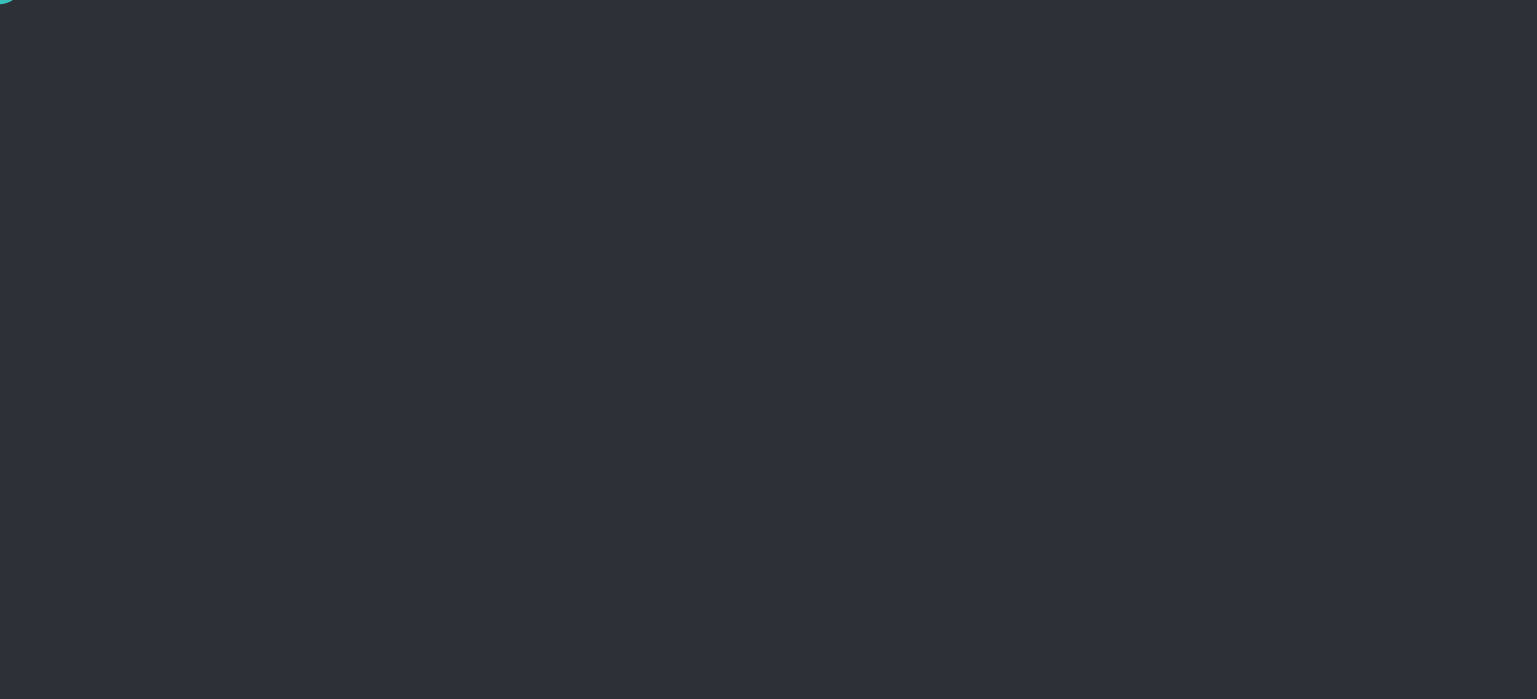


Neuroanatomy & Neuroanatomical Imaging ● in Movement Disorders





Neuroanatomy in Movement Disorders

Neuroanatomy Related to Movement disorder

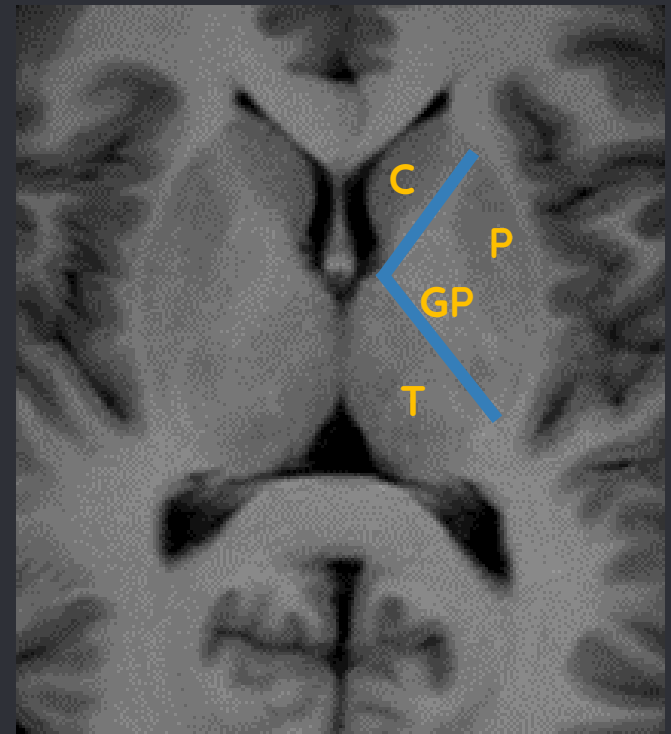
- Basal ganglion
- Cortex (epilepsy, apraxia)
- Brainstem (palatal myoclonus, tonic spasm)
- Cerebellum (tremor)
- Cranial nerve (synkinesis, hemifacial spasm)
- Spinal cord (some myoclonus, spasticity, stiff man)
- Peripheral nerve (synkinesis, painful feet with moving toes)
- Neuromuscular junction (weakness)
- Muscle (rippling muscle disease, fibrosis, calcification)

● Basal Ganglion

- Paired symmetric structures located between lateral ventricle and insular cortex
- Mainly involved in movement and part of extrapyramidal motor system
- Memory, emotion, and other cognitive functions

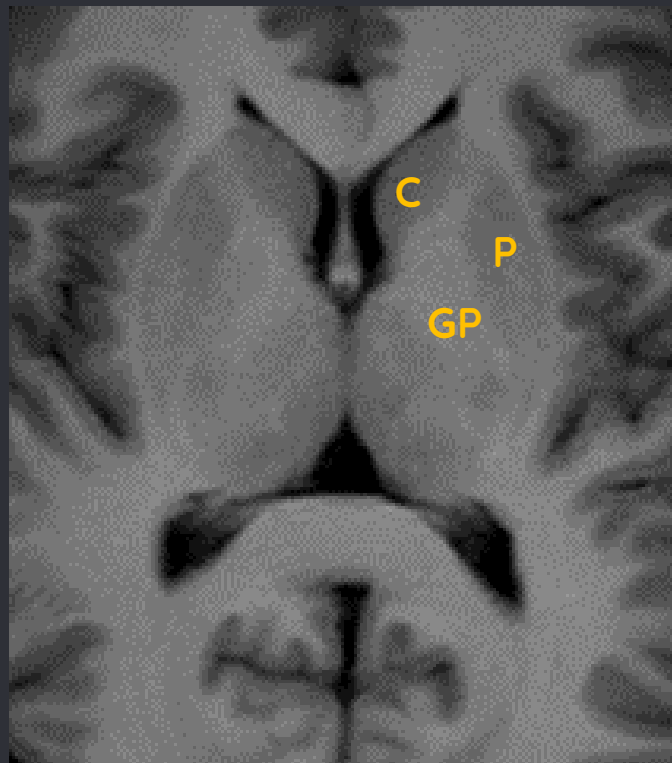
- **Basal ganglia:**

- Caudate nucleus (C)
- Putamen (P)
- Globus pallidus (GP)



● Basal Ganglion

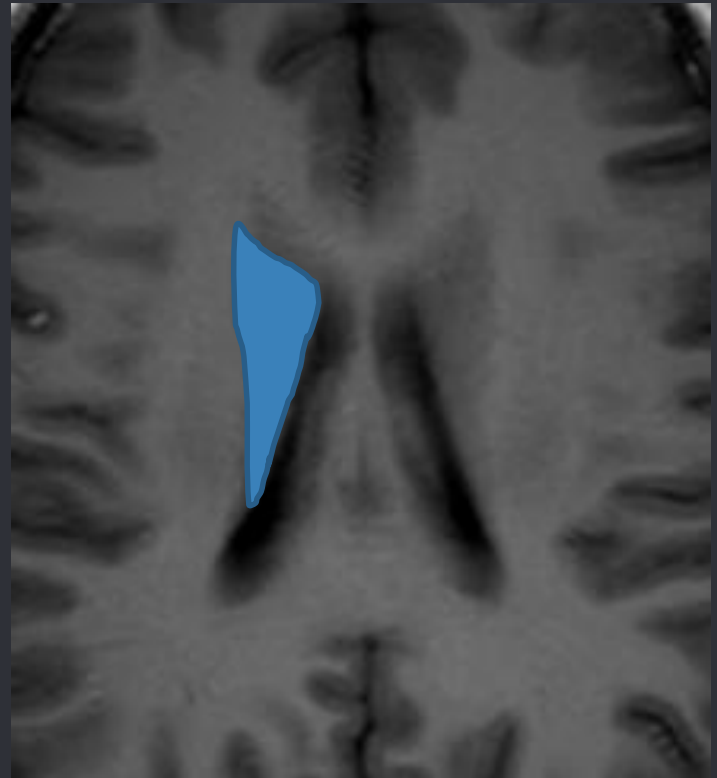
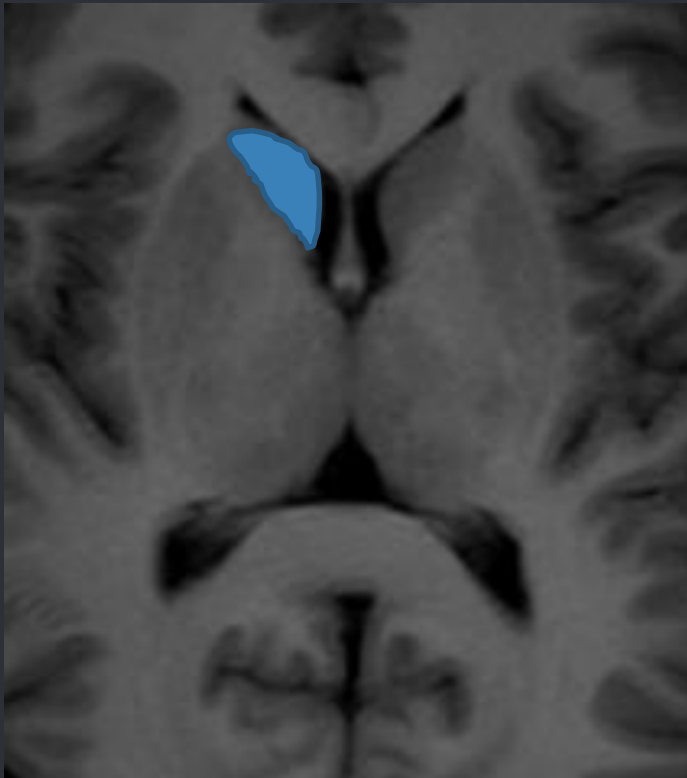
- **Lentiform nucleus:** Putamen + globus pallidus (GP)
- **Corpus striatum:** Caudate nucleus + putamen + GP
- **Neostriatum:** putamen + caudate



● Basal Ganglion

◦ Caudate nucleus:

- "C-shaped" curved nucleus with large head, tapered body, down-curving tail



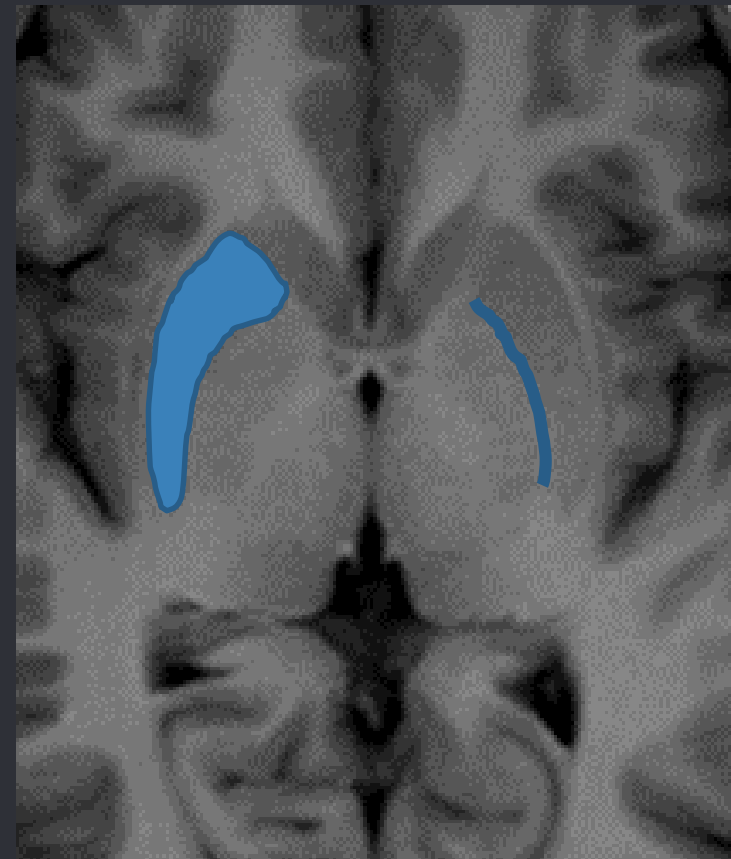
● Basal Ganglion

◦ Putamen:

- Located lateral to GP
- Separated by lateral (external) medullary lamina

◦ GP: Two segments

- Lateral (external) and medial (internal) segments
- Separated by internal medullary lamina



● Basal Ganglion

◦ Putamen:

- Located lateral to GP
- Separated by lateral (external) medullary lamina

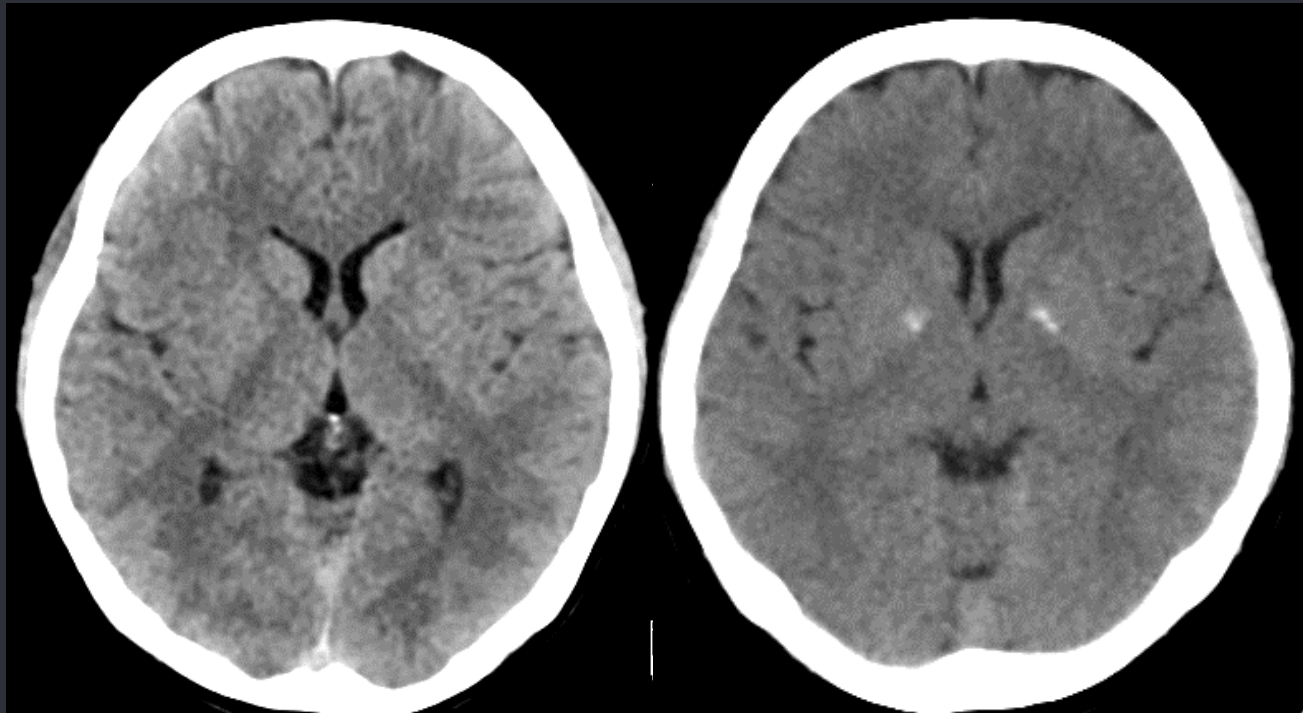
◦ GP: Two segments

- Lateral (external) and medial (internal) segments
- Separated by internal medullary lamina



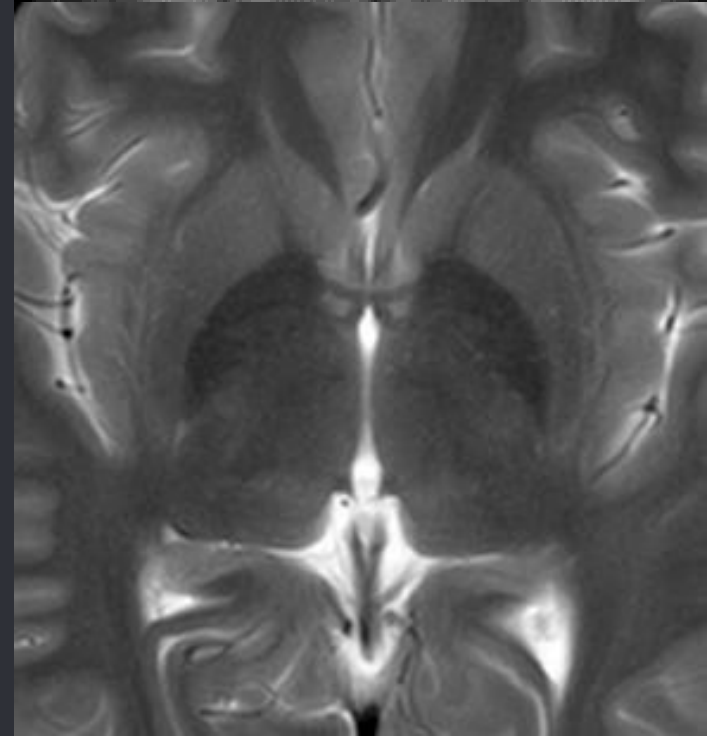
● Basal Ganglion: CT

- Deep gray nuclei hyperdense to white matter
- Isodense with cortex
 - Punctate or dense globular Ca^{++} common
 - Usually symmetric, in medial GP
 - Common in middle-aged, older patients



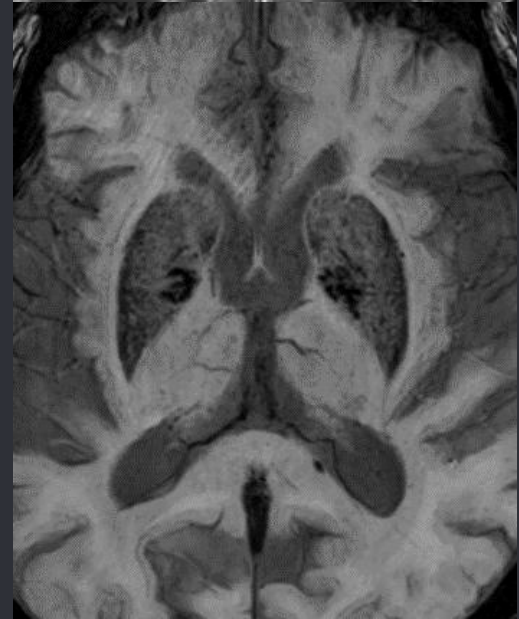
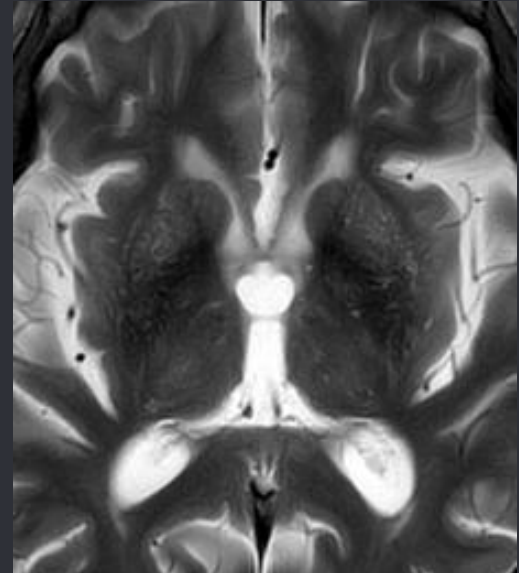
● Basal Ganglion: MRI

- Caudate nucleus and putamen:
 - isointense to the cortical gray matter with all pulse sequences
- Globus pallidus:
 - Slightly hypointense relative to putamen on T2WI
 - Higher myelin content than putamen
 - Progressive iron deposition in aging



● Age-related Iron Deposition in the Basal Ganglia

- Iron deposition in BG occurs with normal aging
- No Fe in brain at birth
- Progressive ↑ with aging
- ↓ signal intensity on T2WI and T2*WI
- GP hypointensity begins to ↑ in 2nd decade
- Putamen = GP hypointensity at 80 yrs



● Substantia Nigra and Subthalamic Nucleus

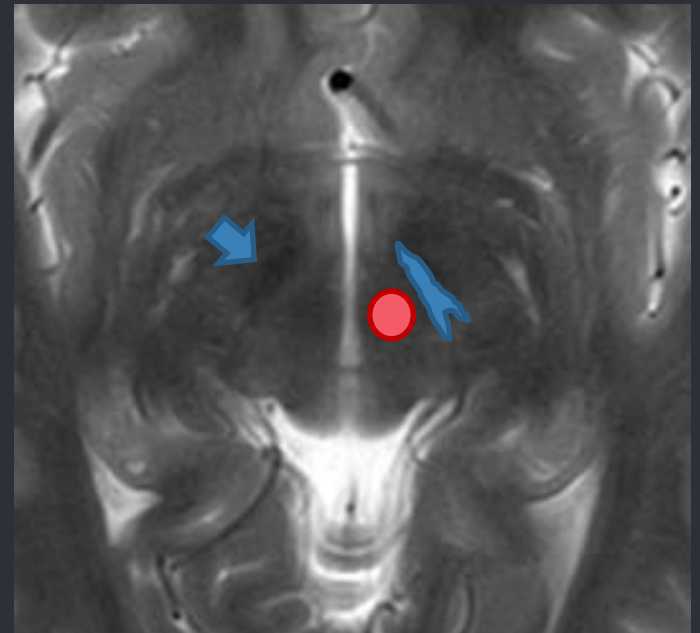
- Substantia nigra (SN)
- Subthalamic nucleus (STN)

} Key nuclei in PD and parkinsonian illnesses such as PSP

- SN: severely affected in both conditions with slightly different topography
- STN
 - A preferred target in stereotactic surgical techniques in PD (DBS)
 - A characteristic site of severe pathologic involvement in PSP

Substantia Nigra: Location and Constituent parts

- Pigmented nucleus important in movement
- Extend through midbrain from pons to subthalamic region
- Posterior to crus cerebri, anterior to midbrain tegmentum
- Inferior and lateral to red nucleus (RN)
- Divided into 2 anatomically and functionally distinct parts:
 - **Pars compacta (SNpc):**
 - Contains dopaminergic cells
 - Inferior and posterior
 - **Pars reticularata (SNr):**
 - Contains GABAergic cells
 - Superior and anterior



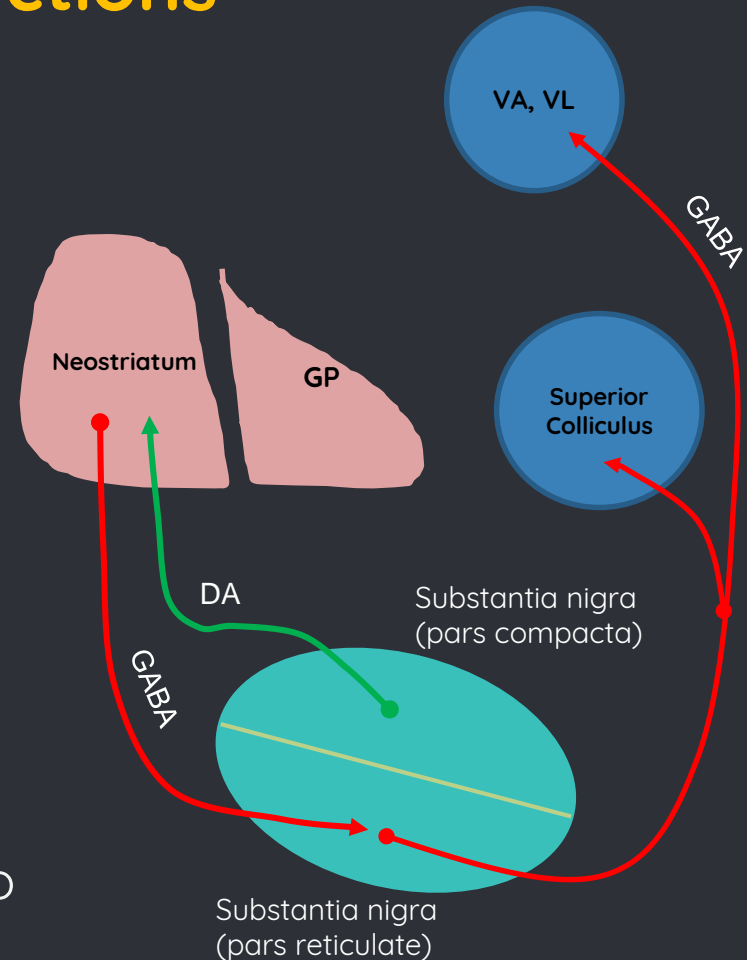
● Substantia Nigra: Connections

- Substantia nigra pars compacta

- “The nigrostriatal pathway”
- Neurons of the SNpc project to the striatum using the neurotransmitter dopamine

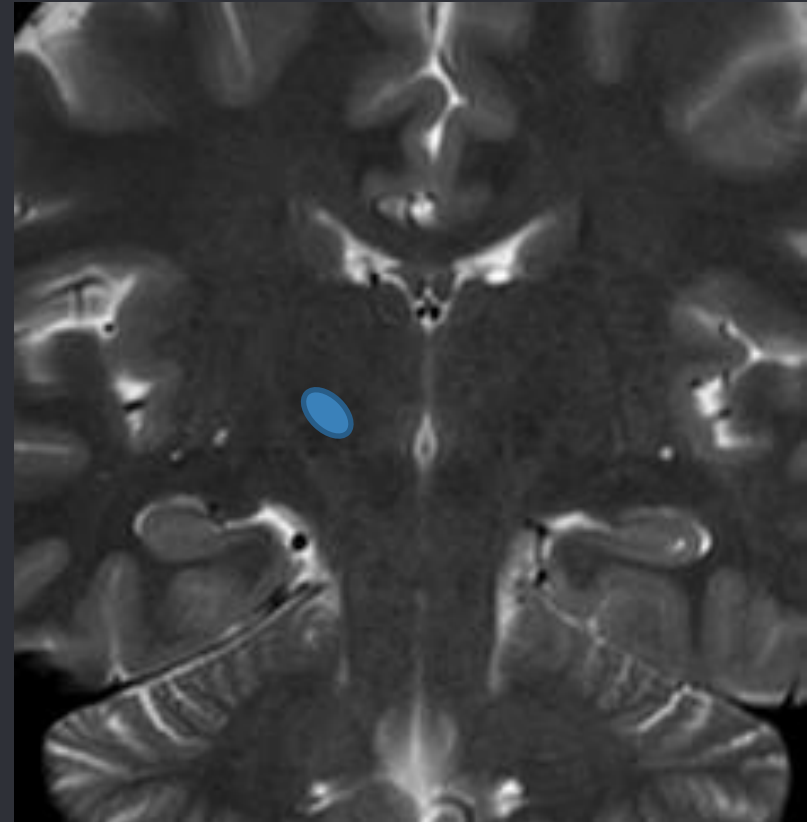
- Substantia nigra pars reticulata

- A reciprocal projection from the striatum that uses GABA, substance P, and dynorphin
- Neurons of the SNr form one of the output nuclei of BG project to thalamus & superior colliculus, using the neurotransmitter GABA



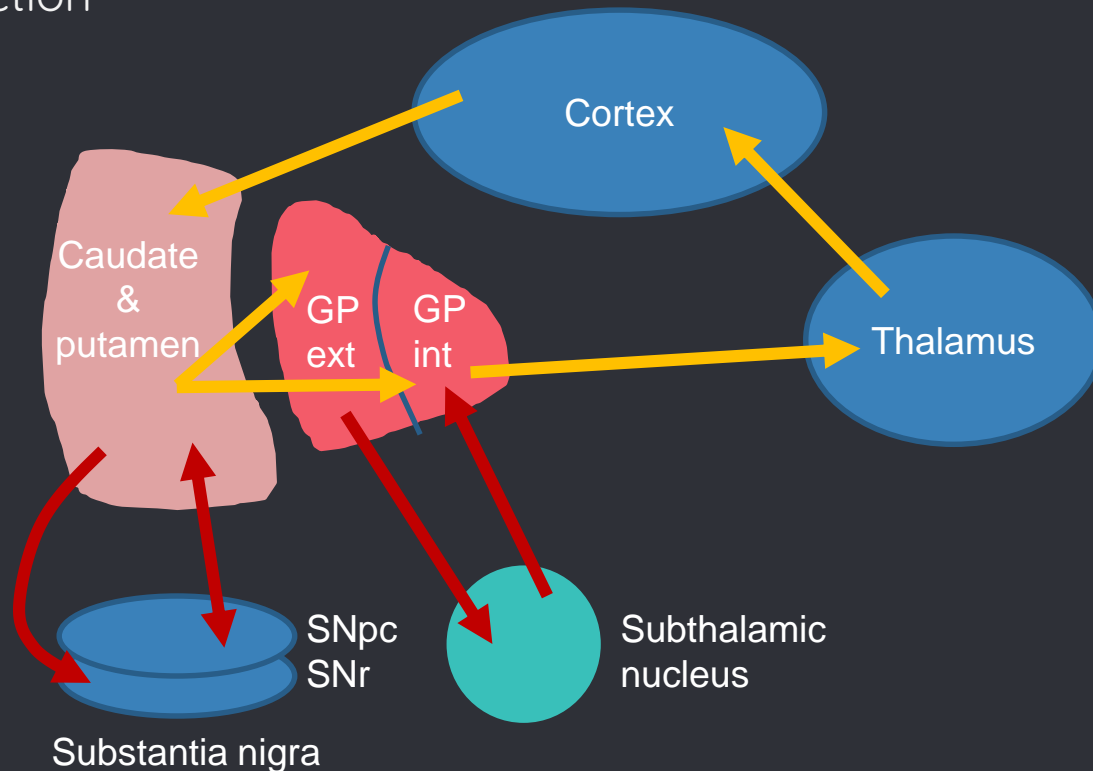
● Subthalamic nucleus: Location

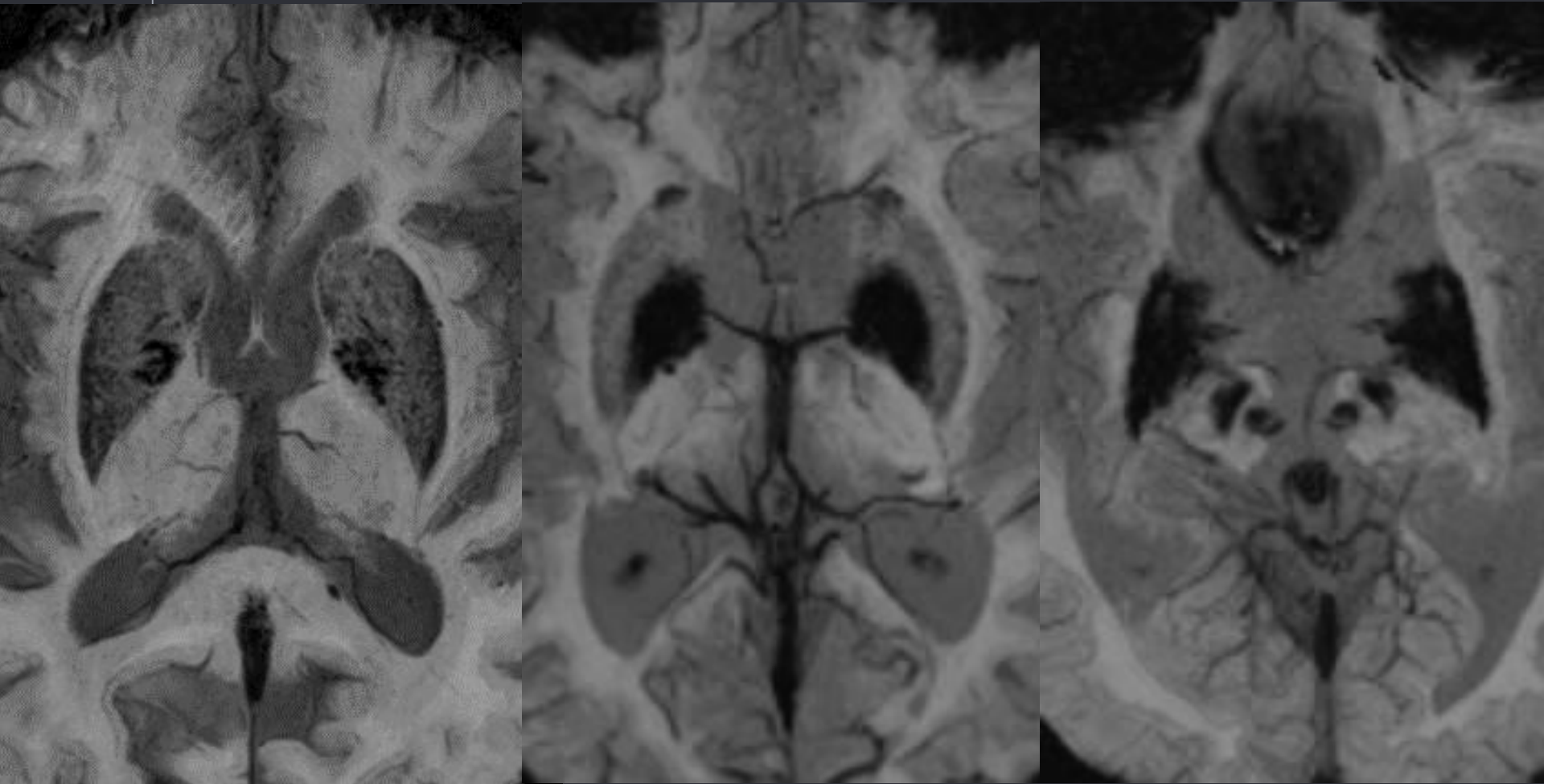
- Major role in normal function of basal ganglia
- Biconvex lens-shaped obliquely oriented nucleus
- Located on dorsomedial surface of peduncular part of internal capsule
- Located lateral to red nucleus and dorsolateral to SN
- Appears as T2-hypointense SI attributed to iron deposition



Subthalamic nucleus: connections

- Receives inputs from the association cortex and from the striatum (using a relay in the globus pallidus externa)
- Part of indirect pathway (GPext-STN-GPint-thalamic-cortical circuit)
- Balance between the nigro-striatal and pallido-subthalamic connection



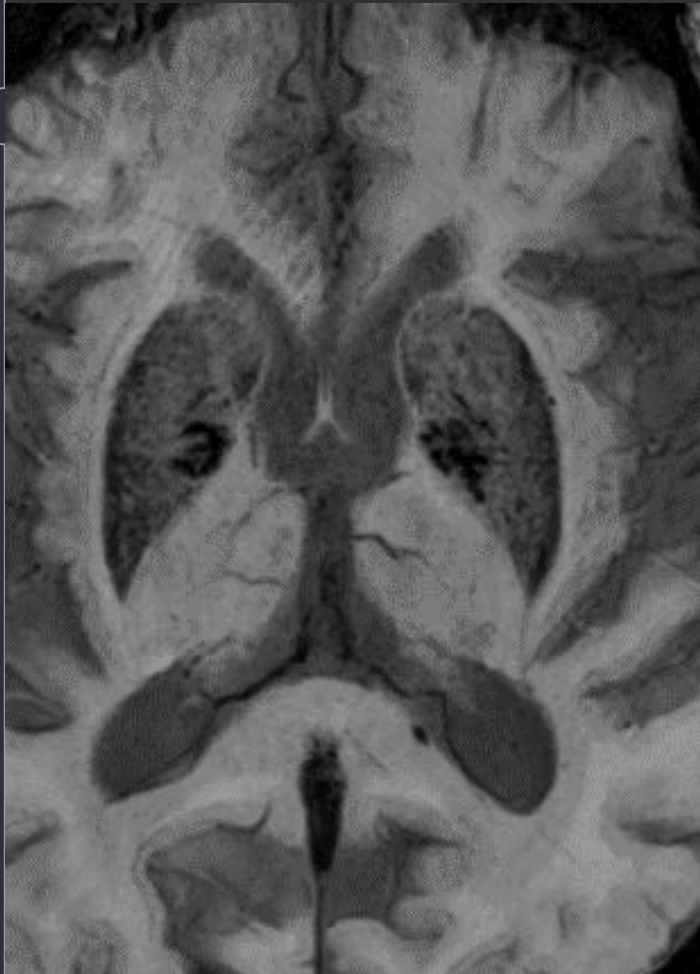


Age-related Iron Deposition vs Abnormal Iron Deposition

● Age-related Iron Deposition in the Basal Ganglia

- Quantitative $R2^*$ maps
- Accumulation of iron in the GP, putamen, caudate nucleus, and SN
 - Depends on age
 - Different in each structure
 - Interindividual variability
- ↑ iron accumulation in GP, putamen, and SN
- SN > GP > putamen > caudate nucleus
- Scarce iron load in caudate nucleus at any age

● Age-related Iron Deposition in the Basal Ganglia



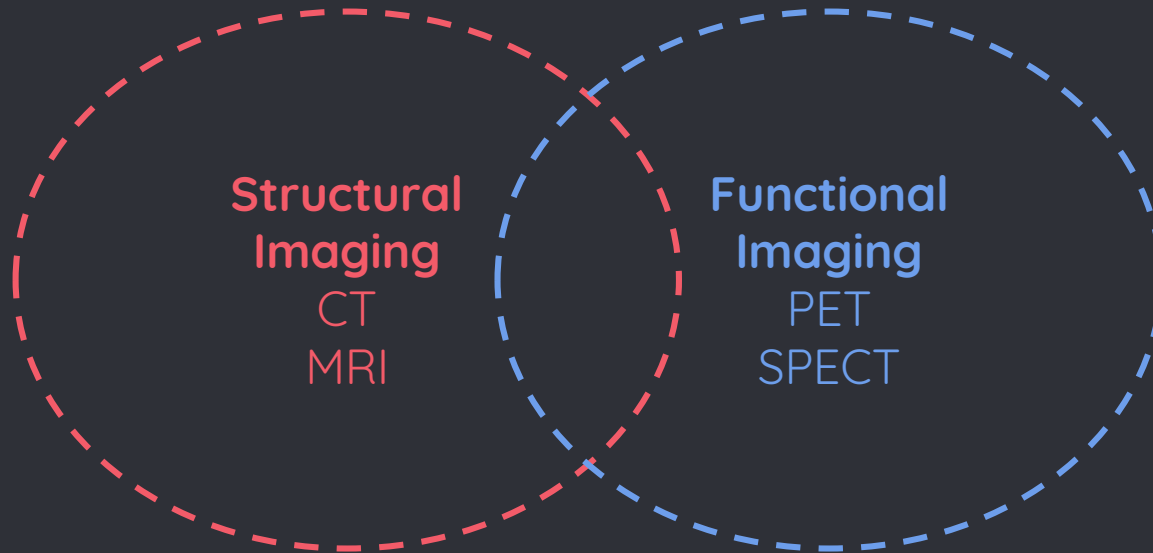
- **Globus pallidus**
 - Posterior to anterior segment
 - Medial to lateral portion
- **Putamen**
 - Extreme lateral portion to medial portion
- **SN**
 - Faster with respect to the GP and reaches a plateau value of at about 15 years



Neuroanatomical Imaging Findings in Movement Disorders

● Imaging in Movement Disorders

○



● Role of Structural Imaging in Movement Disorders



● Diagnosis

● Exclude structural abnormalities

● Aiding in planning of stereotactic neurosurgery

● Role of Structural Imaging in Movement Disorders

○ Imaging recommendations

- Best imaging tool: MRI
- NECT for Ca++

Imaging analyses

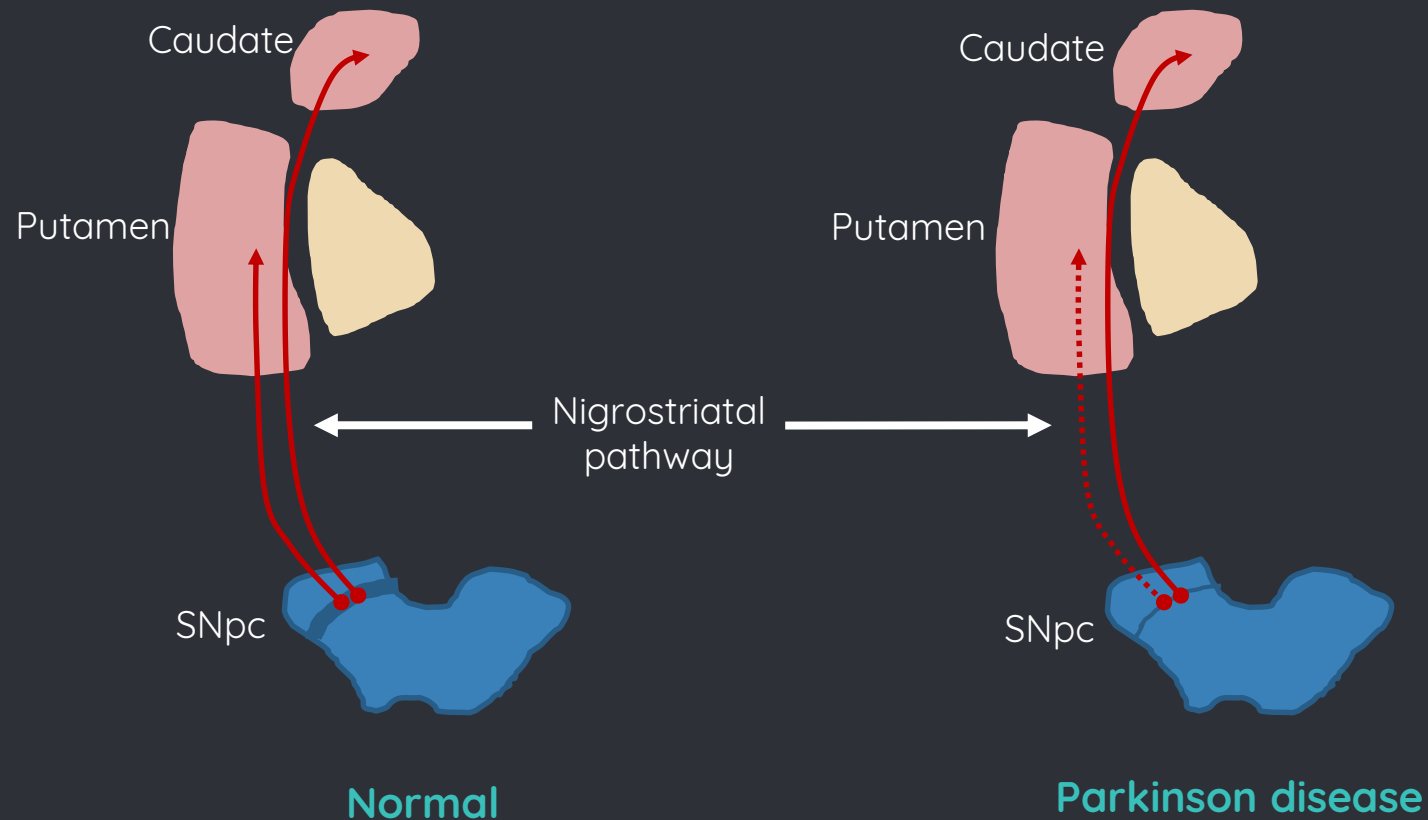
- Visual assessment
- Measurements
- Voxelwise technique

● Movement Disorders

- Parkinson disease
- Parkinson-plus syndrome
 - MSA
 - PSP
 - DLB
 - CBD
- Other: Vascular parkinsonism, NBIA

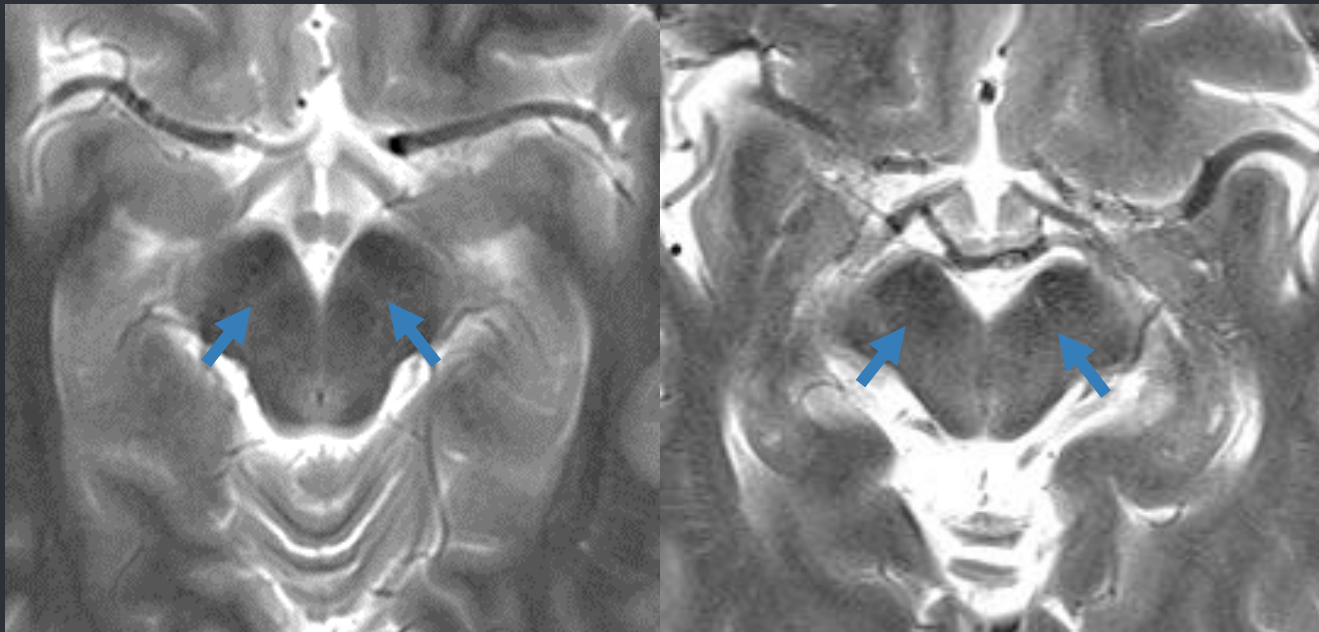
● Parkinson Disease

- Progressive neurodegenerative disease
- Predominantly caused by primary disorder of pars compacta of substantia nigra (SNpc)



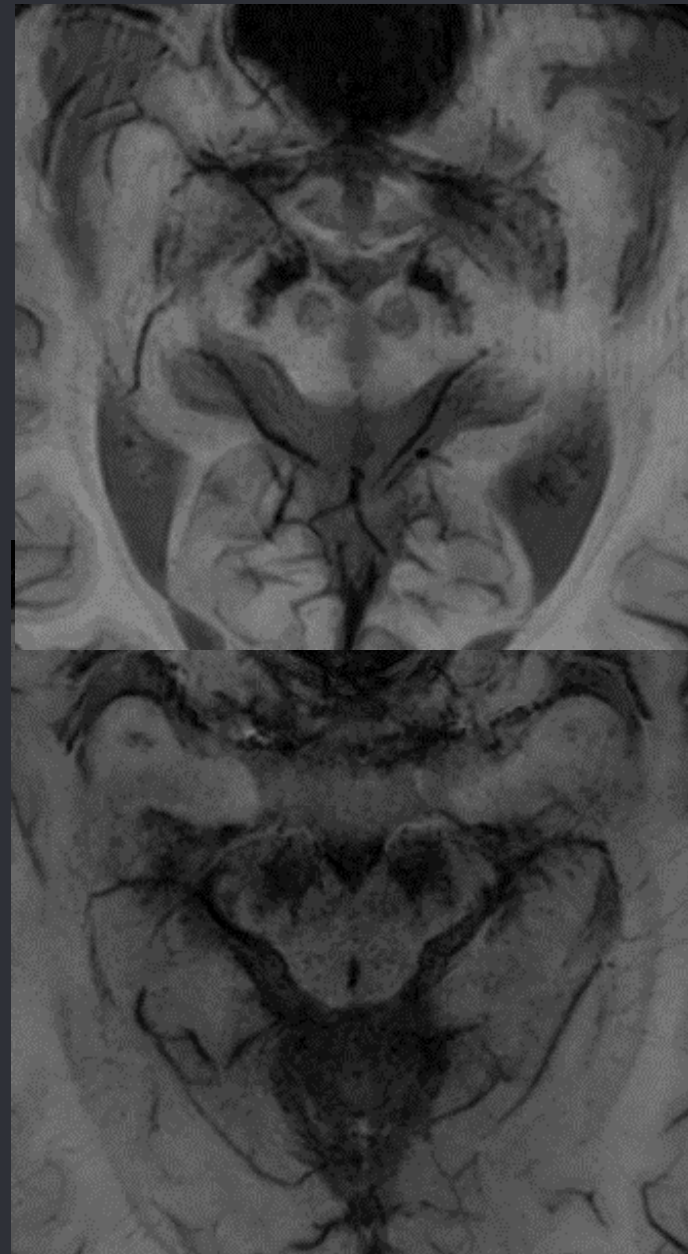
● Parkinson Disease: MRI

- Often normal
- SNpc narrowed/inapparent (T2WI)
- SNpc progressively loses normal hyperintensity (from lateral to medial)
- Border between SNpc, red nucleus blurred on PD



● Parkinson Disease: MRI

- Loss of “Swallow Tail”
- Healthy nigrosome-1
- High-resolution 3T SWI
- Dorsolateral SN
- Sensitivity 100%, specificity 95%, NPV 1, PPV 0.69, and accuracy 96%



● Multiple system atrophy (MSA)

○ Varying degrees of parkinsonism, cerebellar ataxia, and prominent autonomic dysfunction

○ 3 clinical subtypes

○ Cerebellar (MSA-C)

➤ Sporadic olivopontocerebellar atrophy (sOPCA)

○ Extrapyrarnidal (MSA-P)

➤ Striatonigral degeneration (SND)

○ Autonomic (MSA-A)

➤ Shy-Drager syndrome (SDS)

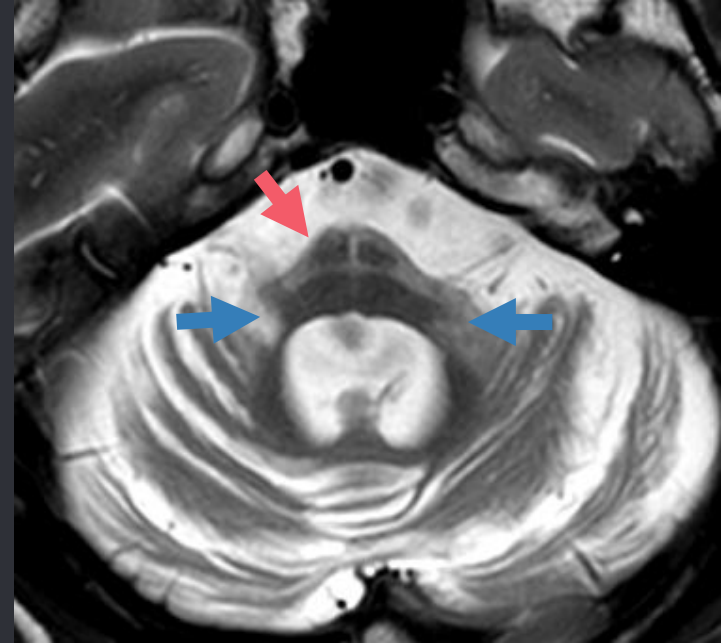
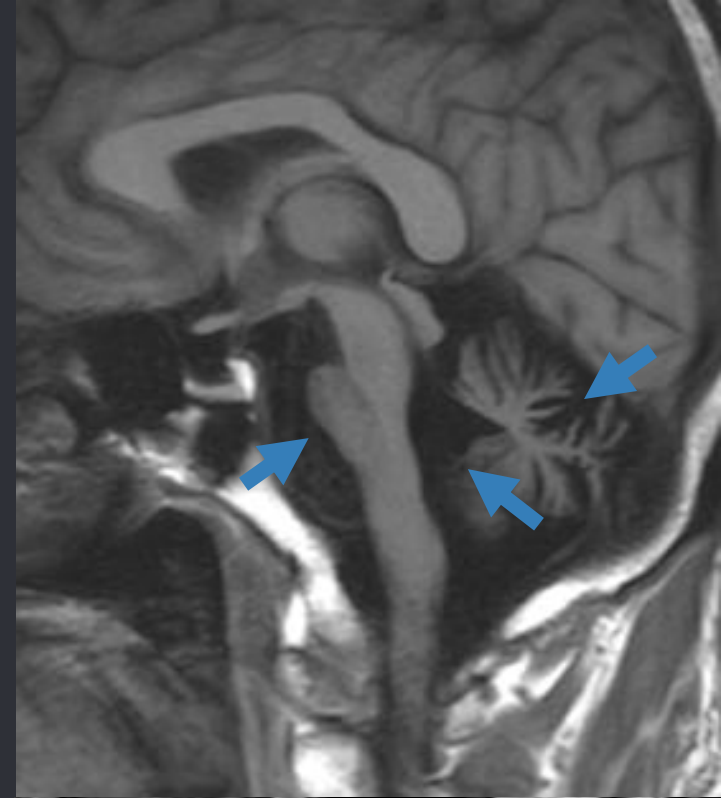
2 distinct imaging subtypes:
MSA-C and MSA-P

● MSA-C

- Selective atrophy of lower portion of basis pontis, medulla, MCPs, and cerebellar hemispheres
- Corresponding ↑ T2 signal
- Hyperintense signal in cruciform shape in pons

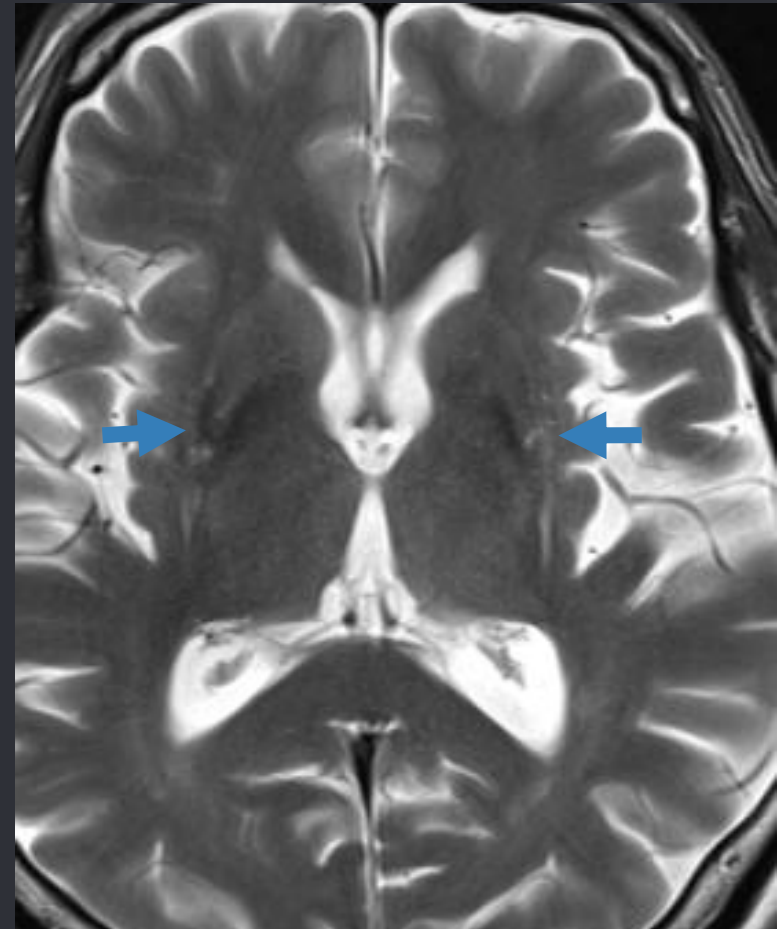
"hot cross bun" sign

- Reflects degeneration of pontine neurons and transverse pontocerebellar fibers



● MSA-P

- Atrophy of putamen
- ↓ signal in dorsolateral putamen
- ± ↑ signal in lateral rim of putamen



● Progressive Supranuclear Palsy

○ ◦ Supranuclear palsy, Parkinsonism, postural instability, pseudobulbar syndrome, & dementia

◦ Location

➤ Midbrain

✓ Tegmentum

✓ Tectum (superior colliculus)

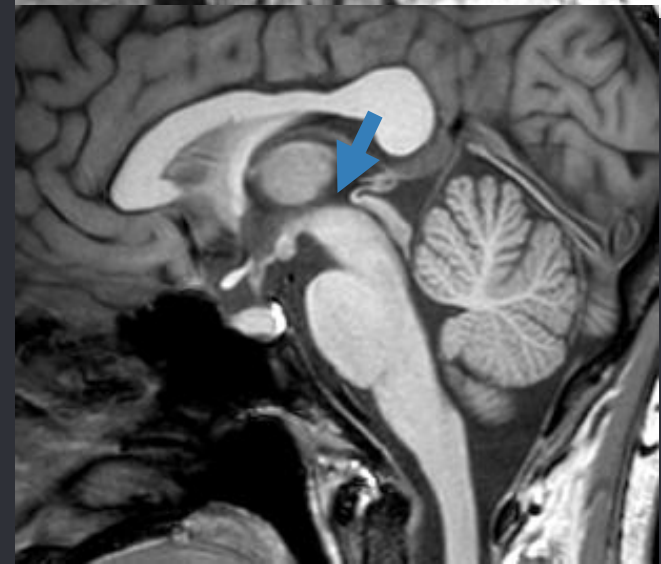
◦ Morphology

➤ Prominent midbrain volume loss

➤ Pons normal

● Progressive Supranuclear Palsy

- Midbrain atrophy
- "penguin" or "hummingbird" sign
- Sagittal: concave/flat upper border of midbrain
- Thinning of superior colliculus

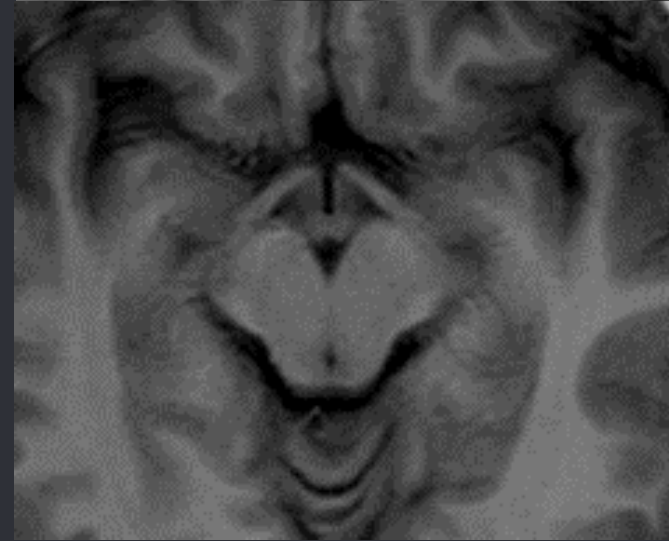
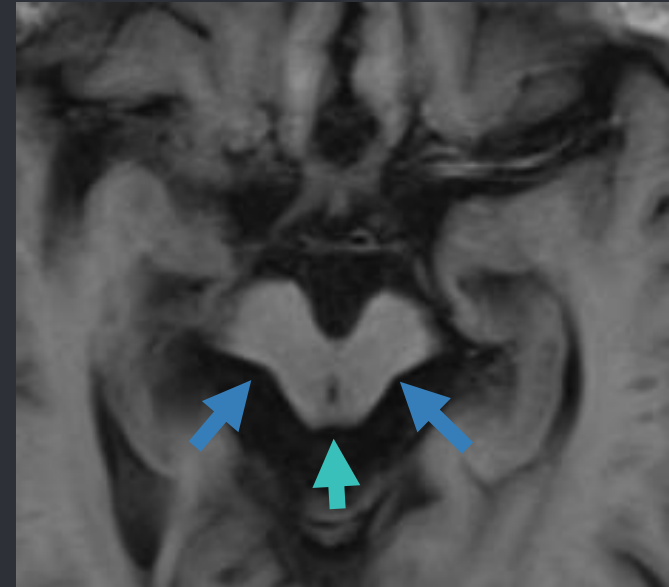
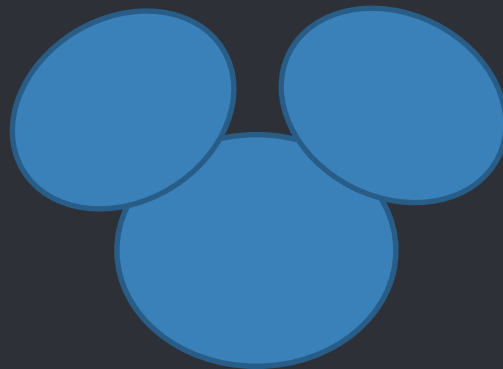


● Progressive Supranuclear Palsy

- Midbrain atrophy

"morning glory" or "Mickey Mouse" sign

- Axial: abnormal concavity of lateral margins of midbrain tegmentum



● Progressive Supranuclear Palsy

- Midsagittal 3D-MPRAGE or FSPGR images
- Ratio of area of midbrain to area of pons in PSP
 - significantly smaller in PSP than in PD, MSA-P, and normal control
- Sagittal midbrain area $< 70 \text{ mm}^2$, ratio of midbrain tegmentum to pons area $< 0.15 \rightarrow$ diagnostic of PSP
 - Sensitivity: 100%; specificity: 91-100%
- MR Parkinsonism index = (pons area/midbrain area x middle cerebellar peduncle width/superior cerebellar peduncle width)
 - Discrimination of patients with PSP from MSA-P, PD, and control
 - 100% sensitivity, 100 % specificity, and 100% PPV
- AP midbrain diameter $< 17 \text{ mm}$

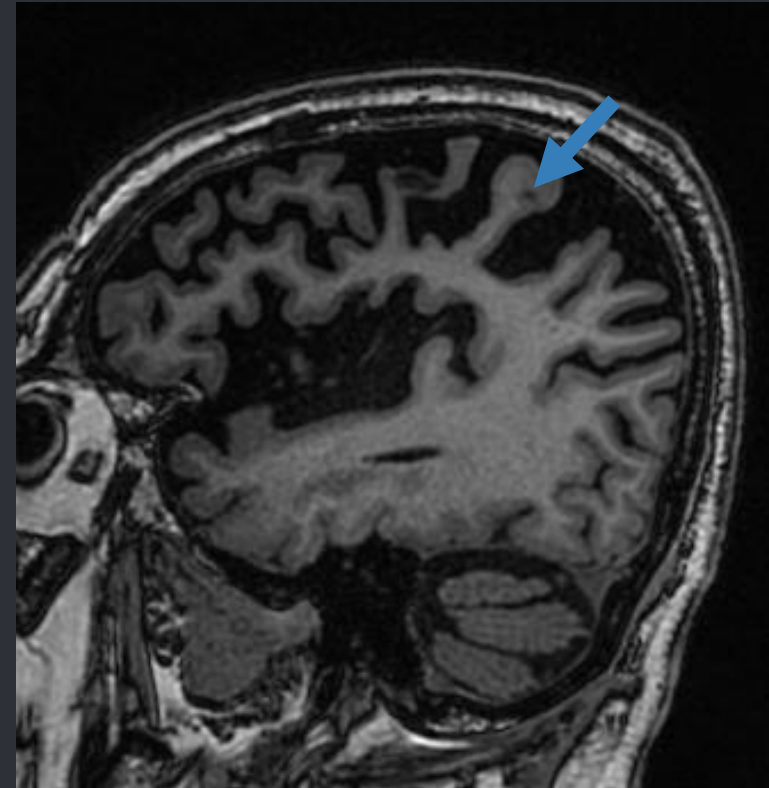
● Dementia with Lewy Bodies

- Cognitive fluctuations, visual hallucinations, and motor parkinsonism
- Pathologic aggregation of α -synuclein protein in neurites (Lewy bodies)
- MRI: nonspecific
 - Varying patterns of atrophy and white matter signal change
- Swallow tail sign
 - Sensitivity of 63%, specificity of 79%, NPP of 89, and accuracy of 76%



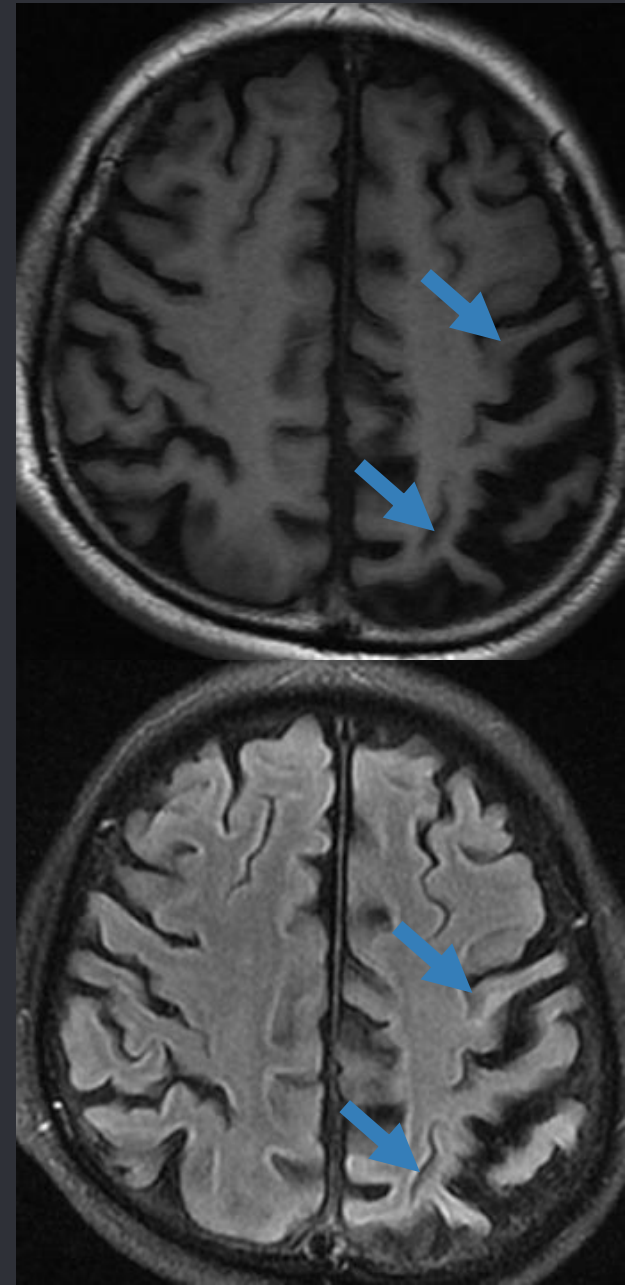
● Corticobasal Degeneration

- Cognitive dysfunction, "asymmetrical" parkinsonism
- Characterized pathologically by cortical and striatal tau protein accumulation
- MRI → Severe focal asymmetric cortical atrophy
 - Perirolandic (posterior frontal, parietal cortex)
 - Relative sparing of temporal and occipital regions



● Corticobasal Degeneration

- ↑ signal intensity in frontal &/or parietal subcortical white matter
- Marked T2 hypointensity
 - Putamen, globus pallidi

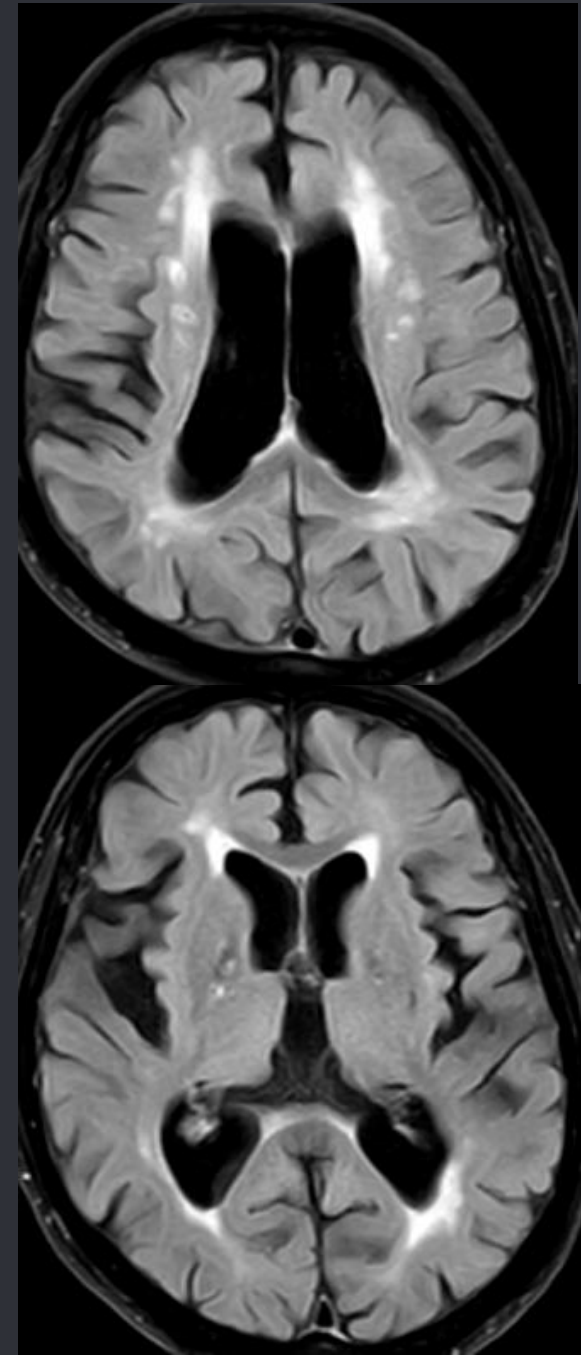


● Common MRI patterns

Disease	MRI Findings
Parkinson disease	Often normal "Swallow tail sign"
MSA-P	Putaminal atrophy and marginally increased T2 signal
MSA-C	"Hot cross bun sign"
PSP	"penguin or hummingbird sign" "morning glory or Mickey Mouse sign"
DLB	Diffuse atrophy +/- Swallow tail sign
CBD	Asymmetric parietal and/or frontal cortical atrophy

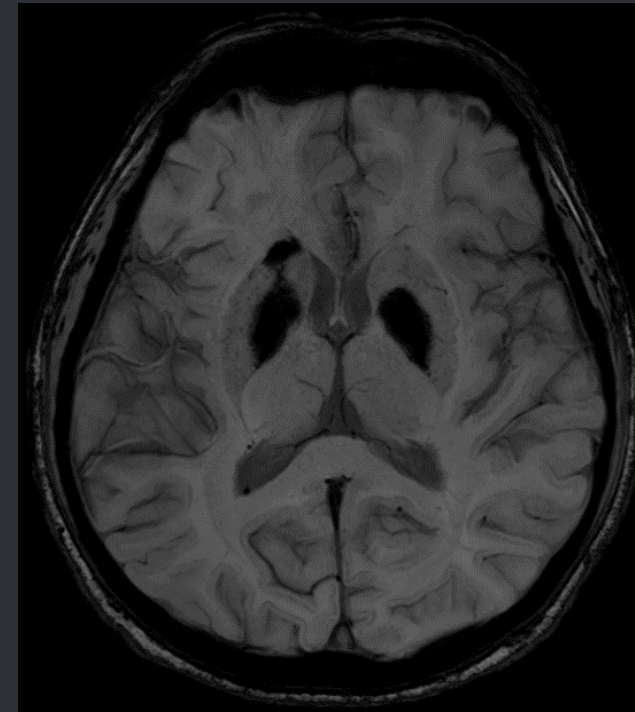
● Vascular Parkinsonism

- Parkinsonism caused by cerebrovascular disease
- 2 Different types of onset
- Insidious onset: White matter lesions in watershed areas
- Acute onset: Contralateral strategic areas (BG or thalamus)
 - ↑ BG motor output (GPe or SNpc)
 - ↓ the thalamocortical drive (VL nuclei of thalamus, large frontal lobe infarct)



Neurodegeneration With Brain Iron Accumulation (NBIA)

- Group of neurodegenerative disorders characterized by dystonia, parkinsonism, and spasticity
- Caused by mutations in L-ferritin gene *FTL1*
- Includes PKAN, INAD, aceruloplasminemia, etc.
- All characterized by abnormal Fe accumulation in BG



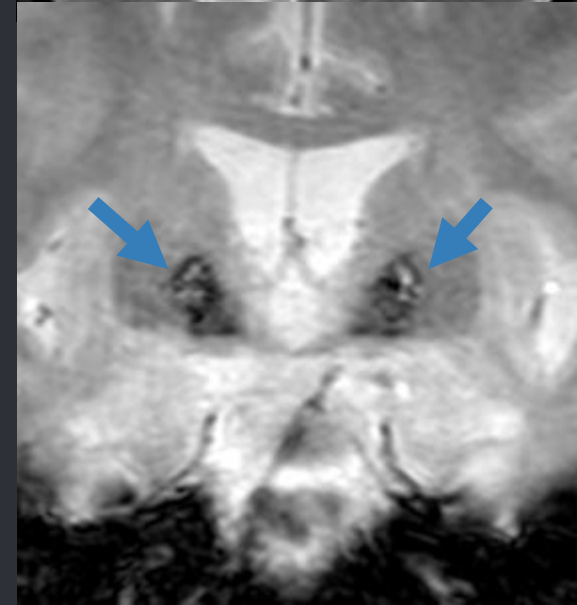
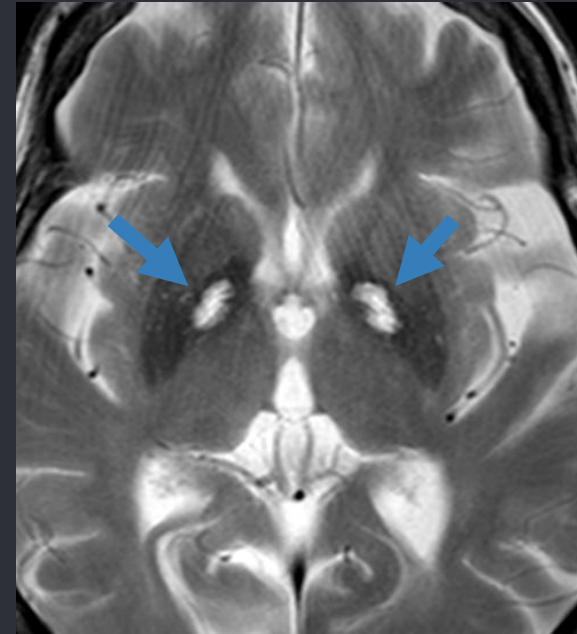
Neurodegeneration With Brain Iron Accumulation (NBIA)

◦ T2WI

- GP hypointensity with central hyperintensity
“Eye of the tiger sign”
- Specific to classic PKAN (*PANK2* mutations)
- May also be seen in neuroferritinopathy
- GP, ± SN, DN, cortex, striatum, and thalamus dark without “eye of the tiger” = other NBIA

◦ T2*WI

- Accentuation of hypointense T2 findings



● Future directions: Advanced MRI

- Structural: T1W, T2WI, IR
- Neuromelanin
- Magnetization transfer
- Relaxometry (T2/T2* measurement)
- Susceptibility weighted imaging
- Diffusion weighted imaging
- Diffusion tensor imaging/Tractography
- Functional MRI
- MR spectroscopy
- MR perfusion

● Summary

- Movement disorders with parkinsonian features are common
- Imaging is playing an increasingly important role in diagnosis and management
- Familiarity and recognition the classic MRI appearances and common patterns of Parkinson disease and APS are important
- Clinical examination + imaging = accurate Dx