Traumatic Brain Injuries

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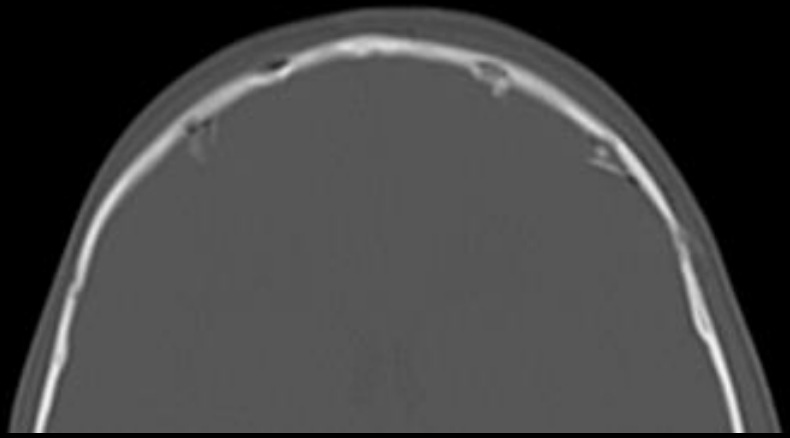
ACR Education Center 2025

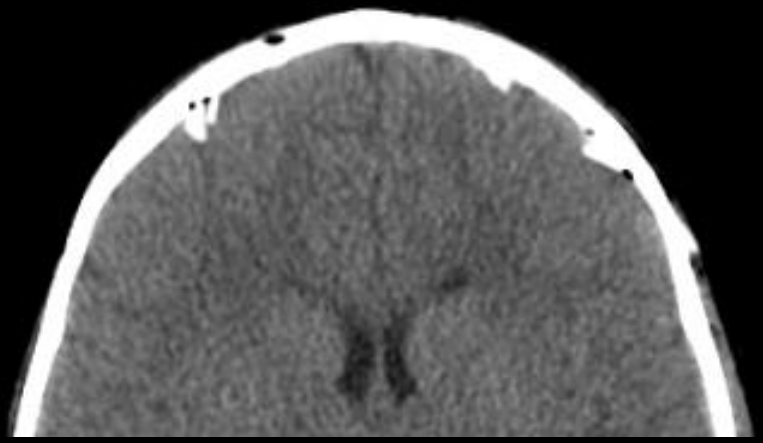
Learning Objectives

- Review the CT and MR appearance of common traumatic brain injuries
- Understand how pathophysiology and anatomy determine the imaging appearance
- Discuss which imaging options offer the greatest sensitivity for diagnosing TBI

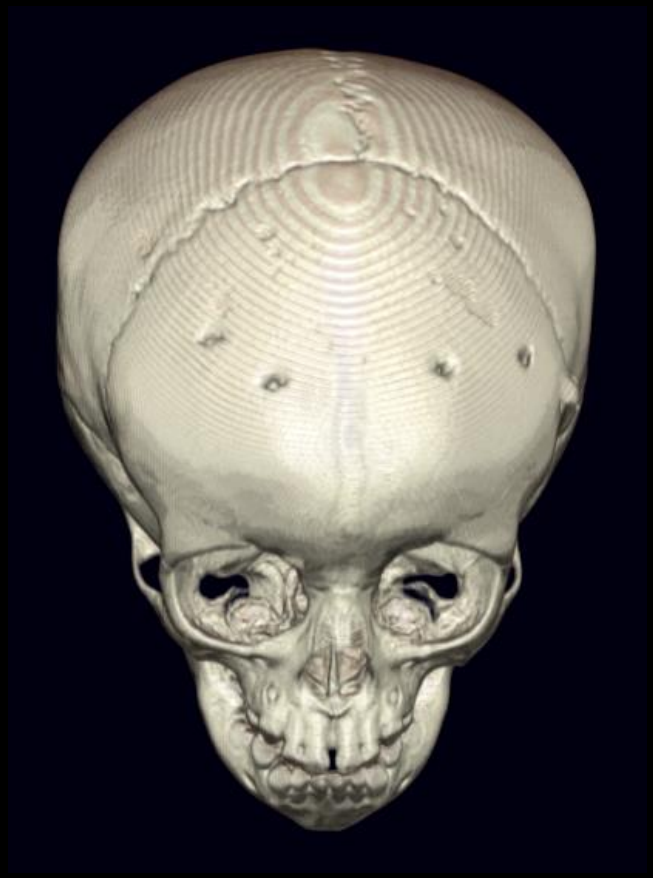
Epidemiology of TBI

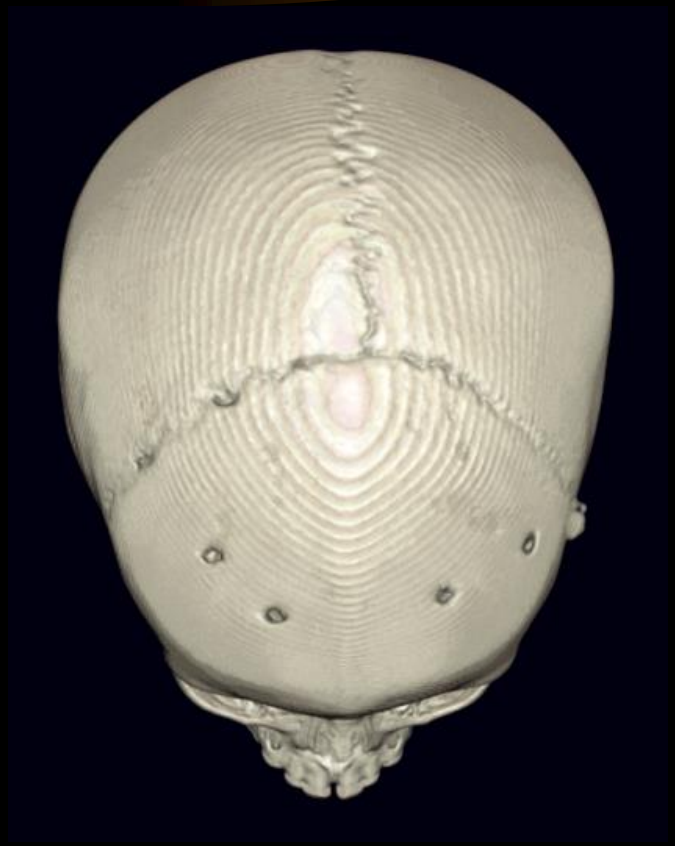
- 52,000 deaths
- 200,000 hospitalization / lasting disability
- 1,740,000 physician visit / temporary disability





Etiology of TBI





Etiology of TBI

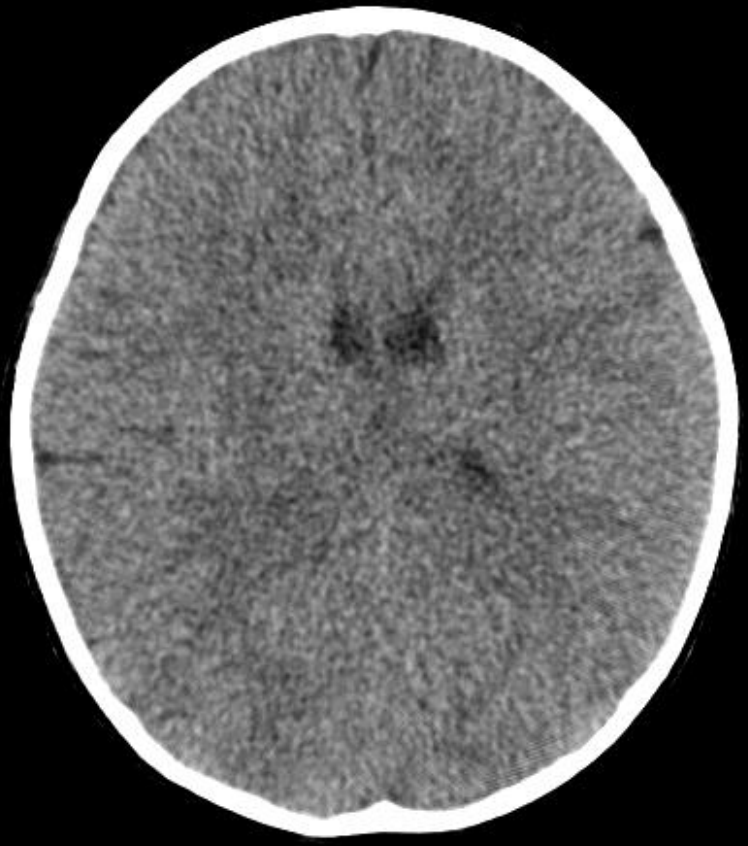
- MVA
  - Young adults
  - Often alcohol related
- Falls
  - Very young
  - Elderly

Mace W. Psychology Today (2016)

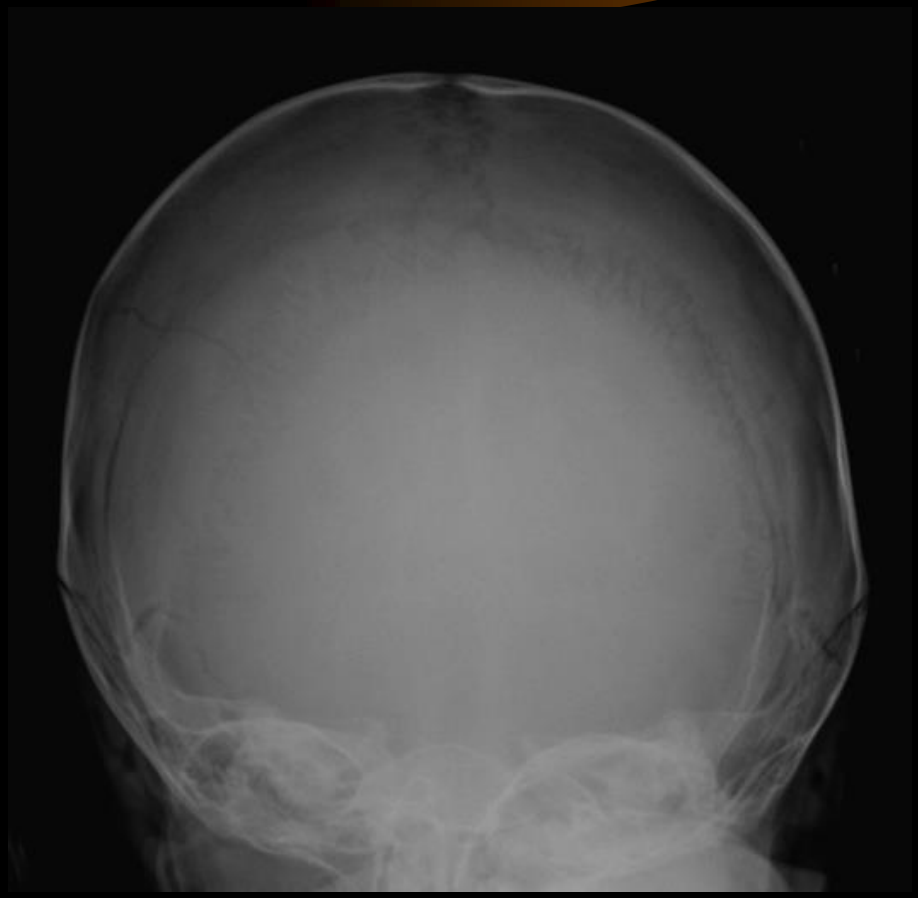
3D CT Depressed Skull Fracture

- Improved delineation of:
  - Depression
  - Comminution
  - Associated facial fractures

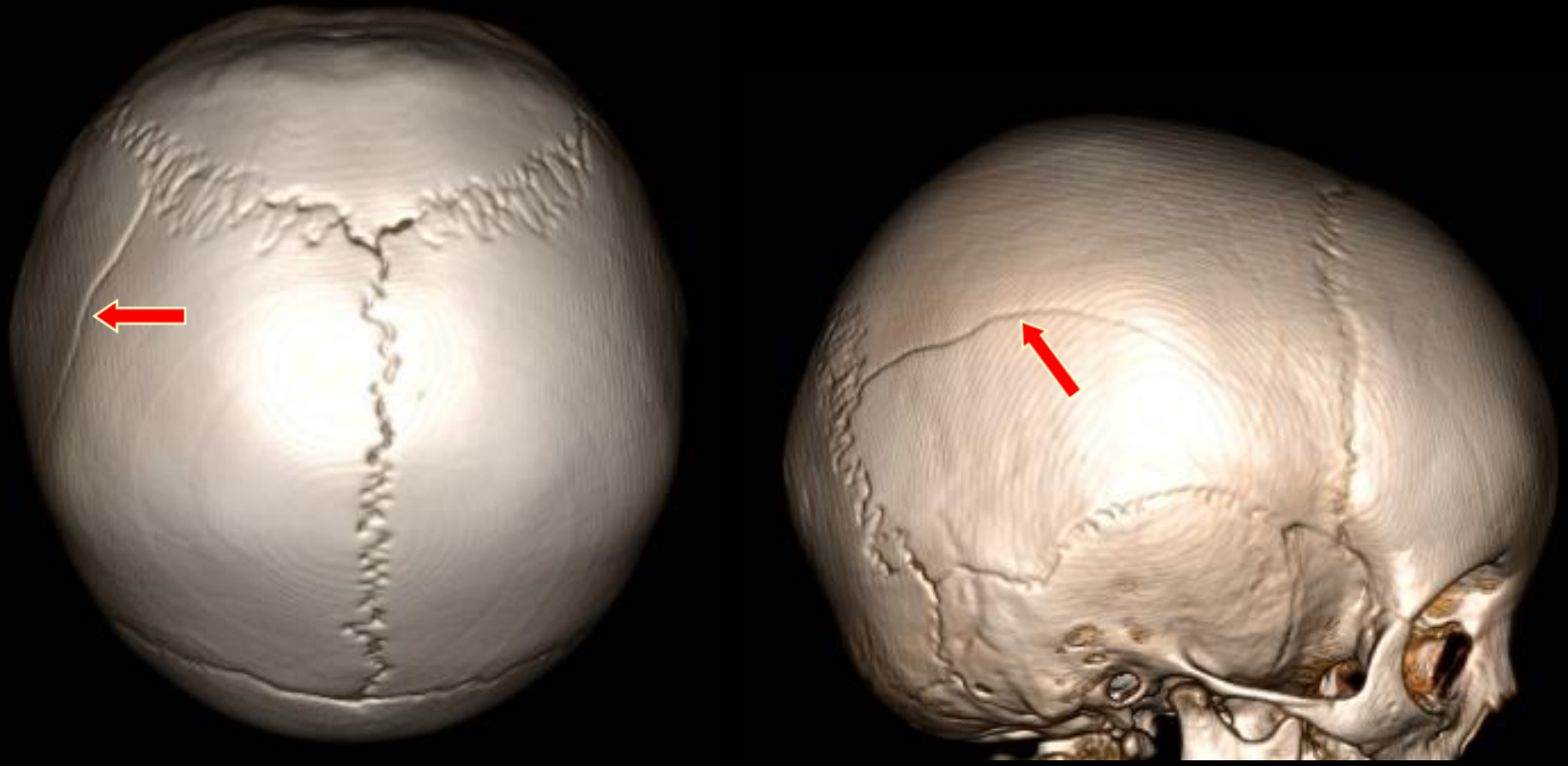
CT: ? TBI in a Child



Skeletal Survey



3D CT Linear Skull Fracture



Decreased Incidence of TBI

- Airbags
- Seat belts
- Decreased alcohol consumption
- Helmets for recreational activities

Decreased Mortality for TBI

- 1950's: intracranial pressure (ICP) monitoring
  - Increased ICP > poor outcome
- 1960's & 1970's: emergent CT
  - Defines primary injury and guides intervention
- 1980's to present: MRI, DWI and DTI
  - Identifies subtle, non-hemorrhagic injury

Indications for Emergent CT

- Canadian Rule (CCHR) & New Orleans Criteria
  - Sensitivity = 97-100%
- “No set of clinical predictors have yet been put together that is capable of identifying all patients who are safe to be discharged without a CT scan”

Borczuk P. Emerg Med Clin North Am. 15:563-579 (1997)

New Criteria for Emergent CT

- Blood test for TBI (i-STAT TBI plasma test)
  - Results available within 15 minutes
  - "A negative result can be used to rule out the need for a head CT scan"
- VR and AI test for TBI
  - Virtual Reality Military Operational Neuropsychological Assessment, or VRMONA
  - VR headset & handheld controllers paired with AI technique (deep neural network learning)

Primary Brain Injury

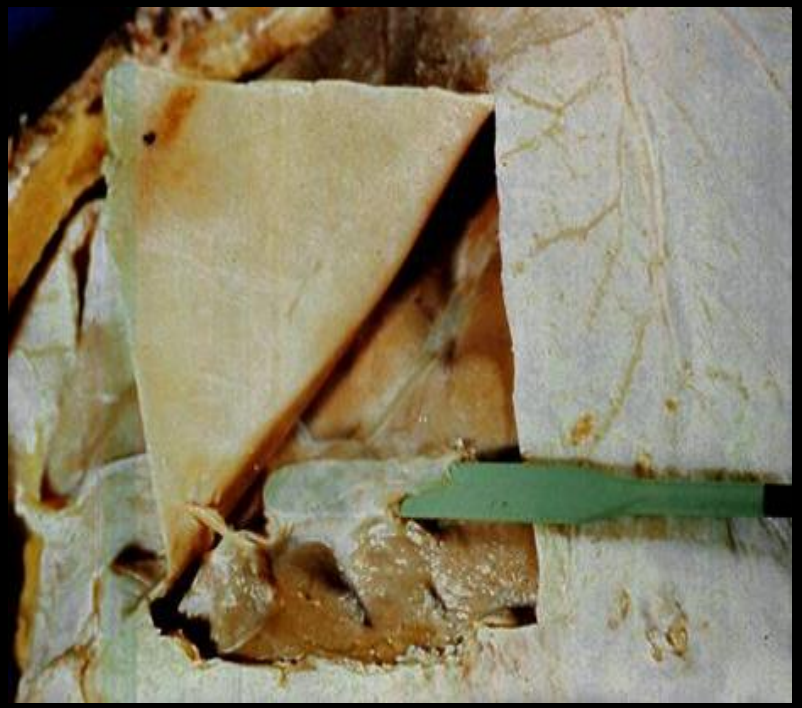
- Applied force strains brain beyond structural tolerance resulting in injury
  - Force = direct contact
    - Compressive strain > contusion
  - Force = translational acceleration
    - Tensile strain > contra-coup hematoma
  - Force = rotational acceleration
    - Shear strain > diffuse axonal injury

Secondary Brain Injury

- Pathophysiologic cascade following initial injury
  - Cellular damage and edema
  - Repair and phagocytosis
  - Vascular proliferation
  - Gliosis

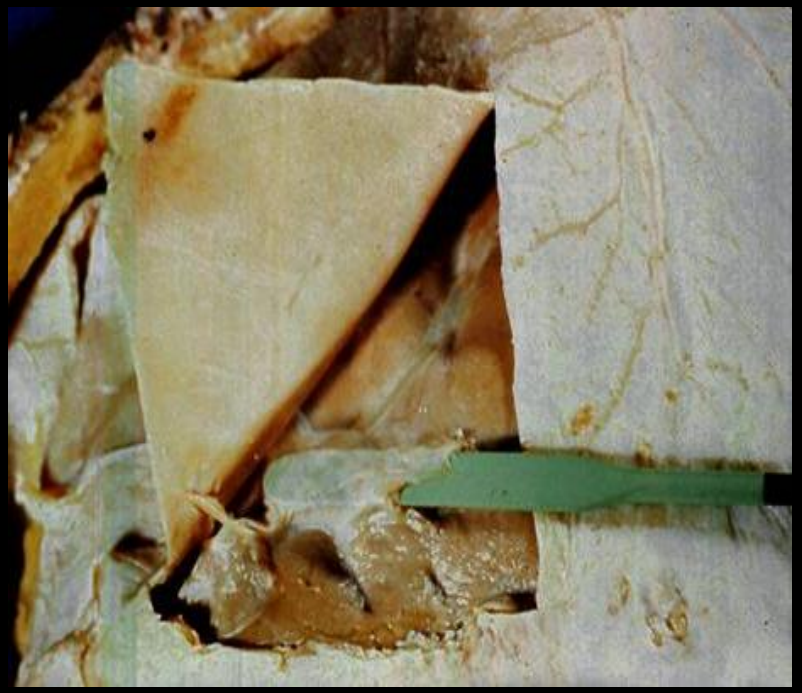
Anatomy of Fluid Spaces

- Subarachnoid between pia and arachnoid
  - Contains Circle of Willis



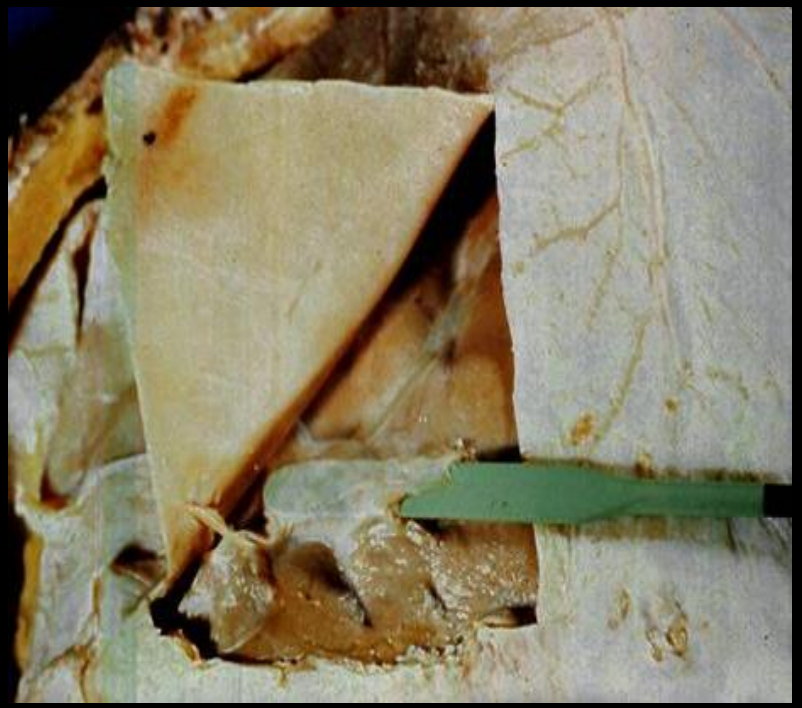
Anatomy of Fluid Spaces

- Subdural between arachnoid and dura
  - Contains cortical veins



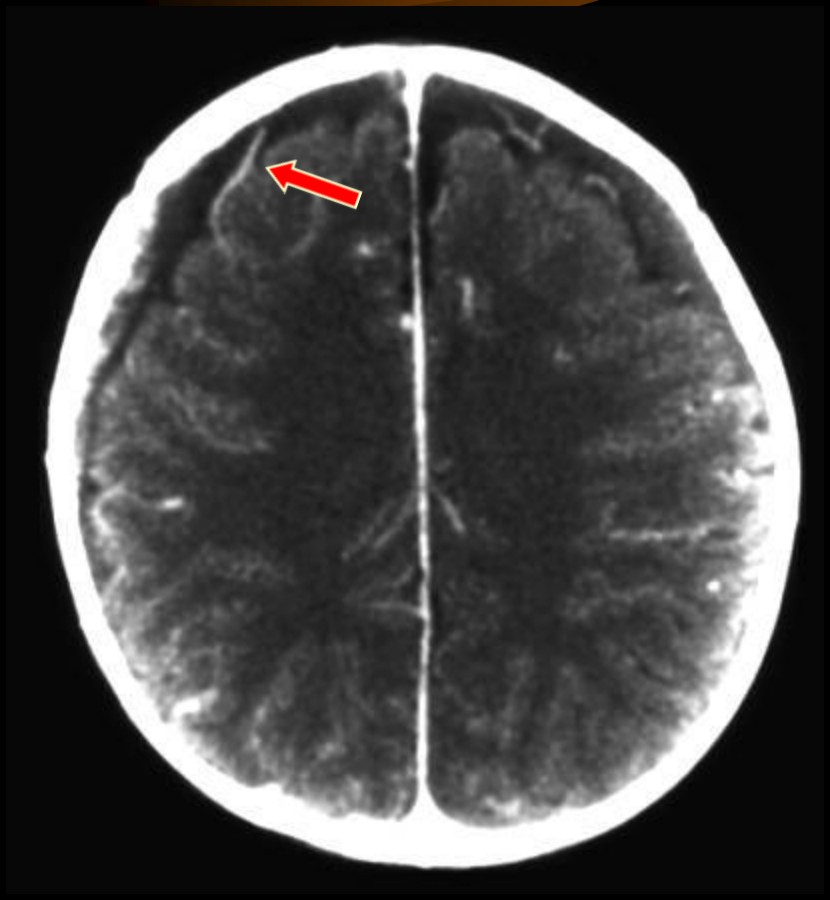
Anatomy of Fluid Spaces

- Epidural between dura and skull
  - Contains middle meningeal artery

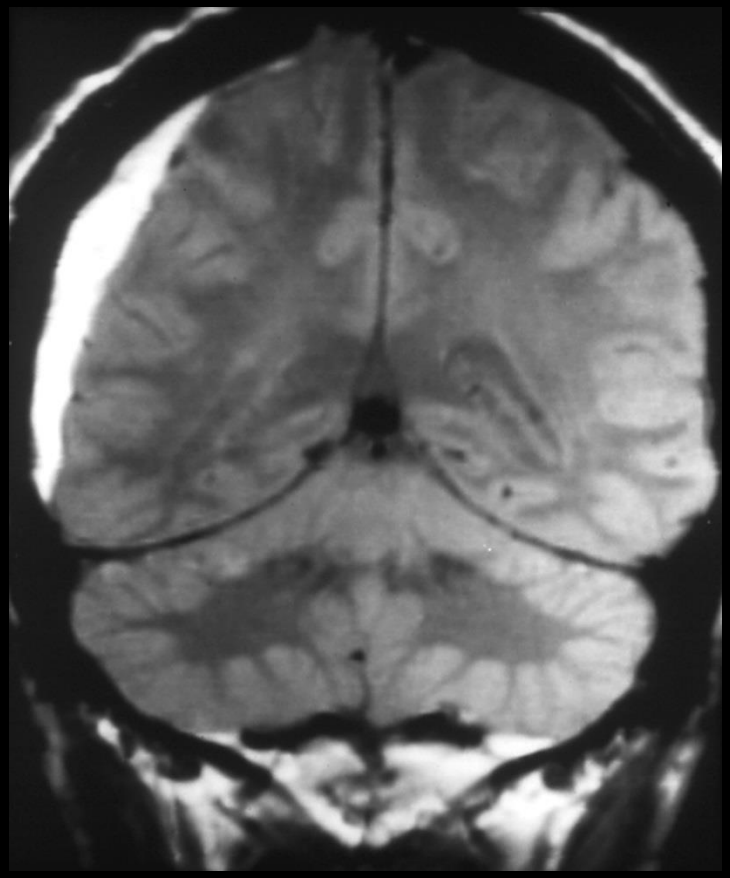


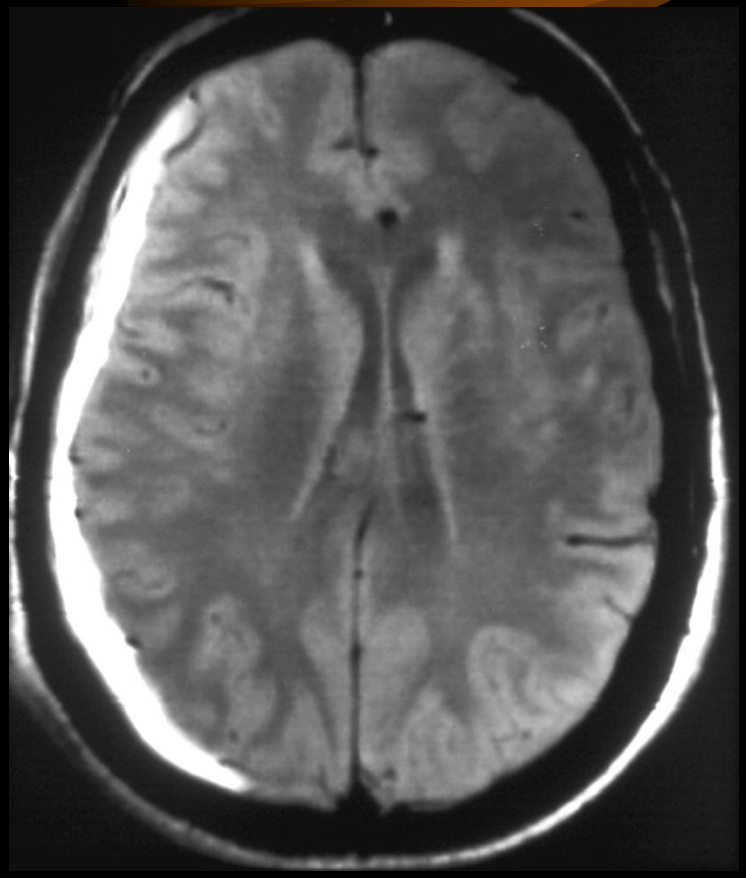
Subdural Hematoma (SDH)

- Serosanguineous fluid collection (CECT)
  - Ruptured cortical veins
- Common over convexity
  - Along dural reflections
- Considerable extent
  - Loose connection of arachnoid and dura
- Crescentic configuration



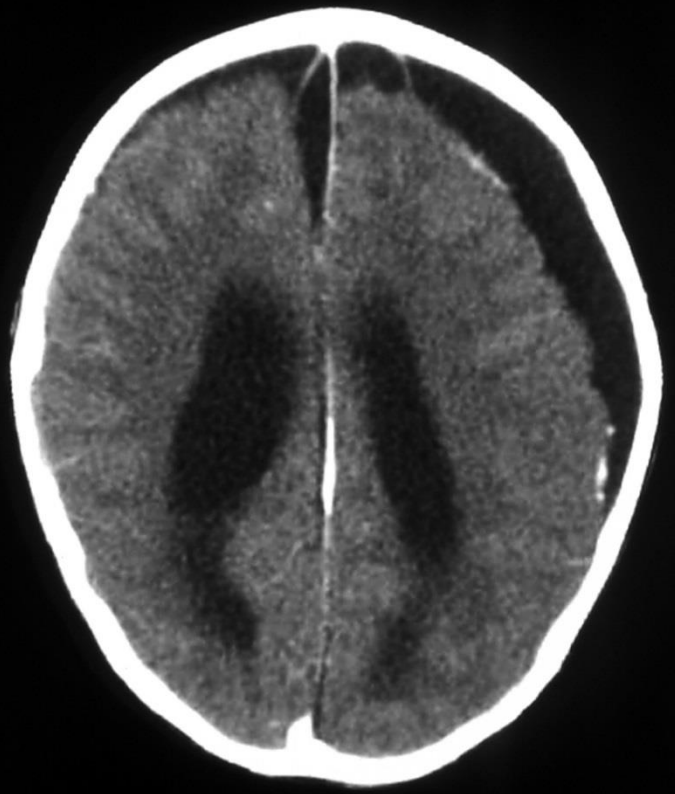
Subdural Hematoma (SDH)





Subdural Hematoma (SDH)

- Evolving CT appearance
  - Acute (1st week)
    - 98% hyperdense
  - Subacute (2-3 weeks)
    - Iso to hypodense
  - Chronic (> 3 weeks)
    - Hypodense
    - Hyperdense if repeated microhemorrhage



SDH Evolution

- Acute CT appearance
  - Most common uniform high density
  - 40% mixed density
    - active bleeding
    - early clot retraction
    - CSF mixing from arachnoid tear

SDH Evolution

- CT after a few hours
  - Usual follow-up is about 6 hours in a stable patient
  - In the interval the SDH has increased slightly in size and become more uniformly dense

SDH Evolution

- CT after a week
  - Now nearly isodese compared with brain
  - Density is slightly heterogeneous
    - early clot retraction
    - CSF mixing from arachnoid tear

SDH Evolution

- CT after a month
  - SDH hypodense compared with brain
  - SDH hyperdense compared with CSF

SDH Evolution

- CT after two months
  - SDH continues to decrease in density
  - SDH is starting to decrease in volume with decreased mass effect

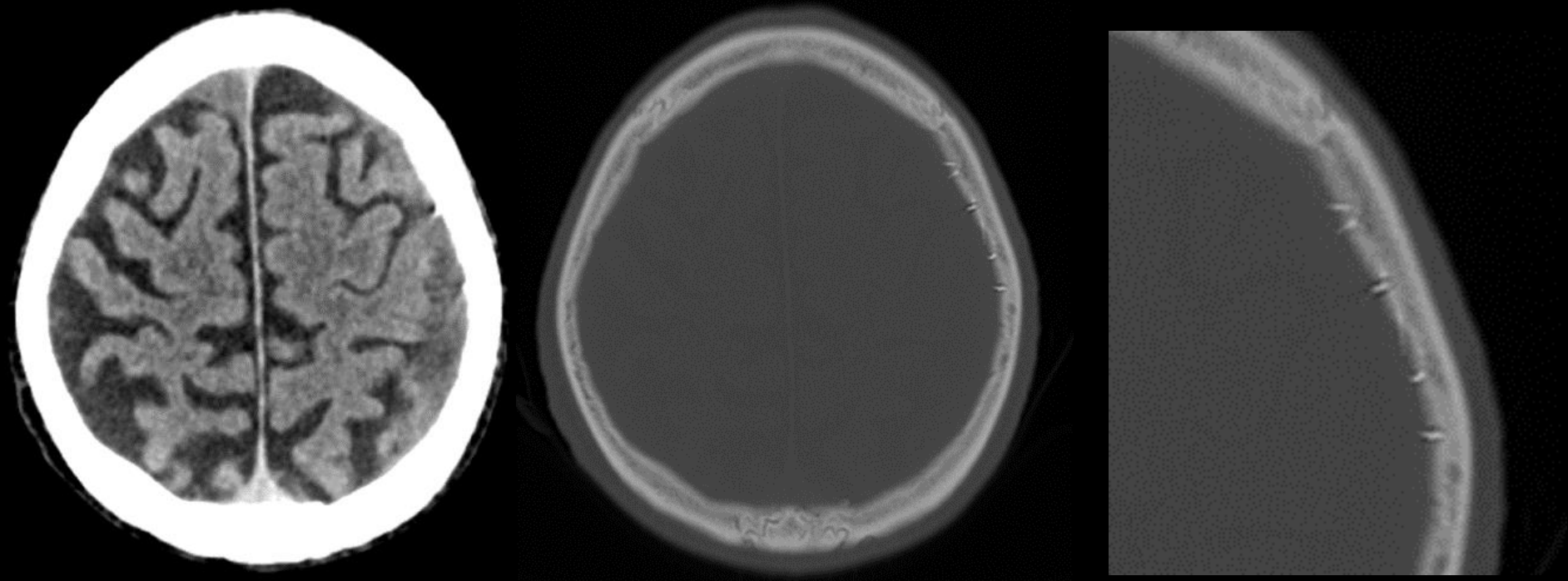
Recurrent SDH

- Asymptomatic patients are typically treated conservatively
- Surgery is reserved for patients who are symptomatic and/or with large SDH
- Treatment of chronic or recurrent SDH via middle meningeal artery (MMA) embolization has been reported

Catapano JS et al. Front Neurol. 11:Article 557233 (2020)

S/P Left MMA Embolization

- CT shows dense material in MMA

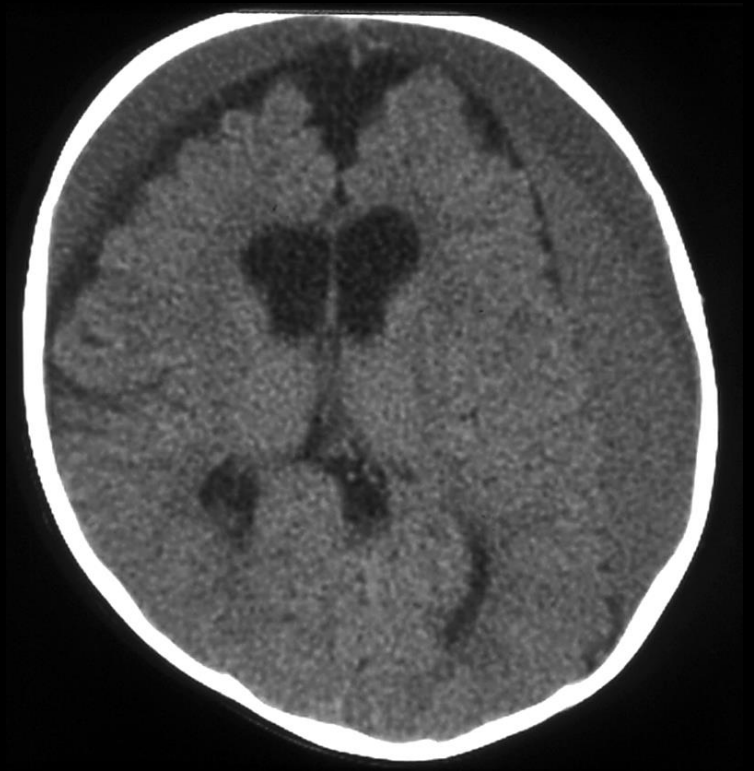


SDH: Non-Accidental Trauma

- Most common intracranial abnormality in the abused child
- May see SDH's of varying ages
  - Differing densities on CT
  - Differing signal intensities on MR
  - Do not meet the medical-legal definitions for nonaccidental trauma

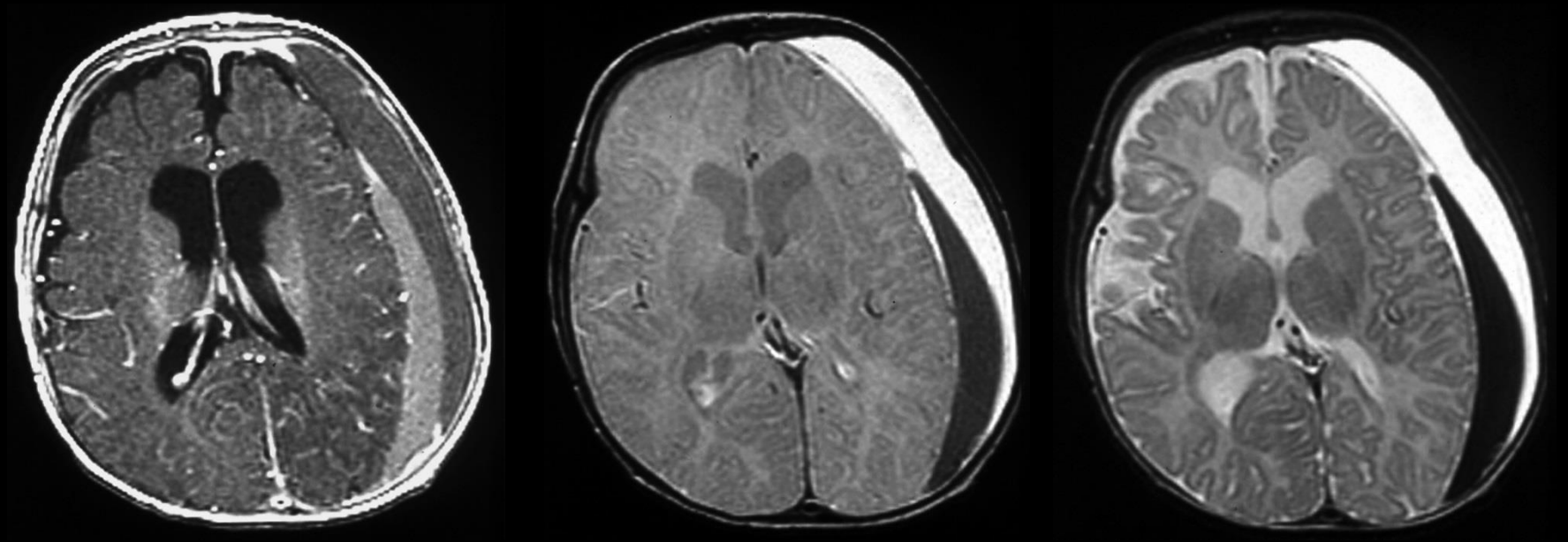
Child Abuse; Bilateral SDH's

- CT
  - Bilateral, extra-axial, cresentic fluid collections
  - Differing densities suggest they are of different ages
  - Probably not medical legally valid

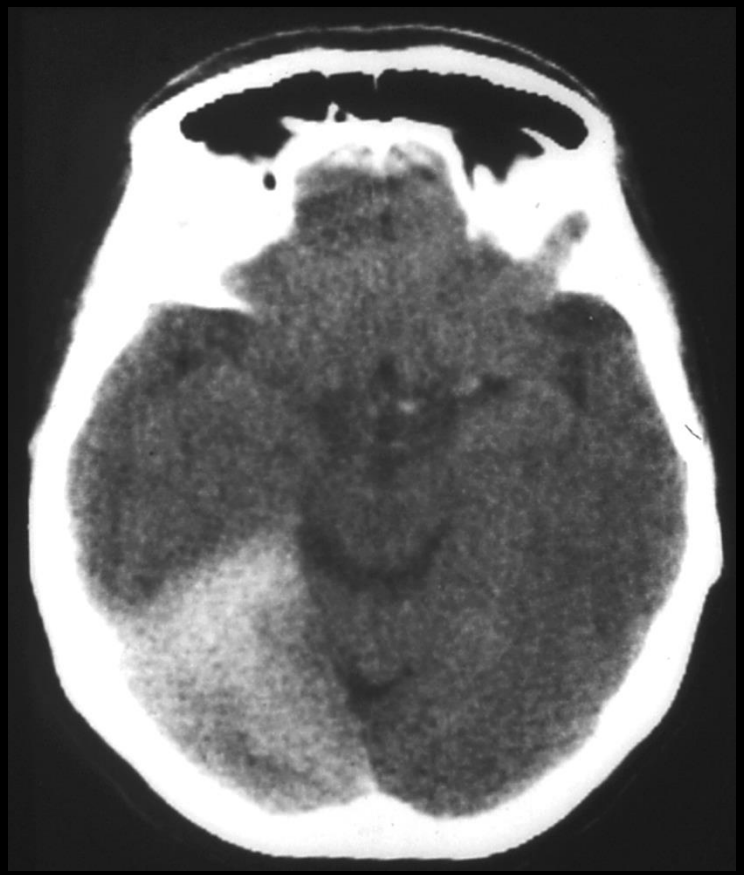


Child Abuse; Bilateral SDH's

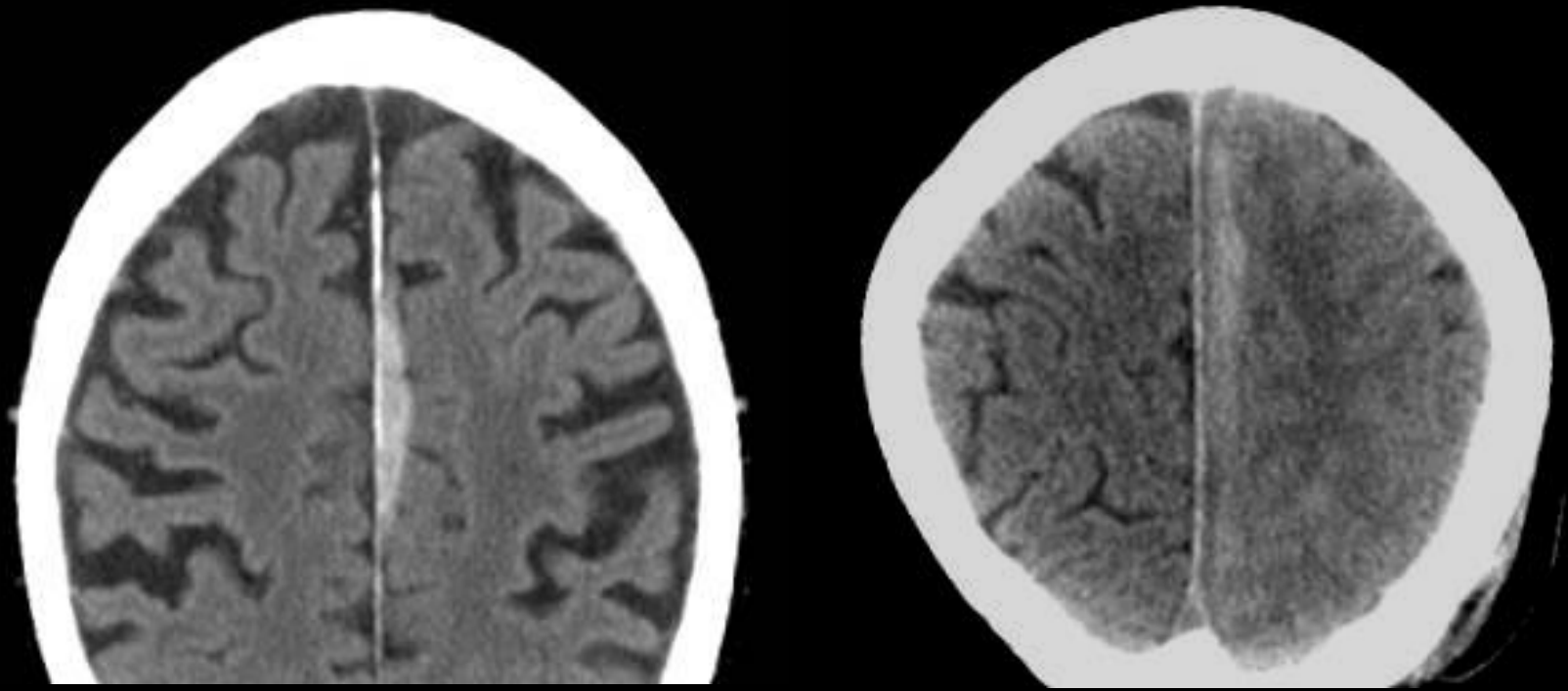
- MR (axial CET1, first and second echo T2)
  - Signal intensities suggest different ages



Tentorial SDH

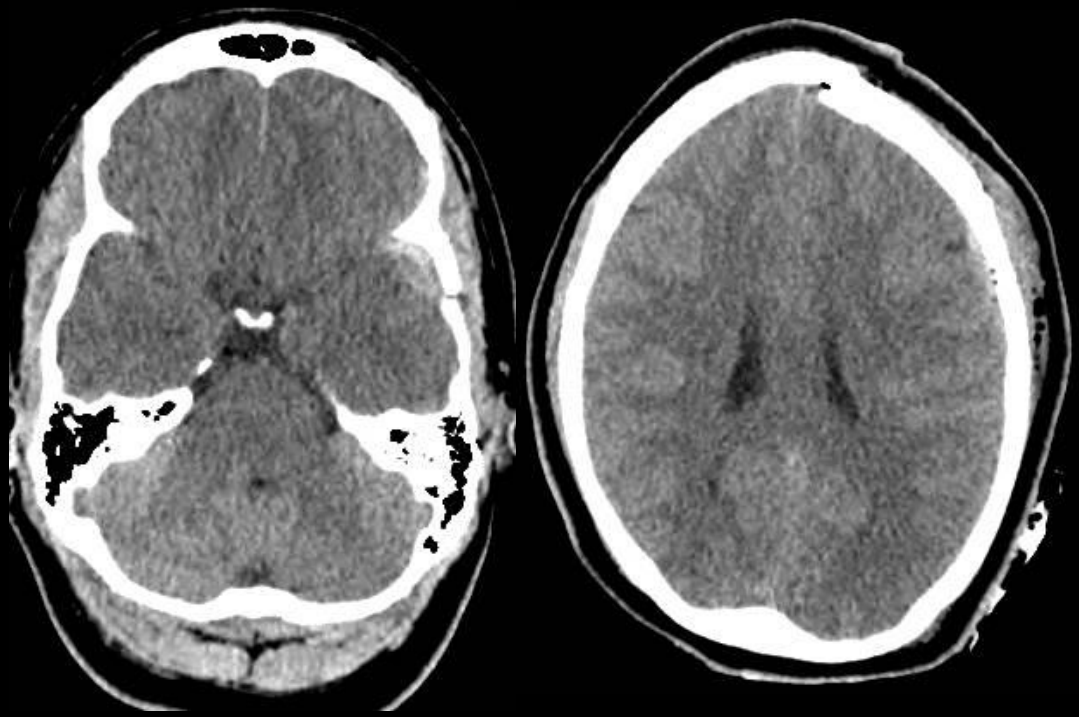


Parafalcine SDH



Case of TBI: CT

- Extra axial blood on left
- Scattered pneumocephalus
- Skull fractures
  - Frontal
  - Skull base?

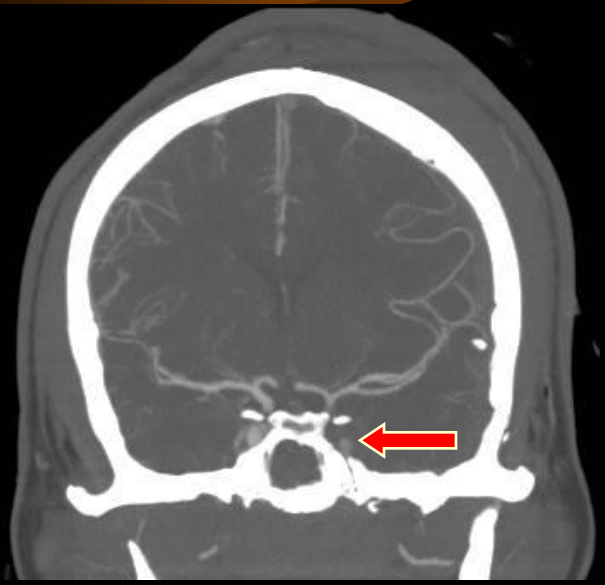


Case of TBI: Bone Detail

- Skull fractures
  - Frontal
  - Skull base
    - Foramen magnum
    - Sphenoid sinus
- Need to evaluate for a vascular injury

Case of TBI: CTA

- L ICA injury
  - Occluded at skull base
  - Probable dissection
  - Reconstitutes at the supraclnoid segment

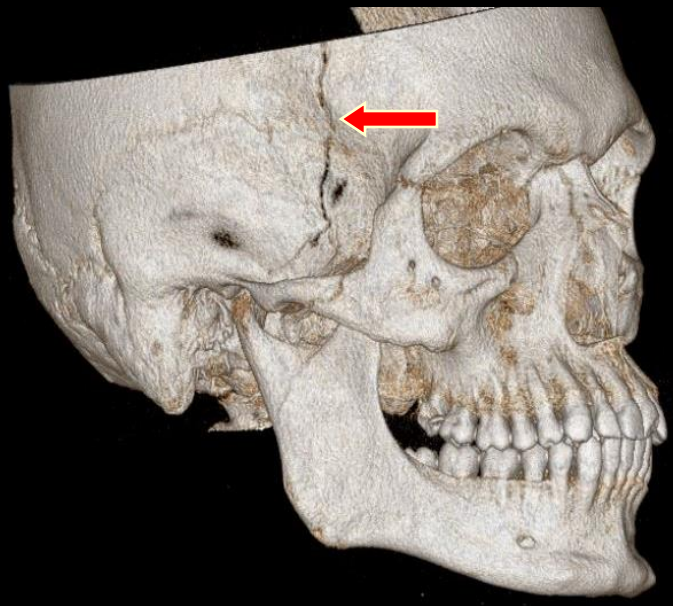


Epidural Hematoma (EDH)

- Dura may separate from the skull due to direct impact especially if there is fracture
- High pressure blood collection from lacerated middle meningeal artery
  - Most common temporal and parietal
- Venous EDH in posterior fossa
  - Nost common from transverse sinus

Epidural Hematoma (EDH)

- Initial CT
  - Over 90% have associated fracture



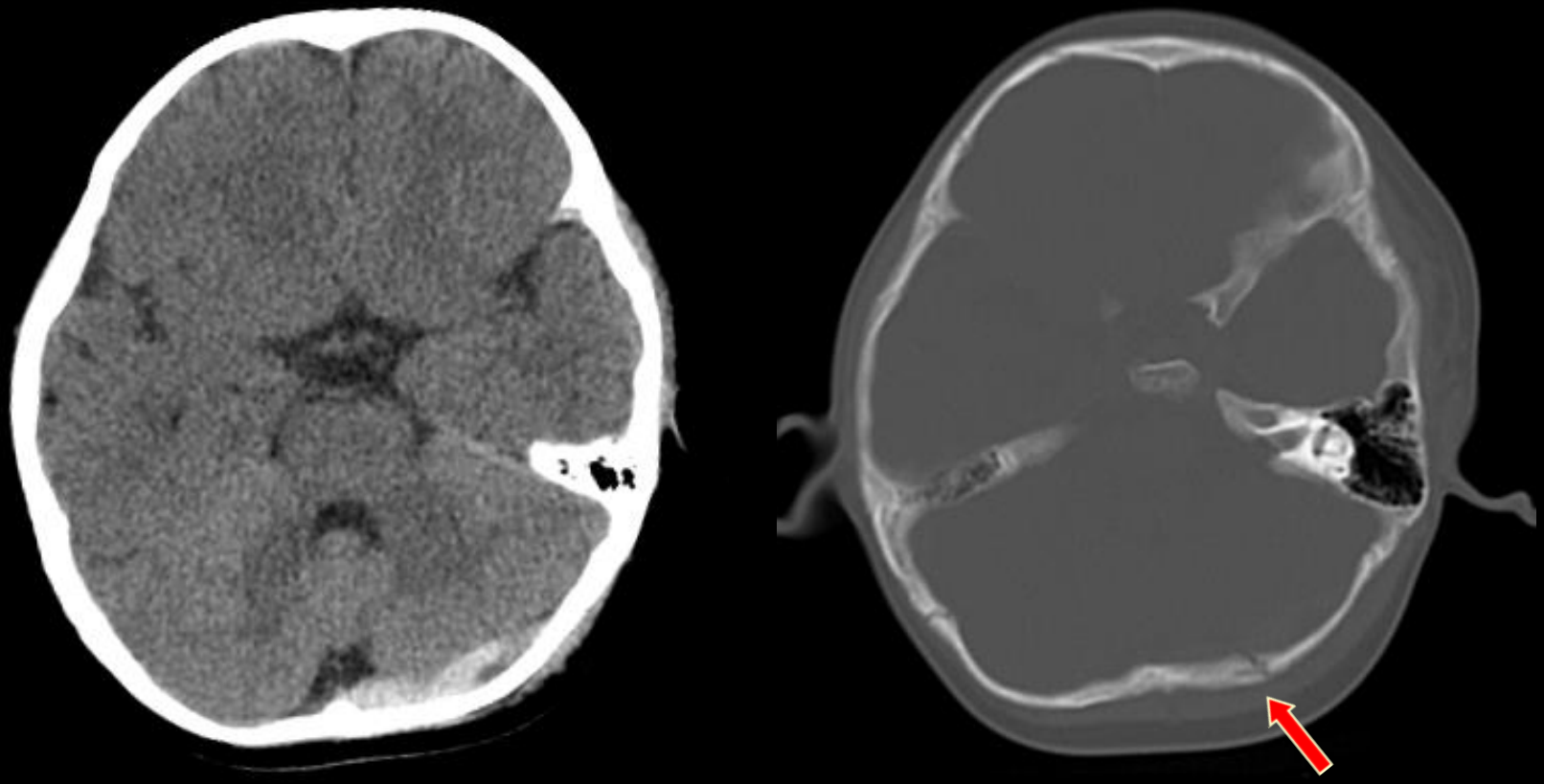
Epidural Hematoma (EDH)

- CT shows rapid enlargement after 4 hours
  - Heterogeneous appearance indicates active bleeding
  - Biconvex due to the firm attachment of the dura to the skull

Bilobed EDH

- CT appearance
  - Bilobed, extra-axial, high density fluid collection
  - Heterogeneous appearance with swirling indicates active bleeding
  - Minimally displaced skull fracture

Venous EDH with Fracture

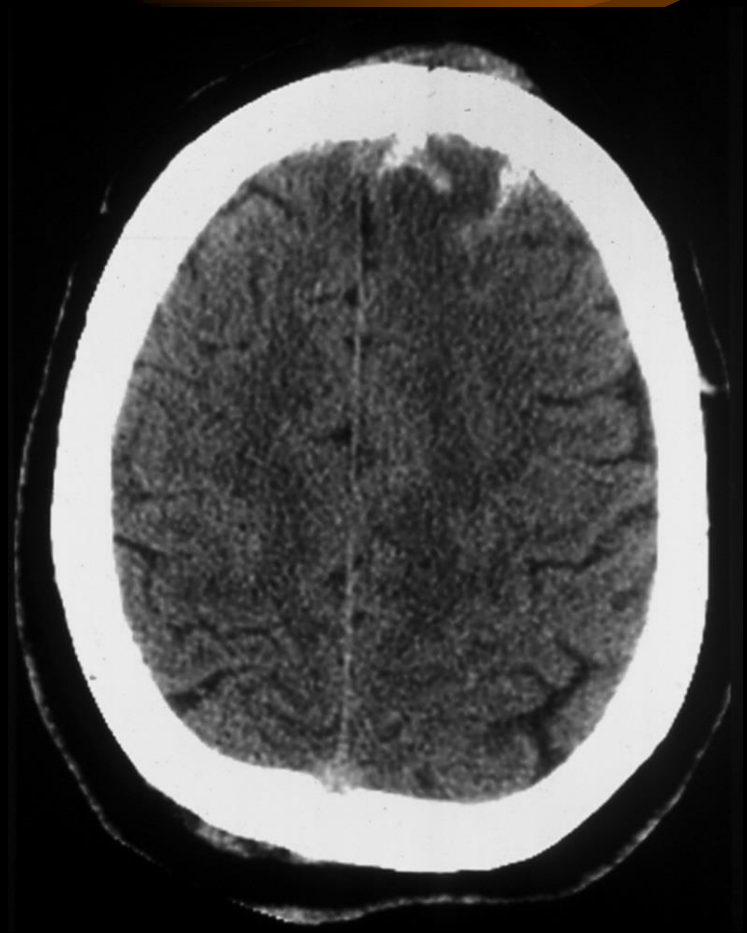


Post Traumatic Subarachnoid Hemorrhage (SAH)

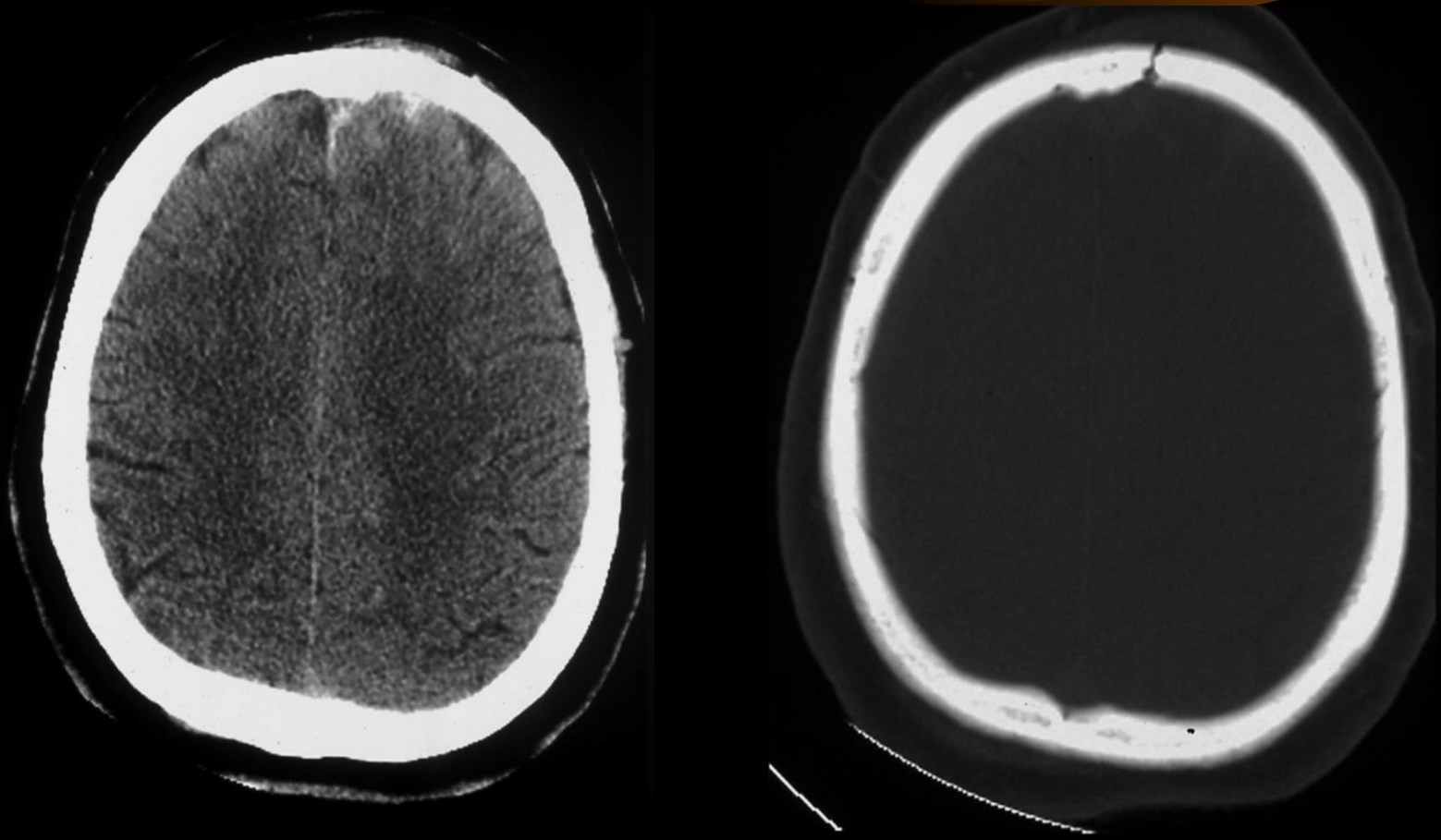
- Bleeding from cortical veins or from extension of intraparenchymal hemorrhage
- Generally, smaller volume and more peripheral than aneurysmal bleed
- On CT, high density conforming to sulci
- Associated contusion is common

Frontal Contusion & SAH

- CT
  - Frontal contusion
  - Small subarachnoid hemorrhage
  - Small subdural hematoma
  - Minimally displaced frontal bone fracture



Frontal Contusion & SAH

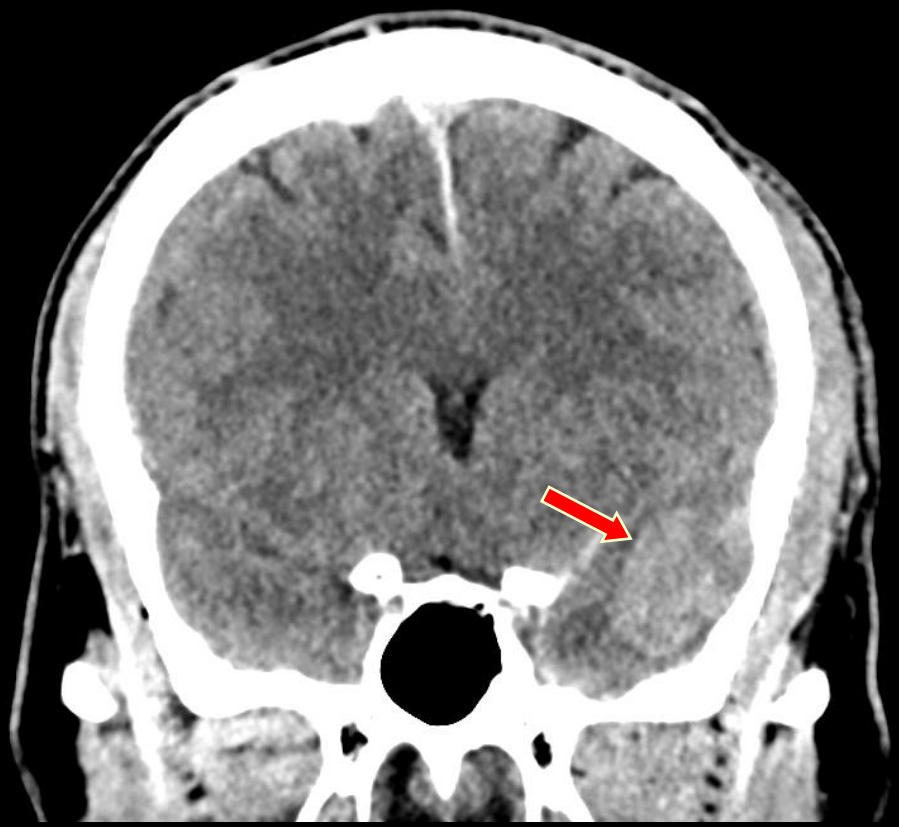


Contusion

- Results when brain impacts the inner table of the skull
- Common in the anterior frontal and temporal lobes after deceleration

Contusion

- Microhemorrhages may coalesce into intraparenchymal hematoma

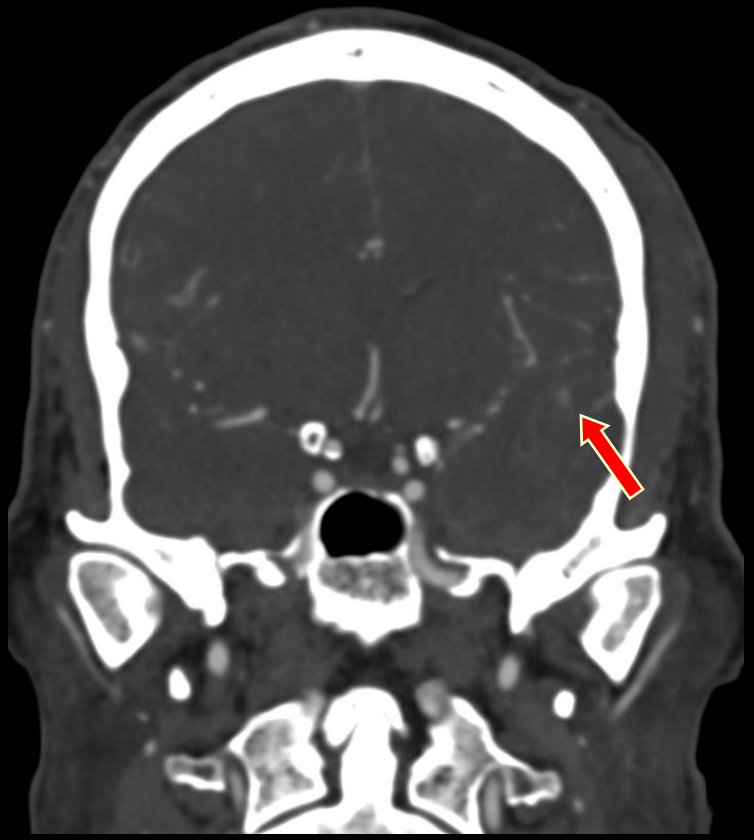


Contusion: CTA

- CTA shows an amorphous collection of contrast within the hematoma and not connected to an artery
- Post traumatic “spot sign”

Contusion: CTA

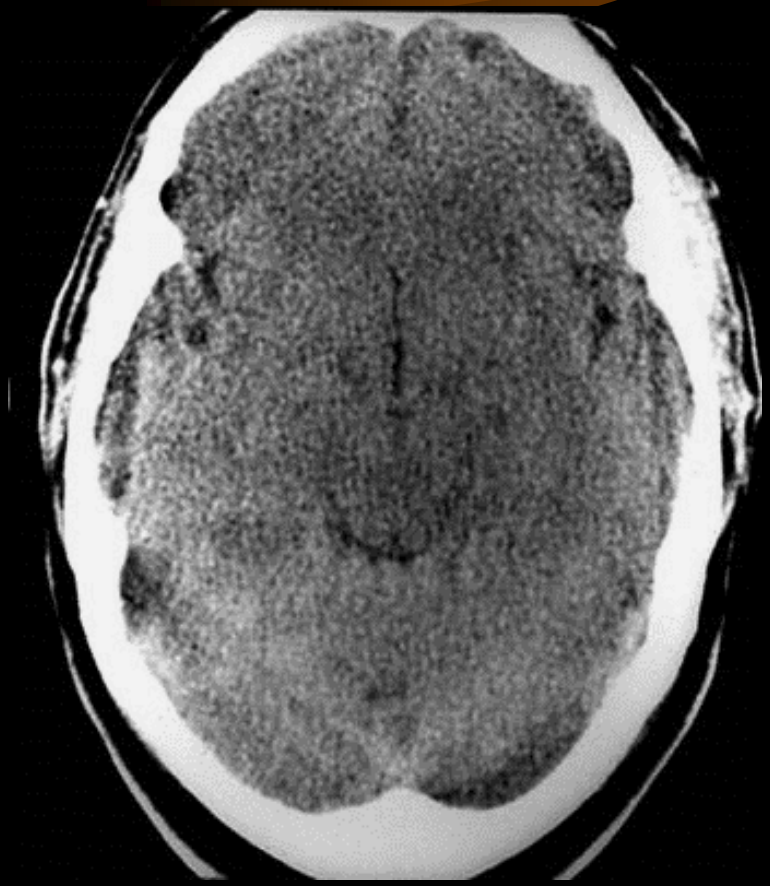
- Post traumatic “spot sign”
- Like the classic spot sign, it is associated with hematoma enlargement



Baldon et al, PLOS ONE 15(7) (2020)

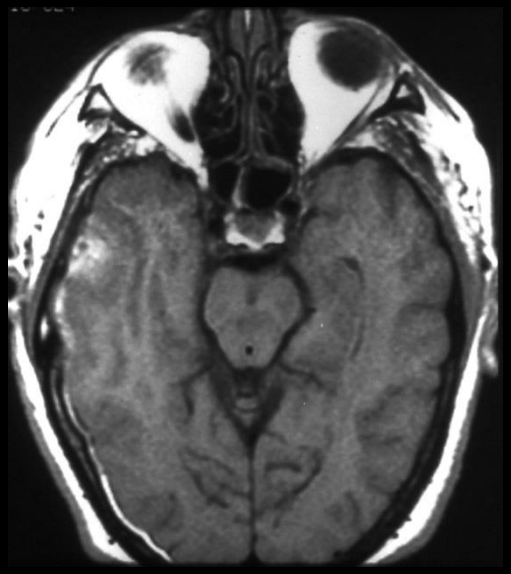
Temporal Contusion?

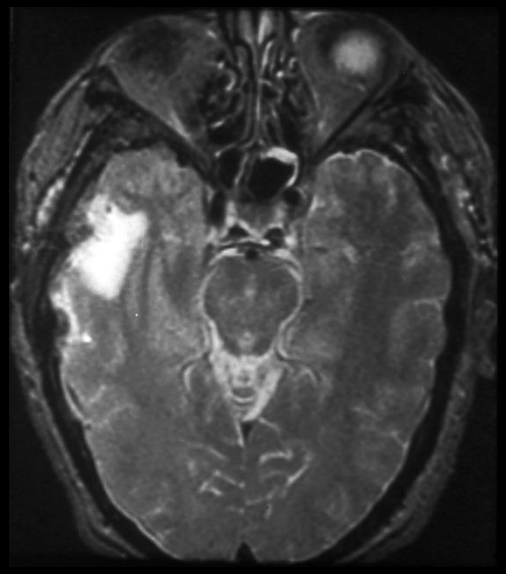
- CT
  - Increased intra-axial density in the anterior right temporal lobe?
  - Possible artifact?



Contusion: MR (T1 & T2)

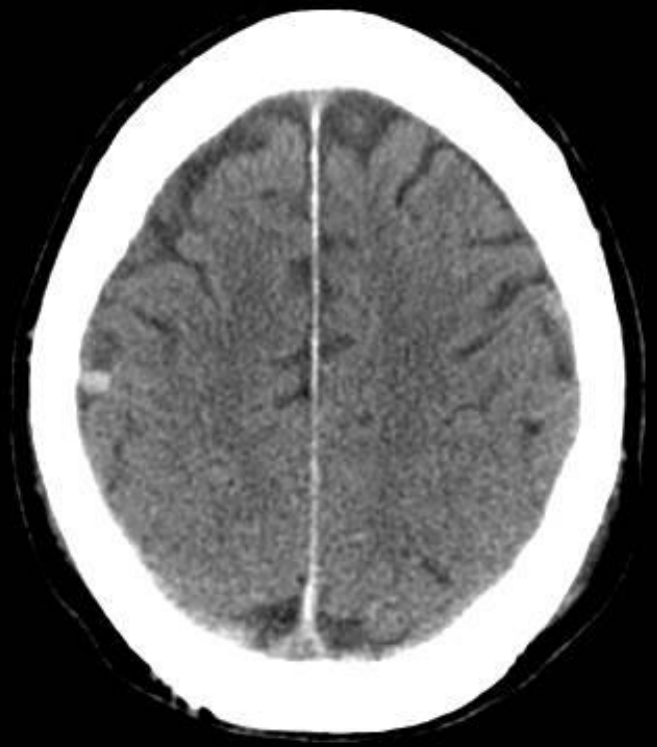
- Increased intra-axial signal intensity in right temporal lobe and a small SDH
- T2 shows the edema to best advantage





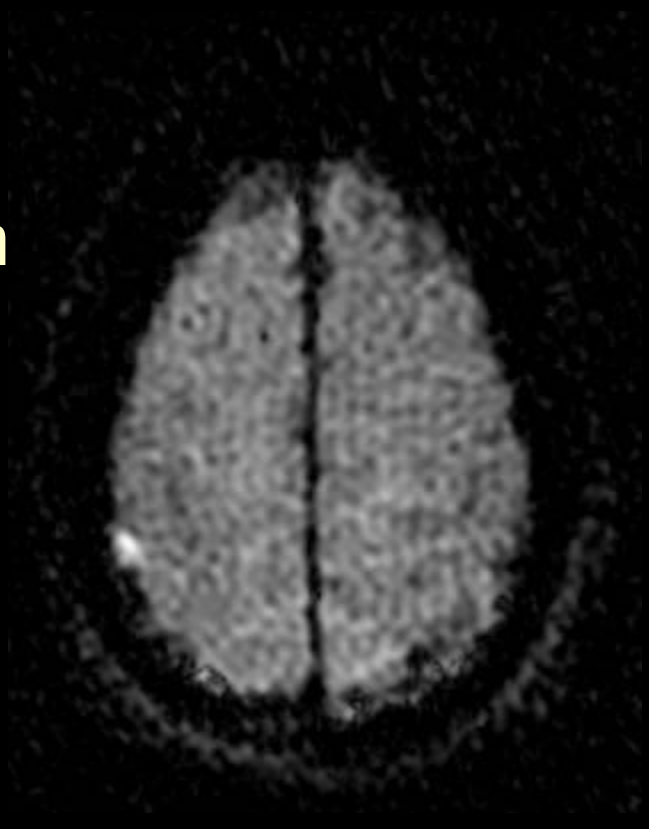
Subtle Contusion vs SAH

- Initial CT
  - Small high density focus in right frontal lobe
  - Where is the blood?
  - Does it conform to the sulcus?
  - Is this a contusion?



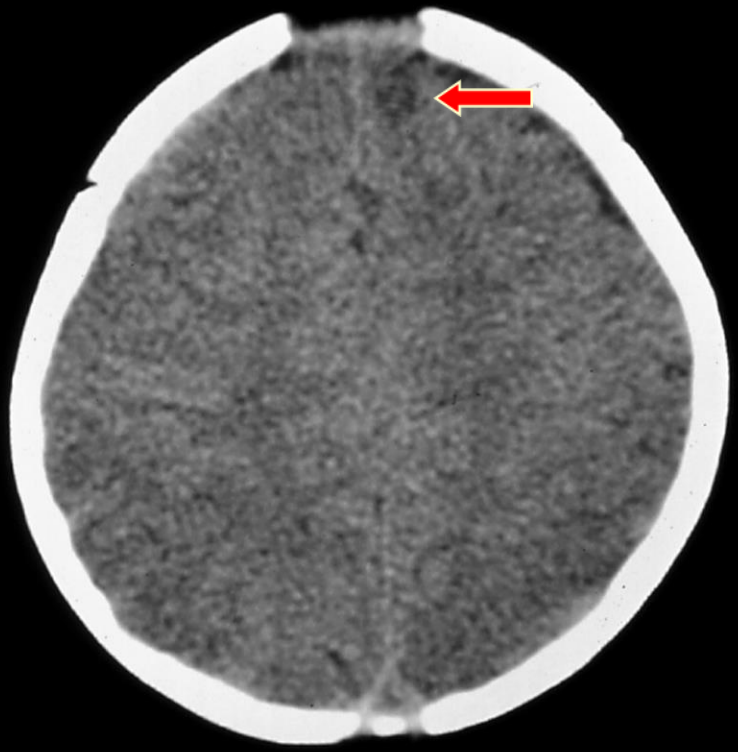
Subtle Contusion vs SAH

- MR DWI
  - Appears bright where diffusion is restricted i.e. cytotoxic edema in an acute infarct
  - SAH should not appear bright
  - Small contusion
    - Local brain swelling
    - Cytotoxic edema



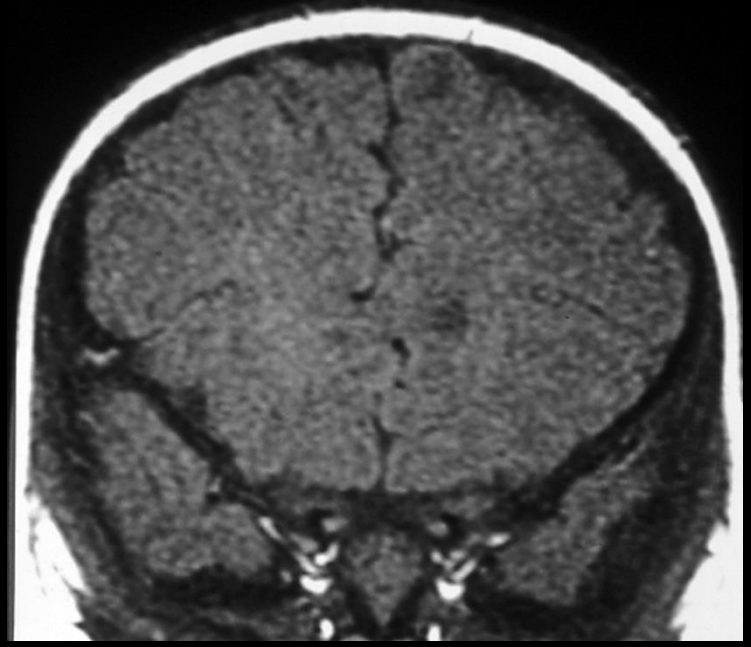
Subtle Contusion

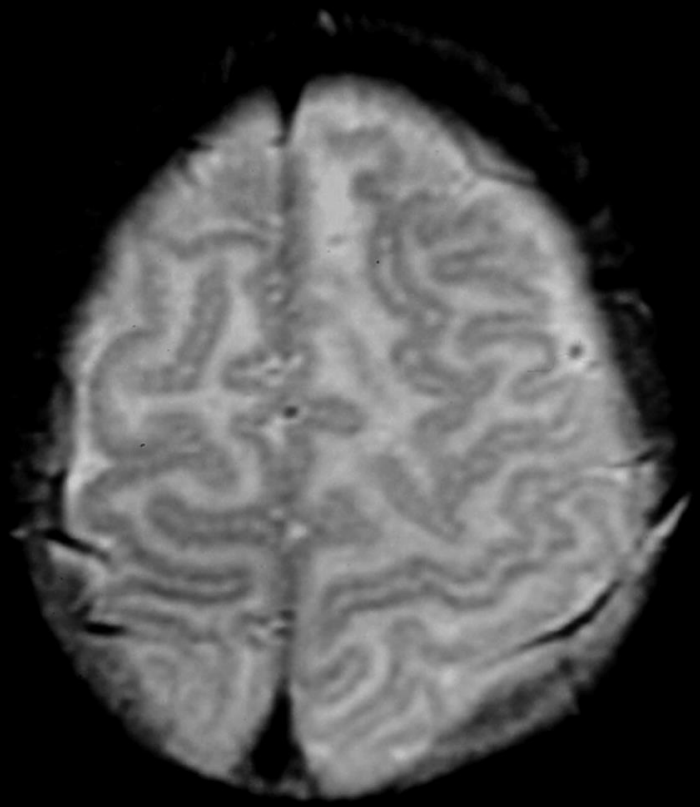
- Initial CT
  - Small low density focus in left frontal lobe
  - Can this be contusion?
  - Where is the blood?



Subtle Contusion

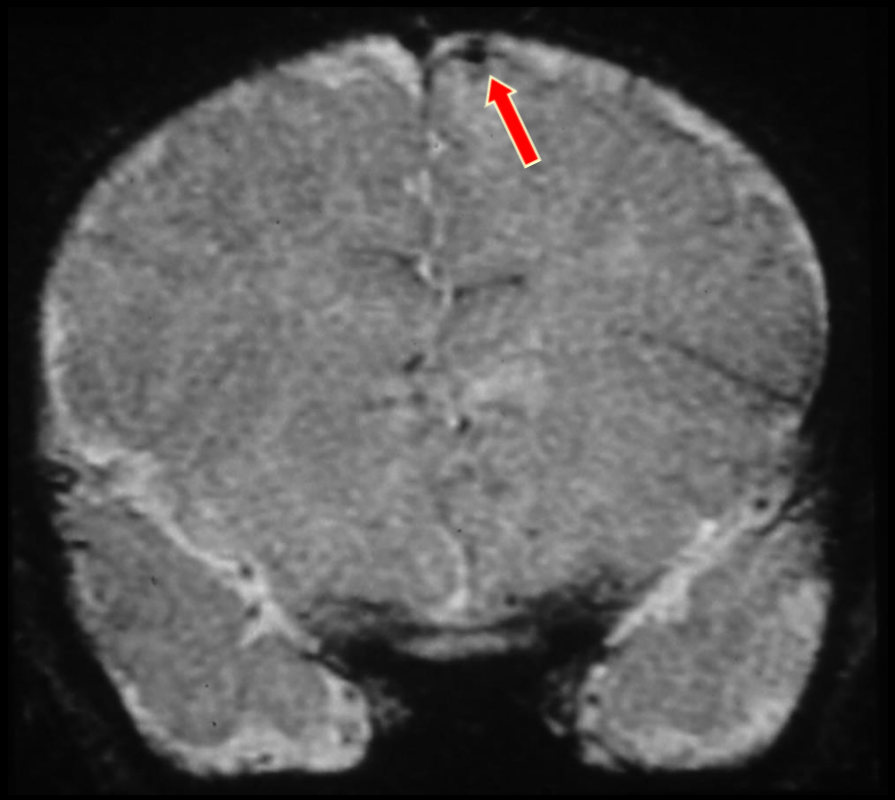
- T1 & T2 MR show edema





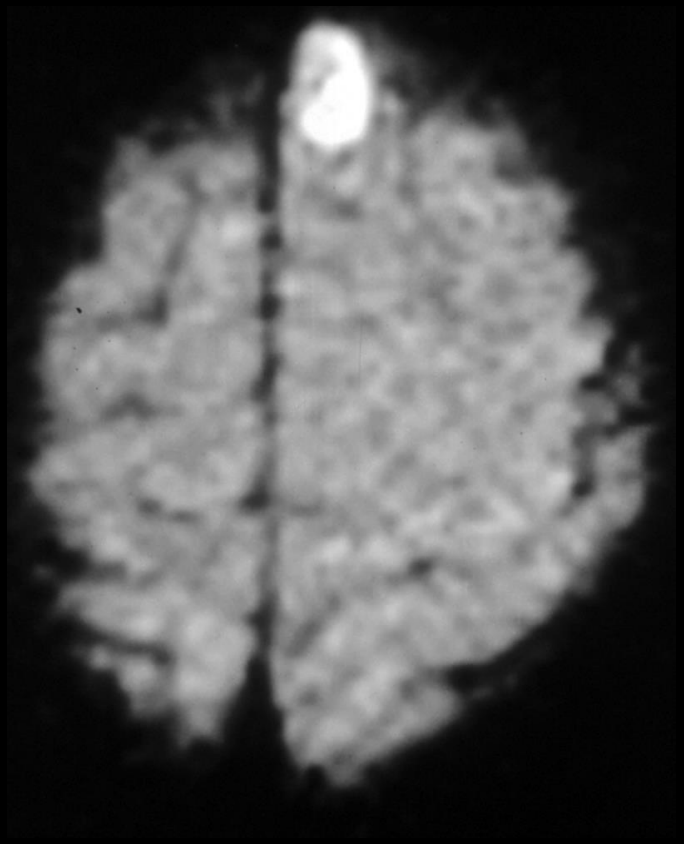
Subtle Contusion

- GRE MR
  - Small hypodensity c/w hemorrhage



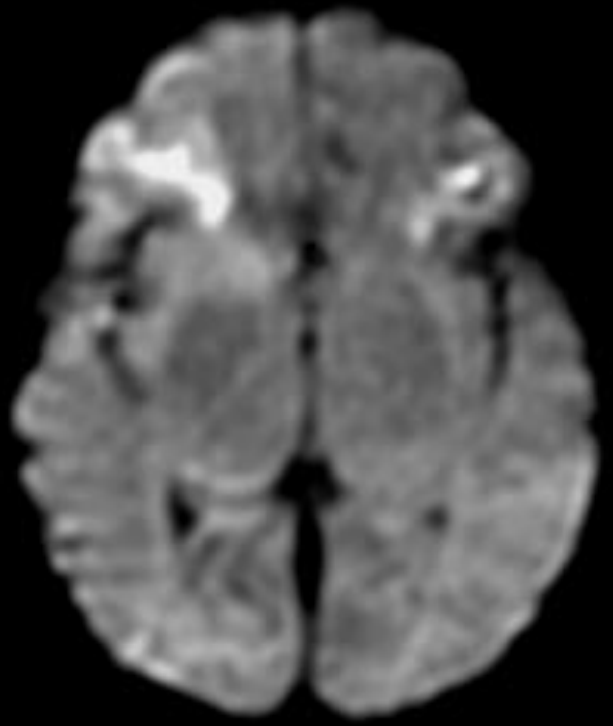
Subtle Contusion

- MR DWI
  - Appears bright where diffusion is restricted i.e. cytotoxic edema
  - The abnormality is larger than the hemorrhagic focus



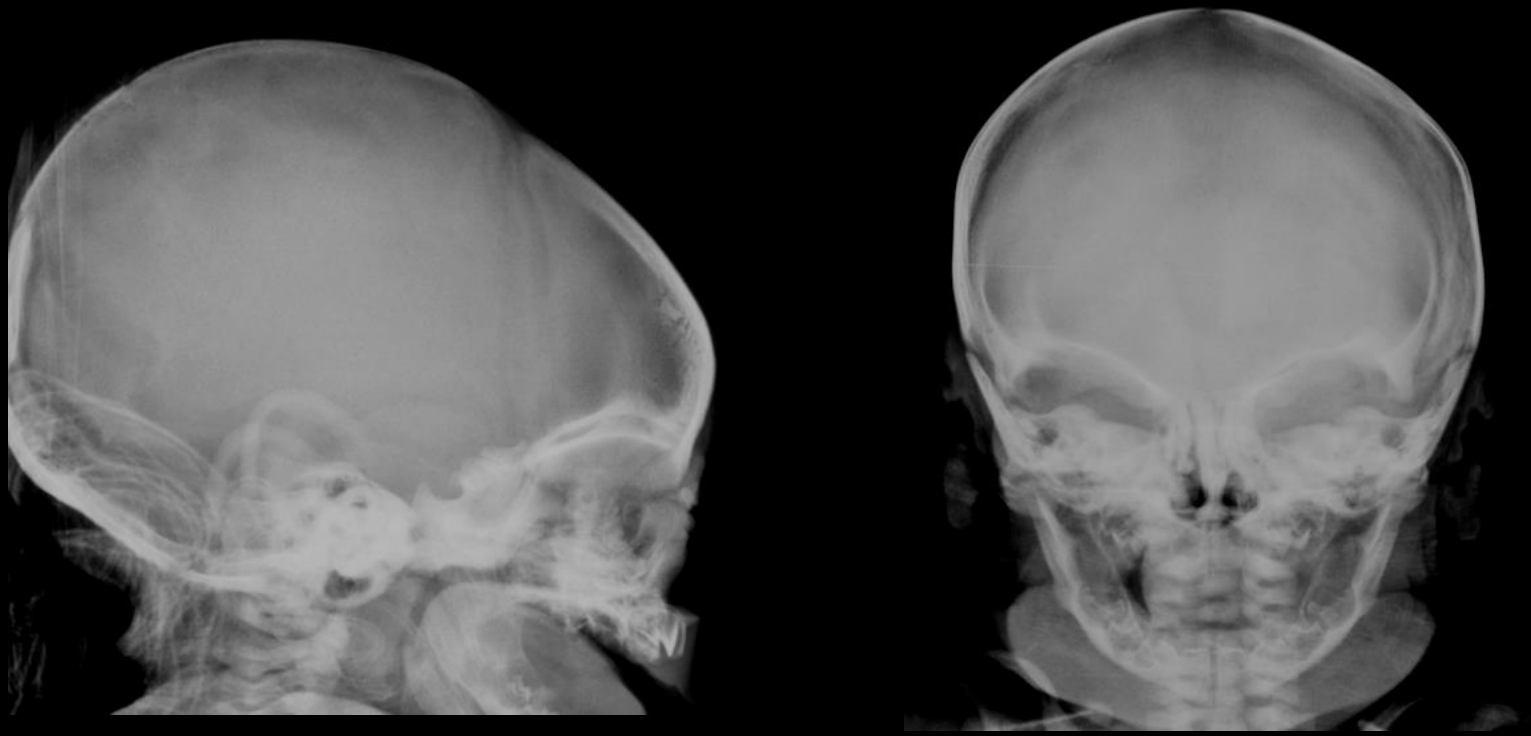
Case: Initial Presentation

- Pediatric seizures
  - CT was normal
  - DWI MR showed multiple areas of restricted diffusion
  - Infection and TBI were considered



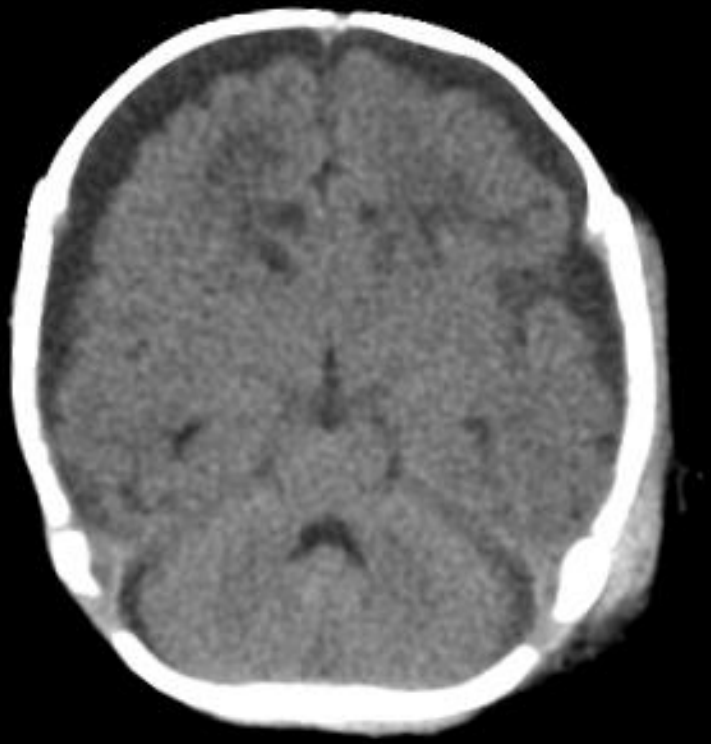
Case: Initial Presentation

- Skeletal survey was normal



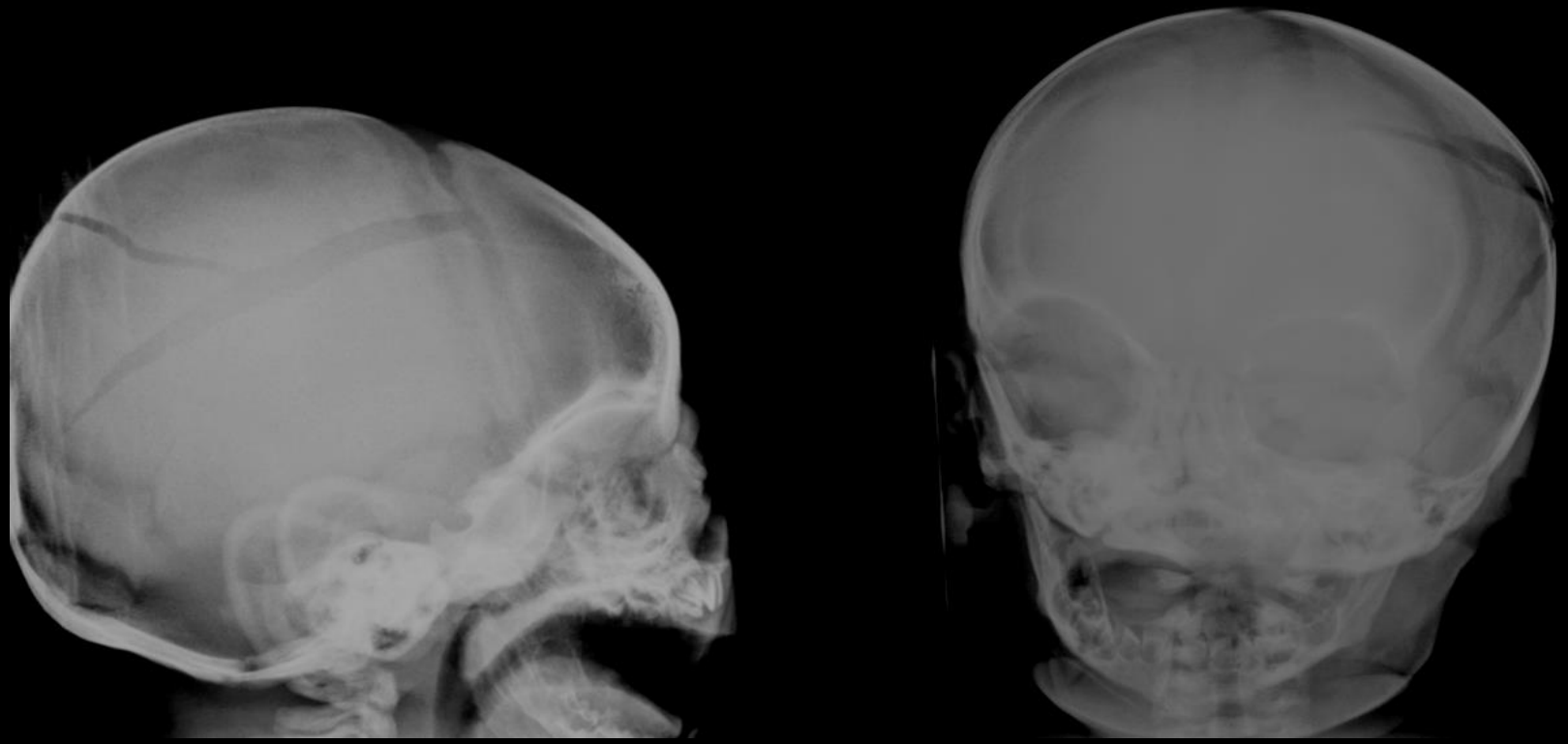
Case : 3 Weeks Later

- Non contrast CT
  - Encephalomalacia in areas of previous restricted diffusion
  - Extensive volume loss
  - Scalp hematomas



Case : 3 Weeks Later

- Skull fractures

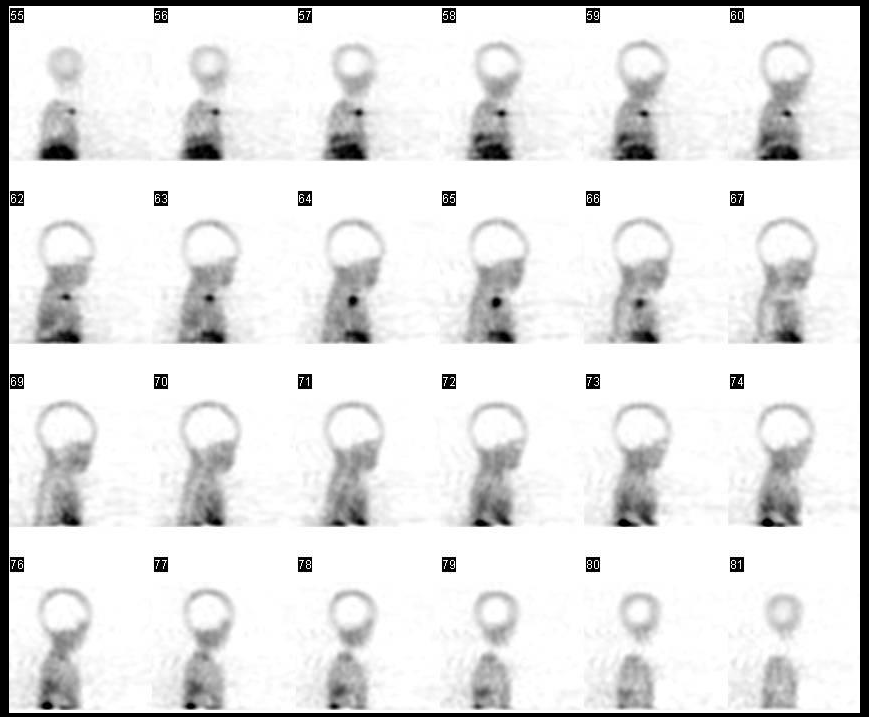


Case: Abusive Head Trauma

- Brain swelling and pseudo-SAH
- Bilateral retinal hemorrhages
- Global anoxic injury

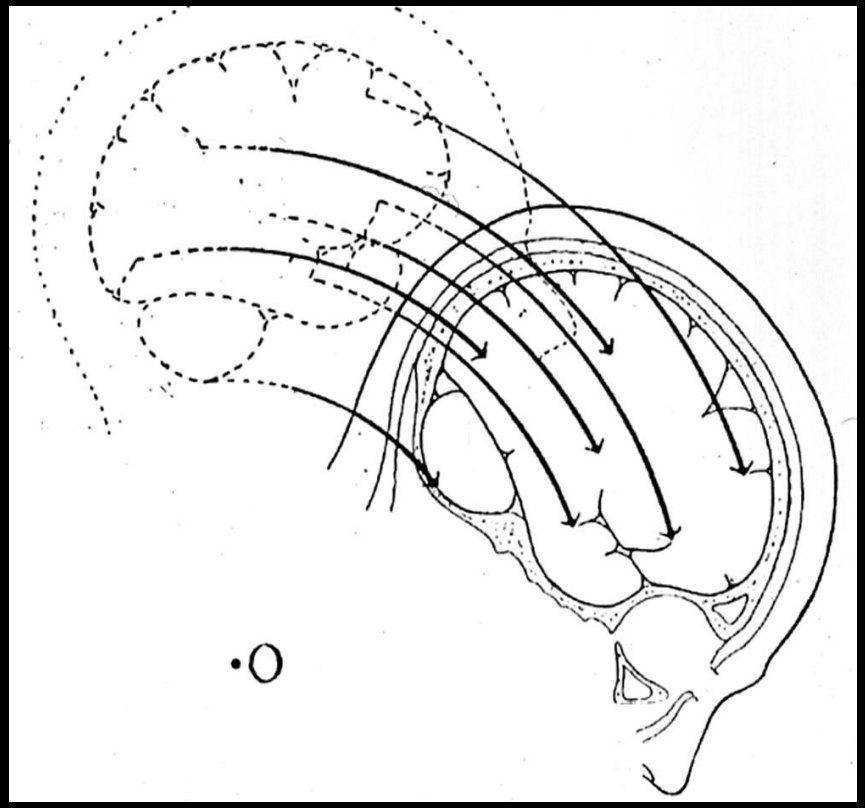
Case: Abusive Head Trauma

- NM brain death study
- Blood flow to face/scalp, none to brain



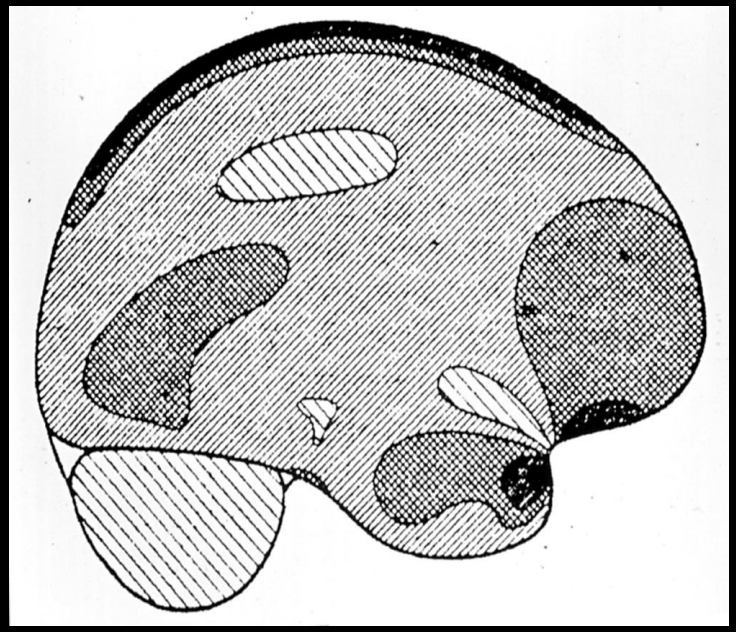
Diffuse Axonal Injury (DAI)

- Small, sometimes hemorrhagic injuries result from shear stress when the head is rotated.
  - Theory elaborated by Holborn in 1940's



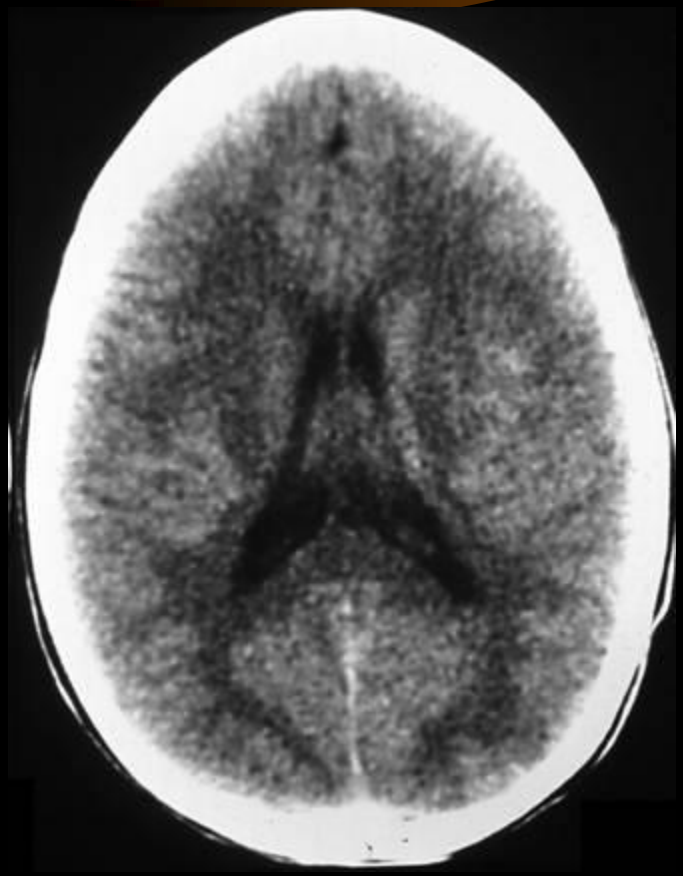
Diffuse Axonal Injury (DAI)

- Rotational acceleration is maximal at the brain periphery
  - Peripheral DAI is more common, less severe trauma
  - Corpus callosum or brainstem DAI is less common, more severe trauma



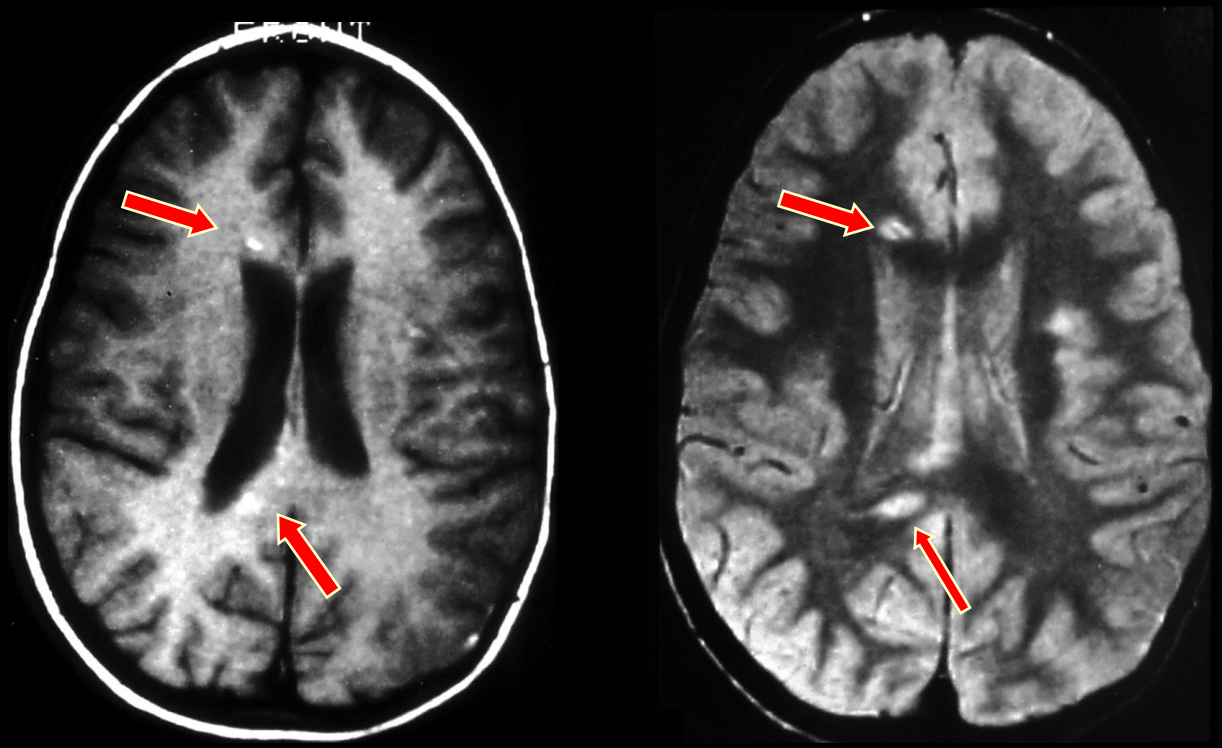
Diffuse Axonal Injury (DAI)

- CT
  - No definite abnormality



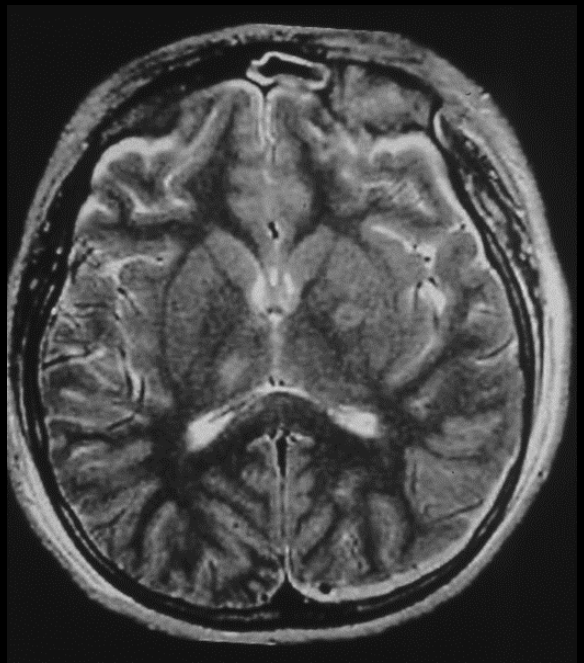
Grade II DAI: (T1 & T2)

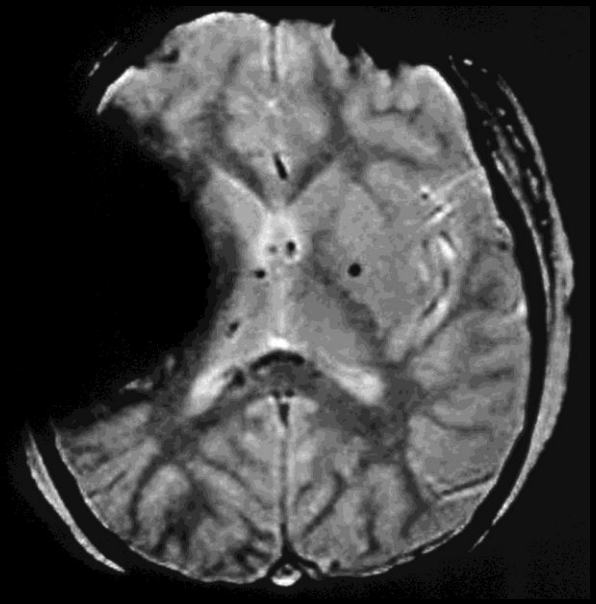
- Hyperintensities in splenium and genu of the corpus callosum (Grade II)



Grade II DAI: (T2 & GRE)

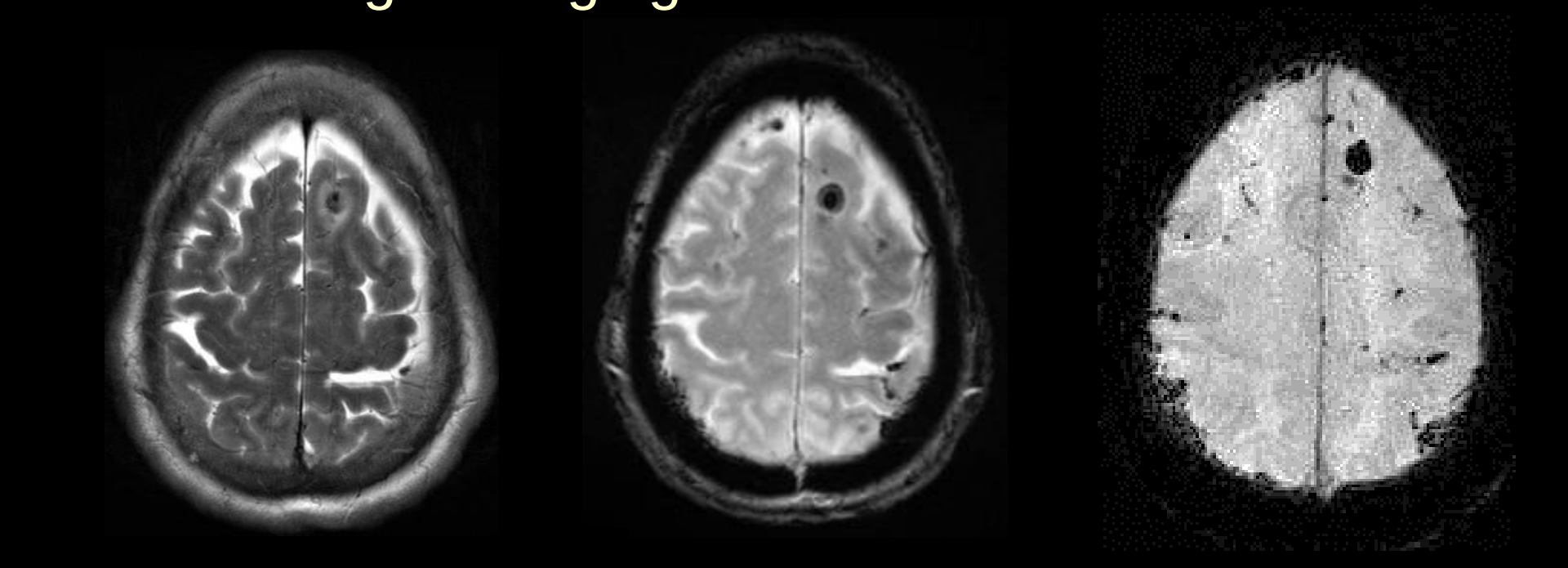
- Small bleeds in splenium of corpus callosum (Grade II) and in basal ganglia
- Large artifact on GRE





Grade I DAI: (T2, GRE, SWI)

- SWI i.e. susceptibility weighted imaging
  - More sensitive than T2 and GRE
  - Longer imaging time

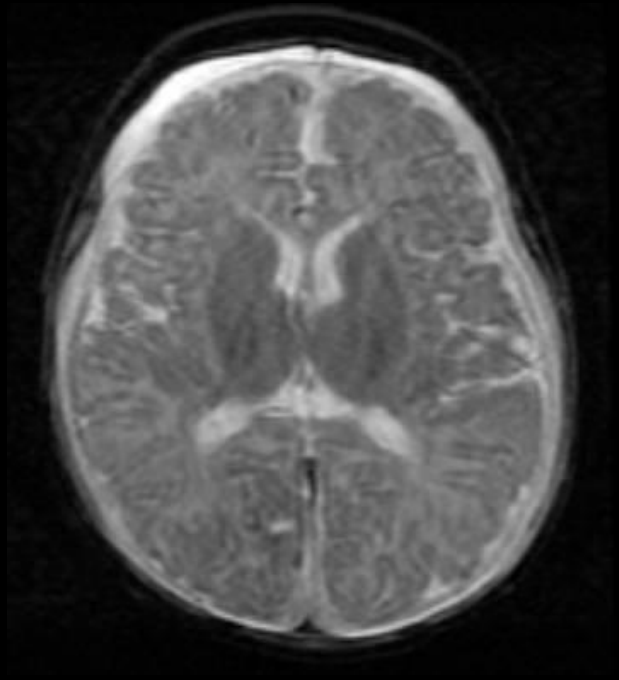


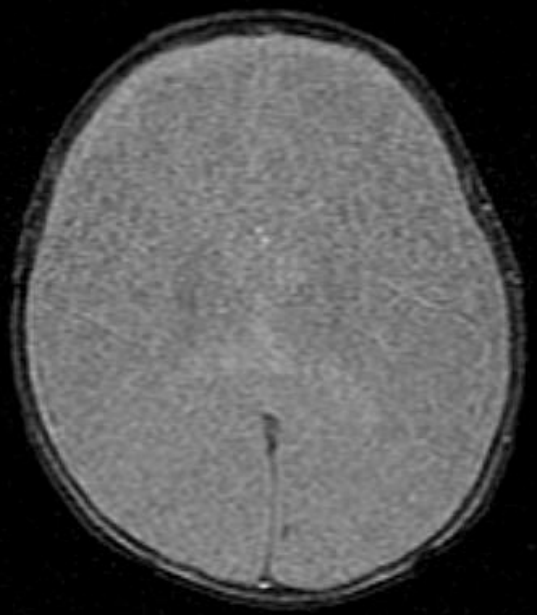
Hemorrhagic Injuries (DAI)

- CT underestimates DAI
  - Sees acute hemorrhage or large lesions
- MR more sensitive both acutely and especially chronically
  - T2 weighted sequences are sensitive
  - GRE sequences are more sensitive
  - SWI sequences are even more sensitive
  - GRE and SWI sequences are subject to extensive magnetic susceptibility artifacts

DAI?: Corpus Callosum

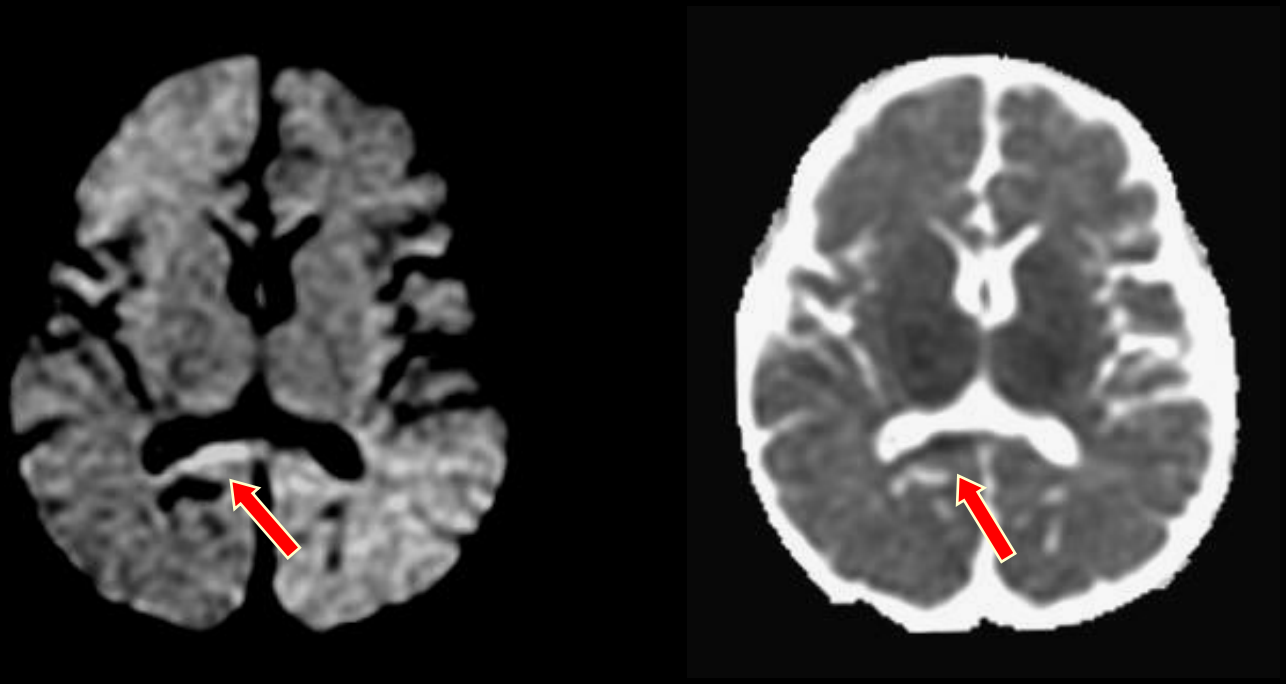
- No T2 prolongation and no hemorrhage in the splenium shown by T2 and GRE





Grade II DAI: (DWI, ADC)

- Subtle hyperintensities in the splenium on DWI confirmed on ADC



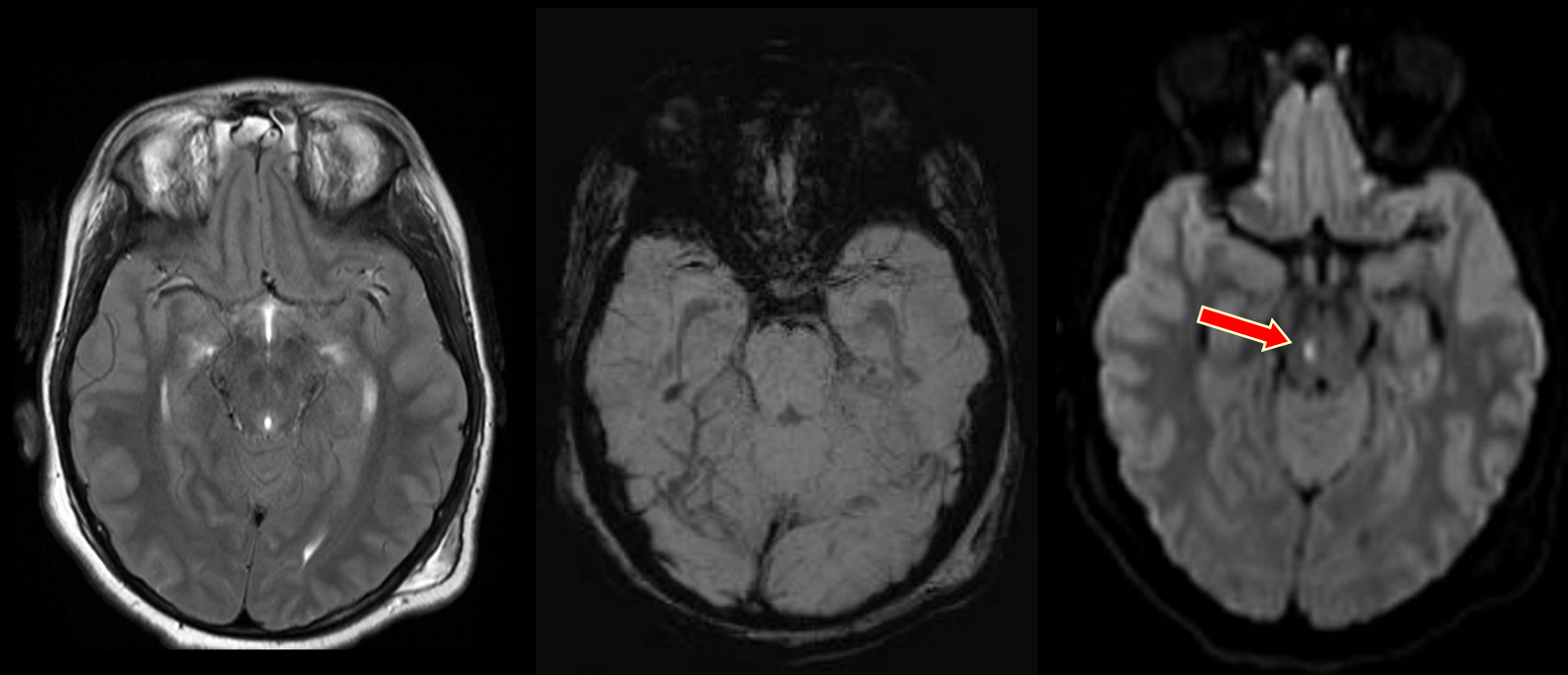
Diffuse Axonal Injury (DAI)

- GRE and SWI are sensitive for acute and chronic hemorrhage
- DWI is sensitive to cytotoxic edema and shows non-hemorrhagic lesions
- DWI obtained 0-2 days post injury correlates with initial GCS and Rankin score at discharge

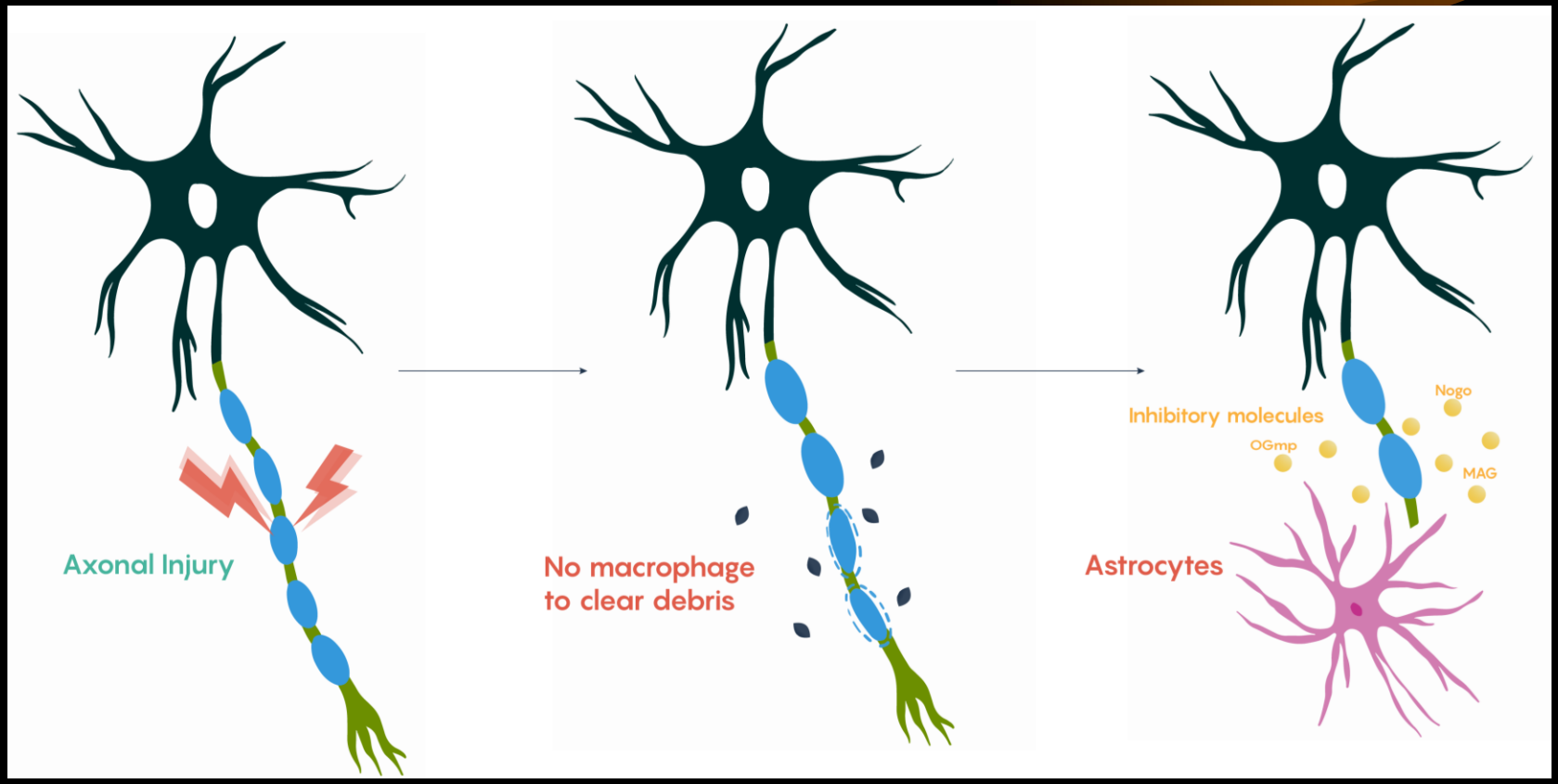
Schaefer PW et al. Radiology 233:58-66 (2004)

Grade III DAI (T2, SWI, DWI)

- Hard to see edema on T2 or hemorrhage on SWI, only on DWI (brainstem)
- Less than half of DAI may be hemorrhagic



Axonal Injury Mechanism



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Secondary Brain Injury

- Pathophysiologic cascade following initial injury
  - Cellular damage and edema
  - Repair and phagocytosis
  - Neuronal loss
  - Vascular proliferation
  - Gliosis

Delayed Bleeding & Herniation

- Initial CT
  - Normal

Delayed Bleeding & Herniation

- CT 24 hours later
  - Diffuse brain swelling
  - Compromised basal cisterns
  - Subfalcine herniation
  - Right frontal hematoma
  - Right subdural hematoma
  - Blurring of gray-white margin

Delayed Bleeding & Herniation

- CT 24 hours later
  - Diffuse brain swelling
  - Compromised basal cisterns
  - Subfalcine herniation
  - Right frontal hematoma
  - Right subdural hematoma
  - Blurring of gray-white margin

Delayed Bleeding & Herniation

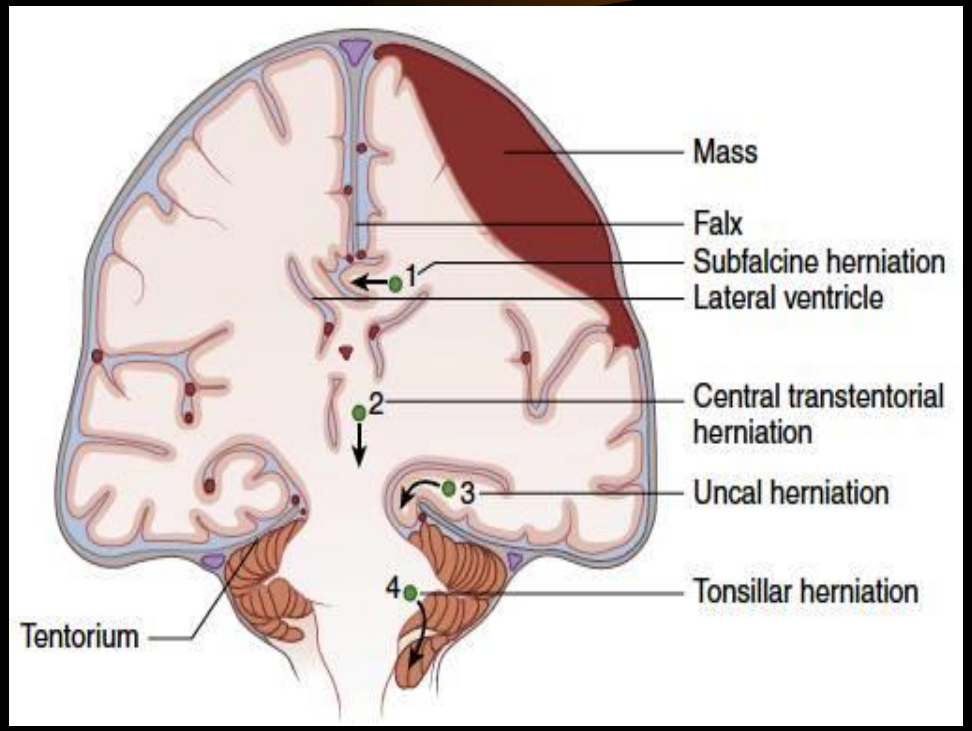
- CT after another 10 hours
  - Increased mass effect
  - Effaced basilar cisterns c/w descending herniation
  - New left frontal hemorrhage
  - Loss of gray-white differentiation

Brain Swelling

- Since the cranium is rigid, even a small increase in volume causes a large increase in ICP
- Cellular swelling (intracellular edema)
- Disruption of blood brain barrier causes extracellular edema
- Loss of auto regulation may result in increased cerebral blood volume

Brain Herniations

- Subfalcine (1)
- Transtentorial (2)
- Uncal (3)
- Tonsillar (4)



Problem Solving in Emergency Radiology (2015)

Summary

- Review the CT and MR appearance of common traumatic brain injuries
  - EDH
  - SDH
  - SAH
  - Contusion
  - DAI

Summary

- Understand how anatomy and pathophysiology determine the imaging appearance
  - Configuration of extra axial collections
  - CT density over time of hematomas
  - Most common locations for contusion
  - Distribution of DAI

Summary

- Discuss which imaging options offer the greatest sensitivity for diagnosing TBI
  - GRE and SWI MR sequences sensitive for acute and chronic hemorrhage
  - Diffusion MR (DWI) is sensitive to cytotoxic edema and shows non-hemorrhagic lesions

Thanks!