Controversies in abusive head trauma
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A disputed diagnosis imprisons parents

Prosecutors build murder cases on disputed Shaken Baby Syndrome diagnosis

Doctors who diagnosed Shaken Baby Syndrome now defend the accused

The unsettled science of Shaken Baby Syndrome

A child abuse diagnosis raises questions, doubts

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Why is there so much controversy?

- Debate about whether shaking alone can cause brain injury came about from a 1987 study which attempted to use biomechanics to study injuries caused by abusive head trauma
  - Created biomechanical model of a one month old infant [weighted Just Born® dolls with wet cotton inside head]
  - Some models were shaken, others were shaken then thrown
  - Angular acceleration and angular velocity measured using accelerometers
  - Angular accelerations and angular velocities for shaking without impact did not exceed the threshold to cause concussion, subdural hematoma (SDH), or diffuse axonal injury (DAI); accelerations were higher in dolls subjected to shaking with impact
  - Authors concluded that shaking alone is insufficient to cause injury

Concerns about the Duhaime study

- Thresholds for brain injury used in the Duhaime study were derived from adult primate data
  - Standards based on primate data of response to strain; data collected from auto industry, and measured response to one event; model assumes that strain does not accumulate during shaking
  - These thresholds are unlikely to apply to infant brains
    - Infant brains with higher water content than adult brains, due to lack of myelin
    - Infants more vulnerable to injury because of relatively larger head, weaker neck muscles, soft skull

AHT: Diagnostic Criteria

- Brain injury
- Hemorrhage of extra-axial space, usually subdural or subarachnoid
- Retinal hemorrhages - bilateral or unilateral
- Other associated injuries increase suspicion for abusive trauma

AHT: Mechanism

- Perpetrator often holds child by chest, compressing the chest while forcefully shaking at full arm extension
- Forces involved are much greater than those involved in normal parenting
- Usually large size differential between perpetrator and victim; adult (or adult-sized person) required
- Rib and extremity fractures can result

AHT: Anatomy

- Potential subdural space lies between the inner dural layer, and dura arachnoid
- Contains bridging veins which extend from brain surface, penetrate arachnoid, and cross subdural space into the intradural space to empty into the dural venous sinuses
Anatomy of dural layers

Contact head injuries

- Skin/scalp/subgaleal contusion
- Skull fracture
- Epidural hematoma
- Focal subdural hematoma
- Cortical contusion

Injuries at deeper tissue layers were caused by greater force

Epidural hematoma

- Not specific indicator of inflicted trauma; can occur with accidental injury
- Can result from seemingly benign fall onto rigid surface
- Occurs deep to site of cranial impact

Epidural Hematoma

Rotational (inertial) brain injuries
(i.e., rotational cranial acceleration or deceleration)

- Interhemispheric or diffuse subdural hemorrhage (SDH)
- Concussion
- Gliding contusions or lacerations
- Diffuse axonal injury
- Cranio-cervical junction injuries
- Diffuse retinal hemorrhage/retinoschisis
Subdural hematoma

Primary brain injury
- Cortical injury
  - Contusions
  - Lacerations
- Axonal injury
- Hemorrhage

Secondary brain injury
- Hypoxic-ischemic encephalopathy
  - Metabolic alterations in ion homeostasis and membrane function
  - Pathologic changes in microvasculature
- Cerebral edema
  - leads to increased intracranial pressure, ischemia, herniation
- Altered neurochemistry
  - Increased release of excitatory amino acids leading to edema
AHT: Clinical presentation

Variable, depending on extent of injury

- Excessive sleepiness (lethargy)
- Irritability
- Poor feeding
- Vomiting
- Loss or alteration of consciousness
- Seizures
- Apnea
- Coma
- Death

Retinal Hemorrhages

- Seen in approximately 80% of AHT
- Diffuse hemorrhages generally not caused by accidental injuries, can rarely be seen when significant forces involved (i.e., MVC, crush injury)
- Hemorrhages can be seen in coagulopathies, meningitis, vasculitis, sepsis
- Diffuse hemorrhages not caused by CPR

Biomechanics of Retinal Hemorrhages

- Vitreous traction theory
  - Shaking produces traction on the tightly adherent vitreous, causing retinal injury
- Finite element modeling studies
  - Computerized modeling using known tissue properties which predicts effect of tissue strains
  - These models predict shear strains with anterior-posterior movement which could disrupt blood vessels and retina
  - Maximal retinal strains occurred at the posterior pole and periphery, corresponding to location of retinal hemorrhages in AHT patients

Normal retina

Retinal hemorrhages

Studies adding to the AHT controversy

- Other studies also did not measure accelerations in the brain injury range from shaking alone
- Such studies also had difficulty with finding a biofidelic model
  - Cory & Jones 2003 - Made several variations to first model used and obtained measurements which at times exceeded the limits for concussion
- Development of a model with better biofidelity produced higher measured acceleration forces
  - Angular acceleration forces were substantially higher than in Duhaime study, mostly exceeding 10,000 radians/sec
  - Cory & Jones - Gas shaking alone caused brain impact - a biomedical assessment of the Duhaime study bailing out the non-linear effects

Finite element modeling studies

- Computerized modeling based upon known tissue properties for the brain and surrounding structures
- Predicts effects of tissue strains with various types of force application
- Continued refinement of models results in better prediction

Animal studies

- Like humans, sheep and pigs have large brains with complex patterns of surface convexity
- Primates are no longer used in neurotrauma research
- Pigs have predominantly postnatal brain development
- Material properties of infant and adult pig brains differ
- Brain tissue responds in non-linear fashion to large and small strains
- Shaking and impact trauma to lambs has caused widespread axonal injury, with multiple symptoms (including death) as a result

Descriptive studies

- Designed for hypothesis generation
- Correlational studies
  - Uses data from entire populations to compare disease frequencies between different groups during the same period of time, or in the same population at different points in time
  - For example, rates of colon cancer have a correlation with per capita meat consumption
- Case reports, case series
  - Case reports are most basic descriptive study of individuals
    - Consists of detailed report regarding a single patient
    - Can expand a case report to a case series
    - Describes characteristics of a number of patients with a given disease

Descriptive studies (con’t)

- Cross-sectional surveys
  - Collects information from individuals regarding disease and exposure to risk factors
  - Information is explored for relationships between disease and various risk factors
Analytical studies

• Designed to answer a research question of interest

• Observational studies
  – Case-control study
    • Patients are selected on the basis of whether or not they have disease, and are compared with a group of people who do not have the disease to determine their exposure to risk factors of interest
    • Groups are compared with each other regarding proportion with risk factor

Analytical studies (con’t)

• Intervention studies [clinical trials]
  – Community trial
    • Non-random assignment to intervention and control groups
  – Clinical trials
    • Random assignment to intervention and control groups

Analytical studies (con’t)

• Observational studies (con’t)
  – Cohort
    • Patients selected on basis of whether they are exposed or not exposed to the risk factor of interest
    • They are followed for a specified period of time [sometimes several years] to determine whether disease develops
  – Retrospective
    • Exposure and outcome of interest has already occurred at the start of the study
  – Prospective
    • Exposure has occurred, but outcome of interest has not yet occurred, at start of study

Literature reviews

• Discusses published information in a particular subject area, sometimes within a certain time period

• Can be simple summary (recap of important information), but is often a summary and synthesis (reorganization or reinterpretation of older information, or designed to show progression in a field)

• The focus is to summarize and synthesize information without adding new contribution

Defense theories regarding child abuse allegations

• Theory proposed that hypoxia, both alone and in combination with infection, can activate a cascade culminating in altered vascular permeability and extravasation of blood within and under the dura. Cerebral venous hypertension, arterial hypertension, and brain swelling, along with immaturity and hypoxia-related vascular fragility, provide an alternative explanation for the characteristic subdural bleed of shaken baby syndrome. Increased central and venous pressure would also account for retinal hemorrhages.

• Geddes based this conclusion upon looking at three strips of dura from 50 children who died of various causes including infections and infection with documented hypoxia, and 3 children who died of abusive head trauma.

• Intracranial hemorrhage (ICH) was seen in 41 children without head injury

• Intracranial hemorrhage (ICH) was seen in 3 children with AHT; she felt that the intracranial blood dissected into the subdural space in all of these children

• Geddes felt that this response could explain the presence of subdural bleeding in some cases of infant head trauma, and that traumatic rupture of bridging veins was not necessary, such that impact or considerable force would not be necessary to account for subdural hemorrhages.

• Dr. Geddes ultimately acknowledged that her statements regarding the cause of subdural hemorrhages were hypotheses.

• She produced several other studies in the same vein, and another research group (Scheimberg, Cohen, etc) continues to perform studies and reach the same conclusions despite the lack of supporting evidence.

Defense theory: Shaking did not (or could not) cause child’s abnormal findings

- An analysis by a biomechanical engineer stated that the amounts of rotational velocity and acceleration required to cause head injury would cause mechanical failure of the cervical spine
- Given the relatively low rates of cervical spine injury among children diagnosed with abusive head trauma, and a series of calculations based on experimental data (obtained from several animal species and neonatal cadavers) showing that spinal cord injury can occur at low thresholds, the author calls for reconsideration of diagnostic criteria for AHT


Re-analysis by different groups of biomechanical engineers raised concern that Dr. Bandak’s neck distraction force calculations and range of rotational acceleration forces for AHT were erroneous
- His incorrect calculations led to his conclusion that neck trauma would result from even the least severe shaking force
- The authors proposed that a more appropriate conclusion would be that the possibility of neck trauma exists with a severe shaking event

Margulies et al. Shaken baby syndrome: a flawed biomechanical analysis. For SciInt 2005

Case report proposed that apparent life-threatening event (ALTE) led to choking
- Infant had cerebral edema, subarachnoid and subdural bleeds, herniation, rib fractures, retinal detachment, and ocular hemorrhages
- Although abusive head trauma can cause symptoms which appear to be an ALTE, choking does not cause the above constellation of findings


Associated features of AHT do not have diagnostic significance

- Case series (2 children) included infant with venous malformation, and toddler who fell off of a moving train
- Children had retinoschisis, optic nerve sheath hemorrhages
- Both had explanatory conditions which accounted for severe head trauma, and were not typical of AHT


Defense theory: An undiagnosed medical condition is responsible for the child’s findings

- Literature review proposing Vitamin C deficiency as a cause for the unexplained subdural hematoma, retinal hemorrhages, and skeletal fractures in some cases diagnosed as abusive
- Explores the symptoms of Vitamin C deficiency, reviews the role of Vitamin C in the body, points out the lack of current data regarding the frequency of Vitamin C deficiency, and the difficulties in testing Vitamin C levels.
- Points out that research is needed to determine role of Vitamin C deficiency in AHT, and that an open mind regarding differential diagnosis is important in cases of suspected AHT

Fung et al. Could Vitamin C deficiency have a role in shaken baby syndrome? Pediatrics International 2006;48:763-75

Defense theory: Babies are fragile and easily injured

- Weber studies dropped infant cadavers onto various surfaces (tile floors, foam mat, folded blanket, carpeted floor, linoleum floor) from heights of 82 cm (32.3 inches)
  - All infants were dropped onto tile floor, carpeted floor, and linoleum floor sustained fractures
  - 1 in 10 infants dropped onto foam mat had fracture
  - 4 fractures resulted from 25 falls onto folded blanket
- Author concluded that infants likely to have fractures from low-height falls
- Author also concluded that the autopsy findings in a suspected abuse case were attributable to skull fragility
  - “Bursting” fractures of bilateral parietal skull; cortical contusions; cerebral edema; bilateral subdural hemorrhages; retinal hemorrhages; multiple hematomas on head, back, extremities

Defense theory: The child was abused, but my client did not hurt the child

Studies regarding timing of symptom onset
• When looking at studies in which children sustain head injury, onset of symptoms usually occurs immediately after traumatic event
• Exceptions occur when perpetrator did not check on child for prolonged period after event
• One lucid interval seen in child with epidural hematoma
• This means that children with severe head injury do not have a lucid interval


Defense studies regarding timing of symptom onset
• Case report and case series involving children ages 9 months to 14 years
• Children had different traumatic injuries (MVCs, falls from varying heights)
• Only one incident involved a child who was neurologically normal after incident; remainder had high GCS scores, but were not normal
• Three of children had autopsies
• Of those with autopsies, constellation of findings was not typical of abusive head trauma injuries
• Authors felt that this report and series proved that children can have lucid interval, but applicability of these children’s injuries to abusive head trauma limited


Defense theory: An accident [short fall, stairway fall] caused the child’s findings

Stairway Falls
• Most injuries resulting from stairway falls are to head and neck
• Most children with no or only minor injuries after stairway fall
• Could have focal subdural, skull fracture, focal brain injury; more severe injuries occurred if child fell with adult
• Rarely (less than 10% of time) had extremity fractures
• No life-threatening injuries; rare to have injuries involving multiple body areas

Childhood Falls

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Cases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>Helfer</td>
<td>246 cases</td>
<td>all falls from beds, 3 linear skull fx, no deaths</td>
</tr>
<tr>
<td>1987</td>
<td>Nimilyongsuk</td>
<td>76 cases</td>
<td>all falls from bed/cribs, 97% minor injuries, 1 linear skull fx, no deaths</td>
</tr>
<tr>
<td>1988</td>
<td>Joffe</td>
<td>363 cases</td>
<td>all stairway falls, 92% minor injury, 6% distal fx, 1 concussion, no deaths</td>
</tr>
<tr>
<td>1991</td>
<td>Williams</td>
<td>106 cases</td>
<td>all witnessed falls, 77 minor injuries, 14 severe injuries (5-40 ft), no lethal injuries &lt;10 feet, 1 death at 70 ft</td>
</tr>
<tr>
<td>1993</td>
<td>Lyons</td>
<td>207 cases</td>
<td>all witnessed falls from cribs/beds, 29 minor injuries, 1 linear skull fx, no death</td>
</tr>
<tr>
<td>1991</td>
<td>Chadwick</td>
<td>317 cases</td>
<td>reported falls, 7 deaths &lt;4 ft (all have to be false), 8 deaths 4-10 ft, 1 death &gt;10 ft</td>
</tr>
</tbody>
</table>
Childhood Falls

2008 Chadwick

Meta-analysis of literature on short falls. National Electronic Injury Surveillance System (NEISS) found 3 short fall deaths among 400,000 children, calculated rate of 0.85 cases per million young children per year. California Epidemiology and Prevention for Injury Control Branch (EPIC) database found 6 short fall deaths per 2.5 million children in five years, or 0.24 cases per 1 million children per year

2010 Harvey

122 children who fell before age 2 years

2010 Osofo

12 children ages 3 years or less

2011 Shields

31264 balcony falls in children

Fall heights ranged from 5 to 87.5 feet, most falls 12.5 feet or less; 2 deaths (girls ages 6 and 11 years), with fall heights ranging from 5 to 50 feet

Childhood falls

• If given a history of serious injury with fall from short distance, history is usually factitious
• Fall from couch, bed, crib, changing table can rarely cause a linear parietal skull fracture; there is almost never a serious or life-threatening injury from such a fall
• Falls down stairs seldom result in serious head injury

Defense literature: short fall can cause extra-axial, retinal hemorrhages

• Gardner published case report of 11 month old child who fell backward from seated position (witnessed by 2 year old sibling), striking head, and had immediate neurologic symptoms. When seen by doctor within hour, child was abnormal.
• Surgery performed to evacuate large space-occupying intracranial bleed
• Retinal hemorrhages involving multiple layers, initially confined to posterior pole, later said to extend to periphery
• Child did well after surgery, no developmental abnormalities or brain injury
• Constellation of findings consistent with contact injury, not rotational injury

Defense literature reviews

• Often review only a highly selected subset of the available literature
• Often exclude large segments of relevant publications
• Categorize studies based on questionable criteria
• Produce unwarranted conclusions regarding diagnosis of AHT

Evaluation of the Potential Effects of a Fall

Decreased Risk

lower height
initial velocity 0
Soft surface
lower mass
high pt elasticity
large impact area

Increased Risk

greater height
+ initial velocity
hard surface
greater mass
low pt elasticity
small impact area

Defense literature

• Case series from Consumer Product Safety Database (CPSC) reviewed files involving head and neck injuries from CPSC, death certificate, Injury/Potential Injury, and In-Depth Investigations files over an 11-year period from 1988 through 1999
  – The author reported that there were 75,000 cases reported in National Electronic Injury Surveillance System (NEISS) file
  – Children ranged in age from 12 months to 13 years
  – 18 deaths from head injury were found, with death rate of 1.3 per 100,000 falls
    – The denominator used is the number of Emergency Department visits over the 11 ½ year period covered by this paper (there were over 120,000,000 visits to EDs every year for falls, translating to over 1.3 million such visits over the study time period)
  – Author felt findings proved that short falls can cause death in children
  – Constellation of injuries consistent with contact injuries, not rotational trauma; limited applicability to abusive head trauma cases


Summary of defense research

• Published defense experts are not using analytical research designs
  – They use case reports, case series, literature reviews
• These non-analytical research designs are appropriate for hypothesis generation, but not for hypothesis testing
• They are basing their conclusions on research which is inappropriate for answering the questions that they raise

Summary of defense literature

• Most publications are case reports or case series, not analytical studies
  – Some case reports involve patients whose findings are not typical of abusive head trauma (AHT), and are therefore not comparable to the population of AHT patients
• When literature reviews are produced by defense experts, they are not meta analyses which critically and impartially review all of the available literature
  – Composed of selected studies which support defense viewpoints
  – Such reviews often ignore significant contributions to the child abuse field
• Conclusions of these limited literature reviews are invalid

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