Pediatric Emergency CT and MRI
No Financial Disclosures
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• Fractures, Accidental and Non-accidental
• Hemorrhage, Accidental and Non-accidental
• Retroclival hematomas
• The basics of emergent pediatric brain MRI
• Demyelinating disorders
• Spine
Objectives

- Review imaging features of imaging during the first day of life
- Review imaging features of non-accidental trauma (NAT) and accidental trauma in the pediatric population
- Discuss anatomic and pathophysiologic aspects of pediatric brain hemorrhage, especially in the setting of NAT
- Review imaging features of demyelinating diseases presenting through the ER
- Review emergent pediatric spine imaging in NAT and others
- An introduction to emergent CT and MRI exam protocols
The Newborn Brain
1 day old

- At birth, brain is 89%-82% water
- This decreases to 82%-72% water in an adult
- This 10% difference is what causes myelination changes on MRI

These are normal, probably
1 day old

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1 day old
1 day old

- Hypoxic Ischemic Encephalopathy
- T1 hyperintense signal in the globi pallidi (or thalami)
- May or may not have associated restricted diffusion or T2 signal abnormality
- Remember, HIE is a clinical diagnosis
  - PH < 7
  - Apgar 0-3
  - Neurological signs
  - Multiple Organ failure
1 day old
Edema in an older child
Fractures, accidental and nonaccidental
Le Bonheur CT protocol

- 5 mm reconstructions in ALL THREE PLANES
- Both bone and soft tissue algorithm
- 3d Calvarial reformats for trauma patients and ALL patients under 2 years old
Axial images show no fracture

Coronal reformats show a fracture which was in-plane to the axial images

Sagittal and coronal reformats require no extra-radiation
  - Can be performed even with axial acquisitions if thin collimation

10 month old, scalp swelling
Confirmed on 3D reformats
3 month old, lethargy

- Bilateral mixed-density extraxial collections
3 month old, lethargy

- Bilateral mixed-density extra-axial collections
- Abnormal appearance of the skull
  - What is a splayed suture, what is a fracture?
3 month old, lethargy

- Splayed sutures
- Fracture
- Superior median fissure
- Mendosal fissure
3D reformats

• No additional radiation required

• Reduces false positive fractures
  • i.e. calling a suture (or vascular channel) a fracture

• Reduces false-negative fractures
  • i.e. thinking a fracture is a suture (or vascular channel)

• We add these routinely on all children under 2 years of age, even if there is no history of trauma
Skull

- Scrutinize for fractures in young children, even when the indication for the study does not include trauma

- NAT may present for a variety of indications
  - Seizure
  - Lethargy
  - Failure to thrive
  - Macrocephaly
  - ...
Trauma and satisfaction of search
Trauma and satisfaction of search
Trauma, SO HOW DO WE MAKE OUR LIVES EASIER?
Scalp Windows!

- High window 300-500
- Low level: 10-60
- Its “neuroradiology speak” for an abdomen window
Scalp/abdomen windows vastly improve detection of skull fractures
Other Windows?
Beware of Contrast enhanced CT!
Beware of Contrast enhanced CT!
Beware of Contrast enhanced CT!

- CT angiograms will miss Hemorrhage
  - Especially in the setting of evolving contusions
- CT with Contrast is not as sensitive as contrast enhanced MRI for empyema/infection
Hemorrhage
In adults, the thought is that the “low density” part is a chronic collection, the high density part is superimposed acute blood.

- The low density part is thought to have been asymptomatic due to atrophy in elderly patients.

In this child, the low density part is large enough to have caused herniation.

This patient was asymptomatic prior to the episode and therefore this is likely an acute mixed density collection.
Mixed density collection

- Mixed-density collections do not necessarily mean mixed age
- Layering blood products do not necessarily mean “acute on chronic,” especially in children
Volume of collection

- Children normally have a relatively smaller volume of the subarachnoid space than adults.
- A thin collection with a broad base may have a large enough volume to be highly symptomatic in a child.
  - A 2-3 mm subdural can result in herniation (possibly life-threatening) if it involves the entire convexity.
12 week old with bruising

- CT shows enlarged extra-axial spaces, with areas of increased density
- Right parietal skull fracture identified
- Follow-up head CT in 6 hours shows a homogeneous intermediate density in the extra-axial space
Hematohygroma

- The mixed density finding on the initial imaging is likely an acute hematohygroma.
- Dural tears allow CSF to join blood products in the subdural collection.
- On delayed imaging, the blood products diffused/redistributed within the hematohygroma resulting in an intermediate density appearance.
- This was related to a single injury, and could have been mistaken for mixed-age blood products initially, or a subacute collection on follow-up.
Macrocephaly

- 2 month old with a head ultrasound performed for progressive macrocephaly
- A membrane was identified within the extra-axial space, demarcating a collection that was slightly more echogenic than CSF
Macrocephaly

- CT confirmed enlarged extra-axial spaces
- Careful windowing of the CT shows collections which are slightly higher density (10 HU) than CSF
Macrocephaly

- MRI further characterized the subdural collections
- Secondary membranes were identified within the collection
- Layering blood products were present
• The collections show variable degrees of signal dropout on FLAIR imaging suggesting varying proteinaceous contents
• Pulsation artifact is seen within a second compartment of the right sided collection that otherwise has near-CSF-like properties
Membranes

- Internal membranes are very rarely seen within a new subdural collection
  - This is therefore a highly suspicious feature arguing against a single recent event
- Membranes can occur within 10 days of initial injury
- The membranes may be fibrous and may have capillaries (and therefore may enhance)
- Subdural membranes can predispose to re-bleeding

Determining chronology

- There are a variety of challenges in identifying the chronicity of blood products.
- Studies have shown that radiologists may perform poorly in attempting to determine the age of collections, especially with incomplete information.
- Therefore, avoid playing “CSI” when you are characterizing collections.

Subdural collections may occur after mild trauma in patients with benign enlargement of the subarachnoid spaces of infancy (BESSI). These collections do not specifically indicate (nor do they exclude) abusive head trauma as the etiology for the collections.

Am J Forensic Med Pathol. 2015; 36(2):111-20
Retinal hemorrhages

- Retinal hemorrhages at times can be identified on SWI

- High specificity (~99%) and high positive predictive value
  - i.e. if you see it on SWI, there will almost always be retinal hemorrhages

- Low sensitivity (~41%) and low negative predictive value
  - i.e. in most cases, retinal hemorrhages identified on fundoscopic exam will not be seen on SWI

ARVO 2014 #5849
ACA injury

- ACA injury can occur due to transverse motion and resultant shearing along the free edge of the falx cerebri, as well as compression due to subfalcine herniation.
PCA injury

- PCA injury can occur due to shearing injury of the PCA along the free edge of the tentorium cerebelli, as well as due to compression when there is effacement of the ambient cistern
Venous injury

- Cortical vein thrombosis
- Often best appreciated on SWI
  - Can be also seen on CT
  - Venography (CT or MR) typically not needed
- Rarely seen in accidental head trauma of low mechanism (i.e. fall from changing table)
Irritant effects of subdural hematomas

- Subdural blood products can result in underlying cytotoxic edema even in the absence of significant mass effect.
- There has not been clear identification of the pathophysiologic mechanisms.

J Neurotrauma 2014 31:1625-1631
Progress Brain Research 2007 161: 293-302
Retroclival hematomas
Normal Craniocervical Junction on different modalities

- Cervical CT
- Brain CT
- Sag Stir
Normal Craniocervical Junction on different modalities

- Cervical CT
- Brain CT
- Sag Stir
Normal Craniocervical Junction on different modalities

- 1-12% of all epidural hematomas
- More common in children (usually pedestrian or bicycle hit by a motor vehicle)
- Thought to be due to increased ligamentous laxity in children
- In adults, nontraumatic causes such as pituitary apoplexy and anticoagulation are more common
- Management is usually conservative

Surg Neurol. 2011:78 Tahir et al
Size of epidural projection and any mass effect up on the brainstem or cord is the most important thing

Heterogenous attenuation of the epidural projection is another worrisome sign

As a broad guideline, the sagittal soft tissue for the CT head is a better predictor than cervical soft tissue windows. But take everything into account.

Similarly, STIR > T2 > T1
General comments

• Size of epidural projection and any mass effect up on the brainstem or cord is the most important thing.

• Heterogenous attenuation of the epidural projection is another worrisome sign.

• As a broad guideline, the **sagittal soft tissue** for the CT head is a better predictor than cervical soft tissue windows. But take everything into account.

• Similarly, STIR > T2 > T1
Tectorial Uplifting or Not???
GOOD JOB!!!
The basics of emergent pediatric brain MRI
First question to ask is whether or not the patient is going to be sedated or not
- If patient will receive general anesthesia for the MRI, it is helpful to make sure all desired sequences are acquired
- If a child is not sedated, or they are “trying”
  - Degree of motion will limit sensitivity to some degree on most non-sedated emergent pediatric MRI
  - Key is to balance severity of patient symptoms with imaging findings

We usually perform coronal 3 mm DWI AND axial 25 direction DTI on most patients under two and those with a high ER suspicion of stroke
- Evaluating restricted diffusion in two planes improves mri sensitivity and specificity in restricted diffusion, especially in smaller brains
- ADC maps provide quantitative information, while DTI makes fiber tracking information
Emergency Pediatric DWI

- Clinical diffusion weighted imaging is typically assessed in a qualitative manner.

- A homogeneous symmetric abnormality can be difficult to detect.

- In general, it is poor form to miss a stroke involving the entire brain.

(although it can EASILY happen)
Emergency Pediatric DWI

• Several options
  • 1- know what it “should” look like
  • 2- know quantitative values (in particular ADC)
  • 3- look for other clues
Emergency Pediatric DWI
• Coronal DWI helps confirm borderline cases and improves localization
• Coronal images confirm frontal lobe involvement and temporal restricted diffusion is confined the superior temporal gyrus
Patterns of DWI

- Edema corresponding to white matter tracts (in particular along the splenium and forceps major white tracts is called Myelinic edema)
- Can be post-ictal in etiology
- Again, localization of diffusion abnormalities are markedly improved due to two separately acquired planes
Traumatic brain injury

- All ER trauma patients getting an Emergent MRI should have susceptibility weighted or gradient echo sequences
  - Most sensitive for parenchymal hemorrhage and diffuse axonal injury
  - Poor evaluation of subdural hemorrhage

- Most of the existing knowledge of accidental traumatic brain injury also applies to NAT

- In particular, a normal CT does not exclude injury
23 month old with fever

- Suspected meningitis? Do Contrast enhanced MRI
- No enhancement on post gadolinium T1
- Volumetric T2 FLAIR postgadolinium imaging has higher sensitivity
- Consider adding when clinical suspicion high
23 month old with fever

- Pre and post contrast T2 FLAIR imaging in meningitis
- Consider adding when clinical suspicion high

Axial reconstructions
Seizures

• Subtle left hippocampal edema

• MRI 6 months later shows resolution

• Different patient, right hippocampal atrophy from mesial temporal sclerosis

• Bottom line, consider thin slice T2 imaging through the hippocampi in patients with seizures
Rapid hydrocephalus protocol

- Shunt patients have repeated CT evaluations, exposing them to radiation multiple times
- Rapid protocol obtains 3-plane T2 weighted images in 40 seconds
- We also add a DTI sequence
- Scan time of about 3:00 minutes
- Careful patient selection is key
  - Must have a prior CT
  - Must be read by a neuroradiologist
  - Subtle changes in ventricular caliber will be hard to detect
  - Evaluation of the shunt catheter itself is limited
Diagnosis?

- No enhancement
- Ipsilateral volume loss and loss of grey-white matter differentiation
- Rapid onset
- Rasmussen’s Encephalitis
Demyelinating diseases
17 yo with headache
Same day emergent MRI
Same day emergent MRI
Biopsy was done
10 days later
10 days later
MRI Spectroscopy
Two months later
ADEM

• Usually children, but can happen in all ages

• 3 forms have been described
  • **Monophasic** - Multifocal clinical syndrome without prior event
  • **Recurrent ADEM** - Second attack involving same anatomic areas more than 3 months after the initial event
  • **Multiphasic ADEM** - Second event in a different anatomic area (clinically or MRI) after 3 months.

• Decreased chance of recurrence in myelitis and encephalopathy
Multiple sclerosis McDonald Criteria DIT & DIS

Dissemination in Space

<table>
<thead>
<tr>
<th>DIS Can Be Demonstrated by $\geq 1$ T2 Lesion$^a$ in at Least 2 of 4 Areas of the CNS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periventricular</td>
</tr>
<tr>
<td>Juxtacortical</td>
</tr>
<tr>
<td>Infratentorial</td>
</tr>
<tr>
<td>Spinal cord$^b$</td>
</tr>
</tbody>
</table>

Based on Swanton et al 2006, 2007.$^{22,27}$

$^a$Gadolinium enhancement of lesions is not required for DIS.

$^b$If a subject has a brainstem or spinal cord syndrome, the symptomatic lesions are excluded from the Criteria and do not contribute to lesion count.

MRI = magnetic resonance imaging; DIS = lesion dissemination in space; CNS = central nervous system.

Dissemination in Time

<table>
<thead>
<tr>
<th>DIT Can Be Demonstrated by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A new T2 and/or gadolinium-enhancing lesion(s) on follow-up MRI, with reference to a baseline scan, irrespective of the timing of the baseline MRI</td>
</tr>
<tr>
<td>2. Simultaneous presence of asymptomatic gadolinium-enhancing and nonenhancing lesions at any time</td>
</tr>
</tbody>
</table>

Based on Montalban et al 2010.$^{24}$

MRI = magnetic resonance imaging; DIT = lesion dissemination in time.
Other considerations

- Nmo
- Vasculitis
- Infection
- Tumor
- “infectious/inflammatory response”
Spine
Spine injury in NAT

- Historically, radiographic skeletal survey was used to evaluate for spine injuries.
- Cross-sectional imaging has shown fractures not (easily) seen on radiographic studies.

Pediatr Radiol (2014) 44 (S4):S604-S612
Spine Ligamentous injury

- Cervical spine ligamentous edema found in 78% of abusive head trauma patients in one study
  - Seen in 46% of accidental trauma patients, 1% of non-traumatic patients (p<0.05)
- Injury most often to the posterior ligamentous complex (interspinous and nuchal ligaments)

Pediatric Radiology 2014 ;44 (9): 1130-1140
Spinal subdural hematomas

- Study of spine imaging in children with abusive head trauma (AHT), with a comparison cohort of children with documented accidental trauma
- 24 of 38 (63%) of patients with AHT with thoracolumbar cross-sectional imaging had spinal subdural collections
- 1 of 70 patients with accidental trauma had spinal subdural hematomas (1%) (p<0.001)

Radiology 2012; 262 (1): 216-23
Outside CT for STAT review
Outside CT for STAT review
Outside CT for STAT review
Take home points
Take home points: *Fractures*

- Skull fractures from minor trauma are more common in young infants prior to development of a diploic space.
- NAT with fractures may present with a non-traumatic history, such as seizures, lethargy, or failure to thrive.
- Multiplanar reformats can help avoid missing fractures that are in the axial plane.
- 3D reconstructions can help in differentiating sutures from fractures.
Take home points:

**Blood**

- Mixed-density/intensity collections can be of a single age
- A low to intermediate density collection may be an acute hematohygroma
- Layering blood products within a subdural collection does not necessarily mean acute-on-chronic
- Internal membranes within a subdural collection are not typically identified in acute collections (<10 days)
- SWI can help identify retinal hemorrhages
  - Negative predictive value inadequate to replace dilated fundoscopic examination
Take home points: 

**Blood**

- A normal CT does not exclude brain parenchymal injury
- Subdural hematomas in NAT can result in cerebral infarctions, possibly related to cytotoxic effects
- Thin (2-3 mm) extra-axial collections with a broad base can result in herniation in young children if the total volume of blood is greater than the volume of the subarachnoid space in the ipsilateral hemicraniun
Take home points: *Blood vessels*

- Injury of the ACA and PCA can occur due to shearing forces along the falx cerebri and tentorium cerebelli, respectively, and impingement can occur due to compression in the setting of herniation.

- Cortical vein thrombosis is a feature suggestive of NAT (as opposed to accidental trauma).
Take home points: 
*Retroclival Hematomas*

- **Sagittal soft tissue** of the CT head is a better predictor than cervical soft tissue windows.

- **STIR** > **T2** > **T1**
Take home points:  
**Demyelinating processes**

- MS is usually periventricular and needs dissemination in time and space
- ADEM can be anywhere
Take home points: Spine

- Osseous and ligamentous injuries of the spine can occur in NAT

- Cross-sectional imaging identifies more fractures than radiographic evaluation

- Posterior ligamentous injury of the cervical spine is seen more commonly in abuse (78%) than accidental trauma (46%) (but is not unique to abuse)

- Spinal subdural hematomas are seen much more often in cases of abuse (63%) vs accidental trauma (1%)
  - If confirmed in multicenter studies may be a feature to improve specificity in identification of abuse
Parting comments

- Don’t play “CSI” - be objective in your analysis
- Our primary responsibility is to take care of the patient, NOT to help them prosecute the perpetrator
- A team-approach is important
- Multiplanar reconstructions and effective windowing can vastly improve detection of skull fractures and hemorrhage
- Depending on the clinical indication, additional sequences, such as Coronal DWI, SWI, post contrast T2 Flair, and thin slice imaging through the hippocampi can improve diagnostic accuracy. Highly consider the above when protocolling emergent MRI for a pediatric patient; especially if sedation is being used.
Thank you to Dr. Karen Lakin and the CARES team (child abuse team) at Le Bonheur Children’s Hospital for their clinical collaboration on these challenging cases.
Thank you!