# Neuroimaging Essentials for the Neurologist:

*What should I order? What am I looking at?*

Alexander Li Cohen MD, PhD

September 21st, 2020

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2

# Over the next thirty minutes, my goal is for you to:

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1. Understand why we have different neuroimaging modalities and what can they tell you about the brain
2. Adopt a systematic approach to reviewing brain imaging
3. Be aware of some common pediatric specific neuroimaging concepts that we should all know

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3. Be aware of some common pediatric specific neuroimaging concepts that we should all know

(This will not be a comprehensive review of pediatric neuroimaging)

# Why is neuroimaging important?

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# Why is neuroimaging important?

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- On the other hand, imaging is the most common bridge between clinical suspicion and pathologic confirmation.
- "The individual armed with both the clinical scenario AND imaging experience is uniquely equipped to interpret neuroradiographic studies"

# Neuroimaging has been rapidly evolving…

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# Neuroimaging has been rapidly evolving… for over a century!

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- 1896 – X-Ray (Nobel Prize 1901)
- 1918 – Ventriculography / Pneumoencephalography
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    - 1945 – Detection of NMR chemical shifts (Nobel Prize 1952)
    - 1960s – Commercial NMR Spectrometers
    - 1977/1978 – Magnetic Resonance Imaging (Nobel Prize 2003)

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- 1941 – Cranial Ultrasound “Scanning”
- 1952 – Somascope
- 1960s – Mechanical B-mode scanning
- 1980/90s – Improvements with transistors/computers

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# So what do we actually use now?

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16

# So what do we actually use now?

Available

- X-ray
- Angiography
- CT (CTA/CTP)

- MRI
- Ultrasound
- TCD

- PET
- SPECT/SISCOM

Most Commonly Used

- CT
- MRI
  - T1
  - T2
  - FLAIR
  - SWAN
  - DWI
  - (MRS)
- Ultrasound

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# However, even skull X-rays can still be useful!

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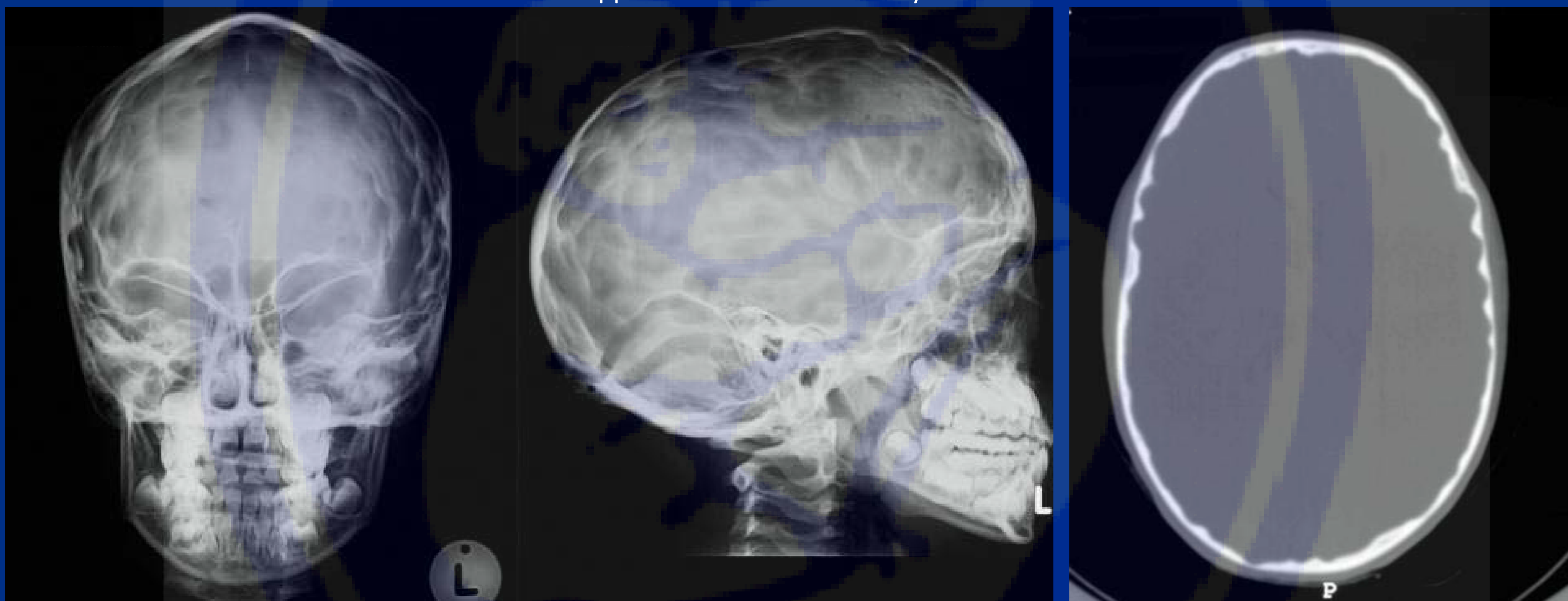
Copper Beaten Skull - craniosynostosis



# Computed Tomography (of x-rays): CT

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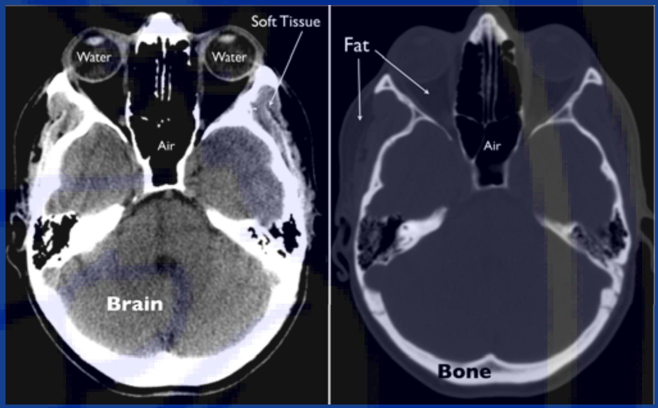
# CT – What is it measuring?

- Provides an absorption value for each voxel
- Most useful for differentiating:
  - CSF
  - Blood
  - Brain
  - Bone





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# CT – What is it measuring?

- Provides an absorption value for each voxel
- Most useful for differentiating:
  - CSF (~ 0-15)
  - Blood (acute ~ 50s)
  - Brain (white<30<grey)
  - Bone (~ 350)

| Substance | HU |
|---|---|
| Air | −1000 |
| Lung | -700 to −600[2] |
| Fat | −120 to −90[3] |
| Chyle | −30[4] |
| Water | 0 |
| Urine | -5 to +15[3] |
| Bile | -5 to +15[3] |
| CSF | +15 |
| Kidney | +20 to +45[3] |
| Lymph nodes | +10 to +20[5] |
| Blood | +30 to +45 |
| Muscle | +35 to +55[3] |
| White matter | +20 to +30 |
| Grey matter | +37 to +45 |
| Liver | +40 to +60 |
| Soft Tissue, Contrast | +100 to +300 |
| Bone | +200 (craniofacial bone), +700 (cancellous bone) to +3000 (cortical bone) |

Chart from Wikipedia – Hounsfield Scale

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- Provides an absorption value for each voxel
- Most useful for differentiating:
  - CSF (~ 0-15)
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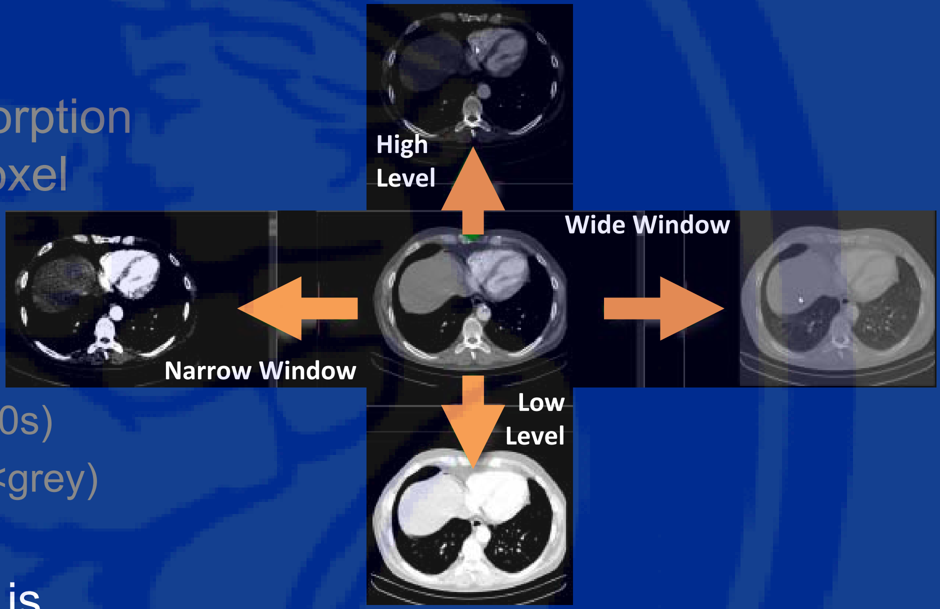
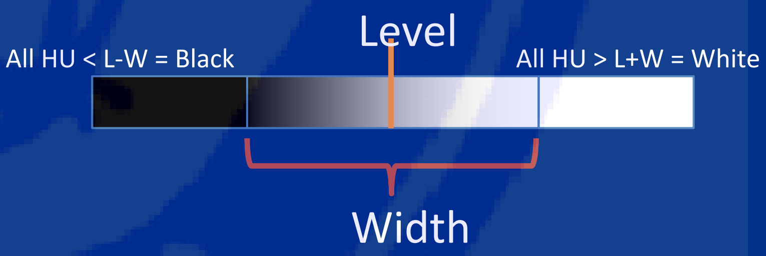
  - Brain (white<30<grey)
  - Bone (~ 350)
- But "Windowing" is important:
  - Level: middle of range
  - Width: range of interest



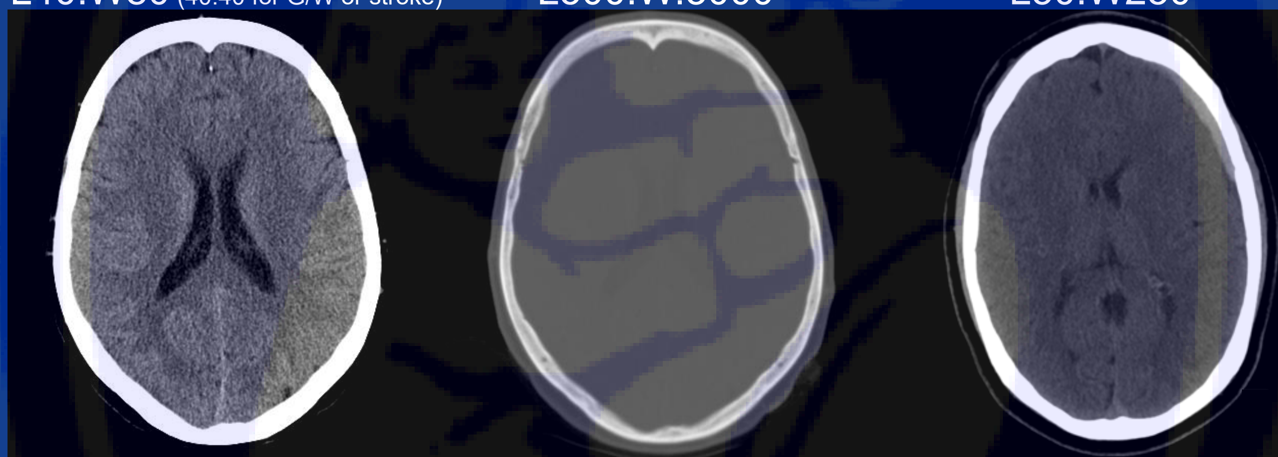



# CT – What is it measuring?

BRAIN window
L40:W80 (40:40 for G/W or stroke)

BONE window
L500:W:3000

SUBDURAL window
L50:W250



| | |
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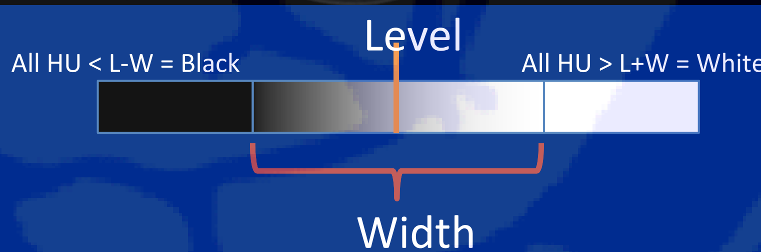

# CT – Do you want contrast with that study?

- When do you want a CT with contrast?

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- When do you want a CT with contrast?
- Usually you don't… The exceptions are:
  - Mass lesion when MRI is going to take a while
    - e.g., patient with focal findings in the ED
  - Looking for infection *when MRI is contraindicated*
  - Performing a CTA to look for an aneurysm, AVM, or dissection *when MRA is contraindicated*

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- CT perfusion studies for adults with acute ischemic stroke to identify candidates for reperfusion (tPA, etc…)
  - Most Pediatric Stroke Protocols go straight to MRI/MRA…

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# CT – Benefits and Limitations

Benefits

- Great at identifying bony or hemorrhagic injury
- Speed
- Widely available
- Can be used when MRI is contraindicated
- Contrast can be used in some cases to gain more information

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Limitations

- Ionizing radiation
- Poor soft tissue discrimination
- Artifacts, e.g., beam hardening in the posterior fossa



29

# Nuclear Magnetic Resonance Imaging: MRI

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# MRI – What does it actually measure?

Physics

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31

# MRI – What can it tell us?

T1

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- Tissues with high water content have relatively long T1 times = dark

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T1

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- What is bright on T1?

# MRI – What can it tell us?

T1

- Tissues with high water content have relatively long T1 times = dark

- The Bright Backyard Grill:
  - Fat
  - Proteinaceous Fluid
  - Subacute Blood products
  - Metals (**Gad**, Mn, Copper)
  - Hydrated Calcium
  - Melanin




35

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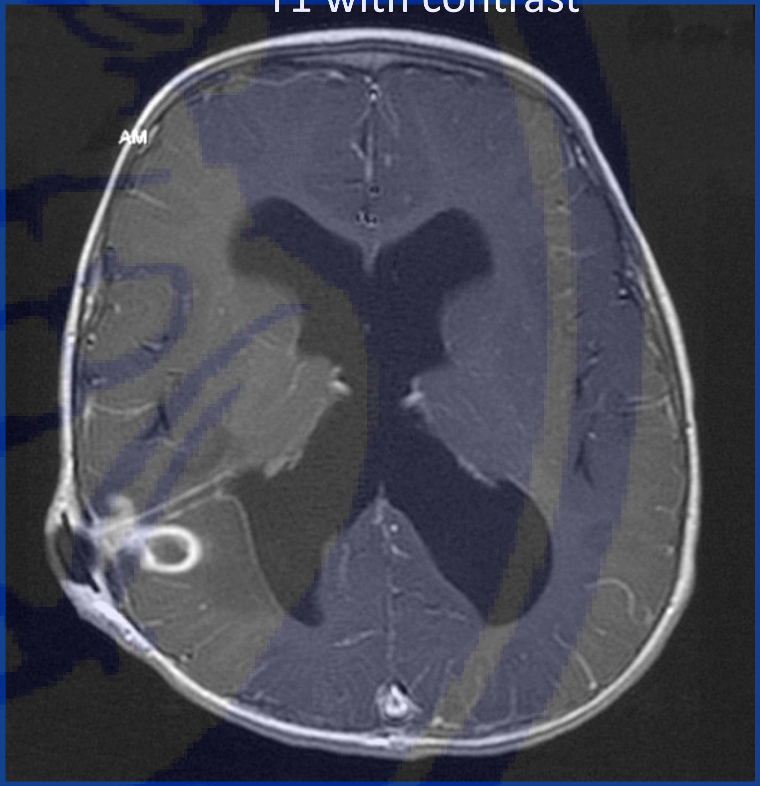
T1 with contrast

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# MRI – What can it tell us?

*$T2 = H_2O$*

T1
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T2
- Pathologic processes normally increase the water content in tissues = bright (edema, etc…)
- Acute hemorrhage, hemosiderin, and iron deposits are dark

Pooley, RSNA 2005

# MRI – What can it tell us?

**T1**

- Tissues with high water content have relatively long T1 times = dark
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**T2**

*T**2** = $H_2$0*

- Pathologic processes normally increase the water content in tissues = bright (edema, etc…)
- Acute hemorrhage, hemosiderin, and iron deposits are dark

**FLAIR and "Fat Sat" images**

- CSF or Fat are suppressed, but pathologic increase is still seen.

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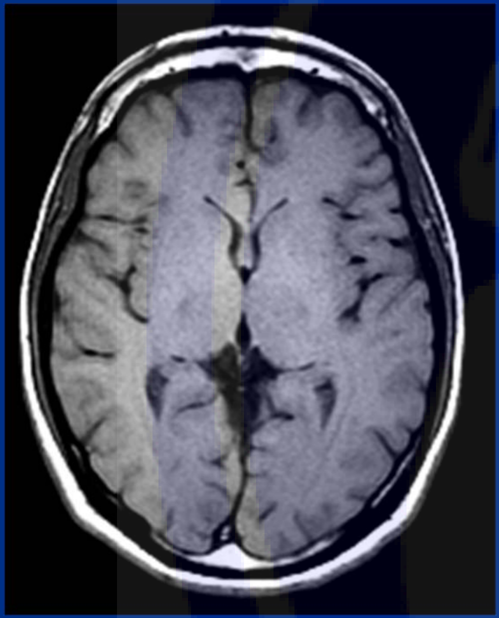
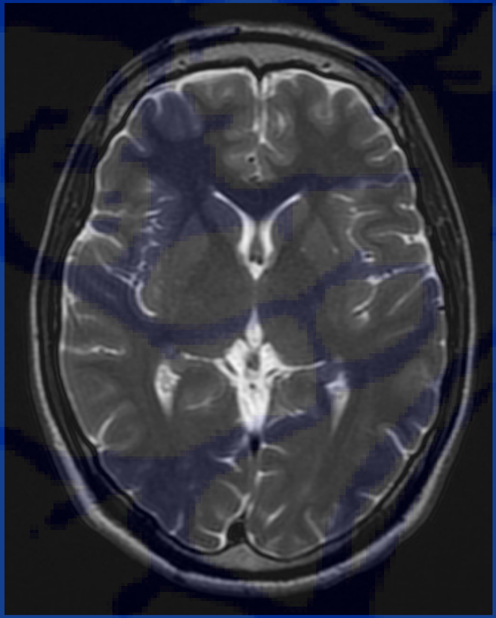
Pooley, RSNA 2005

# MRI – What can it tell us?

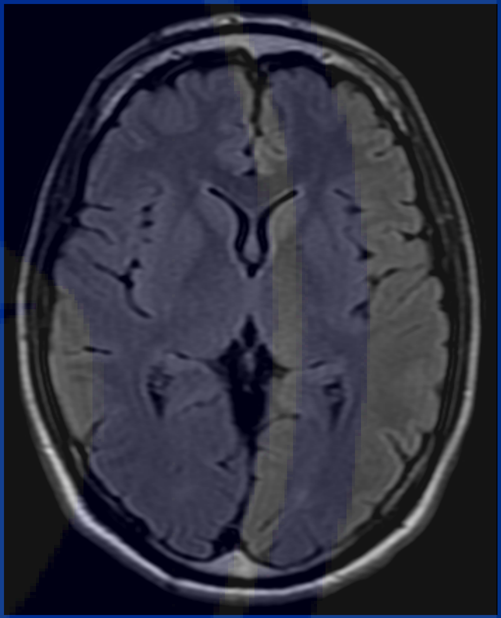
T1



T2



T2 FLAIR



Grey = Grey
White = White
T1 is a “1:1” relationship

Grey = White
White = Grey
T2 is Topsy-Turvy
CSF? On Flair, it’s not there…

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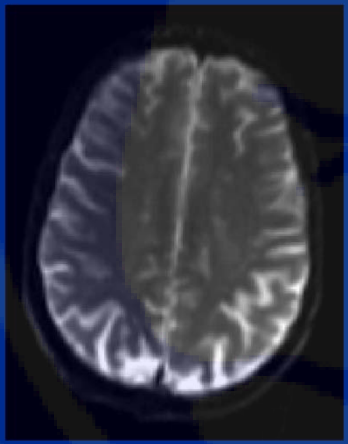
# MRI – What can it tell us?

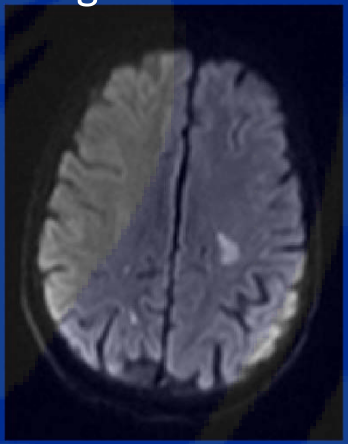
Diffusion (DWI)

- Measures how freely water can move in a voxel
  - ischemic lesions and cytotoxic edema are bright
- This is based on a modified T2 image

T2 ~ b0



diffusion weighted ~ b100 or b1500



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Original work

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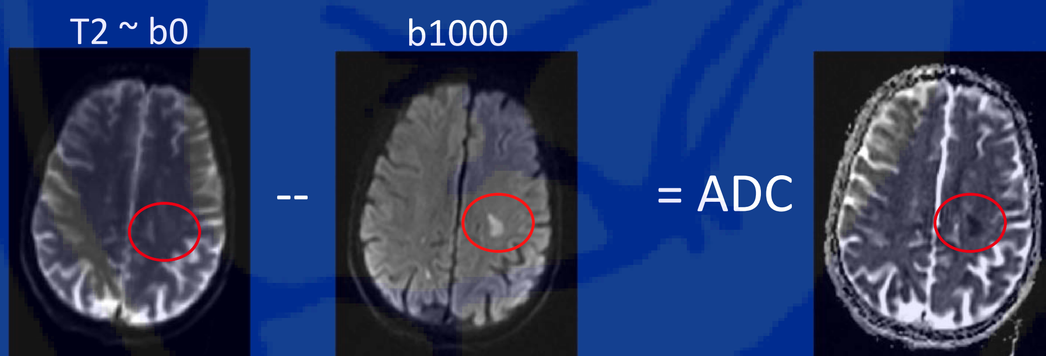
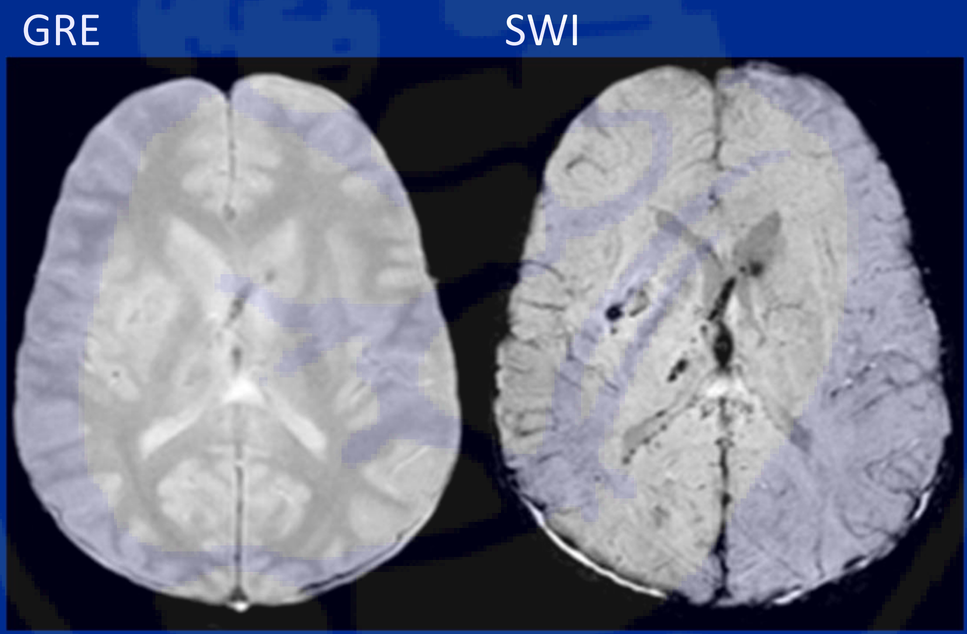
- Measures how freely water can move in a voxel
  - ischemic lesions and cytotoxic edema are bright
- This is based on a modified T2 image
- ADC = Apparent Diffusion Coefficient maps are helpful to differentiate between real diffusion restriction and “T2 shine through”



# MRI – What can it tell us?

GRE and SWI/SWAN

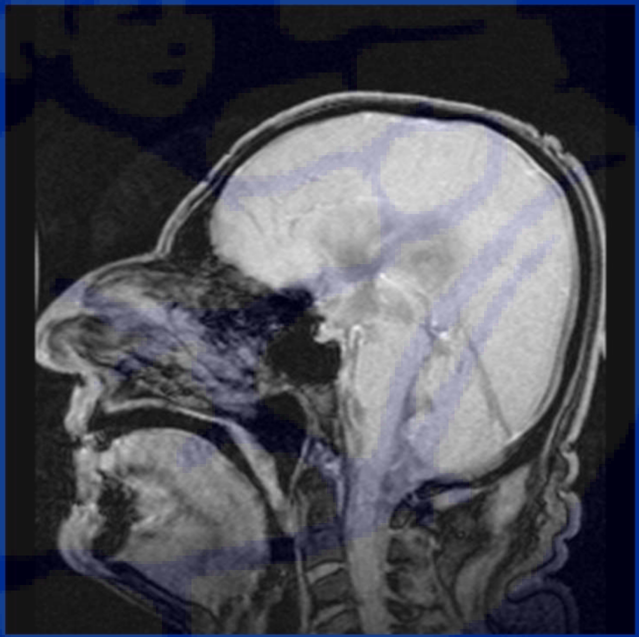
- Modified to increase susceptibility to blood and bone



# MRI – What can it tell us?

CSF Flow studies (*Cine*)

- To identify obstructions in the aqueducts, etc…











43

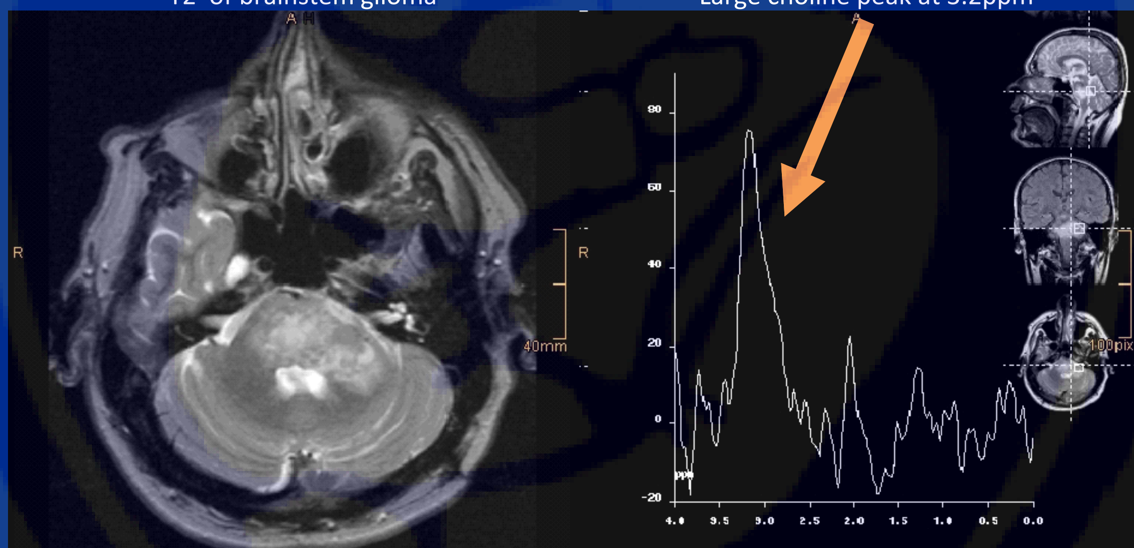
# MRI – What can it tell us?

## MR Spectroscopy

- Can characterize the chemical content of a particular location

T2 of brainstem glioma

Large choline peak at 3.2ppm

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44

# MRI – Benefits and Limitations

Benefits

- Best for soft tissue characterization

- No ionizing radiation
- Safe for repeated exams
- Lots of information

# MRI – Benefits and Limitations

Benefits

- Best for soft tissue characterization
- No ionizing radiation
- Safe for repeated exams
- Lots of information

Limitations

- Time-consuming
- Expensive
- Not as widely available
- Not as sensitive to bony injury
- Too many sequences to always get them all, so clinical context is important

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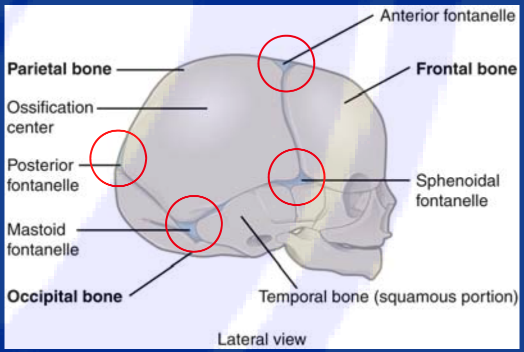
# US – What can it tell us?

# US – What does it measure?

- Uses high-frequency sound to identify *boundaries* between tissue types
- Sound is emitted *and* received in straight lines from the transducer
- Can capture static pictures, movies, or measure blood flow

# US – How can we use it?

- Uses high-frequency sound to identify *boundaries* between tissue types
- Sound is emitted *and* received in straight lines from the transducer
- Can capture static pictures, movies, or measure blood flow
- Soft tissue 'windows' are needed, just like looking between the ribs for echocardiography
- As such, usually limited to neonates and in the first year of life:

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# US – How can we use it?

- Anterior Fontanelle
  - Closes ~24 months
- Posterior Fontanelle
  - Closes ~3 months
- Anterolateral (Sphenoid)
  - Closes ~6 months
- Posterolateral (Mastoid)
  - Closes ~6-18 months

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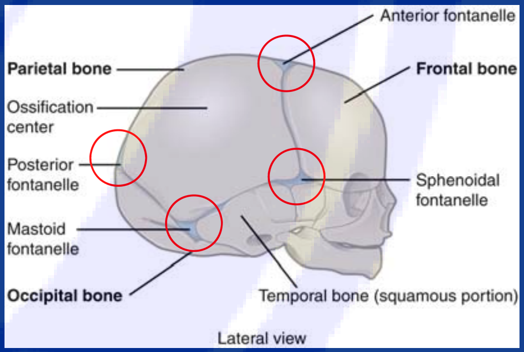


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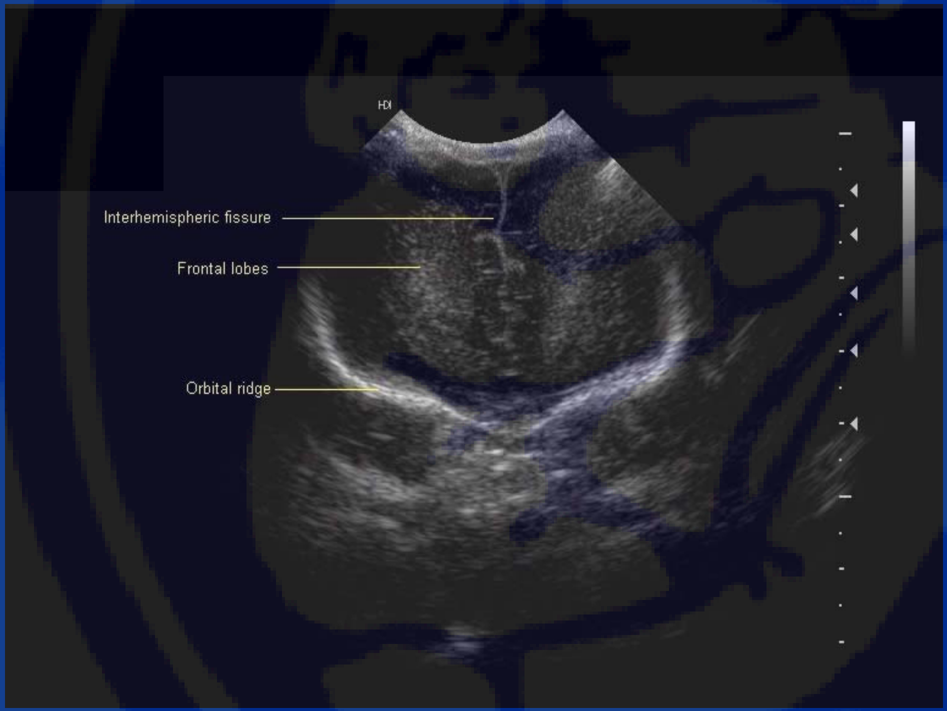
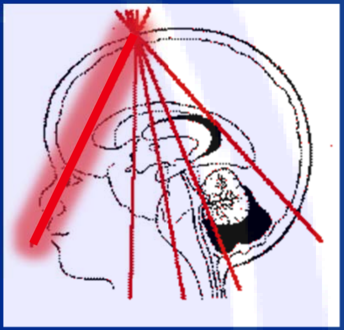
# US – How can we use it?

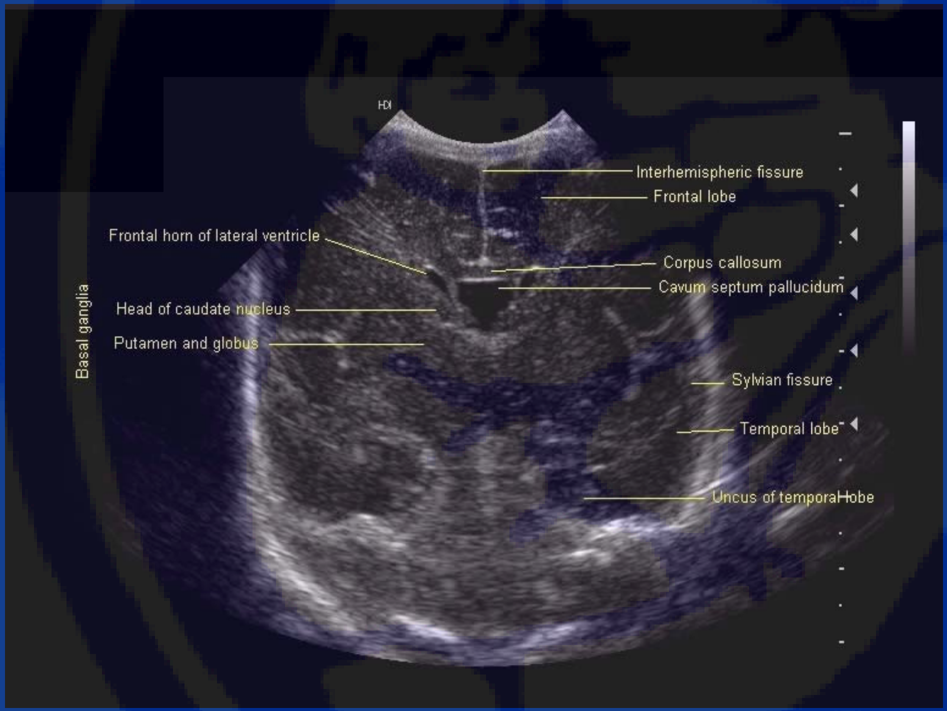
Frontal Lobes

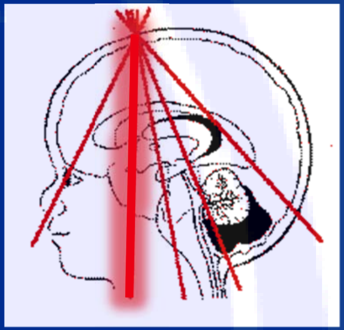


# US – How can we use it?

## Anterior Horns of the Lateral Ventricles



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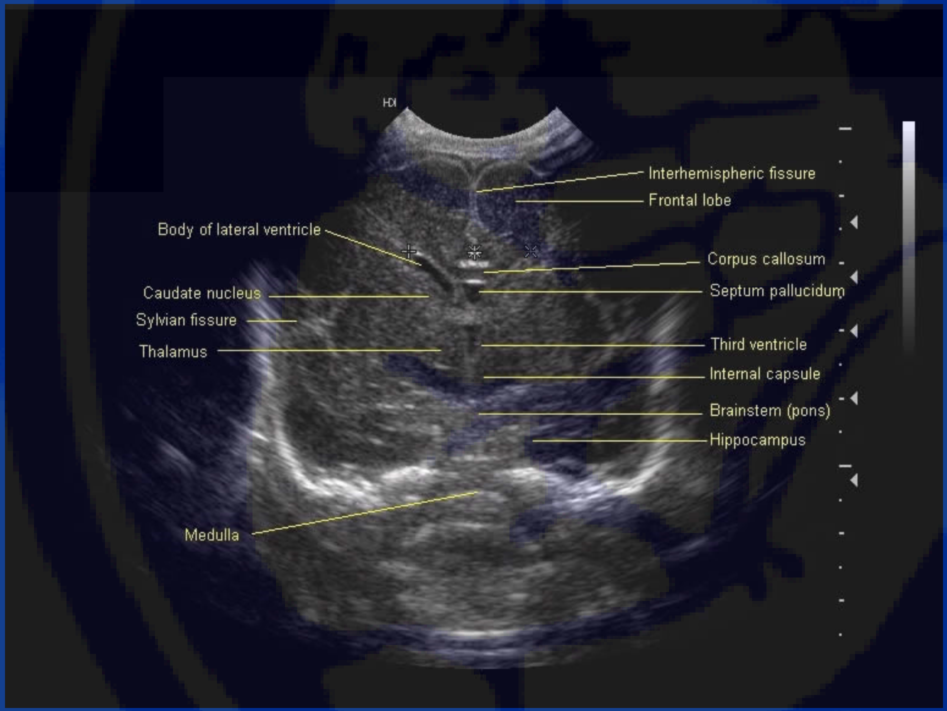
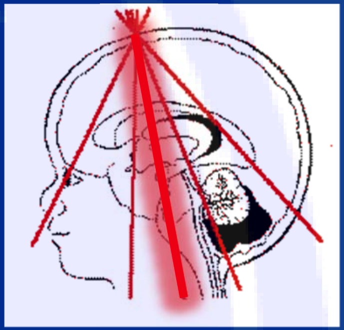
52

# US – How can we use it?

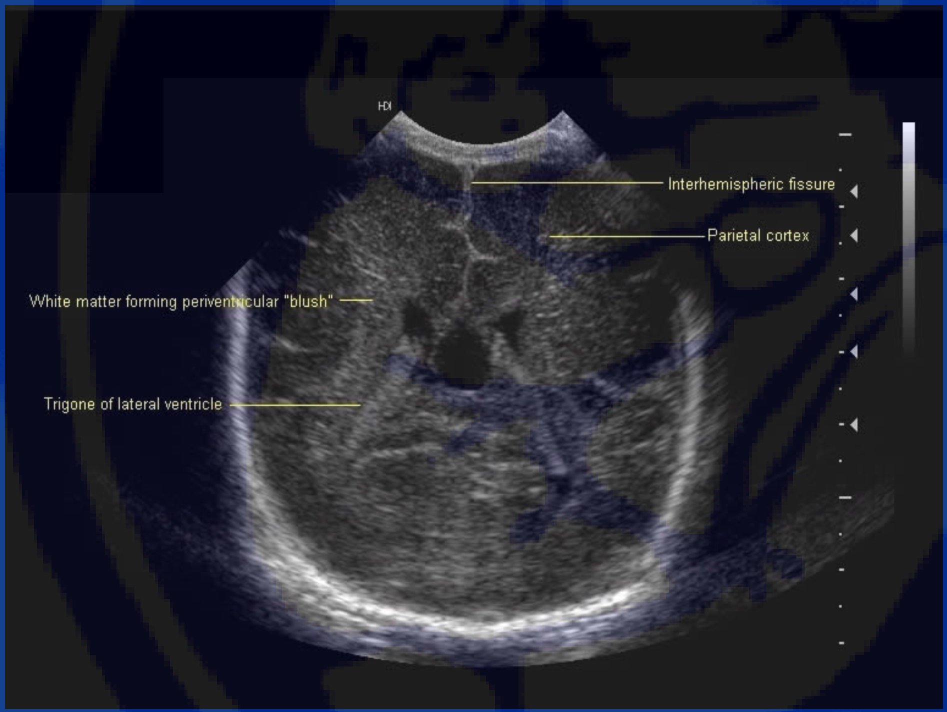
## Third Ventricle

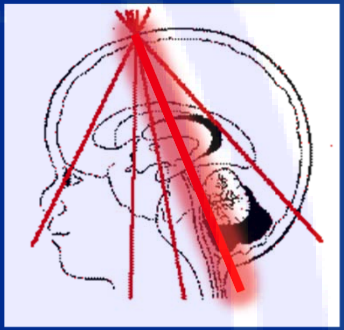


# US – How can we use it?

"Trigones" of the Lateral Ventricles



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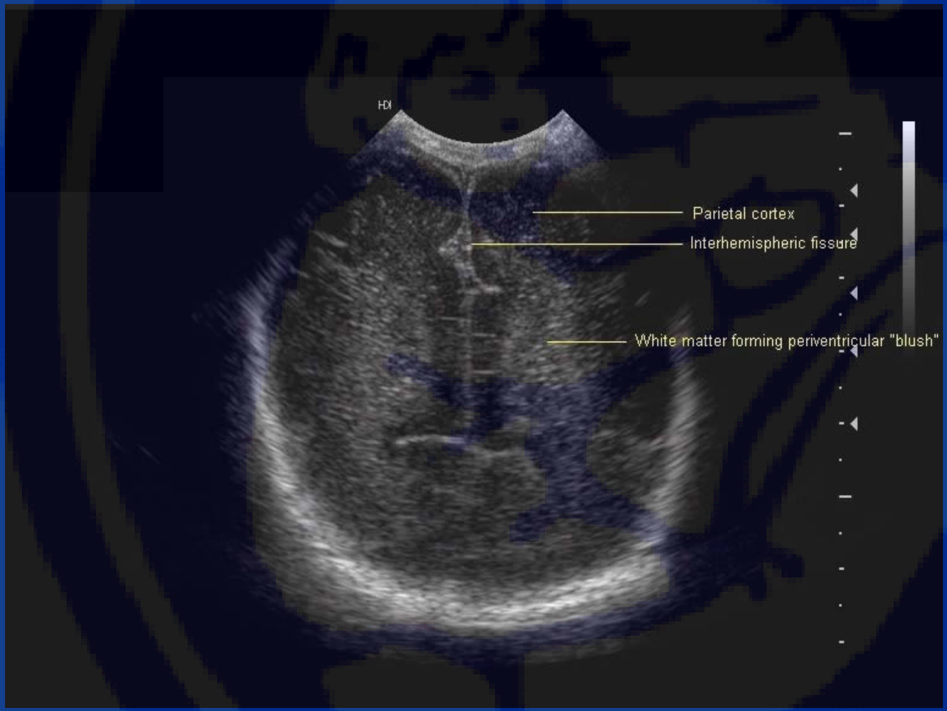
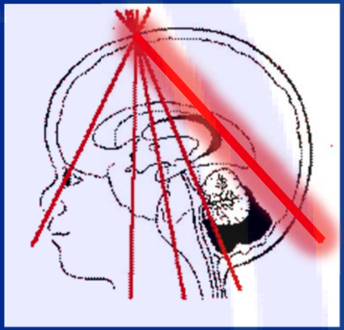
# US – How can we use it?

## Parietal and Occipital Cortex



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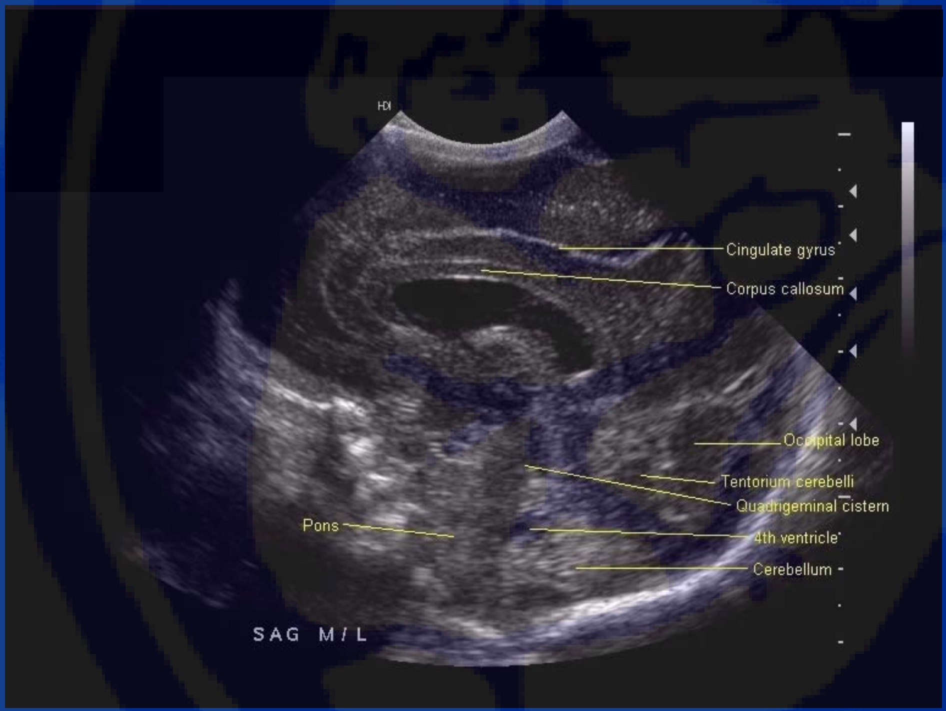
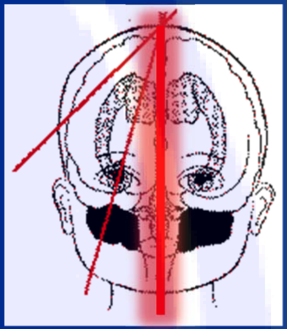
# US – How can we use it?

## Midline Sagittal



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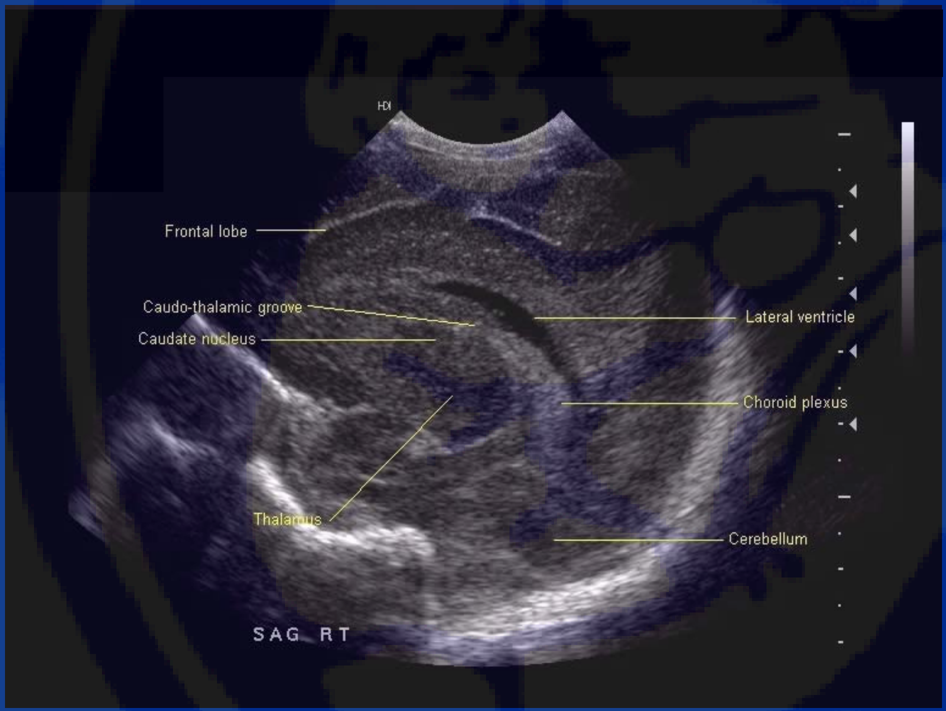
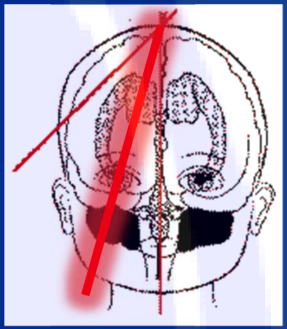
# US – How can we use it?

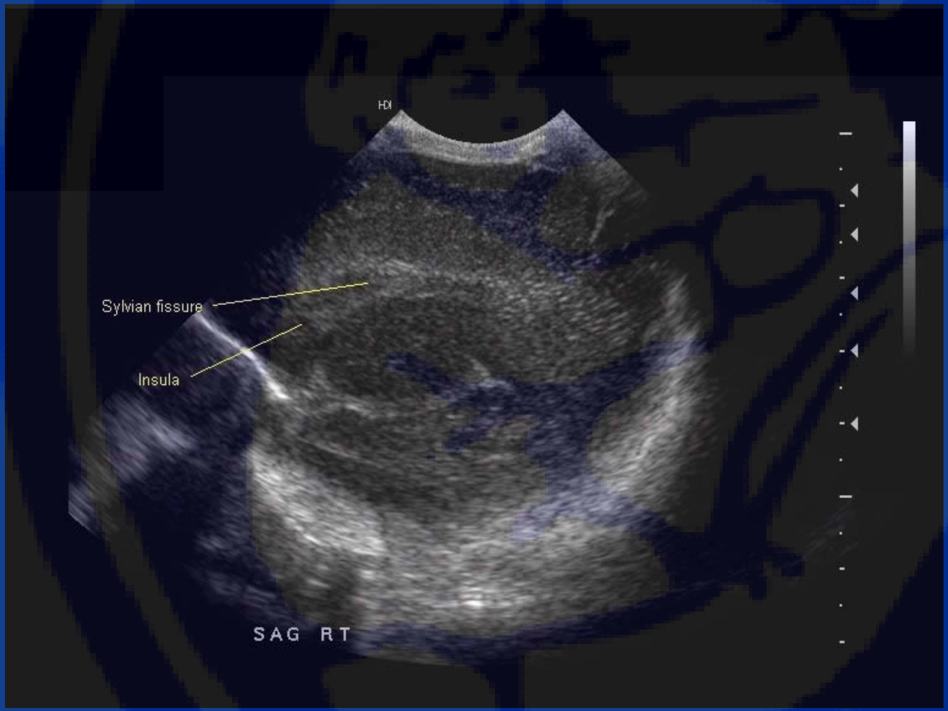
## Angled Parasagittal

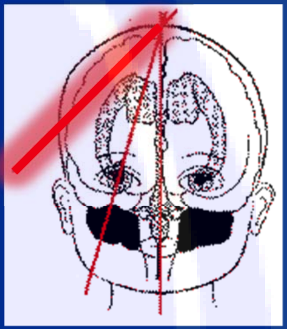


# US – How can we use it?

Tangential Parasagittal



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New Zealand Ministry of Health

# US – Benefits and Limitations

Benefits

- Best for fast and repeated measurements in the in-patient setting

- Speed
- Portable
- Widely available
- Cheap

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# US – Benefits and Limitations

<u>Benefits</u>

- Best for fast and repeated measurements in the in-patient setting
- Speed
- Portable
- Widely available
- Cheap

<u>Limitations</u>

- "Only" available for babies
- Very operator dependent
- Limited depth/field of views, e.g., hard to see cerebellar bleeds

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60

# Systematic Evaluation of Anatomy

# Systematic Evaluation of Anatomy

- Practice makes Consistent
  - Verify you are looking at the correct patient AND the correct scan
  - If a comparison study, verify which one you are currently reviewing

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# Systematic Evaluation of Anatomy

- Practice makes Consistent
  - Verify you are looking at the correct patient AND the correct scan
  - If a comparison study, verify which one you are currently reviewing
  - Always review the anatomy and image quality first
  - T1 → T2 → FLAIR → DWI/ADC → SWI → MRS, etc…

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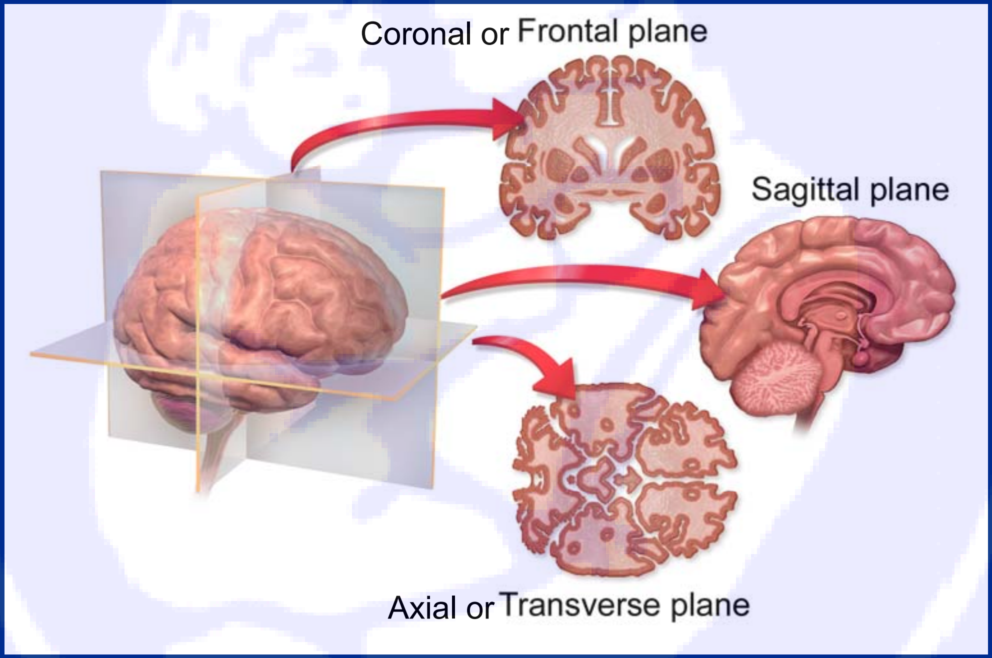
63

# Systematic Evaluation of Anatomy

**First, look at the mid-sagittal plane:**








64

# Systematic Evaluation of Anatomy

Window

↓

Interesting Scenery

**First, look at the mid-sagittal plane:**

# Systematic Evaluation of Anatomy

Window → Interesting Scenery

**First, look at the mid-sagittal plane:**

- Cervical spinal cord and cervical spine
- Foramen magnum & base of skull
- Cerebellar tonsils
- Fourth ventricle
- Cerebellar vermis
- Brain stem
- Basilar artery
- Sella, pituitary & optic chiasm
- Corpus callosum
- Cingulate gyrus
- Cortex
- Superior sagittal sinus
- Review areas:
  - Orbits
  - Sinuses: Ethmoid, sphenoid, and frontal
  - Nasopharynx, Oropharynx

# Systematic Evaluation of Anatomy

Window → Interesting Scenery

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  - Nasopharynx, Oropharynx

**Then, look laterally at parasagittal planes:**

- Hemispheres
- Extra-axial collections
- Carotid & vertebral arteries
- Review areas:
  - Transverse sinuses
  - Sinuses: frontal, ethmoid, sphenoid, mastoid, maxillary
  - Internal auditory canals IAC

# Systematic Evaluation of Anatomy

**Then, move to axial slices:**

**Review the ventricles, cisterns & sulci:**

- When ventricles, cisterns, fissures or sulci are “squashed” we use the term effaced.
- When they are large we just describe them as large or enlarged.
- Interpret these CSF spaces together:
  - Effaced sulci + enlarged ventricles = hydrocephalus.
  - Enlarged sulci + enlarged ventricles = brain volume loss i.e. atrophy.

# Systematic Evaluation of Anatomy

**Vessels arteries, veins & venous sinuses:**

- Arteries: basilar, carotid, vertebral, anterior/middle/posterior cerebral arteries
- Superior sagittal sinus, torcula, transverse sinus, sigmoid sinus, internal jugular vein

**Meninges:**

- Dural involvement/enhancement look at: falx, tentorium, CP angle
- Leptomeningeal enhancement look at: basal cisterns, cerebellar folia, sulcal perivascular spaces

**Extended search:**

- Sella, pituitary & optic chiasm
- Paranasal sinuses (ethmoidal, sphenoid, frontal, mastoid), temporal bone/ears
- Orbits
- Nasopharynx, Oropharynx

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# Systematic Evaluation of Anatomy

**Brain matter, Grey & white matter:**

- Midline shift
- Grey white differentiation
- Deep Structures:
  - Caudate nucleus, Internal capsule, Putamen & globus pallidus, thalamus.
- White Matter as a whole and the brainstem:
  - centrum semiovale, midbrain, pons, medulla, cerebellum

# Systematic Evaluation of Anatomy

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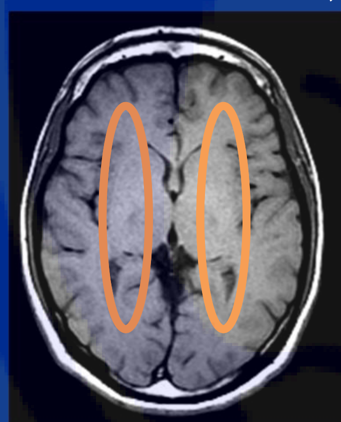

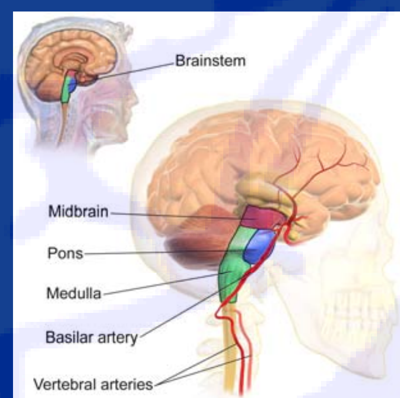



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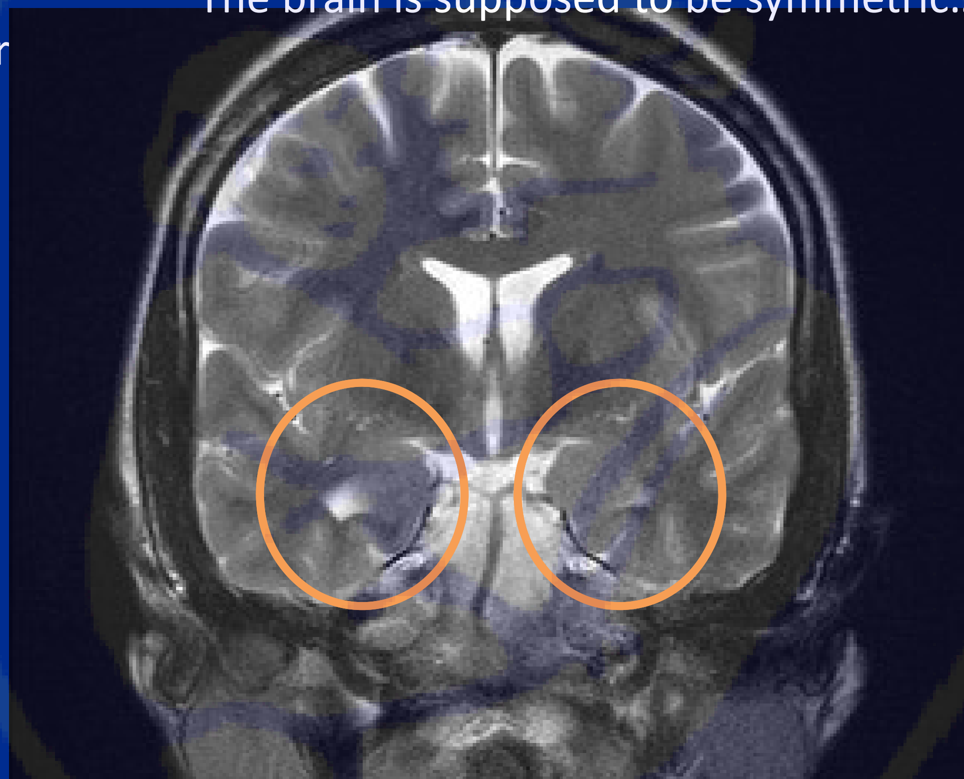
71

# Systematic Evaluation of Anatomy

The brain is supposed to be symmetric…

Always r nmetric:





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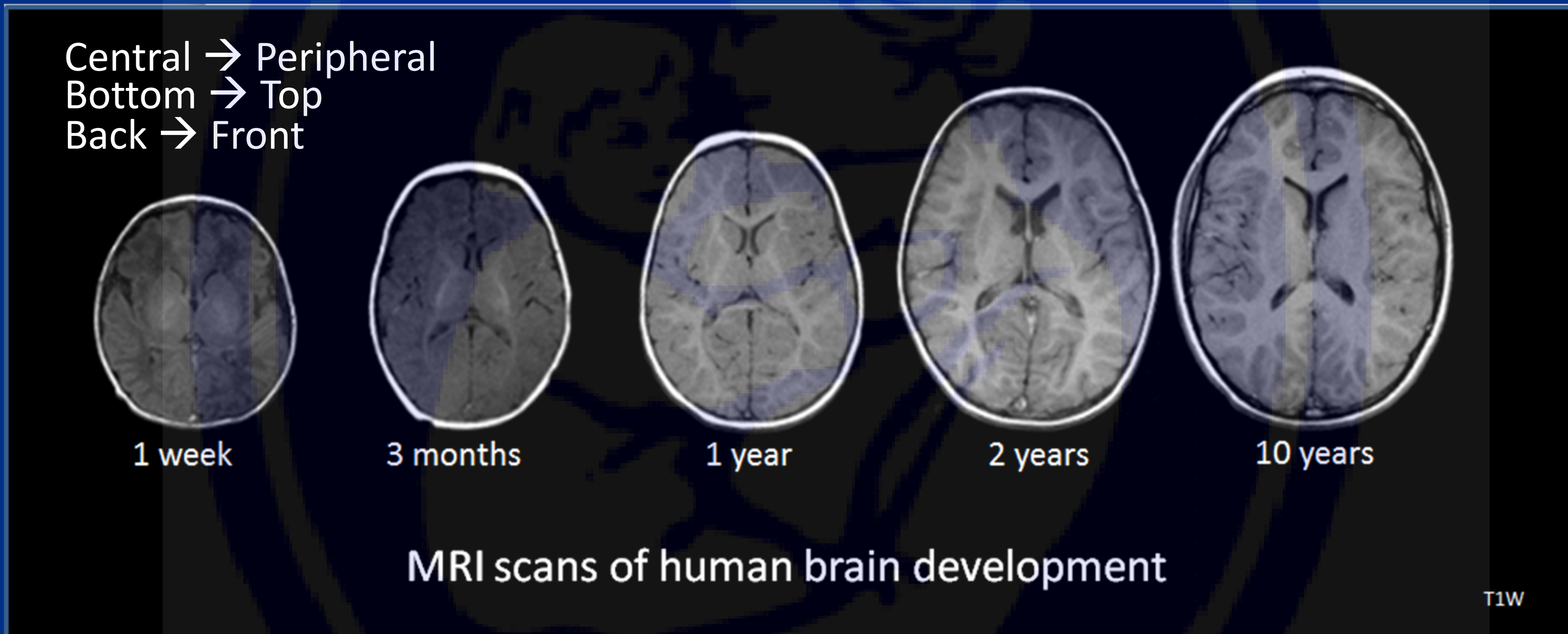
# Myelin changes over development



73

# Myelin changes over development

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# Chiari Malformations

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Ketonen L, Hiwatashi A, Sidhu R. Pediatric brain and spine, an atlas of MRI and spectroscopy. Springer Verlag. (2005)

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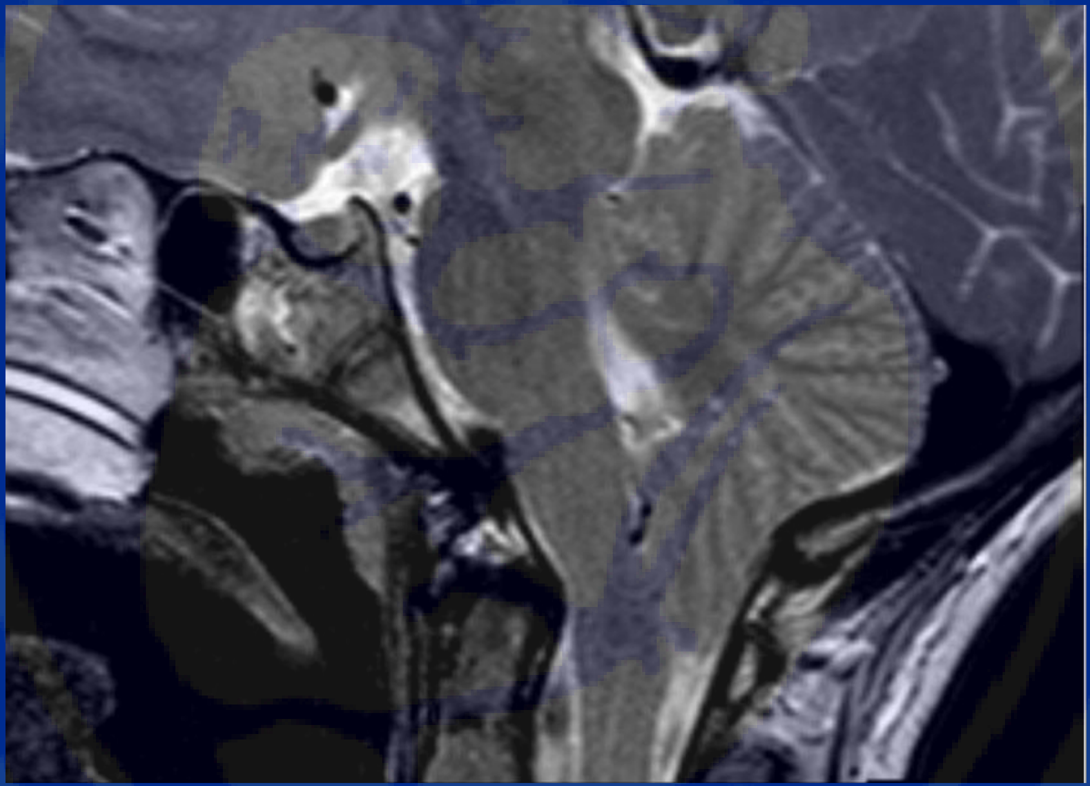
# Chiari Malformations



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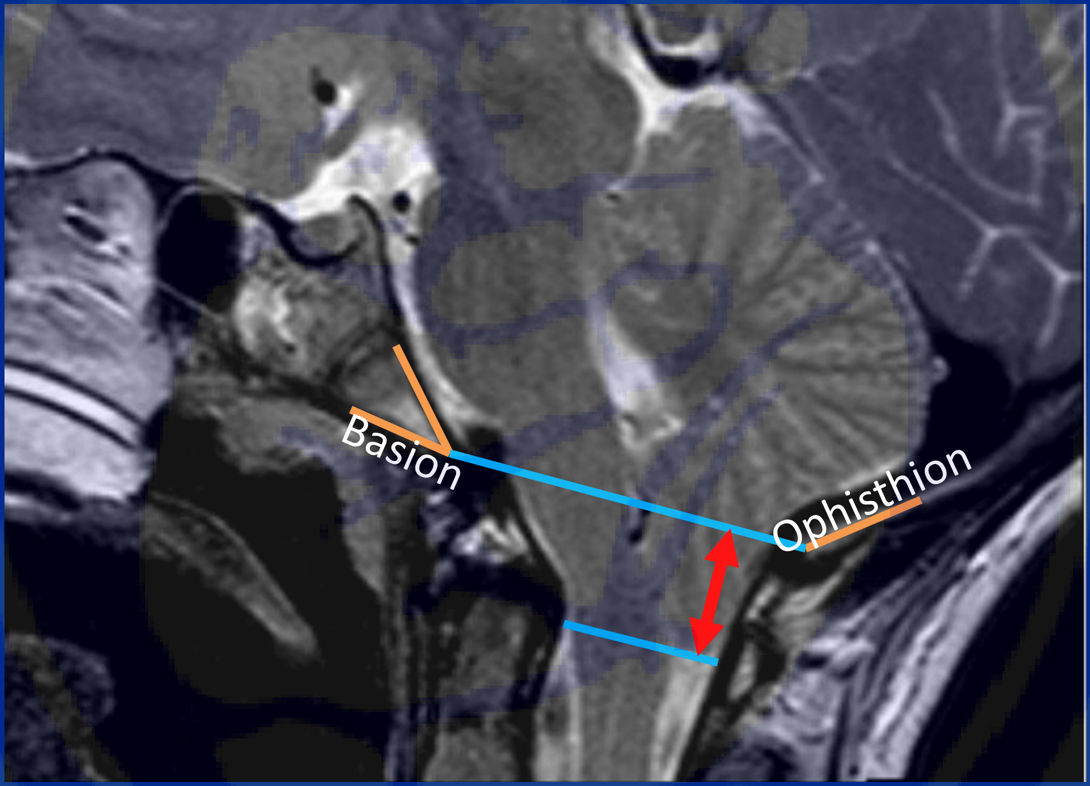
# Chiari Malformations

Measuring tonsillar descent/ectopia



# Chiari Malformations

A Chiari Tangent… Are you a lumper or a splitter?

- Chiari I malformation
  - Symptomatic ~ >5-6mm descent
  - peg-like cerebellar tonsils displaced into the upper cervical canal through the foramen magnum
- Chiari 1.5 malformation
  - described in the literature as both a condition in its own right as well as a variant of Chiari I malformation
  - caudal descent of cerebellar tonsils and brainstem
- Chiari II malformation
  - displacement of the medulla, fourth ventricle and cerebellar vermis through the foramen magnum
  - usually associated with a lumbosacral spinal myelomeningocoele
- Chiari III malformation
  - features similar to Chiari II but with an occipital and/or high cervical encephalocele
- Chiari IV malformation
  - severe cerebellar hypoplasia without displacement of the cerebellum through the foramen magnum
  - probably a variation of cerebellar hypoplasia
- Chiari V malformation
  - absent cerebellum
  - herniation of the occipital lobe through the foramen magnum
- Chiari 0 malformation
  - syrinx
  - no cerebellar tonsil or brain stem descent

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# When to Image the Pediatric Spine

Netter

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# When to Image the Pediatric Spine

- Four big reasons:

Netter

# When to Image the Pediatric Spine

- ~~Four~~ 4.5 big reasons:
  - New onset or inappropriately persistent neurological symptoms
  - New or rapidly progressive scoliosis
  - Persistent back pain and/or signs of infection
  - Trauma to the neck or back
  - (or to evaluate a cutaneous lesion on the back…)

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# In conclusion…

Neil, Sem in Peds Neruo, 2011

# To interpret neuroimaging studies, you need to know:

1. Neuroanatomy sufficient to identify brain structures on imaging studies
2. The standard imaging planes of CT/MRI (and cranial US), how to set up CT windows and understand which MRI sequences give you which pieces of information
3. The characteristic imaging patterns of neurologic disorders
   - (you can only see what you know)
4. How image contrast changes during normal development, especially in relation to myelination
   - (Branson, Neuroimaging Clinics of N America 2013)
5. The temporal evolution of imaging findings for neurologic disorders, particularly stroke and hypoxic-ischemic injury

Use the knowledge and skills from today to help you interpret images throughout the rest of the week

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# Questions?

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