Abusive Head Trauma

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Terminology

• **Shaken Baby Syndrome**
  - Implies a single mechanism

• **Shaken Impact Syndrome**

• **Inflicted Traumatic Brain Injury**

• **Abusive Head Trauma**
  - Recommended by AAP since 2009
Incidence

- Population-based studies suggest an annual incidence of about 30 babies per 100,000 under 1 year.
Incidence

• Abusive head injury is a leading cause of serious head injury in small children
  - Most serious head injury in <1 year
  - 1/3 of head injury hospitalizations in <3 yr
Incidence

- Homicide is leading cause of infant death due to injury
  - 2/3 are due to AHT
  - 6 deaths each year due to AHT for each 100,000 children <1 year
  - Mortality of AHT about 20%
    - About 2% mortality in accidents <3yo (Vinchon)
Risk Factors

- Stress
  - Parent stressed beyond his/her coping skills
  - Crying
Perpetrators

• Most are male
  – fathers most common (53%), mother’s partners (22%), mothers (8%), babysitters (8%), other adult (5%)
• 39% were not parents
• Children <1 most likely to be hurt by father
• Children >1 most likely to be hurt by non-parent

Outcomes

- Vegetative state 5%
- Severe disability 34%
- Moderate disability 25%
- “Good” outcome 13%

Outcomes

- Motor impairments 15-70%
- Cranial nerves impairments 20%
- Epilepsy 11-32%
- Blindness or Visual impairment 18-48%
- Deafness
- Speech and language difficulties 37-64%

Outcomes

- Microcephaly 50%
- Intellectual/cognitive deficits very frequent:
  - intellectual deficiency 54%
  - severe behavioral disorders in at least 38%

Pathologic and Diagnostic Features

- Intracranial hemorrhage
- Injury to the brain substance
- Retinal hemorrhage
- Associated Skeletal and Soft Tissue Injuries
Intracranial Hemorrhage

• Most frequently subdural hematoma
• Dura is a tough connective tissue layer beneath the skull
• Arachnoid lies beneath dura, then CSF, then brain
• Bridging veins cross from brain sinuses between dura and skull
Layers covering the Brain

- Scalp
- Periosteum
- Skull bone
- Dura mater
- Subdural space
- Subarachnoid space
- Brain
SDH Mechanism

- Acceleration/deceleration
- Rupture of bridging veins
- Veins rupture resulting in SDH
  - Often near sinus
Injury to the brain substance

• **Clinically:**
  - Vomiting, seizure, altered consciousness, apnea

• **Radiologic:**
  - Contusion, edema, infarction

• **Pathologically:**
  - TAI
Brain injury

- Brain injury is often diffuse
- Brain stem injury likely plays a significant role
- Injury can be primary or secondary
  - Hypoxia/anoxia
  - Ischemia
  - Edema
Radiographic findings

• **Findings more common in AHT**
  - SDH: multiple, interhemispheric, convexity, posterior fossa
  - Hypoxic-ischemic injury
  - Edema

• **Subarachnoid and focal parenchymal injury found equally in AHT and nAHT**

• **Epidural hematoma more common in nAHT**

Forces Required

• No perfect experimental model exists ... high degree of force
• Brain injury or intracranial injury rare in short falls in young children
• Finite element modeling suggest that sufficient forces can be generated through shaking
• Confessions confirm violence in shaking
Retinal Hemorrhages
RH

- **RH extremely rare in children outside of newborn period**- most commonly trauma
- **50-100% of cases**
  - Highest in fatal cases and lowest in neurologically intact victims
- **Frequently bilateral**
  - Unilateral not found to be consistently associated with unilateral brain injury
- **Papiledema relatively rare**

Normal Retina
Retinal Hemorrhages

- Pathophysiology
  - Most likely vitreoretinal traction
  - Supported by finite element modelling and distribution of RH in AHT
Characterizing Retinal Hemorrhages

• Not positive or negative
• Location and distribution are important
• Description of lesions critical
  – Number, type and location
  – Intra retinal, preretinal, subretinal
• Note other associated findings
  – Retinoschisis
  – Perimacular folds
  – Vitreous hemorrhage
How Much Force?

• No perfect model
• RH rarely reported in severe household falls - even those associated with skull fracture
  – If present they are usually confined to the posterior pole
• RH associated with injuries requiring a great deal of force
Alternate Theories

• **Venous occlusion**
  – Superficial and usually on or adjacent to swollen optic disk

• **Sudden rise in intracranial pressure associated with bleed - Terson’s Syndrome**
  – Preretinal and vitreous

• **Rise in thoracic pressure - Purtscher retinopathy**
  – White retinal patches rarely if ever seen in abusive head trauma
Evaluation Of AHT
Detailed Medical History

History of Present Illness

• Medical providers are not LE or DHS Investigators but...
  − History is the foundation of Medicine
  − Sometimes the initial history is critical

• Detailed account of the injury

• Behavior changes associated with trauma

• Who was present

• What happened next- how long it took to seek care
History

• Ask for details:
  – What happened next?

• Control information exchange
  – Information offered by health care providers will be woven into a false history
  – How could this have happened?

• DO NOT OFFER POTENTIAL EXPLANATIONS
  – Did you squeeze?
  – Did you shake?

• Avoid confrontation or accusation
History Red Flags

• Developmentally inappropriate histories
• No history—particularly in very young infants
• Delay in seeking medical care
• Changing history
• Histories inconsistent with injuries
  - Short falls
  - Injuries inflicted by small children
Infant Development
2 months

- Begins to smile at people
- Tries to look at parent
- Pays attention to faces
- Begins to follow things with eyes and recognize people at a distance
- Begins to act bored (cries, fussy) if activity doesn’t change
- Can hold head up and begins to push up when lying on tummy
4 months

- Smiles spontaneously, especially at people
- Likes to play with people and might cry when playing stops
- Copies some movements and facial expressions, like smiling or frowning
- Holds head steady, unsupported
- Pushes down on legs when feet are on a hard surface
- May be able to roll over from tummy to back
- Lying on stomach, pushes up to elbows
6 months

• Knows familiar faces and begins to know if someone is a stranger
• Rolls over in both directions (front to back, back to front)
• Begins to sit without support
• When standing, supports weight on legs and might bounce
• Rocks back and forth, sometimes crawling backward before moving forward
9 months

- Stands, holding on
- Can get into sitting position
- Sits without support
- Pulls to stand
- Crawls
1 year

• Gets to a sitting position without help
• Pulls up to stand, walks holding on to furniture ("cruising")
• May take a few steps without holding on
• May stand alone
Past Medical History

- Pregnancy, Birth and Neonatal
- Medications
- Nutrition and supplementation
- Previous symptoms
  - Unexplained irritability, lethargy, decreased movement of an extremity, vomiting
- Bleeding problems
  - Circumcision
- Previous Injury
Sentinel Injury

- 401 children <12 months old evaluated by CPT
- 101 non-abused
  - No sentinel injury
- 100 intermediate concern for abuse
  - 8% with sentinel injury
- 200 definite abuse (100 AHT/100 non AHT)
  - 27.5% with sentinel injury
  - 80% were bruises
  - 41.9% medical provider aware

Family History

- Genetic conditions
- Bleeding Disorders
  - Diagnosed
  - Symptomatic
- Bone disorders
  - Diagnosed
  - Symptomatic
Work-up

• Most have many lab studies including evaluation for bleeding disorders and abdominal trauma

• Ophthalmology exam

• Most have a combination of CT and MRI
  – Might be directed by neurosurgery team
  – Spine MRI

• Skeletal survey
Associated Injuries

- Bruises
- Skull fractures
- Rib Fractures
- CML’s
Investigation

• More “minor” injuries cannot be forgotten

• Bruises:
  − Can help to time injury
  − Indicate trauma in a common sense fashion
  − Bruises on the head can indicate impact and can be a clue to more than shaking
  − Can be an indicator of a pattern of abuse

• Fractures
  − Indicate trauma in a common sense fashion
Diagnostic Challenges

- “Head only” injuries
- Real or imagined explanations
  - Accidental injury
  - Birth injury
  - Metabolic
  - Infection
  - Coagulopathy
  - Vascular anomaly
  - Macrocephaly
  - Etc.
- Children without significant brain injury are more difficult
Radiographic Injury Timing

• “fresh” blood appears bright white on head CT (first few days)
• MRI uses multiple “sequences” and can offer some insight into timing.
• Pitfalls:
  − Most timing is based on adult intracranial bleeds
  − The more we learn the less reliable things seem to be
  − Verified acute injury can have multiple densities on HCT
Investigation

• Use extreme caution around “acute on chronic”/multiple injury theories when based only on head CT findings

• Try to confirm with clinical symptoms
Clinical Injury Timing

- Infants most often symptomatic after assault
  - Supported by confession data
- No great evidence to support “lucid interval” in severely injured children
- Defining “lucid” in an infant might be difficult
Clinical Injury Timing Pitfalls

• Less severe brain injury can be challenging
  − Symptoms can be difficult to identify or nonspecific
• Seizures
• Failure to seek prompt care
Some Timing Considerations

• When did someone first note a change
• When was the baby making eye contact
• When was the last feed
  – How much
  – Vomitting
• Sleepy or difficult to arouse
• Sleep pattern
• Irritability
Another Consideration

• In one study, 55% of 29 confessions admitted to shaking on more than one occasion (2-30)
• 62% reported that it stopped the infant’s crying

Falls
Falls in Infants

- 11,000 kids less than 6 mo
- 22% had household falls
- <1% resulted in concussion or fracture
- No deaths

Household falls are common and relatively harmless

# Deaths from Falls in Children: How Far is Fatal?

<table>
<thead>
<tr>
<th>Height</th>
<th>Total</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>10' - 45'</td>
<td>117</td>
<td>1 death (CHI)</td>
</tr>
<tr>
<td>4' - 10'</td>
<td>100</td>
<td>0 deaths</td>
</tr>
<tr>
<td>&lt;4'</td>
<td>100</td>
<td>7 deaths (CHI)</td>
</tr>
</tbody>
</table>

Falling out of bed: 
A relatively benign occurrence

- 207 children < 6 y/o
- fell 25” - 54” from hospital beds
- 1 skull fracture
- 1 clavicle fracture
- 0 intracranial injuries

Stairway Injuries in Children (including falls in walkers)

363 children

• any fracture: 25 (7%) (skull fracture 2%)
  − 40% skull fracture if carried by adult during fall
• concussion: (1%)
• head and neck injuries predominated (73%)
  − only 2.7% had injury to more than one body area

Death from falls

- **Review of published materials**
  - 5 book chapters
  - 2 medical society statements
  - 7 major literature reviews
  - 3 public injury databases
  - 177 peer-reviewed, published articles indexed in the National Library of Medicine

- **Mortality rate for short falls affecting infants and young children is <0.48 deaths per 1 million young children per year**

Courtroom Theories
Evidence-Based Medicine and Shaken Baby Syndrome

Mark Donohoe, MD

(Am J Forensic Med Pathol 2003;24: 239–242)

“attempts to formally rank the available medical scientific evidence by internationally accepted methods, to determine the degree of confidence that can be held on various claims about the condition termed shaken baby syndrome (SBS).”
Evidence-Based Medicine and Shaken Baby Syndrome


Mark Donohoe, MD

- **Methods:** Medline and Internet Explorer searched using “shaken baby syndrome” in 1998.

- “Shaken baby syndrome” not added as a MeSH (Medical Subject Heading) term for Medline searches until 2002 (so, search occurred on single phrase)

- **71 articles identified and then limited to 54 by discarding ones in which SBS was only peripherally mentioned.**

- “Impossible to review the entire article in many cases although major articles were reviewed in full. Remainder assessed by abstract.”
Who cares if Donohoe didn’t really apply good methods to his literature search?

• **Conclusion:** “there was inadequate scientific evidence to come to a firm conclusion on most aspects of causation, diagnosis and treatment or any other matters pertaining to SBS.”

• Cited by > 50 other papers (and growing)
• Once every other month
• Quoted in lay press
• Quoted in legal opinions
Has a Flawed Diagnosis Put Innocent People In Prison?

A Re-Examination of Shaken Baby Syndrome.

By Emily Bazelon
"But closer scrutiny of the body of research that is said to support the diagnosis of shaken baby syndrome has revealed methodological shortcomings."

Reference = Donohoe
And it continues.....

- **Gabaeff S.** Challenging the connection between SDH, RH and SBS. *West J of Emerg Med*, May 2011.
  
  - “Donohoe graded the quality of the child abuse literature from 1966-1998 and found significant weaknesses.”
  
  - Ref #1 = Donohoe
  
  - Ref #10 = Bandak (no reference to the erratum)
Alternate Theory: Lucid Interval

• Injury occurs at some time far removed from symptoms
• Scant evidence to support this
• Work by Plunkett may be cited
  – Older children
  – Not asymptomatic
Timing of injury by clinical course

- Serious head injuries show some degree of symptoms following event.
Alternative Theory: Can’t Shake

• Can’t shake a baby hard enough to cause SDH or brain injury
• Theory based almost exclusively on Biomechanics
• First biomechanical article in 1987
Duhaime 1987

• 2 part study
• Part I reported on 48 infants and young children with AHT (1978-1985). 13 died - all had autopsies
• Part II was a biomechanical experiment measuring rotational acceleration and velocity generated while shaking a model of a 1 month infant
Duhaime 1987 - Clinical

- 30/48 showed evidence of blunt impact to head
  - 12/48 had skull fracture
  - 18/48 had soft tissue contusion
- 18/48 showed no evidence of blunt impact to head
  - 6 had evidence of extracranial trauma
- 13/13 fatalities had evidence of blunt trauma - 7 found only at autopsy
Scaling Relationship Between Sub-human Primates and Man for Concussive Levels of Rotational Acceleration.
Duhaime 1987 - Biomechanics

- 60 shakes - none reached threshold levels for concussion, SDH or DAI
- 60 shakes with impact - all reached concussion thresholds, most reached SDH/DAI thresholds, even when impact was on a padded surface
“It is our conclusion that the shaken baby syndrome, at least in its most severe acute form, is not usually caused by shaking alone. Although shaking may, in fact, be part of the process, it is more likely that such infants suffer blunt impact. The most common scenario may be a child who is shaken, then thrown into or against a crib or other surface...”
Important Points

• Pointed out that the diagnosis of SBS was somewhat sloppy
  – SBS is too narrow
  – Multiple insults could occur in the course of a single assault

• Clinicians might not be able to identify impact well

• Does it prove that shaking can not cause SDH, RH, or brain injury?
Biomechanics

• Biofidelic dolls?
• Single impulse?
• Thresholds based on adult data/adult primate?
• Confessions?
• Interesting but unclear if biomechanical data is conclusive—either way
Biomechanics Debate

- Witnessed and confessed events of shaking leading to death and disability (same constellation of findings).
  - Starling, Archives Peds 2004
  - Biron, CAN 2005
  - Adamsbaum, Peds 2010
  - Vinchon, Child Nerv System 2010
Alternate Theory: Neck Injury

- **Bandak, Shaken Baby Syndrome: A biomechanical analysis of injury mechanisms. Forensic Science Int’l 2005;151.**

  - Forces need to cause head injury exceed point of neck failure so if no neck injury, could not be shaking as cause of injury.

\[
F_{n,\text{high}} = m_{\text{head}}(r) \left( \frac{d\theta}{dt} \right)^2 \\
= (1.59 \text{ kg}) \left( 6.35 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \right) \left( 150 \frac{\text{ rad}}{\text{ s}} \right)^2 = 2272 \text{ N}
\]

However, Bandak reported \( F_{n,\text{high}} \) at 35,931 N in Table 3, a value 15.8 times higher than the correct value. Similarly, to calculate forces for the least severe shaking event discussed by Bandak, we used the minimum values of each parameter range provided by Bandak’s Table 3 and calculated the lower range of the normal force as:

\[
F_{n,\text{low}} = m_{\text{head}}(r) \left( \frac{d\theta}{dt} \right)^2 \\
= (0.68 \text{ kg}) \left( 3.81 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \right) \left( 50 \frac{\text{ rad}}{\text{ s}} \right)^2 = 65 \text{ N}
\]

The corresponding value reported by Bandak in Table 3 is 1027 N.

We repeated the force calculations for all values in Bandak’s Table 3 and our attempts to reproduce these neck force calculations consistently yield values that are at least 10 times lower than those reported for shaking in Table 3 and Fig. 4 of Bandak’s paper. While in some cases the error appears to be a failure to include the neck length, there is no single, simple explanation responsible for the errors that appear in every value in Table 3. Also, Prange and Myers [2] analysis of the

• “While in some cases the error appears to be a failure to include the neck length, there is no single, simple explanation responsible for the errors that appear in every value in Table 3.”

• “When accurately calculated, the range of neck forces is considerably lower and includes values that are far below the threshold for injury.”
Alternative Theory: Hypoxia

• Since shaking cannot cause SDH it is simply the result of hypoxia.

• Primarily based on work by Geddes

• “Unified hypothesis”: Some event happens (choking) that leads to hypoxia, which leads to cerebral edema and SDH.

• Her studies did not reach statistical significance
Testimony of Jennian Geddes

- Dr Geddes, at the beginning of her cross-examination, accepted that the unified hypothesis was never advanced with a view to being proved in court. She said that it was meant to stimulate debate. Further, she accepted that the hypothesis might not be quite correct; or as she put it: "I think we might not have the theory quite right. I think possibly the emphasis on hypoxia - no, I think possibly we are looking more at raised pressure being the critical event."
Testimony of Jennian Geddes

"Q. Dr Geddes, cases up and down the country are taking place where Geddes III is cited by the defence time and time again as the reason why the established theory is wrong.

A. That I am very sorry about. It is not fact; it is hypothesis but, as I have already said, so is the traditional explanation. ... I would be very unhappy to think that cases were being thrown out on the basis that my theory was fact. We asked the editor if we could have "Hypothesis Paper" put at the top and he did not, but we do use the word "hypothesis" throughout."

Section 58, p14 of Court of Appeals (UK) decision issued 7/21/2005
Alternative Theory: Birth Trauma

- Infant has a clinically insignificant bleed at birth that causes collapse some months later.
- Based on three papers that report about 10-45% of births have some asymptomatic intracranial bleeding. (Whitby, Looney, Rooks)
- No cases went on to have any problems and no evidence to support that this results in serious injury or death weeks to months later.
Alternative Theory: RH are Meaningless

- The etiology of retinal hemorrhages is not well defined - True
- RH have been reported in short falls - True
- Description and location increasingly important
  - Number, retinoschisis, location, etc
- Some argue that RH is secondary to increased intracranial pressure
- Terson’s Syndrome - association between ICH and RH
Conditions associated with hypoxia and brain swelling without trauma do not result in findings characteristic of abusive head trauma

- **CPR**
  - Odom, Peds 1997
  - Gilliland, Am J For Med Path 1999

- **Seizure (without trauma)** does not result in widespread RH
  - Zahav, Archives 2002

- **Increased Intracranial Pressure**
  - 0/10 kids with ICH and papilledema had RH
    - Schloff, Ophtha 2002
  - 75 kids with abusive head trauma...those with increased ICP did not differ in character or number of RH compared to those without increased ICP
    - Morad, Am J Ophtha 2002

- **Shunt failures (no trauma)** had no RH
  - Nazir and Phillips JAAPOS 2009
Alternative Theory: Thrombosis

- Cortical vein thrombosis causes SDH
  - From infection, hypercoagulable state, dehydration, etc.

- SDH causes increased intracranial pressure

- Increased ICP causes brain injury and RH

- Most SDH in AHT is thin film
Thrombosis and Subdural

- 36 Nontraumatic IVT
- No SDH
Daubert Review by Narang (MD/JD) Part 1 and 2


  [https://www.law.uh.edu/hjhlp/volumes/Vol_13_2/Narang.pdf]
1. Abusive head trauma: past, present, and future.
Authors: S. Narang and J. Clarke
2. Abusive head trauma in infants and children.
3. Retinal hemorrhages in abusive head trauma.
Author: A. Levin.
4. Alternate theories of causation in abusive head trauma.
Author: C. Jenny
Pediatric Radiology 2014;vol 4 (suppl 44).
Resources

• SEARCH Group Inc,
  • www.search.org

• Association of Prosecuting Attorneys
  • http://www.apainc.org/

• NDAA publication

• National Center on Shaken Baby Syndrome
  • http://www.dontshake.org/index.php