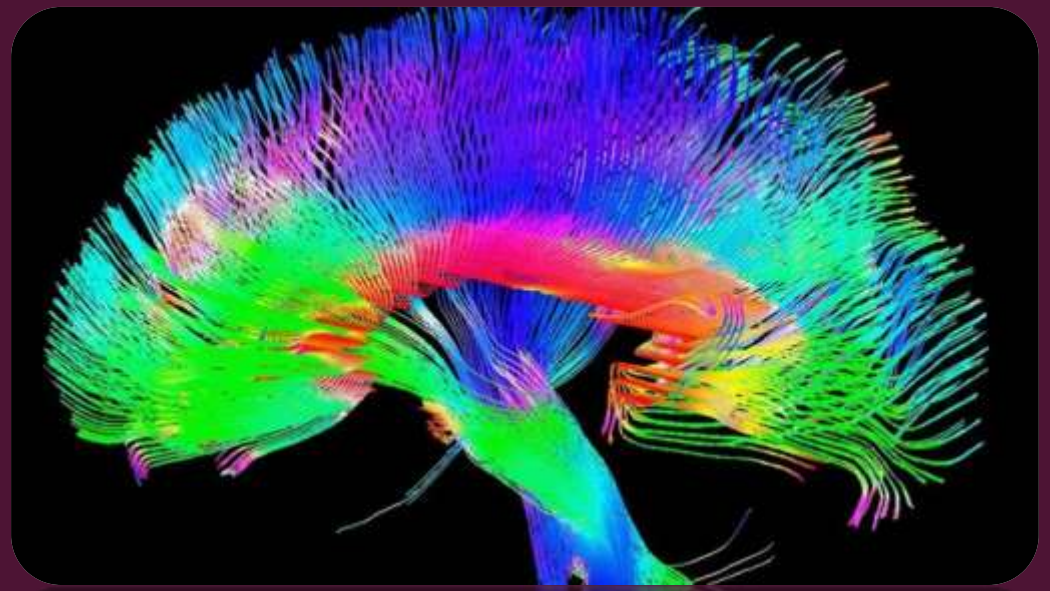
NEUROIMAGING IN PSYCHIATRY

PRESENTED BY: B.OJI ,ASSISTANT PROFESSOR OF PSYCHIATRY ,FELLOWSHIP OF PSYCHOSOMATIC MEDICINE , SHIRAZ UNIVERSITY OF MEDICAL SCIENCES



HISTORY

- Associations of brain **structure and function to behavior** date as far back as the **second and third** century CE when the Greek physician, Galen of Pergamon, suggested that the brain plays a central role in control of perception, cognition, and memory

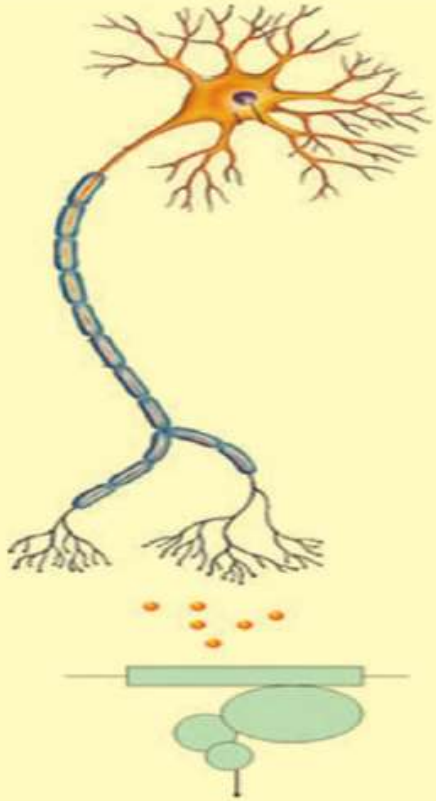
HISTORY

- Attempts by eighteenth-century German physicians, Franz Joseph Gall and Johann Gaspar Spurzheim, at linking specific brain areas to specific mental states gave rise to the **pseudomedical field of phrenology**, namely, the physical examination of the shape and surface of the skull as accurate indicators of psychological traits

- Although phrenology has long been debunked, Gall and Spurzheim's notion of functional localization of cerebral and cerebellar structures and associations of functional brain domains to behavior still hold true.

Today more advanced techniques are available for assessing regional changes in the brain in relation to neurobehavioral disorders, in vivo, **even down to molecular levels**

Table 1. Schematic diagram showing the neurobiological processes assessed by neuroimaging modalities[a]

Neuron	*Neurobiological activity*	*Neuroimaging modality*
	Anatomical assessment	CT/MRI
	Anatomical assessment	DTI
	Electrophysiological assessment	EEG/ERP
	Brain metabolite investigations	MRS
	Studies of cerebral blood flow	fMRI/PET/SPECT
	Probes of neurotransmitter functioning	SPECT/PET

[a]The table indicates the parameters of neurobiological activity that can be measured throughout this process, from action potential to biological response, and the neuroimaging technology best suited to measure these parameters.

CT: computerized tomography; DTI: diffusion tensor imaging; EEG: electroencephalography; ERP: event-related potential; fMRI: functional magnetic resonance imaging; MRI: magnetic resonance imaging; MRS: magnetic resonance spectroscopy; PET: positron emission tomography; SPECT: single photon emission computed tomography.

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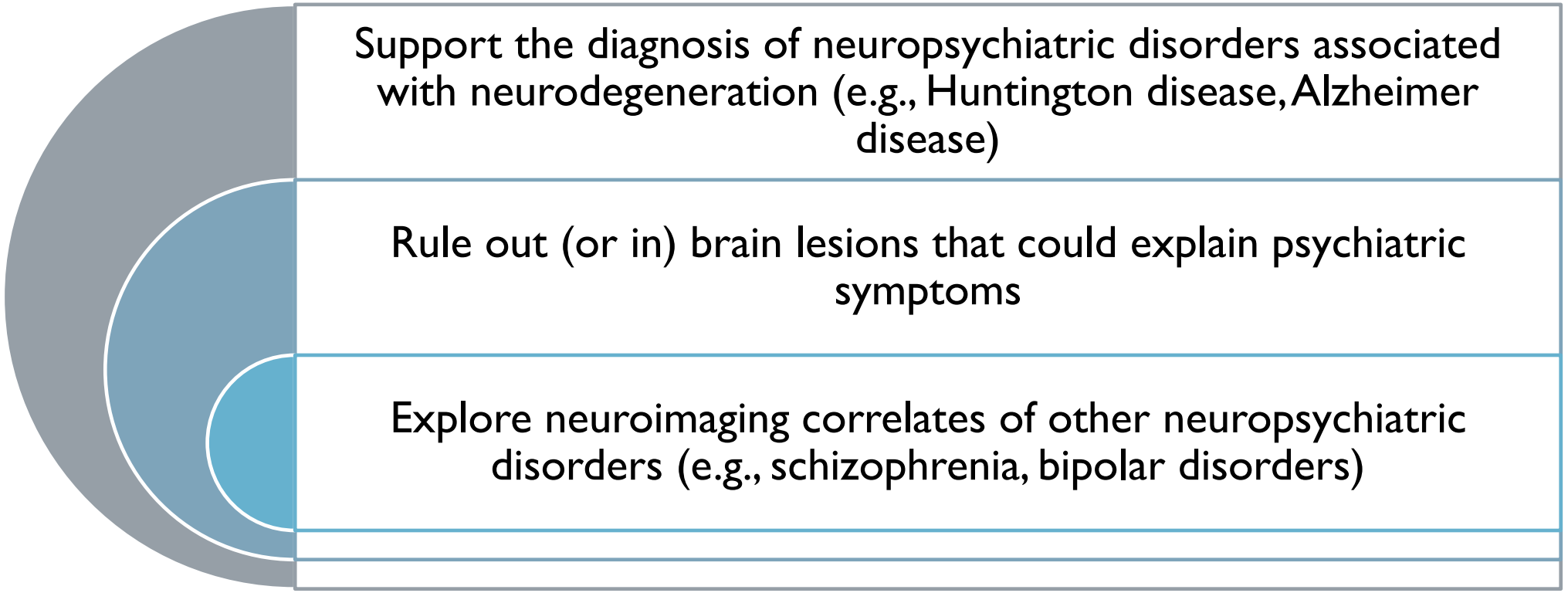
HISTORY

- Radiography by Wilhelm Roentgen in 1895
- Ventriculography and pneumoencephalography by Walter Dandy (a neurosurgeon)in 1918 and cerebral arteriogram by Antonio Egas Moniz (a neurologist) in 1927
- In 1961, William Oldendorf invented Computed tomography (CT) technology, which was applied to clinical use in 1973 as facilitated by Godfrey Hounsfield (an electrical engineer)
- Eventually magnetic resonance Imaging (MRI) was introduced in the **mid-1970s**

IN PSYCHIATRY, NEUROIMAGING HAS BEEN USED FOR THREE MAIN PURPOSES:



CLINICAL INDICATIONS OF NEUROIMAGING IN PSYCHIATRY

- **Dementia**
- **Delirium**
- **Patients with a first manifestation of psychosis or affective symptoms(?)**
- **Neuropsychiatric patients**

TABLE 4–1. Indications for neuroimaging

Historical information/clinical signs or symptoms
New-onset mental illness after age 50
Manifestation of psychiatric symptoms at atypical age for diagnosis
Atypical evolution of psychiatric symptoms
Abrupt personality change
Initial psychotic break
Focal neurological signs
Dementia or cognitive decline
Catatonia
Diagnosis or medical condition
Traumatic brain injury
Alcohol misuse with psychiatric symptoms
Seizure disorder with psychiatric symptoms
Movement disorder with psychiatric symptoms
Autoimmune disorder
Eating disorder
Poison or toxin exposure
Delirium

OXFORD TEXT BOOK OF NEUROPSYCHIATRY

- Broadly speaking, imaging for neuropsychiatric purposes may be indicated in (Cooper et al., 2013; Ikram et al., 2010):

✓ New-onset psychosis.
✓ New-onset mood/memory symptoms.
✓ Occurrence of new or atypical symptoms.
✓ New-onset personality changes.
✓ Anorexia without body dysmorphic symptoms.

- Equally, situations in which neuroimaging for neuropsychiatric issues **may or may not be required** include:

✓ Recurrence of previously controlled psychiatric symptoms
✓ Patients who are refractory to treatment

FIRST-EPISODE PSYCHOSIS

- Presentation is with atypical features (e.g. visual hallucinations, disorientation, memory loss, and decreased consciousness)
- presence of neurological signs
- Older age groups
- Epilepsy
- Inflammatory (vasculitis)/demyelinating conditions
- When neoplastic conditions are being considered

DEMENTIA

- A study of psychiatric patients without dementia found that treatment was changed in 15% of patients as a result of imaging examinations (Erhart et al. 2005).

- A study of psychiatric inpatients (general university hospital) with dementia reported that more than one-third of the structural imaging examinations (i.e., CT, MRI) resulted in a change in diagnosis (Tanev et al. 2012).

EXAMPLES

- Insidious onset cognitive or behavioral impairment in an elderly patients
- Altered mentation with new focal neurological sign or symptom
- New onset psychosis (with or without catatonia or seizure) in patient with known malignancy

DEMENTIA

DEMENTIA

- National Institute for Health and Care Excellence (NICE), recommend the use of 'structural imaging to **exclude other cerebral pathologies and help establish the subtype'**

- Although it 'may not always be needed in those presenting with moderate to severe dementia, if the diagnosis is already clear ?

WHAT IS PREFERRED IMAGING MODALITY ?

PREFERRED IMAGING MODALITY

MRI

- More sensitive than CT to the brain changes associated with the commonest causes of dementia (Alzheimer's and vascular dementia)

- Much more helpful than CT in establishing the rarer underlying diagnoses, for example, fronto-temporal dementia or inflammatory diseases

PREFERRED IMAGING MODALITY

- For the differentiation between Alzheimer's disease (AD), vascular dementia (VD), and frontotemporal dementia (FTD) it can also be useful to identify the characteristic regional deficits in perfusion and glucose utilization with hexamethylpropyleneamine oxime **(HMPAO)-SPECT or FDG-PET** (NICE 2018)

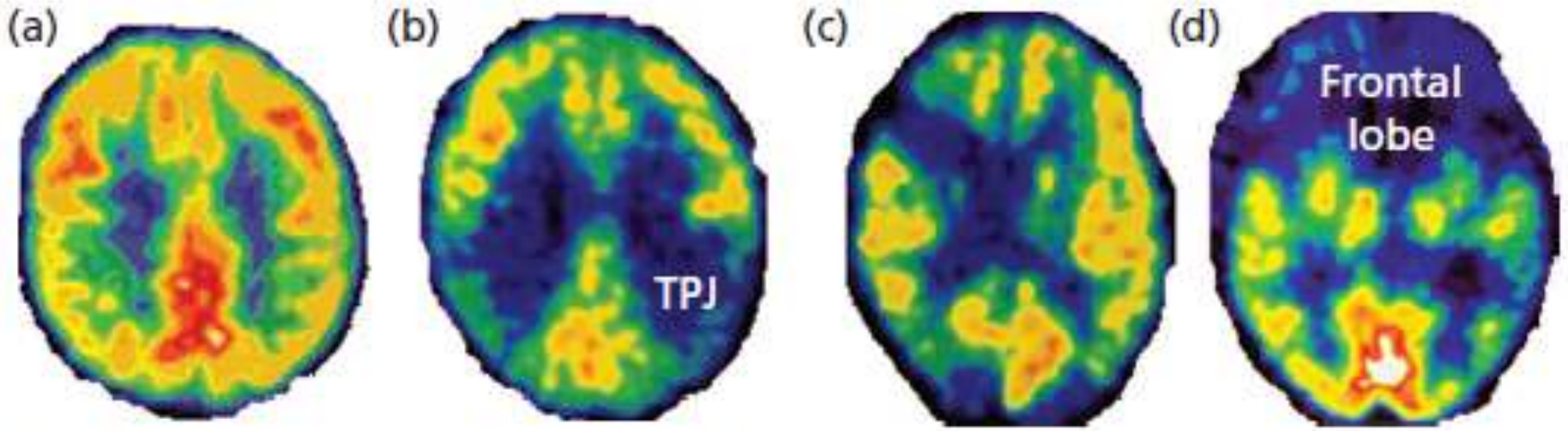


Fig. 4.1 PET distinguishes different types of dementia. Maps of glucose metabolism, measured with FDG-PET, in (a) a healthy control (aged 55); (b) a patient with Alzheimer's Disease (AD) (aged 60); (c) a patient with vascular dementia (VD) (aged 50); and (d) a patient with frontotemporal dementia (FTD) (aged 69). Note that hypometabolism is most marked in the temporoparietal junction (TPJ) in AD and in the frontal lobe in FTD, but more diffuse in VD.

DLB

- If dementia with Lewy bodies (DLB) is suspected, the associated dopaminergic deficit can be documented with a DaTSCAN

DLB

- As in Parkinson's disease, nigrostriatal dopaminergic neurons degenerate in DLB, which results in less binding capacity for the radiolabelled DAT ligand 123I-2-carbomethoxy-3-(4-iodophenyl)-N-(3-fluoropropyl) nortropane (FP-CIT)
- A lower signal on the DaTSCAN would therefore be indicative of DLB.

- The main indication for the DaTSCAN, however, is still the differentiation between PD (dopaminergic deficit) and other movement disorders

DELIRIUM

DELIRIUM

- **Imaging is not routinely part of this**

- Clinical guidelines (Young and George 2006) suggest that **CT scanning should be performed** in patients in whom an intracranial lesion is suspected **:**

1. Focal neurological signs
2. A head injury, a fall
3. Clinical evidence of raised intracranial pressure (for example, vomiting or papilloedema

PATIENTS WITH A FIRST MANIFESTATION OF PSYCHOSIS OR AFFECTIVE SYMPTOMS

- Protocols for the diagnostic assessment of patients with a first manifestation of psychiatric illness are widely debated
- On the one hand, psychosis or affective symptoms can be early indicators of an underlying brain lesion

- One the other hand, large scale screening studies of psychiatric patients may not be cost effective and bring up incidental findings that can cause undue concerns

PATIENTS WITH A FIRST MANIFESTATION OF PSYCHOSIS OR AFFECTIVE SYMPTOMS

- Molecular imaging with PET or SPECT has presently **no place in the diagnostic workup of psychosis or affective disorders**
- Assessing the dopamine system with DAT ligands can have some clinical use in **distinguishing Parkinsonism caused by antipsychotic drugs from PD**
- Because the former is caused by a post-synaptic dopaminergic blockade, whereas the latter is caused by dopamine depletion

- Abnormalities on DAT imaging would therefore only be expected in PD, but not in antipsychotic-induced Parkinsonism

- However, some patients with drug-induced Parkinsonism also have abnormal DAT imaging findings (and some patients with neuropathologically validated PD show no abnormalities) and the diagnostic utility of this molecular imaging technique for the distinction between different Parkinsonian syndromes therefore still requires further studies.

Case 1

This 56-year-old right-handed homemaker had
progressive apathy, social withdrawal, and poor self-care for three years
and was admitted to a psychiatric facility for depression.

Because she was unresponsive to appropriate antidepressant medications,
a CT scan was taken of the head.

This study revealed an enhancing, 8-cm, medial bifrontal mass' 'Total excision of a benign transitional-type meningioma led to rapid and dramatic improvement, and four months after the operation she was animated, cheerful, and motivated to resume her previous life

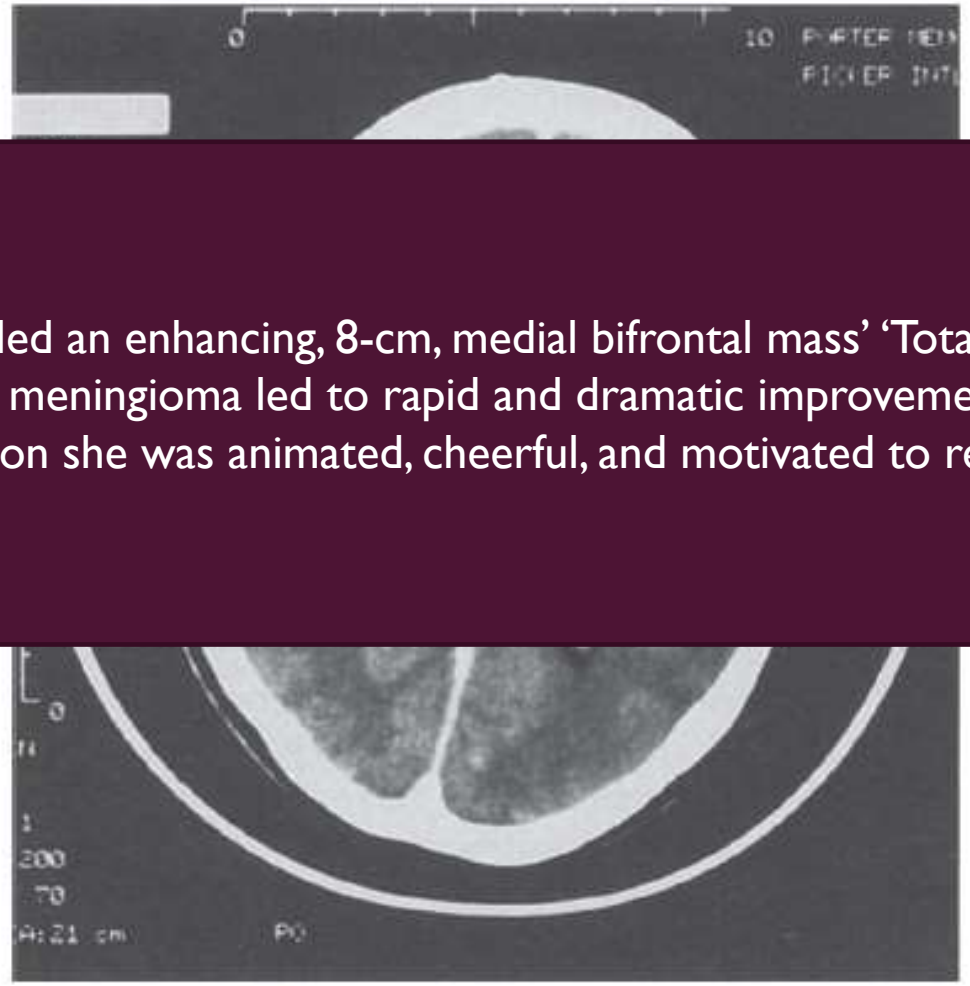


Fig. 4.3 CT scan of Case 1.

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Case 2

An 18-year-old white female was referred by her school because she appeared to be at high risk of psychosis. According to her family, two years previously she started to withdraw from social activities and resented participating in work groups and talking in public. One year later, she felt strangers were staring and laughing at her for no reason, and that the world around her had changed. At her initial evaluation she felt that people were intimidating her and sometimes imagined that television programs were sending special messages to her, although she was not certain about this and could not describe these messages. This patient was neurologically normal and had an above average IQ. She was initially diagnosed with a prodromal syndrome of schizophrenia, but symptoms became rapidly more severe

A routine MRI scan revealed a tumor in the left temporal lobe which was surgically removed. Histopathologically it was a dysembryoplastic neuroepithelial tumor (DNET), a generally benign glial-neural neoplasm

The patient's psychotic symptoms subsequently improved under treatment with risperidone and cognitive behavioural therapy (CBT), but she remained socially withdrawn

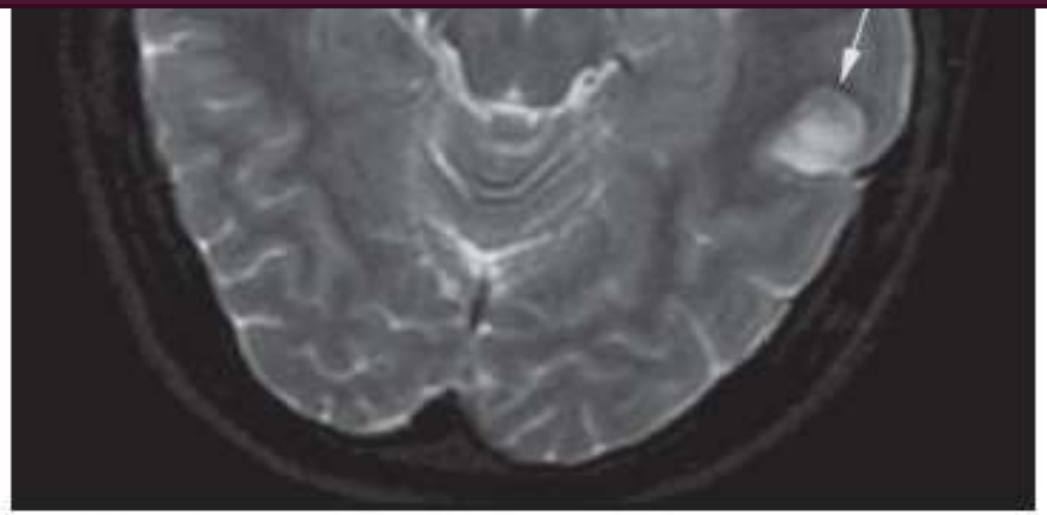

Fig. 4.4 T2-weighted MR scan of Case 2.

Reprinted from *Schizophrenia Research*, 144, 1–3, 'Brain tumor in a patient with attenuated psychosis syndrome', pp. 151–2. Copyright (2013), with permission from Elsevier.

CASE 3

- A 48-year-old female with a history of **major depressive disorder** suffered a relapse of depressive symptoms, which was **not responsive** to her usual combination of paroxetine and risperidone
- She also developed amenorrhea, and laboratory testing revealed hyperprolactinemia and low estrogen
- A pituitary prolactinoma was found on MRI. Both the affective symptoms and the menstrual problems improved after treatment with dostinex, a dopamine agonist, and aripiprazole, a partial dopamine agonist

- These cases illustrate the possibility that classical psychiatric clinical presentations, such as depression or psychosis, arise from brain tumours. Cases 1 and 3 had additional clinical characteristics (non-response totreatment in Cases 1 and 3, and amenorrhoea in Case 3) that may have suggested an atypical cause

These cases underline the importance of detailed history taking and physical examination for the diagnostic workup of patients presenting primarily with psychiatric symptoms

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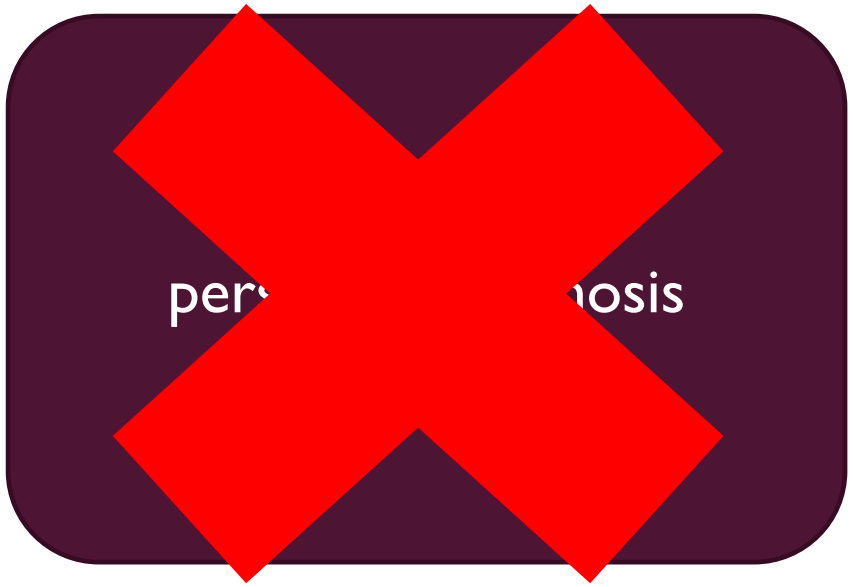
While a number of studies have attempted to outline the indications for neuroimaging in clinical psychiatry, currently there are **no well-established guidelines**

How to order imaging ?

HOW TO ORDER IMAGING ?

- A **succinct clinical history** (rather than just stating 'organic screen') is needed to help guide the radiologist to the appropriate investigations
- The types of information of value to a neuroradiologist include, for example:

- ✓ If a lesion is suspected in a particular location
- ✓ Patient was exposed to a noxious agent (e.g. cyanide, carbon monoxide or chronic heavy alcohol intake)
- ✓ A specific disease process is suspected.
- ✓ If specific imaging sequences are sought to look for specific neuroradiologic changes, these should be listed or discussed with the neuroradiologist, prior to the ordering of imaging



Schizophrenia with a new 12-month history of treatment-resistance and dysexecutive predominant cognitive impairment

EXAMPLES OF INFORMATION THAT IS OF VALUE TO THE RADIOLOGIST INCLUDE THE FOLLOWING:

- "rule out diffuse axonal injury because patient was in a high-speed motor vehicle accident"

- "rule out basal ganglia lesion because patient was exposed to carbon monoxide"; and "patient has long history of alcohol dependence so evaluation of mammillary bodies and anterior thalamus is important."

- The radiologist and technical staff also need information about the patient's **current condition (e.g., delirious, psychotic, easily agitated, paranoid, significant tremor**) that might create difficulties with patient management during the scan

Table 2. Salient points for MRI request

Acuity and pace of onset	Single, intermittent or gradual (e.g. stroke vs. dementia)
Severity	Early or advanced
Certainty	Possible, probable or gene-confirmed
Predominant neurocognitive signs	Frontal: dysexecutive syndrome, upper motor neuron abnormalities Parietal: apraxia, agnosia, upper motor sensory abnormalities Occipital: non-ocular visual problem Temporal: language and speech deficits Hippocampus: seizures, amnesia Subcortical or basal ganglia: extrapyramidal symptoms, working memory and cognitive processing deficits Brainstem: autonomic or cranial nerve abnormalities, mixed upper and lower motor neuron findings Spine: lower motor neuron abnormalities Cerebellum: ataxia
Relevant risk factors	Cardiovascular (e.g. elevated cholesterol, hypertension, diabetes, smoking), electrolyte abnormalities, intravenous drug use, hypoxia, alcoholism, carbon monoxide poisoning, unexplained weight loss, brain injury
Supportive features	Treatment-resistant and atypical age/pattern/progression of onset
Differential diagnoses	Alzheimer's disease vs. frontotemporal dementia
Purpose	Diagnostic, prognosis or treatment

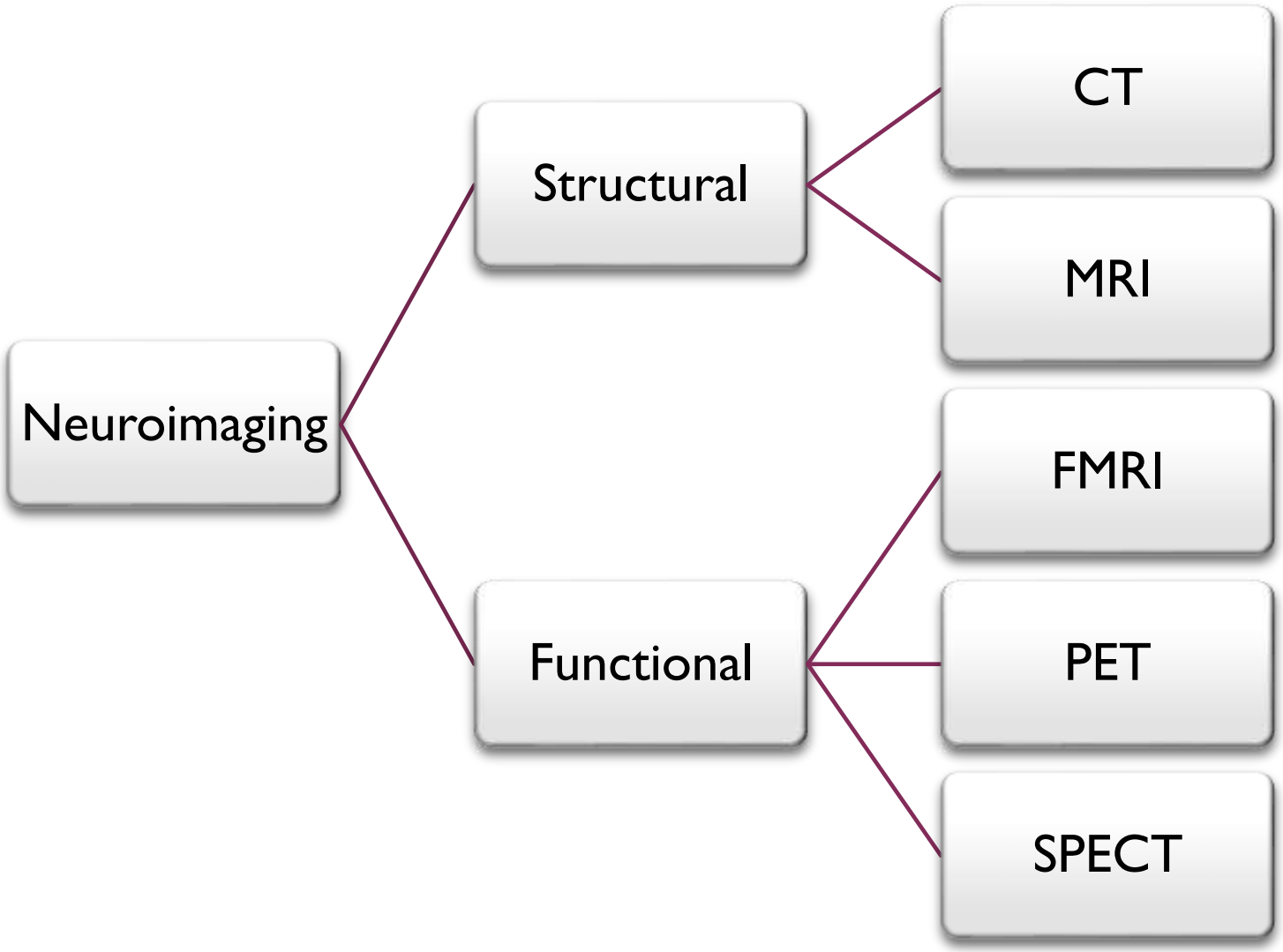
OVERVIEW OF BRAIN IMAGING MODALITIES

Structural

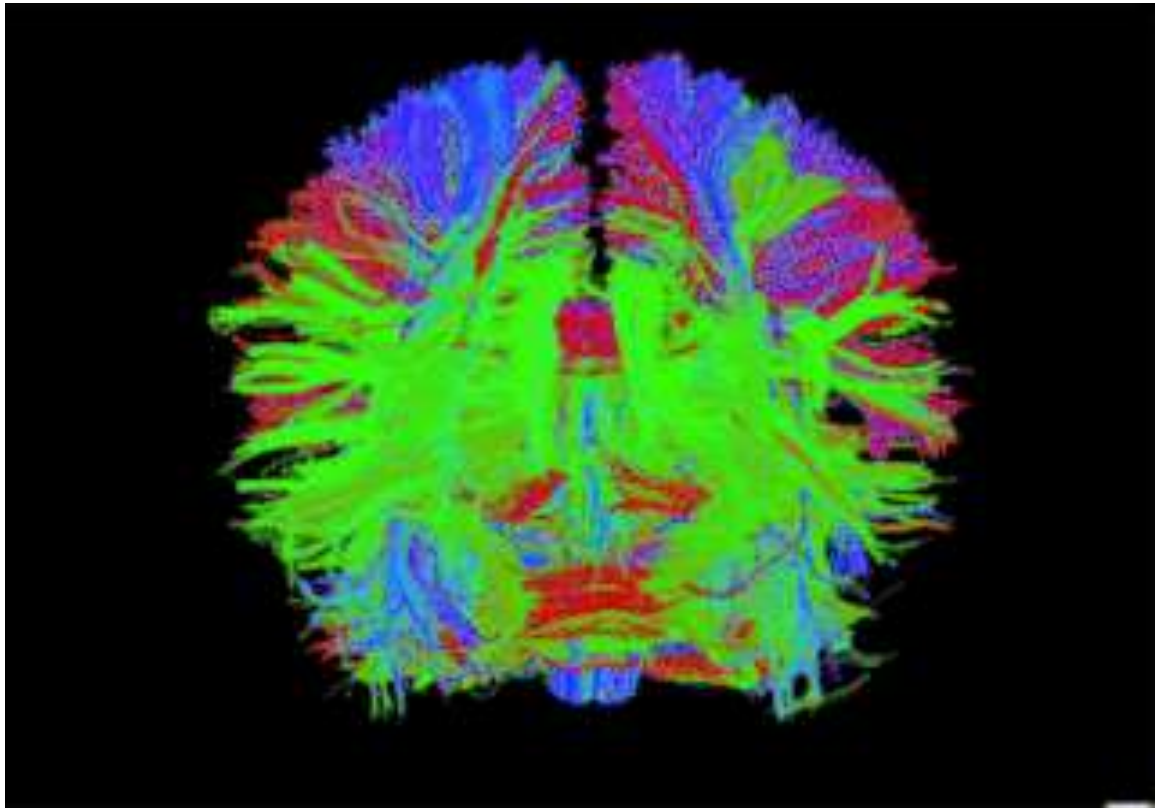
- [ ] CT
- [ ] MRI
- [ ] Skull radiography
- [ ] PNEUMOENCEPHALOGRAPHY

Functional

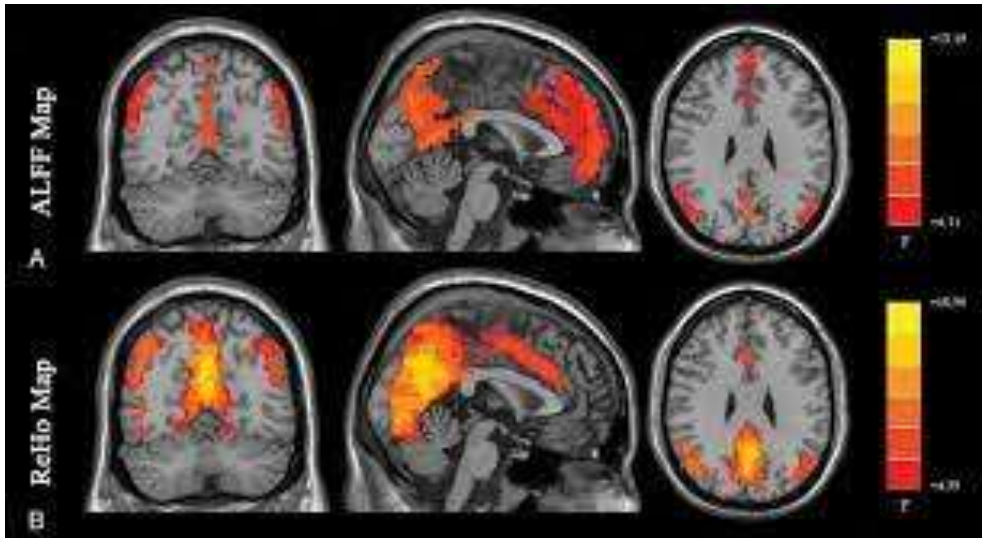
- [ ] FMRI
- [ ] PET
- [ ] SPECT
- [ ] DTI
- [ ] MRS
- [ ] BRAIN ELECTRICAL ACTIVITY MAPPING (BEAM)


Neuroimaging
Structural
Functional
CT
MRI
FMRI
PET
SPECT

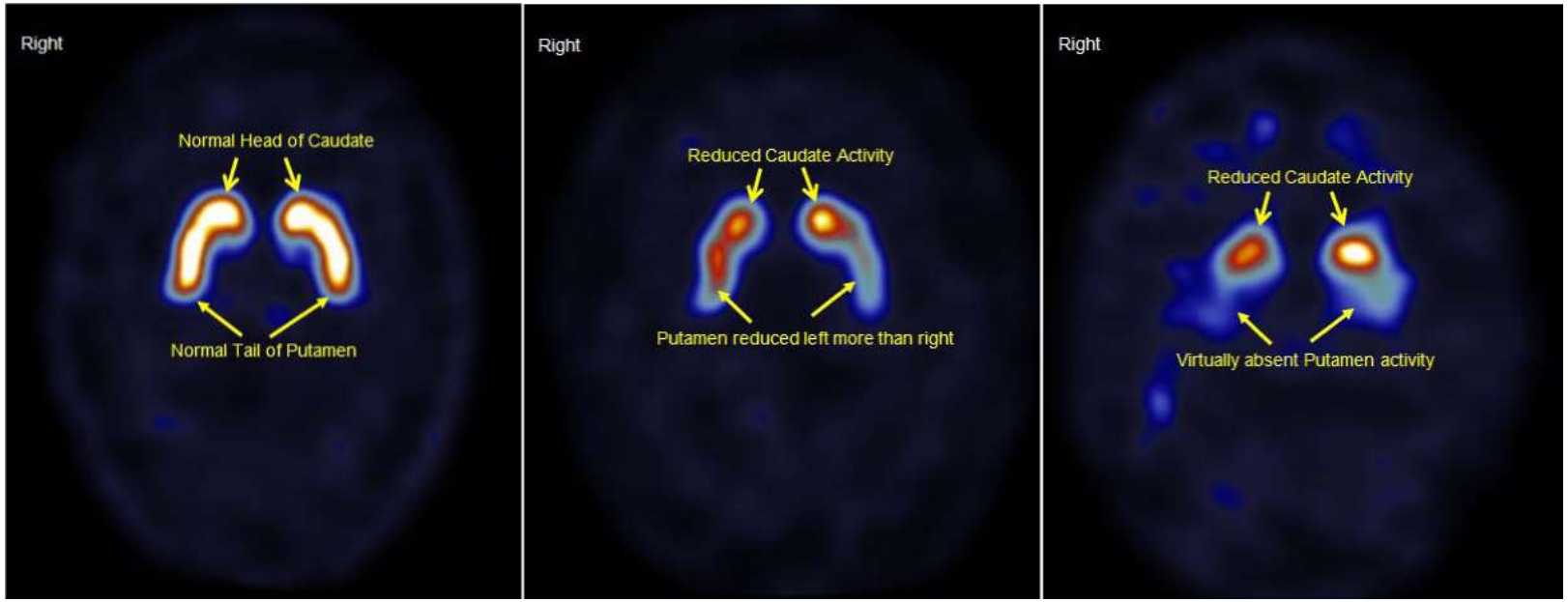
DIFFUSION TENSOR IMAGING



FUNCTIONAL MRI



DAT SCAN


Right
Normal Head of Caudate
Normal Tail of Putamen
Right
Reduced Caudate Activity
Putamen reduced left more than right
Right
Reduced Caudate Activity
Virtually absent Putamen activity

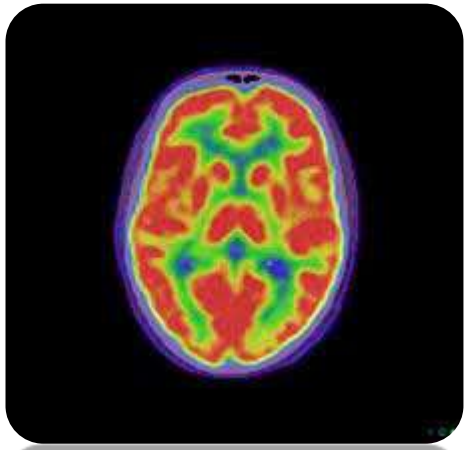
- In most clinical settings**, structural imaging** modalities are established primary care diagnostic tools for detecting changes in brain morphology, volume, and overall integrity

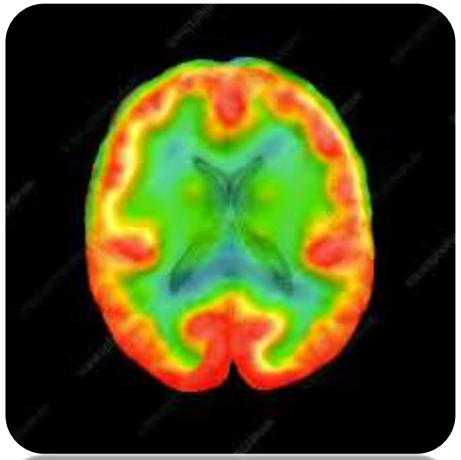
- Recent technological advances in hardware instrumentation and software capabilities, notably in areas of image resolution, data storage, and image reconstruction, have allowed rapid increase in clinical adoption of functional imaging modalities

- Single-photon emission computed tomography (SPECT) and positron emission tomography (PET) are now routinely used to characterize deficits in **brain blood flow and glucose metabolism** in psychiatric patients.

- Each imaging modality contributes to better understanding of neurobehavioral disorders.

PET & SPECT





COMPUTED TOMOGRAPHY (CT)

- Three-dimensional (3D) representation of x-ray absorption from different tissues in the brain.
- Multiple x-ray images acquired around the head at multiple angles from top of the first cervical vertebra through the top of the calvarium, creating cross sections or "slices" of the brain

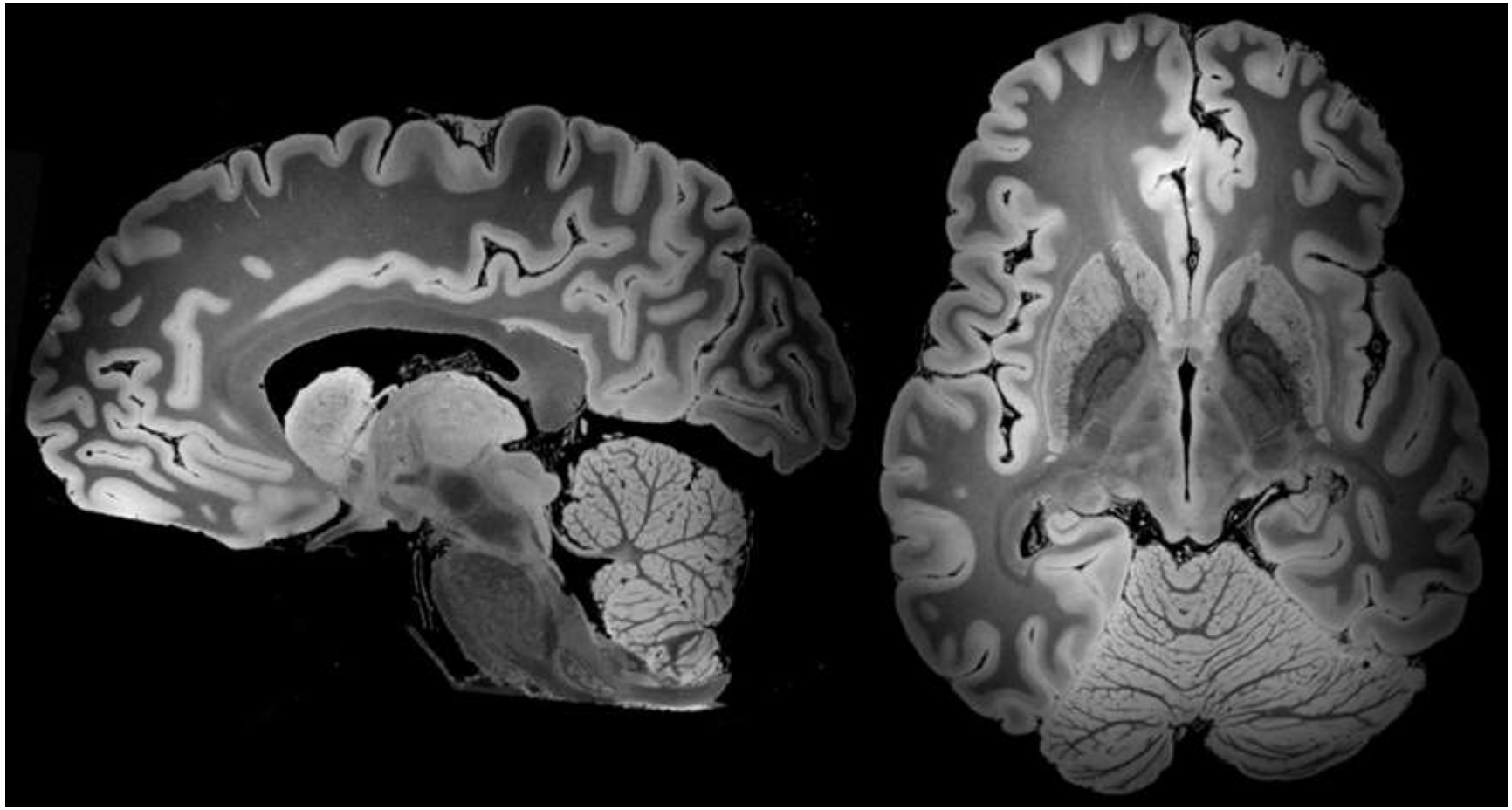
MAGNETIC RESONANCE IMAGING (MRI)

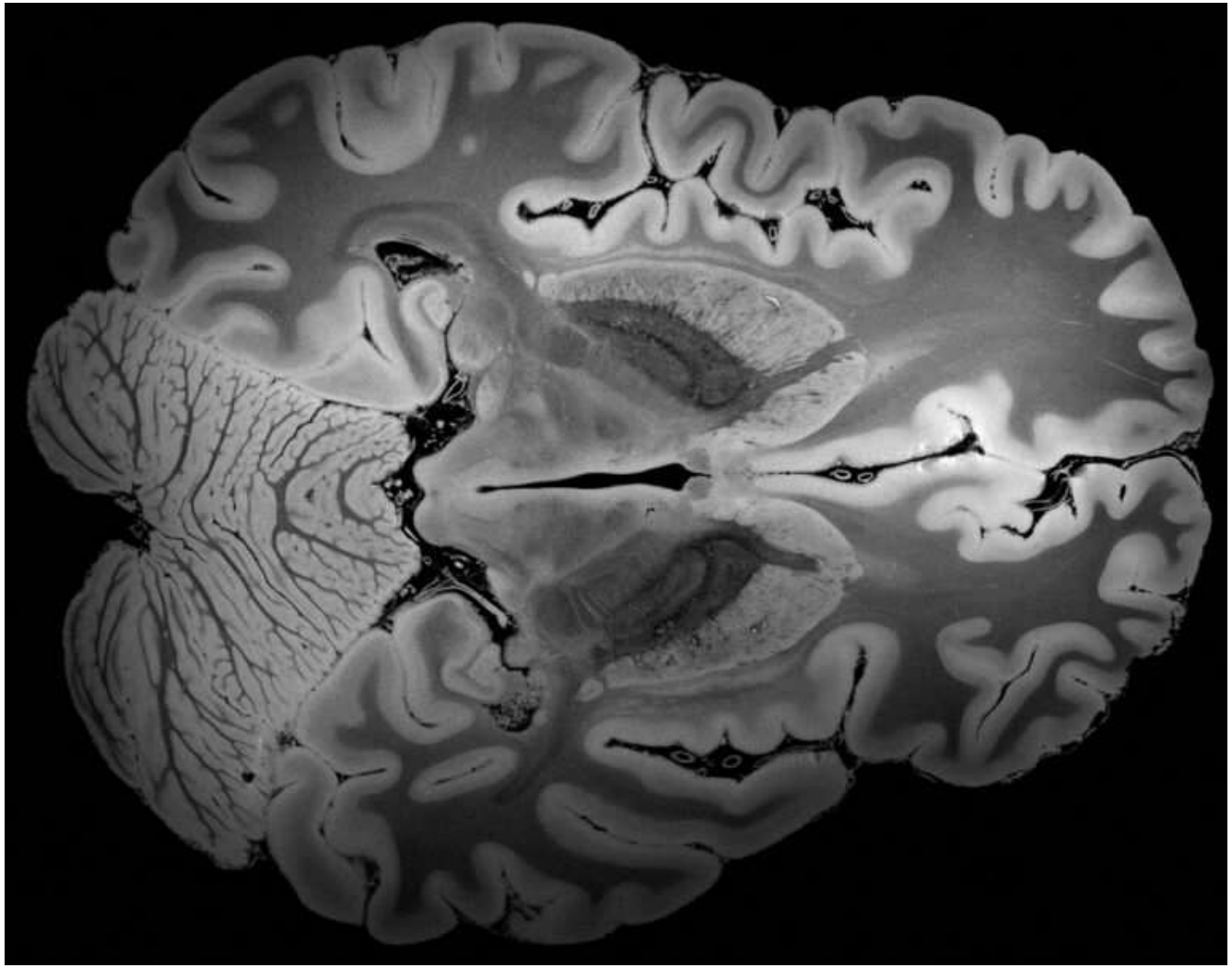
- Since the production of the first MR image of a live human nearly 40 years ago, MRI has rapidly advanced at a pace much faster than other imaging modalities
- The first human scan in July 1977, for instance, was an image of the chest acquired over 4 hours in a scanner twice the diameter and length of current clinical scanners
- Today, a similar image can be acquired in less than 5 minutes with ten times better spatial resolutions

MAGNETIC RESONANCE IMAGING (MRI)

- Tesla (T) is a measure of the magnetic flux density
- Over the past 40 years, the strength of the magnetic field has gone from **0.5 Tesla in the mid-1980s to 7 Tesla**
- In clinical practice, the static magnetic field strength is either 1.5 or 3 Tesla although research magnets **can be as high as 9 T**

A 3-D view of the entire human brain, taken with a powerful 7 Tesla MRI and shown here from two angles, could reveal new details on structures in the mysterious organ.





MRI

- The ability of MRI to produce **high spatial resolution and good soft tissue contrast** makes MRI appealing for investigating subtle anatomical (and to a larger extent, functional) abnormalities

- An MR image of the brain is created when the head is exposed to the **electromagnetic field** produced by a strong MRI magnetic field

- The human body is made up of large pools of hydrogen atoms (H+, a component of water or H2O), each consisting of one subatomic particle in the nucleus, called a proton.


CT
MRI

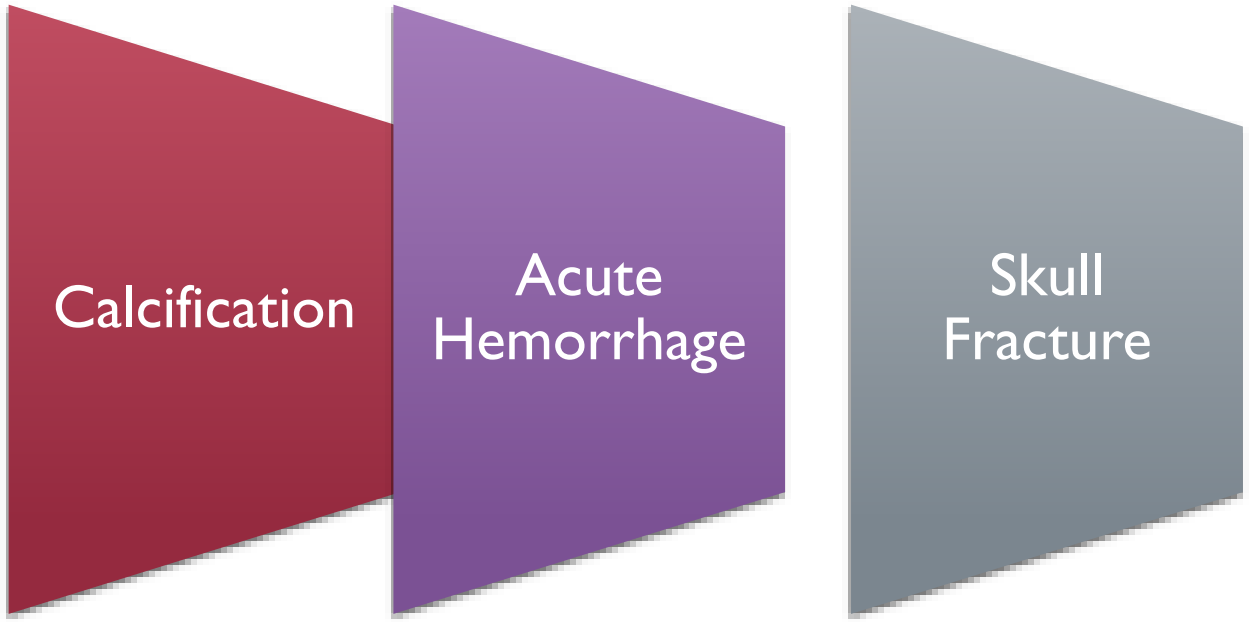
Table 3.5 Comparison of structural brain imaging modalities

	CT	MRI
Radiation burden	1 scan (~2.2 mSv/year)[a] is less than the average annual radiation dose from natural background radiation (3.1 mSv/year)[a]	None
Tissue contrast	Good soft tissue contrast	Excellent soft tissue contrast
Scan time	Faster, order of seconds to less than 1 minute; less prone to patient motion	Slow; few minutes long for each sequence; prone to patient motion
Claustrophobia	Relatively larger bore; easier for claustrophobic-prone patients	Smaller enclosed bore; sedation may be offered
Trauma-friendly	Yes	In certain cases; transfer from emergency room to MRI-safe monitoring devices and intravenous lines are required
Metallic implant contraindication	Safe to scan; metallic streaking artifacts might exist	Conditional-safe; thorough screening is required before admitting patient to MRI suite

[a]NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States. Available at ► www.ncrponline.org, Accessed November 19, 2016

MRI VERSUS CT

- There are a few brain-based conditions best viewed with CT, including



MRI VERSUS CT

- MRI is the **preferred modality** in clinical neuropsychiatry unless it is contraindicated, because visualization of both neuroanatomy and pathology is much better

- MRI does not produce bone-related artifacts (discussed above in subsection "Computed Tomography"), so lesions near bone (i.e., those in brain stem, posterior fossa, pituitary, hypothalamus) are generally well visualized

- When ordering the imaging procedure, the clinician should be mindful to request a study with contrast enhancement if a disease affecting the BBB or cerebrovascular architecture is suspected.

INDICATIONS FOR WHICH A STRUCTURAL CT SCAN MAY BE ORDERED INCLUDE

- Need for quick scanning (e.g., in cases like trauma and/ or acute-onset headache that could be hemorrhagic stroke).
- Cost; availability is more likely for CT scan and, as such, waiting time is usually much shorter
- Heavy and/or claustrophobic patient that cannot be comfortable in MRI tube
- Presence of devices that can malfunction, heat, or get displaced with magnetic field (e.g., pacemaker, ferrogenic clips)
- When looking for calcification or bone-related lesions or when looking for metals (e.g., shrapnel injury)
- In patients that are likely to move in the scanner (e.g., CT scan is brief and as such less vulnerable to motion artifact)

INDICATIONS FOR WHICH A STRUCTURAL MRI SCAN MAY BE ORDERED INCLUDE:

- More details of the anatomy are needed (e.g., evaluation of regional atrophy), because you can acquire different views without having to move the patient
- Looking for small lesions like microbleeds, hemosiderin deposits, and lacunae in strategic locations (e.g.,thalamic lacunae)
- Repeated imaging is required especially in vulnerable patients, this is mainly because of concern regarding ionizing radiation with CT scan
- Evaluating areas adjacent to the bones (CT scan is more vulnerable to bone artifacts, e.g., in posterior fossa structures)

SAFE PREPARATION

Successive missed appointments, non-compliance and psychomotor agitation may compromise the quality of MRI and the interdisciplinary relation

To increase the likelihood of completion, we explain the indication and procedure to the patient and engage the family or caseworker

Claustrophobia, noise sensitivity and the capacity for staying in a fixed position can be difficult for many patients

Mental state factors should be taken into account, and, where necessary, hypnotic or generalized anaesthesia may be required, as motion can impact on the image quality

Where contrast is given in the elderly, a recent renal function test is usually essential

SAFETY CONSIDERATIONS FOR STRUCTURAL NEUROIMAGING IN CLINICAL PRACTICE

- **Computed Tomography**

- Routine brain CT scans deliver a low dose of radiation (less than 5 rads)
- Not contraindicated in healthy pregnant patients

SAFETY CONSIDERATIONS FOR STRUCTURAL NEUROIMAGING IN CLINICAL PRACTICE

- **Magnetic Resonance Imaging**

- There are no unequivocally demonstrated, permanent, hazardous effects from short-term exposure to magnetic fields and RF pulses generated in clinical MRI scanners
- There is no evidence of injury to the developing fetus associated with such exposures, most experts recommend caution when considering MRI of a pregnant woman
- Volunteers scanned using systems with higher field strength have reported effects, including vertigo and nausea.

MRI CONTRAINDICATIONS

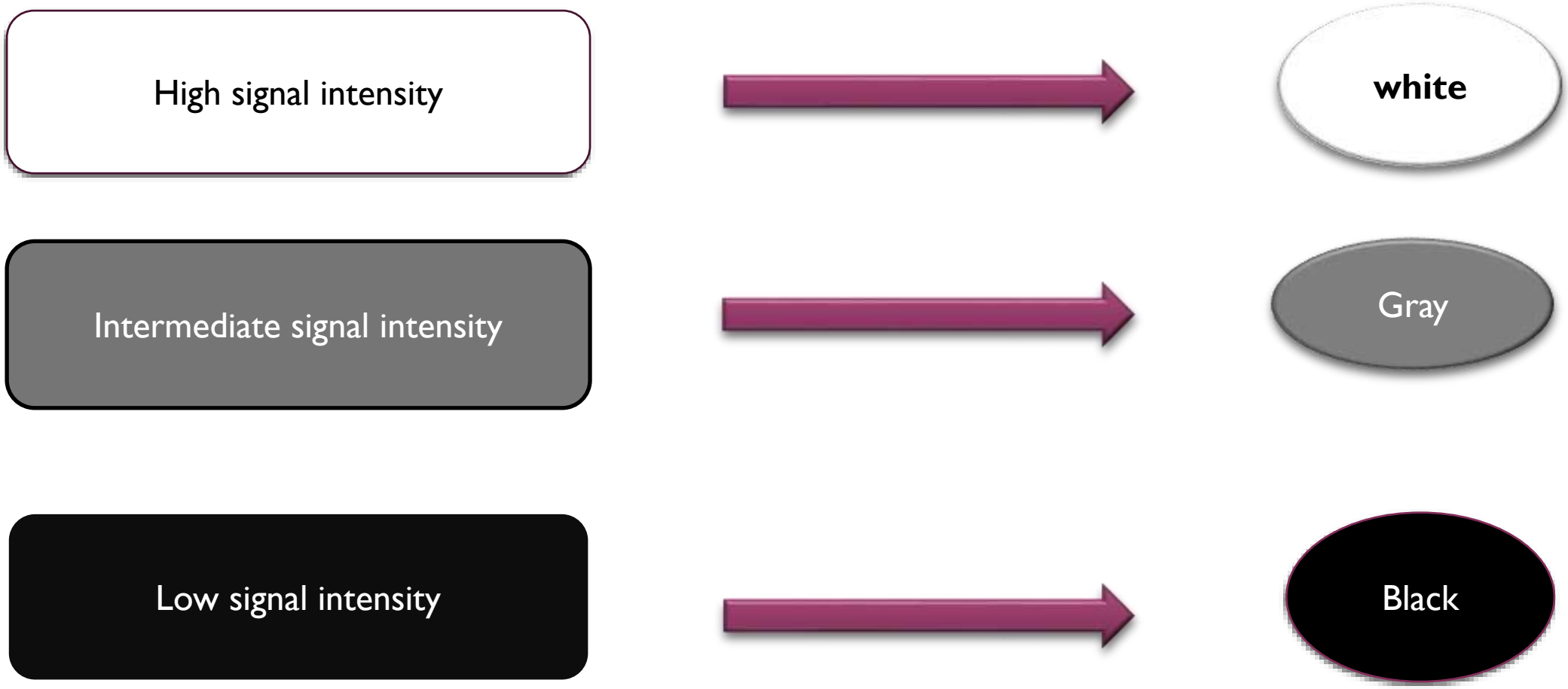
- The magnetic field can damage electrical, mechanical, or magnetic devices implanted in or attached to the patient
- Pacemakers and defibrillators can be damaged by programming changes, possibly inducing arrhythmias
- Currents can develop within the wires, leading to thermal burns, fibrillation, or movement of the wires or the device itself
- Cochlear implants, dental implants, magnetic stoma plugs, bone-growth stimulators, and implanted medication-infusion pumps can all be demagnetized or injure the patient by their movement during exposure to the scanner's magnetic field.
- Metallic implants, shrapnel (see Figure 4–2D), bullets, or metal shavings within the eye (e.g., from welding) can conduct a current and/or move, causing injury
- Medication patches with metal foil backing are at risk for both heating and altered pharmacodynamics
- Difficulties have also been encountered when a patient requires physiological monitoring during the procedure.

BRAIN MRI

SEQUENCES IN CONVENTIONAL MRI

Intensity

- When describing most MRI sequences we refer to the shade of grey of tissues or fluid with the word *intensity*, leading to the following absolute terms:


High signal intensity
white
Intermediate signal intensity
Gray
Low signal intensity
Black

Images are described by signal intensity ("hyper-" bright, "hypo-" dark)

Often we refer to the appearance by relative terms:

- Hyperintense = brighter than the thing we are comparing it to
- Isointense = same brightness as the thing we are comparing it to
- Hypointense = darker than the thing we are comparing it to

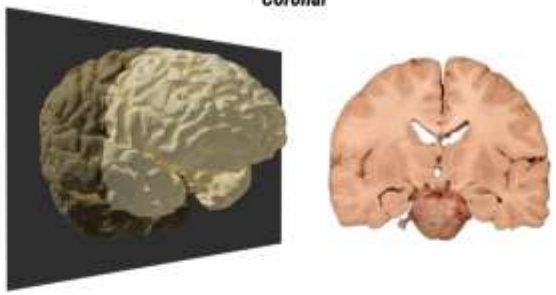
Orientation in the CNS

Planes of Orientation:

- Coronal
- Horizontal
- Sagittal

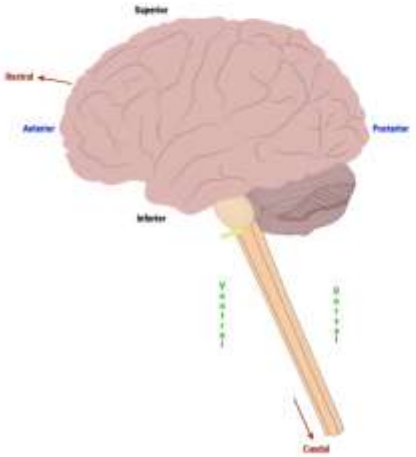
Directions:

- Caudal - Rostral
- Dorsal - Ventral
- Superior - Inferior
- Anterior - Posterior

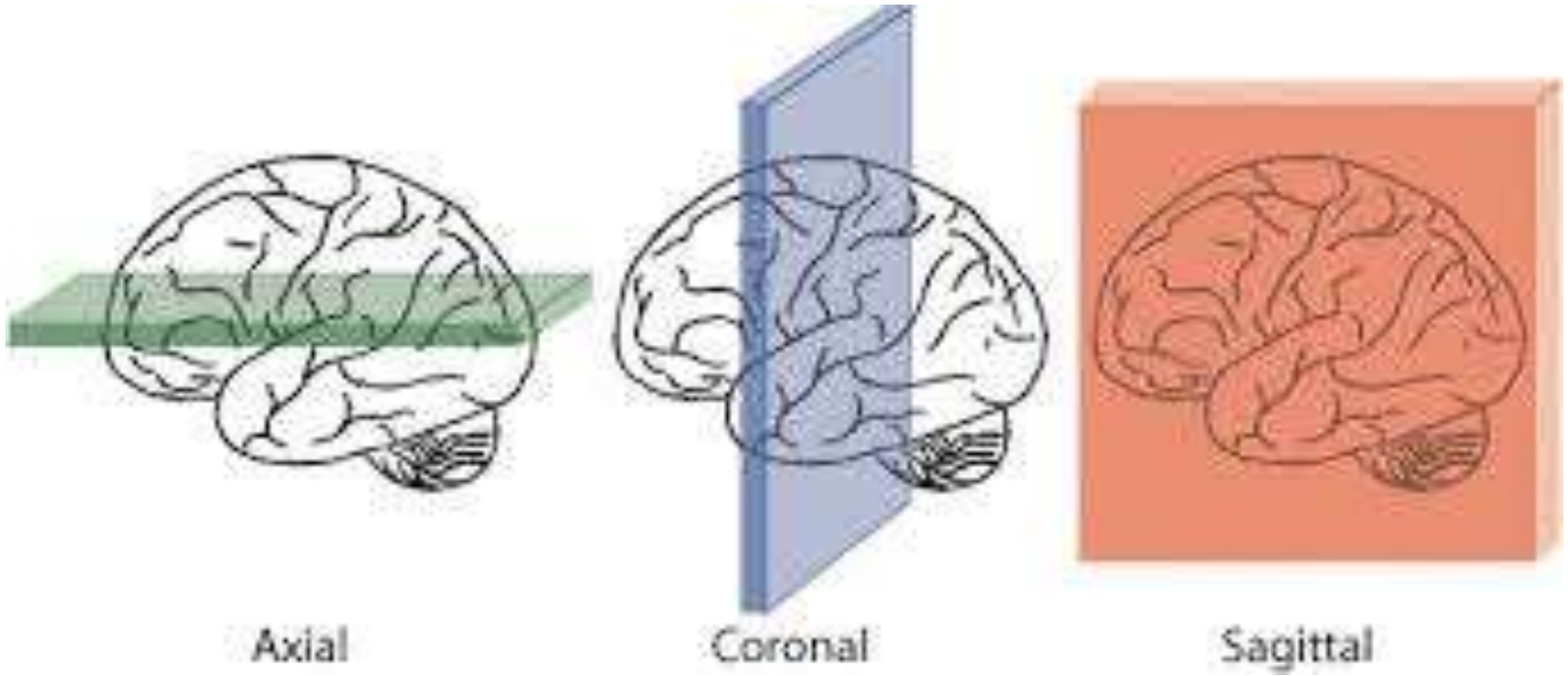


Coronal

Horizontal



Sagittal


Axial
Coronal
Sagittal

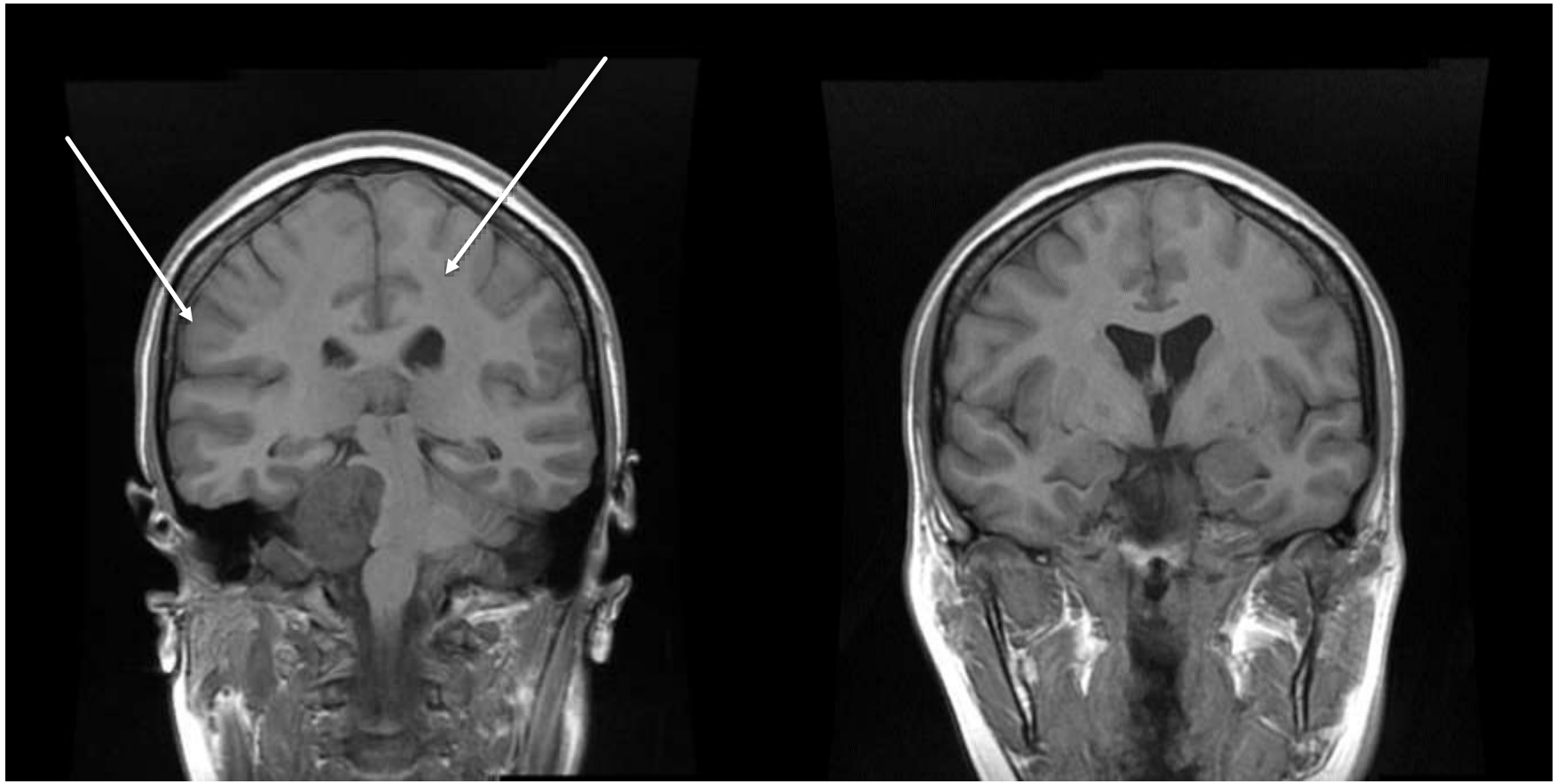
T1 WEIGHTED SEQUENCES

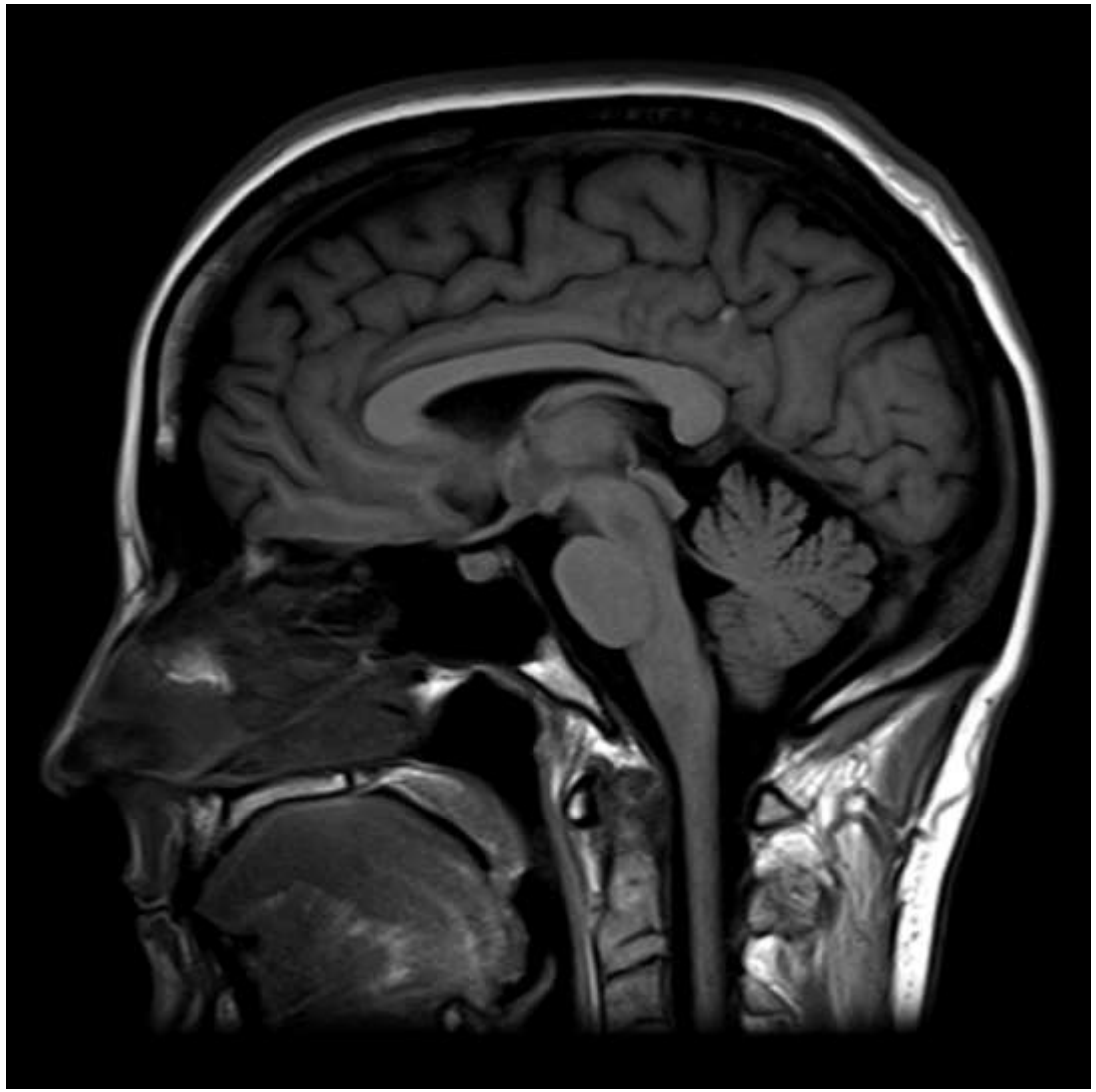
- Tissues with bound hydrogen protons (such as fat) give off high signal and appear bright
- **Fluids** containing large pools of free hydrogen protons such as cerebrospinal fluid (CSF) give off low signal and appear **dark or black**
- The large difference between T1 values of CSF, gray matter, and white matter produces high tissue contrast necessary for evaluating areas of subtle changes in **gray matter structure and volume**

T1 WEIGHTED SEQUENCES

part of almost all MRI protocols and are best thought of as the most **'anatomical' of images**

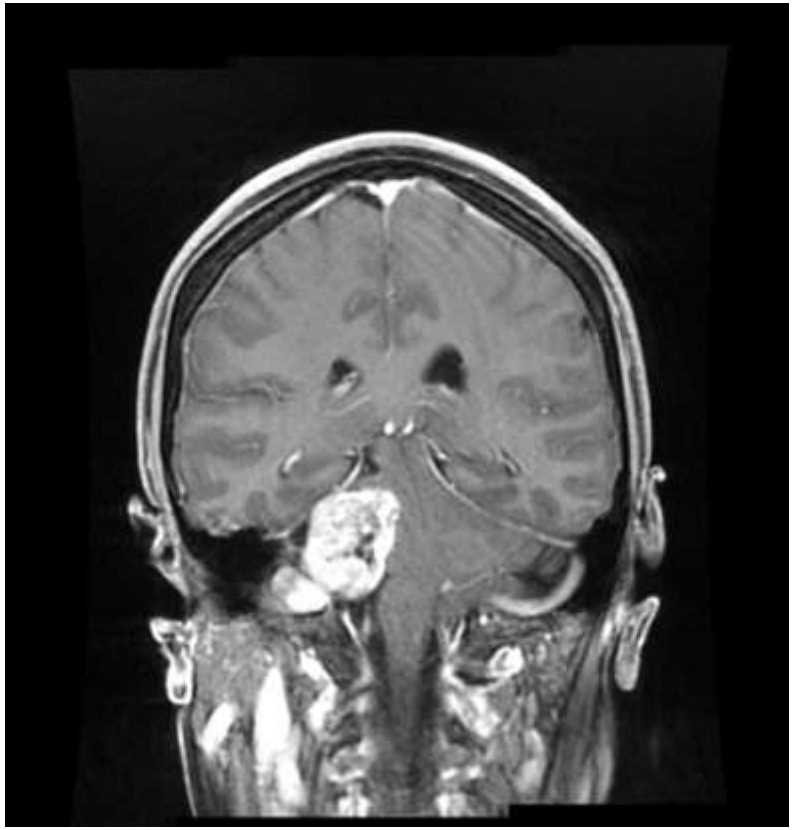
Brain gray matter	• Intermediate signal intensity (gray)
White matter	• Hyper intense compared to gray matter (white-ish)
Fluid (eg csf)	• low signal intensity (black)

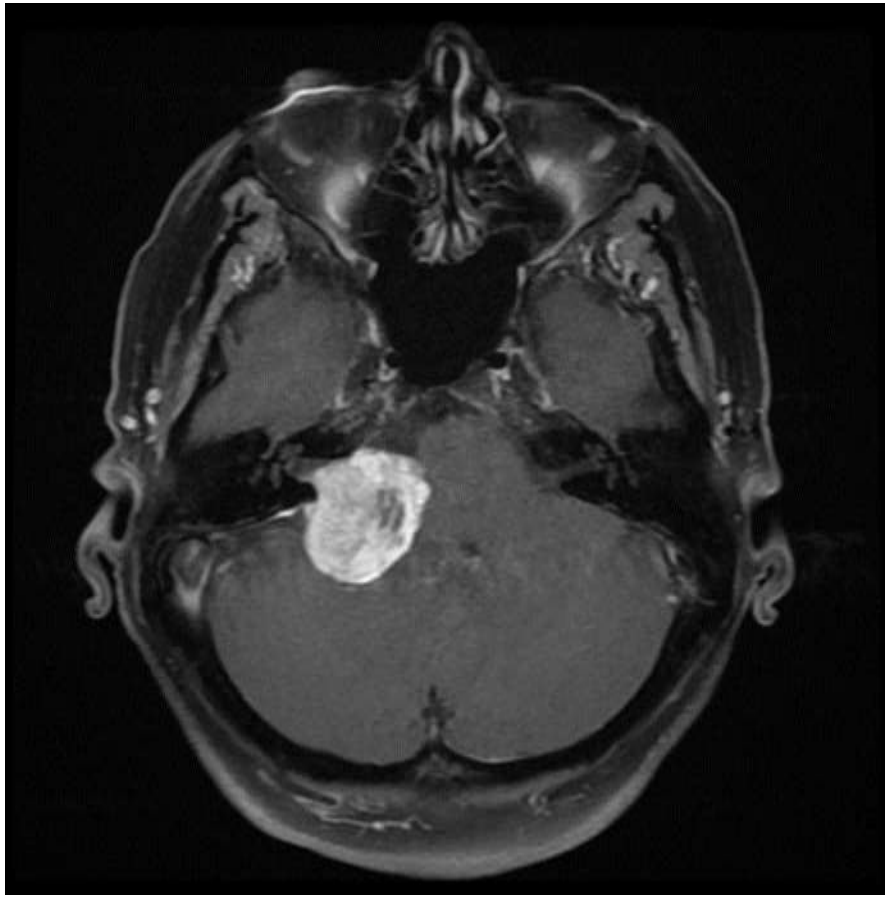




CONTRAST ENHANCED

- The most commonly used contrast agents in MRI are gadolinium based
- The contrast is injected intravenously (typically 5-15 mL) and scans are obtained a few minutes after administration
- Pathological tissues (tumors, areas of inflammation / infection) will demonstrate accumulation of contrast (mostly due to leaky blood vessels) and therefore appear as **brighter than surrounding tissue**

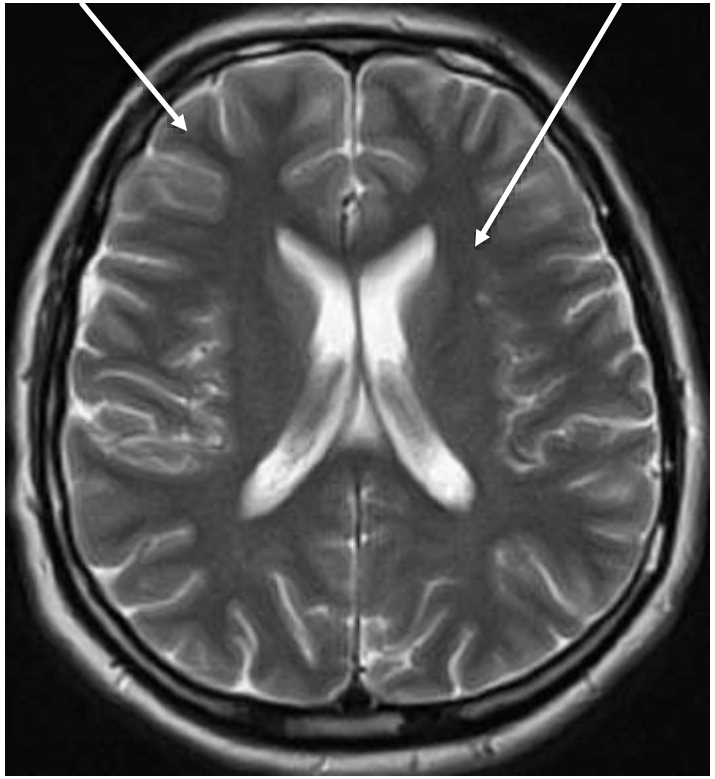


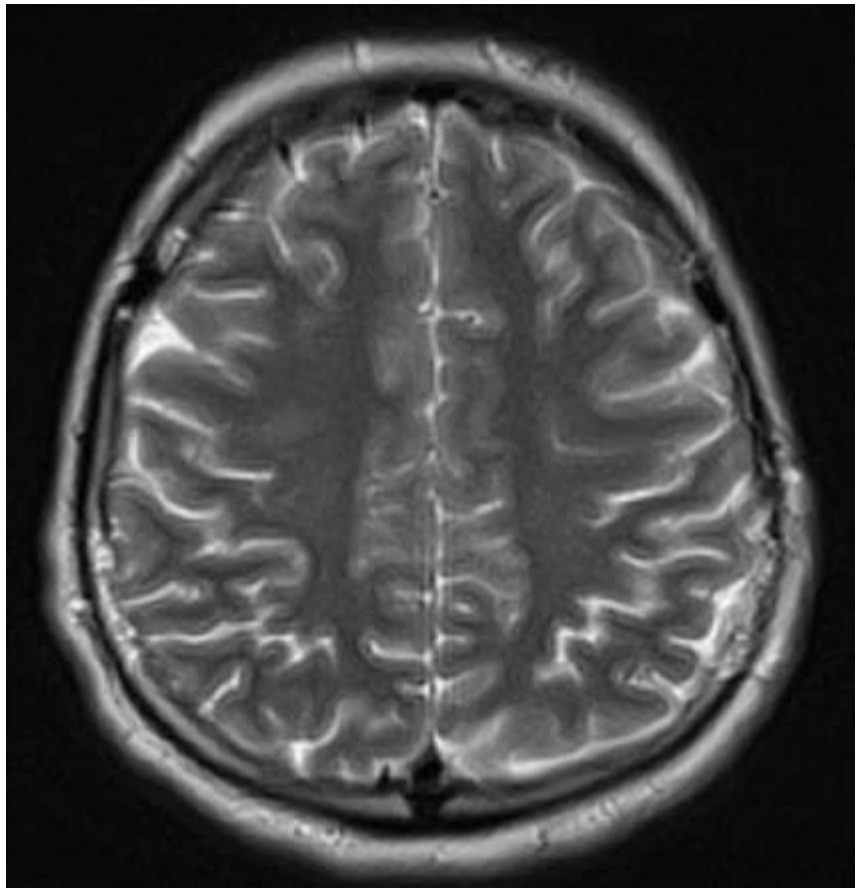


T2 WEIGHTED SEQUENCES

Grey matter	• Intermediate signal intensity (grey)
white matter	• Hypointense compared to grey matter (dark-ish)
Fluid (e.g. CSF)	• High signal intensity (white)

T2 WEIGHTED SEQUENCES





FLAIR (FLUID ATTENUATION INVERSION RECOVERY

- commonly used sequence
- **Similar to T2**, but the fluid is darker or "suppressed"
- Useful for areas of edema or inflammation
- Identify plaques in multiple sclerosis (especially periventricular)

FLAIR (FLUID ATTENUATION INVERSION RECOVERY

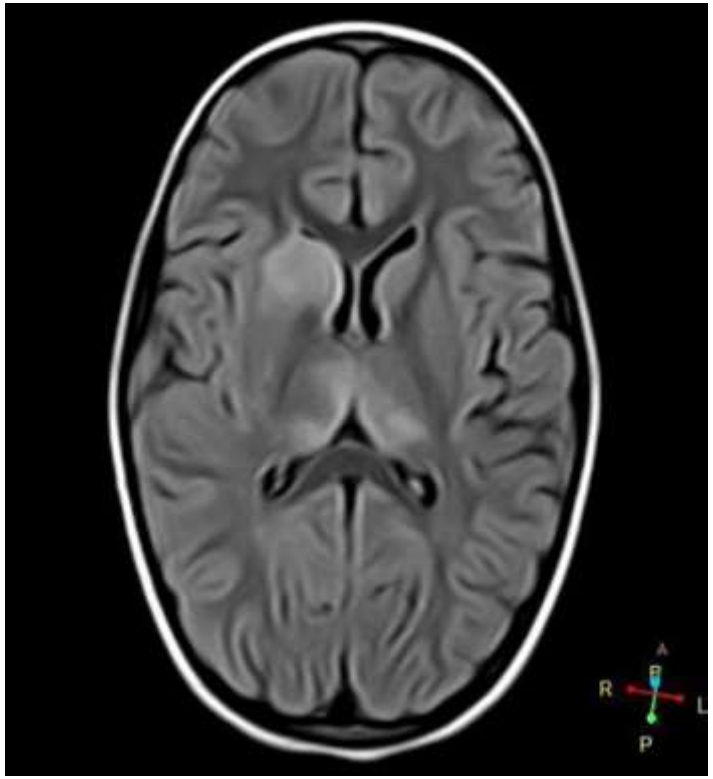
- Similarly in the brain, we often want to detect parenchymal edema without the glaring high signal from CSF To do this we suppress CSF
- Importantly, at **first glance FLAIR images appear similar to T1 (CSF is dark)**

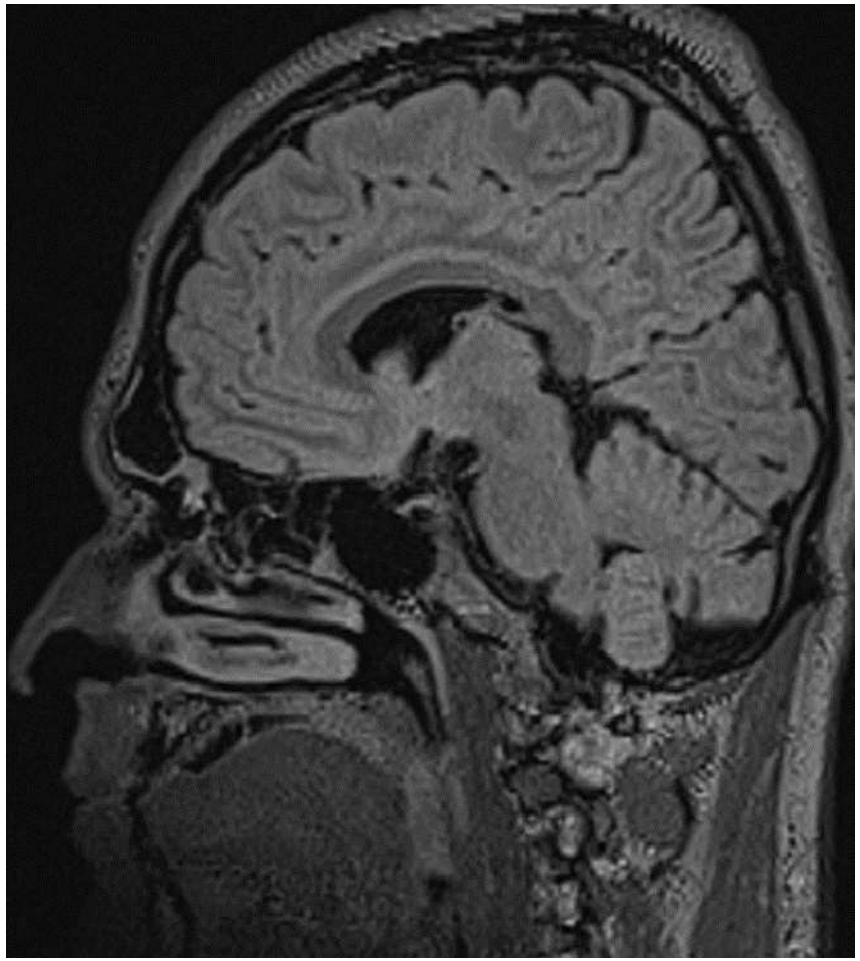
The best way to tell the two apart is to look at the grey-white matter

T1 sequences will have grey matter being darker than white matter

T2 weighted sequences, whether fluid attenuated or not, will have white matter being darker than grey matter

FLAIR (FLUID ATTENUATION INVERSION RECOVERY





DWI AND **ADC** (DIFFUSION-WEIGHTED IMAGING AND APPARENT DIFFUSION COEFFICIENT

- It is a relatively low resolution image with the following appearance

- Acute pathology (**ischemic stroke, cellular tumor, pus**) usually appears as increased signal denoting restricted diffusion

  - Grey matter: Intermediate signal intensity (grey)
  - White matter: Slightly hypointense compared to grey matter
  - CSF: low signal (black)

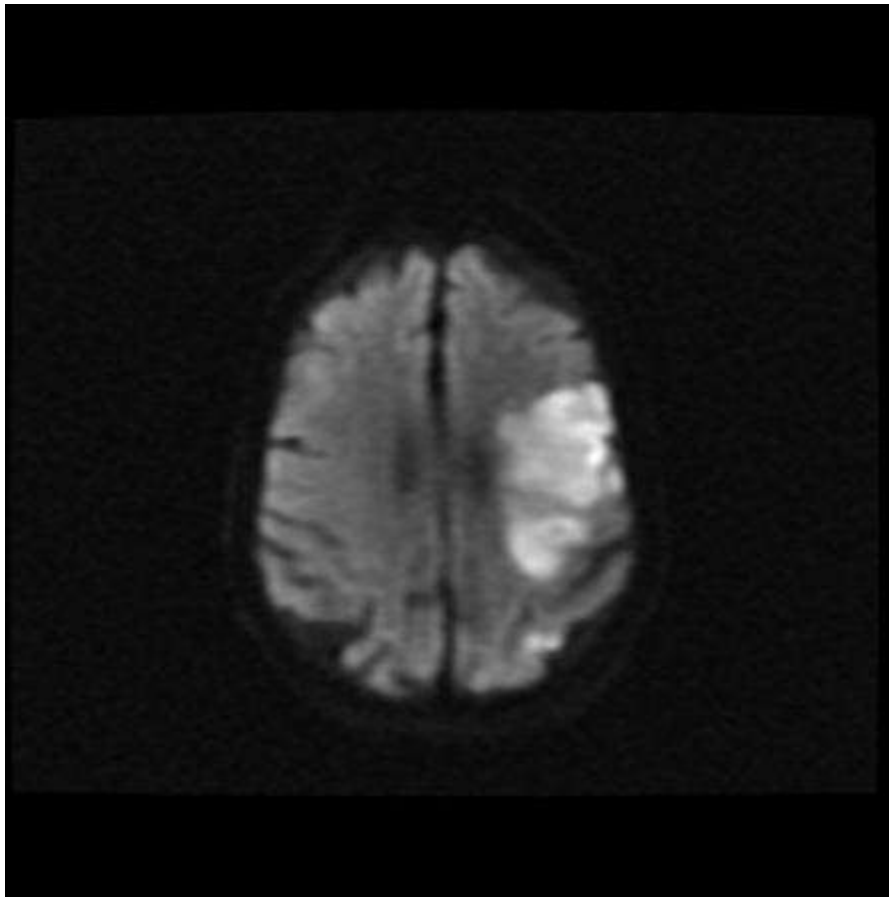
ADC

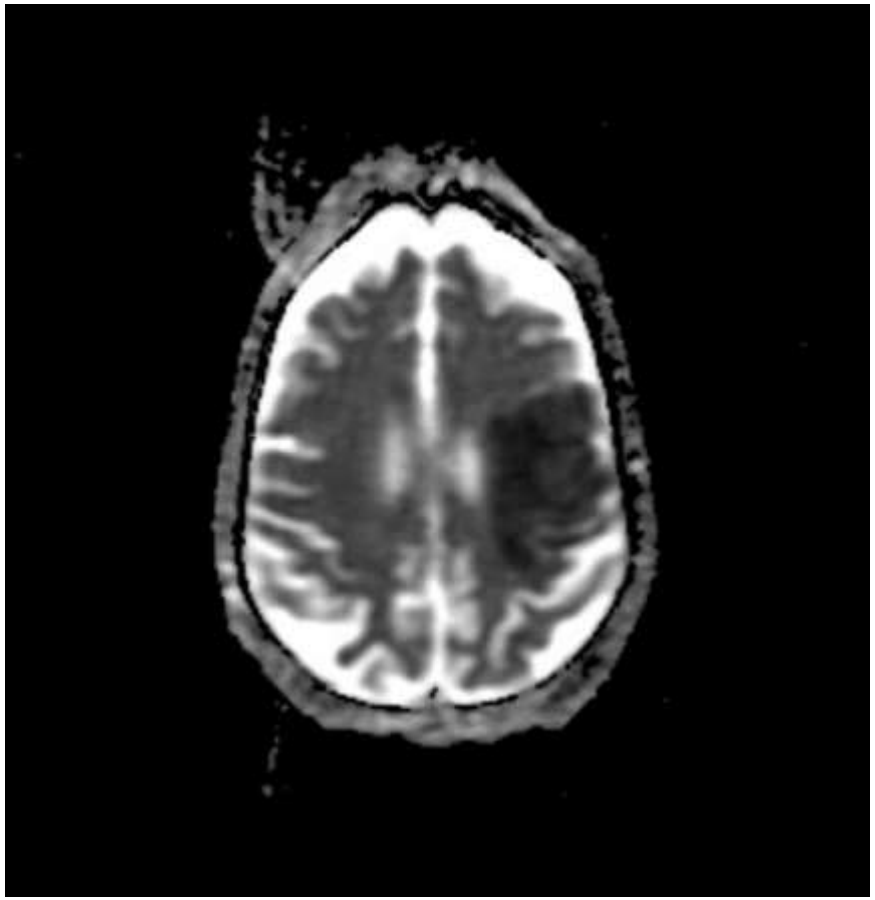
- Apparent diffusion coefficient maps (ADC) are images representing the actual diffusion values of the tissue without T2 effects. They are therefore much more useful, and objective measures of diffusion values can be obtained, however they are much less pretty to look at. They appear basically as grayscale inverted DWI images.

- They are relatively low resolution images with the following appearances:
  - grey matter: intermediate signal intensity (grey)
  - white matter: slightly hyperintense compared to grey matter
  - CSF: high signal (white)

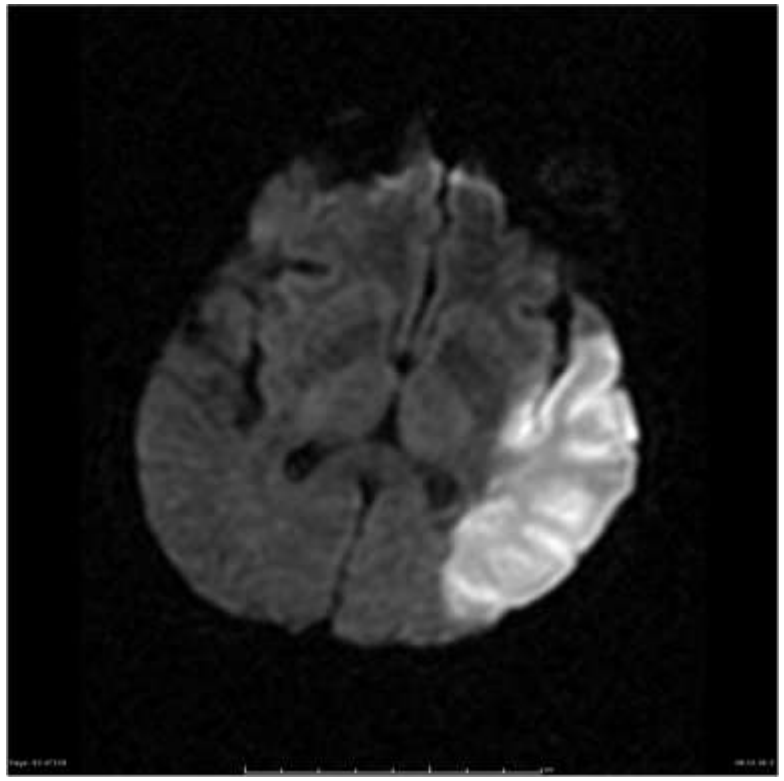
DWI AND **ADC** (DIFFUSION-WEIGHTED IMAGING AND APPARENT DIFFUSION COEFFICIENT

- These "blocky" images show how easily water moves around
- Restricted diffusion occurs in stroke, abscesses and cellular tumors



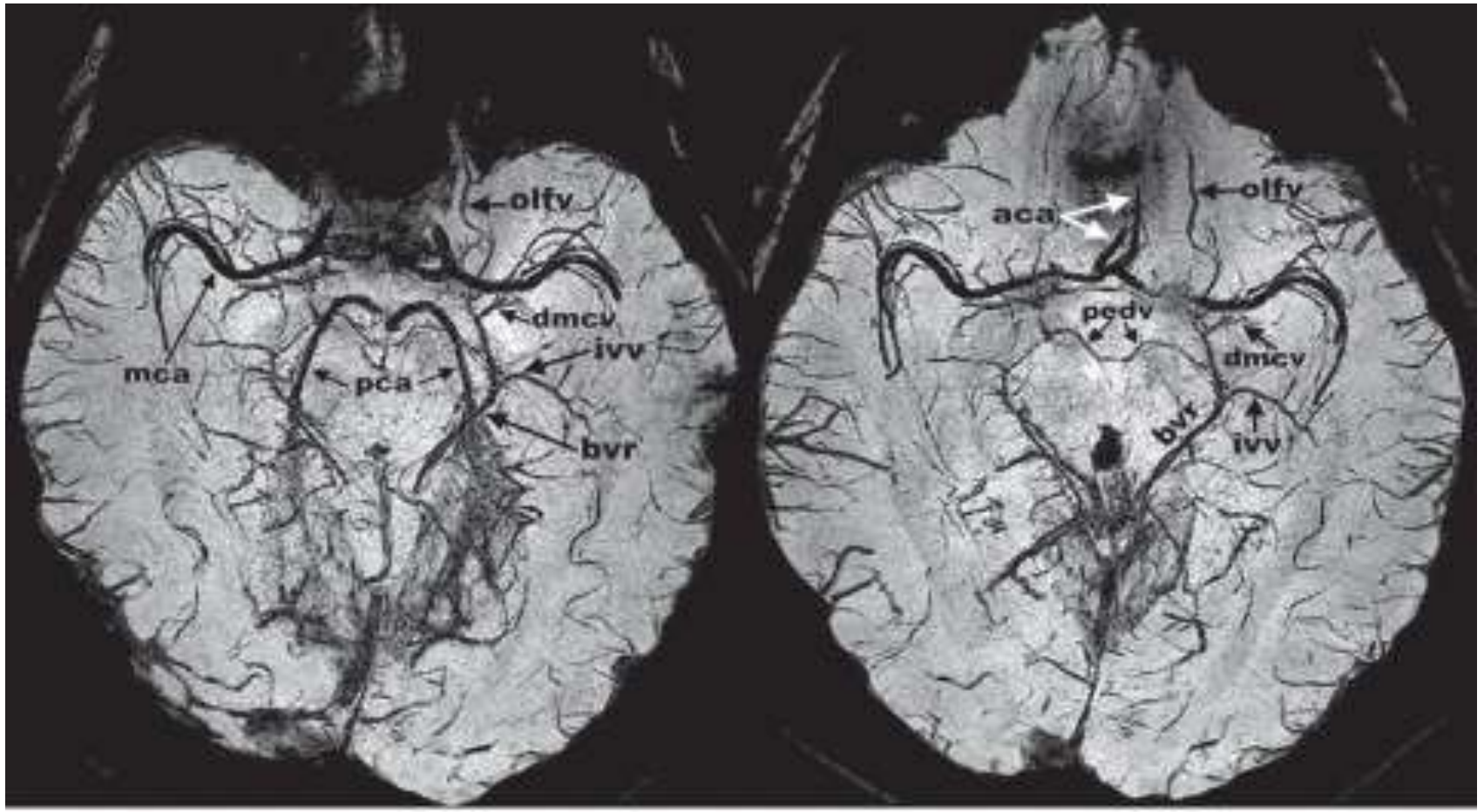


DWI IN LEFT PARIETAL ACUTE STROKE



SUSCEPTIBILITY SENSITIVE SEQUENCES

- Being able to detect blood products or calcium is important in many pathological processes
- Generally these sequences exploit what is referred to as T2* (T2 star) which is highly sensitive to small perturbations in the local magnetic field
- The most common use of SWI is for the identification of **small amounts of hemorrhage/blood products or calcium**, both of which may be inapparent on other MRI sequences

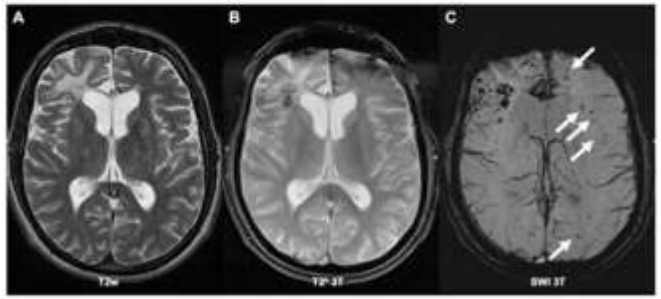


FIGURES 7.1a–e Normal SWI axial images of subject 1 beautifully demonstrating the venous anatomy. There is also visualization of the arterial system

SWI INDICATIONS

- Traumatic brain injury (TBI)
- Coagulopathic or other hemorrhagic disorders
- Vascular malformations
- Cerebral infarction
- Neoplasms
- Neurodegenerative disorders associated with intracranial calcification or iron deposition

Susceptibility-weighted Imaging: Technical Essentials and Clinical Neurologic Applications



Axial MRI scans in a patient with repetitive falls. *A,* T2 image depicts the posttraumatic gliosis in the right frontal pole but shows no microbleeds. *B,* T2* image depicts some evidence of hemosiderin and bleeding, and, *C,* SWI shows diffuse microbleeds, vascular damage in the frontal lobes, and veins because of their inherent deoxyhemoglobin content (arrows).

- Susceptibility-weighted imaging (SWI) is an increasingly important adjunct in diagnosing a variety of neurologic diseases and provides a powerful tool to depict and help characterize microbleeds, veins, and other sources of susceptibility.
- SWI and related sequences improve the depiction of lesions and signs already known from standard T2*-weighted imaging, including cerebral microbleeds, superficial siderosis, iron deposition, and vascular diseases.

Haller S et al. Published Online: February 23, 2021
https://doi.org/10.1148/radiol.2021203071
Radiology

Haller S. Published Online: February 23, 2021
https://doi.org/10.1148/radiol.2021203071
Radiology

NEURODEGENERATIVE DISORDERS

- It is well documented that iron content in the brain increases with age, particularly in the basal ganglia, and that abnormal levels of iron in the central nervous system (CNS) are seen in various neurodegenerative diseases.

- In fact, increased iron deposition occurs in Parkinson disease, Huntington disease, Alzheimer disease, multiple sclerosis (MS), amyotrophic lateral sclerosis, Hallervorden-Spatz syndrome, and pantothenate kinase-associated neurodegeneration

NEUROANATOMY

January 7, 2022 - Dr. Krebs (claudia.krebs@ubc.ca)

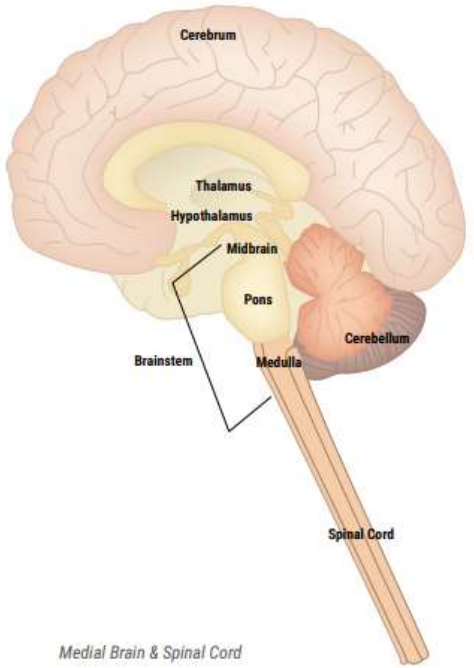
Gross Anatomy of the CNS

Surface Anatomy:

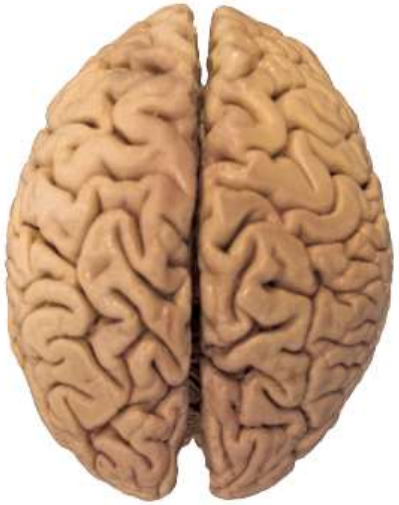
- Gyrus = ridge
- Sulcus = groove between ridges
- Fissure = deep sulcus ('fissure of Sylvius')

Brain:

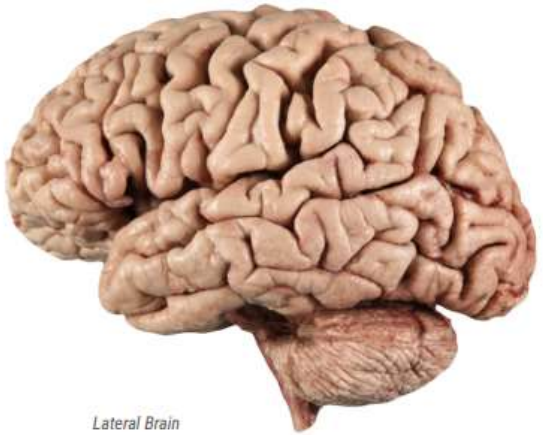
- Forebrain
  - telencephalon
    - cerebrum
    - basal ganglia
  - diencephalon
    - thalamus
    - hypothalamus
    - subthalamus



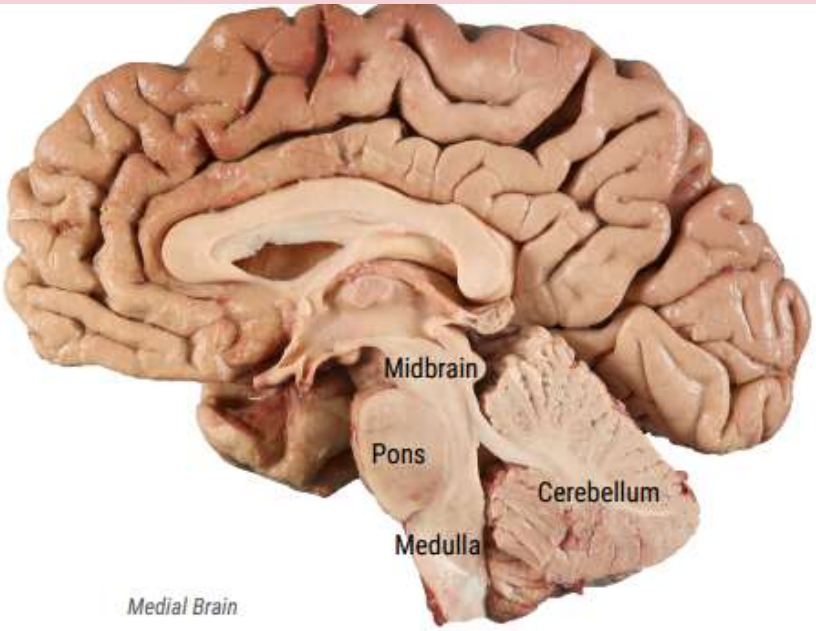
Medial Brain & Spinal Cord



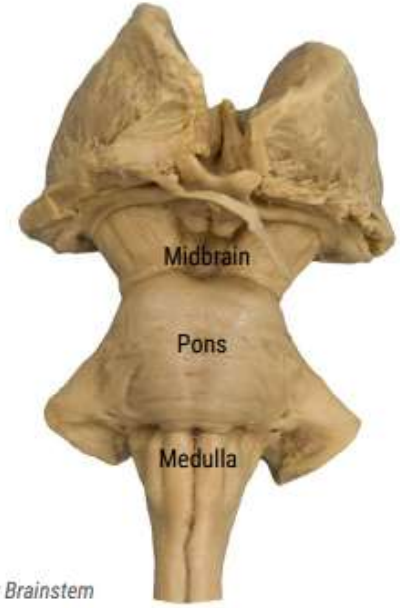
Superior Brain



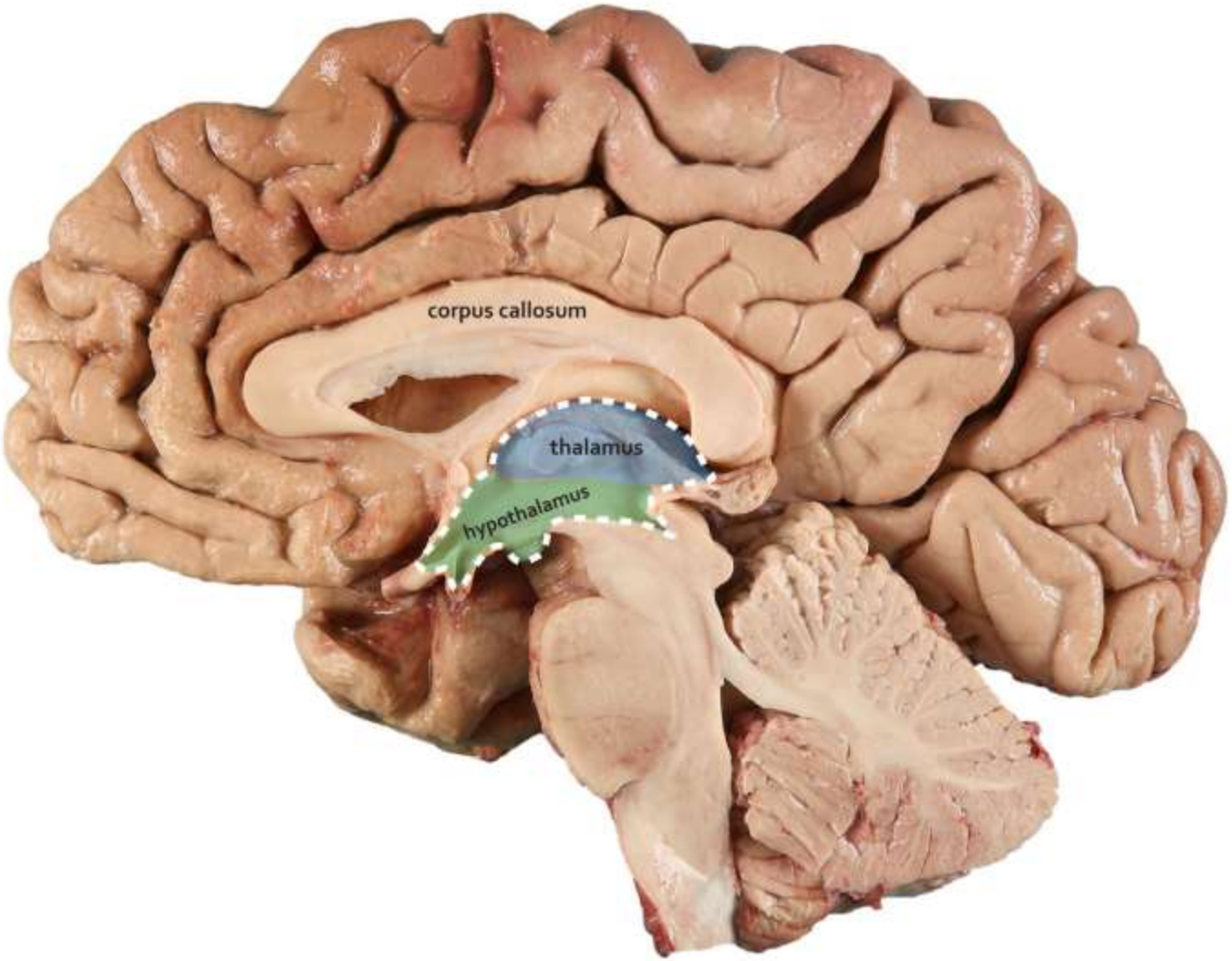
Lateral Brain



Medial Brain



Anterior Brainstem

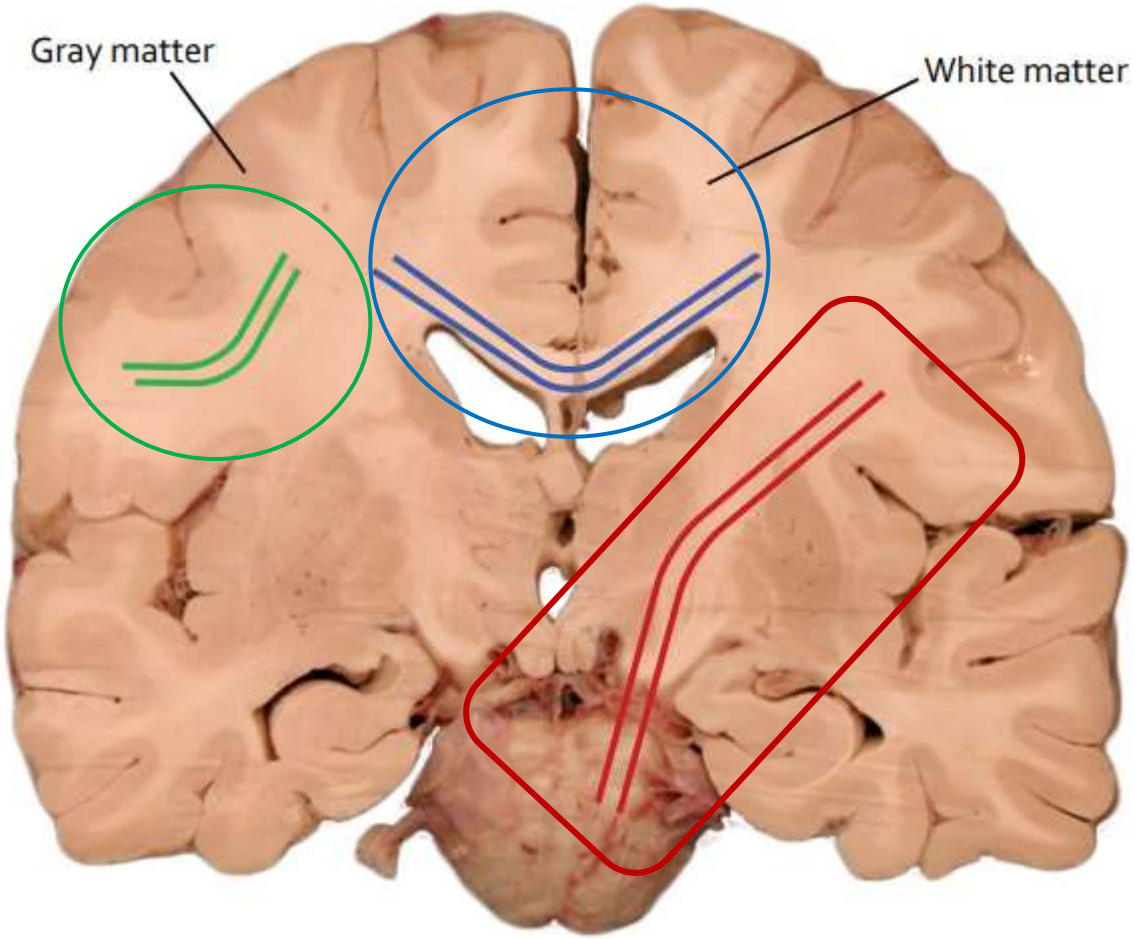


Diencephalon in Medial Brain

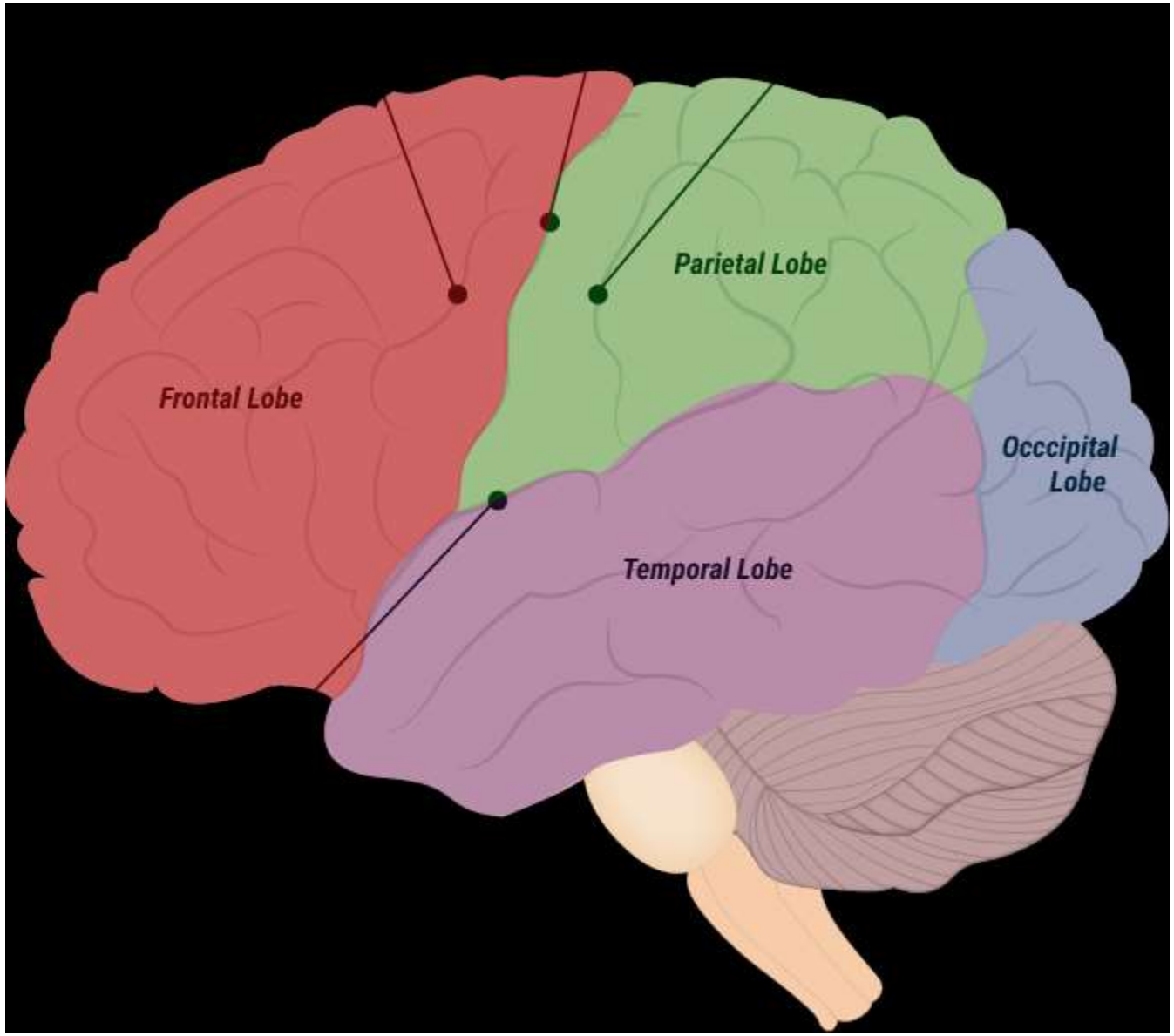
Association fibers
are confined to the same hemisphere. Short association fibers connect cortical areas in adjacent gyri; long association fibers pass between cortical areas that are further removed from each other.

Commissural fibers
originate from cell bodies in the cortex of one hemisphere, cross the midline, and synapse with neurons in corresponding areas of cortex of the other hemisphere. The largest bundle of commissural fibers is the corpus callosum.

Projection fibers
project to and from the cortex.



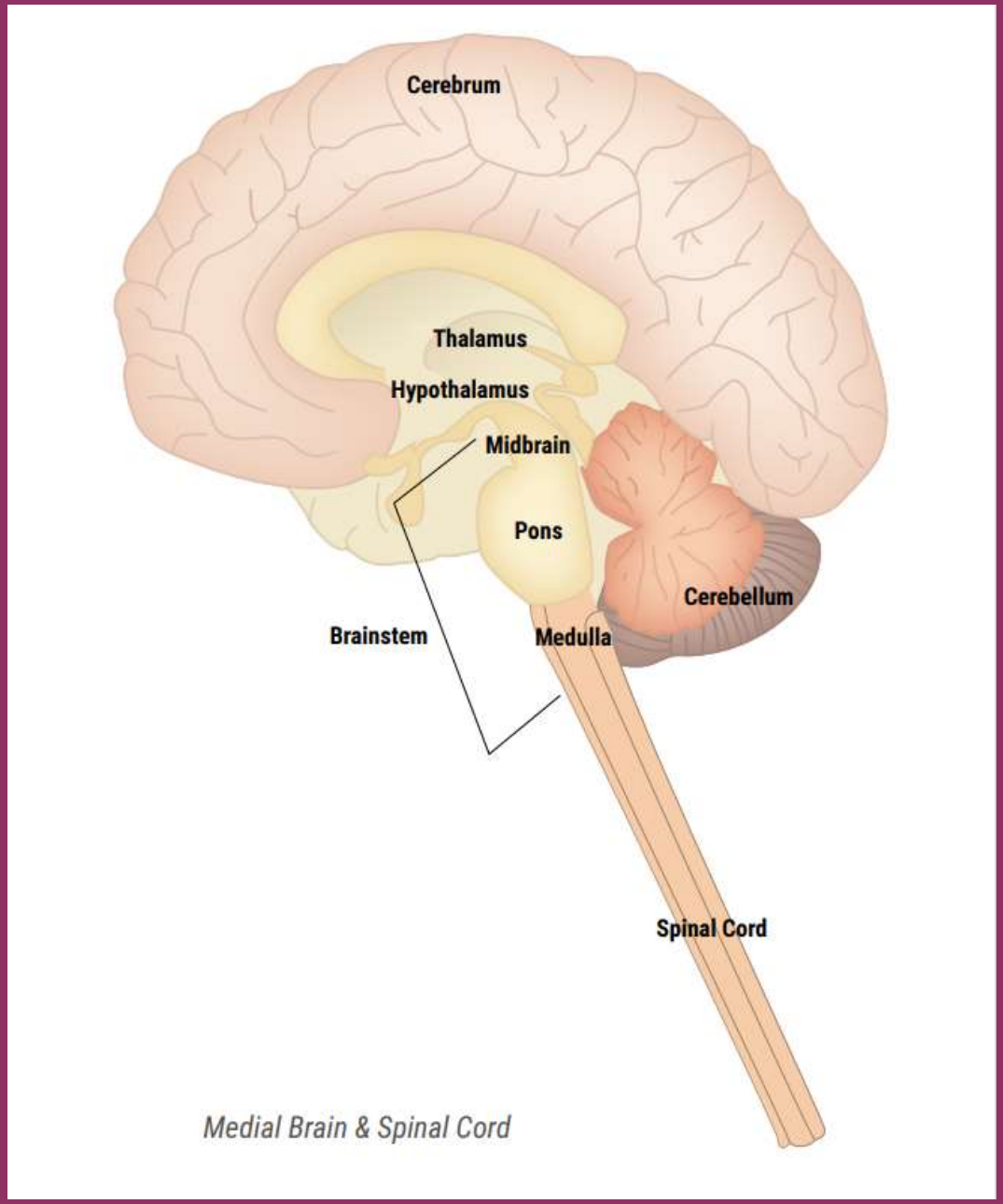
Coronal Brain Section


Parietal Lobe
Frontal Lobe
Occcipital Lobe
Temporal Lobe

GROSS ANATOMY OF THE CNS

Surface Anatomy:

- Gyrus = ridge
- Sulcus = groove between ridges
- Fissure = deep sulcus (‘fissure of Sylvius’)

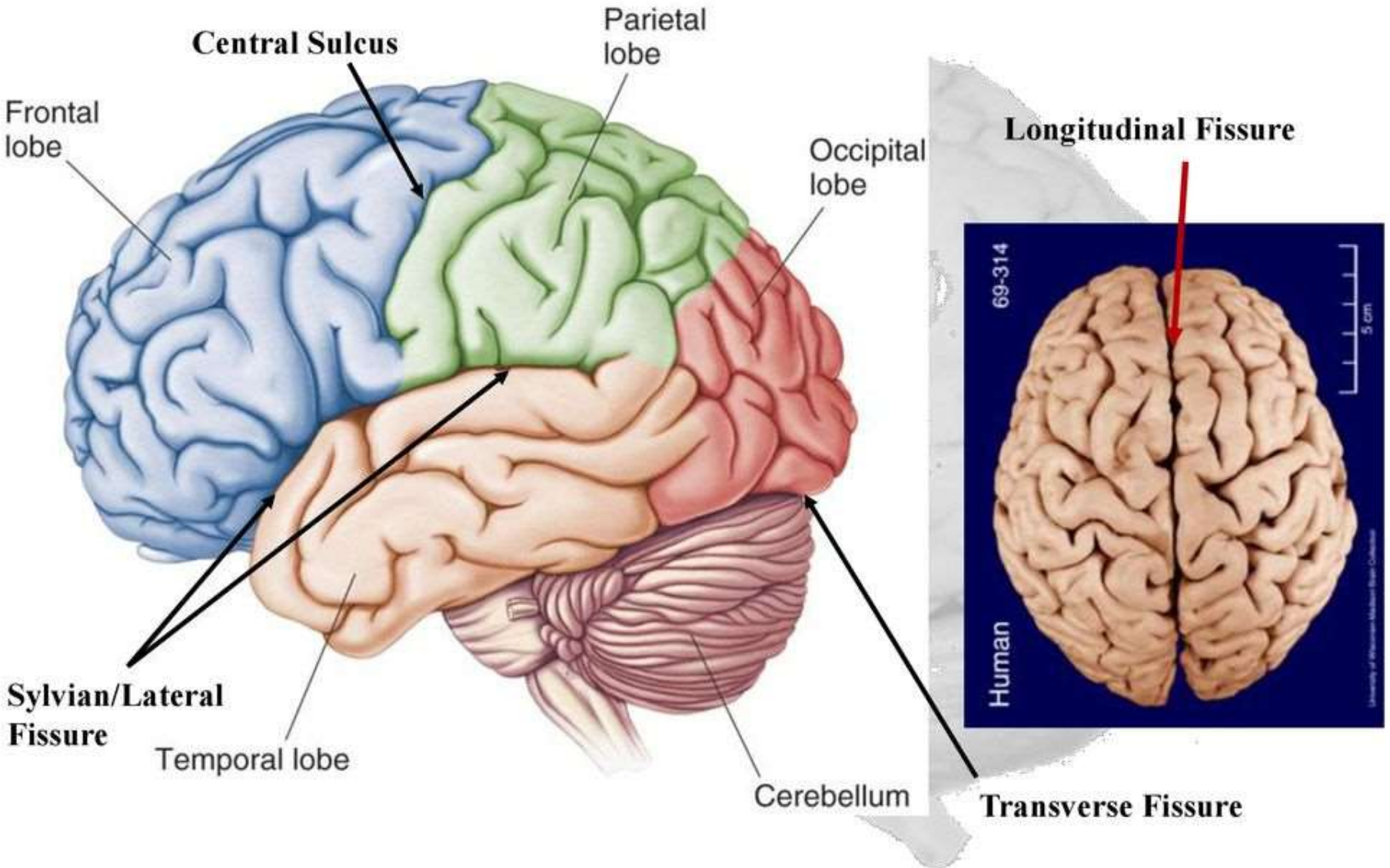


Medial Brain & Spinal Cord

- Cerebral hemispheres are composed of four major (frontal, temporal, parietal, and occipital) lobes

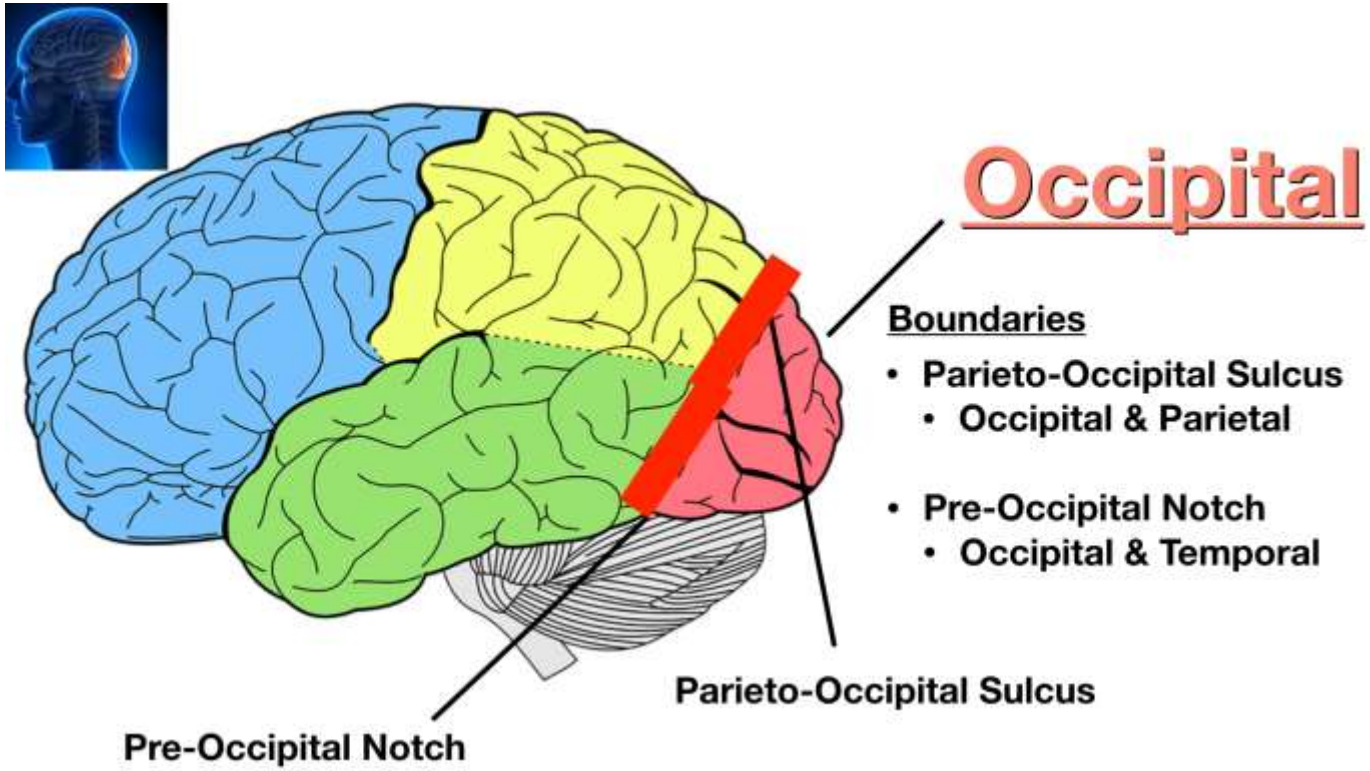
- When examining brain surface from the lateral aspect, we can appreciate the landmark sulci and fissures that divide the cerebral hemisphere into different lobes
- **Oblique fissure** that separates the frontal lobe from the temporal lobe anteriorly and temporal lobe from the parietal lobe posteriorly, in its depth lays the insular cortex
- **Central sulcus** that separates the frontal lobe from the parietal lobe,
- **Parieto-occipital sulcus** that separates the parietal lobe from the occipital lobe.

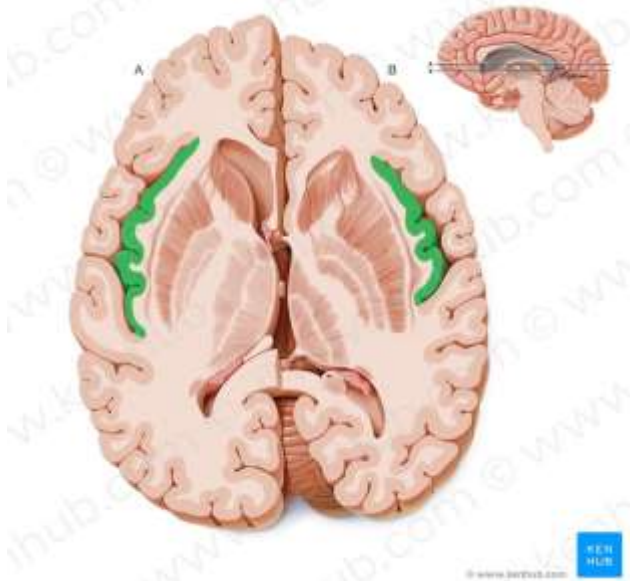
Specific Sulci/Fissures:

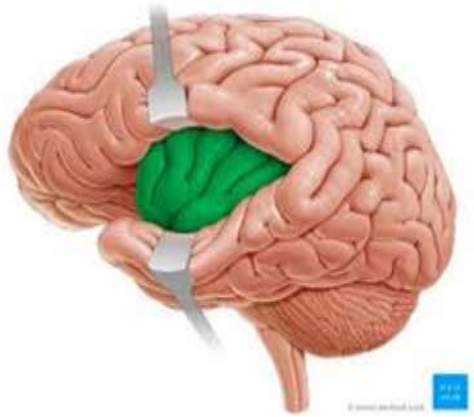


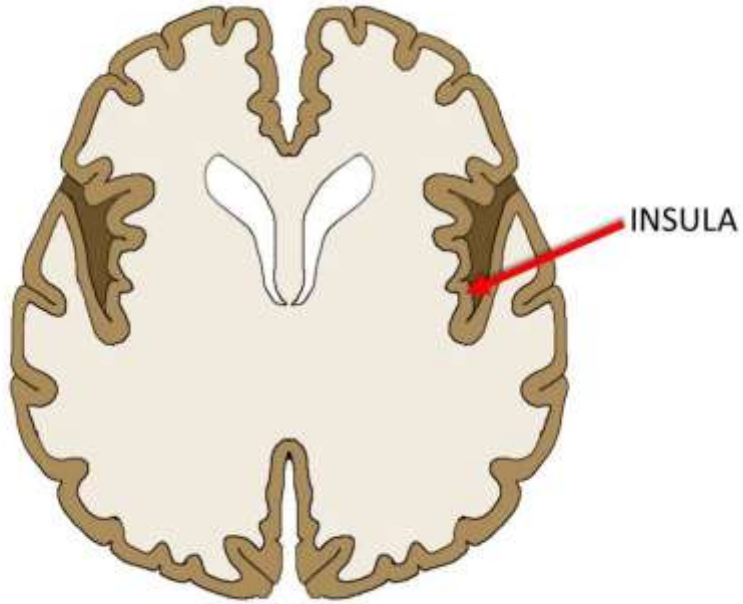
http://www.bioon.com/book/biology/whole/image/1/1-8.tif.jpg

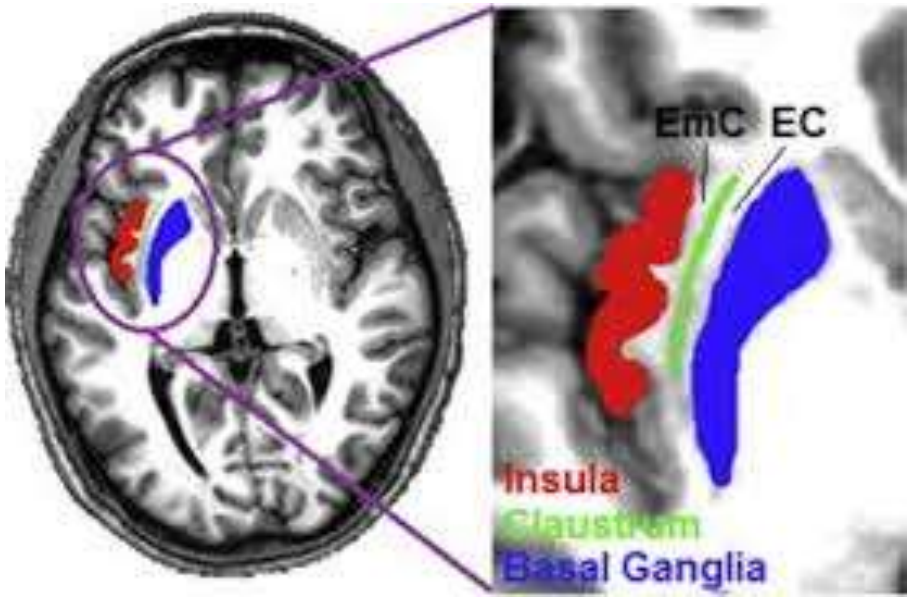
http://www.dalbsoutss.eq.edu.au/Sheepbrains_Mc/human_brain.gif

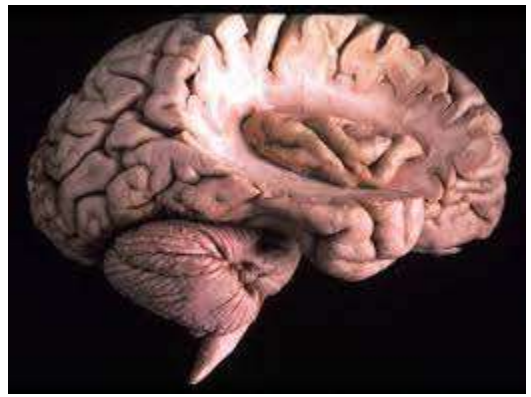

Occipital
Boundaries
• Parieto-Occipital Sulcus
• Occipital & Parietal
• Pre-Occipital Notch
• Occipital & Temporal
Parieto-Occipital Sulcus
Pre-Occipital Notch


A
B




INSULA


EmC
EC
Insula
Claustrum
Basal Ganglia



https://www.neuroanatomy.ca/horizontals.html

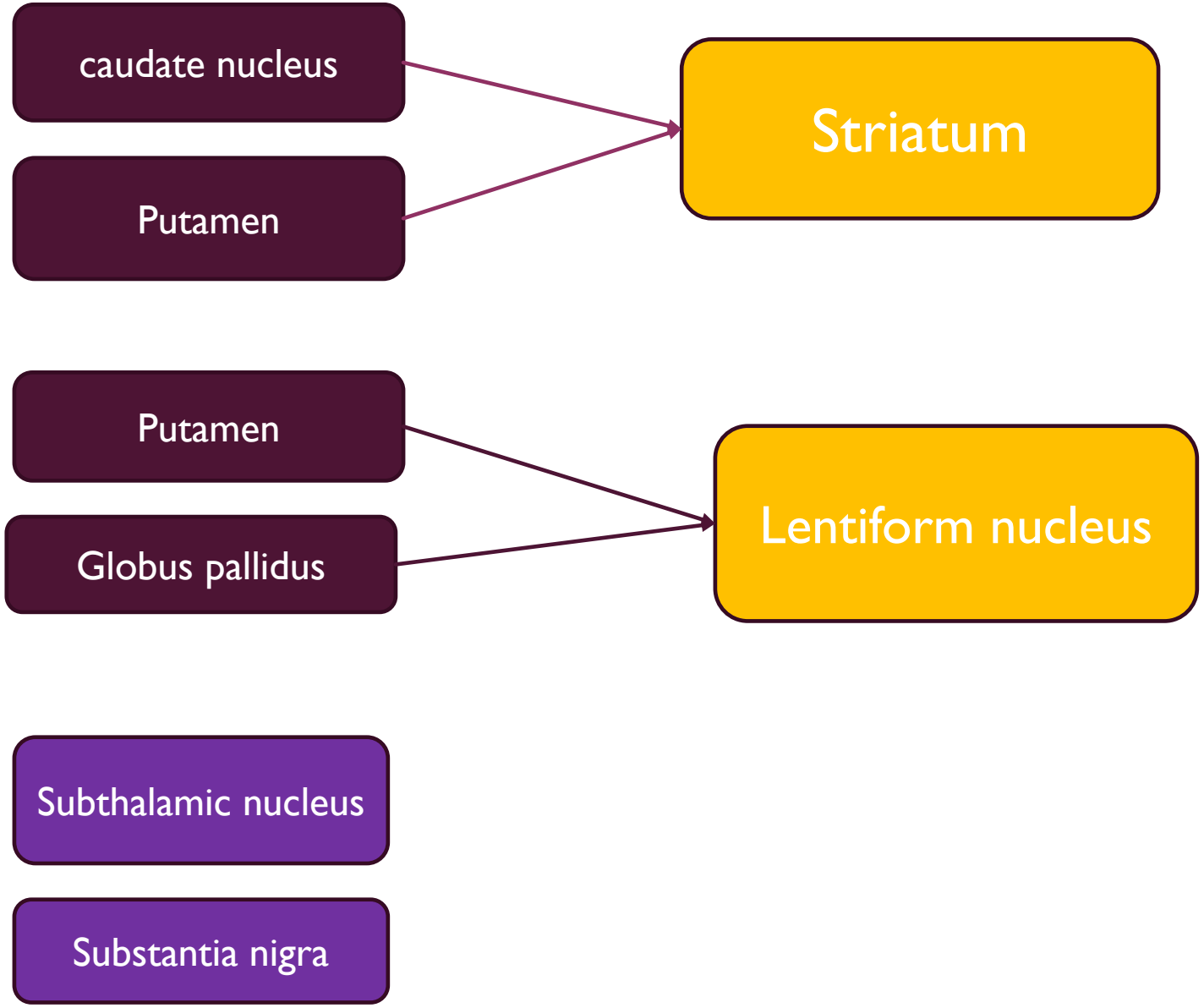
BASAL GANGLIA

BASAL GANGLIA

- The **basal ganglia** are a group of grey matter nuclei in the deep aspects of the brain that is interconnected with the cerebral cortex , thlami and brainstem

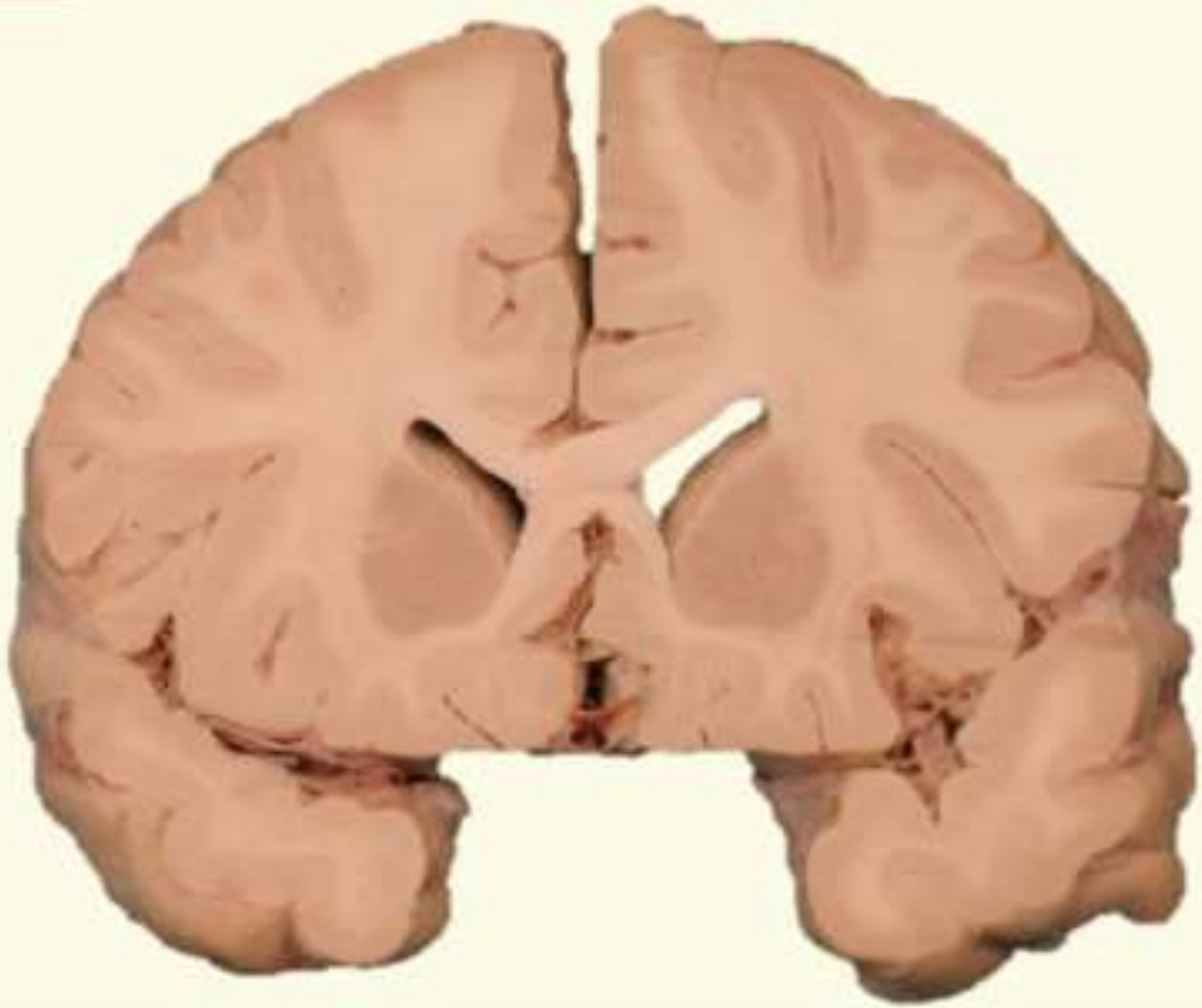
- Comprise a set of deep forebrain nuclei that integrate cortical activity into one behavioral (motor) output

Basal Ganglia: Conceptual Overview


caudate nucleus
Putamen
Striatum
Putamen
Globus pallidus
Lentiform nucleus
Subthalamic nucleus
Substantia nigra

BASAL GANGLIA in CROSS SECTION (CORONAL)

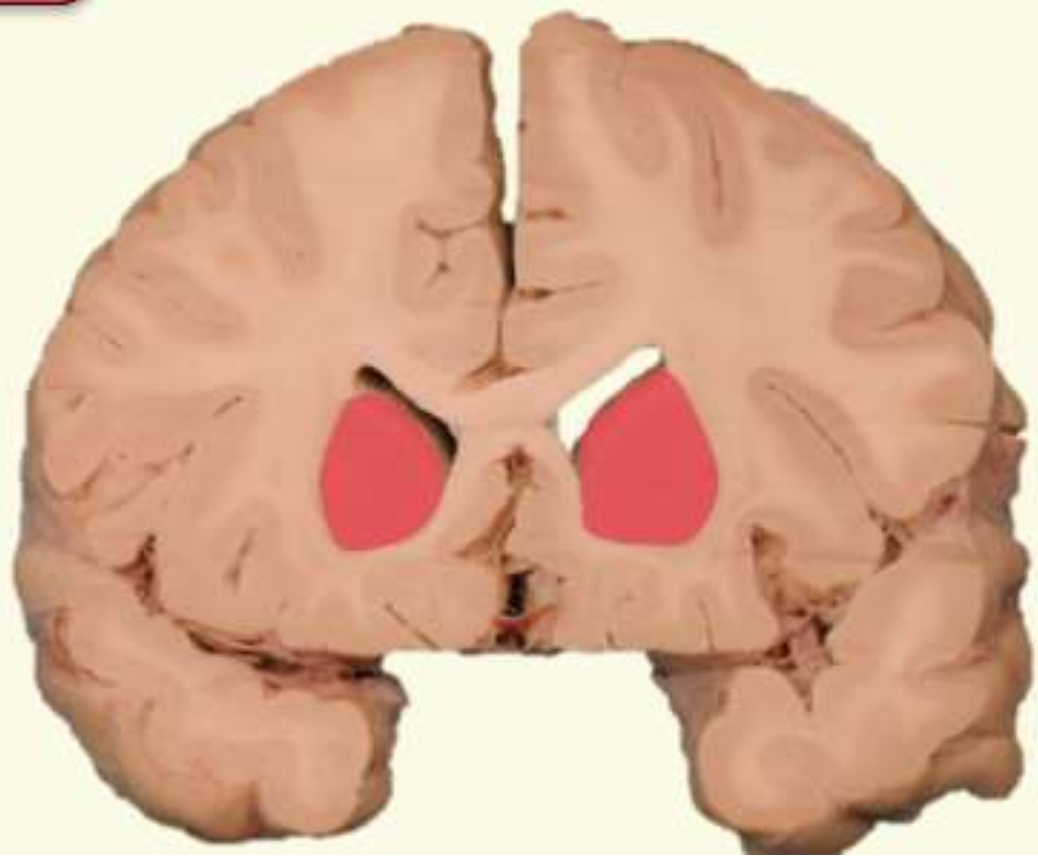
Head of
Caudate Nucleus



Basal Ganglia

BASAL GANGLIA in CROSS SECTION (CORONAL)

Head of
Caudate Nucleus



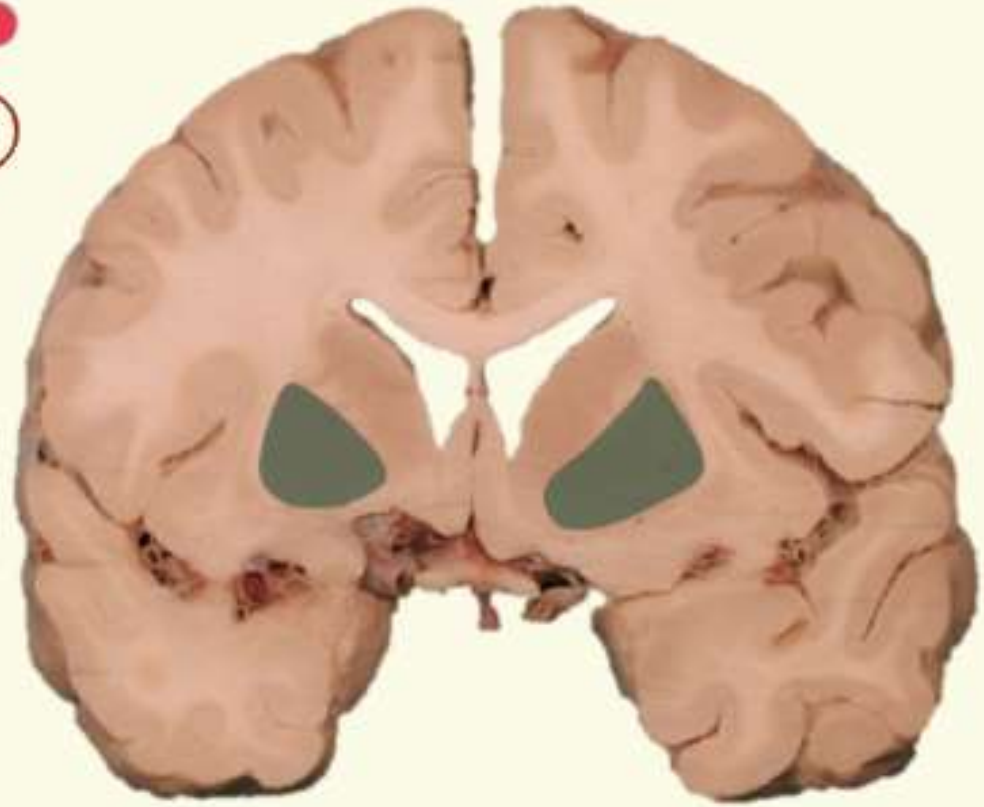
Basal Ganglia

BASAL GANGLIA in CROSS SECTION (CORONAL)

Putamen

Caudate Nucleus

Nucleus Accumbens



‹ PREV NEXT ›

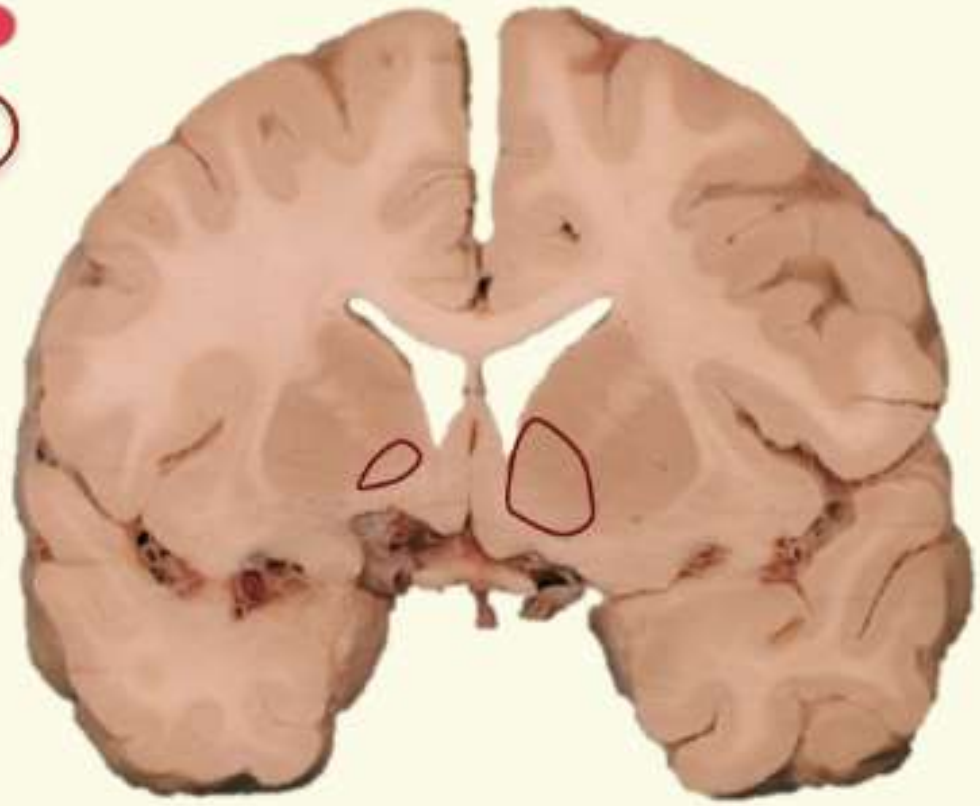
Basal Ganglia

BASAL GANGLIA in CROSS SECTION (CORONAL)

Putamen

Caudate Nucleus

Nucleus Accumbens



BASAL GANGLIA TERMINOLOGY

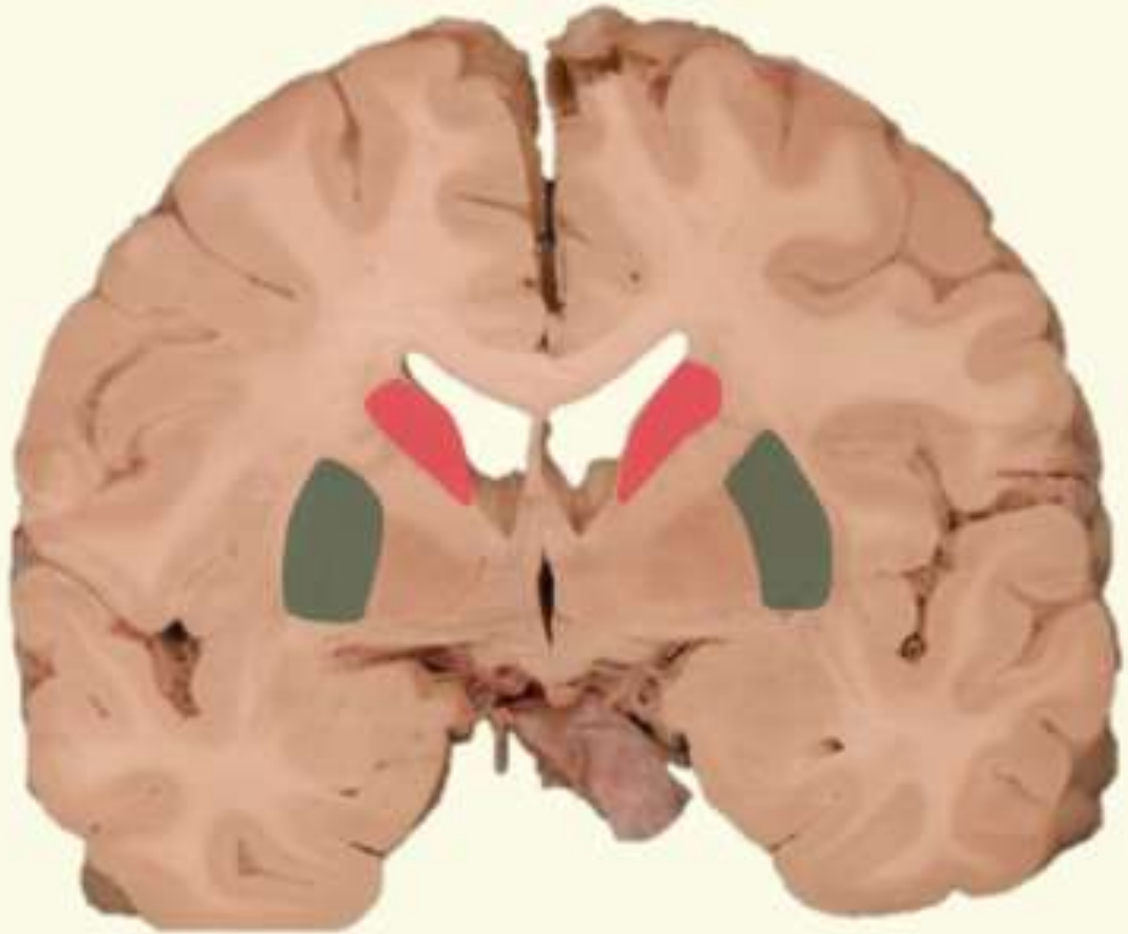
Parts of the basal ganglia can be referred to using different terms:

Lentiform Nucleus

Striatum

Caudate

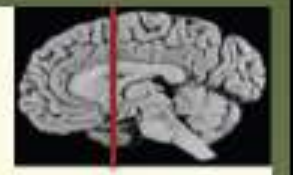
Putamen



Basal Ganglia

BASAL GANGLIA TERMINOLOGY

Parts of the basal ganglia can be referred to using different terms:

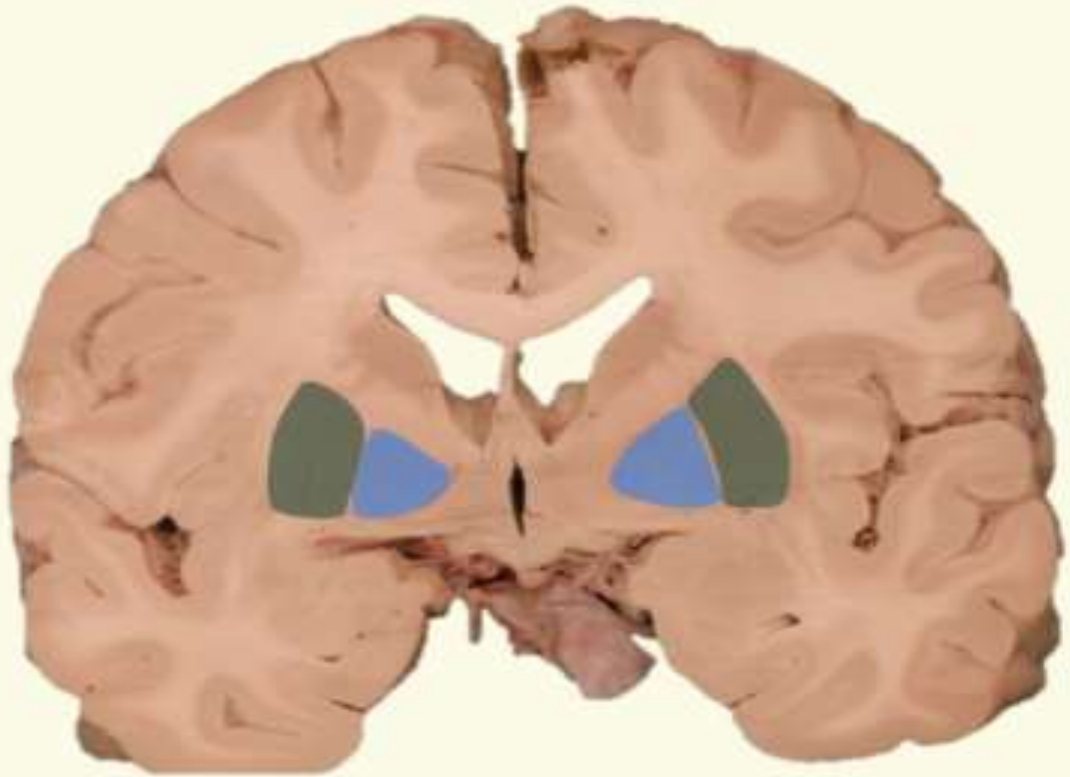


Lentiform Nucleus

Putamen

Globus pallidus

Striatum



< PREV NEXT >

Basal Ganglia

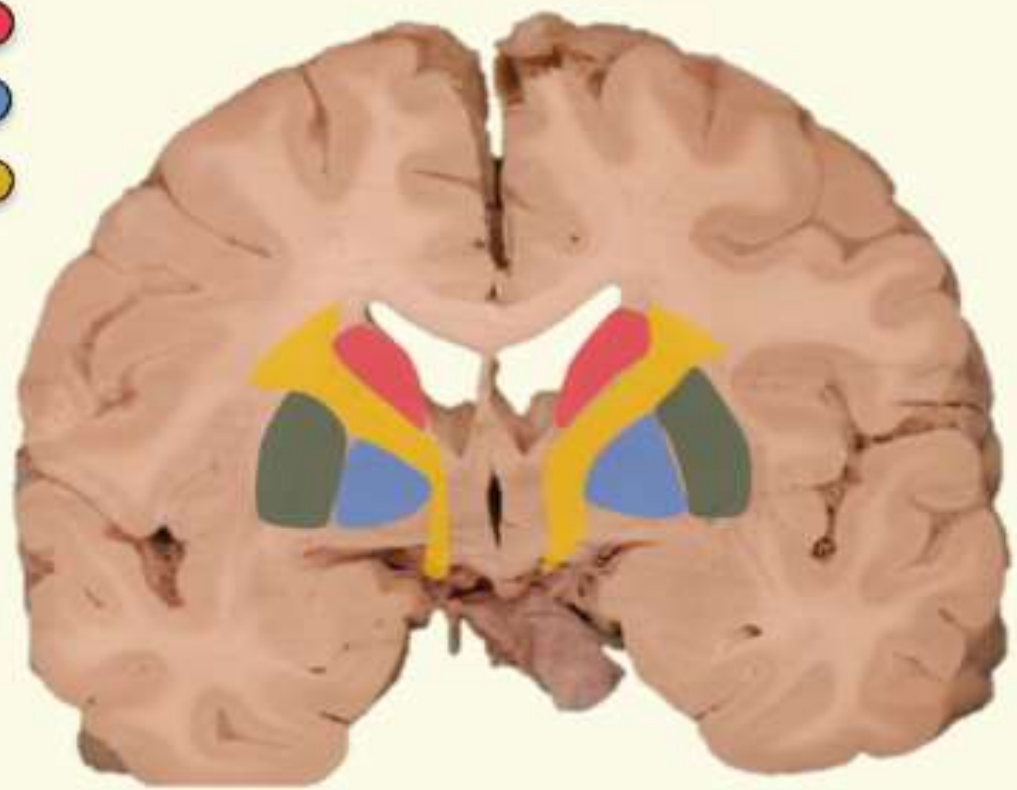
BASAL GANGLIA in CROSS SECTION (CORONAL)

Putamen

Caudate Nucleus

Globus Pallidus

Internal Capsule



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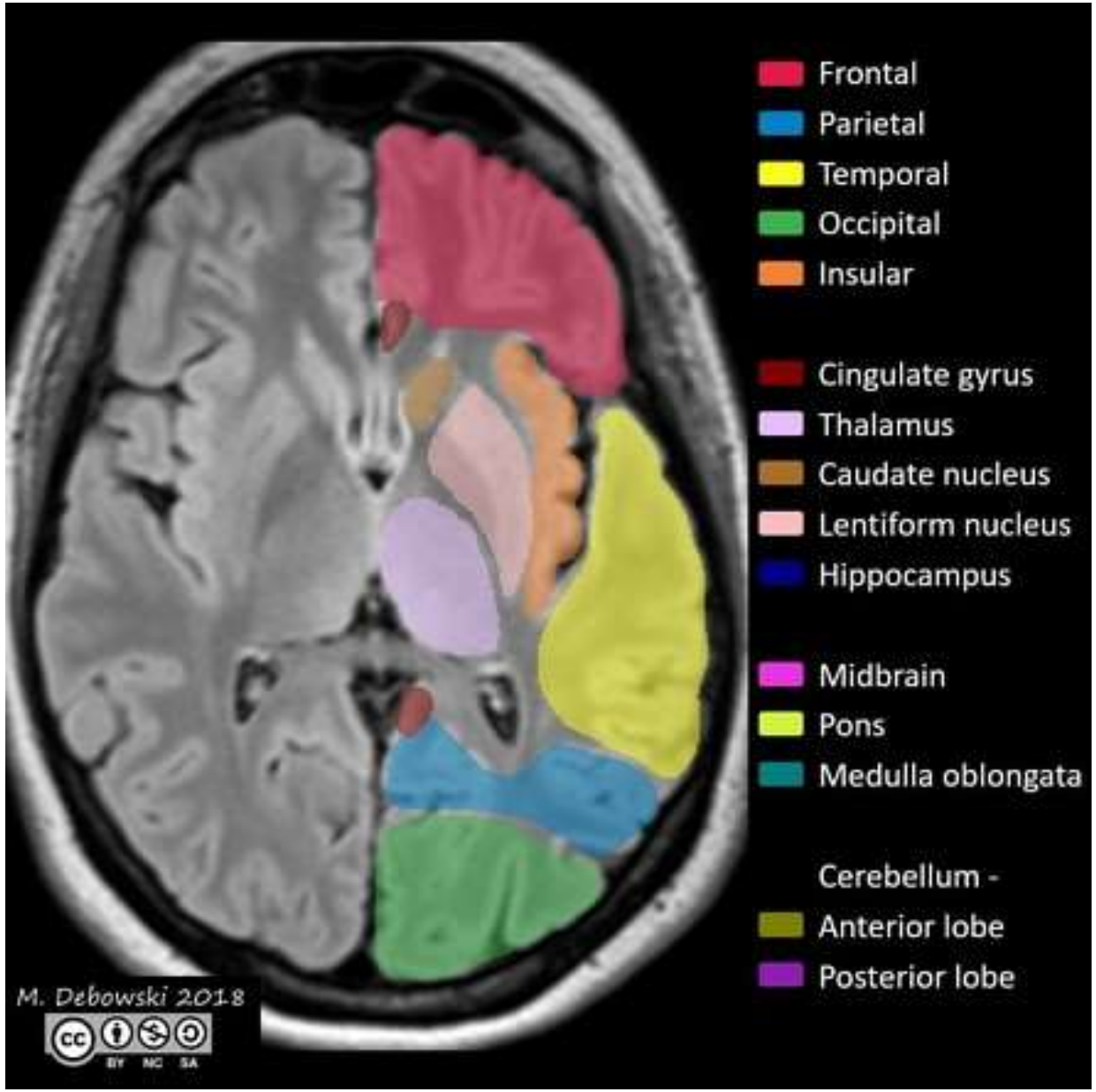
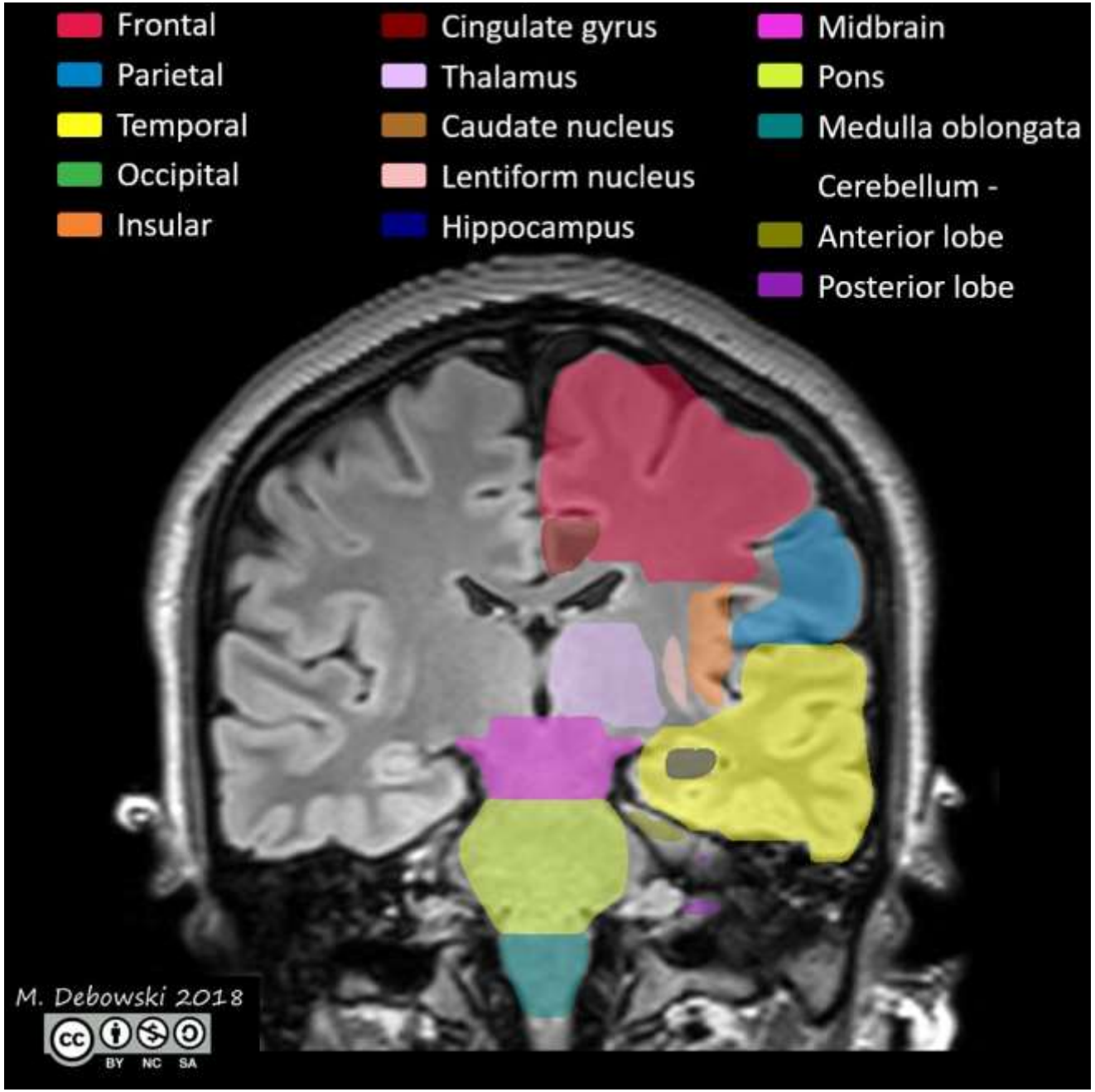
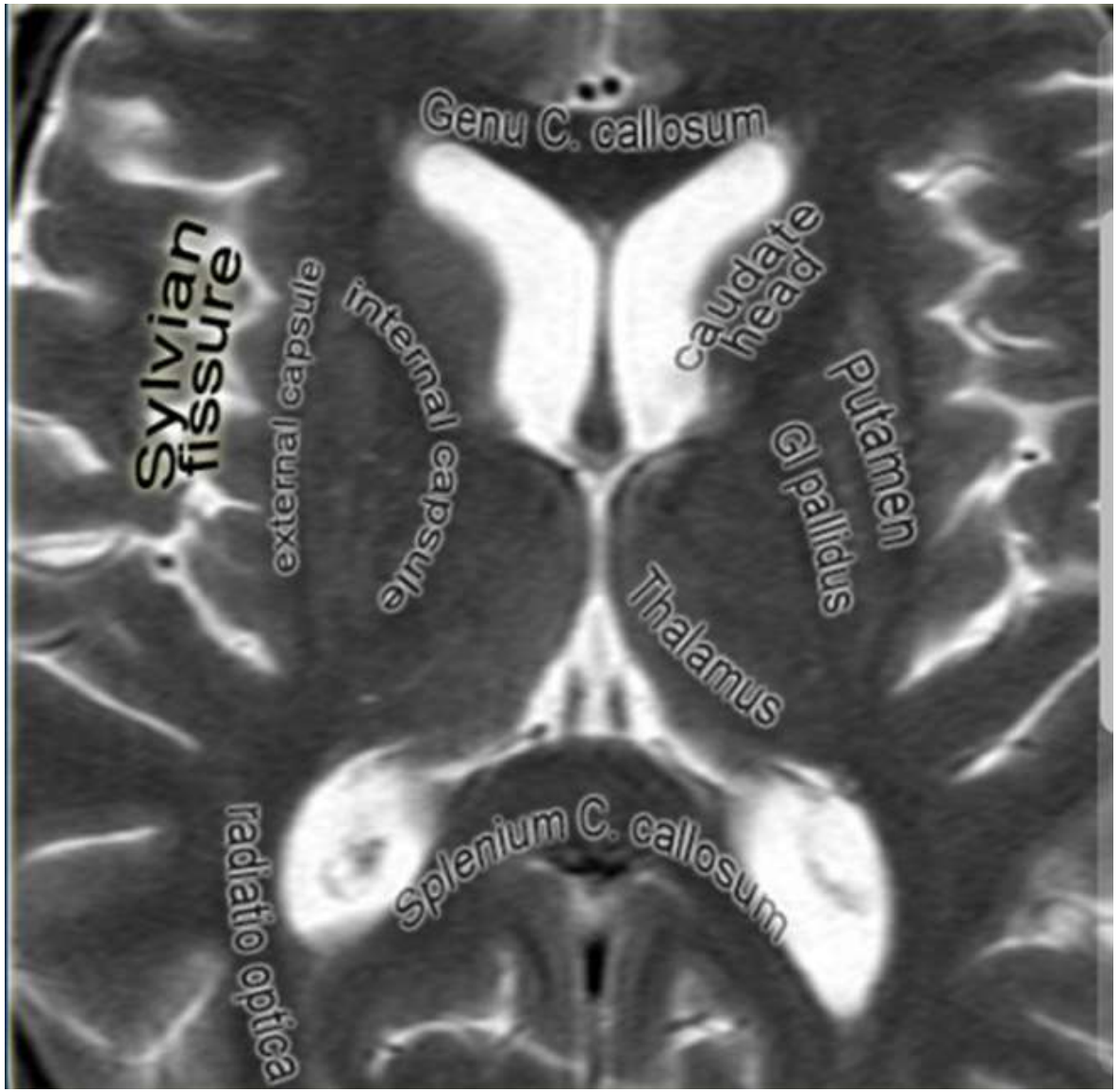
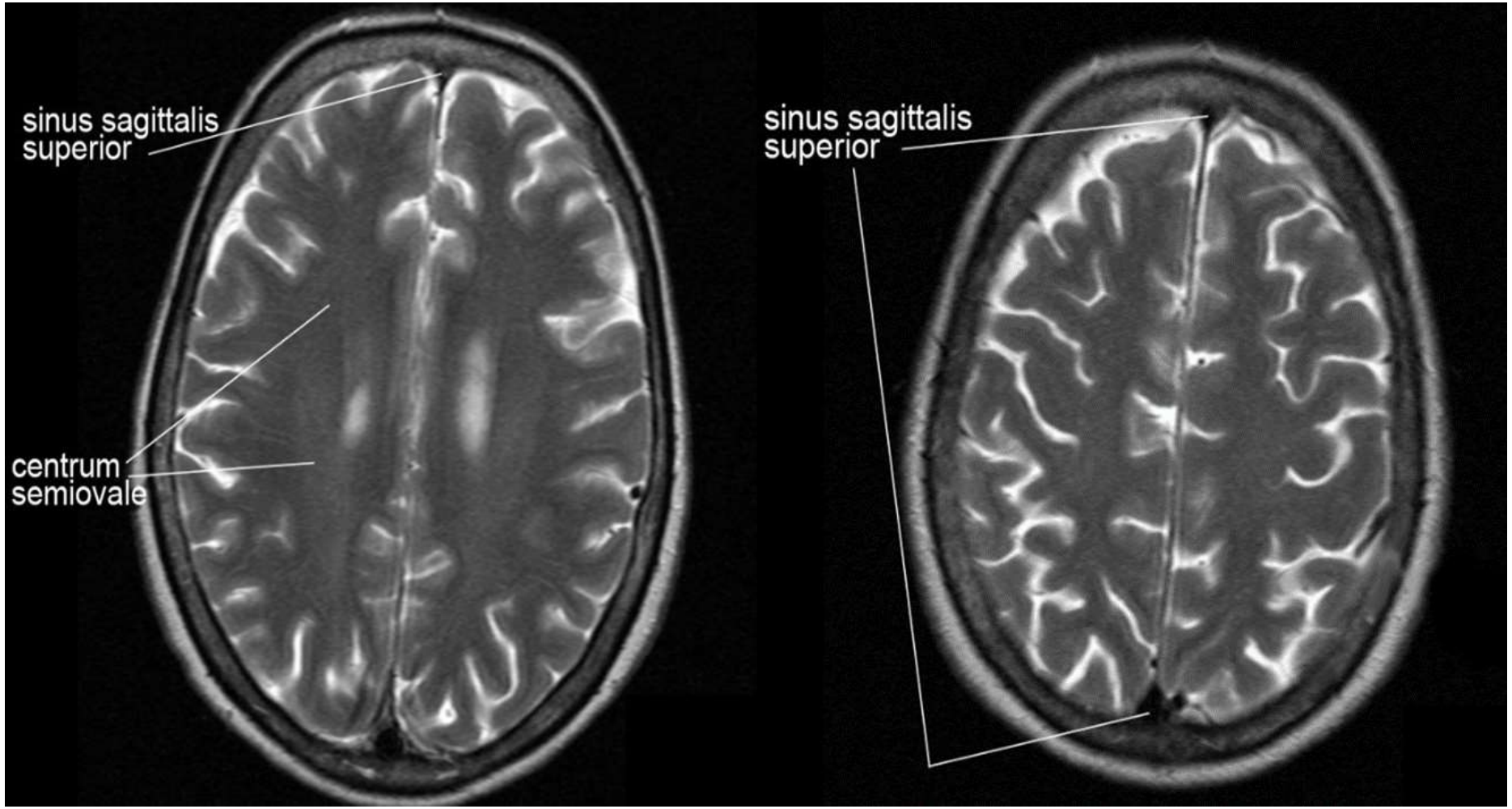

Frontal
Parietal
Temporal
Occipital
Insular
Cingulate gyrus
Thalamus
Caudate nucleus
Lentiform nucleus
Hippocampus
Midbrain
Pons
Medulla oblongata
Cerebellum -
Anterior lobe
Posterior lobe
M. Debowski 2018
BY NC SA

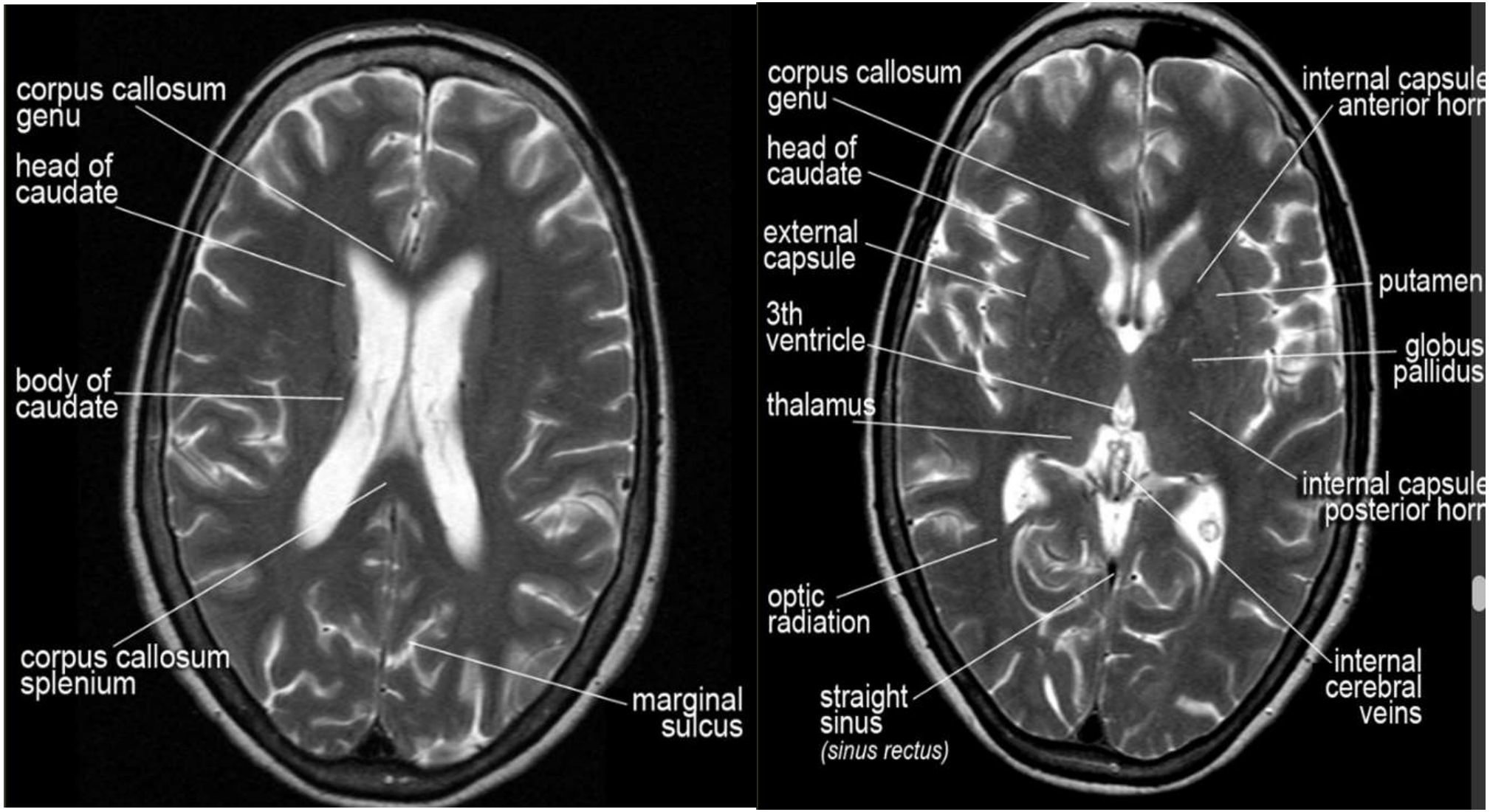

Frontal
Parietal
Temporal
Occipital
Insular
Cingulate gyrus
Thalamus
Caudate nucleus
Lentiform nucleus
Hippocampus
Midbrain
Pons
Medulla oblongata
Cerebellum -
Anterior lobe
Posterior lobe
M. Debowski 2018
BY NC SA


Genu C. callosum
Sylvian fissure
external capsule
internal capsule
caudate head
Putamen
Gl pallidus
Thalamus
radiatio optica
Splenium C. callosum

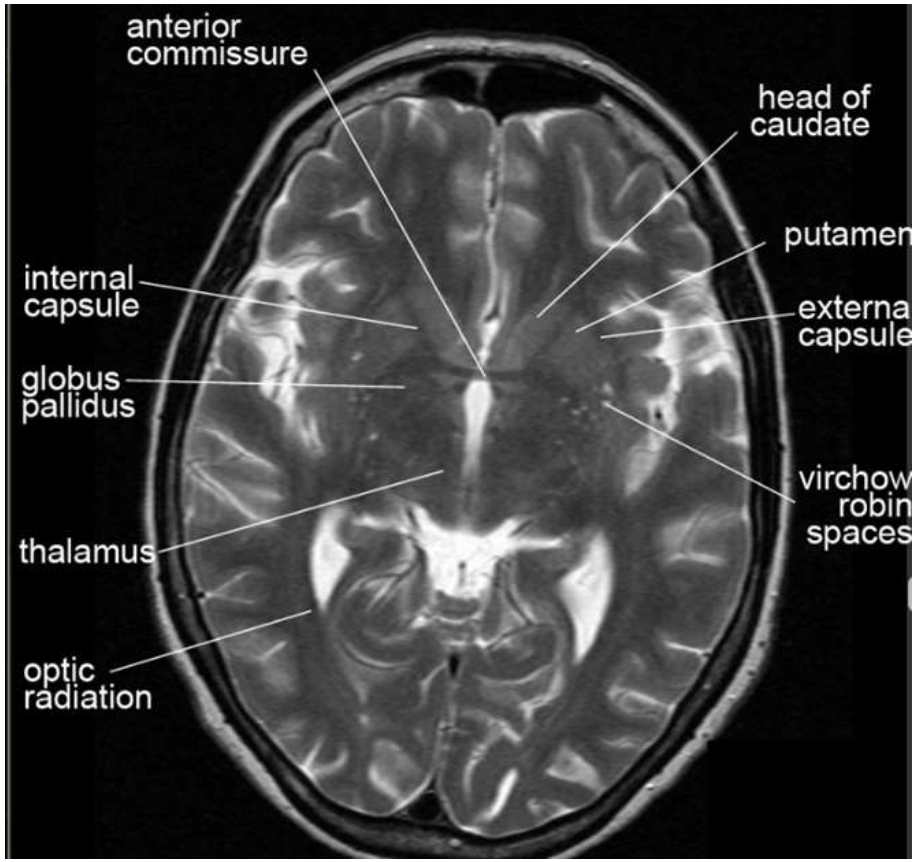
NORMAL BRAIN MRI

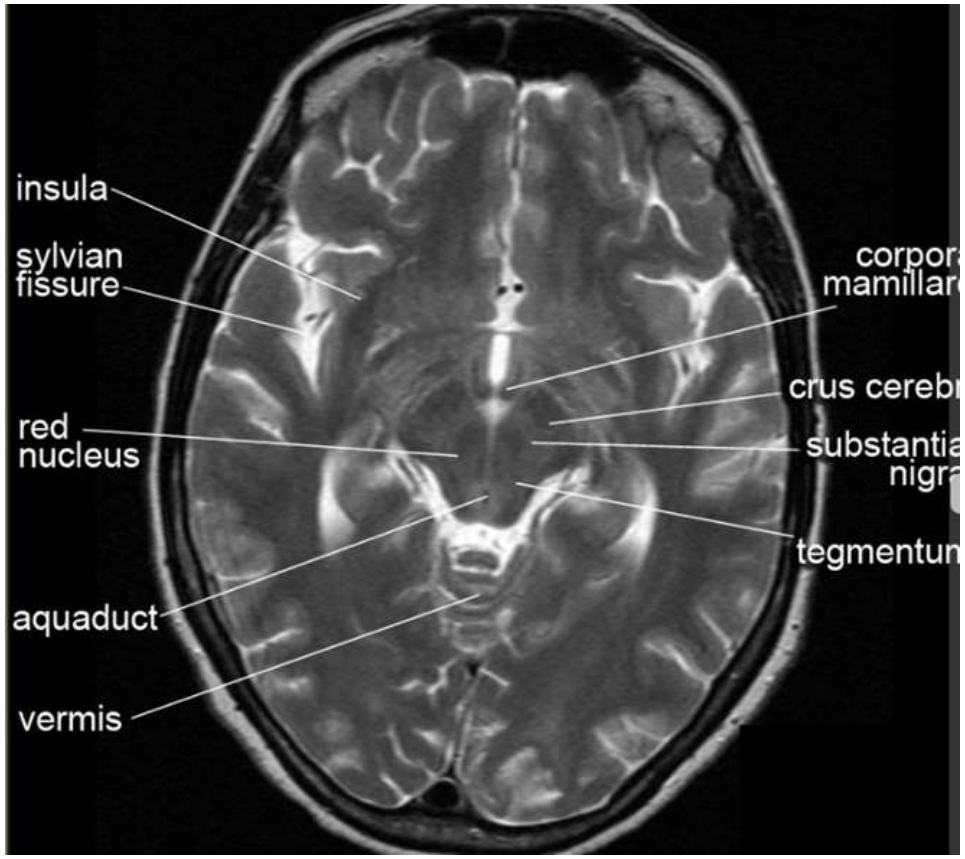


NORMAL BRAIN MRI

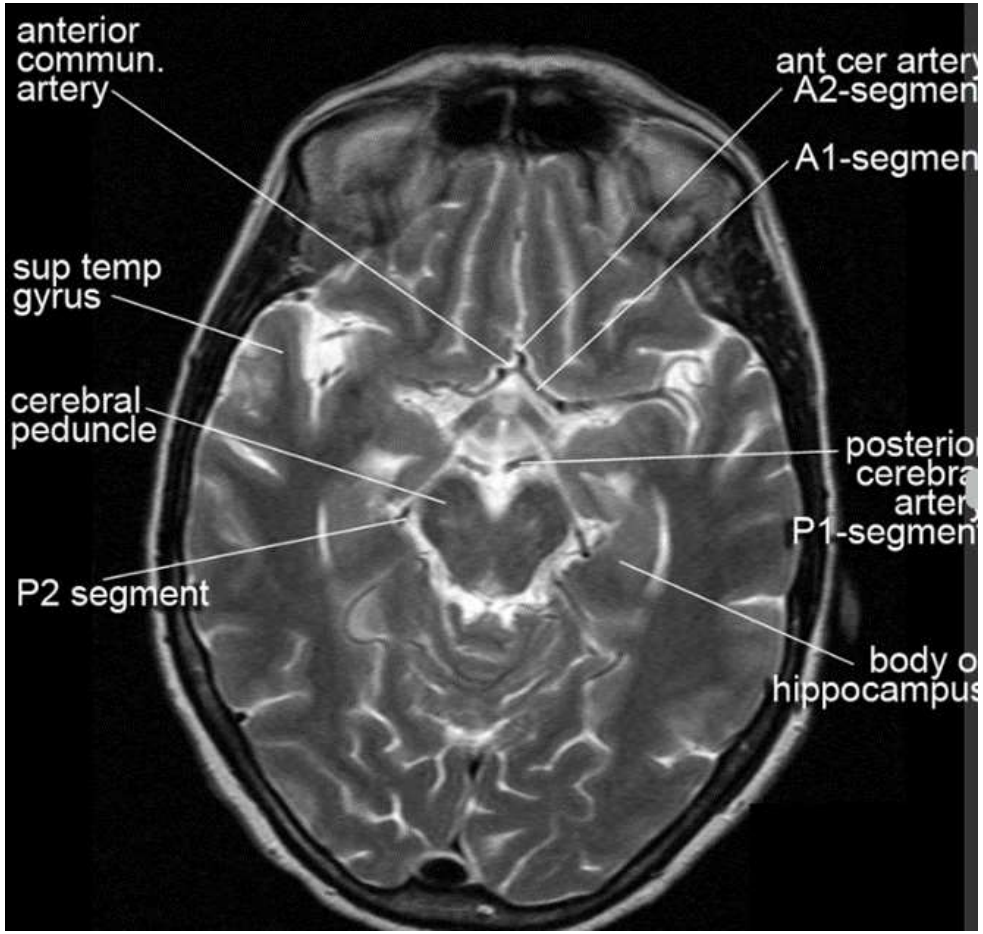


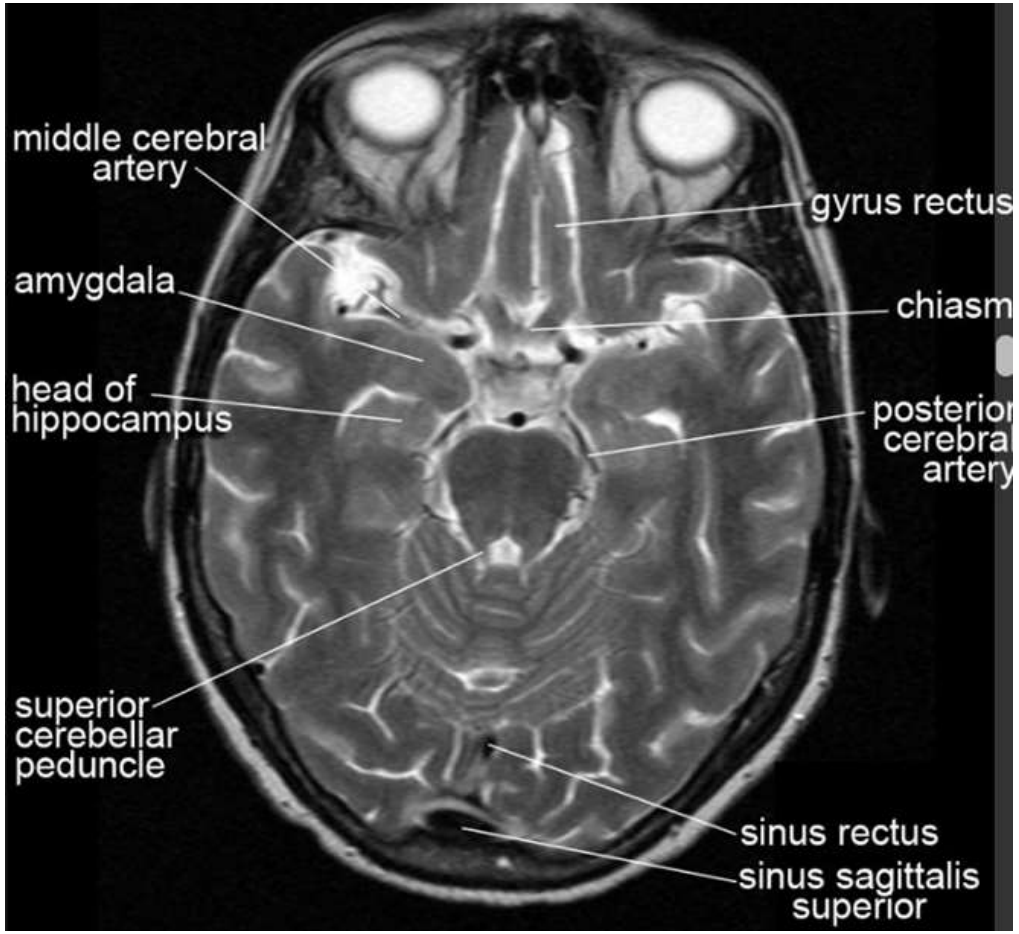
NORMAL BRAIN MRI



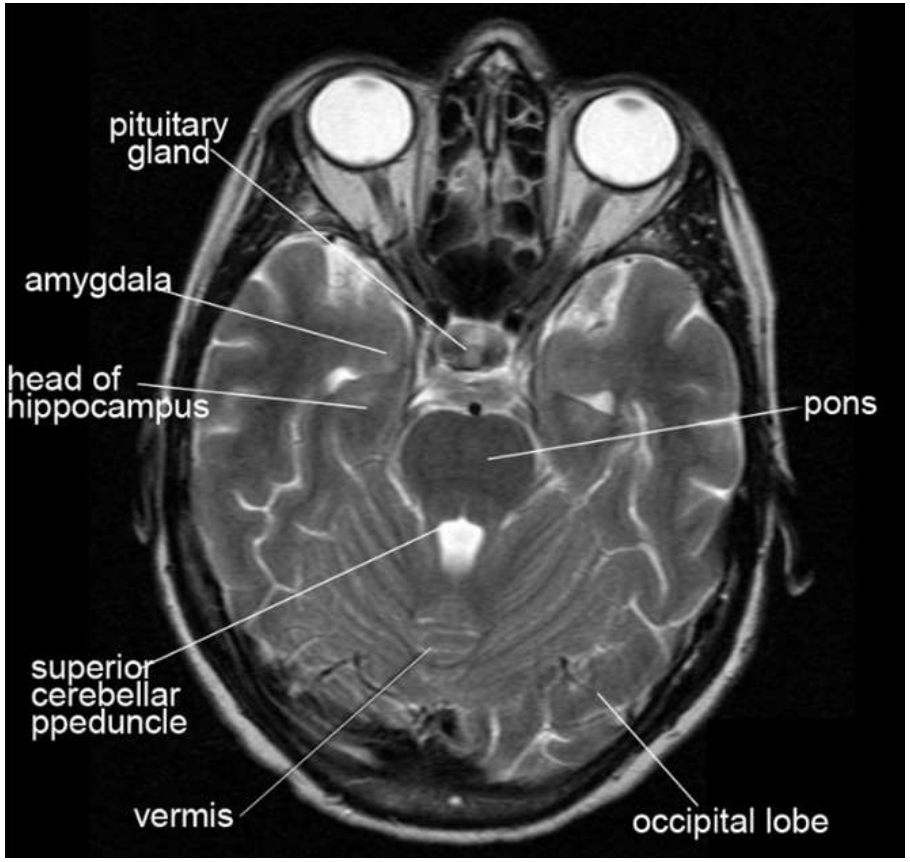


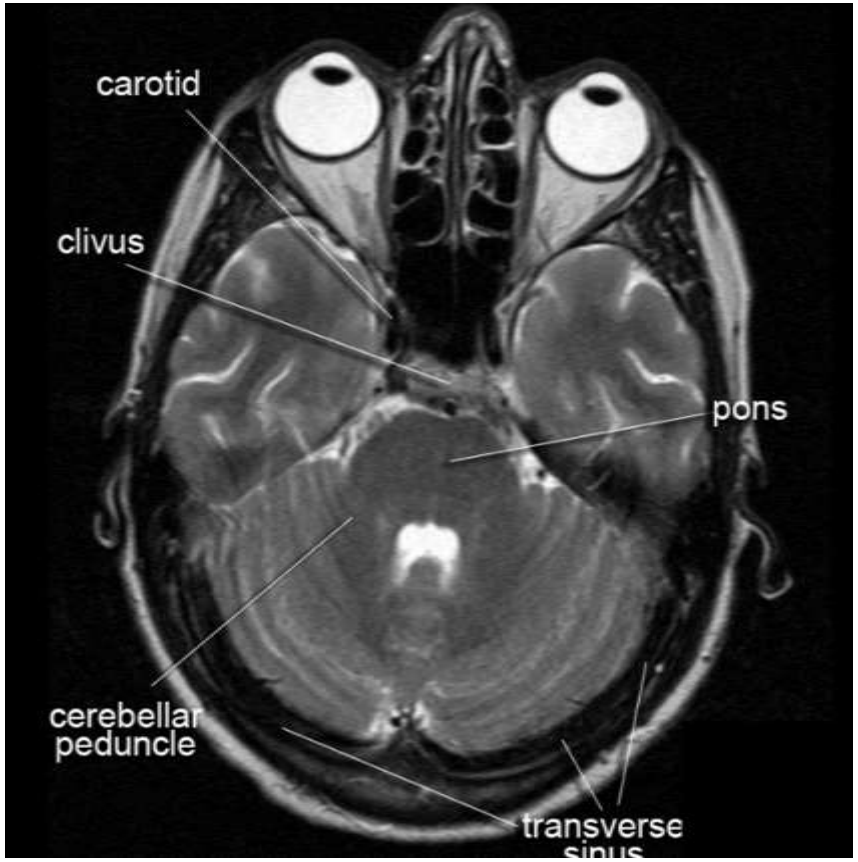
NORMAL BRAIN MRI



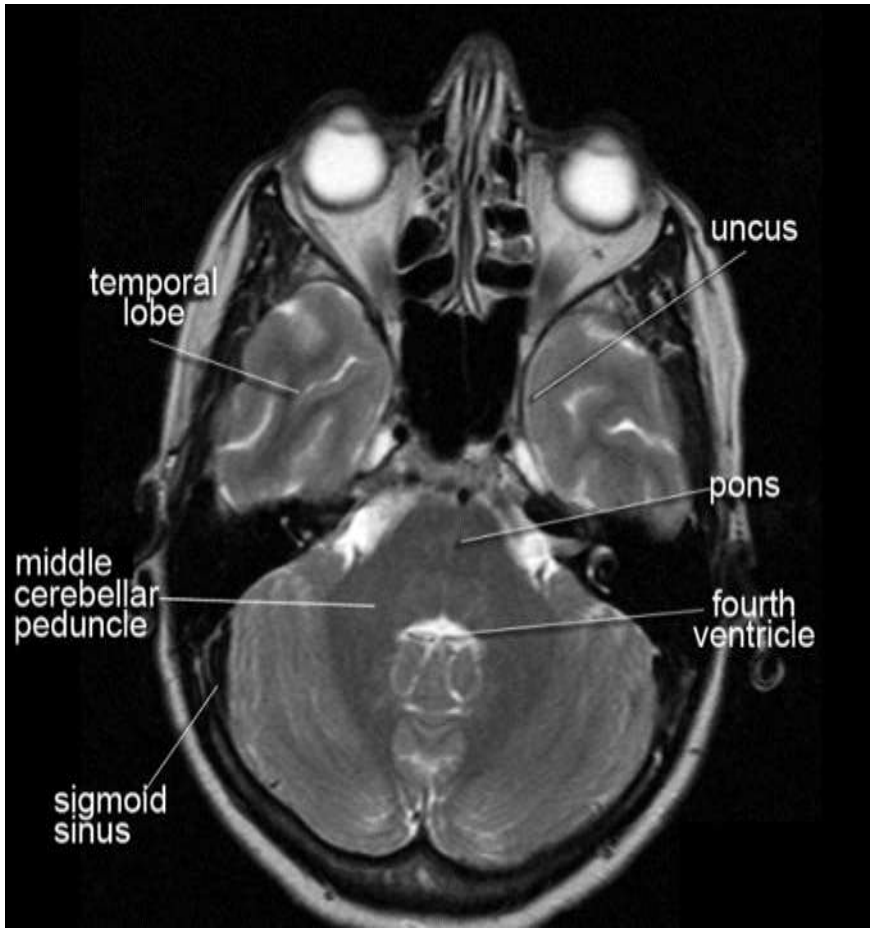


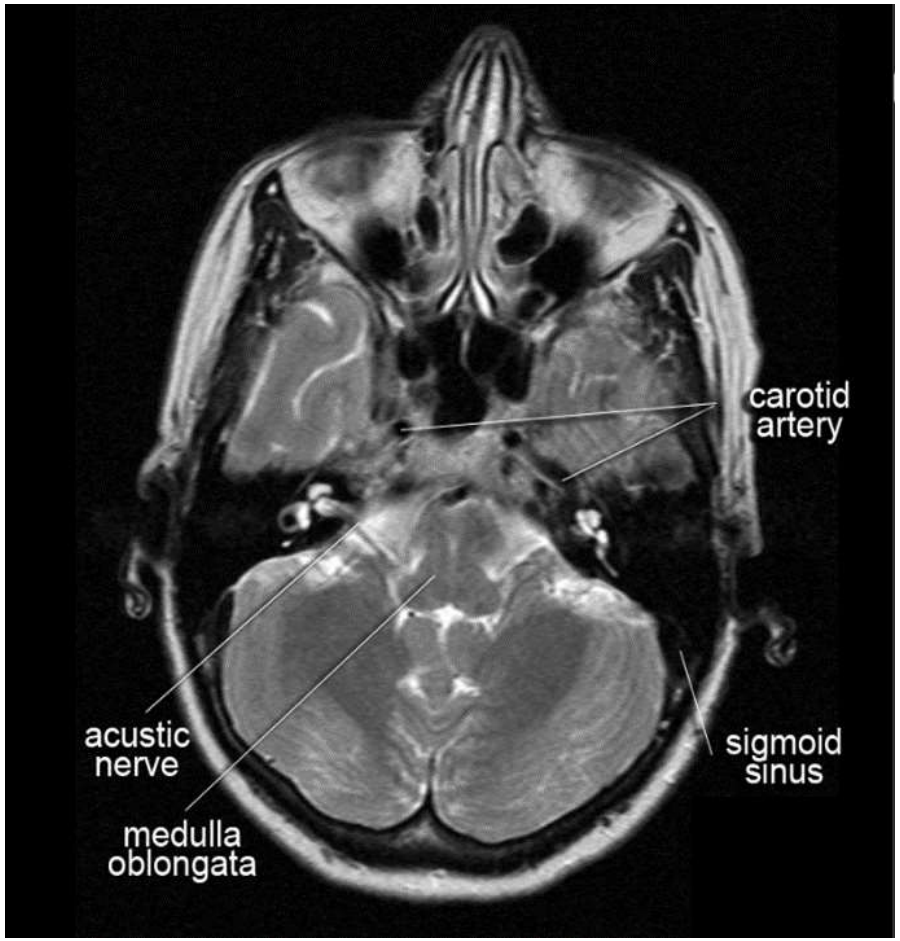
NORMAL BRAIN MRI





NORMAL BRAIN MRI

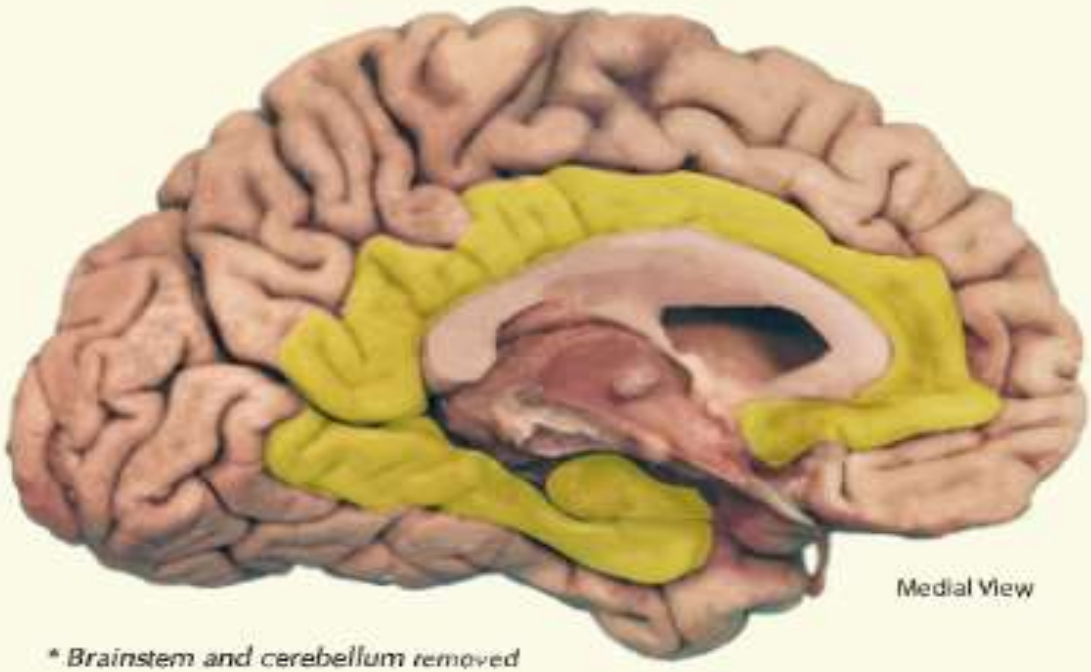




LIMBIC SYSTEM

General Anatomy

The limbic system refers to a collection of cortical and subcortical regions of the brain primarily associated with regulating emotion, motivation, learning and memory. The major components of the limbic system include the limbic lobe, the hippocampus and the amygdala.



Medial View

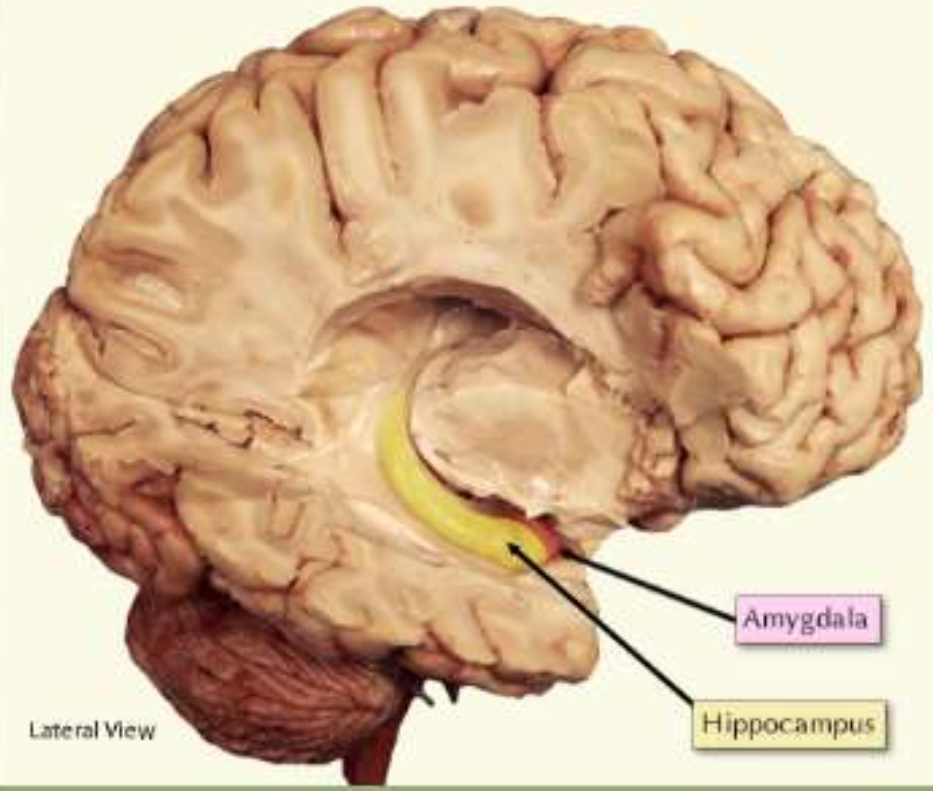
* *Brainstem and cerebellum removed*

The Limbic System

SUBCORTICAL STRUCTURES

Hippocampus and Amygdala

As seen here, the hippocampus is located deep within the temporal lobe, and serves as the floor of the inferior horn of the lateral ventricle. The amygdala is located just rostral/anterior and medial to the hippocampus.



Hippocampus

- Learning
- Memory Formation & Retrieval
- Site of Adult Neurogenesis

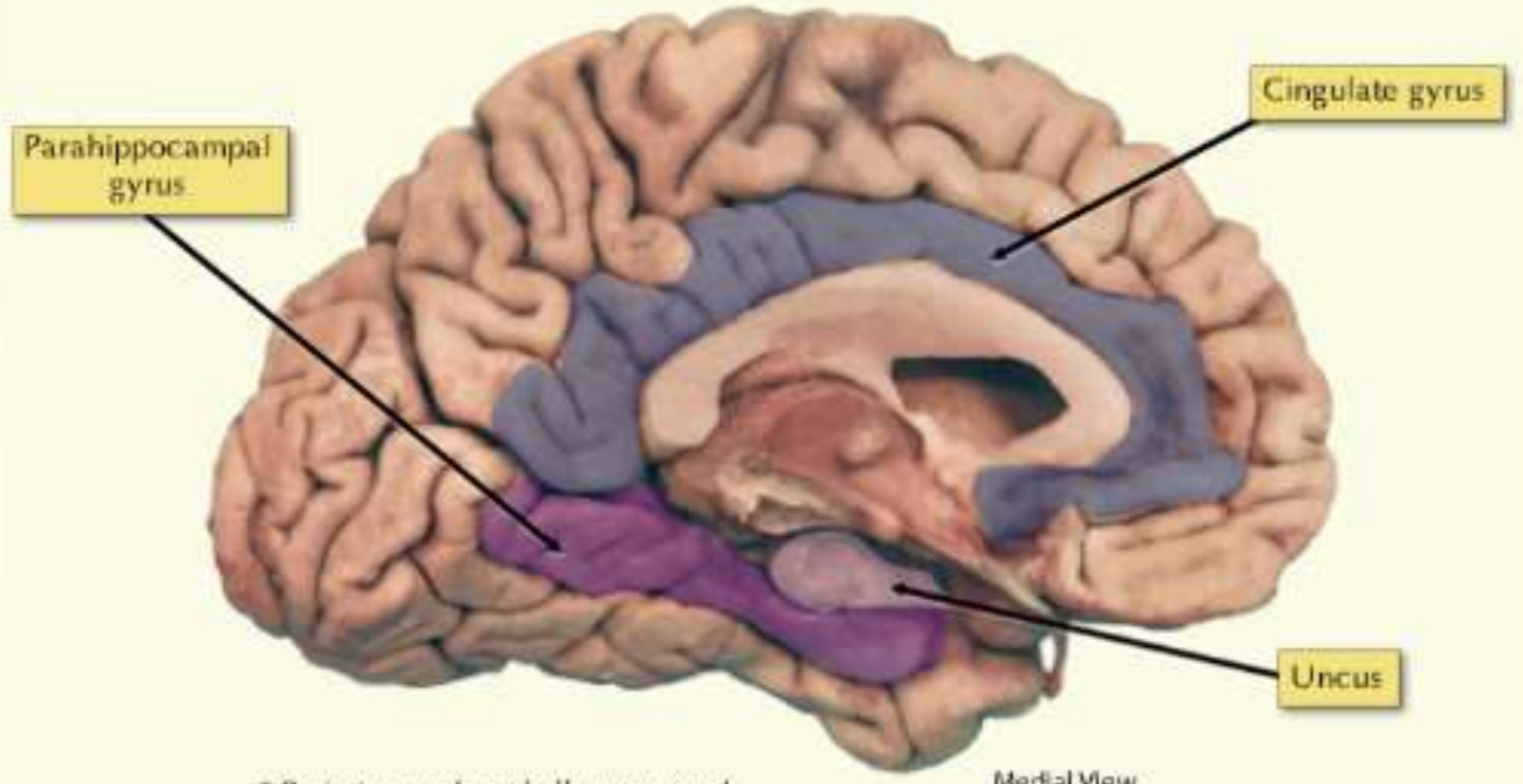
Amygdala

- Emotional Learning & Memory
- Fear
- Reward

LIMBIC LOBE

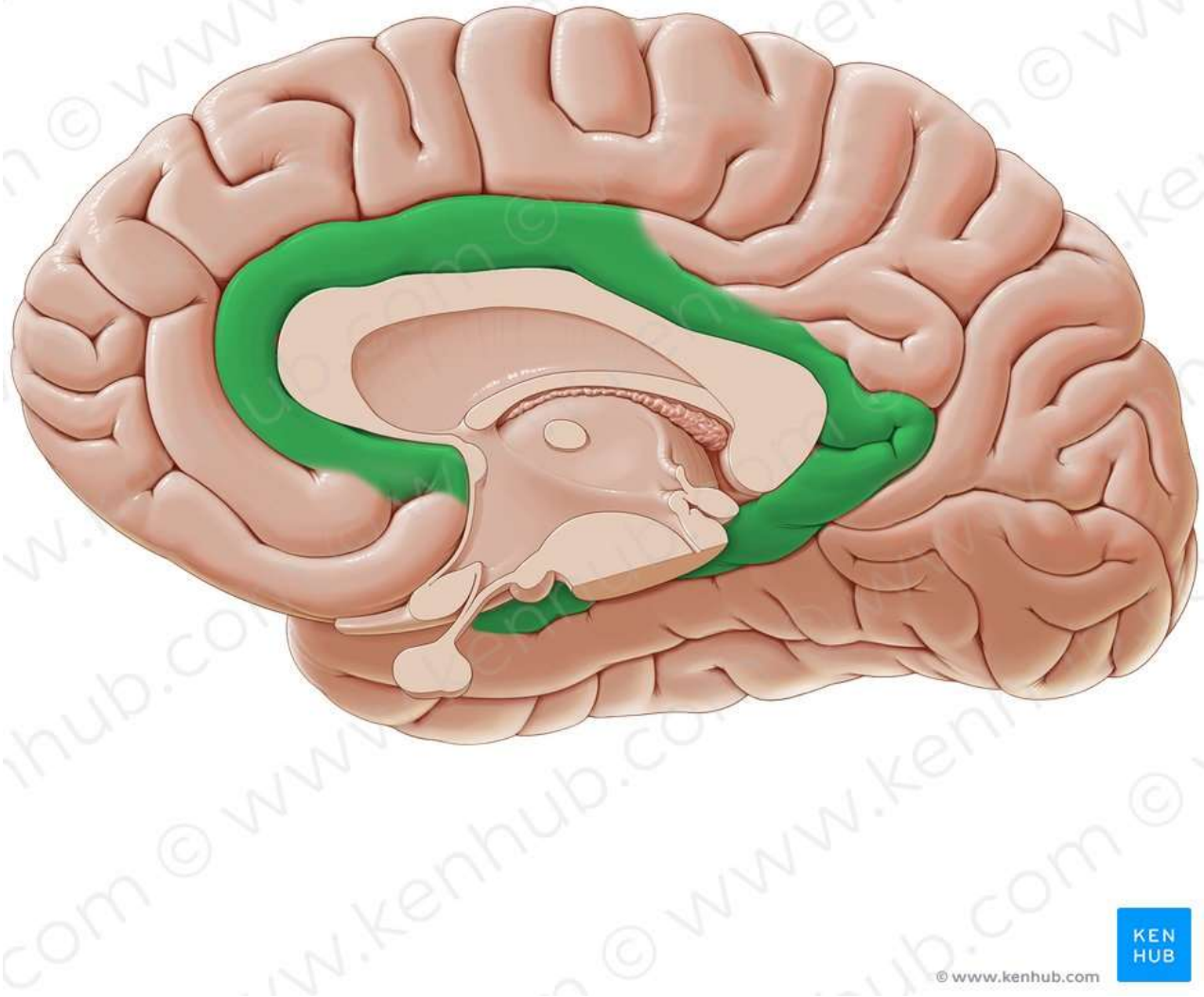
General Anatomy

The limbic lobe is not a true lobe; rather, it comprises a ring of cortex on the medial surface of the brain, spanning aspects of the frontal, parietal, and temporal lobes.



* *Brainstem and cerebellum removed*

Medial View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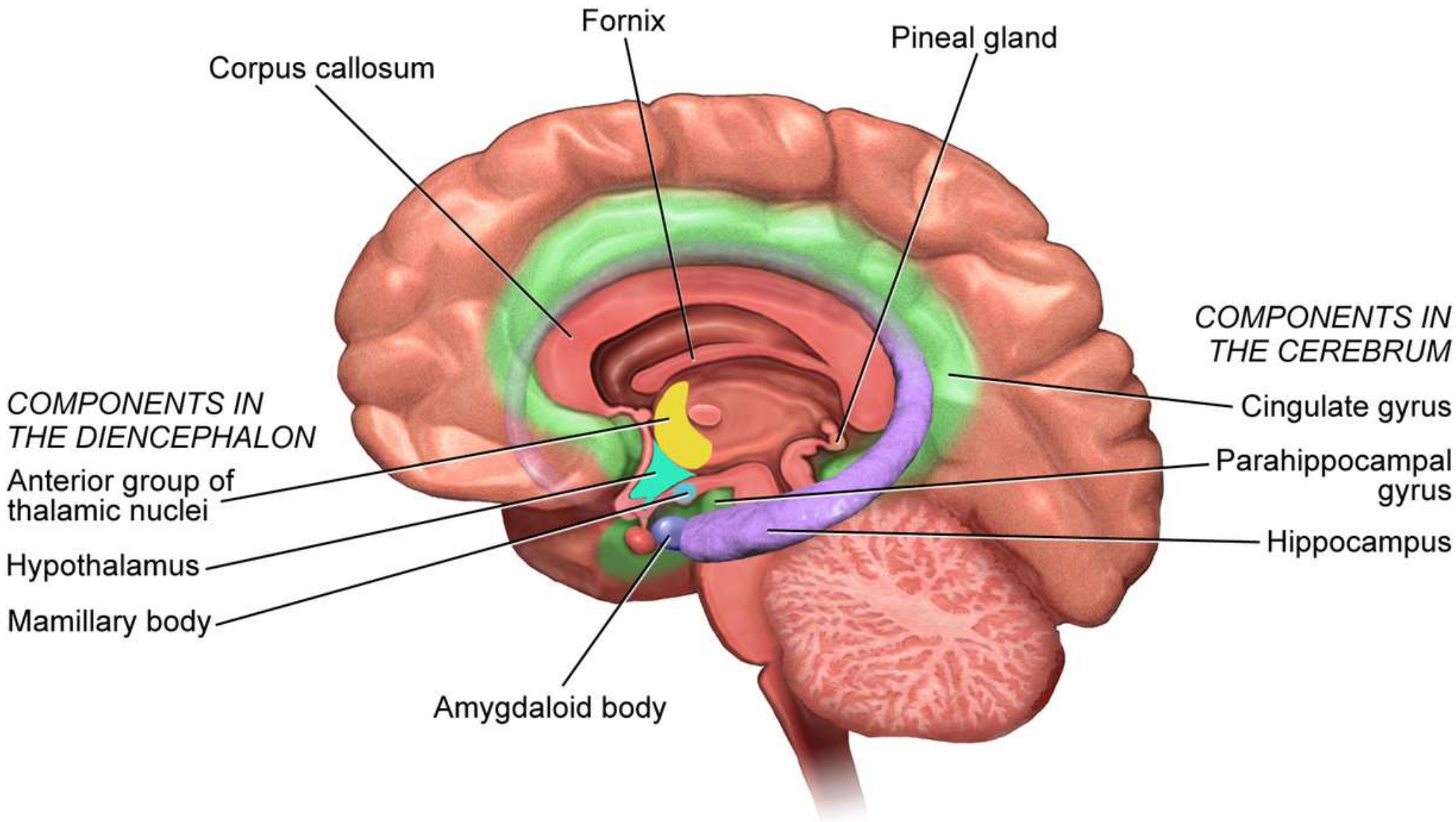
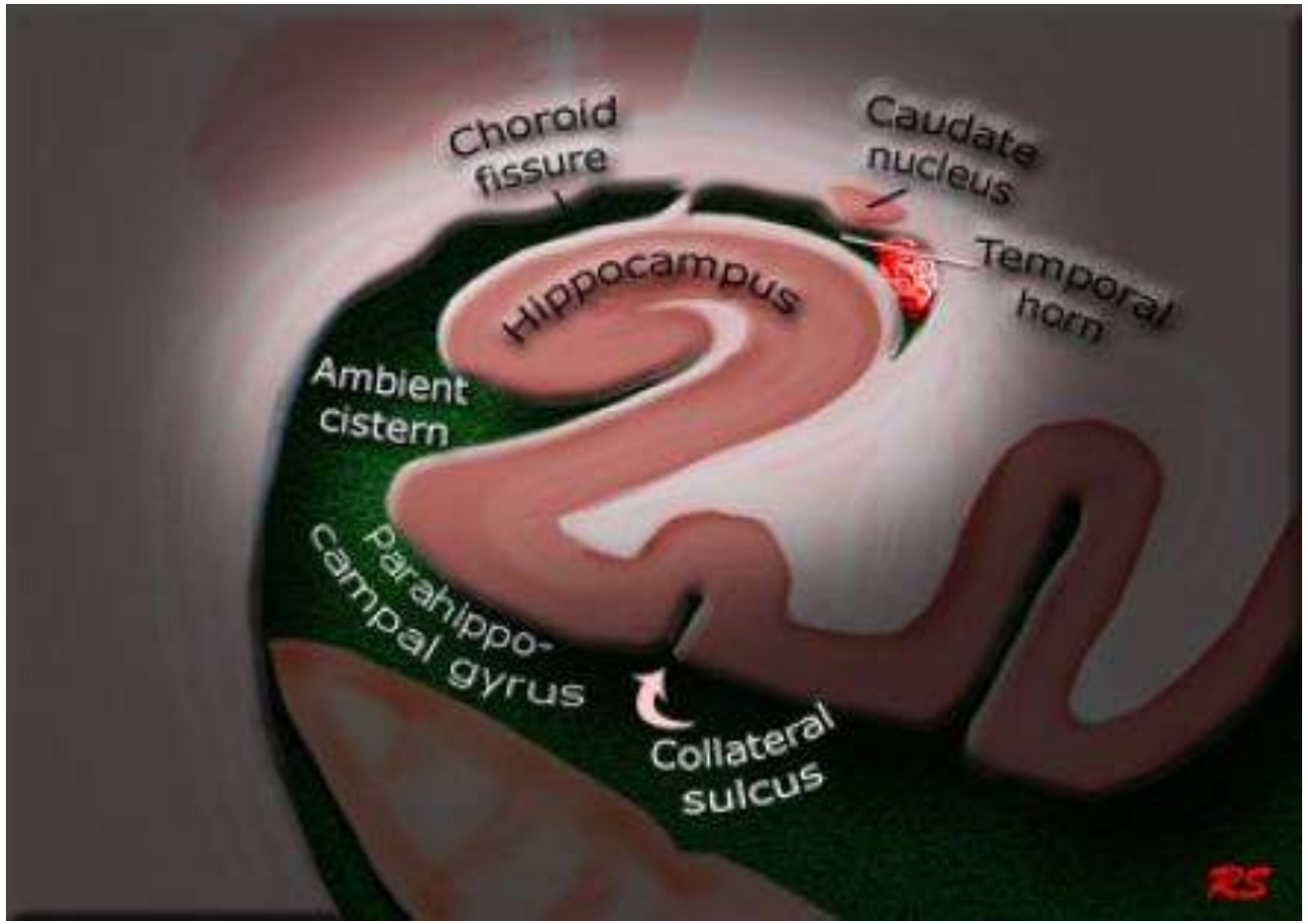
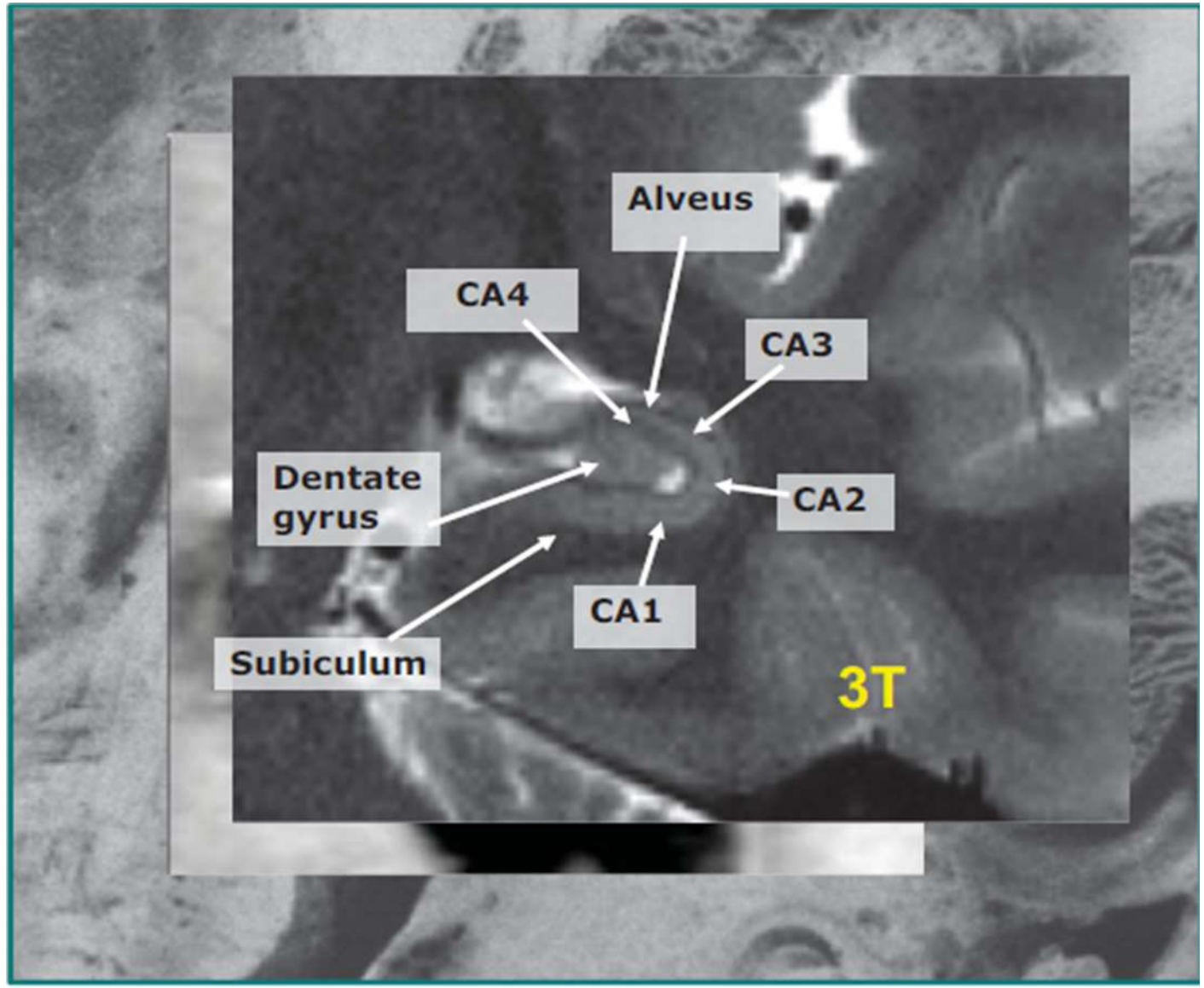
The Limbic System

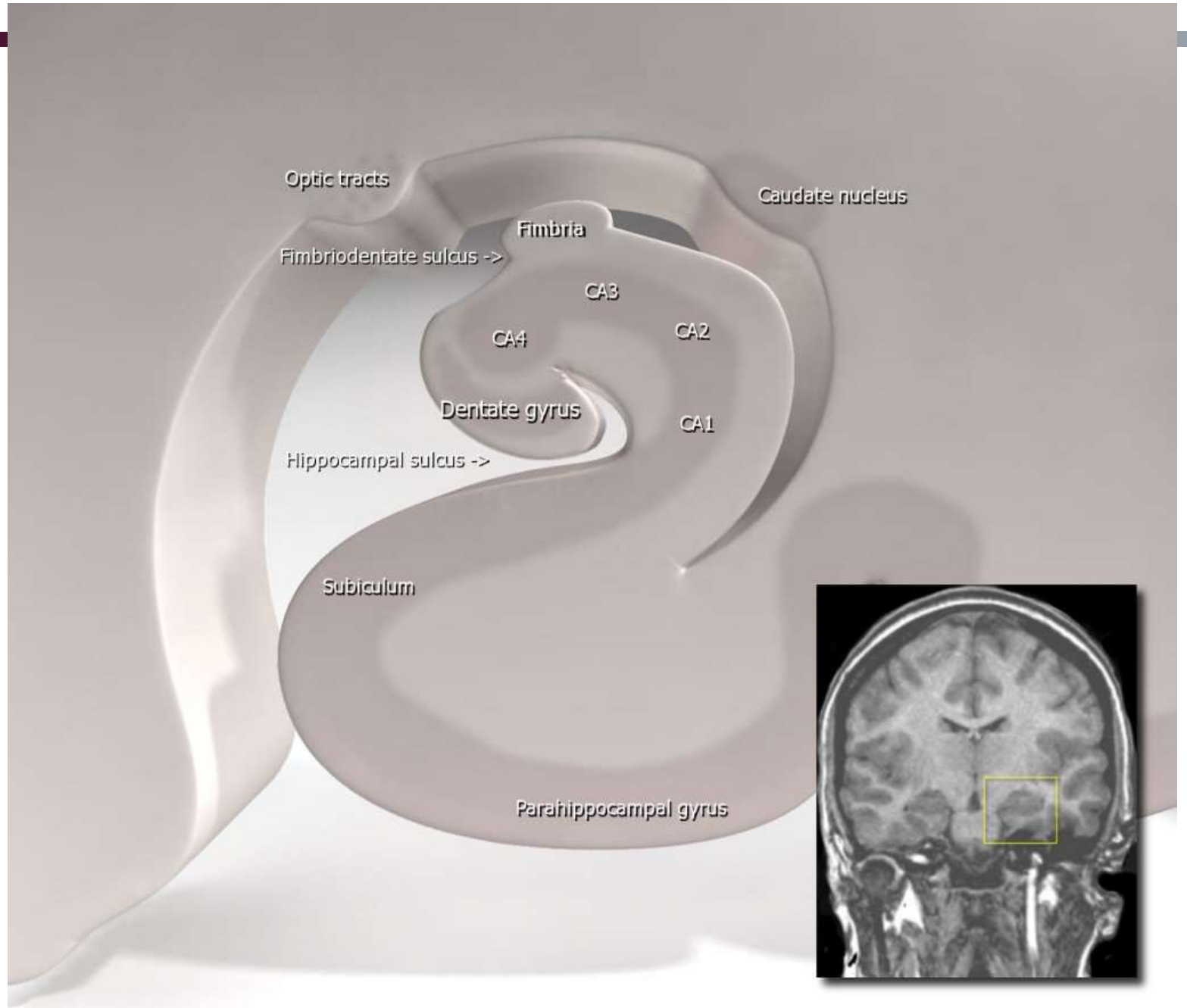


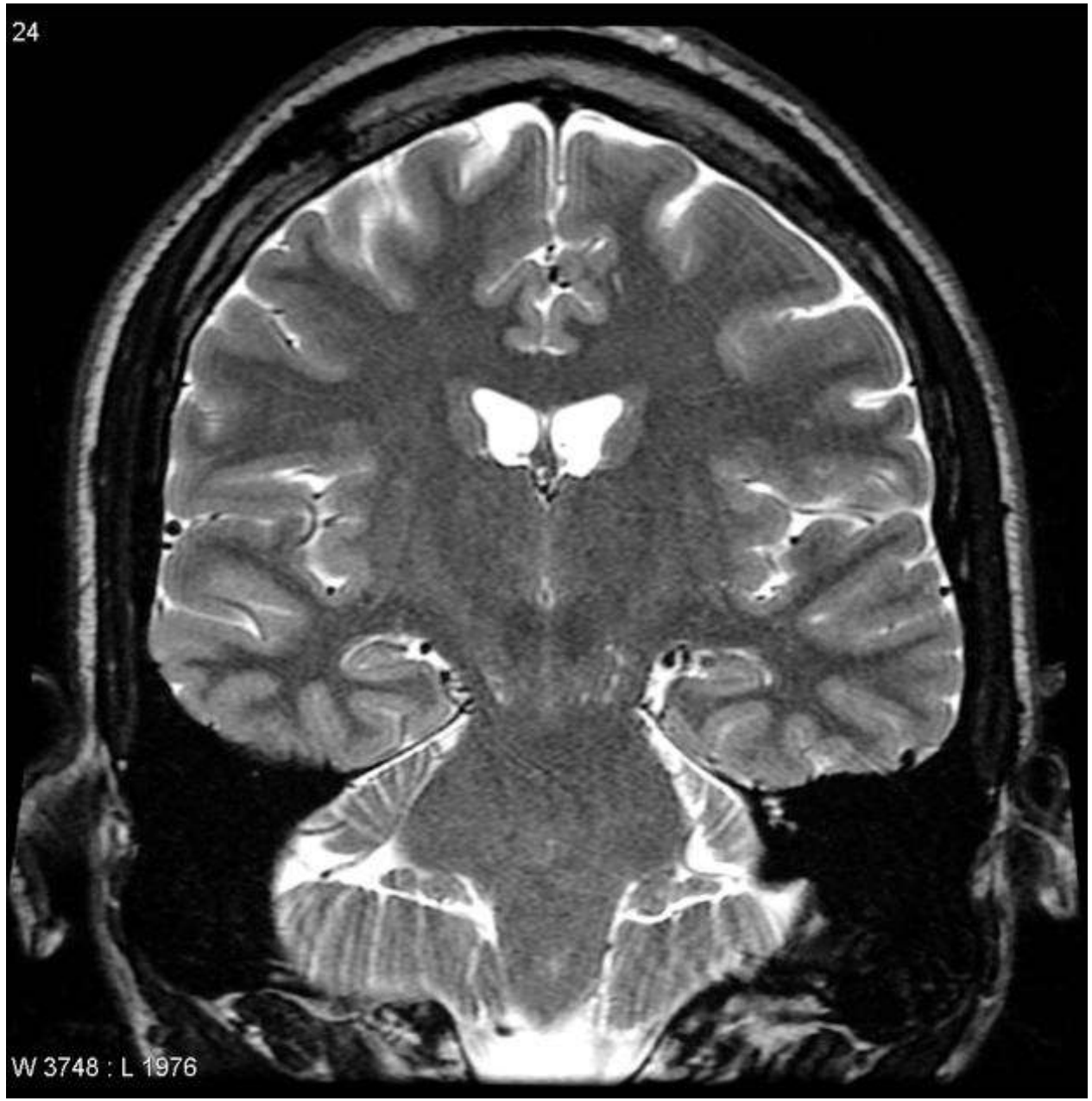
HIPPOCAMPUS

- Important component of the human brain, situated in the temporal lobe
- Information processing and the reproductive cycle and is **involved in Alzheimer disease**
- Lies in the hippocampal sulcus immediately below the **floor of the temporal horn of the lateral ventricle**, and in cross section (coronal) has appearances that are reminiscent of a sea horse
- It has a head (posterior to the amygdala), a body, and a tail (which follows the upwardly curving lateral ventricle)


Choroid fissure
Caudate nucleus
Hippocampus
Temporal horn
Ambient cistern
Parahippo-campal gyrus
Collateral sulcus


Alveus
CA4
CA3
Dentate gyrus
CA2
CA1
Subiculum
3T


Optic tracts
Caudate nucleus
Fimbria
Fimbriodentate sulcus ->
CA3
CA4
CA2
Dentate gyrus
CA1
Hippocampal sulcus ->
Subiculum
Parahippocampal gyrus

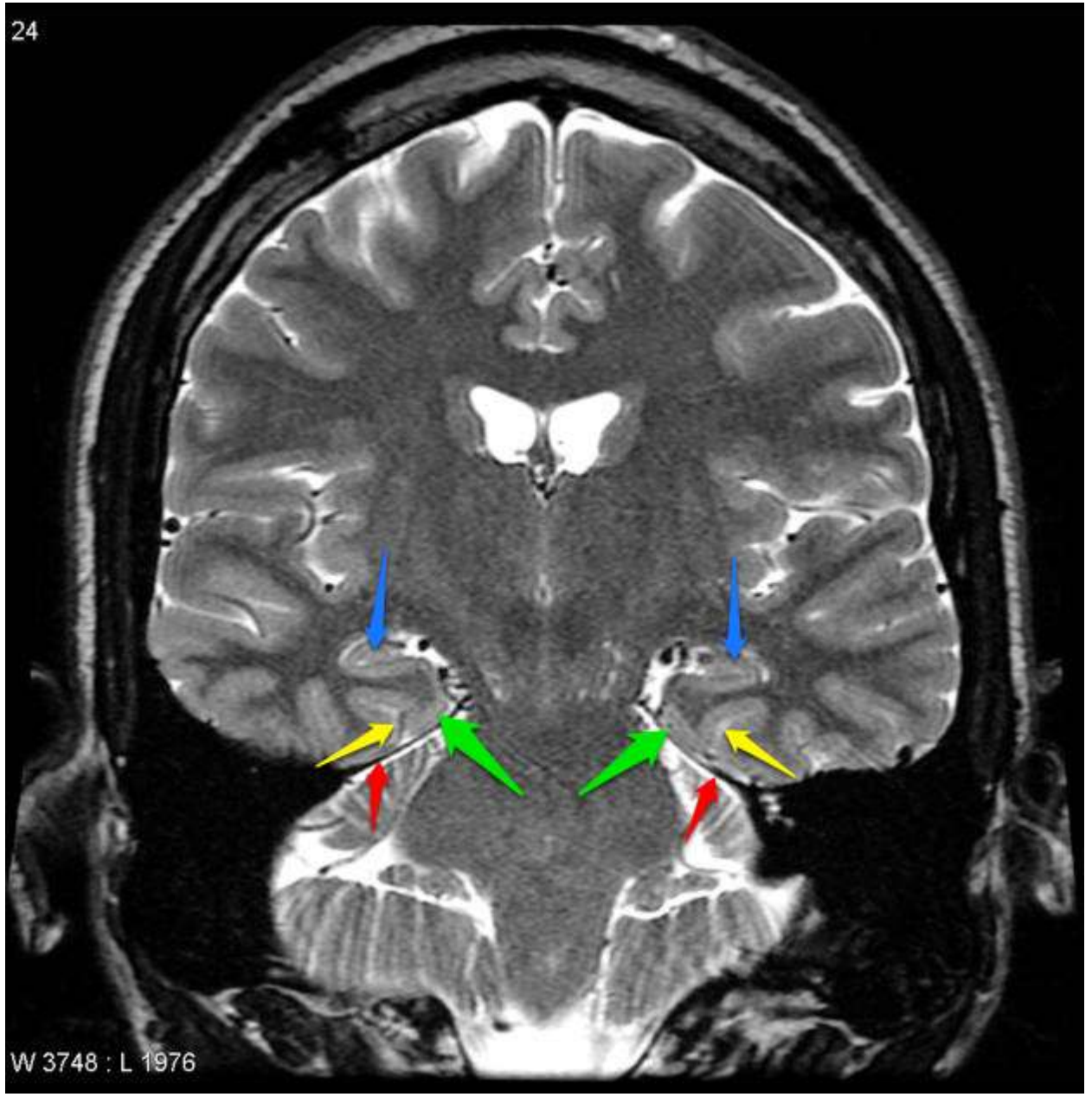

24
W 3748 : L 1976

Hippocampus

Parahippocampal gyrus

collateral sulcus

Tentorium cerebelli



GLOBAL CORTICAL ATROPHY SCALE

- Assess cerebral atrophy, especially in the context of neurodegenerative diseases

- Evaluates atrophy in brain regions assessed separately in each hemisphere and resulting in a final score that is the sum of all regions

GLOBAL CORTICAL ATROPHY SCALE

Global cortical atrophy scale.

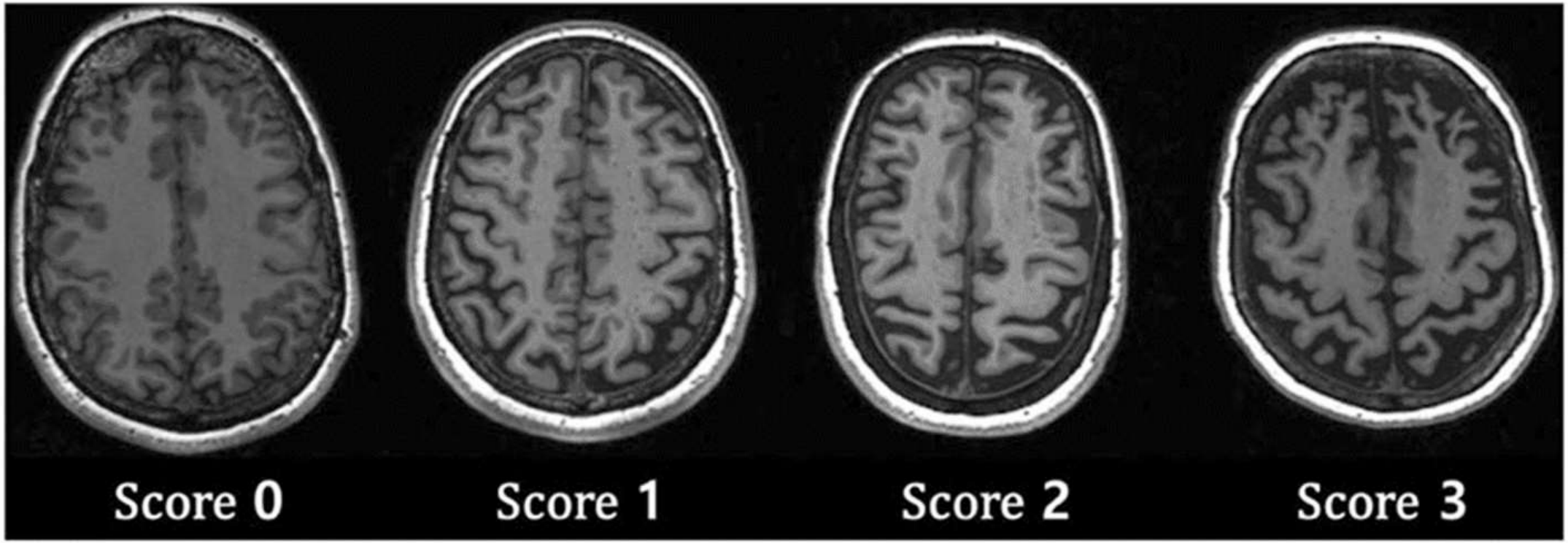
GCA score	0	1	2	3
	No atrophy	Mild Atrophy	Moderate atrophy	Severe atrophy
Gyri	Normal	Normal	Reduced	Knife blade
Sulci	Normal	Some opening	Enlarged	Severely enlarged

Adapted from Pasquier F, Leys D, Weerts JG, *et al.* Inter- and intraobserver reproducibility of cerebral atrophy assessment on MR imaging scans with hemispheric infarcts. *Eur Neurol.* 1996;36:268–72.

GLOBAL CORTICAL ATROPHY SCALE

0	• No cortical atrophy
1	• Mild atrophy: opening of sulci
2	• Moderate atrophy: volume loss of gyri
3	• Severe (end-stage) atrophy: 'knife blade' atrophy

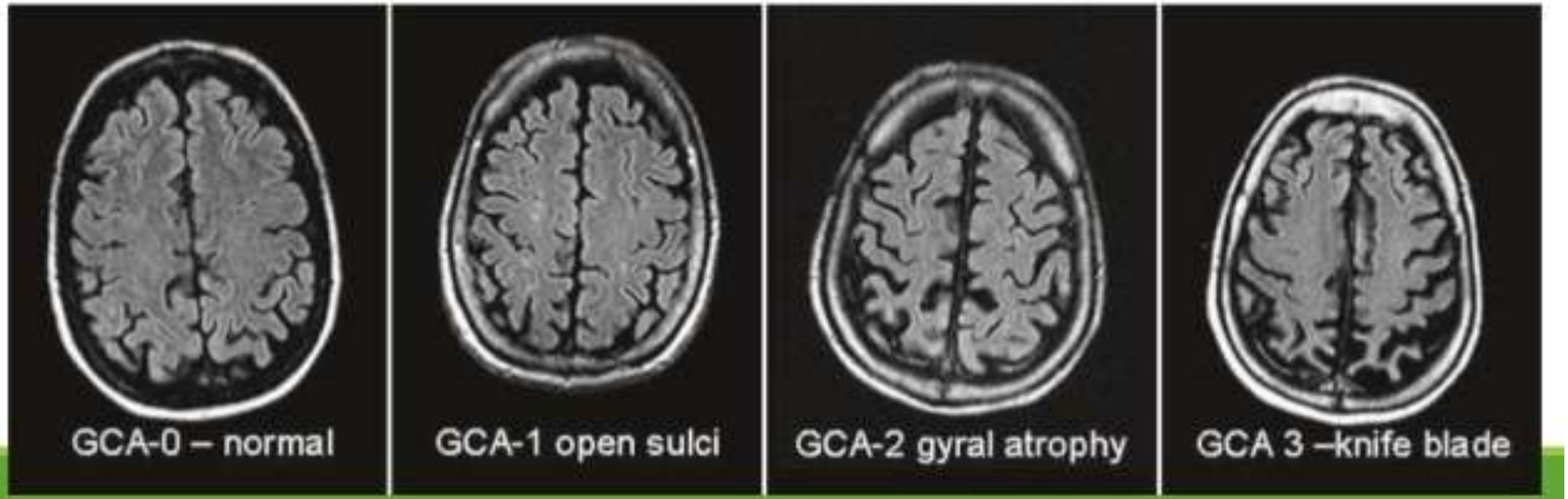
Cortical atrophy is best scored on FLAIR images



score 2 before 75 y/o
Score 3 at any age

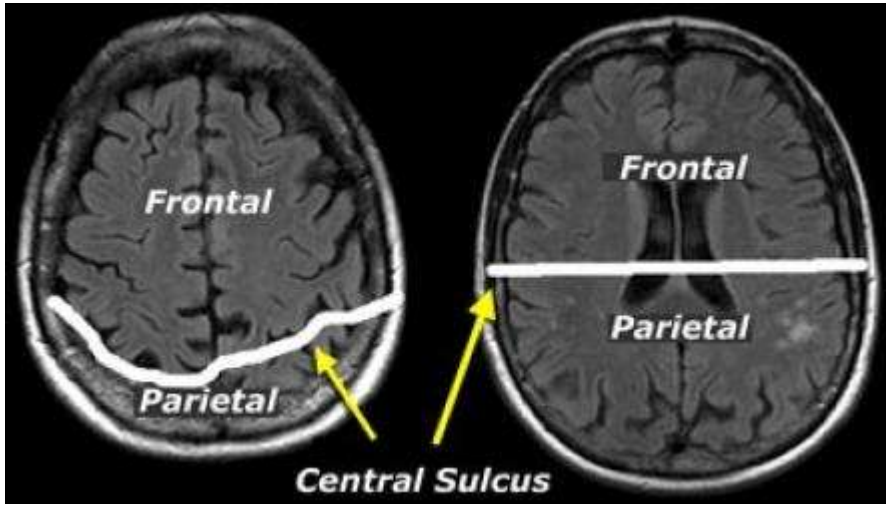
Visual rating scale

- Global cortical atrophy scale:-
- Best assessed on FLAIR or 3D T1 weighted images.



GCA-SCALE FOR GLOBAL CORTICAL ATROPHY

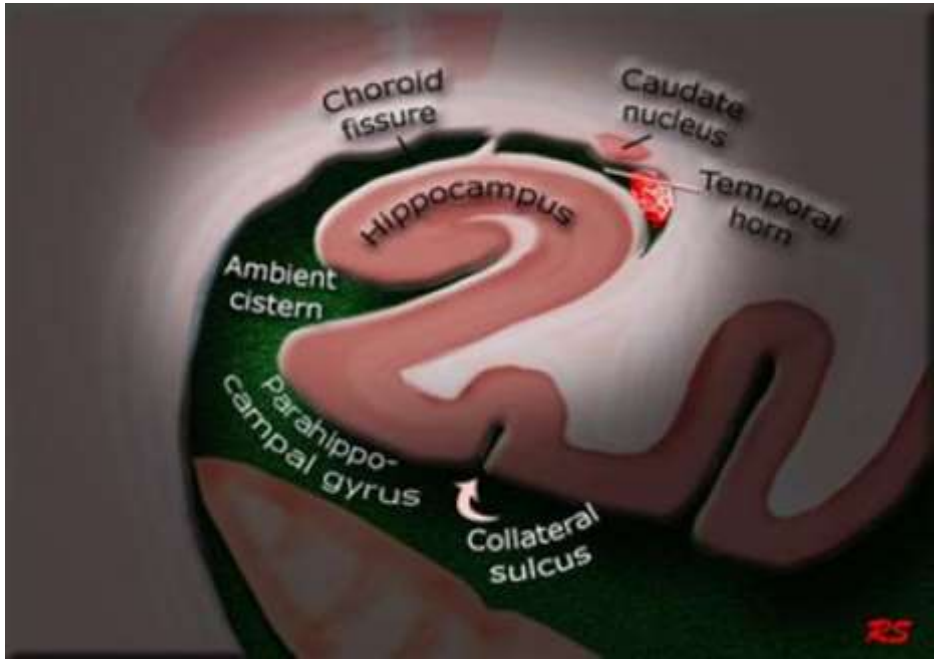
- When assessing atrophy in different regions keep in mind that cranially, the central sulcus lies more posteriorly than you would expect .

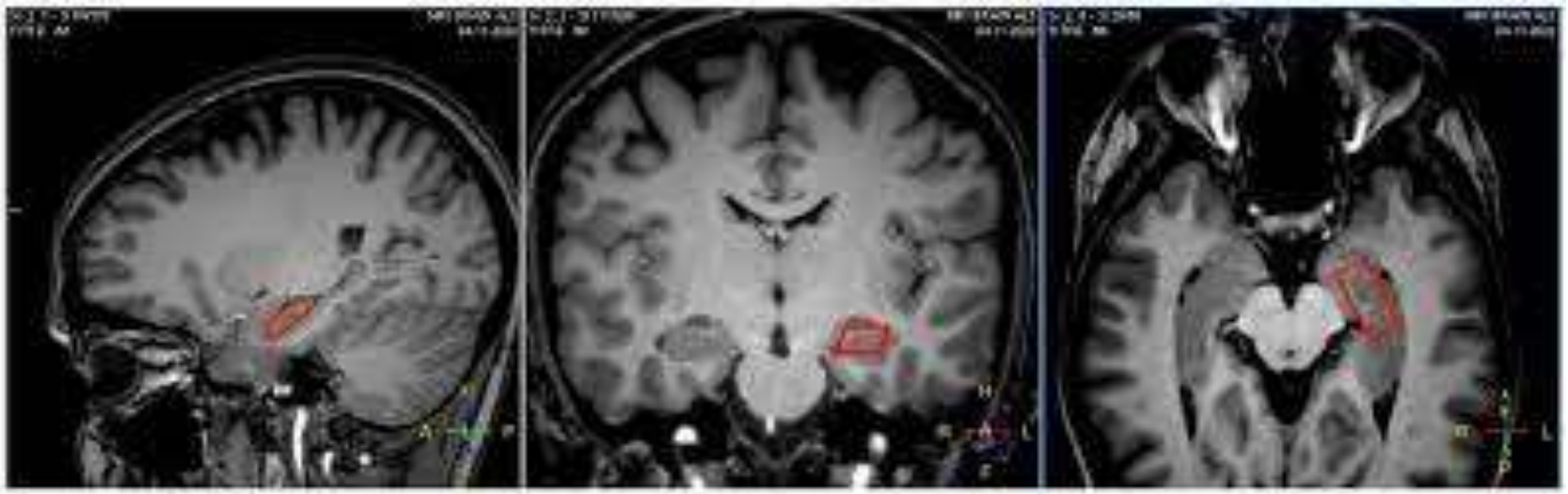


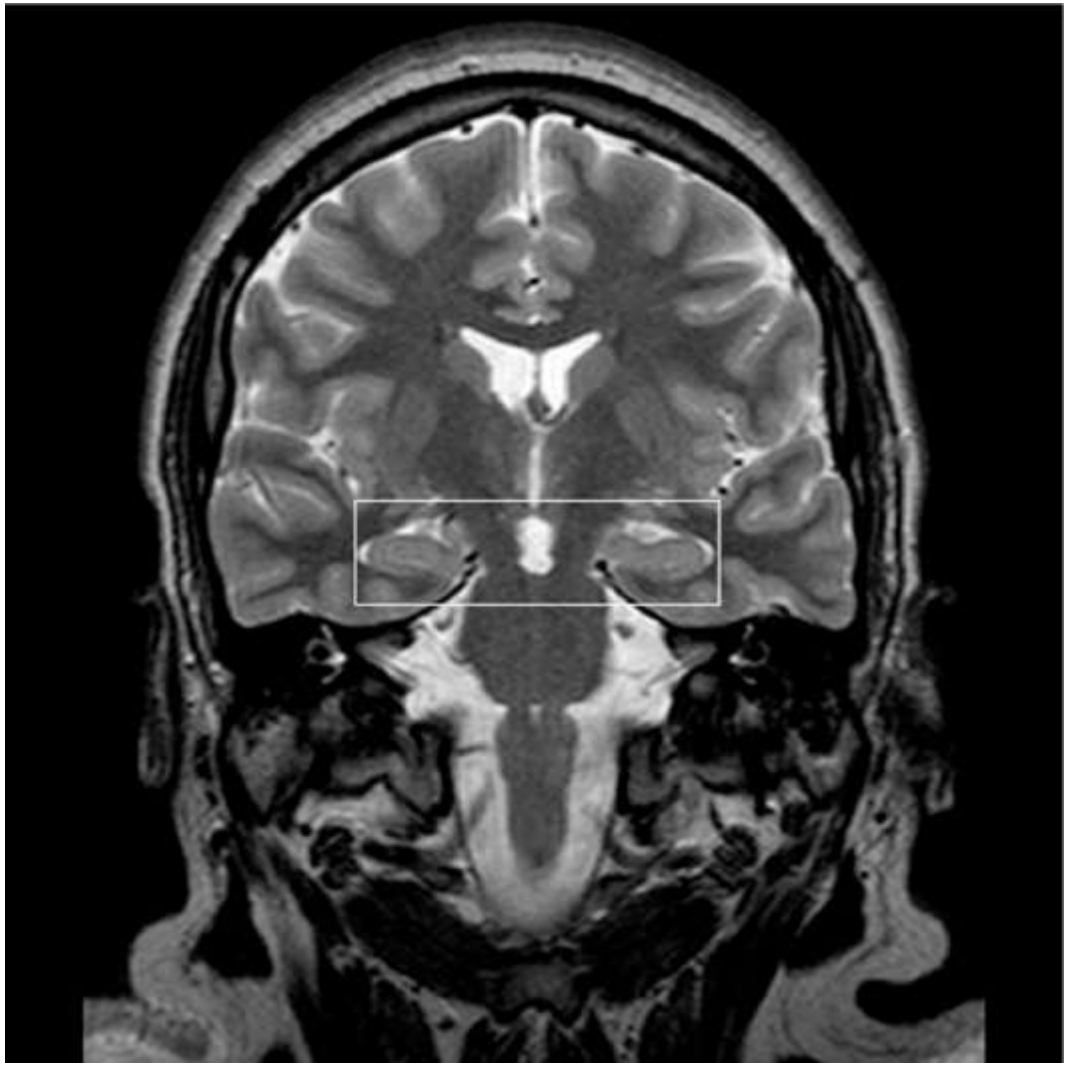
MEDIAL TEMPORAL LOBE ATROPHY SCORE (MTA)

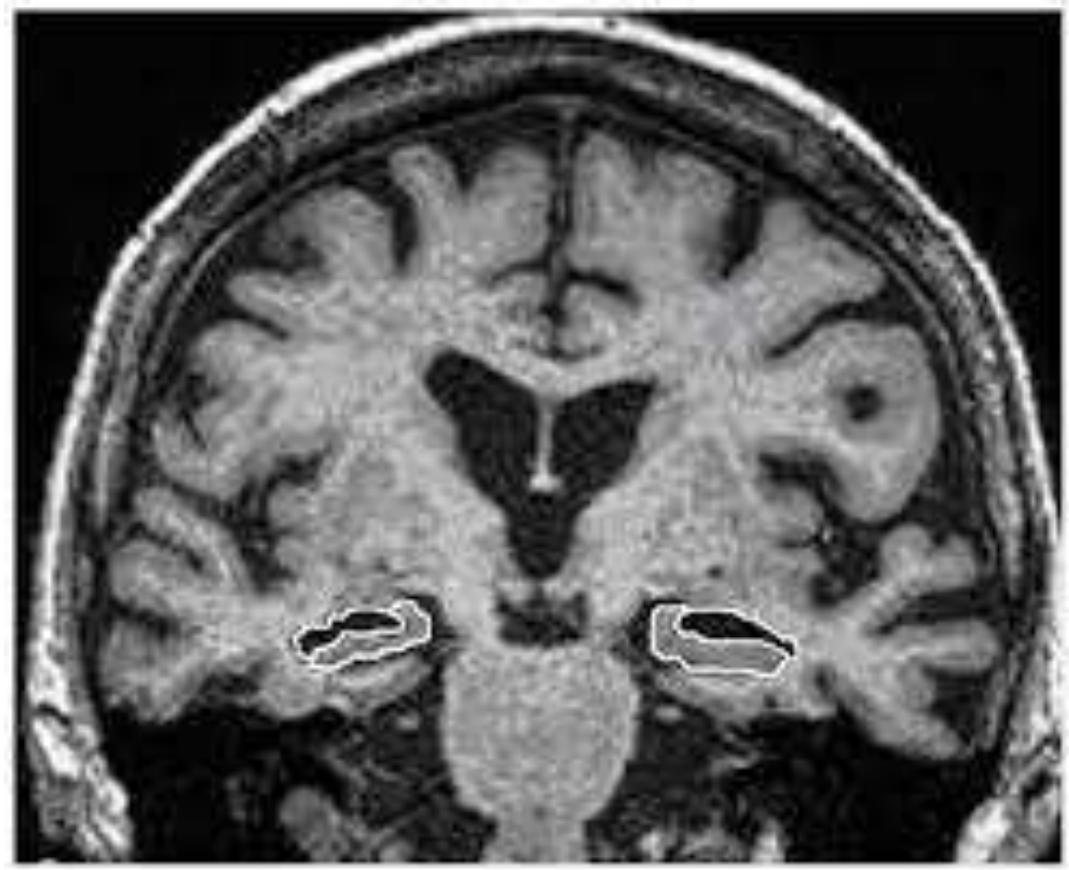
- Visual score performed on MRI of the brain using **coronal T1 weighted images** through the hippocampus at the level of the anterior pons. It is based on three features

1. Width of the choroid fissure
2. Width of the temporal horn of the lateral ventricle
3. Height of the hippocampus

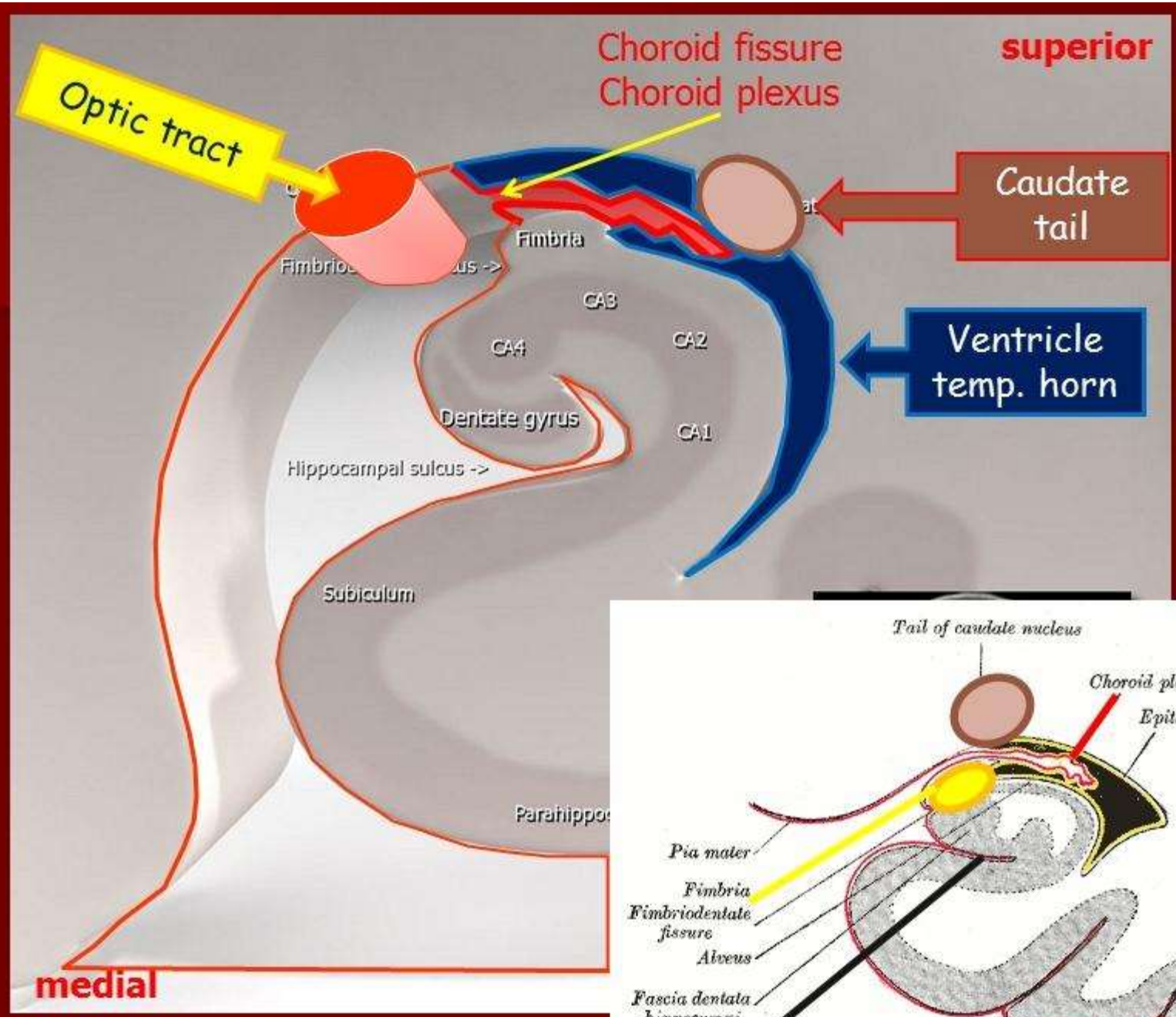








MedPix®



Modified from:

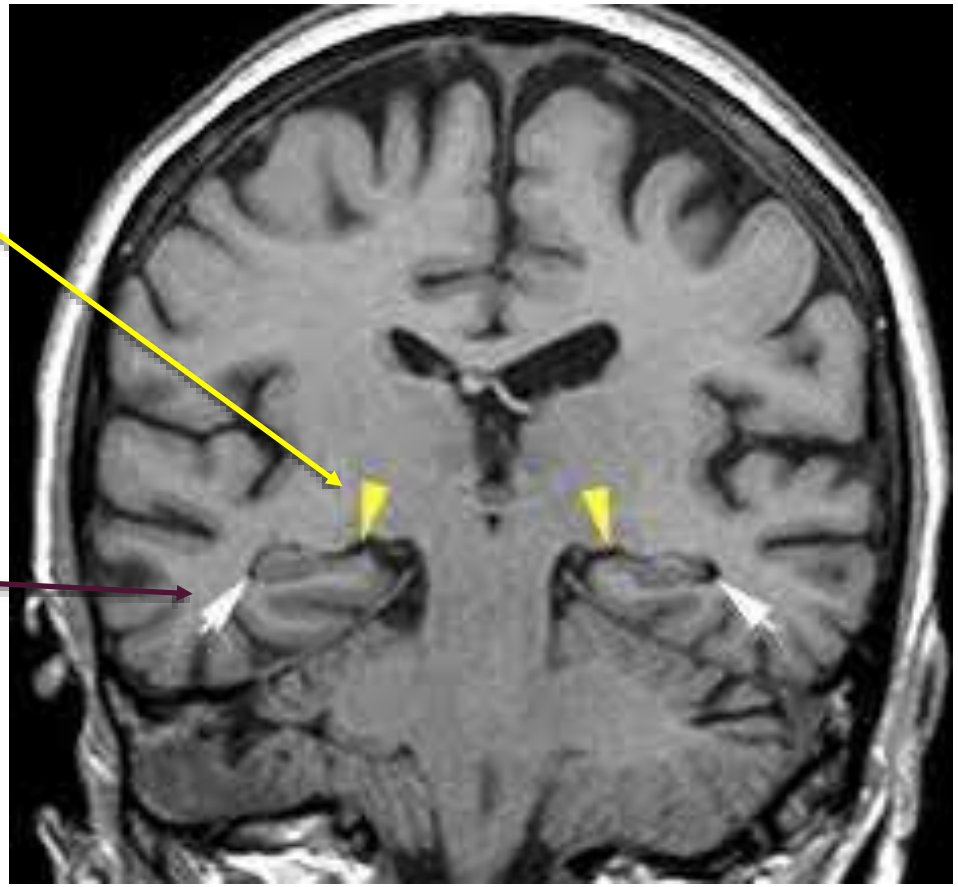
MEDIAL TEMPORAL LOBE ATROPHY SCORE (MTA)

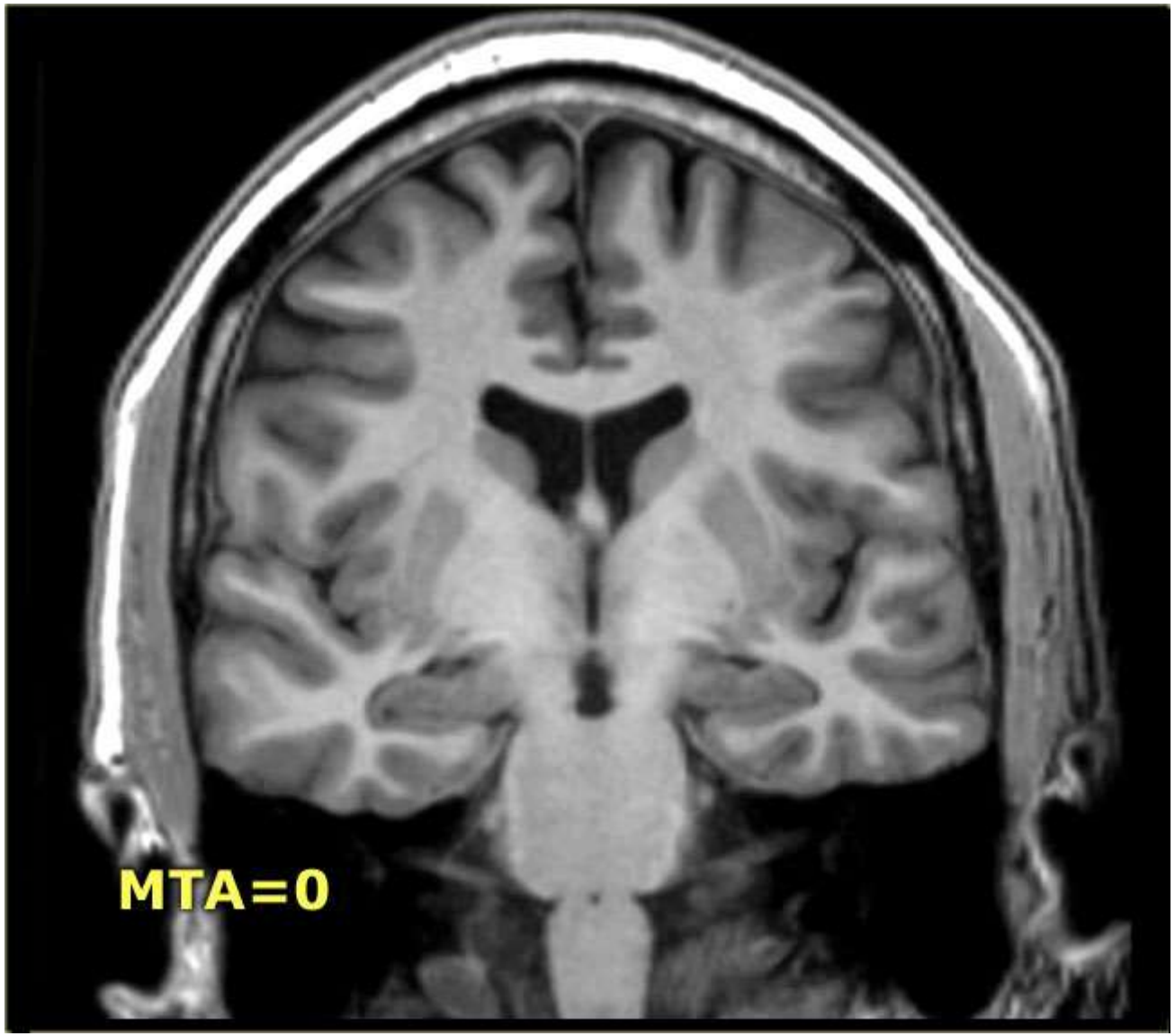
- score 0: no atrophy
- score 1: only widening of choroid fissure
- score 2: also widening of temporal horn of lateral ventricle
- score 3: moderate loss of hippocampal volume (decrease in height)
- score 4: severe volume loss of hippocampus

- <75 years: ≥2 is abnormal
- ≥75 years: ≥3 is abnormal

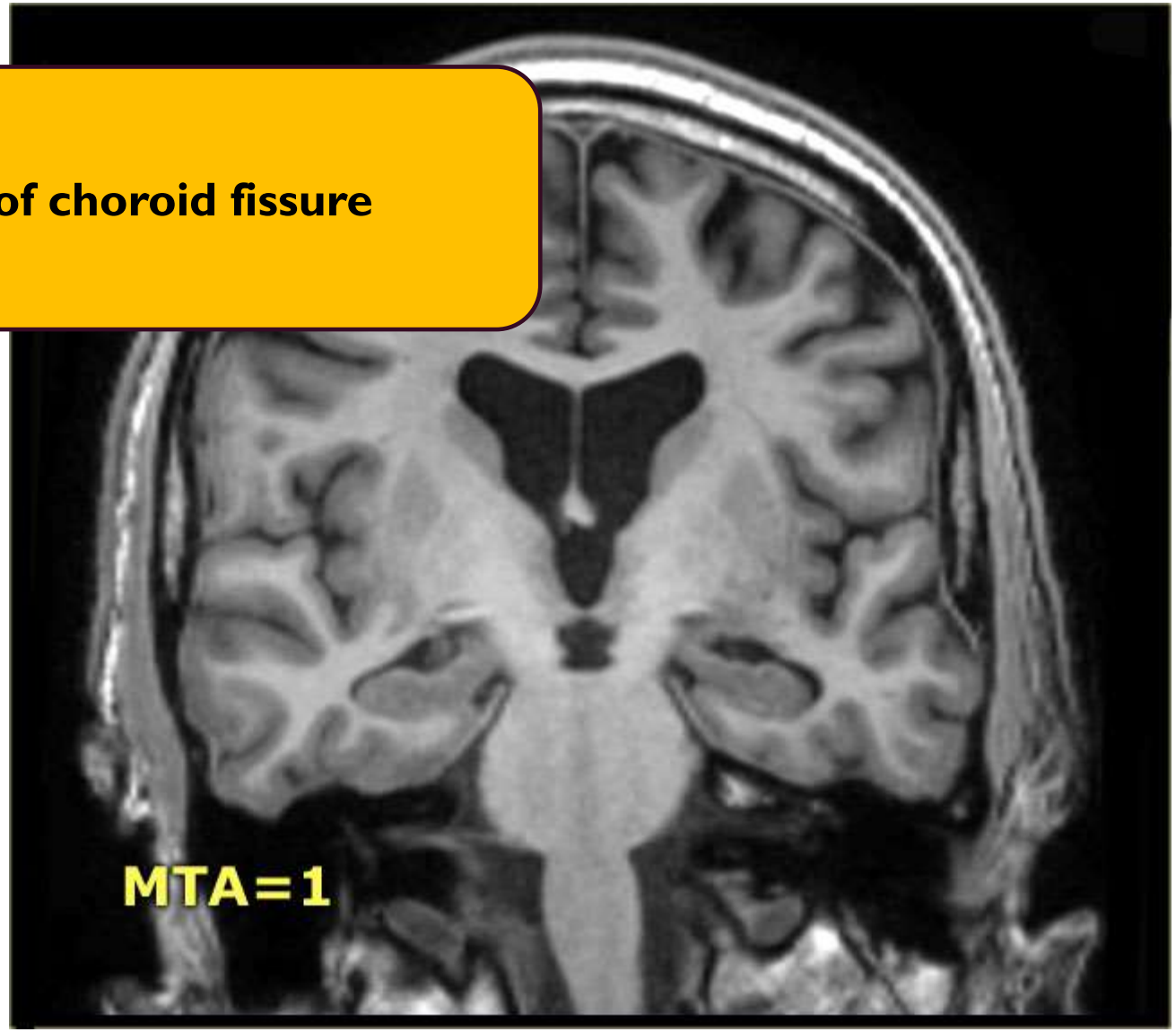
choroid fissure

Temporal horn of lateral ventricle

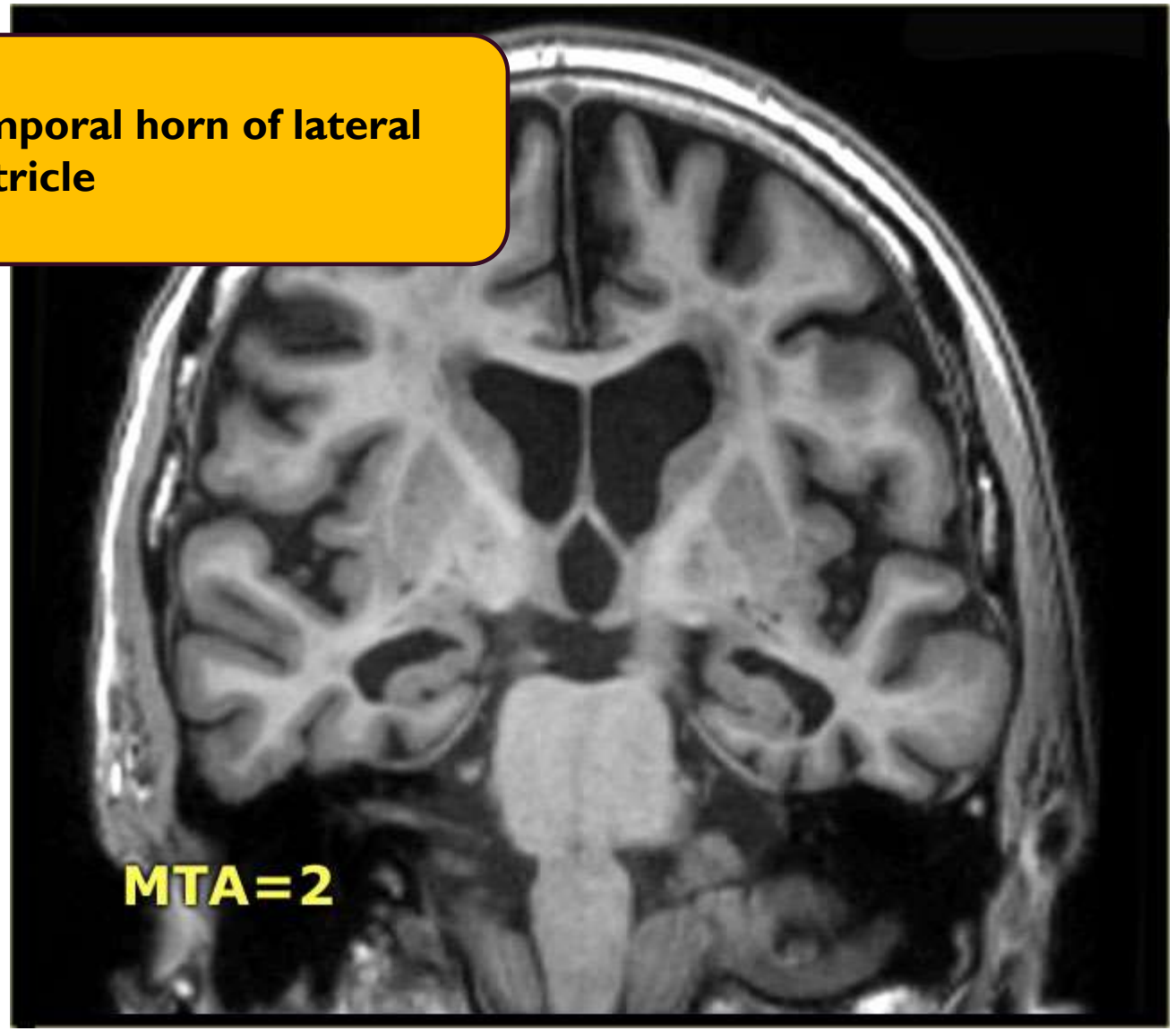



MTA=0

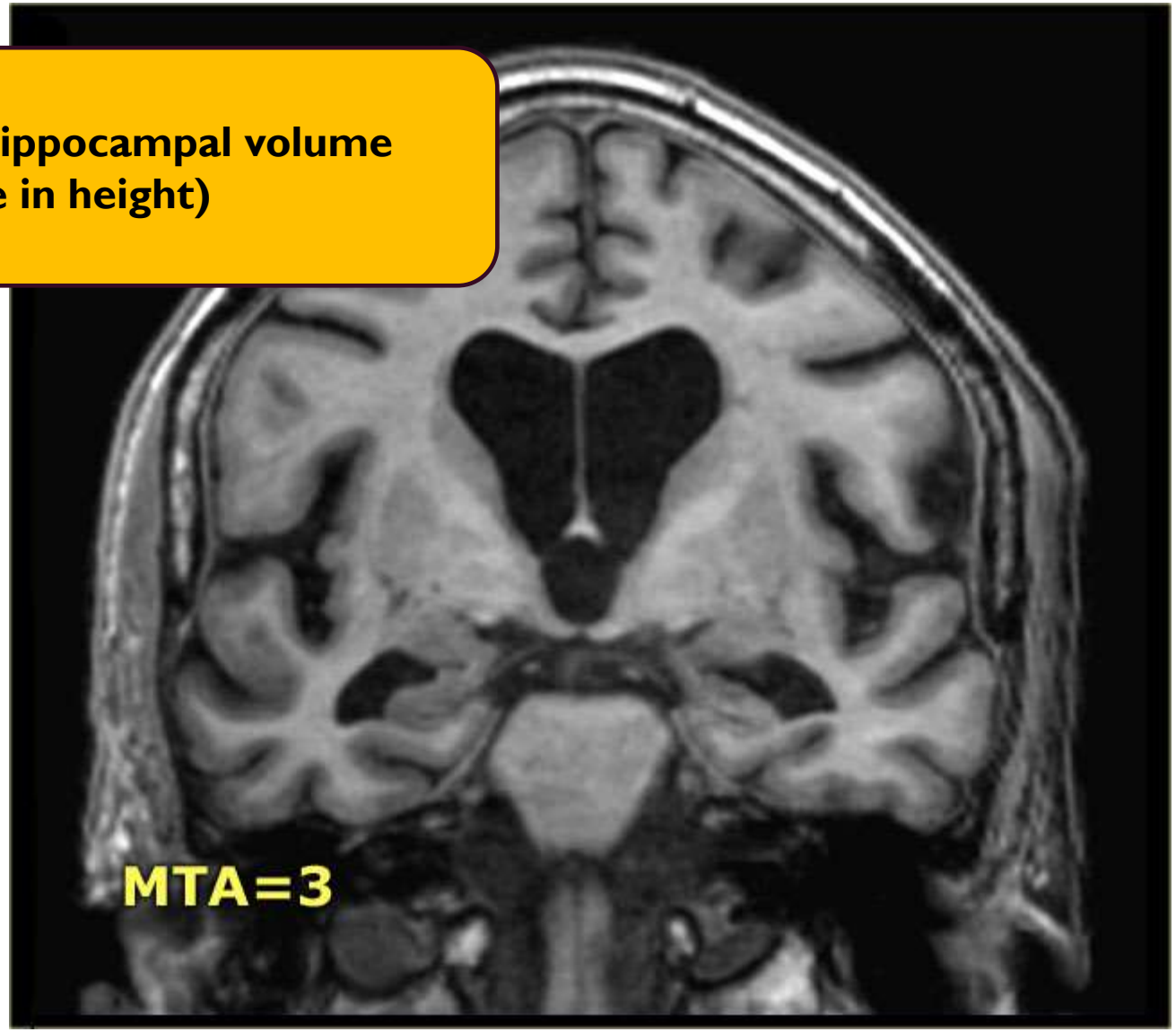
Only widening of choroid fissure



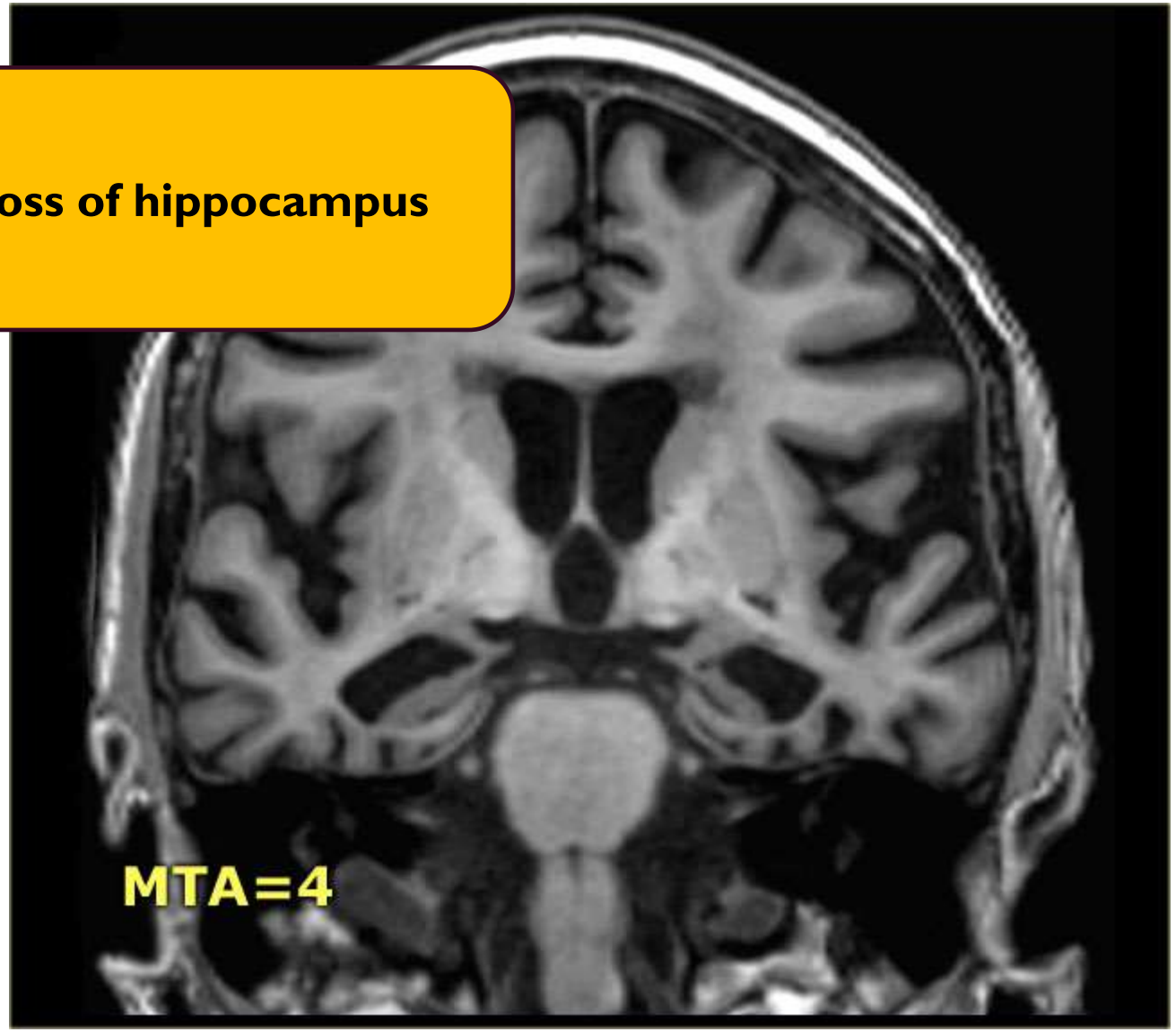
Also widening of temporal horn of lateral ventricle

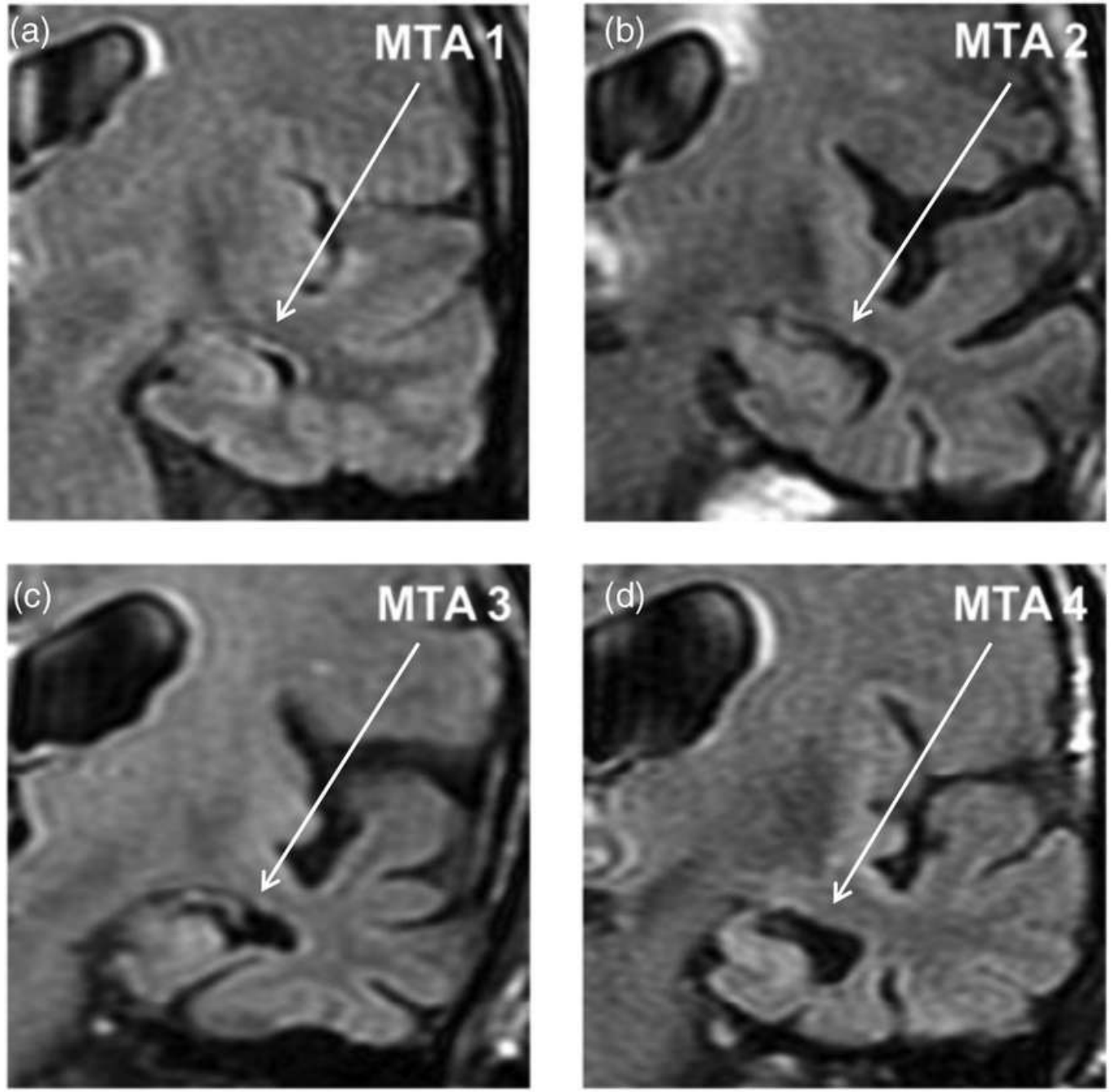


Moderate loss of hippocampal volume (decrease in height)

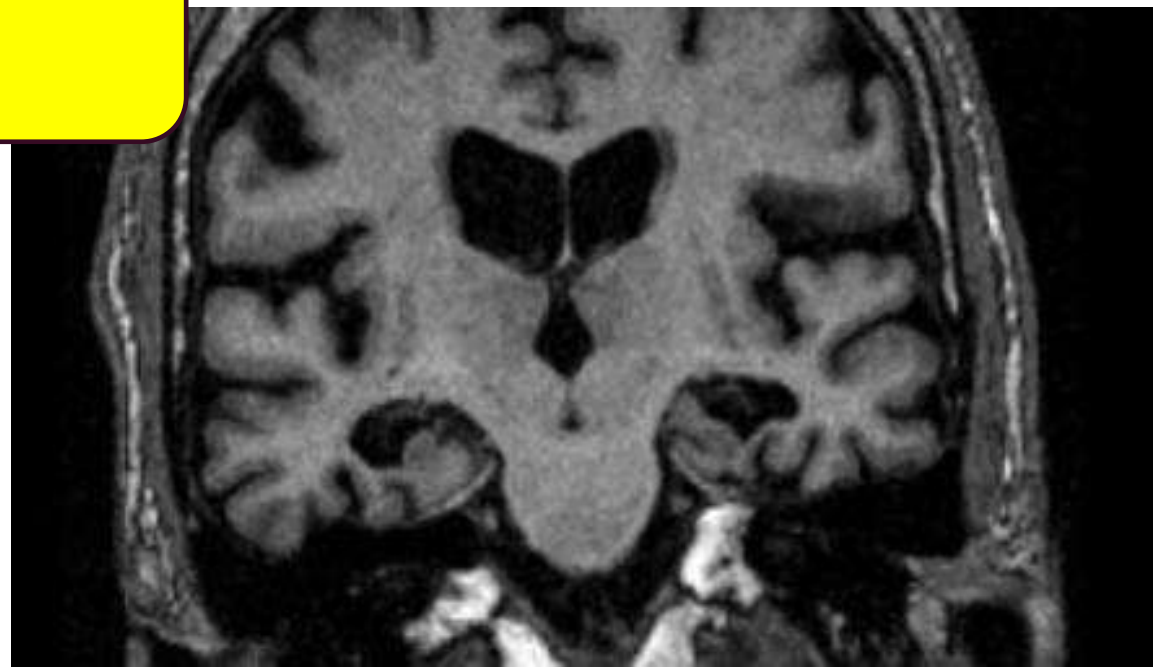


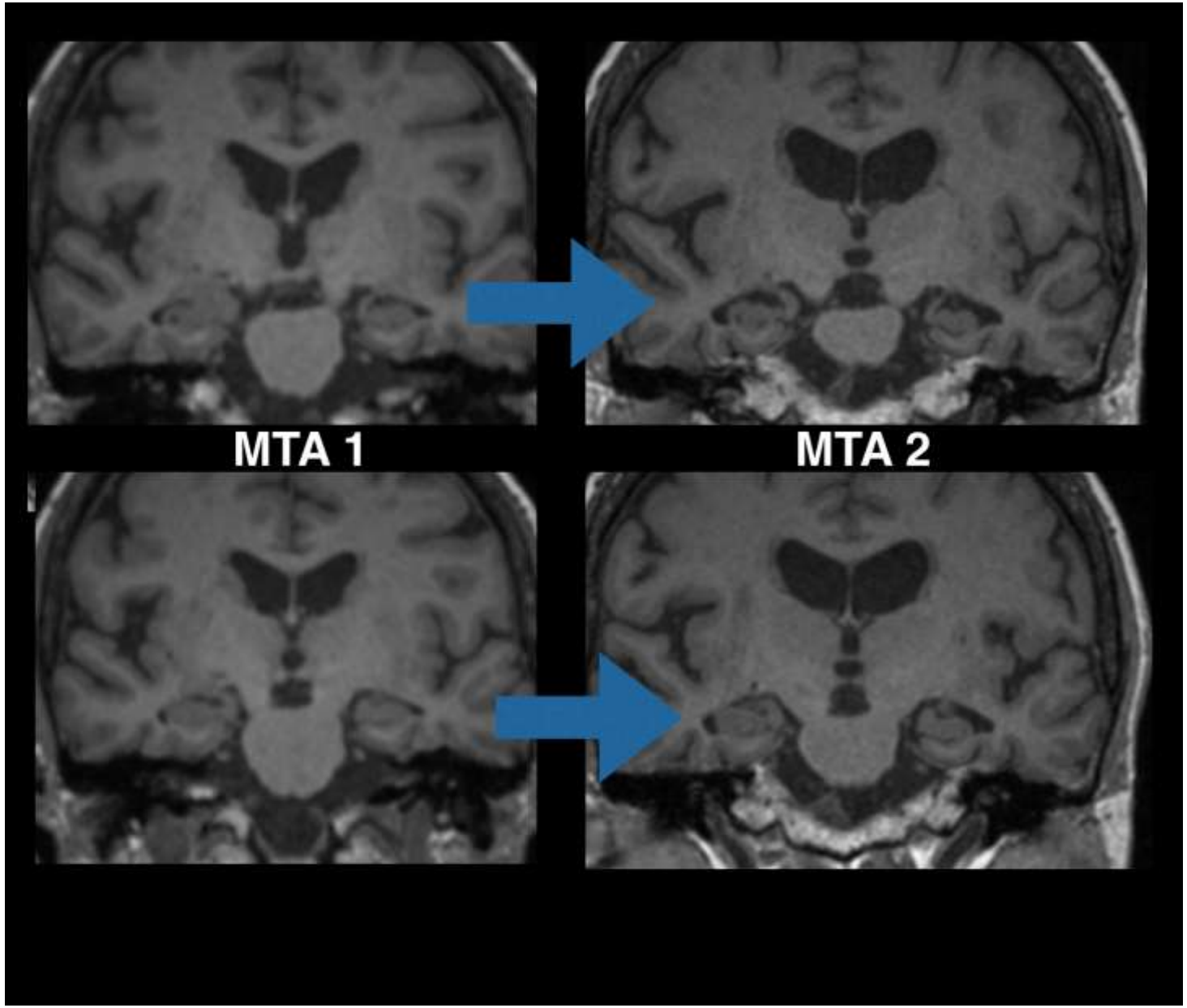
Severe volume loss of hippocampus




(a)
MTA 1
(b)
MTA 2
(c)
MTA 3
(d)
MTA 4

MTA score 4




MTA 1
MTA 2

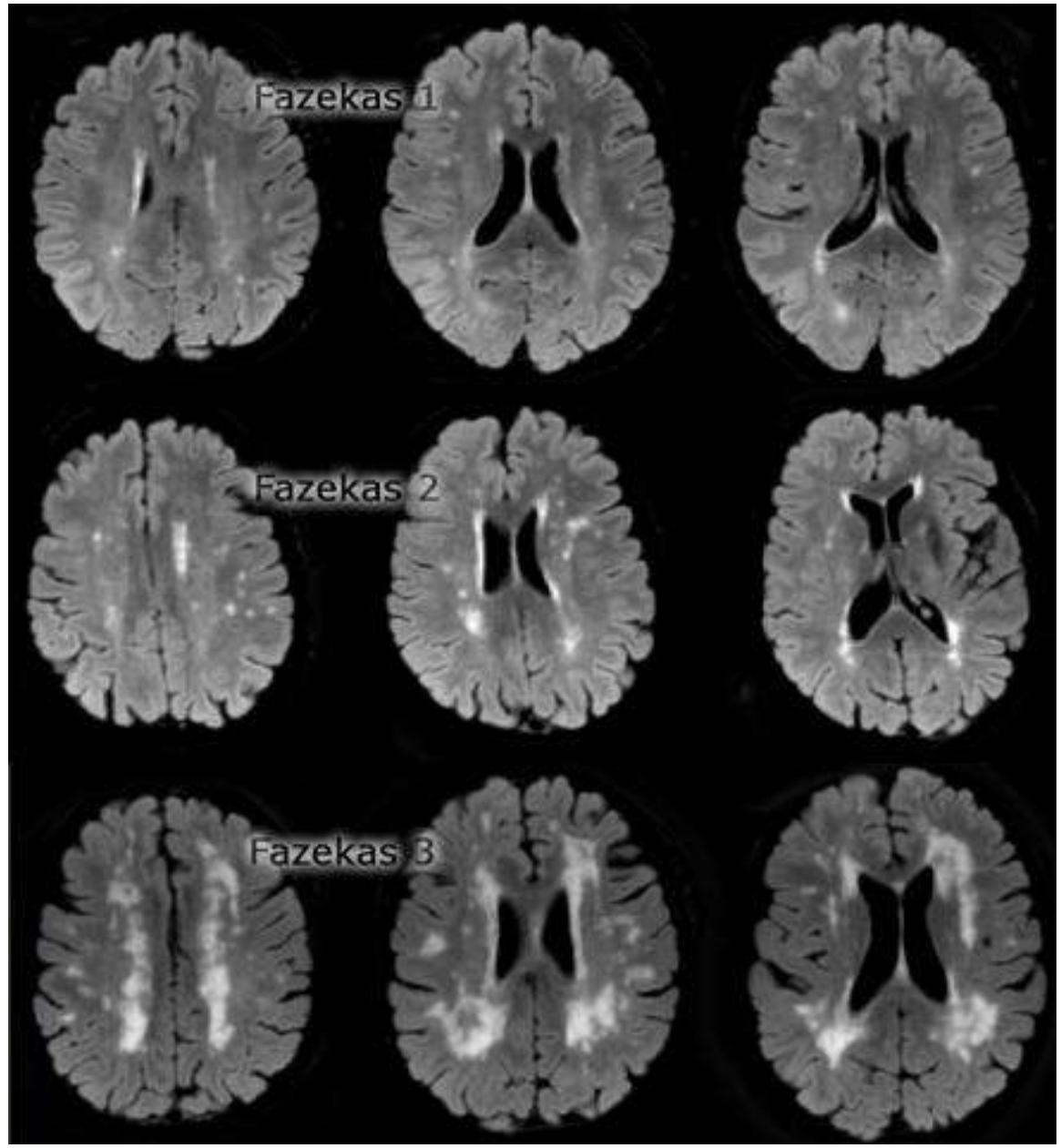
FAZEKAS SCALE FOR WM LESIONS

- Fazekas-scale provides an overall impression of the presence of WMH in the entire brain. It is best scored on transverse **FLAIR or T2-weighted images**
- Fazekas 0: None or a single punctate WMH lesion
- Fazekas 1: Multiple punctate lesions
- Fazekas 2: Beginning confluency of lesions (bridging)
- Fazekas 3: Large confluent lesions

FAZEKAS SCALE FOR WM LESIONS

- Fazekas 1 is considered normal in the elderly

- Fazekas 2 and 3 are pathologic, but may be seen in normally functioning individuals
  They are however, at high risk for disability


Fazekas 1
Fazekas 2
Fazekas 3

POSTERIOR ATROPHY SCORE OF PARIETAL ATROPHY

- Koedam score
- Developed to enable visual assessment of parietal atrophy on MRI, and is useful in the assessment of patients with possible dementia, especially atypical or early onset Alzheimer's disease

POSTERIOR ATROPHY SCORE OF PARIETAL ATROPHY

- To generate this score, the brain must be viewed in three planes, and multiple structures assessed:

1. sagittal plane
    1. posterior cingulate sulcus
    2. parieto-occipital sulcus
    3. precuneus gyrus
2. coronal plane
    1. posterior cingulate sulcus
    2. parietal gyrus
3. axial plane
    1. posterior cingulate sulcus
    2. parietal lobes

POSTERIOR ATROPHY SCORE OF PARIETAL ATROPHY

- The worse features are used to generate a grade of 0 to 3

- Grade 0: closed sulci, no gyral atrophy
- Grade 1: mild sulcal widening, mild gyral atrophy
- Grade 2: substantial sulcal widening, substantial gyral atrophy
- Grade 3: marked sulcal widening, knife-blade gyral atrophy

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