Pediatric Neuroimaging in Cases of Suspected Non-Accidental Head Trauma

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HMS Class of 2010
BIDMC PCE 2008-2009

Note: All case images are courtesy of Children’s Hospital Boston
Non-Accidental Head Trauma (NAHT)

- CNS injury is the principle cause of death from child abuse.
- Up to 64% of head injuries in infants 3-11mos are secondary to abuse.
- Crying is believed to be the main provocative factor.
- Outcomes: Mortality ranges from 15-38%
Why are infants more vulnerable?

Mechanism:
- Generally believed to be due to acceleration/deceleration forces especially of the rotational type.
- There is significant controversy regarding whether or not impact is required to cause significant damage. (“Shaken-Impact Syndrome”).
- Apnea and brain swelling leading to hypoxic-ischemic encephalopathy.

Infant Susceptibility:
- Peak @ 6 months of age.
- Relatively large heads
- Weak neck muscles
- Relatively large subarachnoid spaces
- Immature myelination and small size axons leading to softer brains
- Thin, soft skulls that easily transmit forces from the impulse to deeper structures
- Infants are more prone to apnea

Shaken Baby Syndrome Simulator
The Role of Radiographic Evidence

NAHT is often misdiagnosed or missed and imaging may be the first indication of abuse...

1. Diagnosis
2. Documentation

Assessment –
- Identify the extent of injury
- Elucidate all image findings
- Suggest a differential diagnosis

... but the implications are extremely serious!

Note: Skeletal trauma is the main radiological manifestation of non-accidental trauma.
Our Patient ~ “Casey”*

Abbreviated History

CC: “Casey” is a previously healthy 4 month old girl brought to the Boston Children’s Hospital Emergency Room by her grandmother with an apparent ALTE (acute life threatening event).

HPI: On the day of admission “Casey” was taking her morning bottle when she began to act very sleepy, became limp and then turned blue. The grandmother reports that “Casey” has had several other episodes where she becomes slightly limp, but these episodes have resolved within several minutes without noticeable color change. The pediatrician was aware of the episodes and, at the time, attributed them to a viral illness that several family members were suffering from.

PMH: “Casey” was a full-term delivery vaginally without complications. Grandmother reports that she developmentally normal. She has never had surgery or been hospitalized.

SH: “Casey” lives with her 18 year old mother, her grandmother and several other family members. Her father lives with the paternal grandmother and “Casey” spends one day a week with him. The maternal grandparents are in the process of legally adopting “Casey”.

* All patients’ name have been changed to protect their identities.

In the ED “Casey” gets a CT Head...
“Casey” Images 1 & 2: Axial C- Head CT. Right subdural hematoma over right convexity measuring 3mm in width and along the right tentorial margin as well as extension to falx. The ventricles are normal in size. There is no evidence of hydrocephalus. There is no midline shift or mass effect. No definite fractures are identified. No intraparenchymal hemorrhage is seen.
Subdural Hemorrhage

The classic intracranial process believed to be caused by shaking (possibly with impact) is the subdural hemorrhage.

Depiction of tearing of the bridging vessels during violent shaking. (Label adapted from the original labeled as “subarachnoid hemorrhage”.)
http://i126.photobucket.com/albums/p111/jovi99/med-08-shaken-baby.jpg
“Casey” ~ Sagittal Head MRI

“Casey” image 3: Sagittal Head MRI showing high signal bleeding along the posterior tentorial margin.
“Casey” ~ Head MRI

“Casey” image 5: T1-weighted Axial MRI showing high signal blood along the right tentorial margin.

“Casey” image 6: Gradient echo sequence (MPGR) Axial MRI showing dark signal blood, “blooming artifact”, along the right tentorial margin.
Building a case for or against NAHT

- History (e.g. unlikely or changing story)
- Physical (e.g. outward signs of abuse)
- Imaging
  - Skeletal Survey (e.g. classic fractures, multiple fractures and fractures of different ages)
  - Radionuclide bone scan (e.g. subtle rib fractures)

➤ Neuroimaging
- Ophthalmologic Exam (e.g. retinal hemorrhages)
- Full Dept of Child Protective Services Evaluation
Neuroimaging Modalities

1. Ultrasound Head
2. Skull Radiograph
3. Head Computed Tomography
4. Head Magnetic Resonance Imaging

• **WHEN** do we use each modality?
• **WHY** do we use each?
• **WHAT** do we look for specifically with each?
• **HOW** do we assess for these findings?
• **WHICH** features suggest NAT?
WHEN?

ACR Appropriateness Criteria® in Suspected Physical Child Abuse

**Variant 1:** Child 2yrs or less, no focal signs or symptoms.

<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Comments</th>
<th>RRL *</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray skeletal survey</td>
<td>9</td>
<td>Includes at least 2 views of the skull.</td>
<td>Med</td>
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<tr>
<td>MRI head</td>
<td>5</td>
<td>For evidentiary purposes only.</td>
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<tr>
<td>NUC Tc-99m bone scan whole body</td>
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<td>May be useful in selected cases. For evidentiary purposes only.</td>
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<td>High</td>
</tr>
<tr>
<td>US abdomen</td>
<td>2</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

**Rating Scale:** 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level*
WHEN?

**ACR Appropriateness Criteria® in Suspected Physical Child Abuse**

**Variant 2:** Child 2 years or less, head trauma by history, no focal findings, no neurological abnormality.

<table>
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</tr>
<tr>
<td>US abdomen</td>
<td>2</td>
<td></td>
<td>None</td>
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</table>

**Rating Scale:** 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level*
Variant 3: Child up to age 5, seizures or neurological signs and symptoms, with or without physical findings.

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</tr>
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<td></td>
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<tr>
<td>X-ray skeletal survey</td>
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<td>Med</td>
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<td>May be appropriate as alternative to CT or</td>
<td>None</td>
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<tr>
<td></td>
<td></td>
<td>following CT.</td>
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<tr>
<td>NUC Tc-99m bone scan whole body</td>
<td>4</td>
<td>May be useful in selected cases. For</td>
<td>Med</td>
</tr>
<tr>
<td></td>
<td></td>
<td>evidentiary purposes only.</td>
<td></td>
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<tr>
<td>US head</td>
<td>2</td>
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<td>None</td>
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</table>

Rating Scale: 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level

www.acr.org
WHEN?

ACR Appropriateness Criteria® in Suspected Physical Child Abuse

Variant 4: Child of any age, visceral injuries, discrepancy with history, physical and laboratory examinations inconclusive.

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<td>Med</td>
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<tr>
<td>CT abdomen and pelvis with contrast</td>
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<td></td>
<td>High</td>
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<tr>
<td>MRI head</td>
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<td></td>
<td>None</td>
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<tr>
<td>MRI abdomen and pelvis</td>
<td>2</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>CT head</td>
<td>2</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>US abdomen and pelvis</td>
<td>2</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>CT abdomen and pelvis without contrast</td>
<td>2</td>
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<td>High</td>
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*Relative Radiation Level

Rating Scale: 1=Least appropriate, 9=Most appropriate
Cranial Imaging Modalities

✓ WHEN to use each modality?
  • WHY do we use each?
  • WHAT do we look for specifically with each?
  • HOW do we assess for these findings?
  • WHICH features suggest NAT?

(and some examples)
1. Head Ultrasonography

When?
- Immediate triage
- Never as the sole investigative modality

Why?
- Can be performed at the bedside in clinically unstable children
- Doesn’t require conscious sedation
- Highly sensitive for detection of frontoparietal white matter tears
- Can differentiate convex subdural from subarachnoid fluid collections.

What?
- Subdural hemorrhage
- Cystic changes due to shear injuries

How?
- Performed via the anterior fontanelle in young infants.

Which?
- Any fluid collections should be concerning for hemorrhage in an unstable infant.

U/S Image: Sagittal sonography showing a hypoechoic tear with echogenic margins and large echogenic subdural collections overlying the subarachnoid spaces.

Kleinman 1998
2. Skull Radiograph

When?
- In any child <2y with suspected NAT

Why?
- Radiography of the skull is preferred over CT, because fractures parallel or nearly parallel to the section orientation are missed at CT

What?
- Skull fractures

How?
- Two views (anteroposterior and lateral) are recommended as part of the skeletal radiographic survey, with additional views taken as necessary, especially if head trauma is suspected

Which?
- Multiple and/or bilateral fractures
- Fractures that cross sutures
- Midline or occipital fractures
- Diastatic (separated) fractures
- Depressed fractures

Note: The absence of a skull fracture does not rule out the possibility of intracranial abnormalities!

Example ~ Companion Patient 1 ~ “Thomas”

Skull Radiograph demonstrating a skull fracture.

“Thomas”: 6 month old who was taken to clinic to see PCP due to a "soft, boggy, swelling of the head" that the mom had noticed that morning.

Mom reported that “Thomas” pulls himself up and subsequently falls a lot.

He was noted to have 3 posterior rib fractures as well.

“Thomas” Image 1: AP Skull Radiograph demonstrating a linear fracture line.
3. Head Computed Tomography

When?
- Non-contrast CT is a part of the initial evaluation of suspected inflicted head injury and is the most important imaging modality for assessing acute NAHT

Why?
- Very sensitive for detecting fresh blood & edema.

What?
- Hemorrhage
- Edema
- Anoxic-ischemic encephalopathy (i.e. infarction)
- Often reconstructed, wide window “bone” images are used to detect skull fractures

How? Non-contrast

Which?
- Intra hemispheric subdural hemorrhage
- Different age hemorrhages
- Subarachnoid hemorrhage
- Cerebral edema
- The “Reversal Sign” – Diffuse loss of grey-white matter differentiation with decreased attenuation of the cortex and relative brightness of the basal ganglia, cerebellum, thalami and brain stem
- The “White Cerebellum Sign” – Relative hyperdensity of the cerebellum in contrast with ischemic cortex

Note: A negative CT does not preclude the presence of a subdural hemorrhage.
Remember “Casey” ~ Axial C- Head CT

CT demonstrating the “classic” subdural hematoma.

“Casey” Images 1 & 2: Axial C- Head CT. Right subdural hematoma over right convexity measuring 3mm in width and along the right tentorial margin as well as extension to falx. The ventricles are normal in size. There is no evidence of hydrocephalus. There is no midline shift or mass effect. No definite fractures are identified. No intraparenchymal hemorrhage is seen.
Example ~ Companion Patient 2 ~ “Sarah”

CT demonstrating cerebral edema.

“Sarah”:
3 month old found limp by babysitter.
The extensive intracranial injury was highly suspicious for child abuse.
“Sarah” died 2 days later.

“Sarah” image 1: Axial C- Head CT showing subdural blood layering along the cerebellar tentorium and a small focus of subarachnoid hemorrhage.
“Colin”:

4 month old presents to his pediatrician’s office for vomiting and is noted to have a rapidly enlarging head circumference.

Found to have a skull fracture…

“Colin” image 1: Obliquely oriented reformatted image from CT demonstrating a long linear skull fracture.
“Colin” ~ CT Skull Reconstruction

Reformatted Head CT demonstrating a skull fracture.

“Colin” image s 2 & 3: Reconstructed digitalized Skull CT demonstrating a long linear temporal fracture.
"Colin" images 4 & 5: Head CT. **Bifrontal subdural collections** that are intermediate density and heterogeneous, indicating that the blood is not acute (which you would expect to be dense or bright on CT), but rather more subacute. The collections look somewhat **heterogeneous**, raising suspicion for repeat episodes of bleeding possibly indicating multiple separate traumatic episodes.
Example ~ “Reversal Sign”

Figure: Transverse unenhanced CT scan demonstrates reversal sign with decreased attenuation overall and loss of gray-white differentiation. Note relatively increased attenuation of (a) basal ganglia (arrows), (b) thalami (thin arrows), and cerebellum (wide arrows). (Explination and marking taken from the original paper).

High association with NAT, especially when in conjunction with a subdural hemorrhage.

BUT... not specific for NAT – Can also be seen in drowning, trauma and accidental trauma.

C- Axial Head CT.
Kavanagh 2007
Example ~ “White Cerebellum Sign”

Considered an early sign of brain edema. Often seen in non-accidental causes of hypoxia such as strangling or suffocation. BUT... again, not specific, can be seen in drowning or circulatory collapse.

Dwarakanath et al. 2006

Figure 2: A, B Plain CT brain: revealing diffuse hypodensity of both cerebral hemispheres with patchy areas of isodensities in the brain parenchyma with relative hyperdensity of cerebellum (black arrow), i.e. ‘white cerebellum sign’
4. Head Magnetic Resonance Imaging

When?
- Always indicated when NACT is suspected and CT does not show any abnormalities.
- MRI is the modality of choice is assessing the damage to the brain after the acute insult.

Why?
- Superior anatomical resolution, multiplanar imaging capability and the absence of artifact caused by the skull on CT allows for the detection of very small hemorrhage and extra-axial fluid collections.

What?
- Generally same as CT plus early hemorrhage and contusion.
- Can be used for evaluation of retinal hemorrhage, but does not replace a full ophthalmologic exam.

How?
- Imaging protocol should include:
  - T1 weighted spin-echo images in different planes: Subacute hemorrhage
  - T2 weighted gradient-echo: Detects old shear hemorrhages
  - Diffusion weighted images: Early parenchymal changes consistent with contusion.

Which?
- Subacute subdural hemorrhage
- Fluid-fluid levels suggestive of bleeds of different ages (i.e. repeated trauma).

Normal Head MRI.
A&C. T1&T2 Axial B&D. T1&T2 Sagittal.
http://www.vumc.nl/afdelingen-themas/135370/27788/749371
Example ~ “Thomas” (again)

MRI demonstrating soft tissue injury.

“Thomas” image 1: T2 weighted image MRI sequence demonstrating a right-sided subgaleal hematoma.

“Thomas” image 2: T1 weighted MRI sequence with IV gadolinium contrast demonstrating a right-sided subgaleal hematoma.
**Remember “Casey” ~ MRI Head**

MRI demonstrating a subdural hemorrhage.

“Casey” image 5: T1-weighted MRI showing high signal blood along the right tentorial margin.

“Casey” image 6: Gradient echo sequence (MPGR) MRI showing dark signal blood, “blooming artifact”, along the right tentorial margin.
Example ~ “Colin” (again)

MRI head demonstrating bilateral subdural hemorrhages.

“Colin” image 6: T1 weighted MRI sequence. Bilateral subdural collections shown as high signal indicating subacute blood. Temporal bone fracture is also noted on this slide.
Example ~ “Colin” ~ Complications

MRI Head demonstrating meningitis as a complication of the subdural bleeds.

“Colin” image 6: T1 weighted MRI with IV gadolinium contrast. Diffuse leptomeningeal or meningeal enhancement indicative of meningitis.
Example ~ “Colin” ~ Complications

MRI Head demonstrating a subdural empyema as a complication of the meningitis.

“Colin” image 7: Restricted diffusion MRI. Area of high signal in subdural space indicative of standing debris-filled fluid. Correlated with the clinical picture of fever and nucal rigidity and radiographic signs of meningeal irritation to be pus.
Differential Diagnosis of Intracranial Bleeding in Infants

- Non-accidental Head Trauma
  - Accidental Injuries and Falls
  - Birth Trauma
  - Congenital coagulopathies
  - Congenital TORCH infections
  - Congenital vascular malformations
  - Neuroblastoma
  - Benign infantile enlargement

- Glutaric aciduria type I
  - Hemophagocytic lymphohistiocytosis
Glutaric Aciduria Type I

Glutaric aciduria type 1 (GA-1) is an autosomal recessive inborn error of lysine, hydroxylysine and tryptophan metabolism that results from a deficiency of glutaryl-CoA dehydrogenase. It is characterized by subdural hematomas and frontotemporal atrophy in both symptomatic and asymptomatic patients.

Recommend for diagnosis:

- Urinary organic acid analysis
- Measurement of blood spot glutaryl carnitine
- Total and free plasma carnitine concentrations
  results should be confirmed by measuring glutaryl-CoA dehydrogenase activity in leukocytes or cultured fibroblasts.

Note:

- Subdural hemorrhages have been found in symptomatic and asymptomatic patients as early as the immediate postnatal period
- GA-1 does not cause skeletal abnormalities or predispose patients to fractures
- Subdural hemorrhages have not been reported in GA-1 without frontotemporal atrophy

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Elsori, 2004
~Putting it all together ~

Building a case for or against NACT

- History (e.g. unlikely or changing story)
- Physical (e.g. outward signs of abuse)
- Imaging
  - Skeletal Survey (e.g. classic fractures, multiple fractures and fractures of different ages)
  - Radionuclide bone scan (e.g. subtle rib fractures)
  - **Neuroimaging:**
    - **U/S** – Fluid collections? White matter tears?
    - **Skull Radiograph** – Fractures?
    - **C- CT** – Hemorrhage? Edema? Ischemia?
    - **MRI** – Subtle hemorrhage? Age of blood? Contusions? Infection?
- Ophthalmologic Exam (e.g. retinal hemorrhages)
- Full Dept of Child Protective Services Evaluation
References

Acknowledgements

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