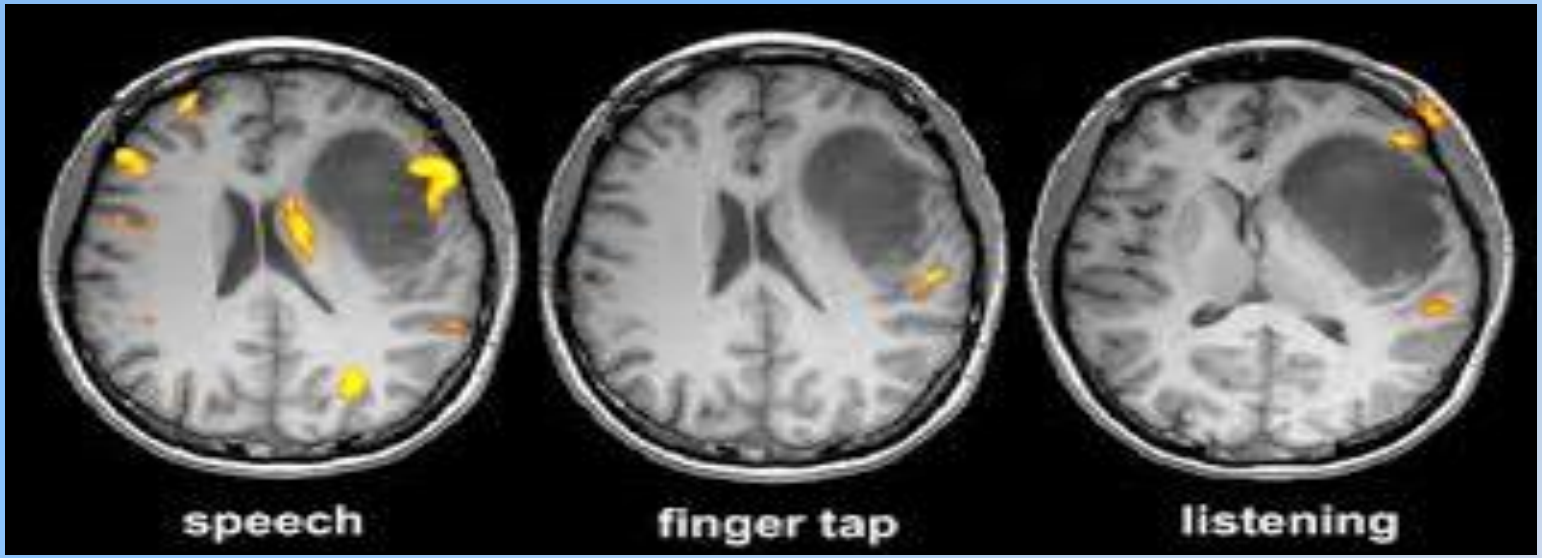
- Case at left is an AD patient

SPECT SISCOM



SISCOM - Substraction Ictal SPECT Coregistered with MRI

fMRI – functional MRI



- Blood oxygen level dependent (BOLD) contrast method is the basis for fMRI
- When the brain is activated by a task there is increase in blood flow to specific areas and more oxyhemoglobin
- Oxyhemoglobin becomes bright in fMRI

References

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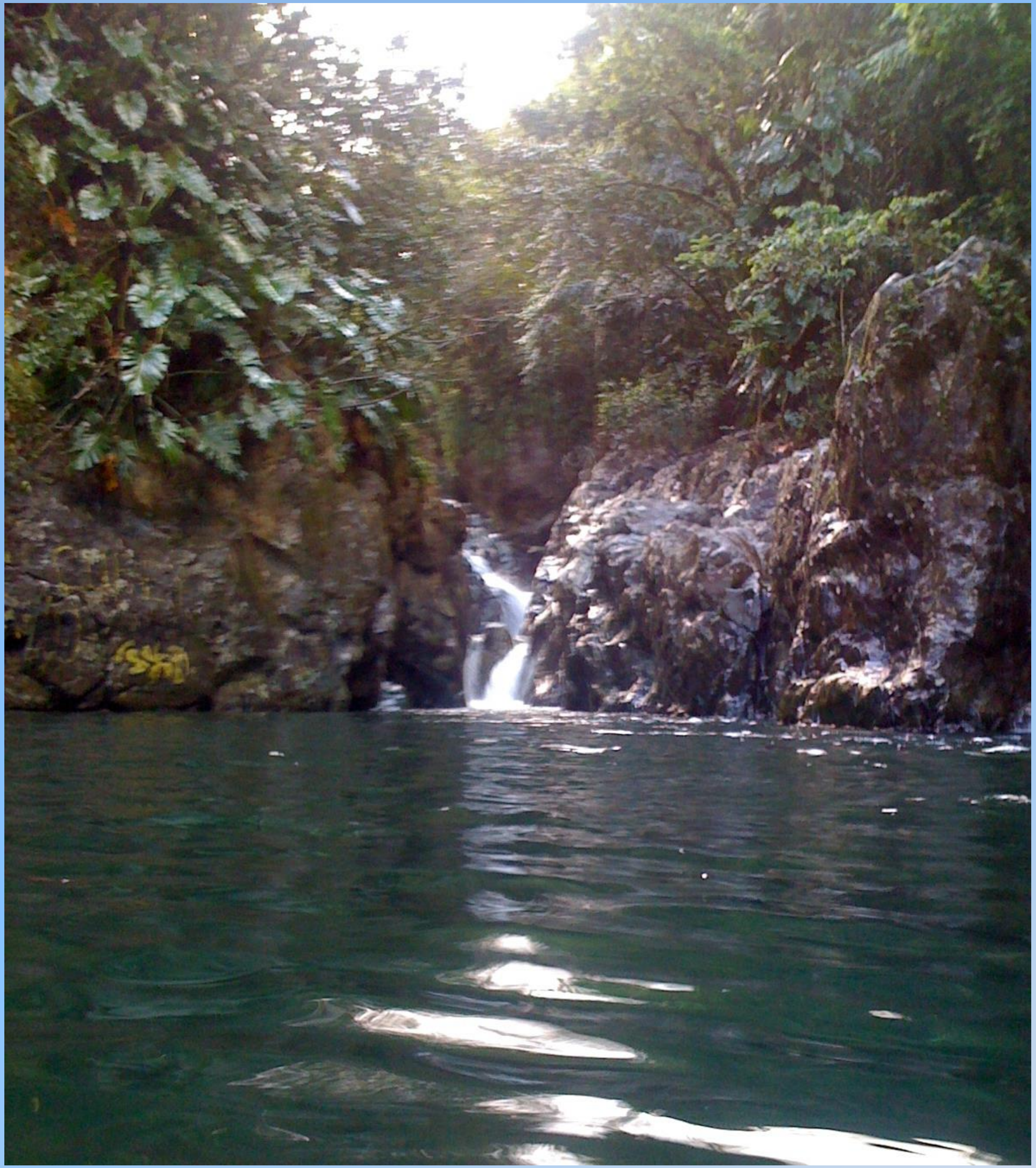

QUESTIONS?

Fajardo – Puerto Rico