ALL-DAY CONFERENCE

CHILD ABUSE EVIDENCE:
Perspectives from Law, Medicine, Psychology + Statistics

Friday, November 6 from 8:30 a.m. to 4:30 p.m.
University of Michigan Law School Honigman Auditorium, 100 Hutchins Hall
Child Abuse – Nonaccidental Injury (NAI)
Abusive Head Trauma (AHT)

Medical Imaging

Issues and Controversies
in the
Era of Evidence-Based Medicine

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Child Abuse Evidence Conference
University of Michigan November 2015
Child Abuse, NAI, AHT, and the Mimics:

- **Centre for Forensic Science and Medicine**, (Gouge Inquiry). University of Toronto, Toronto Ontario, Canada, Sept. 25, 2009.
- **National Association of Criminal Defense Lawyers (NACDL) and the Innocence Network** (Bureau of Justice Assistance Grant), April 15, 2010, Atlanta GA.
- **The Innocence Network**. SBS Defense Network.
- **Narang S**. A Daubert Analysis of Abusive Head Trauma / Shaken Baby Syndrome. 11 Houston J Health Law & Policy 2011;505.
- **Guthkelch A.N.** Problems of Infant Retino-Dural Hemorrhage with Minimal External Injury. 12 Houston J Health Law & Policy 2012; 201.
“Shaken Baby Syndrome (SBS) is a form of physical non-accidental injury (NAI) to infants, characterized by

acute encephalopathy with subdural hemorrhage and retinal hemorrhage (i.e. the Triad),

occurring in the context of inappropriate or inconsistent history and

commonly accompanied by other apparently inflicted injuries (e.g. fractures).”

Am Acad Peds (AAP). Pediatrics 1993;92:872;
Brit Med J 2004; 328: 720
Shaken Baby Syndrome (SBS)

Battered Child Syndrome / Shaken Baby Syndrome  
The “Traditional” Literature

- **Caffey J.** Multiple fractures in the long bones of infants suffering from chronic subdural hematoma. Am J Roentgenol 1946; 56: 163-173.


Head Injury in NAI
Mechanisms

- Battering
- Shaking (Shaken Baby Syndrome)
- Impact
- Shaking-Impact
- Strangulation / Suffocation
- Combined (Shake-Bang-Choke)
- Other
Child Abuse - NAI

The Numbers?

- >100,000 Emergencies / year USA.
- Half of deaths infancy to puberty.
- NAI >80% deaths (>3,000/yr.) from traumatic brain injury in children < 2 yr.
- Peak incidence 6 months of age.
- Transplant Organ Harvesting and Adoption Issues?

Nonfatal Maltreatment of Infants
US Oct. 05 - Sep. 06
CDC MMWR Report April 4, 2008

More Numbers ?

- National Child Abuse and Neglect Data System (NCANDS).
- CDC and ACF (Admin. For Children and Families).
- 905,000 < 18 yrs. (3.6 million investigated).
- 91,278 infants < 1 yr. (23 per 1000 annual).
- 29,881 < 1 wk. (33%).
- Neglect 68%, Physical Abuse 13%.
- No standardized definitions. No details of maltreatment.

www.cdc.gov/mmwr
• Verified Cases of Child Abuse/Neglect Decline in California.

• In California and nationwide, rates of substantiated child abuse and neglect cases are falling.

• Child welfare experts differ on the reasons for the decline, but many suggest that public awareness and prevention programs, as well as changes in how cases are investigated, may play a role.

• In 2012, there were 487,016 reported allegations of child abuse and neglect in California. Of those cases, 17% were substantiated (verified) by the state child welfare.
Head Injury (i.e. Triad) – Suspected NAI

Imaging can not reliably distinguish nonaccidental injury from accidental injury, or from predisposing or complicating medical conditions.


The Triad
Differential Diagnosis

- Trauma (AI vs. NAI)
- Hypoxia-Ischemia / Reperfusion
- Birth Injury
- Venous thrombosis
- Apnea / Choking / Respiratory Arrest
- Infection & Post-infectious (e.g. vaccinial)
- Status Epilepticus
- Hematologic (Coagulopathies)
- Vitamin Deficiency (C, D, K).
- Metabolic Disorders (e.g. GA1, Menkes)
- Vascular / Connective Tissue Diseases (e.g. OI).
- ECMO
- Congenital Heart Disease
- Cervical Spinal Cord Injury
- Multifactorial / Synergistic (including CPR)
- **No Body Knows**
Skeletal Injury – Suspected NAI

Imaging can **not reliably** distinguish nonaccidental injury from accidental injury, or from predisposing or complicating medical conditions, including the Bone Fragility Disorders.


NAI – Bones
Skeletal Fragility Disorders

- Fractures, often multiple, unexplained
- Ribs, CMLs, etc.
- Varying ages
- Skeletal Survey
- DXA scan
- SOS Ultrasound
- QCT


Rickets vs. Abuse


Ayoub D, Miller M, Hyman C. Evidence of metabolic bone disease in young infants with multiple fractures misdiagnosed as child abuse (PAS, RSNA, ASBMR).


4mM ALTE (Vita D Defic Hypocalcemia)
CT Brain – Global Injury (hypoxia-ischemia)
4mM ALTE (Vita D Defic Hypocalcemia)
CT Skull Craniotabes, Fracture
4mM ALTE (Vita D Defic Hypocalcemia)
MRI – Global Brain Injury (hypoxia-ischemia)
4mM ALTE (Vita D Defic Hypocalcemia)
Increased Intracranial Pressure, Craniotabes - Rickets
4mM ALTE (Vita D Defic Hypocalcemia)
Ribs - Rickets
4mM ALTE (Vita D Defic Hypocalcemia)
Rickets
3m infant with alleged NAI; also, “history” consistent with **Congenital Rickets**. Chest film (a) shows bilateral recent and old, healing rib fractures (pseudofractures? rachitic rosary? - arrows). Knee films before (b) & after (c) vitamin D supplementation show “healing” CML (arrows)?


Vita D Rickets References

NAI – Bones

- Fractures, often multiple, unexplained
- Ribs, CMLs, etc.
- Varying ages
- NAI vs. AI
- Birth Injury
- Bone Fragility Disorder
- Skeletal Survey
- DXA scan
- QUS
- QCT


Congenital / Neonatal Rickets


Vitamin D Update


Evidence Base

Conclusions

- **The Triad**: RH + SDH + Encephalopathy **not specific for NAI**.
- **Bone “Fractures”** (e.g. CML) **not specific for NAI**.
- May occur with accidental trauma.
- May occur with medical conditions.
- Must consider Predisposing Risk Factors.
- Must consider Multifactorial, Synergistic, & Cascade Effects.
- **Multidisciplinary Approach**.
- **Imaging cannot provide precise causation or timing of “Injury.”**


Child Abuse – Nonaccidental Injury (NAI) Recommendations
“A Compassionate Approach”

- Thorough Medical & Forensic Work-Up.
- Child & Family Protective Evaluation & Management.
- Timely Imaging – CT, MRI, Skeletal Survey.
- Differential Diagnosis.
- Multidisciplinary Approach.
- Research - Genetic / Molecular Predisposition.
- Reframing Neglect / Abuse - Opportunities for Prevention.
- Prenatal Care 84%, Medical Setting Births 99%.
- Early Risk Detection, Management.
- Parent training (e.g. during pregnancy).
- Home visitation.
- Social Support.
- Transplant Organ Harvesting & Adoption Issues.
- **Stop Cost-Shifting from Medical / Social System to Criminal Justice System.**

CDC MMWR Report April 4, 2008
www.cdc.gov/mmwr
Child Abuse – NAI
“Traditional” Medical Diagnosis
Mandatory Reporting & Provider Immunity

- Injury out of proportion to history (unwitnessed)
- Tearing or shearing of brain, blood vessels, bone.
- Injuries of varying ages
- SDH +RH + Encephalopathy (the Triad)
- +/- Skeletal Lesions (the Tetrads)

Clinical & Imaging Criteria?
- Quality of Evidence?
- Mimics including accidental trauma?
- Child Abuse Pediatrician?
- Multidisciplinary CPS?

Evidence-Based Medicine
Quality of Evidence (QOE)
Diagnosis or Prognosis

- **Class I**: Prospective study; broad case spectrum v. controls; gold standard; blinded evaluation; tests for diagnostic accuracy.
- **Class II**: Prospective study, narrow case spectrum; Retrospective study broad case spectrum; gold standard; controls; blinded evaluation; tests for diagnostic accuracy.
- **Class III**: Retrospective study; narrow case / control spectrum; blinded evaluation;
- **Class IV**: Non-blinded evaluation; expert opinion alone; descriptive case series; no controls.
- **Experienced-Based ?? (COCAN / AAP).**

Guyatt et al. Users’ guides to the medical literature. XXV. Evidence-based medicine. JAMA 2000;284:1290-1296;
Crosskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med 2003;78:775-780.
Evidence-Based Medicine
Quality of Evidence (QOE)
Recommendations

• **Level A:** Established useful / predictive (or not) for given condition / population; [1 Class I or 2 Class II studies] = Standard.
• **Level B:** Probably useful / predictive; 1 Class II or 3 Class III studies] = Guideline.
• **Level C:** Possibly useful / predictive [2 Class III studies] = Optional.
• **Level D:** Data inadequate or conflicting; Unproven; = Contraindicated.
• **Experienced-Based ?? (COCAN / AAP).**

INFORMED CONSENT

Crosskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med 2003;78:775-780.
Evidence-Based Medicine
Shaken Baby Syndrome
Quality of Evidence (QOE)

• Few published reports merit a rating above class IV.

• Class IV: test not applied in blinded fashion; expert opinion alone; descriptive case series without controls.

• Not basis for standards or guidelines.

• Inconsistent Diagnostic Criteria; Faulty Inclusion Criteria; Circular Logic; Conviction and Confession based.

• Why not Exculpatory Polygraphs, Not-guilty Verdicts, Post-Conviction Exonerations ??


Rules of Evidence – Standards for Admissibility of Expert Testimony

• **Frye Standard** - testimony generally accepted in the relevant scientific community.

• **Daubert Standard (Kumho)** - assessment of scientific reliability of testimony.

• **Civil Action** - money at risk; “preponderance of evidence”.

• **Criminal Action** - life or liberty; due process; innocent until proven guilty “beyond a reasonable doubt” vs. “clear and convincing evidence”; constitutional right to confront accusers; “burden of proof” on the prosecution.

• **SBS cases** – Expert defines SBS / NAI as presence of injury (e.g. the Triad) without sufficient historical explanation; unconstitutionally shifts burden to defendant to prove the expert theory wrong.

Texas v. Hurtado (Daubert), Udashen, Sperling 2006.
Lyons. SBS. Utah Law Rev 2003;1109.
SBS - NAI
Prosecution

- SDH + RH + Encephalopathy = SBS / NAI  [the “Triad”]

- Shaking alone in otherwise healthy child can cause SDH leading to death.

- Never due to short fall.

- Immediately symptomatic, i.e. “no lucid interval.”

- Symptoms in child with prior head injury = newly afflicted injury and not spontaneous rebleed (e.g. BECC or Chronic SDH).

- Last caretaker always guilty (“Unwitnessed”).

Head Injury in AHT & NAHT
Overlapping Clinical & Imaging Findings

- Scalp – swelling, hemorrhage.
- Cranial – fractures, suture splitting.
- Intracranial – subdural hematoma, contusion, shear injury (TAI), edema.
- +/- Skeletal Injuries – CML, Rib Fx’s, etc.

Interhemispheric SDH +/- Edema = SBS / NAI (Myth?)

Tearing of Veins & Brain


SDHs of Varying Age =
Multiple Inflicted Injuries (Myth?)
Tearing of Veins & Brain

Hyperacute right SDH = NAI
(Myth?)
Tearing of Brain & Veins

Multiple **Skull Fractures** of Varying Age + SDH

= Abuse (Myth?)


Case # 1

- 19 y au pair phones 911: 8 m/o boy in resp. distress 3y/o sibling boy also at home.
- Mother and father physicians at work.; EMT responds, CPR, intubation unsuccessful.
- IV access, intubation; CBC, clotting studies, blood gases normal; Negative prior medical history; No history of trauma; Child irritable that day; A little “rough” handling by au pair.
- CT: mixed density right convexity and interhemispheric SDH, edema, herniation, right occipital skull fracture, scalp swelling?; No MRI; Skeletal Survey - healing right distal radius fracture 2-4 wks. old.
- Emergency craniotomy for hyperacute SDH; Ventilator dependant infant dies 5 days later; Postmortem confirms fracture, SDH, infarctions.
- Au pair charged with first degree murder, in custody >1 year. Battle of experts at trial - new injury vs. old injury with rebleed (not admissible: child fell out of shopping cart on to head 1 mo. PTA; sibling with # arm fractures in past).
- Au pair convicted of manslaughter, sentenced to time served, and released.

[Baby Eappen - Nanny Case]
Case #1

CT: Hyperacute / Acute SDH (white arrows).

Case # 2

- 41 y/o physician father phones 911 (social worker mother at dentist); 5 m/o girl (29 wk. premi, IVF; DPT-2, HIB-2, 1 wk PTA, fussy); respiratory distress, shaken, CPR, EMT response;
- ER: status Sz, intubated; High WBC, low HCT; abnormal PTT, fibrinogen; Bilateral RH with fibrosis (ROP);
- CT: asymm. cerebral low Ds, loss of GWD, and enhancement; high Ds + enhancement IHF / falx / tent. / DVS; high and low density SA and SD collections;
- CTV: nonopacified segments of SSS, nonopacified adjacent cortical veins (hemorrhages, thromboses, infarctions, subdural collections, communicating hydrocephalus, meningoencephalitis / venous thrombosis); no MRI; skeletal survey negative;
- Brain death at 3 days; death at 3 wk; autopsy: normal neck, cx spine; no skeletal injuries; neuropath – widespread postmortem necrosis & small hemorrhages, perivascular inflammatory cellular infiltration, venous thrombosis, meningeal fibrosis;
- Appeal, conviction, appeal.

[Baby Scoon Case]
Case #2
Dural Venous Sinus Thrombosis. Hemorrhages / thromboses (a), enhancing cortical infarctions (b), & thrombosis superior sagittal sinus (c,d).

Cerebral Venous Thrombosis as a Mimic of NAI (Pediatr Radiol; Rejected 1999)
Head Injury in NAI Prosecution

- Shaking alone in otherwise healthy child may cause SDH leading to death.
- Otherwise, such injury requires:

  “Force equivalent to motor vehicle accident or a 2-story fall.”

\[
F = MA
\]

Force = Mass x Acceleration
Evidence Base
Shaken Baby Syndrome
Biomechanics - The Brain


- Ommaya A. Whiplash injury and brain damage. JAMA 1968; 204: 75-79.


Evidence Base
Shaken Baby Syndrome
Biomechanics - The Brain


- Luck JF, Prange M, Nightingale RW, Loyd A, Dibb A, Ottaviano D, Tran L, Myers BS. Tensile mechanical properties of the pediatric human osteoligamentous cervical spine. Injury & Orthopaedic Biomechanics Research Laboratory, Department of Biomedical Engineering, Duke University, Durham, NC, USA. (5979 5.3 Spine Kinematics and Injury Biomechanics S15T).


Caffey 1972 Whiplash Shaking

“Our evidence, both direct and circumstantial, indicates that manual whiplash shaking of infants is a common primary type of trauma in the so called Battered Infant Syndrome”.

[Caffey cites Guthkelch]

“Current evidence, though manifestly incomplete and largely circumstantial, warrants a nationwide educational campaign on . . the potential pathogenicity of habitual . . shaking of infants . .”

Child Abuse Centers Established (e.g. Kempe, Chadwick)


Caffey. The whiplash shaken infant syndrome: manual shaking by the extremities with whiplash induced intracranial and intraocular bleedings, linked with residual permanent brain damage and mental retardation. Pediatrics 1974;54; 1.

“This suggests that in some cases repeated acceleration-deceleration rather than direct violence is the cause of the haemorrhage, the infant having been shaken rather than struck by his parents”.

[Guthkelch cites Ommaya]


Ommaya 1968 Whiplash Injury

Rear-end auto collision simulation.
Adult rhesus monkeys on a sled.
Measure angular accelerations head on neck, without head impact.
Results: Brain injury -19; Neck injury-11.
40g Threshold for intracranial injury (concussion, subdural hemorrhage, shear injury).

Caffey & Guthkelch not realize such injury thresholds may not be attained in SBS.


1-month-old infant ATD model subjected to adult shakes and impacts.

“All shakes (11g) fell below injury thresholds . . , while impacts (52g) spanned concussion, subdural hematoma, and diffuse axonal injury ranges.”

“Severe head injuries commonly diagnosed as shaking injuries require impact to occur and that shaking alone in an otherwise normal baby is unlikely to cause the shaken baby syndrome.”

Autopsy series: all fatal cases (13) had signs of blunt head impact (more than half noted only at autopsy); all with uncontrollable increased intracranial pressure.

“Shaken-Impact Syndrome”


Prange 2003 Falls, Shakes, Impacts

1.5 month old infant model subjected to minor falls, shakes, inflicted impacts.

“In general, peak angular acceleration and maximum change in angular velocity increased with increasing fall height and surface hardness”.

“These findings suggest that inflicted impacts against hard surfaces may be more frequently associated with clinically significant inertial brain injuries than vigorous shaking or falls from less than 1.5-m”.

“In addition, there are no data showing that the peak angular acceleration and maximum change in angular velocity of the head experienced during shaking and inflicted impact against unencased foam is sufficient to cause SDHs or TAI s in an infant”.

Maximum Head Acceleration (g)

- **Horizontal Falls**
  - Resulting in Occipital Head Impact (a)
  - 5 ft
  - 4 ft
  - 3 ft
  - 2 ft
  - 1 ft

- **Car Crash Severe/Fatal Injury**
  - Skull Fracture/Hemorrhage (c)

- **American Professional Football Concussion (e)**
  - IRV* = 87 g

- **Shaking (b)**

- **No Head Injury (d)**
  - IRV* = 51 g

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*Chris Van Ee Ph.D, Design Research Engineering* ([www.dreng.com](http://www.dreng.com)):


Evidence Base
Shaken Baby Syndrome
Biomechanics - The Neck

“Thus, while it is possible to produce trauma in an infant by shaking, e.g. SDH, particularly when shaking is prolonged and repeated at intervals, the injuries would include the cervical cord and spine, but not the brain case, nor contusions in the cerebrum or cerebellum if no impact was also imposed.”


“Head acceleration and velocity levels commonly reported for SBS generate forces that are far too great for the infant neck to withstand without injury. . . and can potentially cause severe, if not lethal, spinal cord or brain stem injury. . . at levels well below those reported for the SBS.”

Evidence Base
Shaken Baby Syndrome
Biomechanics - The Neck

Shaking may *theoretically* cause brain injury if associated with *cervical spinal cord injury (phrenic nerve injury??)*.

**Short-distance falls** (or any impact, accidental or NAI) can produce brain injury.

In addition to **fall height, impact surface and type of landing** are important factors.

**Head-first impacts** in young infants are the most dangerous.

Should always do both **Brain and Cervical Spine CT, as well as MRI (STIR)**.

Imaging may not distinguish accidental from nonaccidental injury!!
Normal Infant MRI T2 CervicoThoracic Spinal Column and Spinal Cord
2 yM SCIWORA: Partial High Cervical Cord Transection, SAH, SDH, RH, and Hypoxic-Ischemic Brain Injury (CT, Path, Biomech).

Evidence Base
Head Injury in NAI
Neuropathology

Geddes et al – Neuropathology of Inflicted Head Injury “Young Infant”

- 37 / 53: infants < 9 mo. age
- Shaken only 8 (1 admission).
- Apnea, respiratory distress (ALTE)
- **Old injury (15)**
- Retinal Hem’s, fracture, **thin SDH**
- Increased ICP / swelling
- **Hypoxic-ischemic axonal brain injury** (no TAI !!)
- **Traumatic axonal brainstem / cord injury** (impact in all)


Geddes J et al. Dural Haemorrhage (DH) in Non-traumatic Infant Deaths

- Autopsy series
- 50 cases without trauma
- < 5 months of age
- **Infection** - 6
- **Hypoxia-ischemia** – 26
- **Infection + HI** – 8
- SIDS – 4
- C/W SBS – 3

Geddes et al. Dural Vascular Plexus Haemorrhage (DH) in Non-traumatic Infant Deaths

- **Common Features**: severe hypoxia-ischemia, infection, cerebral venous hypertension, arterial hypertension, brain swelling, venous immaturity / fragility and increased permeability.

- **Result**: intracranial venous dural hemorrhage [+ retinal hemorrhage].

- **Also**: hypoperfusion followed by reperfusion, especially via dural arterial supply with dural hemorrhage (no blood-brain-barrier).

- **Coagulopathy**.

- **“The Unified Hypothesis”** (i.e. the **Cascade**).


Dural Border Cell Layer/Subdural Compartment & Dural Vascular Plexus

- The **DBC** is approximately 8 microns thick.
- The **DBC** is the “weakest link” in dural/arachnoid interface due to scarcity of tight junctions and prominent interstitial spaces.

Haines, 1993
Dural Vascular Plexus Haemorrhage vs. Bridging Vein Rupture in Non-traumatic Infant Deaths

Hypoxia-ischemia (Reperfusion), Infection, Venous Hypertension, Vascular Fragility, Coagulopathy = **Edema + Thin SDH.**


Dural Vascular Plexus Hemorrhage / Hygroma (DH)
Julie Mack, Hershey Medical Center

Fetal

Neonatal

BECC

Spontaneous Intracranial Hypotension

Osteogenesis Imperfecta

GA1
Acute Life Threatening Event
ALTE


- Apnea – Central, Obstructive, Mixed.
Differential Diagnosis of ALTE

Gastrointestinal (33%)
- Gastroesophageal reflux
- Gastroenteritis
- Esophageal dysfunction
- Colic
- Surgical abdomen
- Dysphagic Choking
Differential Diagnosis of ALTE

Neurologic (15%)
• Seizure
• Central apnea/hypoventilation syndromes (apnea of prematurity, Ondine’s curse)
• Head injury (intraventricular hemorrhage, subarachnoid hemorrhage)
• Meningitis/encephalitis
• Hydrocephalus
• Brain Tumor
• Neuromuscular disorders
• Vasovagal reaction
• Congenital malformation of the brainstem
Differential Diagnosis of ALTE

Respiratory (11%)
- Respiratory syncytial virus
- Pertussis
- Aspiration pneumonia
- Other lower or upper respiratory tract infection
- Reactive airway disease
- Foreign body

Otolaryngologic (4%)
- Laryngomalacia
- Subglottal and/or laryngeal stenosis
- Obstructive sleep apnea
Differential Diagnosis of ALTE

Cardiovascular (1%)
- Congenital heart disease
- Cardiomyopathy
- Cardiac arrhythmia/prolonged QTc
- Myocarditis

Metabolic/endocrine
- Electrolyte disturbance
- Hypoglycemia
- Inborn error of metabolism

Other infections
- Sepsis
- Urinary tract infections
Differential Diagnosis of ALTE

**Child maltreatment syndrome**
- Shaken Impact syndrome
- Intentional suffocation
- Munchausen-by-proxy syndrome

**Other diagnoses**
- Physiologic event (periodic breathing, acrocyanosis)
- Breath-holding spell
- Choking
- Drug or toxin reaction
- Unintentional smothering
- Anemia
- Hypothermia
- Idiopathic ALTE/apnea of infancy (23%)
Acute Life Threatening Event (ALTE)
Dysphagic Apnea - Choking


DH + RH in Pertussis

American Academy of Pediatrics Red Book Online: Pertussis. 2003 (see also The Centres for Disease Control & Prevention website)
Mimic - Choking + Hypoxia-Ischemia

6m infant with Triad and alleged NAI; acute choking event while feeding. CT (a-d) shows bilateral cerebral edema with acute SAH and SDH (arrows), including along the falx, and tentorium. Autopsy confirmed the hemorrhages, a subdural membrane, and hypoxic-ischemic brain injury.

[Courtesy, The Wisconsin Innocence Project]


Dural Hemorrhage & Hypoxia-Ischemia

Dural Hemorrhage & Hypoxia-Ischemia

Dural Venous Sinus Thrombosis. Hemorrhages / thromboses (a), enhancing cortical infarctions (b), & thrombosis superior sagittal sinus (c,d).

Cerebral Venous Thrombosis as a Mimic of NAI (Alberico et al AJNR 1999).
Mimic - Venous Thrombosis

Alleged NAI with Triad: Infection with Dural & Cortical Venous Sinus Thrombosis with Dural Hemorrhage & Retinal Hemorrhage

CT: Dural Venous Sinus Thrombosis. High densities along dural venous sinuses, tentorium, and falx (arrows). Enhancing right temporo-occipital infarction shown on later CT (right image – arrows).
MRI: Dural venous sinus thrombosis. (T1 left, T2 middle, MRV right) T1 high intensity interhemispheric hemorrhage along tentorium (T1 arrows) and straight sinus. T2 hypointense hemorrhage / thrombosis is present along right lateral sinus (T2 arrows). MRV shows partial thrombosis of right lateral sinus plus multiple collaterals (MRV arrows).

- The Canadian Pediatric Ischemic Stroke Registry.
- Incidence of the disorder 0.67 case per 100,000 children per year.
- Neonates were most commonly affected.
- Fifty-eight percent of the children had seizures, 76 percent had diffuse neurologic signs, and 42 percent had focal neurologic signs.
- Risk factors included head and neck disorders (in 29 percent), acute systemic illnesses (in 54 percent), chronic systemic diseases (in 36 percent), and prothrombotic states (in 41 percent).
- Venous infarcts occurred in 41 percent of the children.
- Neurologic deficits were present in 38 percent of the children, and 8 percent died; half the deaths were due to sinovenous thrombosis.
- Predictors of adverse neurologic outcomes were seizures at presentation and venous infarcts.
- Sinovenous thrombosis in children affects primarily neonates and results in neurologic impairment or death in approximately half the cases. The occurrence of venous infarcts or seizures portends a poor outcome.


McLean L, Frasier L, Hedlund G. Does intracranial venous thrombosis cause subdural hemorrhage in the pediatric population. AJNR 2012; Table 1 (11< 1yr; CVT-1).

Pollanen M. Subdural hemorrhage in infancy: keep an open mind. Forensic Sci Med Pathol 2011;7:298-300 (p.299, Table 1)

Interhemispheric SDH +/- Edema
= SBS / NAI (Myth?)
Tearing of Veins & Brain


Mimic - Vascular Malformation + Hemorrhage

20 m infant with Triad & Alleged NAI. Left SDH with cerebral cortical and pial AVM at autopsy. CT (a,b) shows left mixed-density SDH & SAH (long arrows) plus interhemispheric hemorrhage (short arrows) with marked left cerebral swelling and shift.

[Courtesy - Shaku Teas, MD, Forensic Pathologist, Chicago, IL]

Mimic - Coagulopathy

9mF with Triad & alleged NAI; also, recent fall & coagulopathy (later confirmed platelet disorder). Initial CT (a) shows mixed-density right SDH with right cerebral edema. Postoperative CT 5 days later shows other cerebral & intraventricular hemorrhages. T1 MRI (c) 11 days postoperatively shows evolving right cerebral high-intensity cortical injury & hemorrhages.

Mimic - Vitamin K Deficiency

Home-delivered newborn with seizures at 1 week of age; also, no vitamin K given at birth. T1 (a) & T2 (b) MRI show acute-subacute left SDH (long arrows) plus right cerebral hemorrhage (short arrows); vitamin K deficiency confirmed & treated.

In cases of suspected non-accidental injury in children, it is vital that a haematologist confirms the presence or absence of a haemostatic disorder so that the child welfare and legal systems can make accurate judgements regarding the cause of isolated injuries.

The present paper will discuss commonly used methods for the diagnosis of coagulation disorders in children, and will describe how the investigation of easy bruising and bleeding can be highly problematic.

For instance, some frequently used tests for the assessment of haemostasis in children are insensitive, inappropriate, or based on values derived from adult populations.

Furthermore, artefact is a frequent problem, and many cases present with a negative family history of bleeding.

Crucial to eliminate coagulation factor deficiencies (including factor XI and factor XIII), vWD, platelet disorders (including thrombocytopenia and leukaemia), and rare conditions such as $\alpha$2-antiplasmin deficiency. The tests to eliminate these conditions alone incur considerable expense and do not include measures to eliminate other potentially relevant disorders, such as plasminogen activator inhibitor-1 or vitamin C deficiencies.


Mimic - Infection

Presumed NAI with Triad: Pneumococcal Meningitis with DH+RH
Delayed Edema + Herniation

Mimic - Metabolic Disorder

12m infant with triad & alleged NAI. Glutaric Acidopathy Type 1. CT (a) & T2 MRI (b) show bilateral SDH of varying age (long arrows), wide sylvian fissures, plus basal ganglia and cerebral white matter abnormalities (short arrows).

Arachnoid Cyst

16m with Triad (right RH) and alleged NAI; also, short fall with right scalp impact. CT (a) shows left sylvian arachnoid cyst (c) and right hyperacute SDH (arrows). T2 MRI (b) 2 days later shows acute right SDH (long arrows) and smaller left sylvian arachnoid cyst (c) with subdural hygroma (short arrows).

10 deaths in infants under 12 months old.
Toxicology findings include over-the-counter (OTC) cold medications.
Ephedrine, pseudoephedrine, dextromethorphan, diphenhydramine, chlorpheniramine, brompheniramine, ethanol, carbinoxamine, levorphanol, acetaminophen, and the anti-emetic metoclopramide.
Majority of these deaths were either toxicity from the OTC cold medications directly or as a contributory factor in the cause of death.
Only two of the cases were the result of possible child abuse.
Caregiver mistaken notion that OTC cold medications formulated for children are also safe for use in infants.
OTC cold medications in infants can result in toxicity that can lead to death.
CDC / FDA Ban.
Child abuse is a terrible crime and the failure to recognize it is unforgivable. An erroneous diagnosis of inflicted head trauma is just as tragic and the resulting destruction of a family is one of the gravest injustices of modern times. Many have recently questioned the existence of the so-called “Shaken Baby Syndrome” and the concept that the last caretaker must have been guilty. Careful reviews often uncover relevant findings that were missed or ignored. Recent pediatric vaccinations have been suspected as precipitating factors. A recent combination of seven antigens is the focus of this investigation.

VAERS - Vaccine Adverse Event Reporting System CDC & FDA.
Neuropathology + Biomechanics
Evidence Base
Conclusions

• **Shaking** may *theoretically cause* brain injury if associated with **cervical spinal cord injury**.

• **Impact** may produce direct or indirect brain injury (accidental or NAI).

• **Brain edema with thin SDH** (dural vascular plexus origin) may reflect **Hypoxia-Ischemia + Cascade** (accidental or NAI).

• **Brain edema with thin SDH** may result from medical causes (e.g. **Hypoxia-Ischemia + Cascade**) from any cause of ALTE).

• Should always do both **Brain and Cervical Spine CT, as well as MRI**.

• Imaging may not distinguish accidental from nonaccidental injury, or from predisposing or complicating medical conditions.
Evidence Base for Short Falls & Lucid Intervals - “Sutures!”

Malignant Edema

Evidence Base for **Short Falls & Lucid Intervals - “Sutures!”**

**Malignant Edema**


Malignant Edema
Lucid Intervals vs. Fatal Progression

Bruce et al (1981) Accidental & NAI:
• Higher GCS (>8) subgroup, 8 / 14 lucid interval; all complete recovery.
• Lower GCS (<8) subgroup, 34 with immediate / continuous coma, 15 lucid interval, 6 deaths, and 11 with permanent disability.


Steinbok et al (2006) witnessed accidental injury:
• 5 children (4 < age 2yr.; 3 falls)
• SDH and cerebral edema by CT 1-5 hours post-event.
• Immediate coma and rapid progression to death.


Clinical Series + Neuropathology + Biomechanics
Evidence Base
Conclusions

• Significant head injury, including death, may result from low fall levels (or any Impact, accidental or NAI).

• Such injury may be associated with a lucid interval (i.e. caretaker blamed for delay).

• The lucid interval invalidates the premise that the last caretaker is always responsible in alleged NAI.

• In other cases, the injury may result in immediate deterioration with malignant edema & progression to death.

• Predispositions including Genetic? Trigeminal Reflex?

• Imaging may not distinguish nonaccidental from accidental injury.
Evidence Base
Benign Extracerebral Collections (BECC)
SDH - Rebleed


Evidence Base
Benign Extracerebral Collections (BECC)
SDH - Rebleed


5m infant with the Triad and alleged NAI; also, macrocephaly from birth, recent seizure but "no" trauma. CT (a) and T2* MRI (b) show large extracerebral collections with smaller recent hemorrhages (arrows). CT 3 months post-drainage (c) shows rehemorrhage (arrows).

Diagnosis: BECC or chronic SDHG with rehemorrhage?

Evidence Base for SDH with Rebleed

- Dyer O. Brain Haemorrhage in Babies may not Indicate Violent Abuse. BMJ 2003; 326; 616.
Evidence Base for SDH with Rebleed

Evidence Base SDH - Rebleed

Birth Factors


Evidence Base SDH - Rebleed

Birth Factors


Mimic - BECC vs. SD Hygroma at birth (a) with SDH - rehemorrhage one month later (b).

Mimic - Birth Trauma

9w infant with Triad and alleged NAI; also, history of traumatic labor and delivery. Skull film (a), CT (b) plus FLAIR (c), T2 (d), T1 (e) MRI show bilateral skull fractures with left growing fracture (long white arrows), chronic bifrontal cerebral white matter clefts (short white arrows-c), plus acute, subacute, & chronic subdural hemorrhages / rehemorrhages (black arrows).

Evidence Base - BECC & SDH
Conclusions and Recommendations

- **Re-hemorrhage** may occur in an old SDH without recent trauma and be associated with a **lucid interval** (Sutures !!).
- SDH occurs in **benign extracerebral collections**.
- **Old SDH** may date back to **Birth**.
- **Serial head circumference measurements**, caregiver education, preventive measures, attention to nonspecific symptoms, early imaging “before the crash”.
- **Imaging** may not distinguish nonaccidental injury from accidental injury.
CT & MRI in Alleged NAI

Limitations

**Timing of Hemorrhage (Thrombosis)**

**CT Limitations**

- High density (i.e. clotted, acute to subacute) 3 hr. to 7-10 days;
- Not differentiate hemorrhage v. thrombosis (e.g. venous)
- Iso-Hypodense (i.e. nonclotted):
  - Hyperacute (<3 hrs.)
  - Chronic (> 7-10 days)
  - BECC or subdural hygroma (acute or chronic)
- Blood levels unusual in acute stage except coagulopathy.
- Not distinguish acute hemorrhage from re-hemorrhage upon BECC or chronic SDH
- Interhemispheric SDH not characteristic for NAI
- Mixed-density SDH may occur in AI.

Hyperacute right SDH vs. chronic SDH with re-hemorrhage?
+/- Unilateral Edema = NAI
(Myth?)

Timing of Hemorrhage (Thrombosis)

MRI Limitations

- **Hyperacute** (< 12 hr.): T1 iso-hypointense, T2 hyperintense;
- **Acute** (1-3 days): T1 iso-hypointense, T2 hypointense;
- **Early Subacute** (3-7 days): T1 hyperintense, T2 hypointense;
- **Late Subacute** (7-14 days): T1 hyperintense, T2 hyperintense;
- **Early Chronic** (> 14 days): T1 hyperintense, T2 hyperintense;
- **Late Chronic** (> 1 – 3 months): T1 isohypointense, T2 hypointense).


Timing of Hemorrhage (Thrombosis)

MRI Limitations

- **Mixed intensity** - problematic regarding timing.
- **Blood Levels** - subacute hemorrhage vs. coagulopathy.
- **Timing guidelines** - sediment not supernatant.
- **CSF Component** - BECC v. acute SDHG v. hyperacute SDH v. chronic SDH, SDHG.
- **GRE** - iron-sensitive but not assist with timing unless matched with T1, T2, and CT.
- **GRE / SWI** - sensitive to venous thromboses (e.g. cortical, medullary, subependymal) that may not detected by MRV.
- **FLAIR** sensitive, but not specific for hemorrhage unless matched with T1, T2, GRE, CT.


BECC vs. Chronic SDH with Re-hemorrhage vs. Acute Subdural Hygroma + Hematoma
Timing of Hemorrhage

Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. Pediatr Radiol Online 21 March 2009

Density evolution of hemorrhage on CT images.

- **Hyperacute**: Isodense <3 hours
- **Acute**: Hyperdense Few hours → 7–10 days
- **Subacute**: Isodense 2–3 weeks
- **Chronic**: Hypodense >3 weeks
Timing of Hemorrhage

Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. Pediatr Radiol Online 21 March 2009

Signal evolution of SDH on MRI.

- **Hyperacute**: <12–24 h  T1↓ or↔   T2↑
- **Acute**: 1–3 days  T1↓ or↔   T2↓↓
- **Early subacute**: 2–3 days → 1–2 weeks   T1↑   T2↓↓
- **Late subacute**: 1–2 weeks → 1–2 months   T1↑   T2↑↑
- **Chronic**: Few weeks → months/years  T1 ↔   T2 ↓↓
- **Chronic**: Few weeks → months/years  T1↓ (>CSF)   T2↑
Head Injury in NAI - Prosecution

Retinal Hemorrhage (RH) only occurs in SBS / NAI.

Evidence-Based Challenges

• Tongue A. The ophthalmologists role in diagnosing child abuse. Ophthalmology 1991;98;1009-1010.
Head Injury in NAI - Prosecution

Retinal Hemorrhage only occurs in SBS / NAI.

Evidence-Based Challenges

Evidence-Based Challenges to SBS / NAI as the only cause for the “Triad”

- Plunkett 2001. RHs in 2/3 of the fatal accidental head injuries.
- Gilles 2003. RHs reflect increased intracranial pressure after head injury.
- Lantz 2004. RH with perimacular folds in a case of crush injury to an infant’s head.
- Goldsmith 2004. extensive RHs; videotaped fatal short.
- Forbes. AAPOS 2007. RHs in 60% of accidental infant EDH.
- Obi. AAPOS 2007. RHs, schisis, folds in both AI & NAI.
- Binenbaum. AAPOS 2007. No RHs in 3-5 day old piglets subjected to rotational acceleration / deceleration 40x inflicted ‘shaking’ reported by Prange 2003.
- Emerson. 2007. Finds no support for the vitreous traction hypothesis for RH.
- Gilliland MGF 2006. Use of the triad of scant SDH, brain swelling, and retinal hemorrhages to diagnose non-accidental injury is not scientifically valid. NAME 2006.


Evidence Base

Conclusions

• **The Triad**: RH + SDH + Encephalopathy **not specific for NAI**.
• **Bone “Fractures”** (e.g. CML) **not specific for NAI**.
• May occur with accidental trauma.
• May occur with medical conditions.
• Must consider Predisposing Risk Factors.
• Must consider Multifactorial, Synergistic, & Cascade Effects.
• **Multidisciplinary Approach**.
• **Imaging cannot provide precise causation or timing of “Injury.”**


Child Abuse – Nonaccidental Injury (NAI) Recommendations
“A Compassionate Approach”

- Thorough Medical & Forensic Work-Up.
- Child & Family Protective Evaluation & Management.
- Timely Imaging – CT, MRI, Skeletal Survey.
- Differential Diagnosis.
- Multidisciplinary Approach.
- Research - Genetic / Molecular Predisposition.
- Reframing Neglect / Abuse - Opportunities for Prevention.
- Prenatal Care 84%, Medical Setting Births 99%.
- Early Risk Detection, Management.
- Parent training (e.g. during pregnancy).
- Home visitation.
- Social Support.
- Transplant Organ Harvesting & Adoption Issues.
- **Stop Cost-Shifting from Medical / Social System to Criminal Justice System.**

*CDC MMWR Report April 4, 2008*
*www.cdc.gov/mmwr*
Child Abuse – Nonaccidental Injury (NAI) Abusive Head Trauma (AHT)

Issues and Controversies in the Era of Evidence-Based Medicine

Blood, Brain, & Bones

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World Congress on Infant Head Trauma
November 2013
NAI – Bones
Skeletal Fragility Disorders

- Fractures, often multiple, unexplained
- Ribs, CMLs, etc.
- Varying ages
- Skeletal Survey
- DXA scan
- SOS Ultrasound
- QCT


Rickets vs. Abuse


Ayoub D, Miller M, Hyman C. Evidence of metabolic bone disease in young infants with multiple fractures misdiagnosed as child abuse (PAS, RSNA, ASBMR).


NAI – Bones

- Fractures, often multiple, unexplained
- Ribs, CMLs, etc.
- Varying ages
- NAI vs. AI
- Birth Injury
- Bone Fragility Disorder
- Skeletal Survey
- DXA scan
- QUS
- QCT

Vitamin D Deficiency – Congenital Rickets


3m infant with alleged NAI; also, “history” consistent with congenital rickets. Chest film (a) shows bilateral recent and old, healing rib fractures (pseudofractures? rachitic rosary? - arrows). Knee films before (b) & after (c) vitamin D supplementation show “healing” CML (arrows)?


Radiographic Findings
Congenital Rickets
Skull

Radiographic Findings
Congenital Rickets
Facial Bones - Pre & Post Vitamin D Therapy

Radiographic Findings of Congenital Rickets
Looser’s Zones + Metaphyseal Changes (2m, 4m, 15m)

Radiographic Findings of Congenital Rickets
Wrist Changes Pre & Post Vitamin D Therapy

Radiographic Findings of Congenital Rickets
Lower Extremity (distal tibial tilt)

4mM ALTE (Vita D Defic Hypocalcemia)
CT Brain – Global Injury (hypoxia-ischemia)
4mM ALTE (Vita D Defic Hypocalcemia)
CT Skull Craniotabes, Fracture
4mM ALTE (Vita D Defic Hypocalcemia)
MRI – Global Brain Injury (hypoxia-ischemia)
Evidence-Based Update
Brain Imaging in Nonaccidental Injury and the Mimics

Blood, Brain, & Bones

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ALL-DAY CONFERENCE

CHILD ABUSE EVIDENCE:
Perspectives from Law, Medicine, Psychology + Statistics

Friday, November 6 from 8:30 a.m. to 4:30 p.m.
University of Michigan Law School Honigman Auditorium, 100 Hutchins Hall