

BASIC APPROACH TO HEAD CT INTERPRETATION

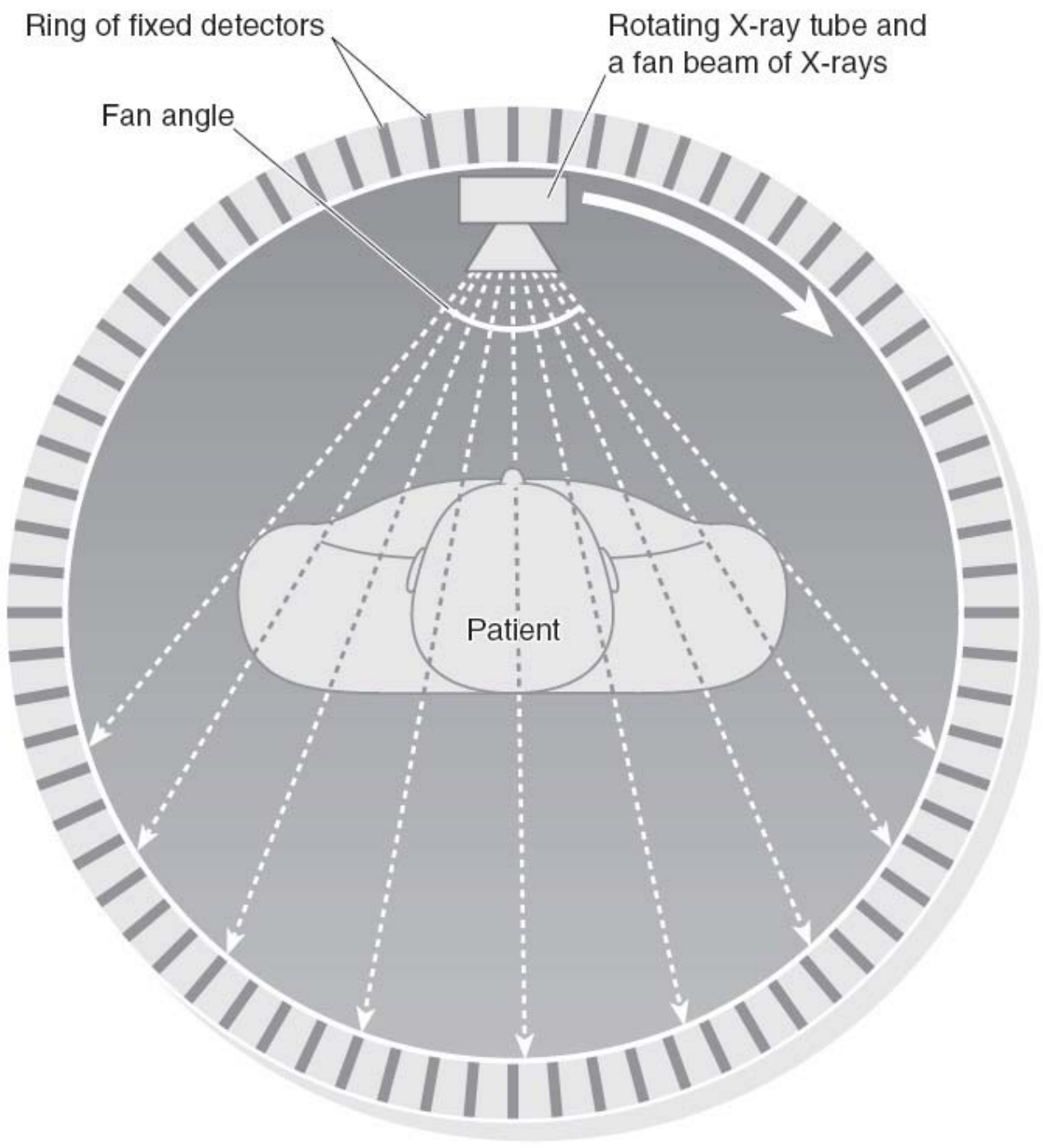
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Contents

- Basic principles of CT
- CT Neuroanatomy
- Disease Processes evaluated with CT

Basic Physics of CT

CT uses X-rays to generate cross-sectional, two-dimensional images of the body. Images are acquired by rapid rotation of the X-ray tube 360° around the patient. The transmitted radiation is then measured by a ring of sensitive radiation detectors located on the gantry around the patient (Fig. 1.1). The final image is generated from these measurements utilizing the basic principle that the internal structure of the body can be reconstructed from multiple X-ray projections.



CT Scanning

In **spiral CT** the X-ray tube rotates continuously in one direction whilst the table on which the patient is lying is mechanically moved through the X-ray beam. The transmitted radiation thus takes on the form of a helix or spiral. Instead of acquiring data one slice at a time, information can be acquired as a continuous volume of contiguous slices (Fig. 1.2a, b). This allows larger anatomical regions of the body to be imaged during a single breath hold, thereby reducing the possibility of artefacts caused by patient movement. Faster scanning also increases patient throughput and increases the probability of a diagnostically useful scan in patients who are unable to fully cooperate with the investigation.

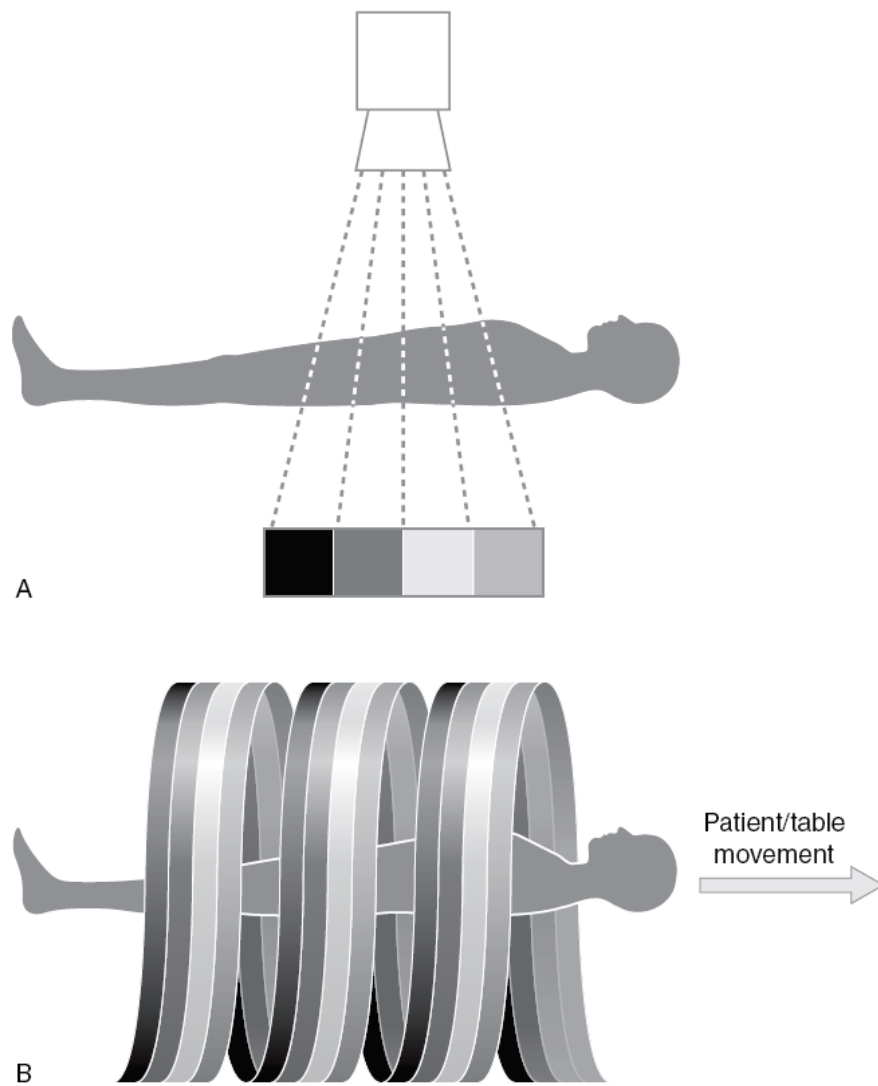


Fig. 1.3 (A) Multidetector system (four rings shown here). (B) Multislice helical CT.

How is a CT image produced?

Every acquired CT slice is subdivided into a matrix of up to 1024×1024 volume elements (**voxels**). Each voxel has been traversed during the scan by numerous X-ray photons and the intensity of the transmitted radiation measured by detectors. From these intensity readings, the density or **attenuation value** of the tissue at each point in the slice can be calculated. Specific attenuation values are assigned to each individual voxel. The viewed image is then reconstructed as a corresponding matrix of picture elements (**pixels**).

What is a Hounsfield unit or CT number?

Each pixel is assigned a numerical value (CT number), which is the average of all the attenuation values contained within the corresponding voxel. This number is compared to the attenuation value of water and displayed on a scale of arbitrary units named **Hounsfield units (HU)** after Sir Godfrey Hounsfield.

This scale assigns water as an attenuation value (HU) of zero. The range of CT numbers is 2000 HU wide although some modern scanners have a greater range of HU up to 4000. Each number represents a shade of grey with +1000 (white) and -1000 (black) at either end of the spectrum (Fig. 1.4).

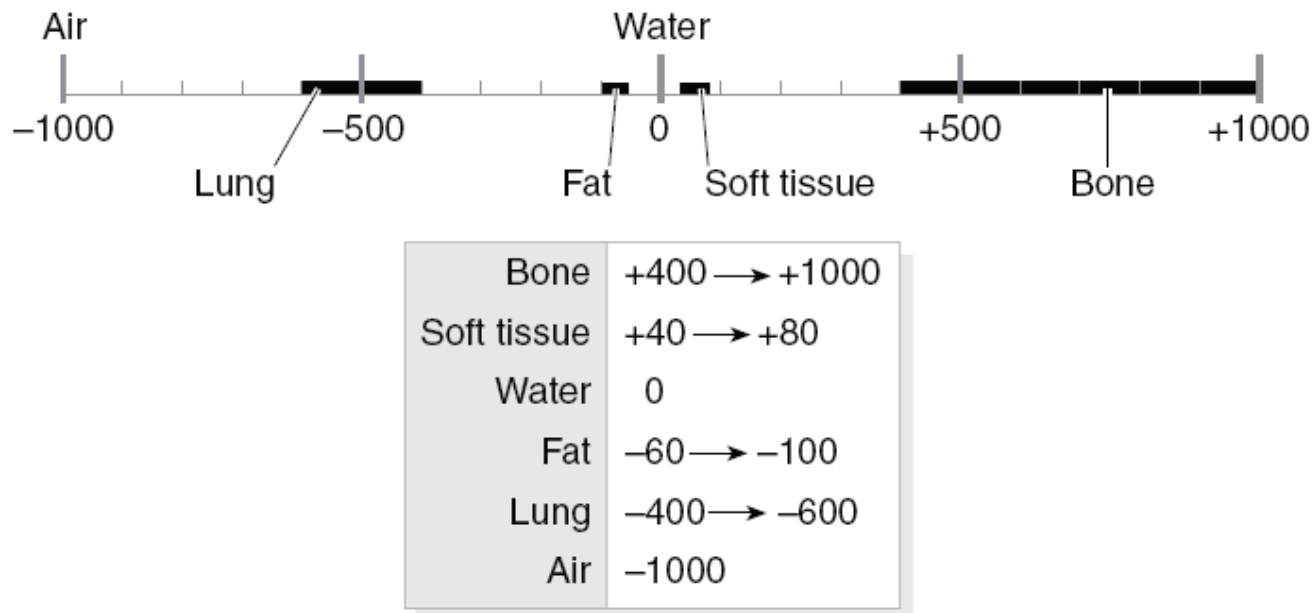
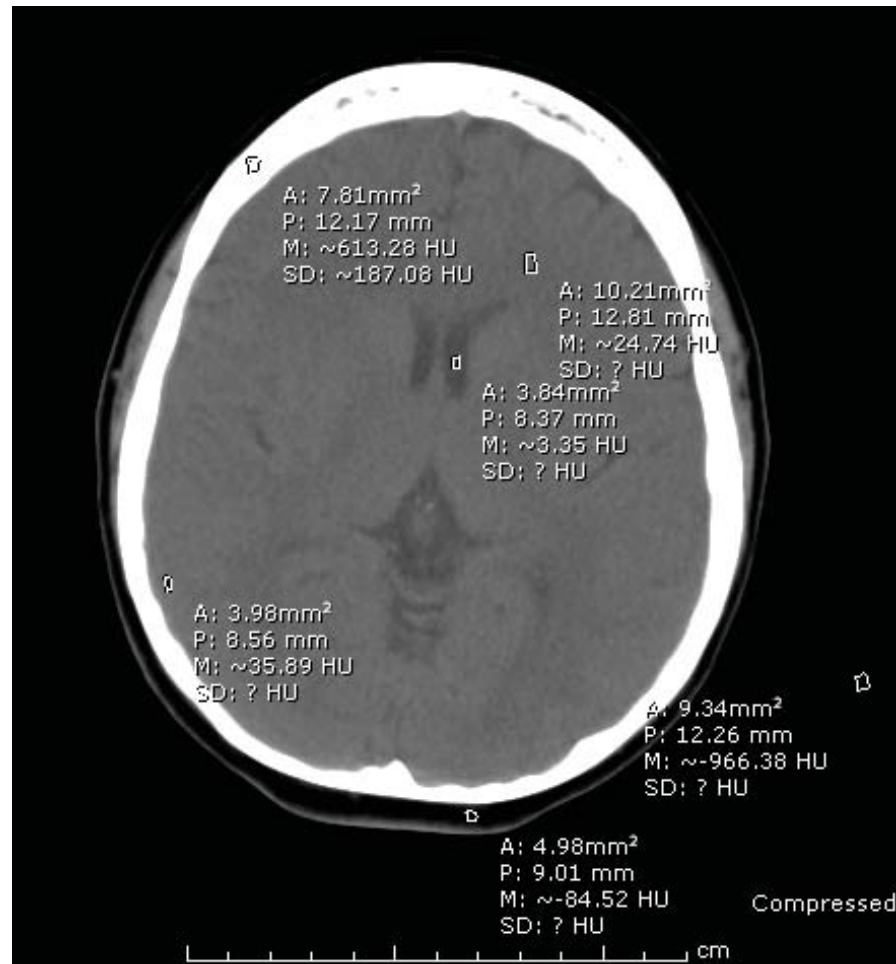


Fig. 1.4 The Hounsfield scale of CT numbers.

Hounsfield Unit Measurements

- Bone ~ +613 HU
- White Matter ~ +24.7 HU
- Gray Matter ~ +35.8 HU
- CSF - Ventricle ~ +3.3 HU
- Scalp Fat ~ -84.5 HU
- Air ~ -966.3 HU



Tissue Density Differences

- Lower density substances allow more photons pass through to the detectors, resulting in a grayer or blacker appearance on CT – like CSF
- The X-ray beam is attenuated to a higher degree by calcium, therefore less photons pass through bone to the detectors, resulting in its ‘white’ appearance on CT
- White matter is less cellular, contains myelinated axons (fat), and has a higher water content than gray matter, resulting in slightly lower attenuation values or density

Window level (WL) and window width (WW)

Whilst the range of CT numbers recognized by the computer is 2000, the human eye cannot accurately distinguish between 2000 different shades of grey. Therefore to allow the observer to interpret the image, only a limited number of HU are displayed. A clinically useful grey scale is achieved by setting the WL and WW on the computer console to a suitable range of Hounsfield units, depending on the tissue being studied.

The term 'window level' represents the central Hounsfield unit of all the numbers within the window width.

The window width covers the HU of all the tissues of interest and these are displayed as various shades of grey. Tissues with CT numbers outside this range are displayed as either black or white. Both the WL and WW can be set independently on the computer console and their respective settings affect the final displayed image.

For example, when performing a CT examination of the chest, a WW of 350 and WL of +40 are chosen to image the mediastinum (soft tissue) (Fig. 1.5a), whilst an optimal WW of 1500 and WL of -600 are used to assess the lung fields

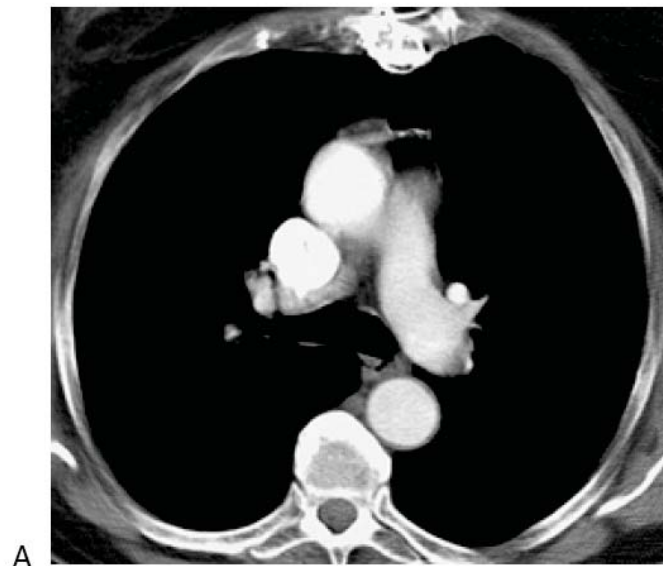
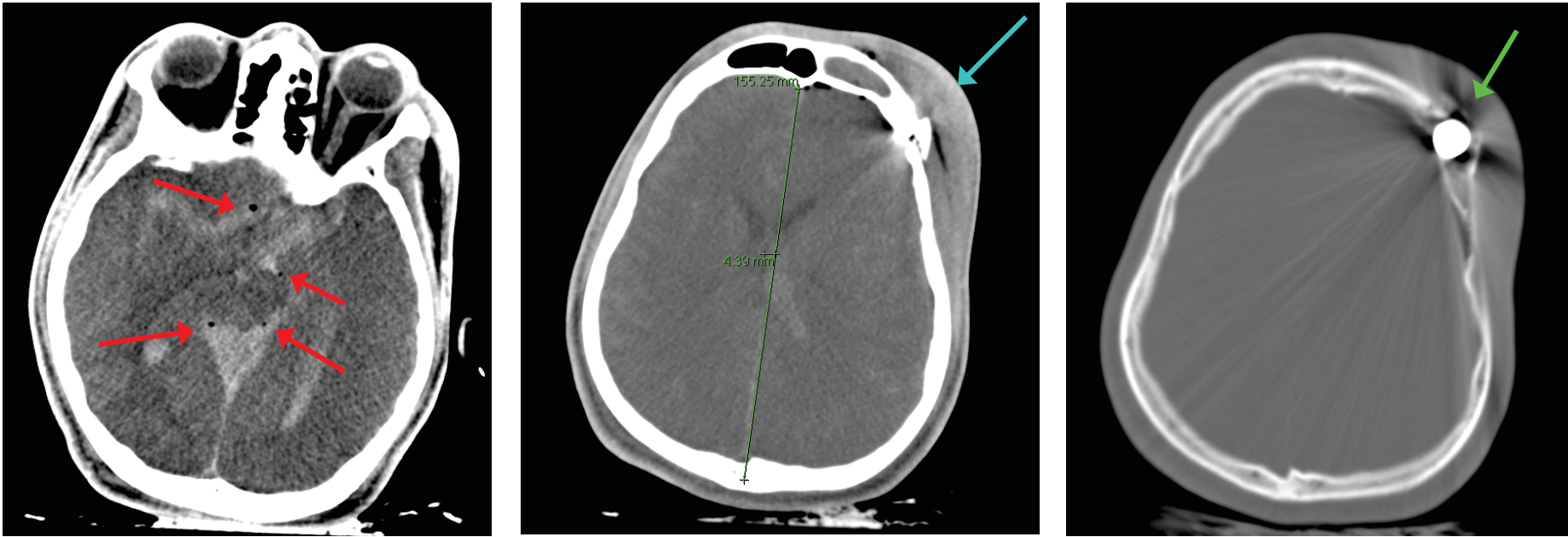


Fig. 1.5 These two images are of the same section, viewed at different window settings. **(A)** A window level of +40 with a window width of 350 reveals structures within the mediastinum but no lung parenchyma can be seen. **(B)** The window level is -600 with a window width of 1500 Hounsfield units. This enables details of the lung parenchyma to be seen, at the expense of the mediastinum.

Different Window Levels



- Brain Window – shows subarachnoid hemorrhage (blood proteins/clot) is high density in the basilar cisterns with small foci of air (red arrows) related to trauma
- Soft Tissue Window – shows scalp hematoma
- Bone window – shows bullet fragment and fracture

Image reconstruction

The acquisition of volumetric data using spiral CT means that the images can be postprocessed in ways appropriate to the clinical situation.

- **Multiplanar reformatting (MPR)** – by taking a section through the three-dimensional array of CT numbers acquired with a series of contiguous slices, sagittal, coronal and oblique planes can be viewed along with the standard transaxial plane (Fig. 1.7).

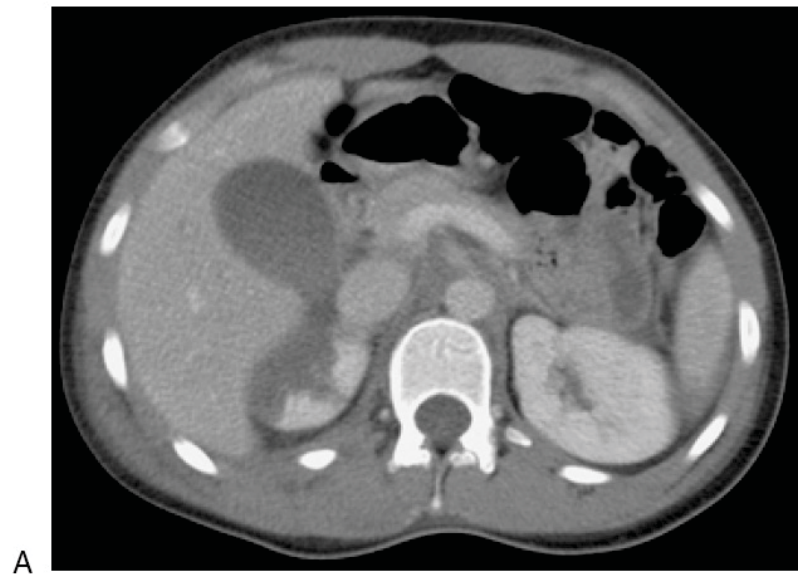


Fig. 1.7 The three images demonstrate a haemoperitoneum, shattered right kidney and a lacerated spleen in axial (A), sagittal (B) and coronal (C) planes.

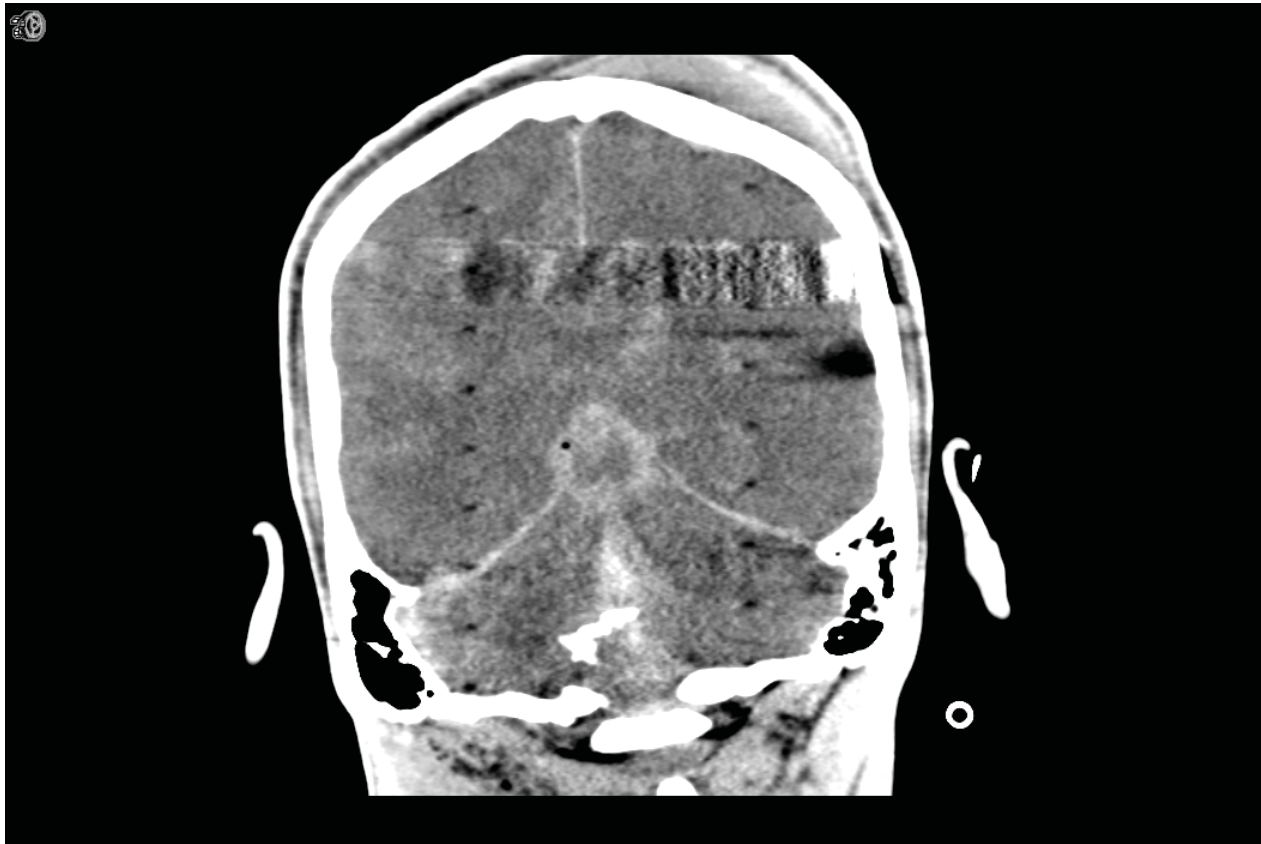
CT Artifacts

- **Artefacts** – an artefact is a feature or appearance that is seen on an image, which does not actually exist. They occur in all imaging modalities and are often unavoidable. Recognizing the presence of artefacts is important in order to avoid confusion with pathology. However, with the increasing speed of image acquisition in a single breath hold by the most modern scanners, many artefacts are being minimized or eliminated. Types of artefact include:
 1. *motion* – from patient movement during a scan, commonly due to breathing
 2. *streak (beam hardening)* – dark ‘streaks’ behind high-density objects, e.g. dental amalgam and metallic joint replacements
 3. *partial voluming* – different tissue densities within a *single* voxel lead to ‘averaging’ of data. For example, a small black object within a larger white space would look like a shade of grey.

Beam Hardening Artifact from Metal Alloy in a Lodged Bullet

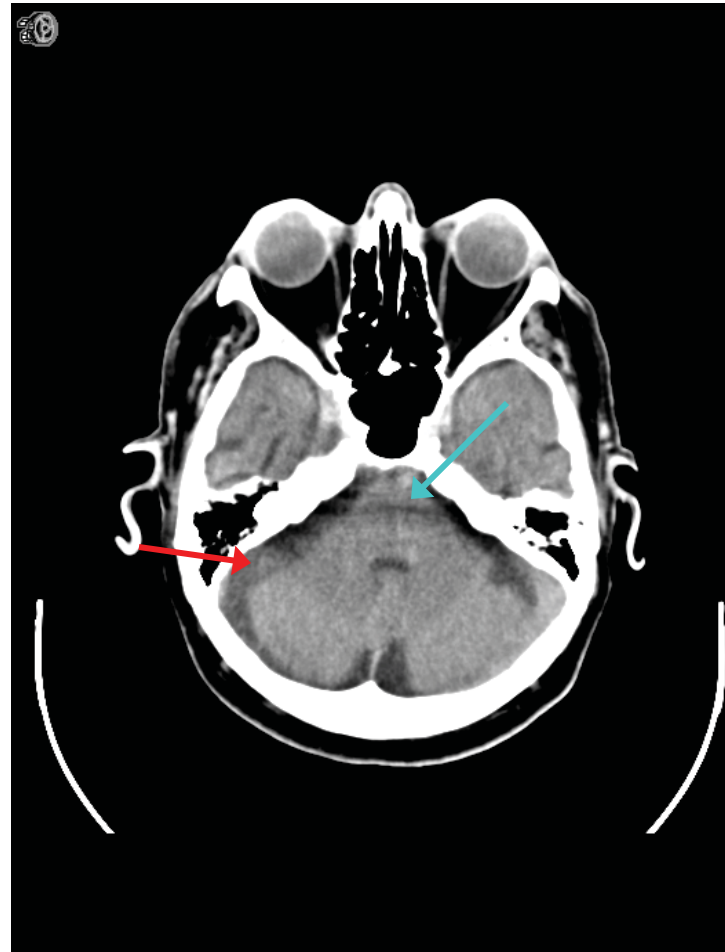


Streak Artifact in the Coronal Plane



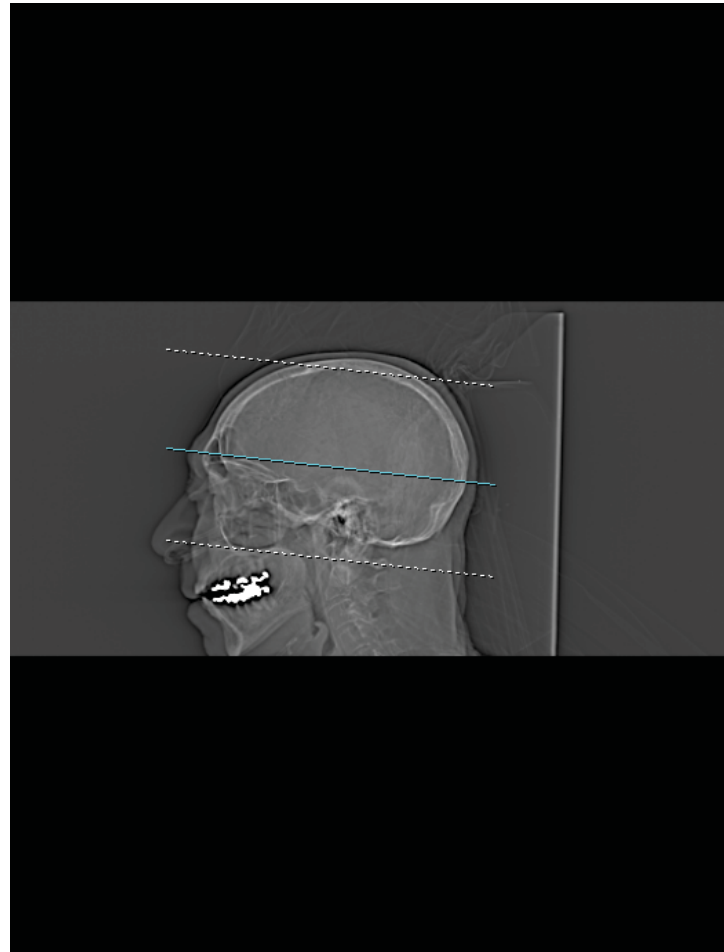
Partial Volume Artifact

- Note the red arrow, in the extra-axial space adjacent to the right cerebellar hemisphere, there is slightly increased density related to averaging of the sigmoid sinus, cerebellum, and CSF in this slice
- Blue arrow – band of streak artifact limits evaluation of the pons

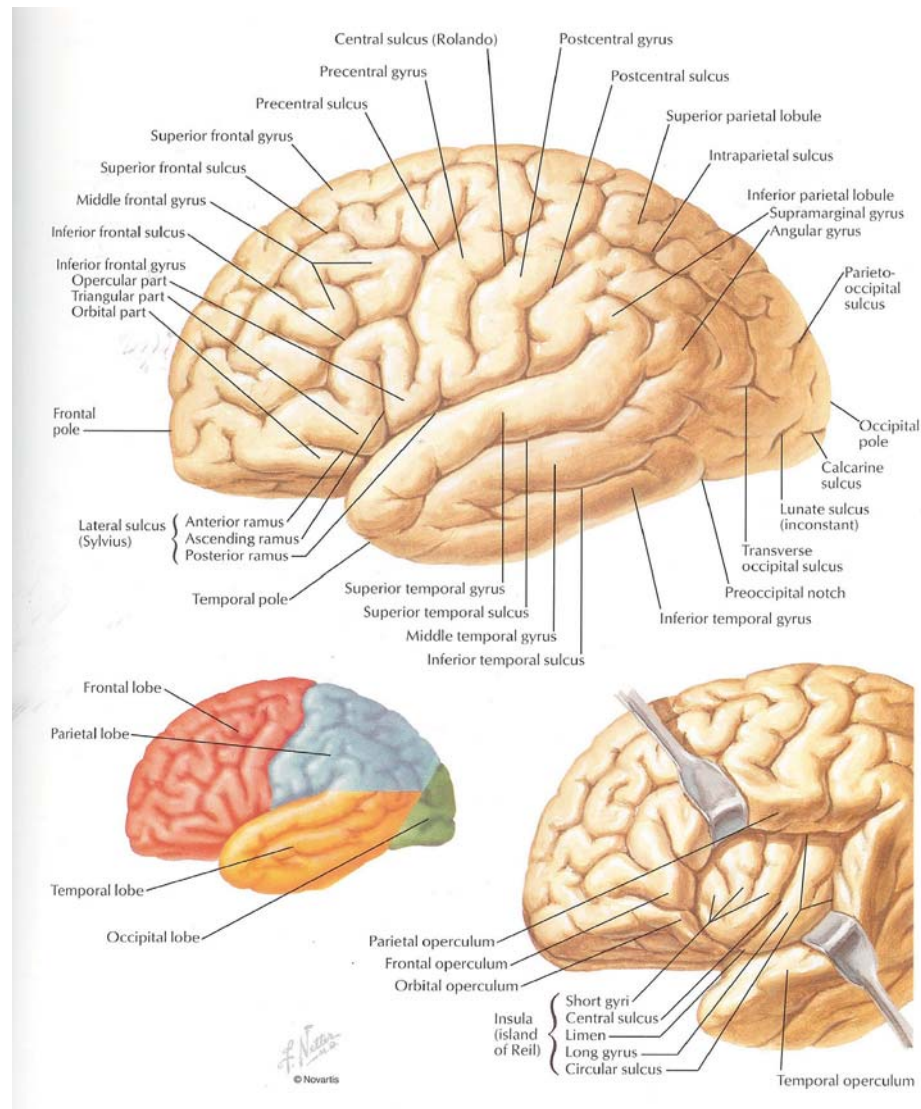


CT Neuroimaging

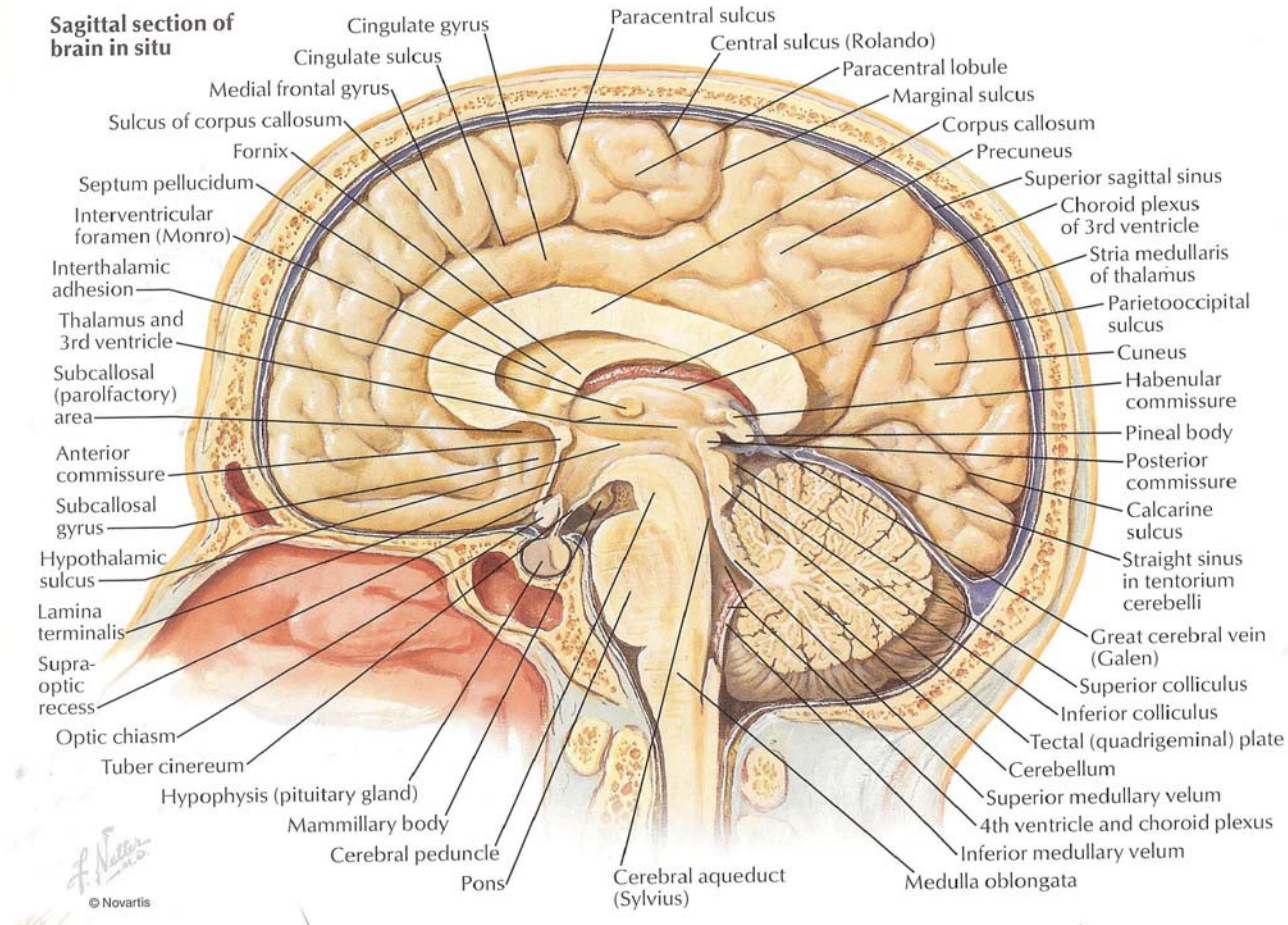
- The head is routinely scanned using sequential imaging in the axial plane with each section measuring 5 mm thick
- Helical imaging is used for CT angiograms of the head/neck and other parts of the body



Illustrative Neuroanatomy

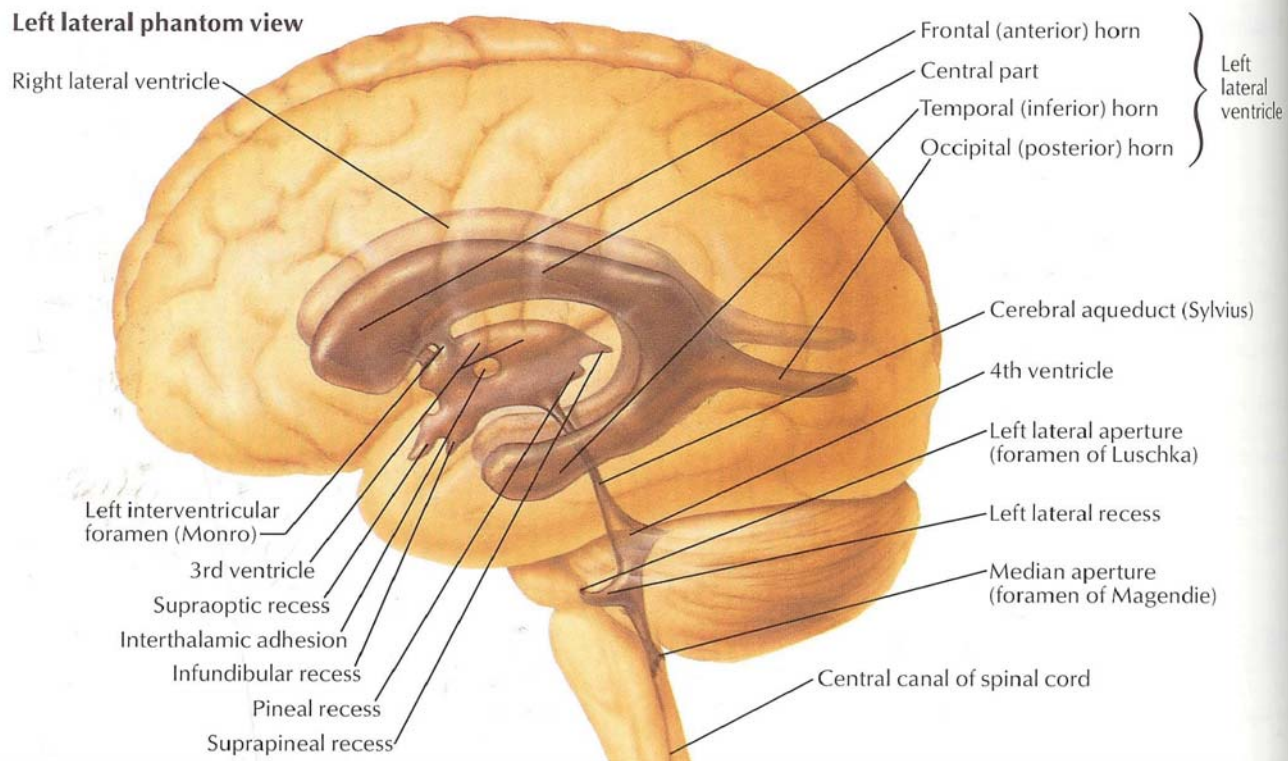


Illustrative Neuroanatomy

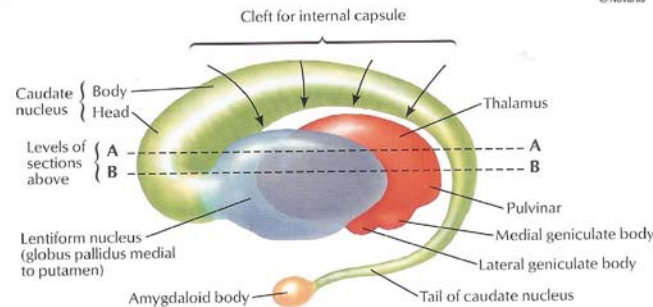
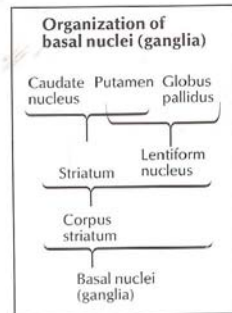
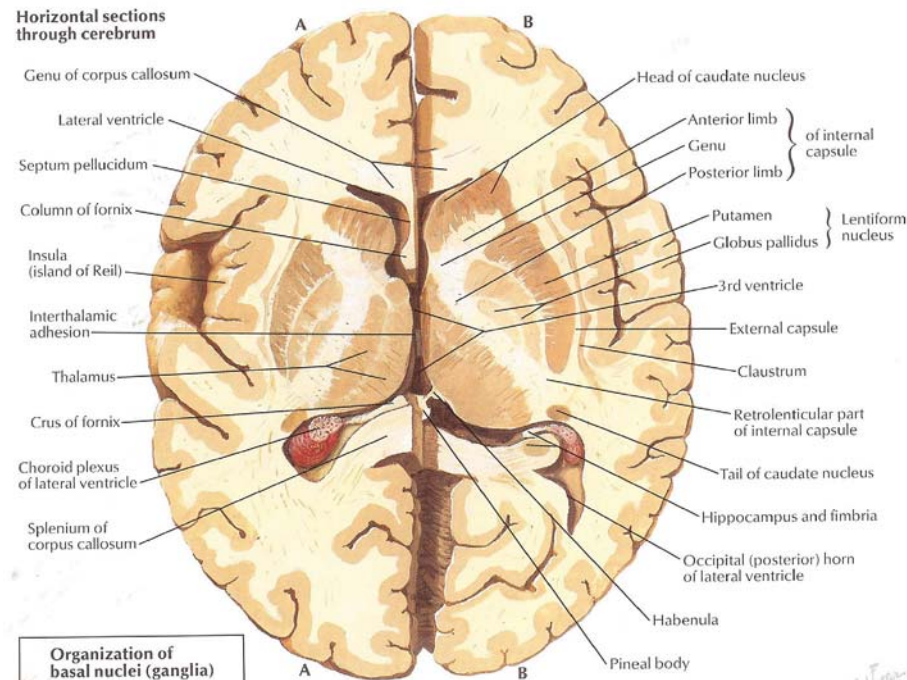


Illustrative Neuroanatomy

Ventricles of Brain



Illustrative Neuroanatomy



F. Netter
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Head CT Approach

- First - evaluate normal anatomical structures, window for optimal brain tissue contrast
- Second – assess for signs of underlying pathology such as: mass effect, edema, midline shift, hemorrhage, hydrocephalus, subdural or epidural collection/hematoma, or infarction
- Third – evaluate sinuses and osseous structures with bone windows
- Fourth – use a soft tissue window to assess extracranial anatomy – orbits, face, scalp

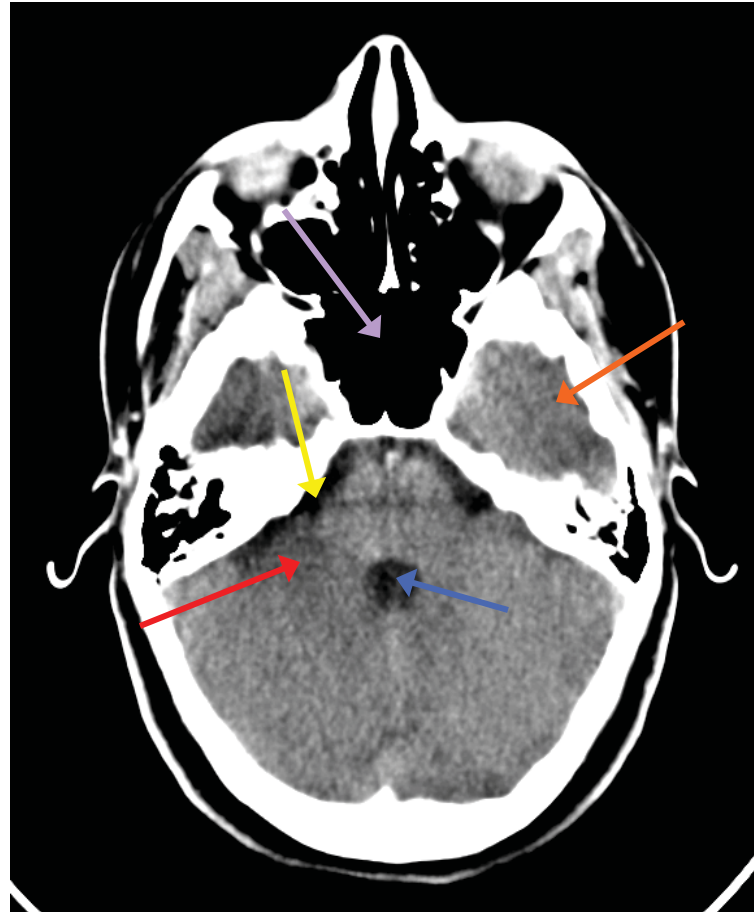
Anatomy

- Red – Cerebellar Hemisphere
- Blue – Cerebellar Vermis
- Green – Medulla
- Pink – Masticator muscles
- Orange – Maxillary sinus



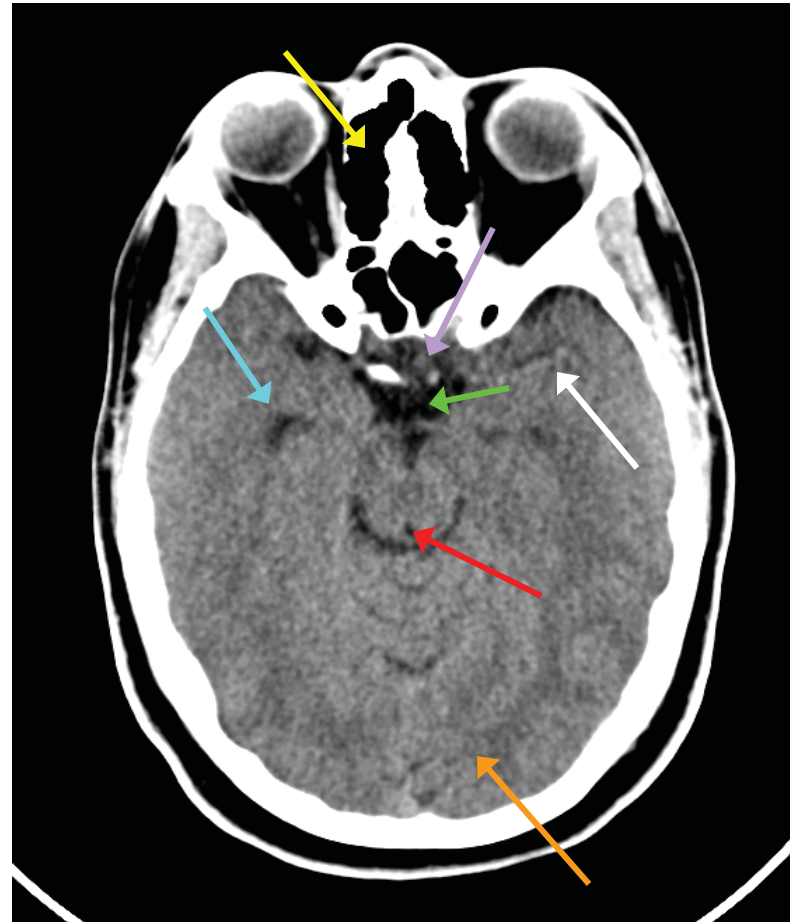
Anatomy – Level of the Pons

- Purple – Sphenoid sinus
- Yellow – cerebellopontine angle
- Red – Middle cerebellar peduncle
- Orange – Temporal lobe
- Blue – Fourth ventricle



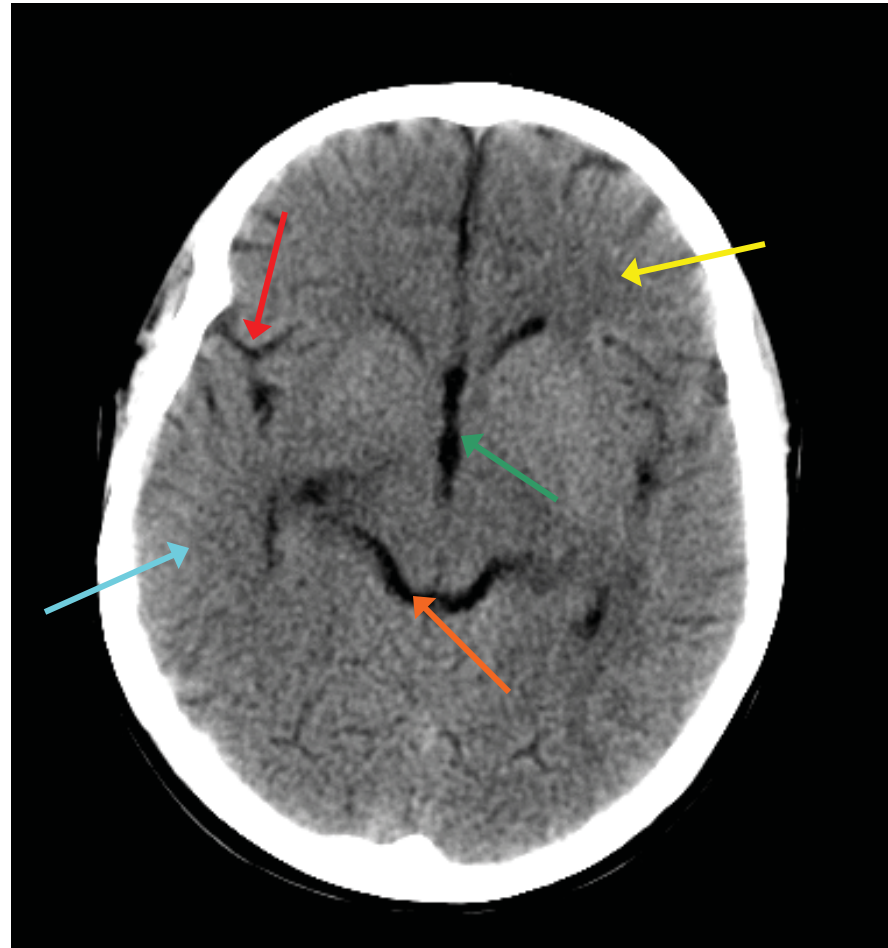
Anatomy – Midbrain Level

- Yellow – Ethmoid sinus
- Purple – Sellar fossa
- Green – Suprasellar cistern
- Red – Cerebral aqueduct
- Blue – Temporal horn of ventricular system
- Orange – Occipital lobe
- White – Middle cerebral artery, note that it is isodense to gray matter



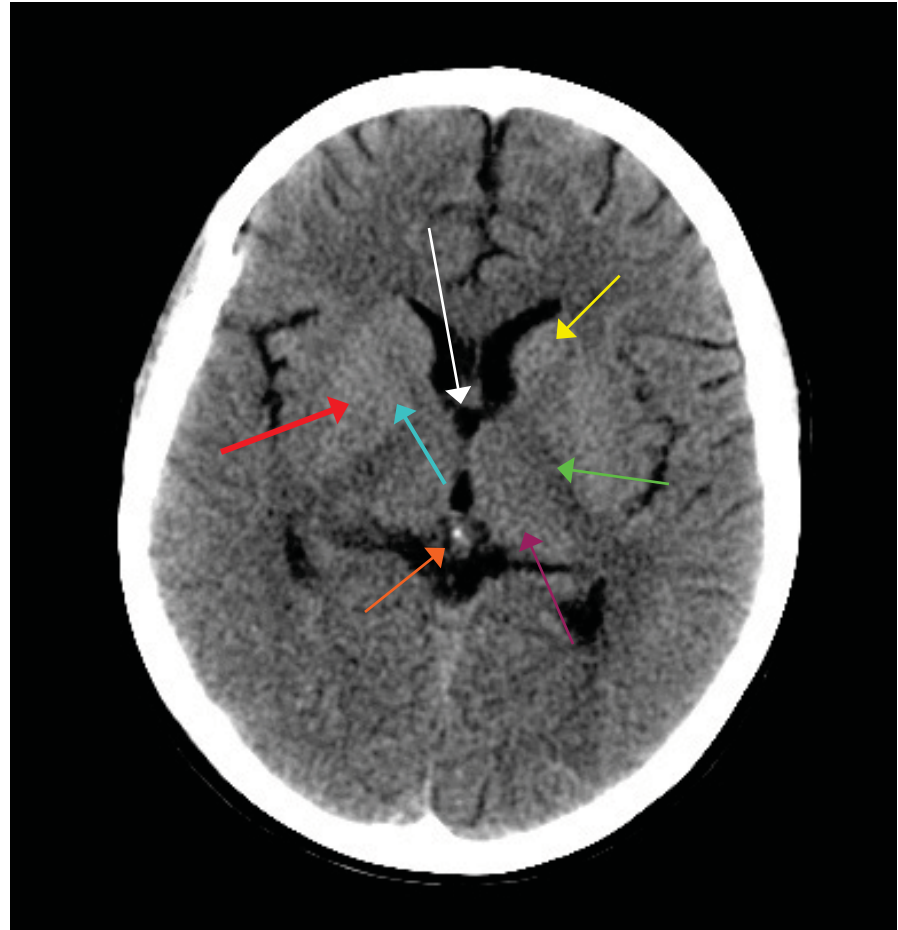
Anatomy

- Green – Third Ventricle
- Yellow – Frontal lobe
- Red – Sylvian fissure
- Blue – Temporal lobe
- Orange – Quadrigeminal Plate cistern



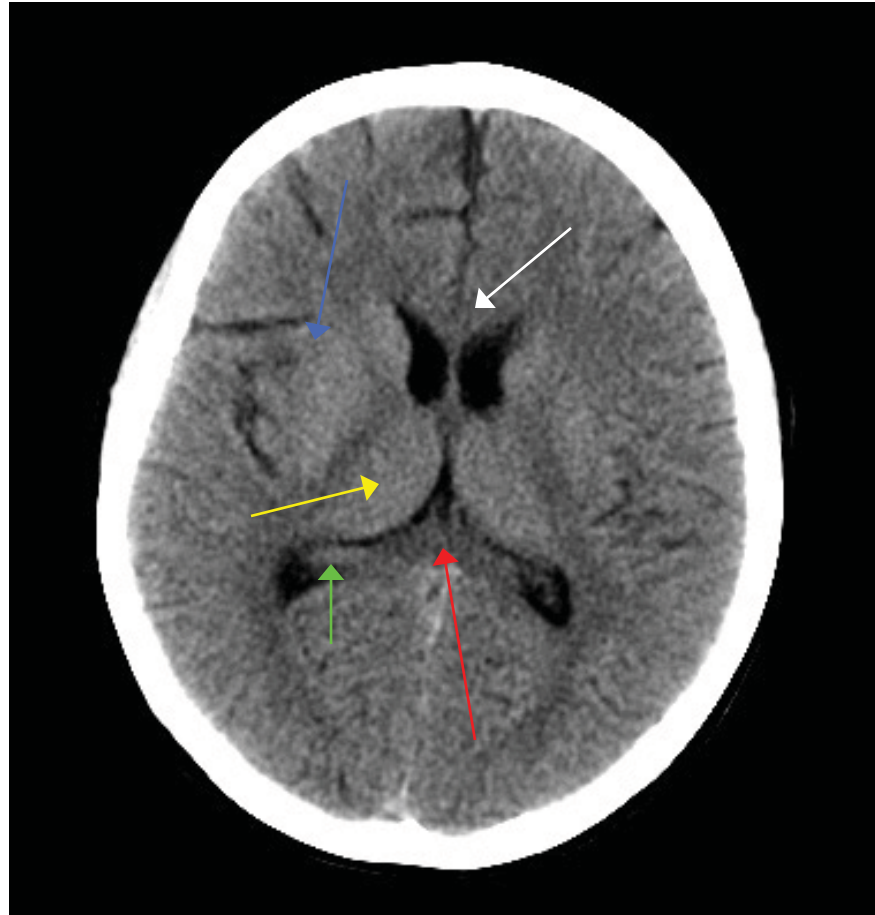
Anatomy

- White – foramen of Monroe connects lateral to third ventricle
- Yellow – caudate head
- Blue – globus pallidus
- Red – putamen
- Purple – thalamus
- Green – posterior limb of the internal capsule
- Orange – pineal gland with calcification



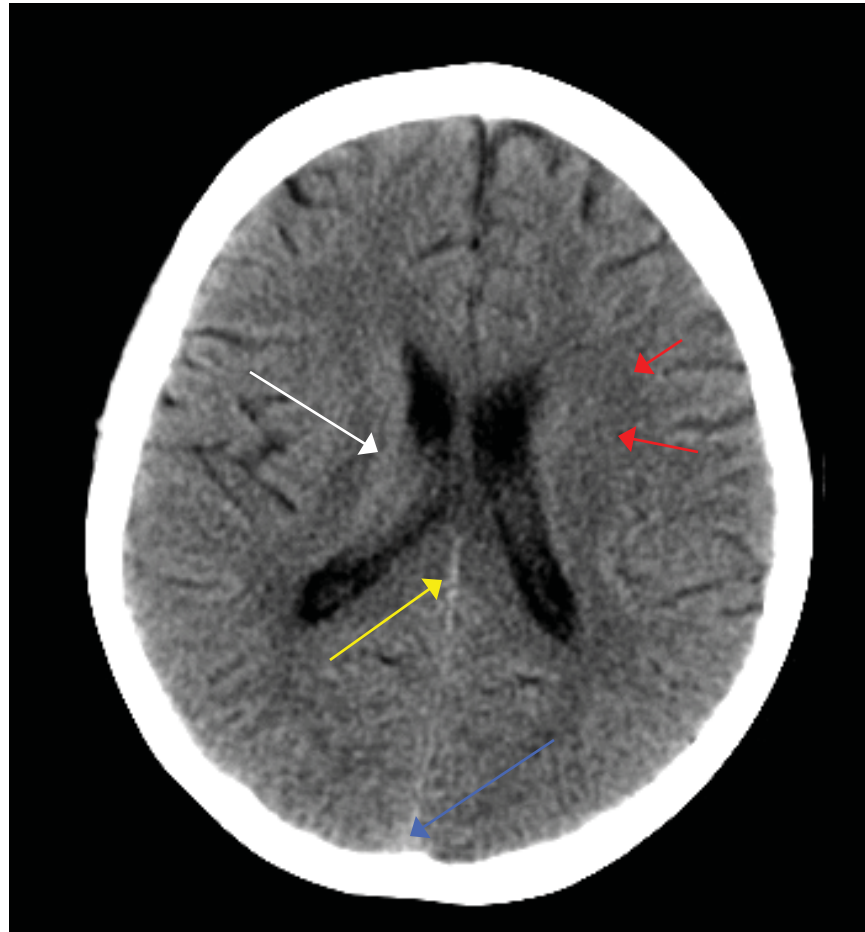
Anatomy

- White – genu of the corpus callosum
- Red – splenium of the corpus callosum
- Yellow – thalamus
- Green – choroid plexus in lateral ventricle
- Blue – external capsule between the insular cortex laterally and the putamen of the basal ganglia medially



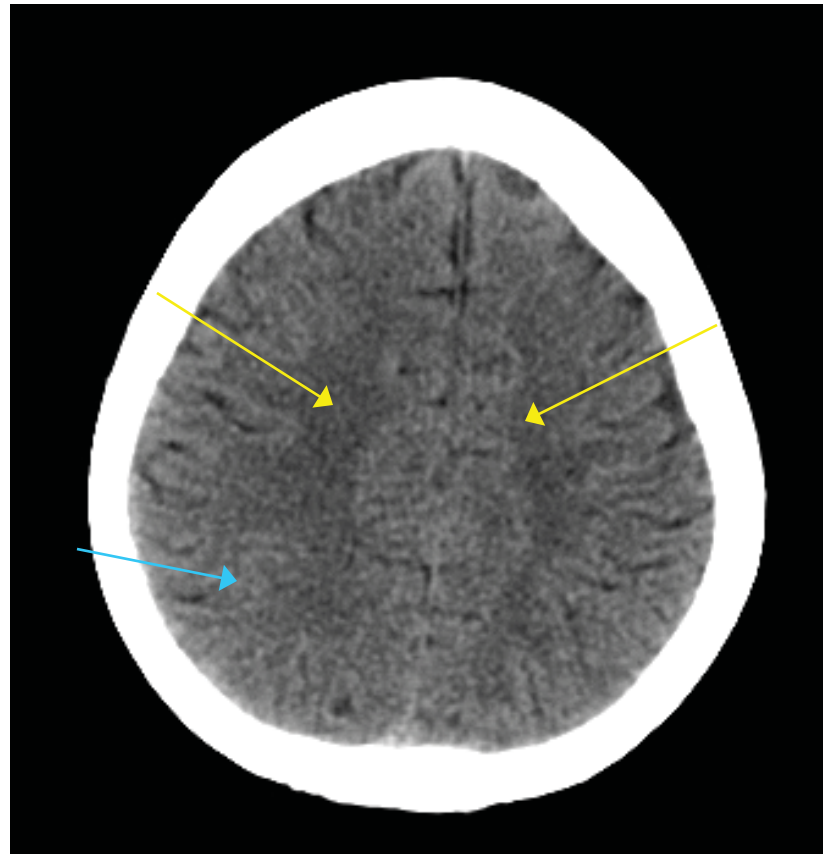
Anatomy

- White – body of the caudate
- Red – corona radiata are white matter tracts
- Yellow – falx cerebri
- Blue – superior sagittal sinus



Anatomy

- Yellow – centrum semiovale are supraventricular white matter tracts running to and from the cerebral cortex
- Blue – parietal lobe

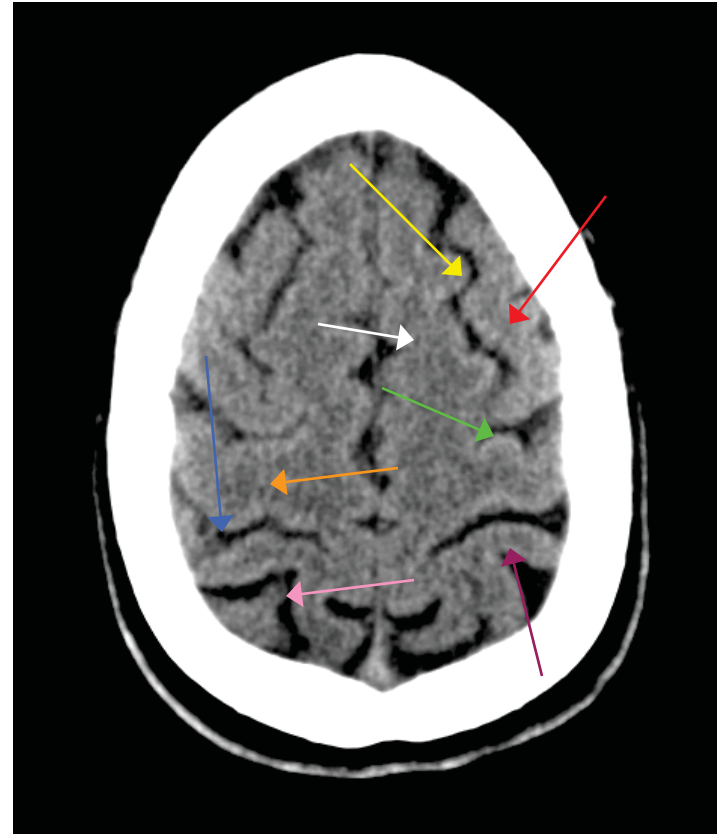


Anatomy – vertex or top of the Brain



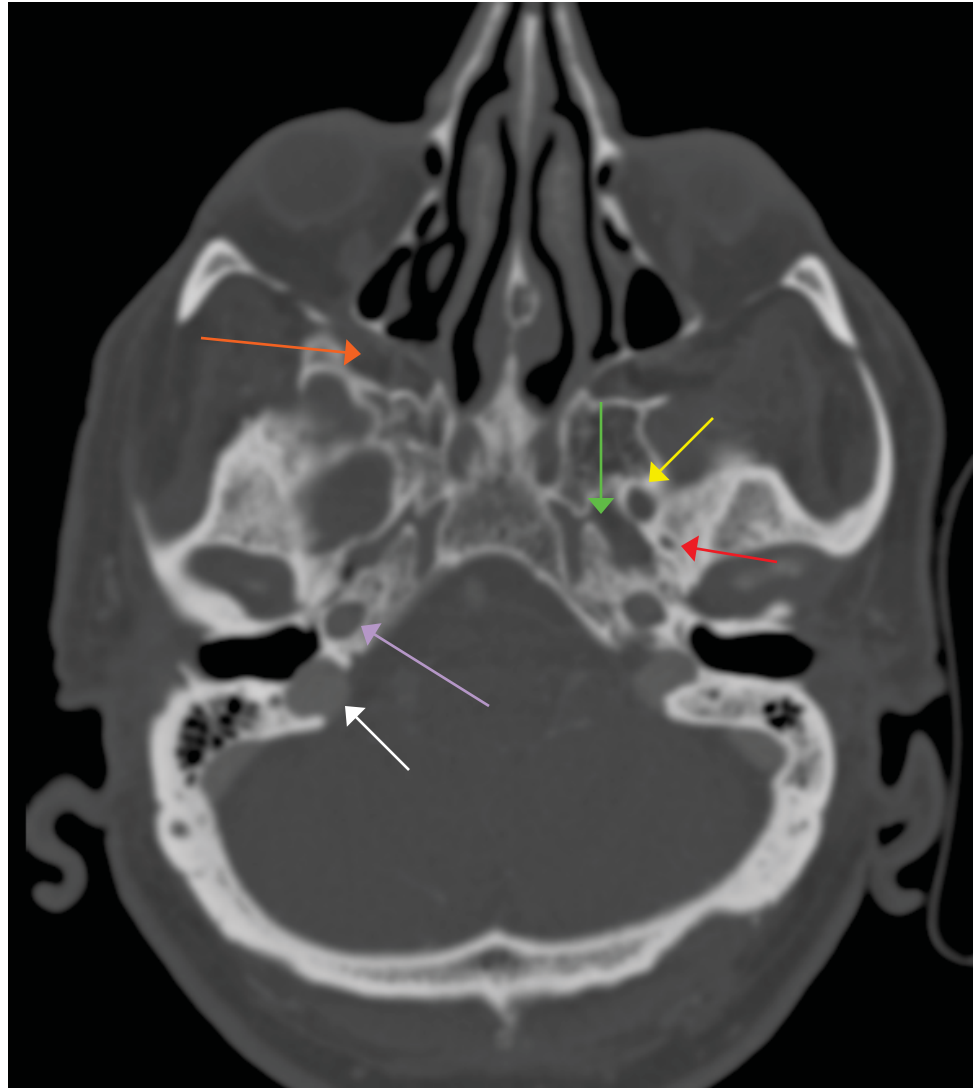
Anatomy

- White – superior frontal gyrus
- Yellow – superior frontal sulcus
- Red – middle frontal gyrus
- Green – prefrontal sulcus
- Orange – motor strip or prefrontal gyrus
- Blue – central sulcus
- Purple – sensory strip or post central gyrus
- Pink – post central sulcus



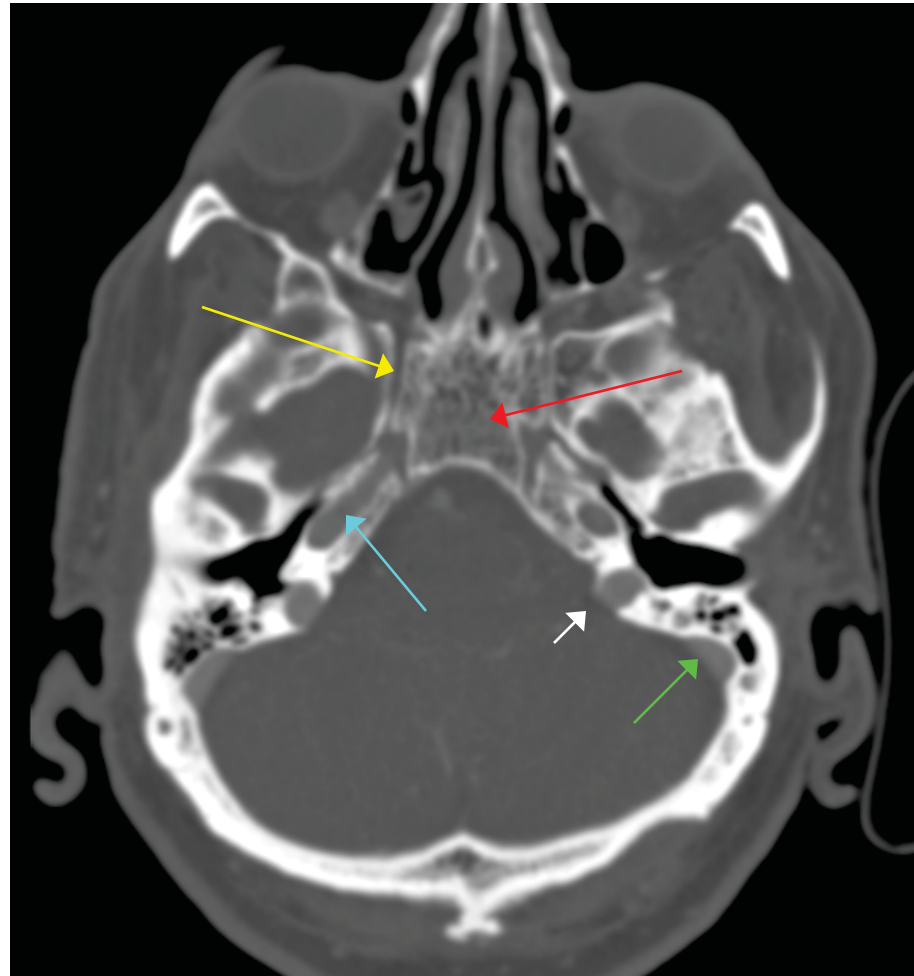
Bone Window - Anatomy

- Orange – inferior orbital fissure
- Green - foramen lacerum
- Yellow – foramen ovale transmits 3rd division of CN V
- Red – foramen spinosum for middle meningeal artery
- Purple – petrous portion of the internal carotid artery
- White – jugular vein

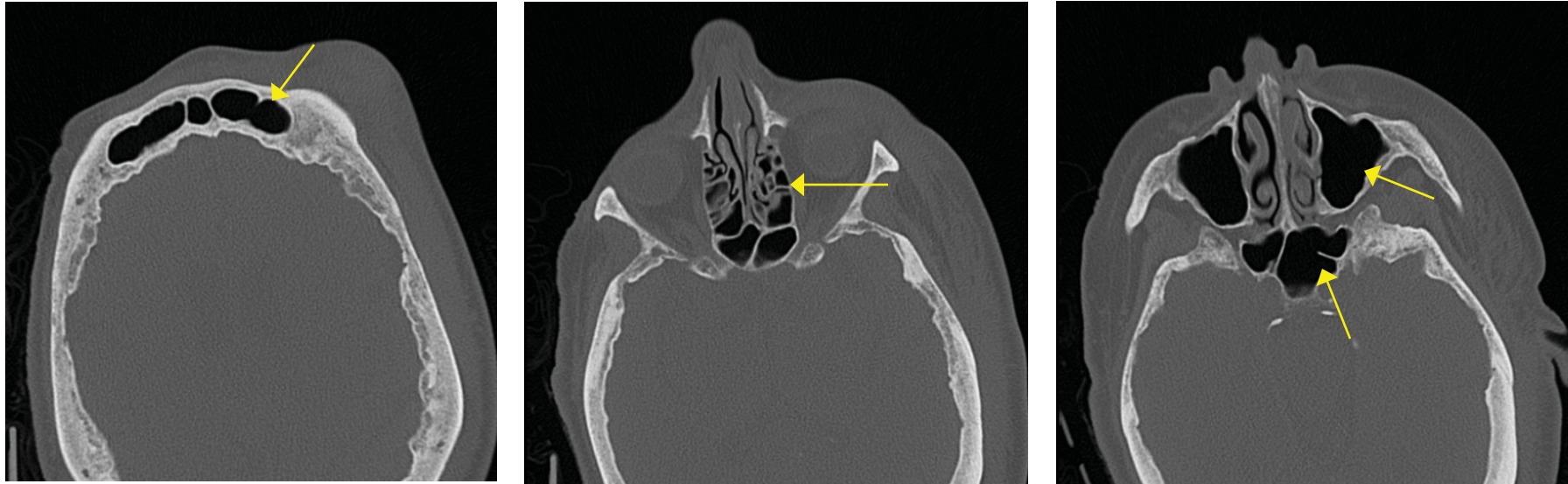


Bone Window - Anatomy

- Yellow – vidian's canal transmits greater petrosal nerve from CN VII
- Red – clivus
- Blue – carotid canal
- White – jugular vein
- Green – sigmoid sinus



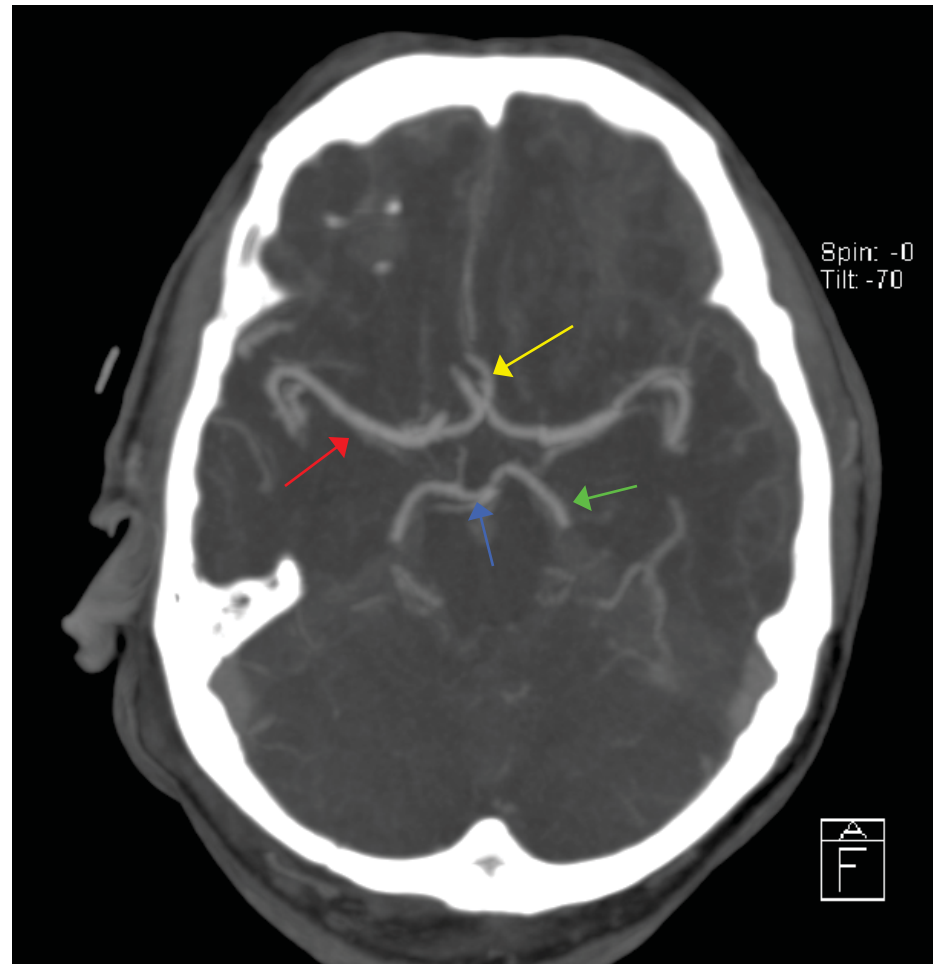
Sinuses in the Axial Plane



- Left to right: frontal sinus, ethmoid sinus, maxillary sinus and sphenoid sinus

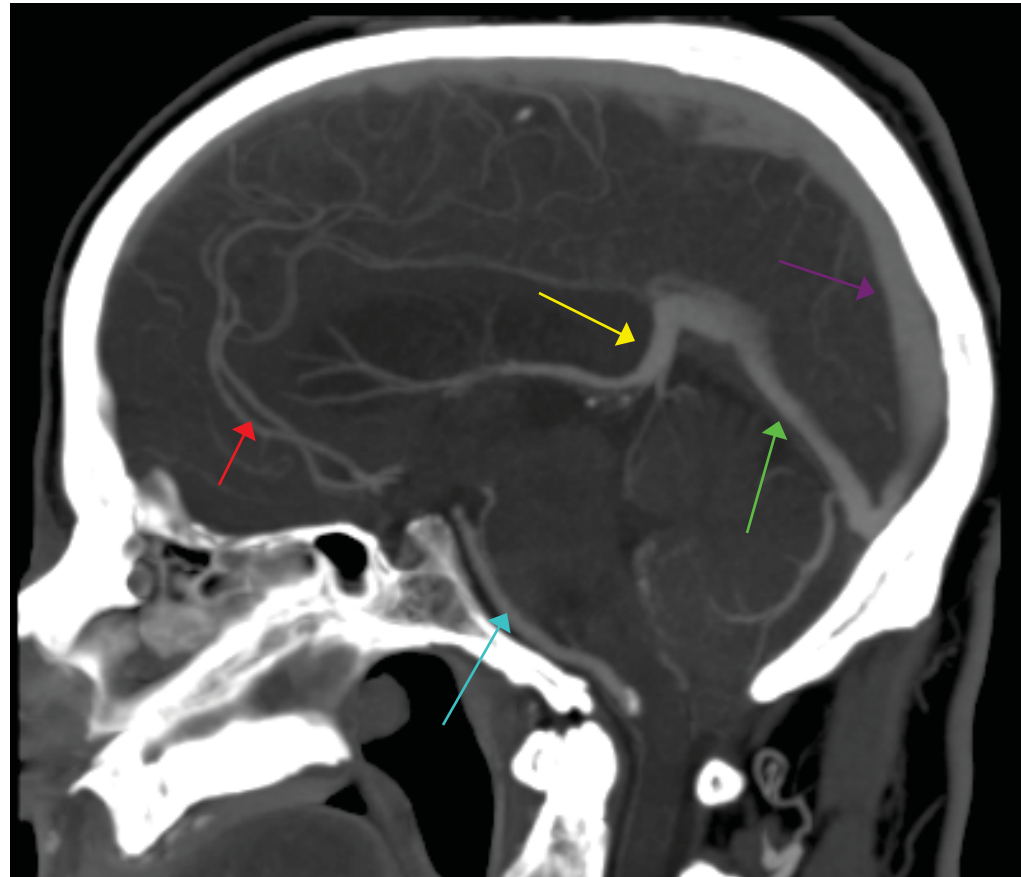
CT Angiographic Anatomy

- Red – MCA or middle cerebral artery
- Yellow – ACA
- Green – PCA
- Blue – Basilar artery



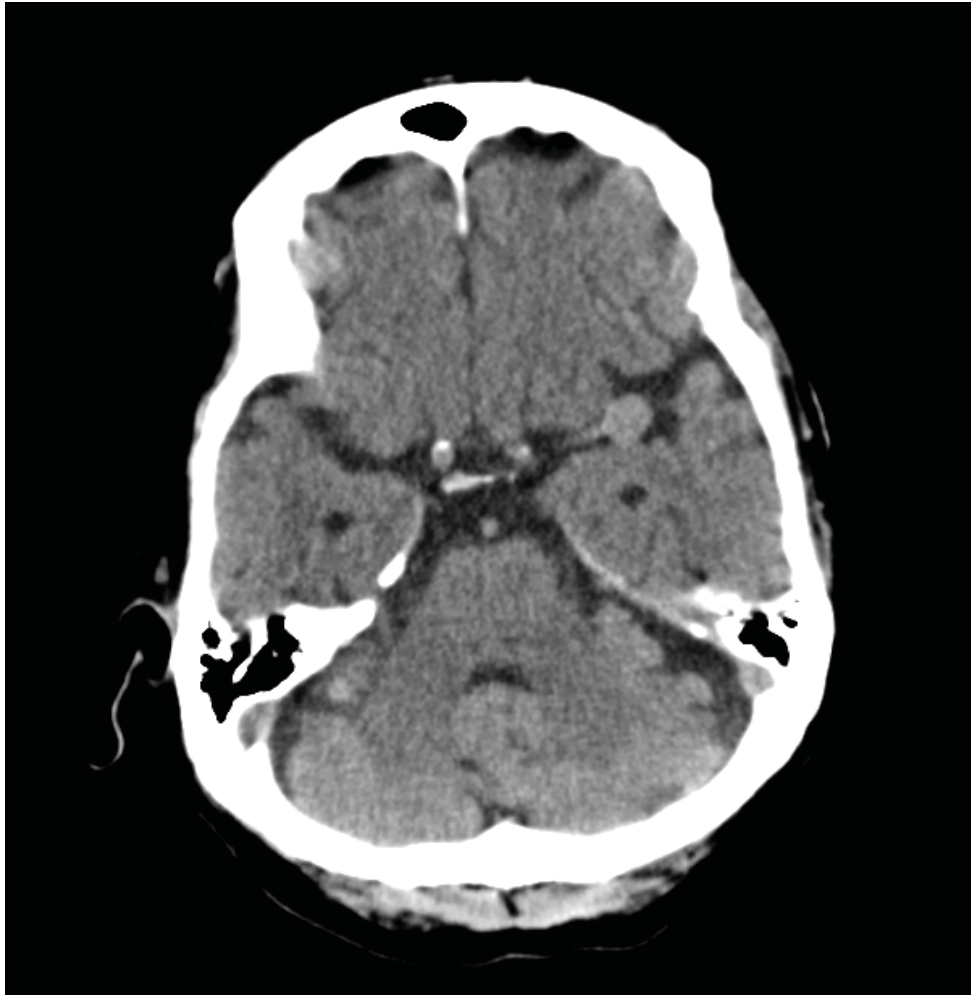
CT Angiographic Anatomy

- Red – anterior cerebral arteries
- Yellow – vein of Galen
- Purple – superior sagittal sinus
- Green – straight sinus
- Blue – basilar artery

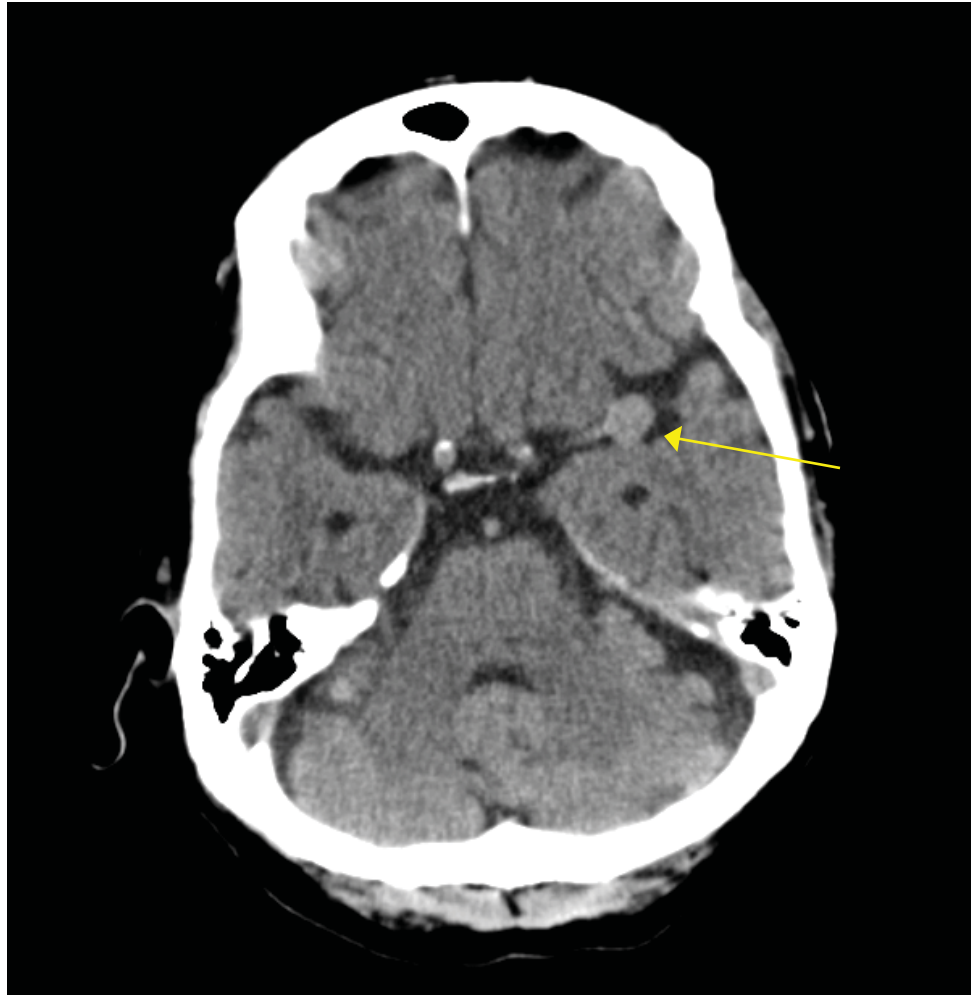


Pathology on Head CT

Can You Find the Abnormality?

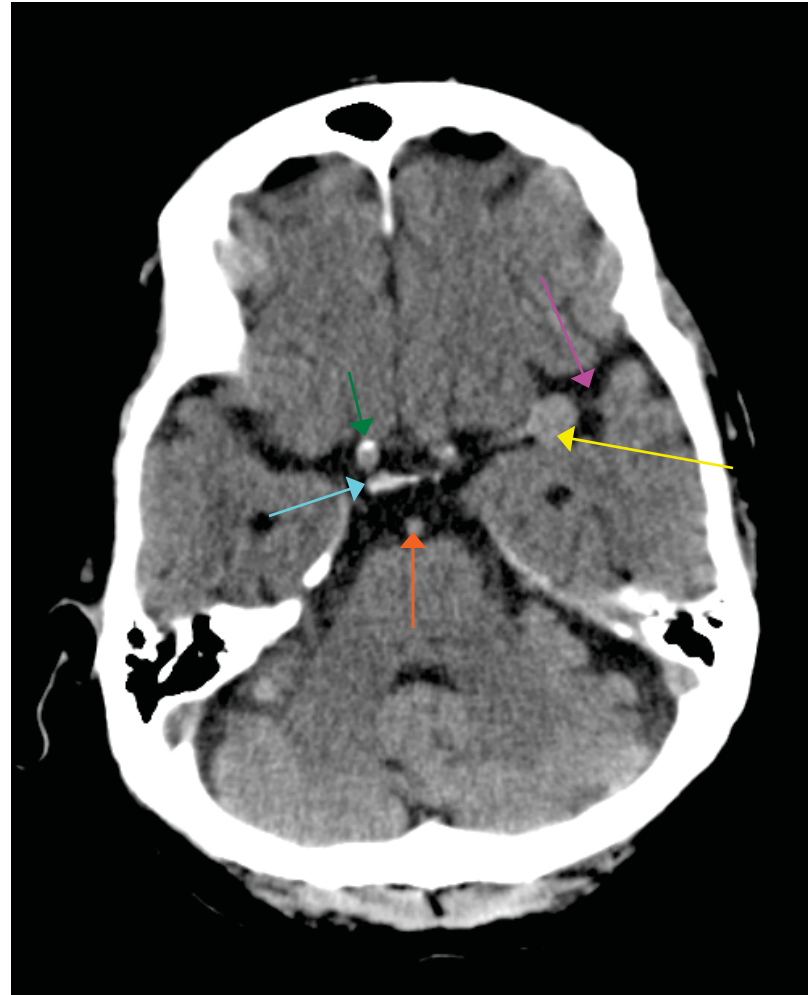


Left Middle Cerebral Artery Aneurysm on a Non-contrast CT



Left Middle Cerebral Artery Aneurysm on a Non-contrast CT

- Yellow – MCA bifurcation aneurysm
- Pink – Sylvian fissure
- Orange – Basilar artery
- Green – Supraclinoid ICA
- Blue – Bony dorsum sella



TRAUMA

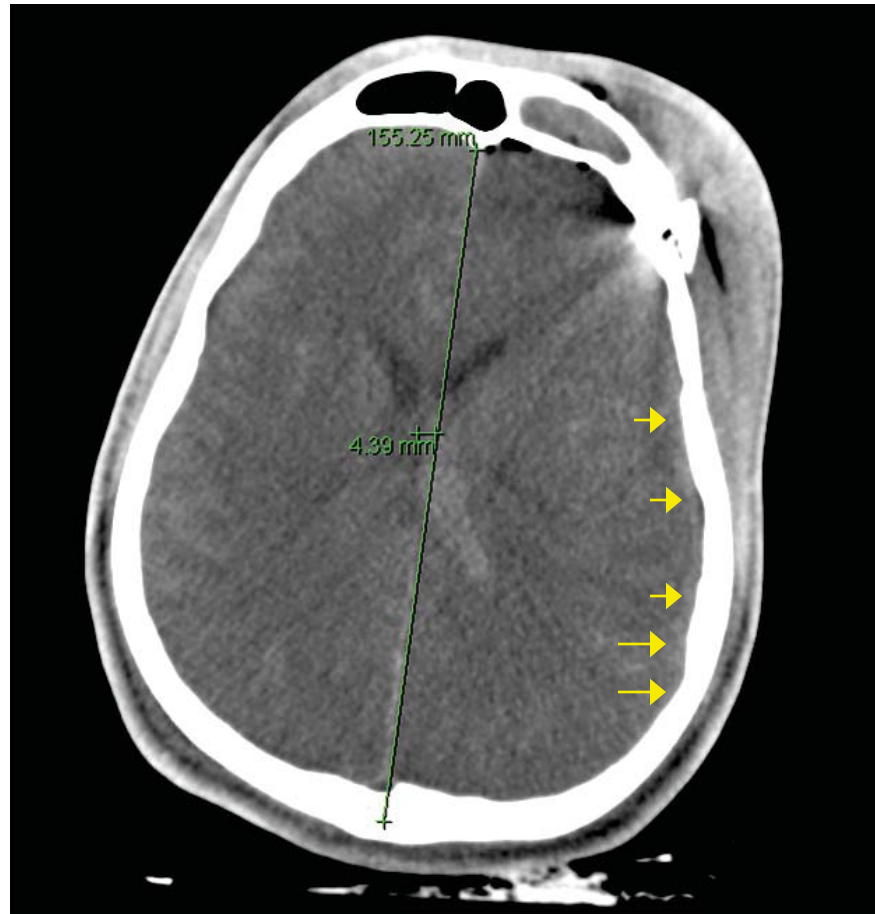
Trauma from a gunshot wound

- Acute hemorrhage is bright on CT, due to increased attenuation of the X-ray photons by blood proteins as clot forms
- In this case, there is subarachnoid and intraventricular hemorrhage

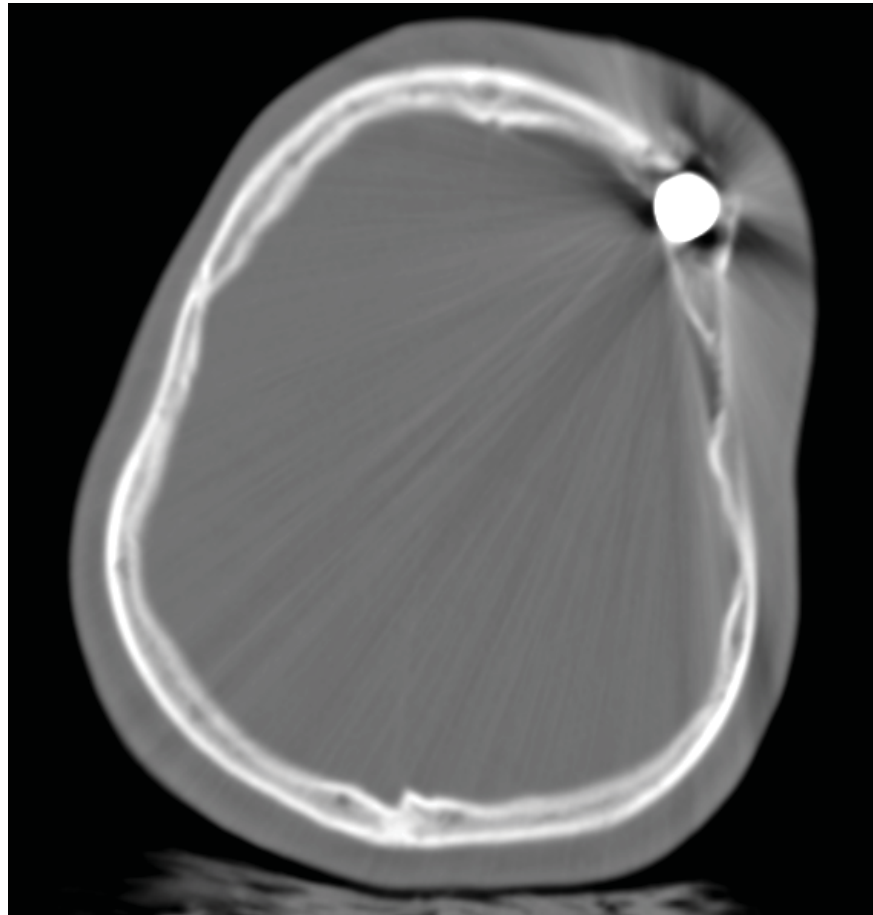


Trauma – Same Case

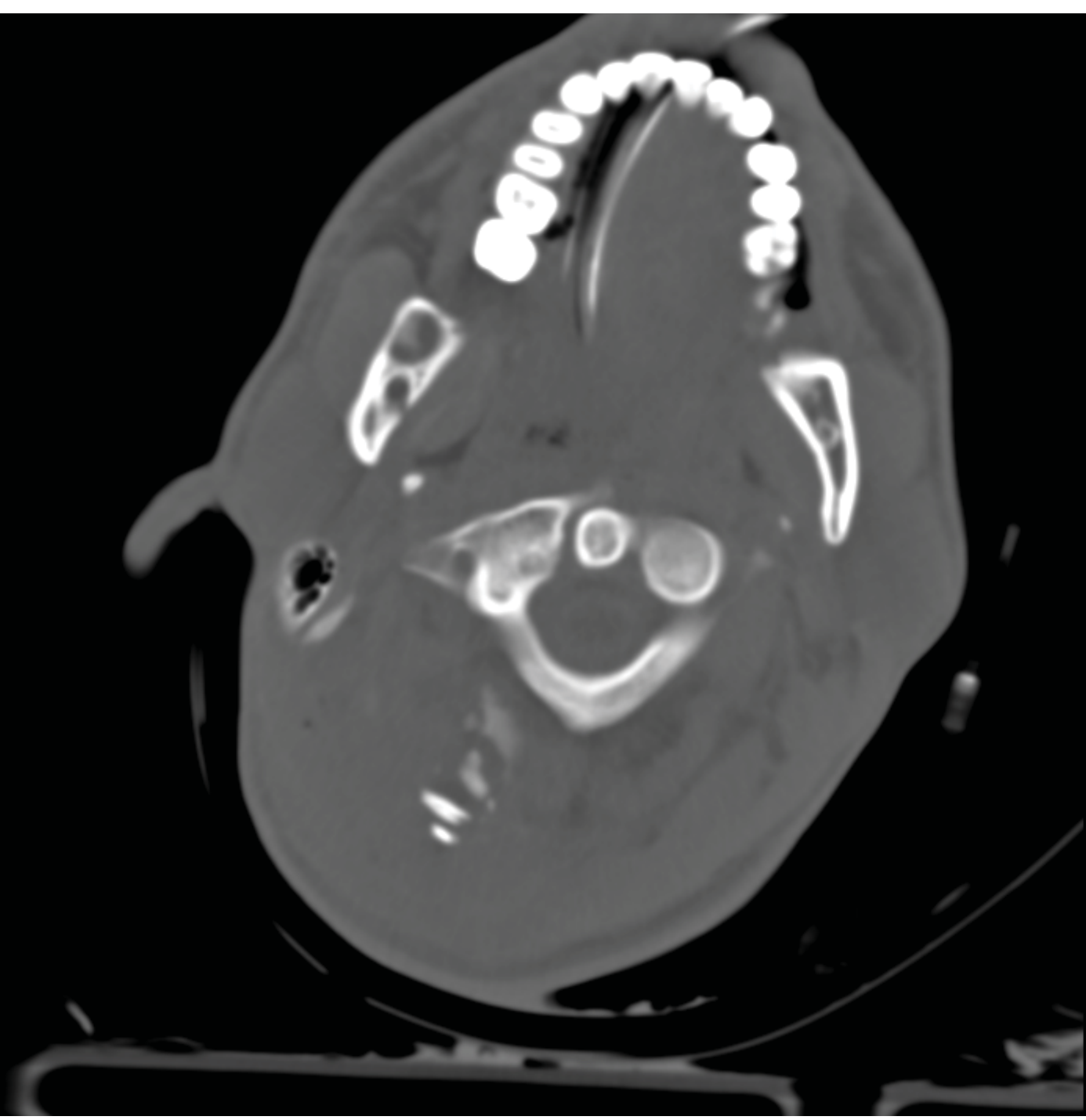
- Soft tissue windowing shows significant scalp swelling. The left frontal sinus is opacified
- Diffuse cerebral edema with a subdural hematoma (yellow arrows) have resulted in midline shift of structures to the right side

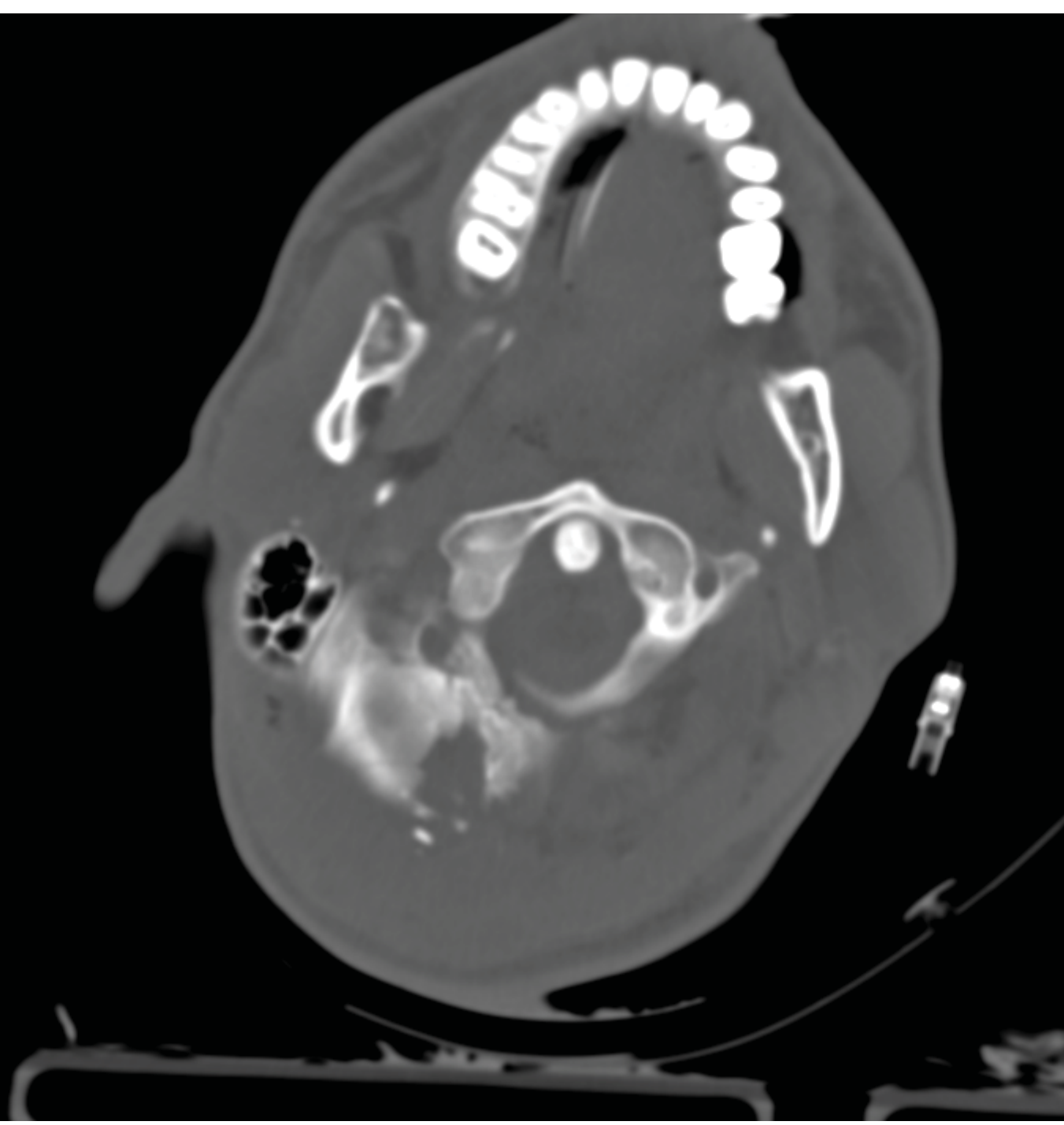


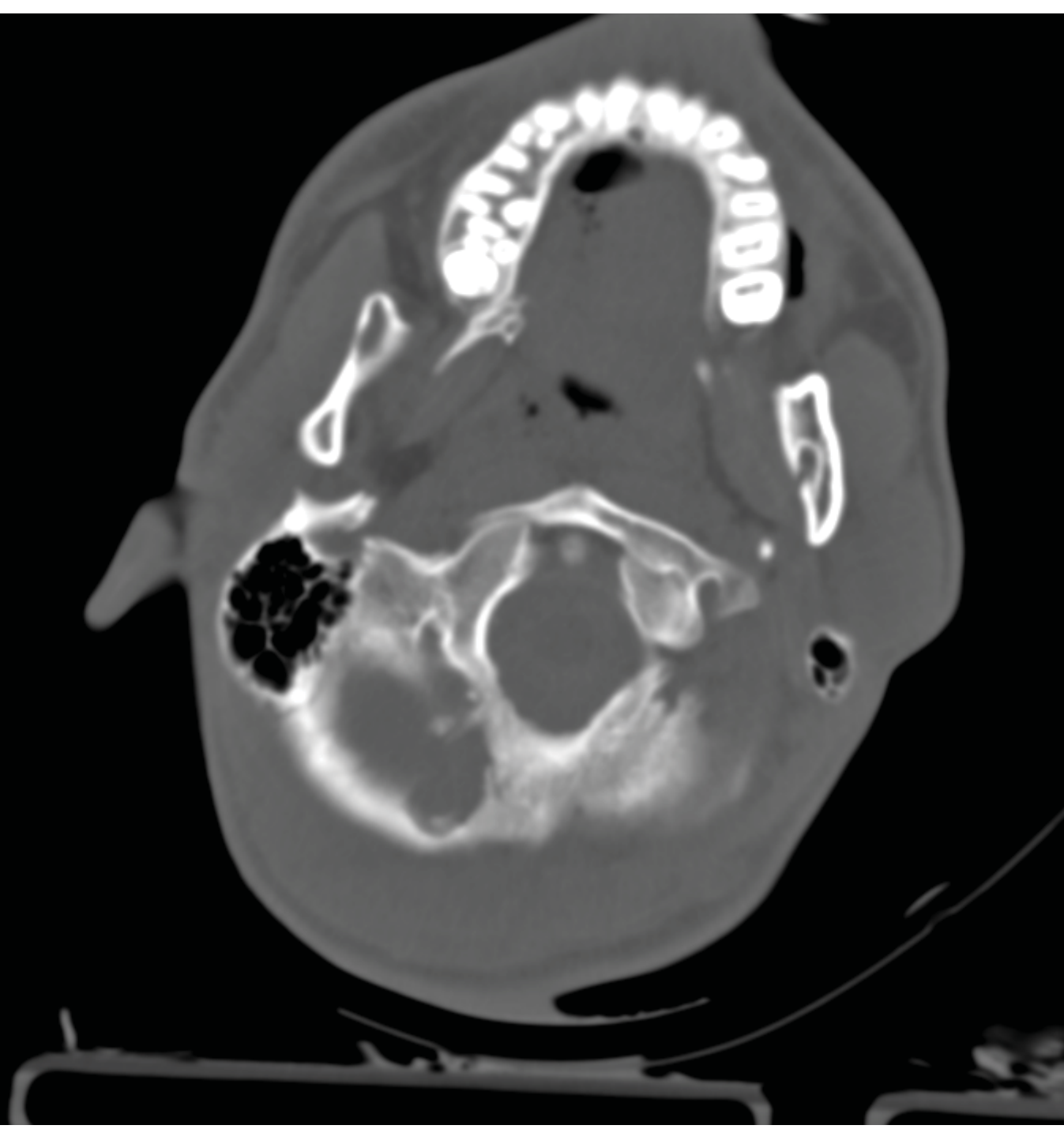
Bone Windows with Lodged Bullet

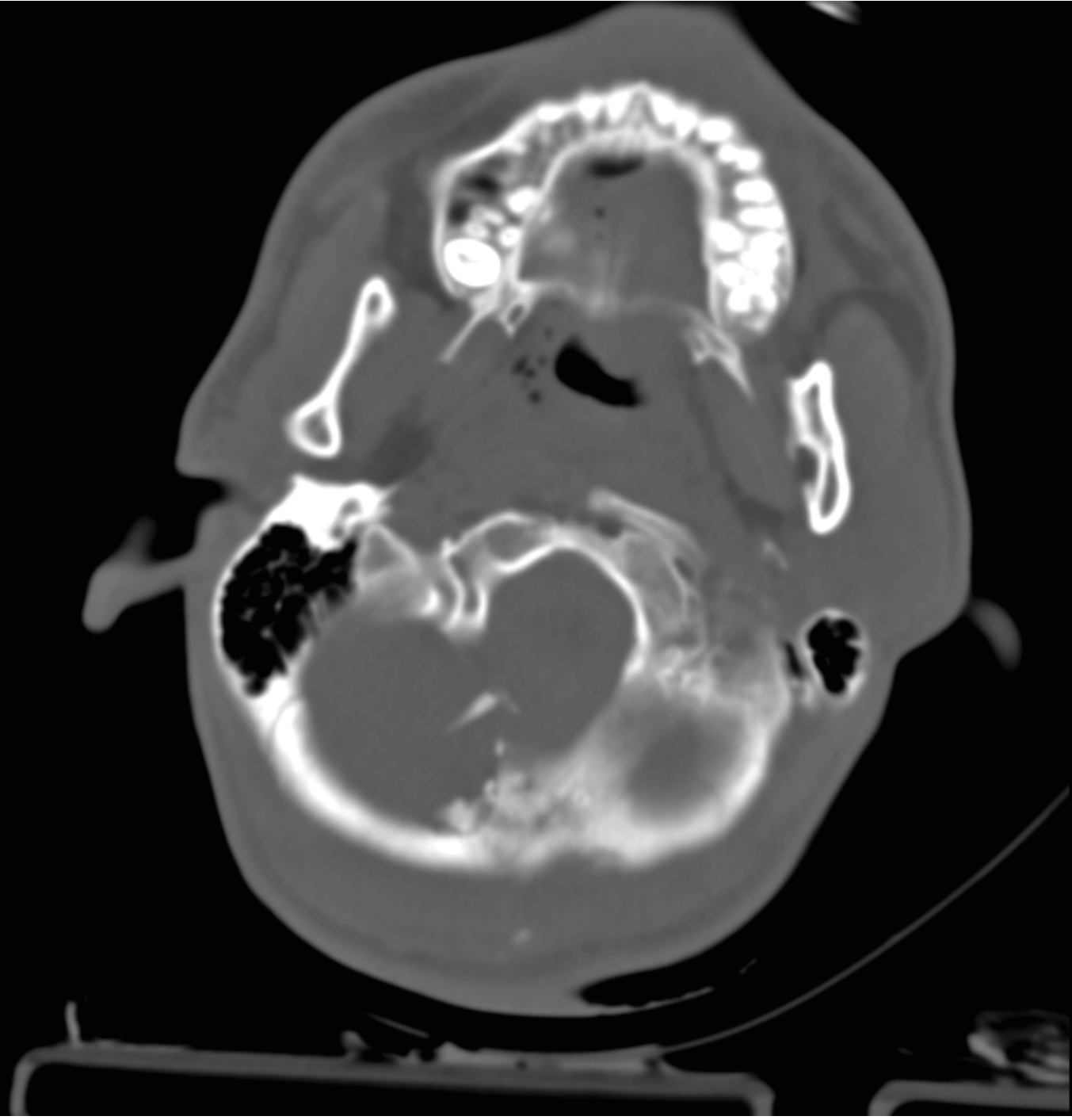


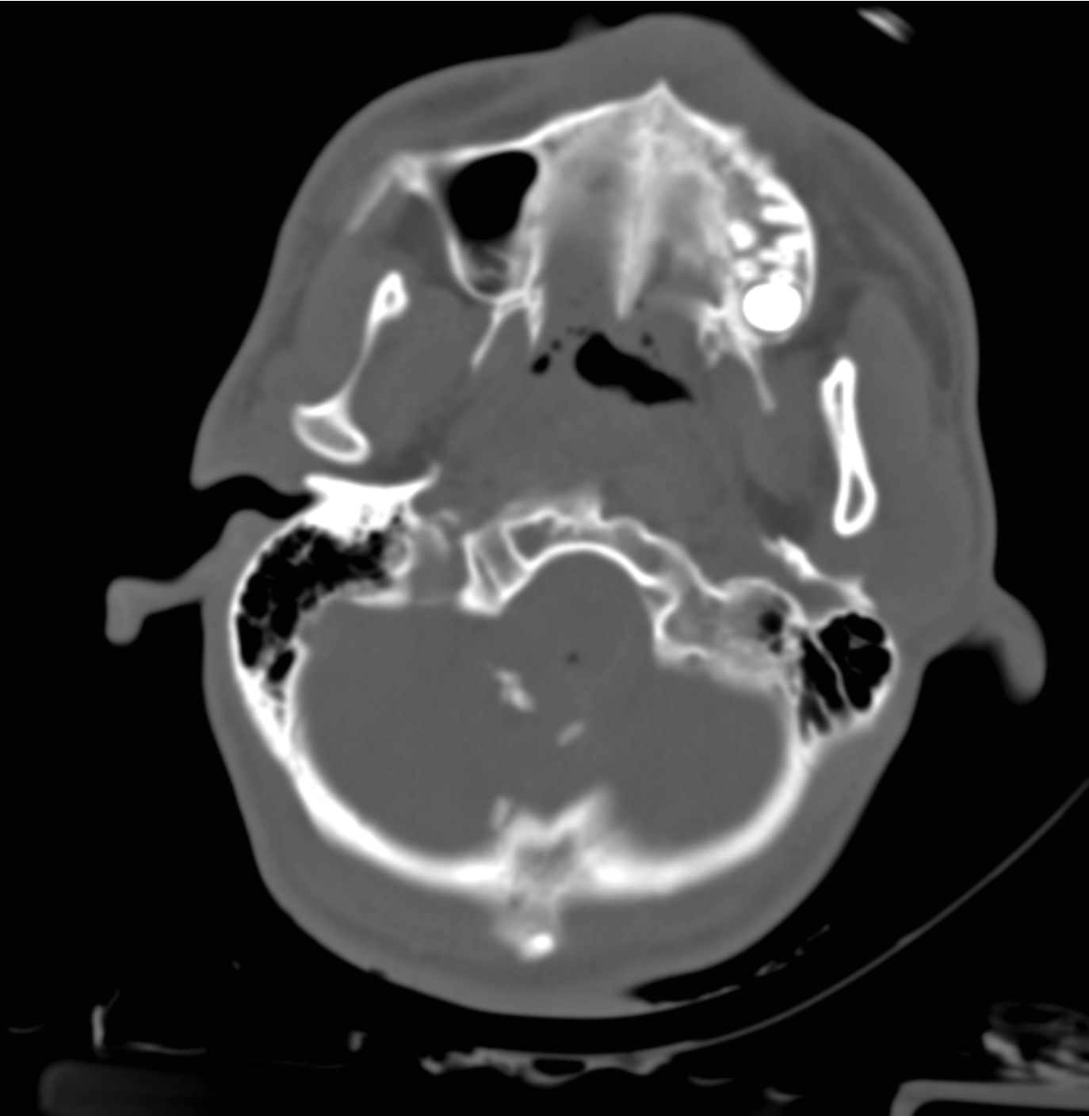
Axial CT images on following slides demonstrate the entry site of the bullet in the right occipital skull with comminuted fracture fragments



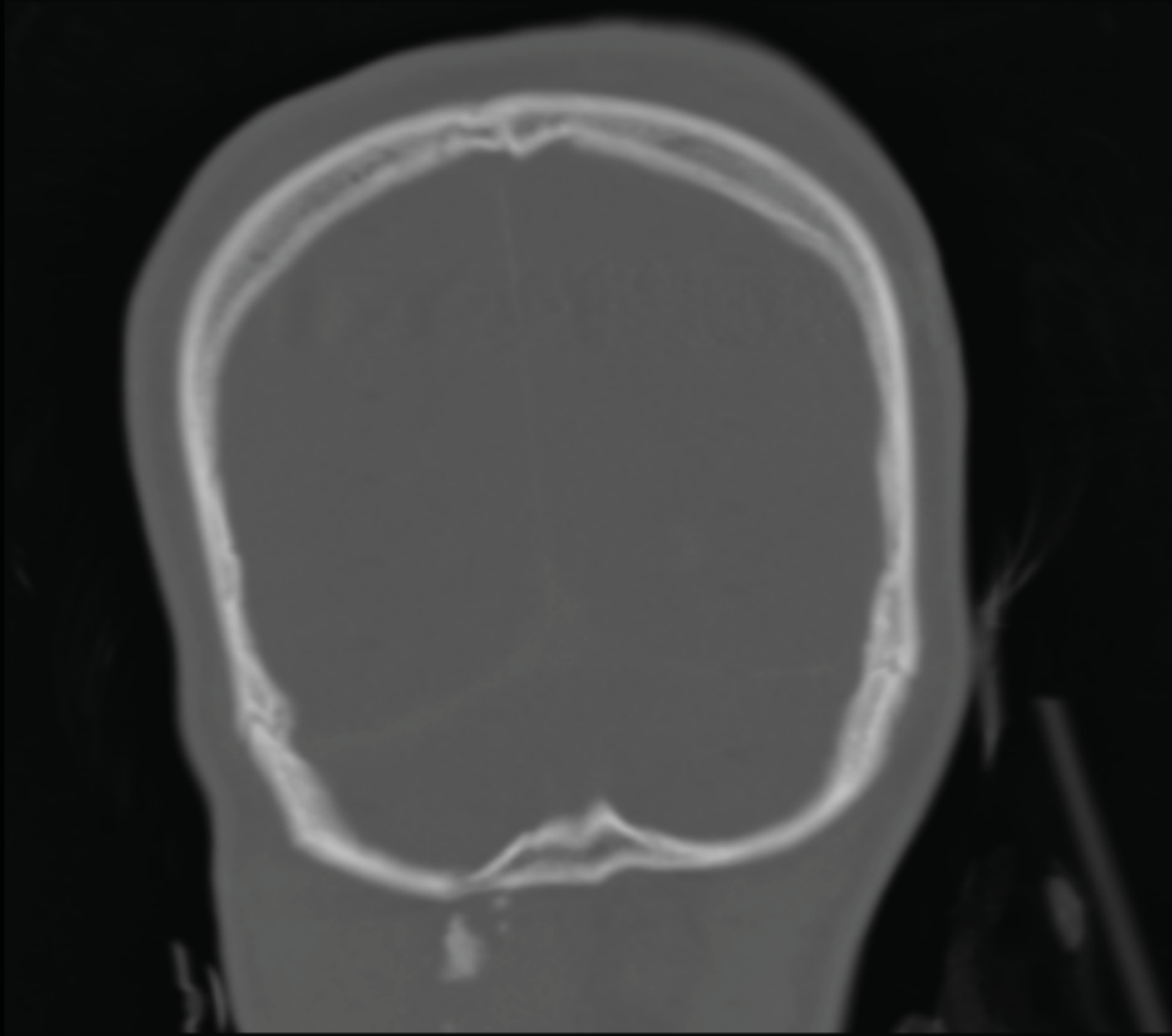


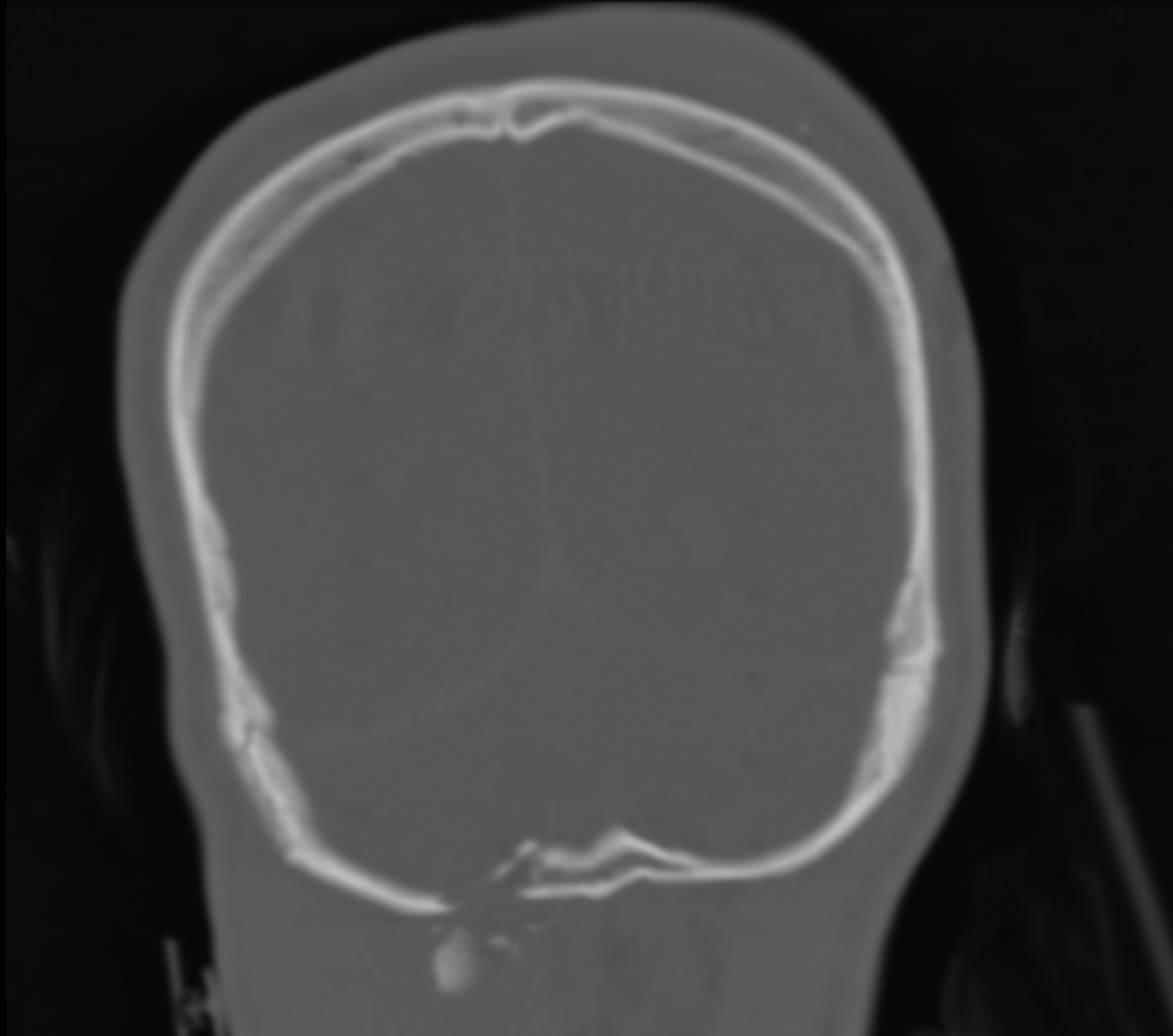


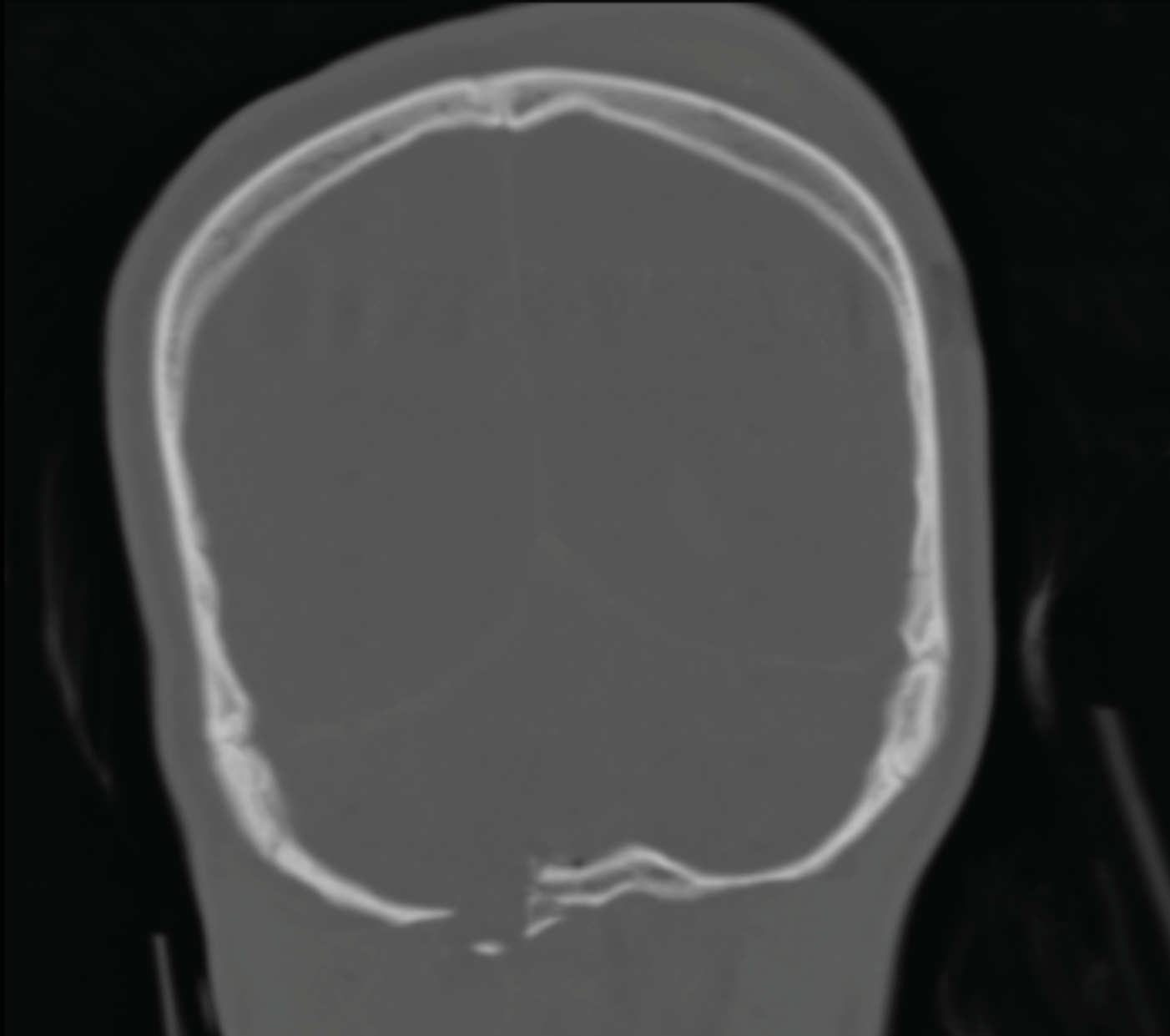


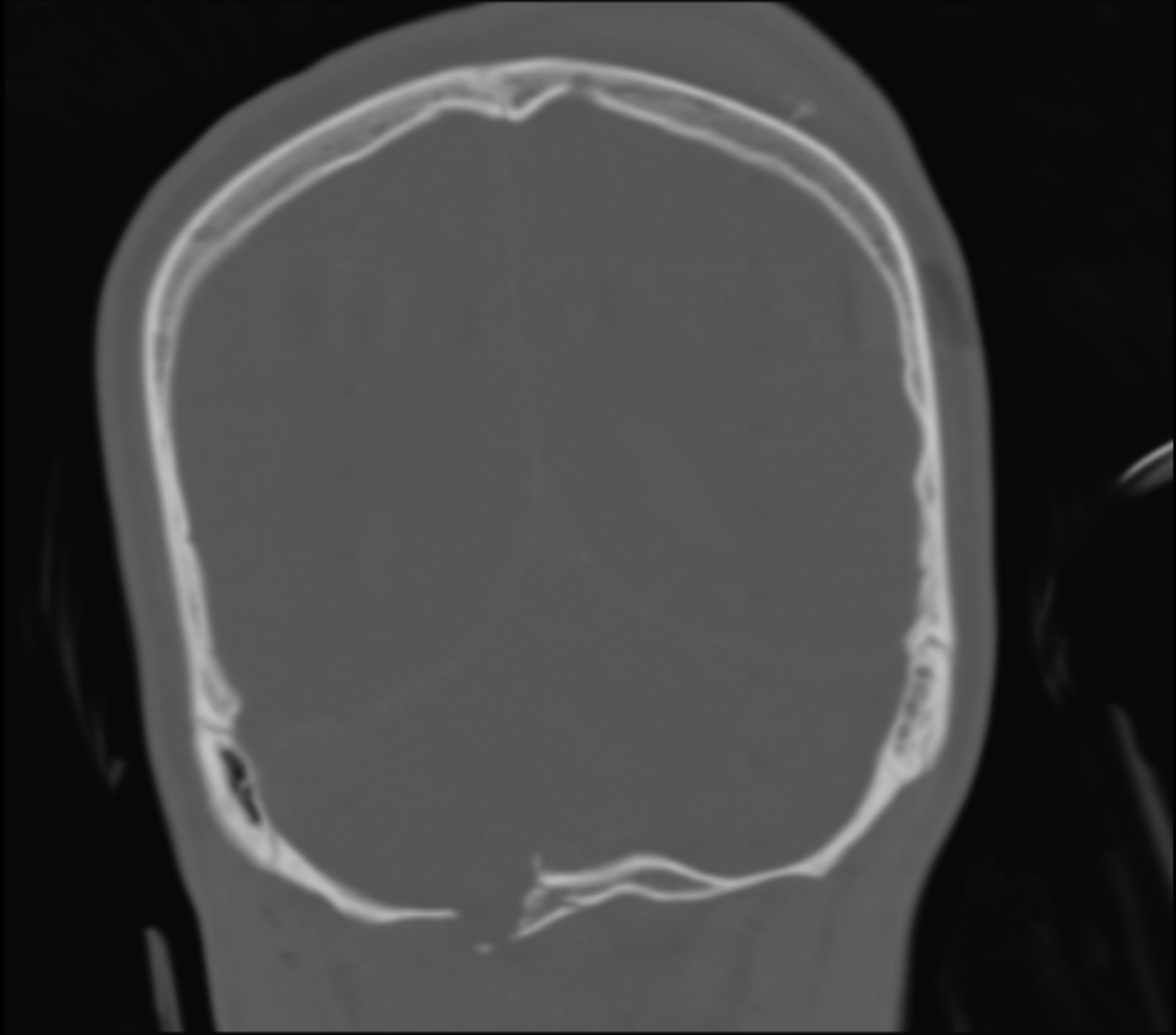


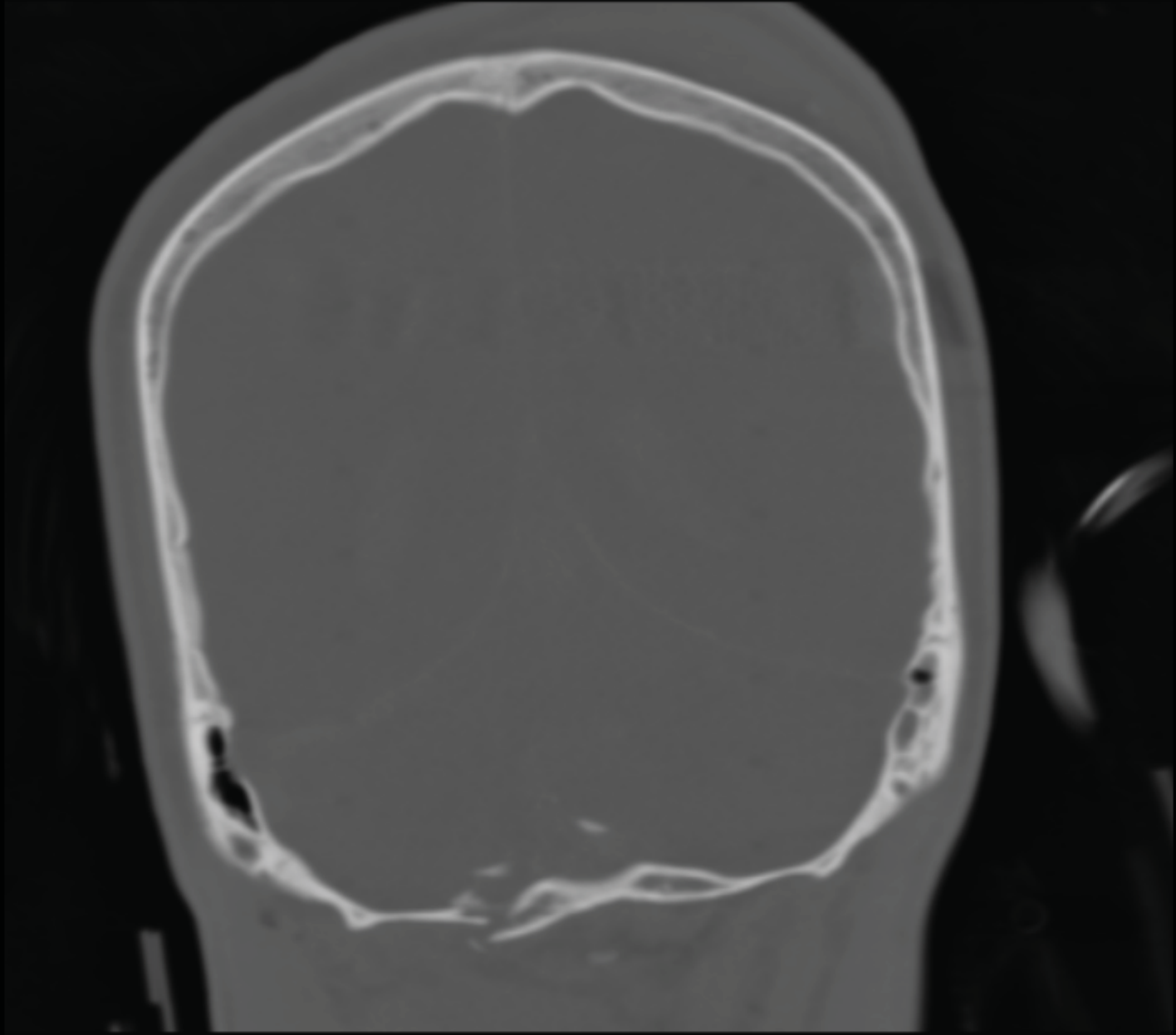
CT data can be reformatted into the coronal plane to evaluate calvarial fractures

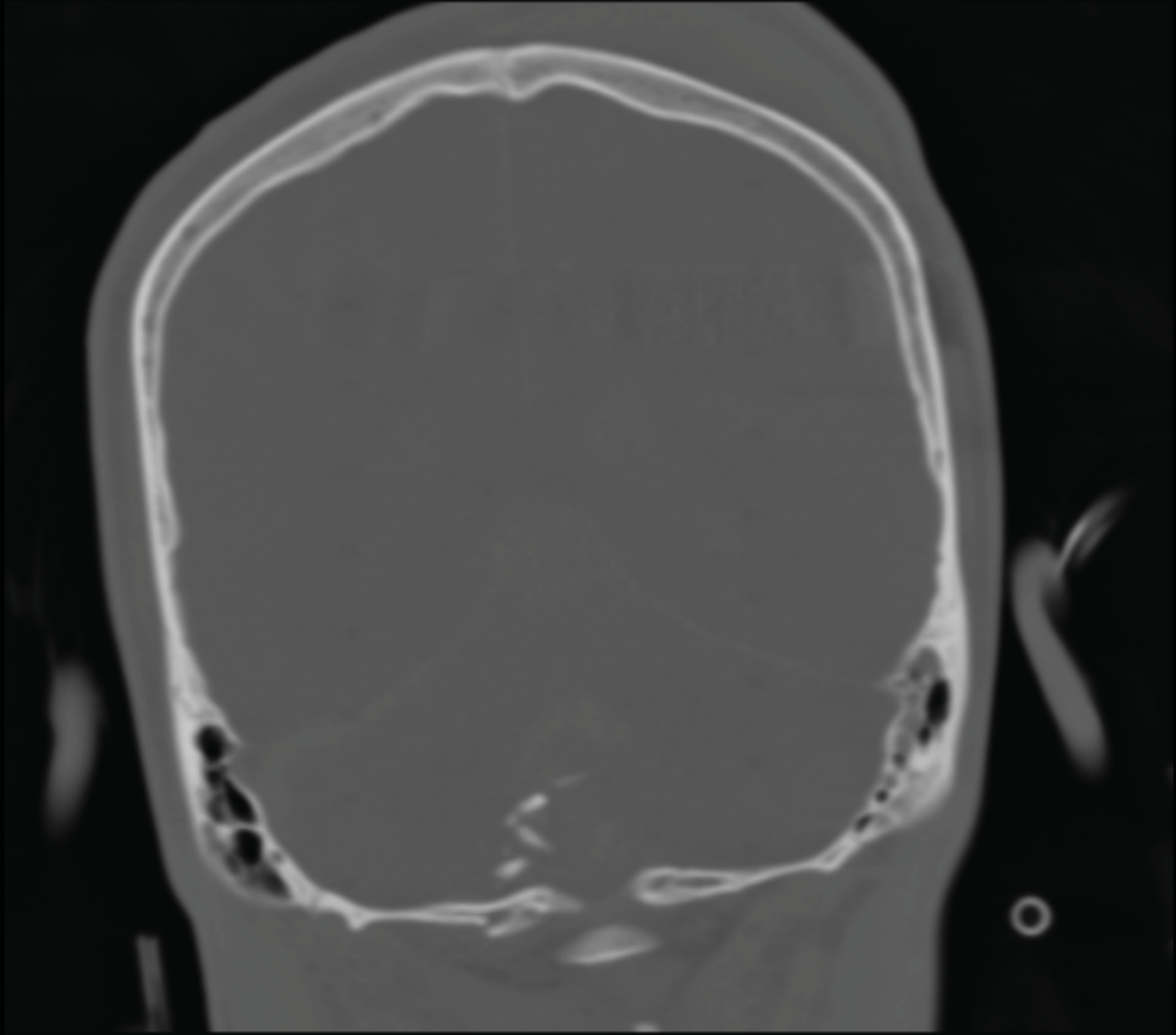


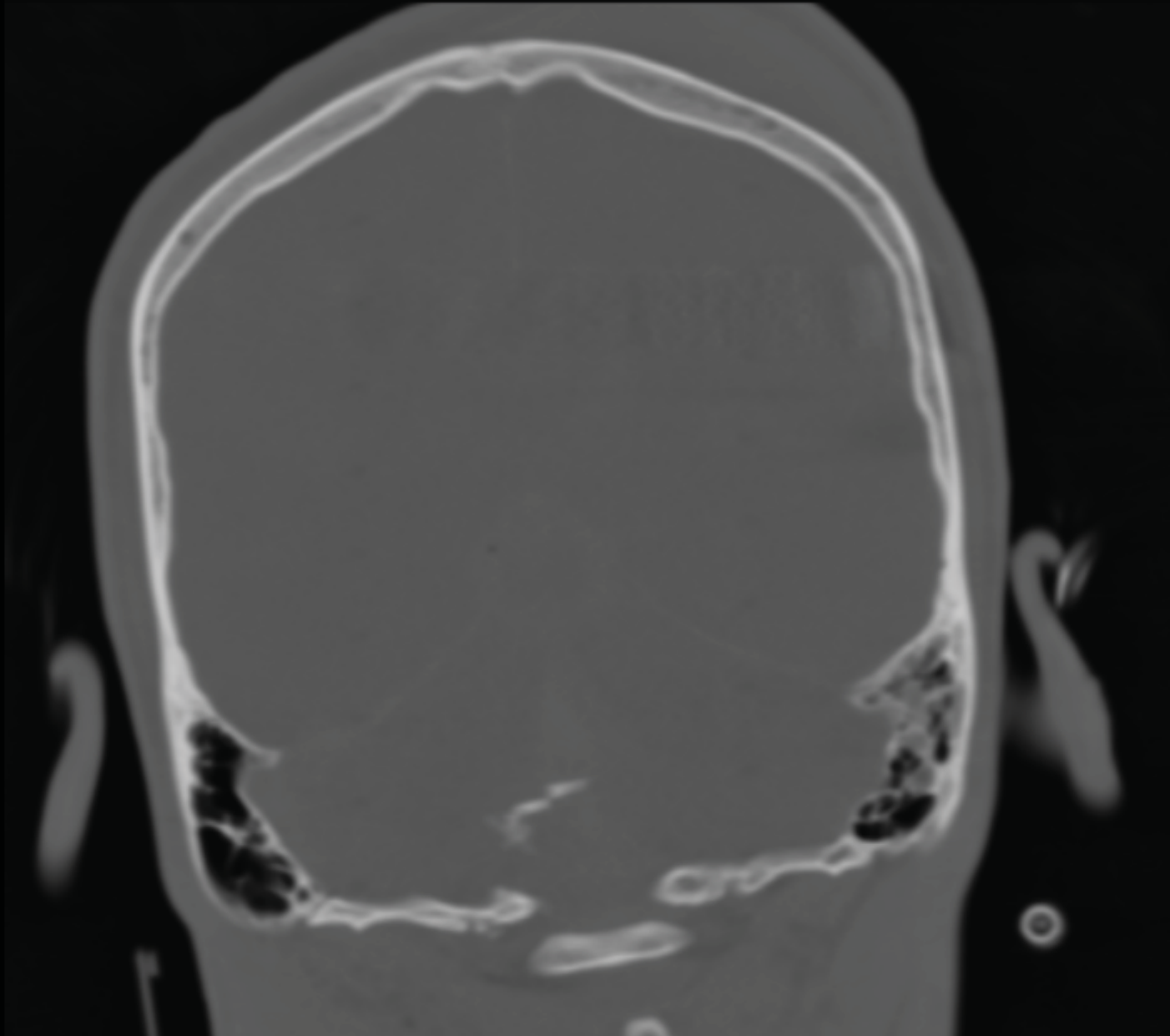








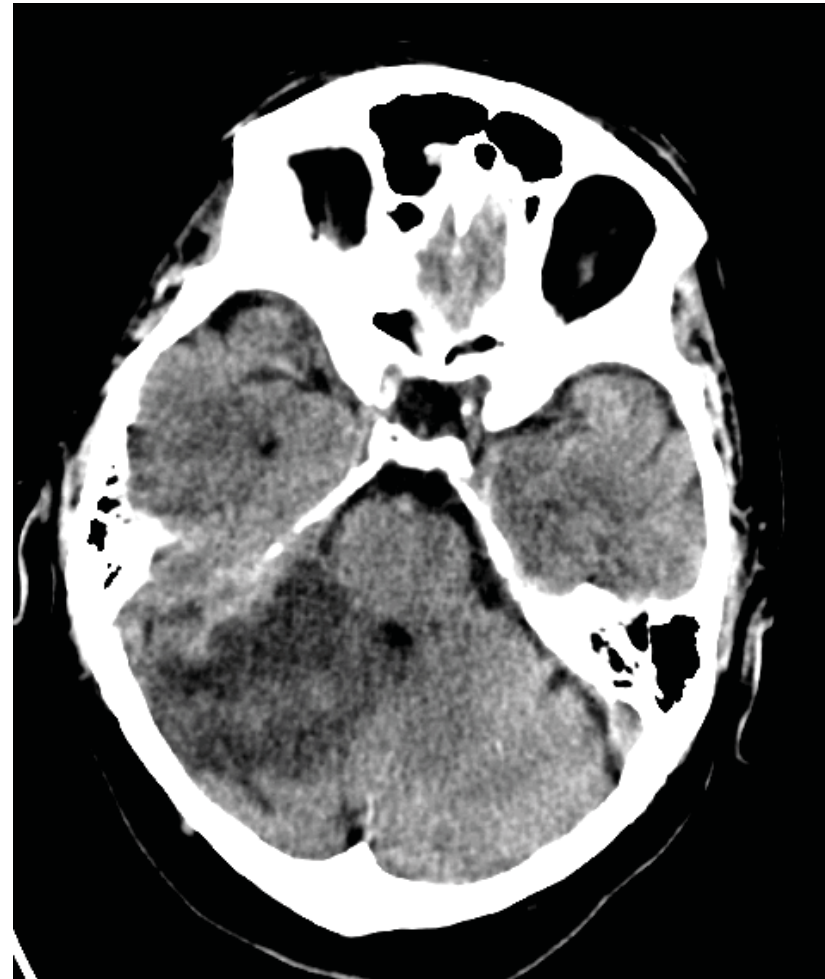




STROKE

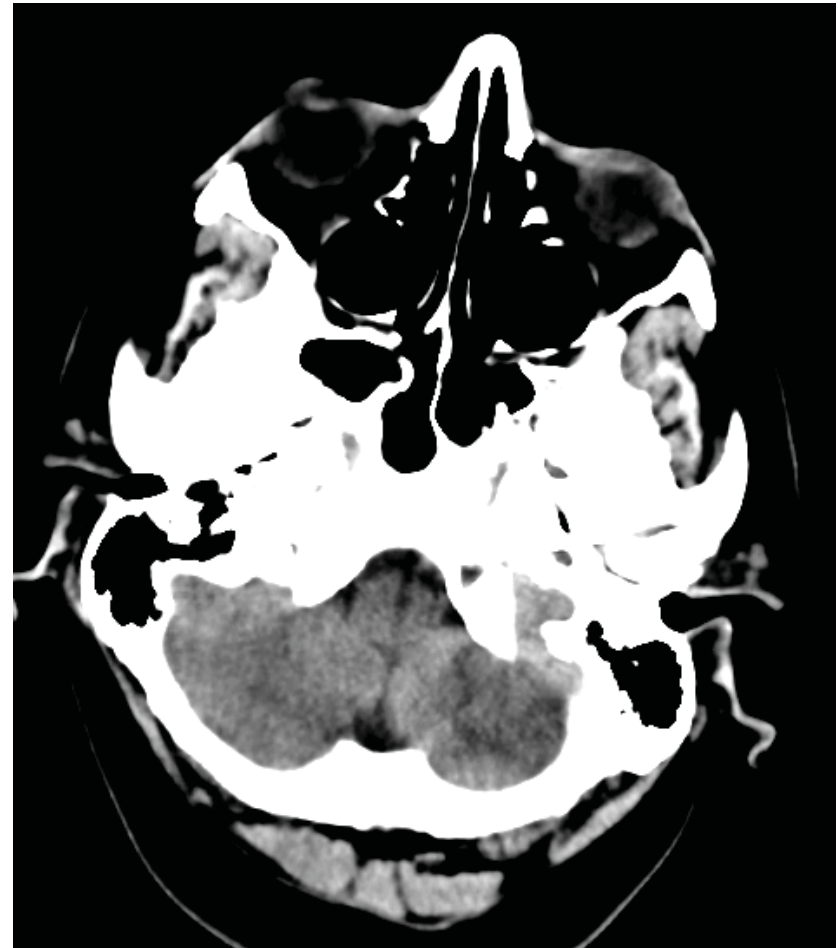
Right Cerebellar Infarct

- Infarcts are initially ill-defined with lower attenuation/density or “darker gray” appearance
- Chronic infarcts are black like CSF because tissue loss from neuronal cell death liquifies and is known as encephalomalacia

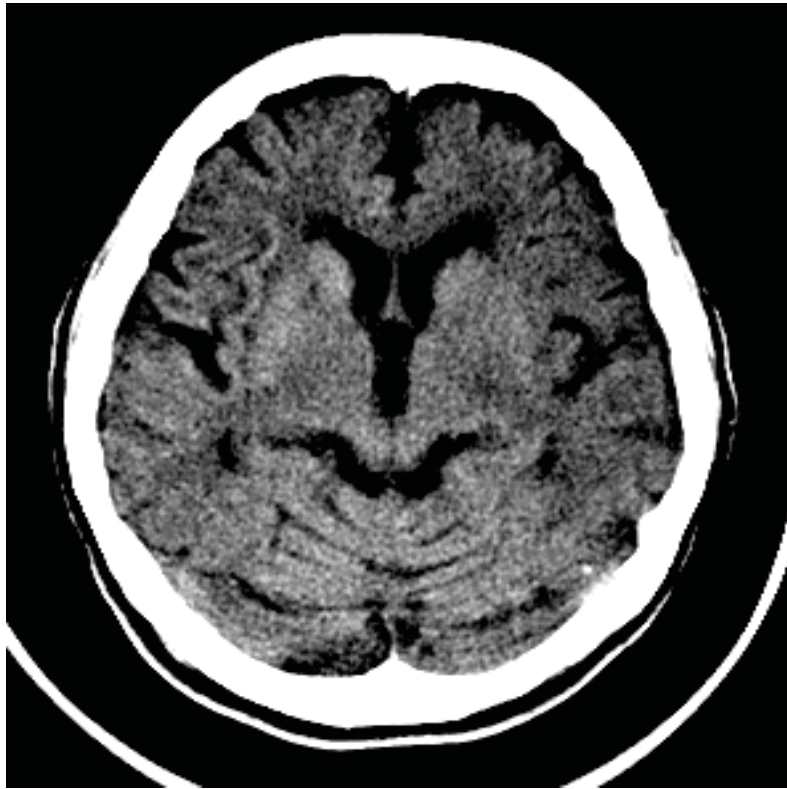


Left Cerebellar Infarct

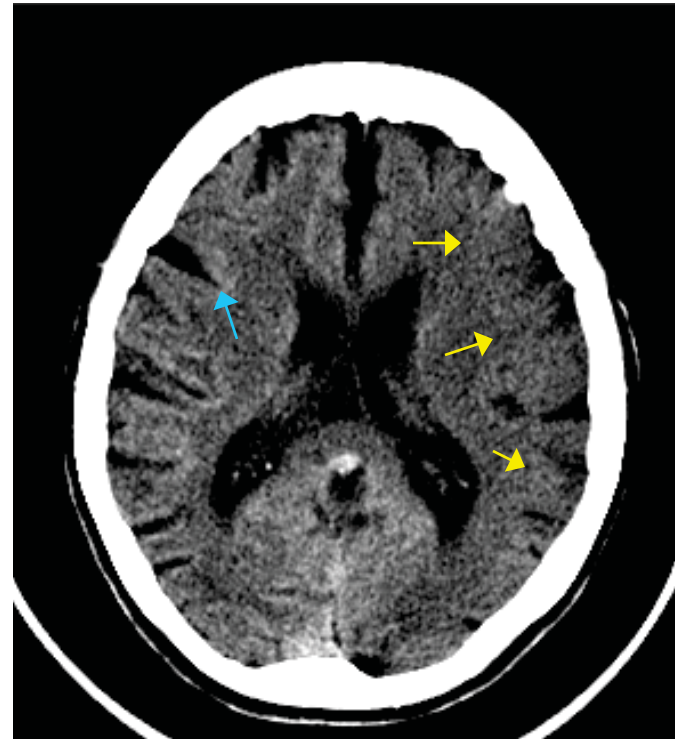
- Cytotoxic edema in infarctions involves the gray and white matter – therefore abnormal low attenuation extends to the cortex
- Important to know vascular territories: this is a posterior inferior cerebellar artery (PICA) infarct
- Acute to subacute stage of infarction can lead to mass effect from edema



Is There Asymmetry Between the Two Hemispheres?



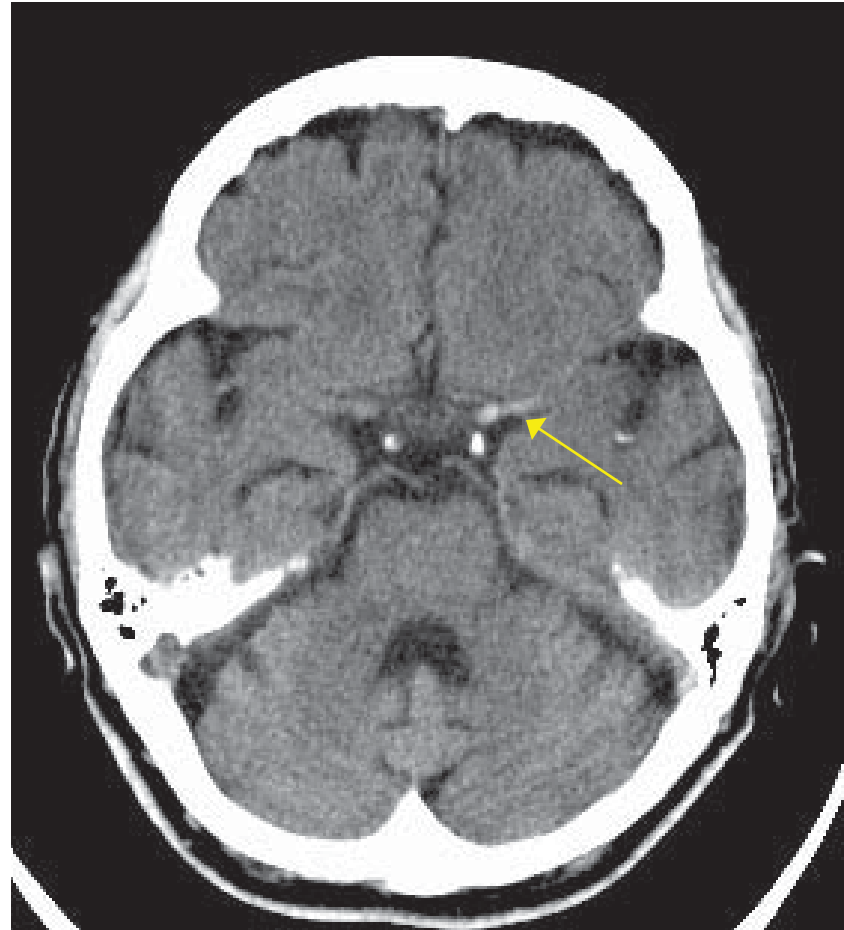
Acute Left Middle Cerebral Artery Territorial Infarction



- Arterial occlusion from thrombus or embolus causes loss of gray to white matter differentiation when ischemia develops
- Note the loss of the white cortical ribbon of gray matter in the left hemisphere (yellow arrows) as compared to the normal contralateral side (blue arrows)

Dense MCA Sign in Acute Infarct

- Notice how thrombus is whiter in the occluded left middle cerebral artery on this non-contrast study

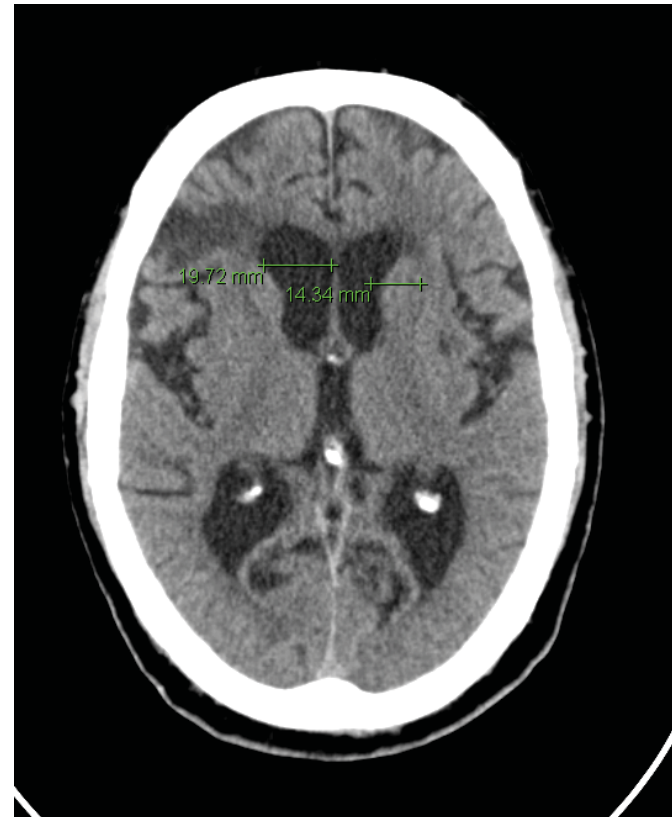


Subacute Infarction

- In 5-7 days after the initial event, the completely infarcted area has a well-defined geographic appearance with mass effect
- Chronic infarcts have volume loss
- Infarcts can undergo hemorrhagic conversion usually within the first few days



Chronic Right Frontal Lobe Infarct – note ex vacuo dilatation of the right frontal horn secondary to parenchymal volume loss



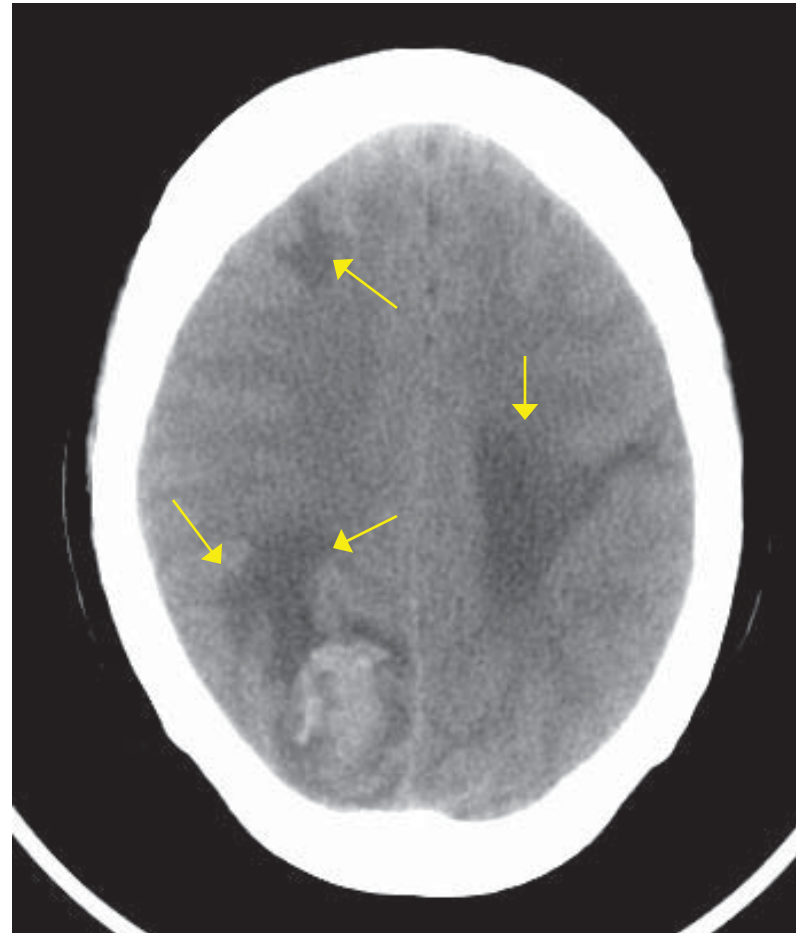
Chronic Left MCA Infarct with parenchymal volume loss



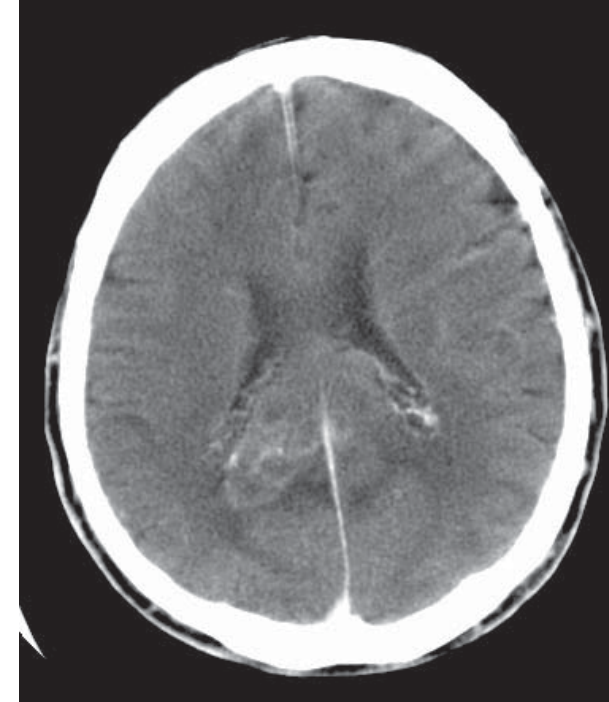
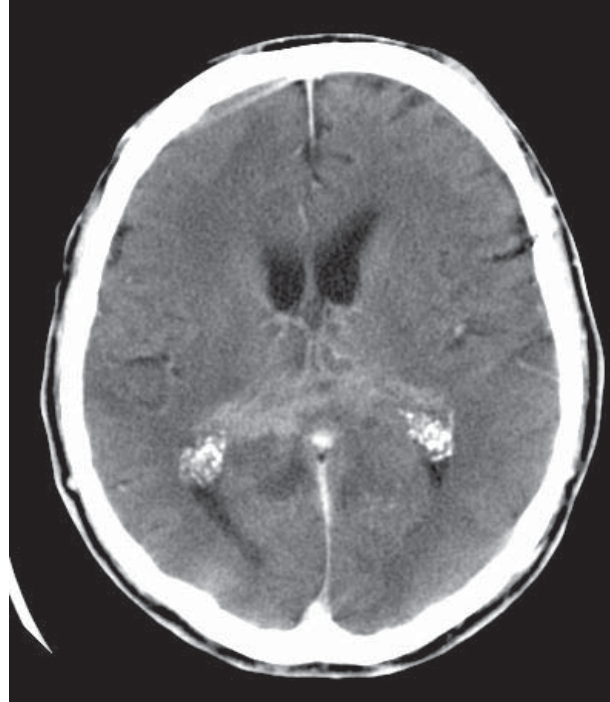
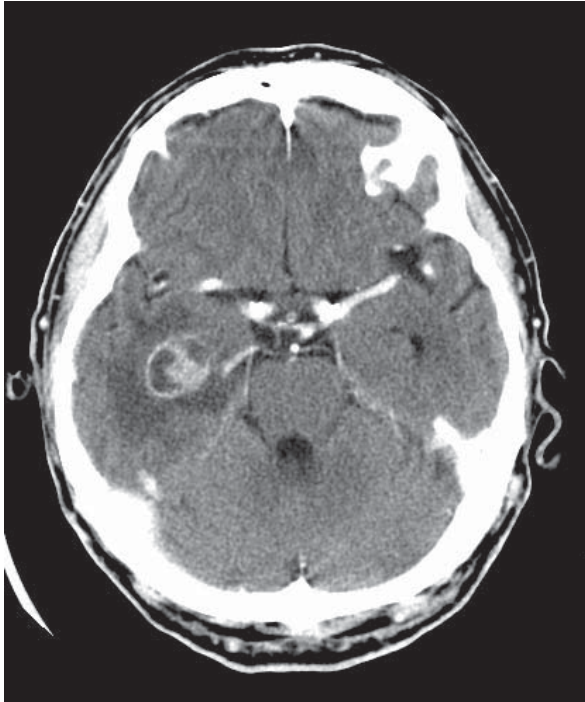
Brain Masses and Edema

Hemorrhagic Brain Metastasis

- Hyperdense mass in the left posterior parietal lobe has a hemorrhagic component
- Note the pattern of vasogenic edema (yellow arrows) as compared to cytotoxic edema in infarction. Edema has finger-like projections along white matter only
- Vasogenic edema results in increased fluid in the interstitium from mass effect
- Cytotoxic edema is intracellular swelling from cell death, which involves gray and white matter. However, infarcts also have a vasogenic component



Glioblastoma



Glioblastoma

- Previous slide is a contrast-enhanced CT depicting an aggressive heterogeneously enhancing mass that infiltrates the white matter and spreads across the splenium of the corpus callosum
- Glioblastoma multiforme (GBM) is by far the most common and most malignant of the glial tumors. Composed of a heterogeneous mixture of poorly differentiated neoplastic astrocytes, glioblastomas primarily affect adults, and they are located preferentially in the cerebral hemispheres

Hydrocephalus

Hydrocephalus

- The ventricles are dilated to a greater degree than the subarachnoid spaces
- Causes include an obstructing mass (non-communicating hydrocephalus) or a failure of CSF resorption in the arachnoid granulations that may not function properly after a history of subarachnoid hemorrhage or meningitis: this form is known as communicating hydrocephalus

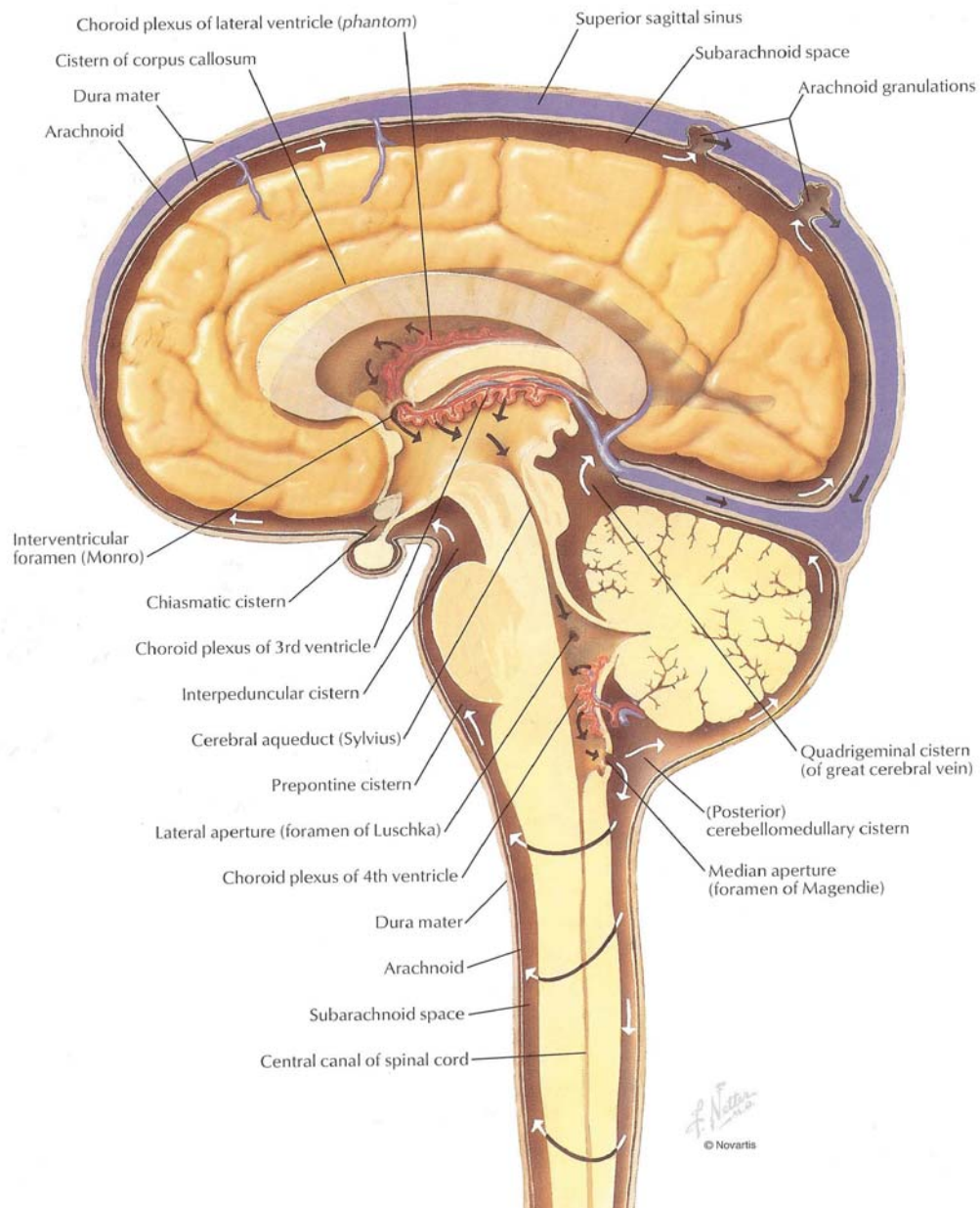


Signs of Hydrocephalus

- A good indicator is abnormal dilatation of the temporal horns, which are normally slit-like
- Note here how the temporal horns are slightly dilated, whereas the subarachnoid spaces are not

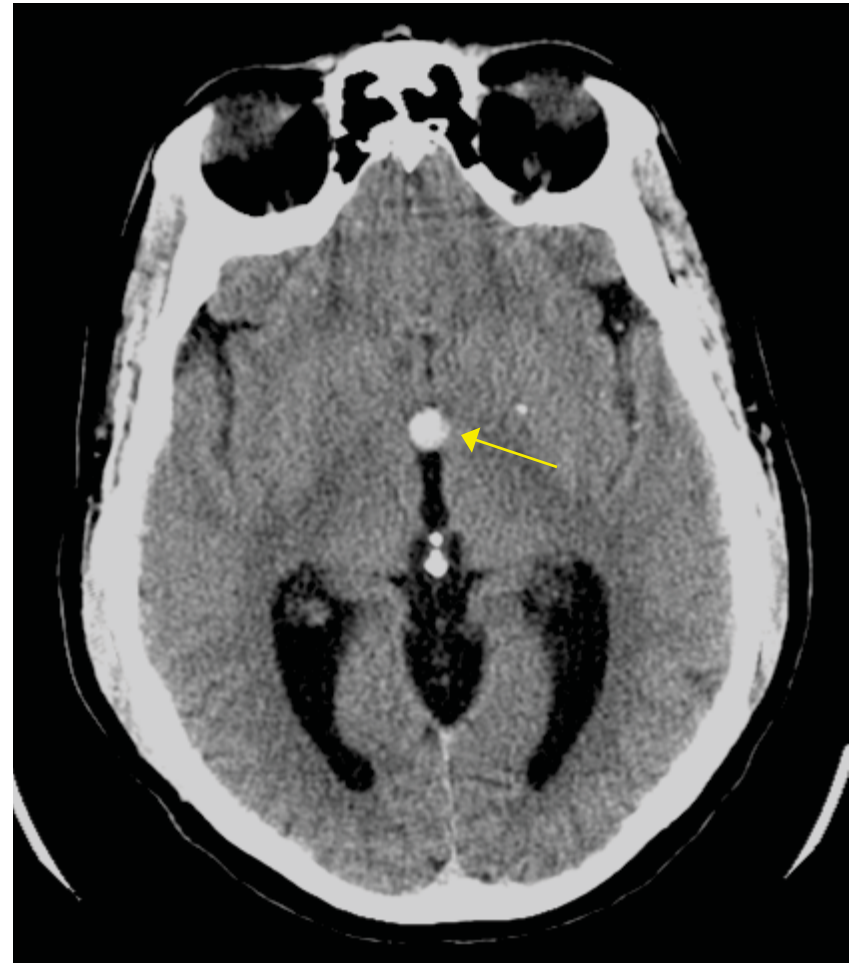


Circulation of Cerebrospinal Fluid



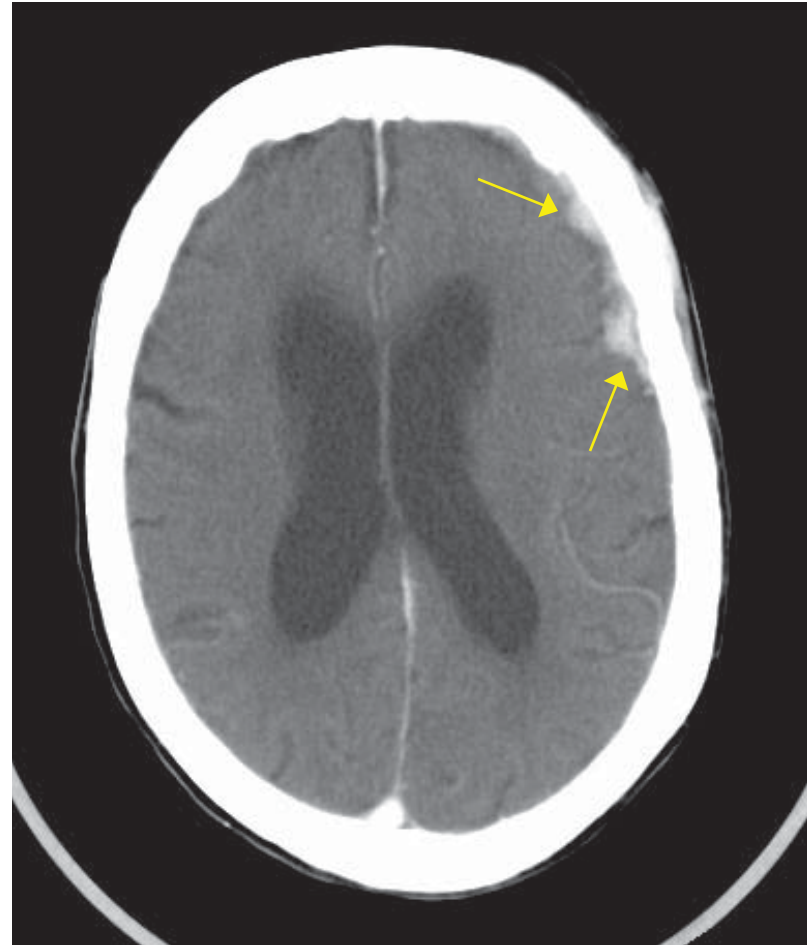
Obstructive Hydrocephalus

- Hyperdensity of this benign colloid cyst is due to high protein content
- The cyst is situated in the anterior third ventricle at the level of the foramen of Monroe and has resulted in dilatation of the lateral ventricles
- Chief complaint is severe headaches with increased intracranial pressure
- Neurosurgical resection is imperative



Hydrocephalus

- Another cause of communicating hydrocephalus is leptomeningeal carcinomatosis or spread of metastatic disease to the meninges, which will affect CSF resorption
- Note the dilatation of the ventricles and the enhancing plaque-like mass along the surface of the left frontal lobe on this contrast-enhanced CT



Atrophy

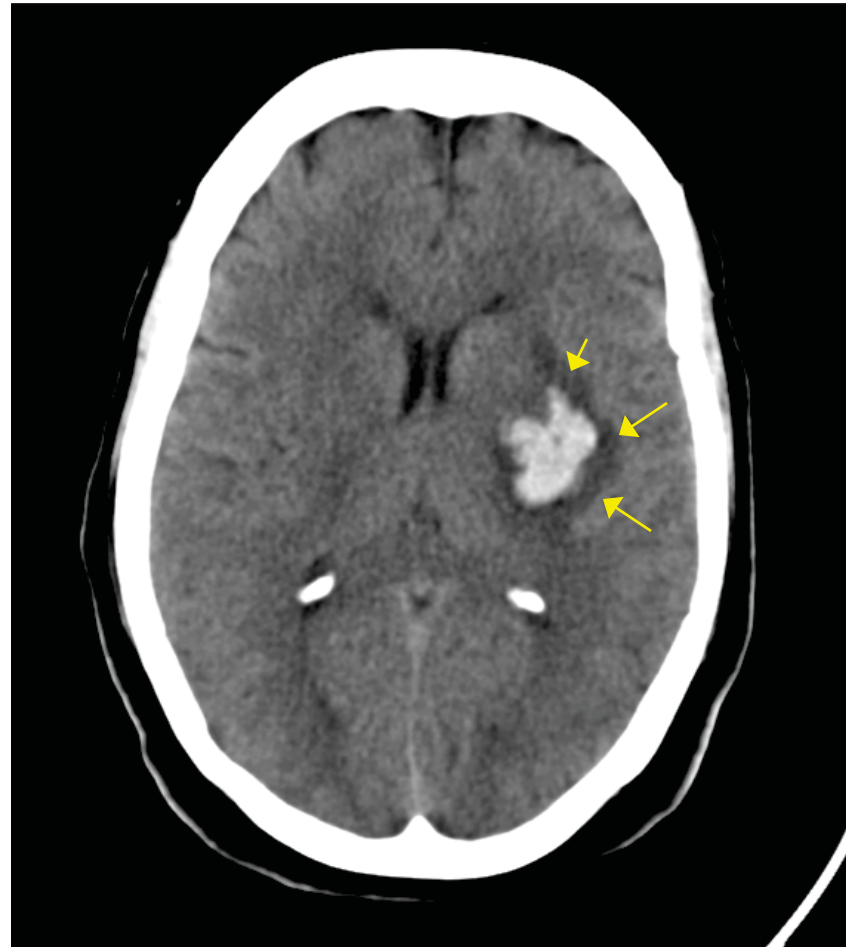
- The ventricles are dilated, but so are the subarachnoid spaces: this would not be expected in hydrocephalus
- The combination of these two findings is consistent with diffuse volume loss or atrophy in this 80 year old patient



Cerebral Hemorrhage

Cerebral Hemorrhage

- Parenchymal hemorrhage or hematoma centered on the left basal ganglia with a mild amount of surrounding vasogenic edema (yellow arrows)
- The basal ganglia, pons, and cerebellum are common locations for a hypertensive bleed



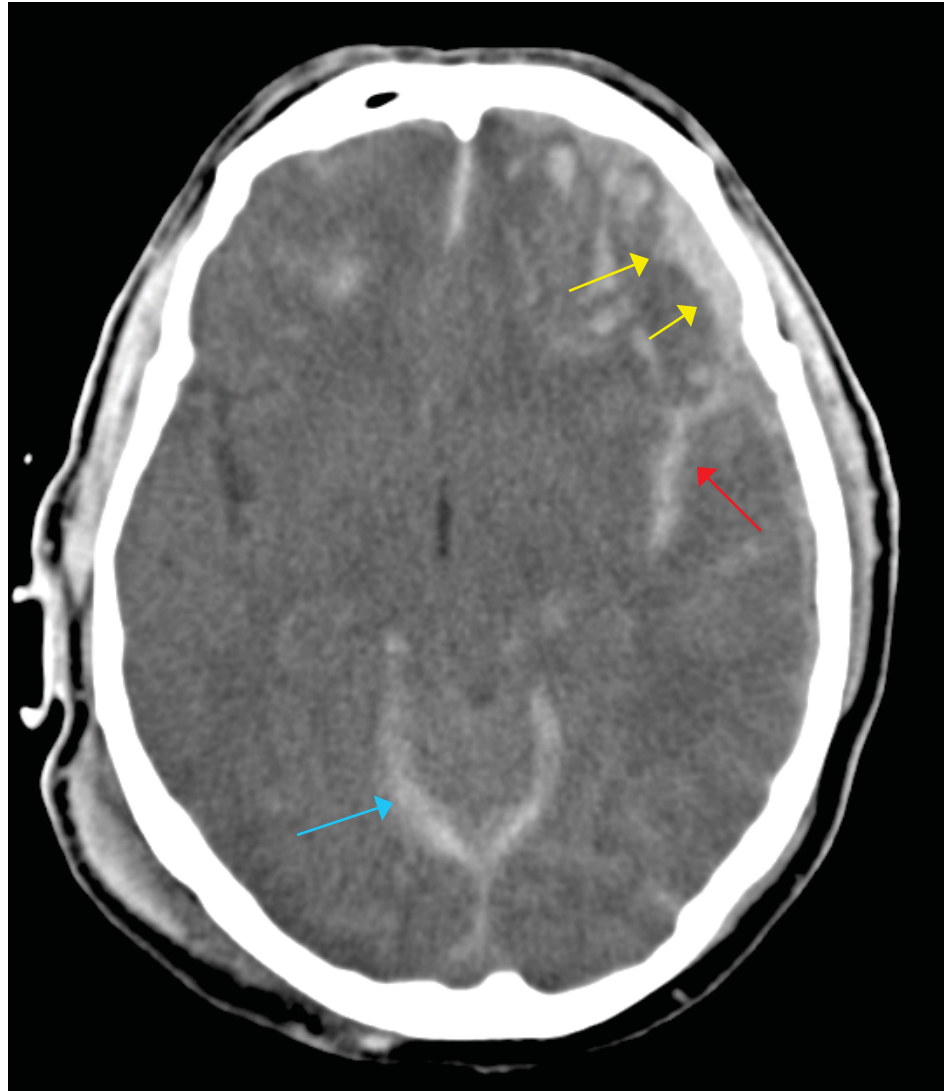
Causes of Parenchymal Hemorrhage

- Hypertension
- Hemorrhagic Stroke
- Trauma
- Coagulopathy in leukemia
- Coumadin
- Ruptured aneurysm
- AVM and Dural fistula
- Vascular dissection
- Diffuse axonal injury
- Cocaine abuse
- Amyloid angiopathy
- Radiation vasculopathy
- Toxoplasmosis
- Tumor

Subdural hematoma

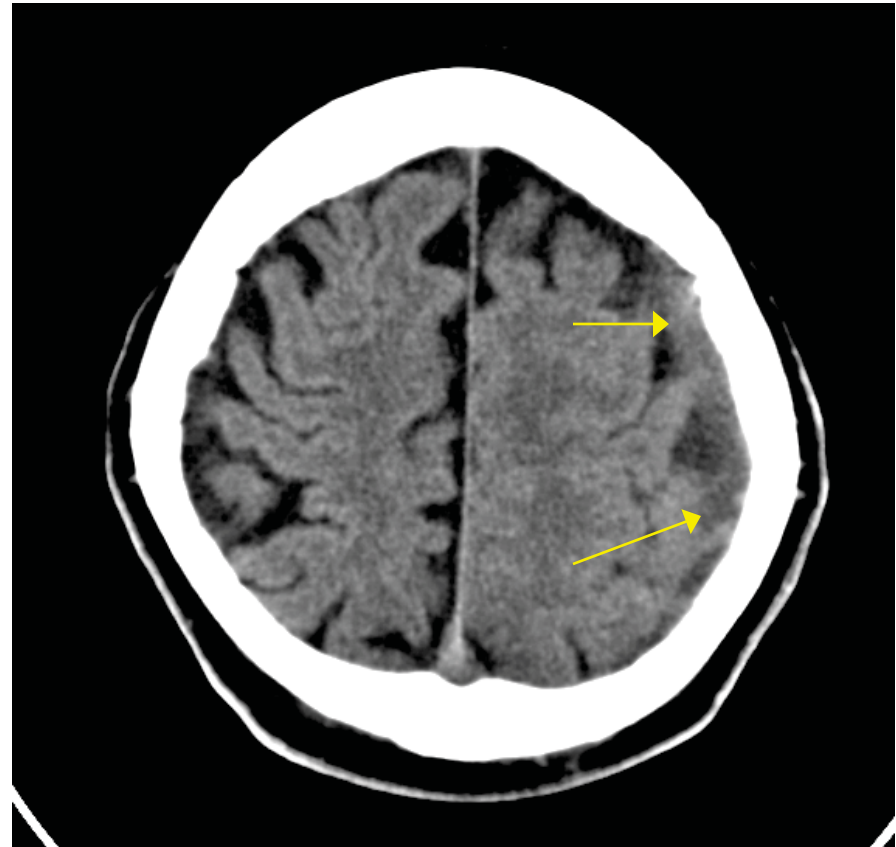
Acute Subdural Hematoma

- Yellow – subdural hematoma around the left frontal lobe convexity
- Blue – subdural hematoma along the tentorium
- Red – subarachnoid hemorrhage in the Sylvian fissure

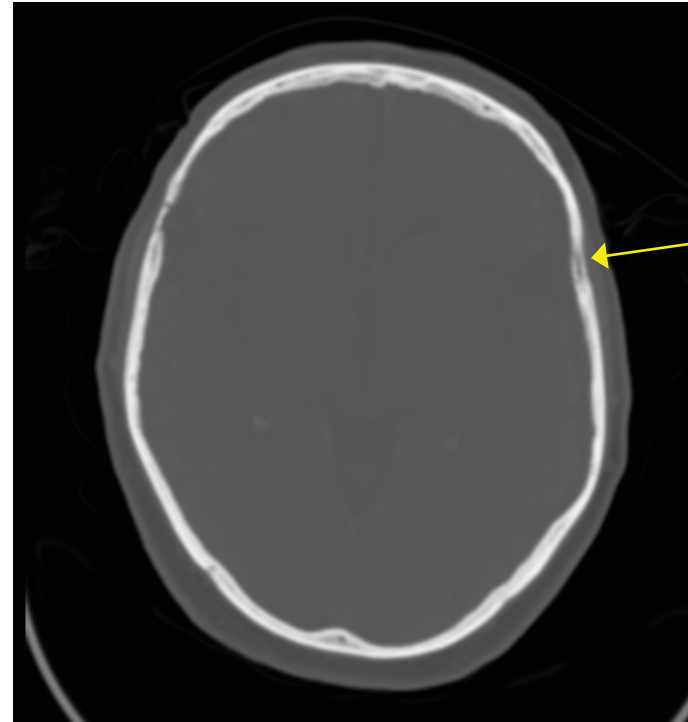
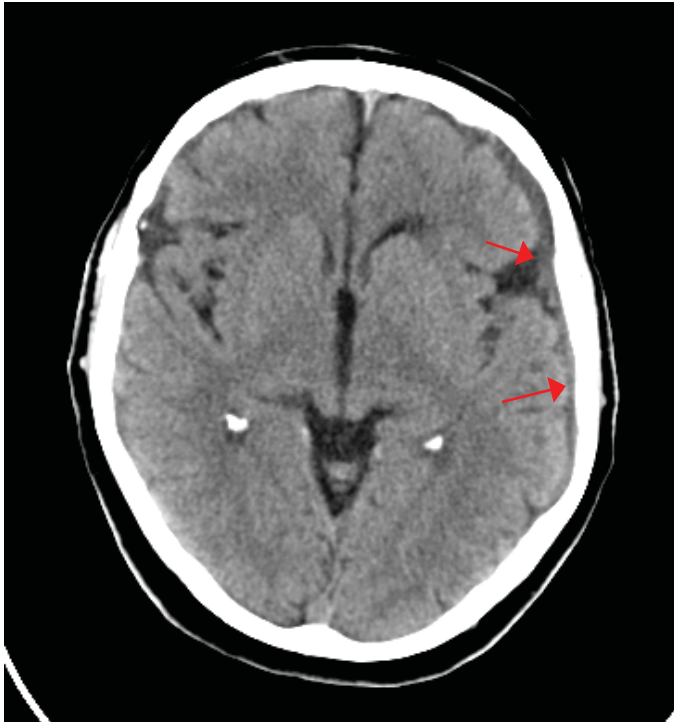


Subacute Subdural Hematoma

- Subacute blood products will be isodense to adjacent brain parenchyma and could be easily overlooked
- Observe how the sulci of the left hemisphere are tighter and more compressed due to mass effect



Subdural Hematoma

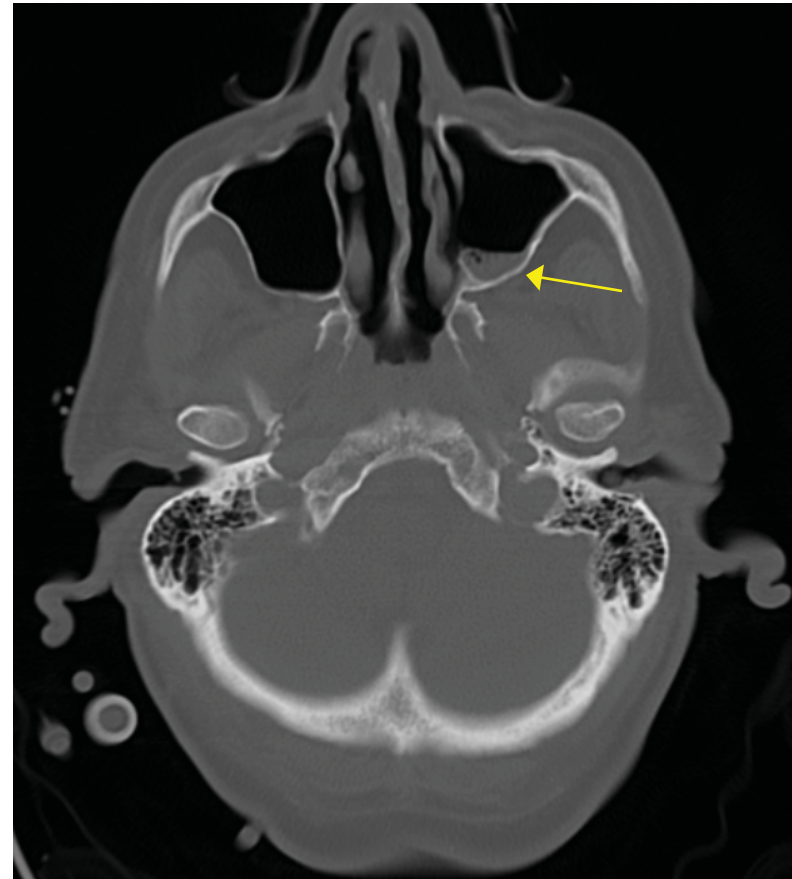


- Note how the subdural hematoma overlies CSF in the subarachnoid space and how it crosses the coronal suture (yellow arrow), where an epidural collection would not.

Outside the Brain with Bone and Soft Tissue Windows

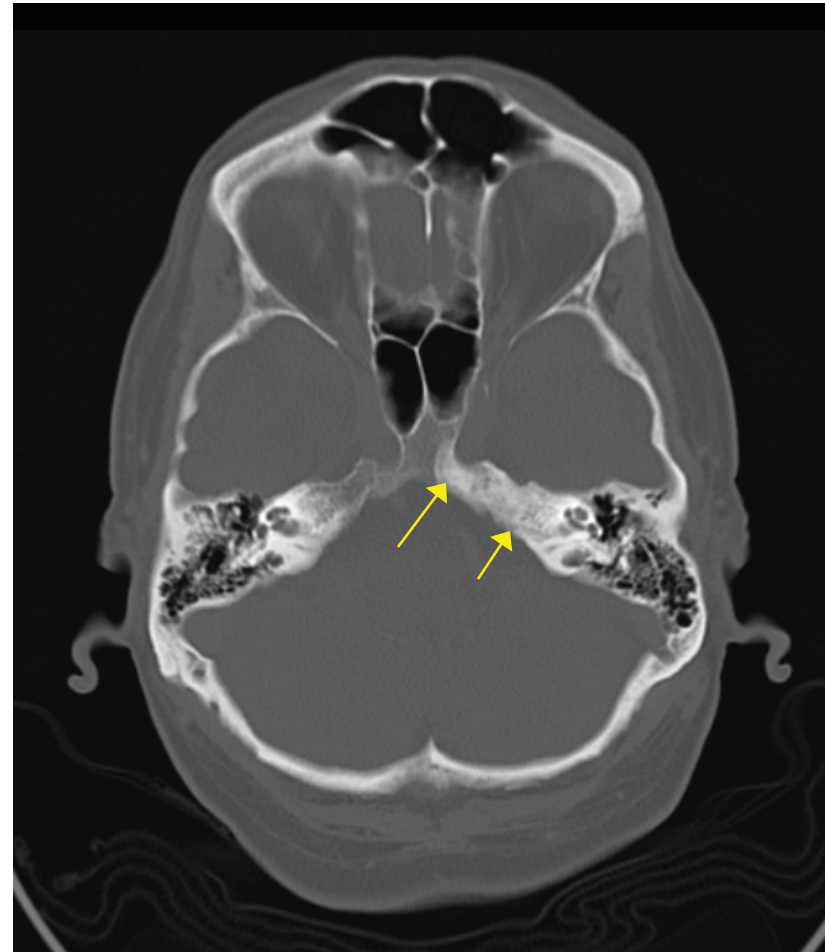
Maxillary Sinusitis

- Air-fluid level in the left maxillary sinus is not specific for acute sinusitis, however correlation with symptoms is always suggested



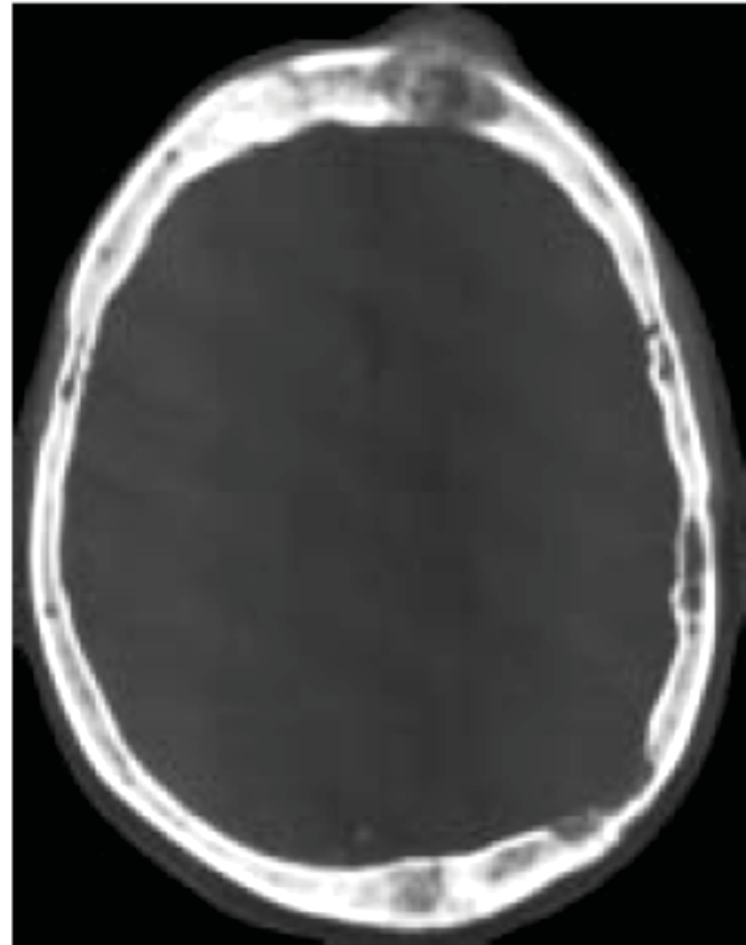
Bone Windows – Osseous Disease

- Prostate cancer with metastatic disease to the left petrous bone and clivus
- Prostate and often breast cancer metastases result in sclerotic lesions that have higher density, due to increased osteoblastic activity in the bone



Lytic Metastases

- Bone windows demonstrate scattered irregular holes or lytic lesions in the calvarium from lung cancer
- Multiple myeloma, renal cell carcinoma, and breast cancer can have an identical appearance



Lymphoma

- Always important to look with soft tissue windows at orbits, scalp, and facial region
- Bilateral enlargement of the lacrimal glands in a patient with lymphoma



Periorbital Traumatic Swelling

- Soft tissue windows useful in evaluating extent of edema, scalp hematoma (red arrow), and inflammatory soft tissue swelling
- Also aids in evaluating musculature and the globes



Summary

- Understand the anatomy
- Utilize different CT windows to assess for pathology in the soft tissue, brain, sinuses, and bones
- **GOOD LUCK!**

References

- Netter, Frank. Atlas of Human Anatomy. Novartis, 1997.
- Jackson, Simon. Cross-Sectional Imaging Made Easy. Churchill Livingstone, 2004.