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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Diagnostic Imaging
can not be
its own
Gold Standard

Child Abuse, NAI, AHT, and the Mimics:

Controversies in the Era of Evidence-Based Medicine

- Shaken Baby Death Review Team (Gouge Inquiry). Ministry of the Attorney General, Province of Ontario. Toronto Ontario, Canada, Sept. 24, 2009.
- 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.
- Co-Founder & Member, Child Abuse Task Force & SCAN Team, Lucile Packard Children's Hospital, Stanford University Medical Center, and Santa Clara Valley Medical Center, 2008.
- Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.
- Forensic Science Report. Forensic Science Commission. National Institute of Standards & Technology. The National Academies - Advisors to the Nation on Science, Engineering, and Medicine. Washington, DC, 2008.

SBS / NAI / NAT
The Triad

"Shaken Baby Syndrome (SBS) is a form of physical non-accidental injury (NAI) to infants, characterized by

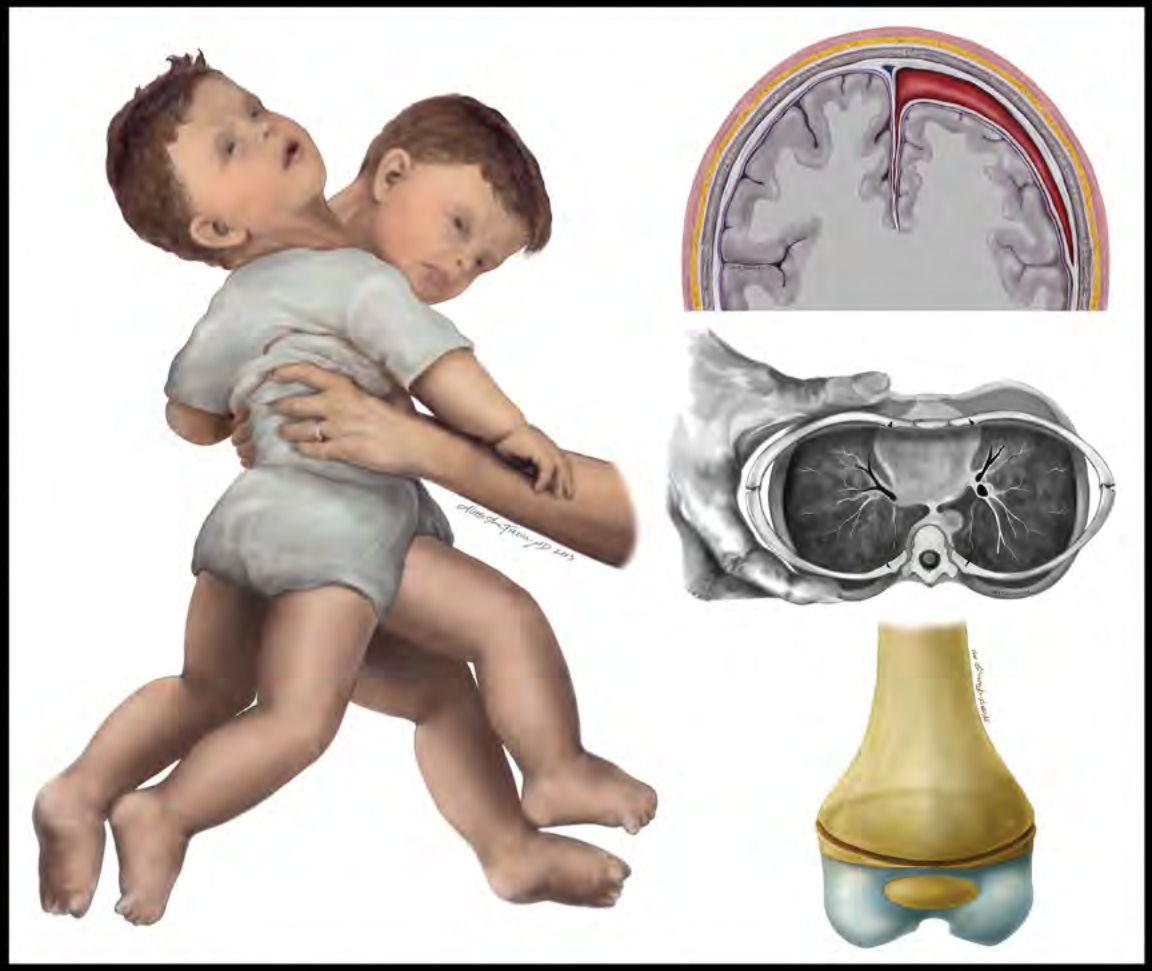
acute encephalopathy with subdural hemorrhage and retinal hemorrhage (i.e. the Triad),

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;
AAP COCAN. Shaken baby syndrome. Pediatrics 2001;108;206.
Brit Med J 2004; 328: 720
Kellogg N, COCAN. Evaluation of suspected child physical abuse. Pediatrics 2007;119:1233.
Christian C, Block R, COCAN. Abusive head trauma in infants and children. Pediatrics 2009;123:1409.

Shaken Baby Syndrome (SBS)



Lonergan G, et al. From the Archives of the AFIP. Child abuse: radiologic-pathologic correlation. RadioGraphics 2003;23:811-845.

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.
- Kempe C, Silverman F, et al. The battered child syndrome JAMA 1962; 181: 17-24.
- Guthkelch A. Infantile subdural haematoma and its relationship to whiplash injuries. BMJ 1971; 2: 430-431.
- Caffey J. On the theory and practice of shaking infants. Am J Dis Child 1972; 124: 161-169.
- Kleinman P. Diagnostic Imaging of Child Abuse, Mosby Year Book, New York, 1998.
- Lonergan G, et al. From the Archives of the AFIP. Child abuse: radiologic-pathologic correlation. RadioGraphics 2003;23:811-845.

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 ?

- Traumatic CNS Injury – leading cause of morbidity / mortality in children.
- >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?

Kleinman P. Diagnostic Imaging of Child Abuse, Mosby Year Book, New York, 1998.

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

Head Injury (i.e. Triad) – Suspected NAI

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

Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18:53-74.

Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. Pediatr Radiol 2009;39:586-590.

Sirotnak A. Medical disorders that mimic abusive head trauma. In Frasier L et al, Abusive Head Trauma in Infants and Children, GW Medical Publishing, St. Louis, 2006, 191-226.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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 distinguish nonaccidental injury from accidental injury, or from predisposing or complicating medical conditions, including the Bone Fragility Disorders.

Rickets vs. Abuse

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Kleinman P. Problems in the diagnosis of metaphyseal fractures. Pediatr Radiol 2008;38 (Suppl 3):S388-S394.

Kemp AM, Dustan F, Harrison S, et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ 2008; 337: 1-8.

Sprigg A. Temporary brittle bone disease vs. suspected non-accidental injury. Arch Dis Child. Online Oct. 27, 2010. doi:10.1136/adc.2009.180463.

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

Holick MF, Binkley NC, Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP, Murad HM, Weaver CM. Evaluation, Treatment, and Prevention of Vitamin D Deficiency: An Endocrine Society Clinical Practice Guideline. *Journal of Clinical Endocrinology & Metabolism,* July 2011, 96(7): 1911–1930.

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

Jenny C et al. [AAP COCAN]. Evaluating infants and young children with multiple fractures. Pediatrics 2006;118: 1299-1303.

Bishop N et al. Unexplained fractures in infancy: looking for fragile bones. Arch Dis Child 2007;92:251-256.

Kellogg N et al. [AAP COCAN]. Evaluation of suspected child abuse. Pediatrics 2007; 119: 1232-1241.

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Kemp AM, Dustan F, Harrison S, et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ 2008; 337: 1-8.

Keller K, Barnes P. Rickets vs. abuse – the evidence: Reply. Pediatr Radiol 2009;39:1130.

Vitamin D Deficiency – Congenital Rickets

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216.

Keller K, Barnes P. Rickets vs. abuse – the evidence: Reply. Pediatr Radiol 2009;39:1130.

Dawodu A, Wagner C. Mother-child vitamin D deficiency: an international perspective. Arch Dis. Child 2007;92:737-740.

Merewood A, et al. Association between vitamin D deficiency and primary C-section. J Clin Endocrinol Metab 2009;94:940-945.

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Yorifuji J et al. Craniotabes in normal newborns: the earliest sign of subclinical vitamin D deficiency J Clin Endocrinol Metab 2008;93:1784-1788.

Kleinman P. Problems in the diagnosis of metaphyseal fractures. Pediatric Radiology 2008;38:S388-S394.

Kemp A et al. Patterns of skeletal fractures in child abuse: a systematic review. BMJ 2008;337;a1518:1-8.

Offiah A et al. Skeletal imaging of child abuse. Pediatr Radiol 2009;39:461-470.

Jenny C et al. [AAP COCAN]. Evaluating infants and young children with multiple fractures. Pediatrics 2006;118: 1299-1303.

Bishop N et al. Unexplained fractures in infancy: looking for fragile bones. Arch Dis Child 2007;92:251-256.

Kellogg N et al. [AAP COCAN]. Evaluation of suspected child abuse. Pediatrics 2007; 119: 1232-1241.

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."

Geddes J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropath and Applied Neurobiol 2003; 29: 14-22)

Cohen M, Scheimberg I. Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol 2008 Nov. 13:1 [Epub ahead of print].

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Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18:53-74.

Sirotnak A. Medical disorders that mimic abusive head trauma. In Frasier L et al, Abusive Head Trauma in Infants and Children, GW Medical Publishing, St. Louis, 2006, 191-226.

Kellogg N et al. [AAP COCAN]. Evaluation of suspected child abuse. Pediatrics 2007; 119: 1232-1241.

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.

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 Tetrad)

- 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.

Guyatt et al. Users' guides to the medical literature. XXV. Evidence-based medicine. JAMA 2000;284:1290-1296;

Collins J. Evidence-based medicine. J Am Coll Radiol 2007;4(8):551-554.

Blackmore C, Medina LS. Evidence-based radiology and the ACR appropriateness criteria. J Am Coll Radiol 2006;3(7):505-509.

Crosskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med 2003;78:775-780.

Best Available Science. The Institute for Regulatory Science.

Evidence-Based Medicine
Quality of Evidence (QOE)
Recommendations

- Level A: Established useful / predictive (or not) for given condition / population; [1Class 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.

INFORMED CONSENT

Guyatt et al. Users' guides to the medical literature. XXV. Evidence-based medicine. JAMA 2000;284:1290-1296.

Collins J. Evidence-based medicine. J Am Coll Radiol 2007;4(8):551-554.

Blackmore C, Medina LS. Evidence-based radiology and the ACR appropriateness criteria. J Am Coll Radiol 2006;3(7): 505-509.

Crosskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med 2003;78:775-780.

Best Available Science. The Institute for Regulatory Science.

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.

Donohue M. Evidence-based Medicine and Shaken Baby Syndrome 1966-1998. Am J Forensic Med Pathol 2003; 24: 39-242

Leestma J. Case analysis of brain injured admittedly shaken infants, 54 cases 1969-2001. Am J Forensic Med Pathol 2005: 26:199-212.

Greeley C. A wolf in evidence clothing: denialism in child abuse pediatrics. AAP Grand Rounds 2011;26:24. DOI: 10.1542/gr.26-2-24.

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.
Comm. Kentucky v. Davis (Daubert) 2006.
Lyons. SBS. Utah Law Rev 2003;1109.
Gena. SBS. Wisc Law Rev 2007;701.
Tuerkheimer D. Next Innocence Project: SBS. Wash Univ Law Rev 2009;87.

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.

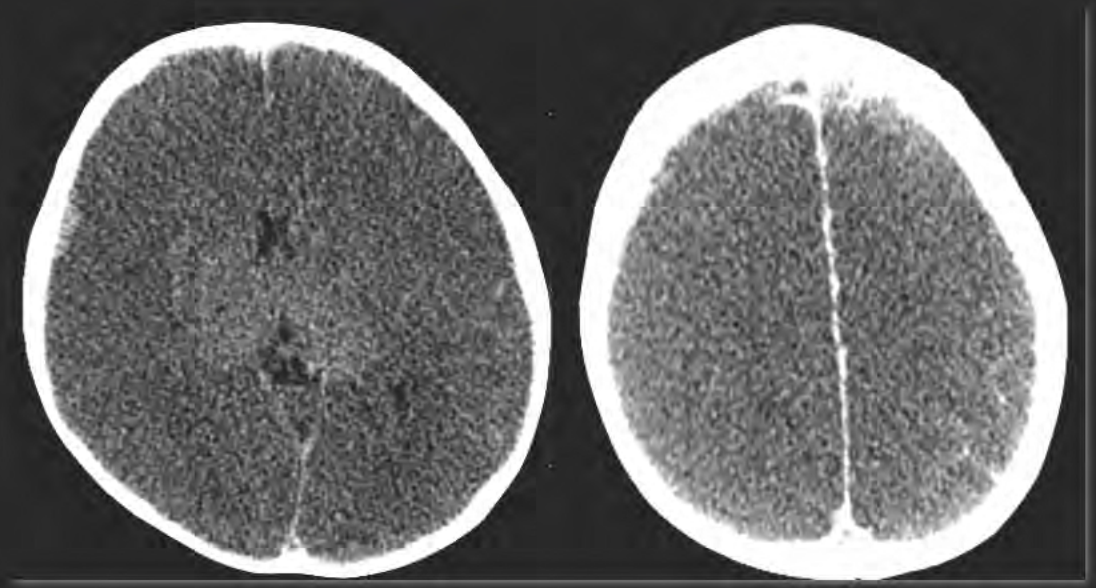
Kleinman P, Barnes P. Head Trauma; Kleinman P, Diagnostic Imaging of Child Abuse, Mosby Year Book, New York, 1998, 285-342.

Frasier L et al, Abusive Head Trauma in Infants and Children, GW Medical Publishing, St. Louis, 2006.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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

Tearing of Veins & Brain



Zimmerman R, et al. Interhemispheric acute SDH. A CT manifestation of child abuse by shaking.Neuroradiology 1979;16:39-40.

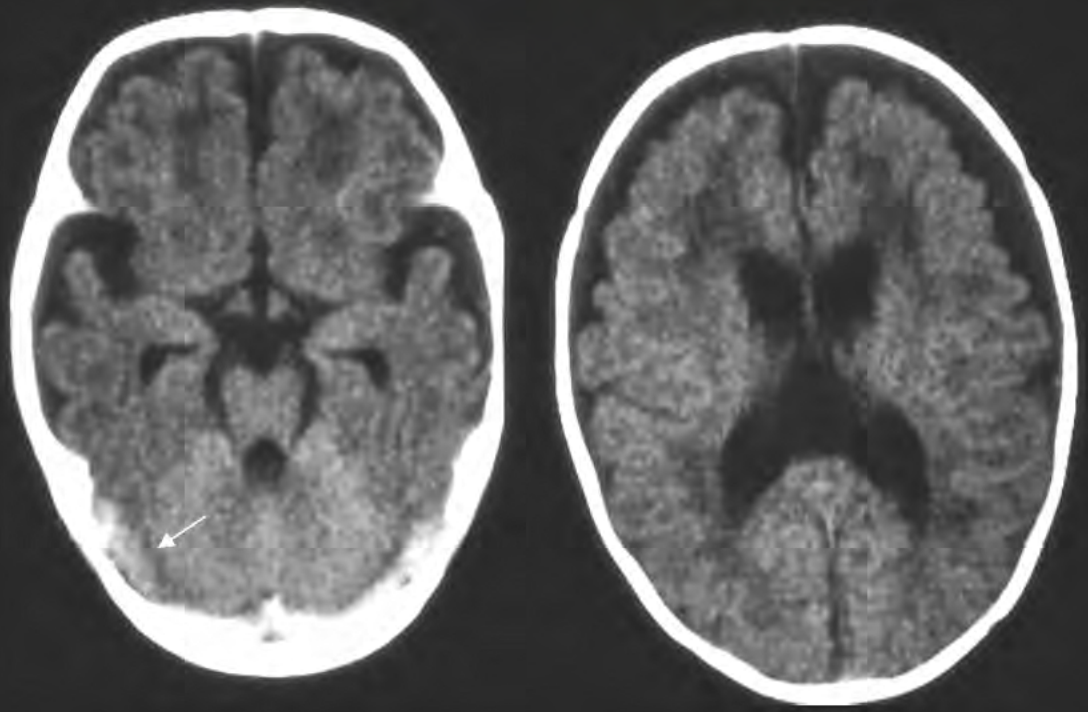
Bruce D, et al. Diffuse cerebral swelling following head injuries in children: the syndrome of "malignant brain edema." J Neurosurg 1981;54:170178.

Kleinman P, Barnes P. Head trauma. In: Kleinman P,ed. Diagnostic Imaging of Child Abuse. 2nd edition. New York, Mosby Year Book;1998:285-342.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

SDHs of Varying Age = Multiple Inflicted Injuries (Myth?)

Tearing of Veins & Brain

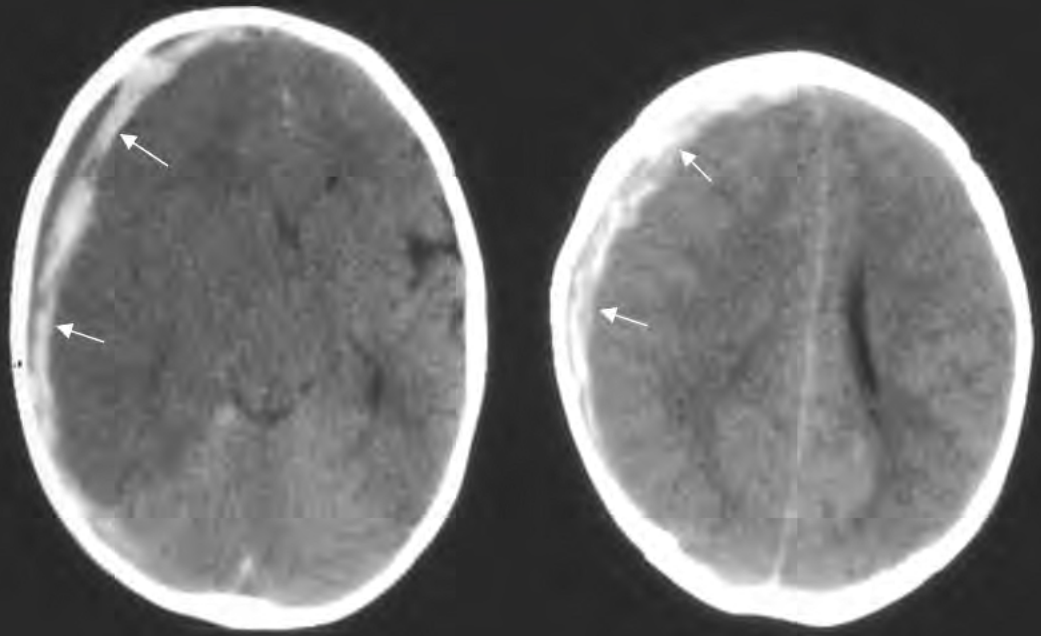


Kleinman P, Barnes P. Head trauma. In: Kleinman P,ed. Diagnostic Imaging of Child Abuse. 2nd edition. New York, Mosby Year Book;1998:285-342.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence Based Medicine. Radiol Clin N Am, Jan. 2011.

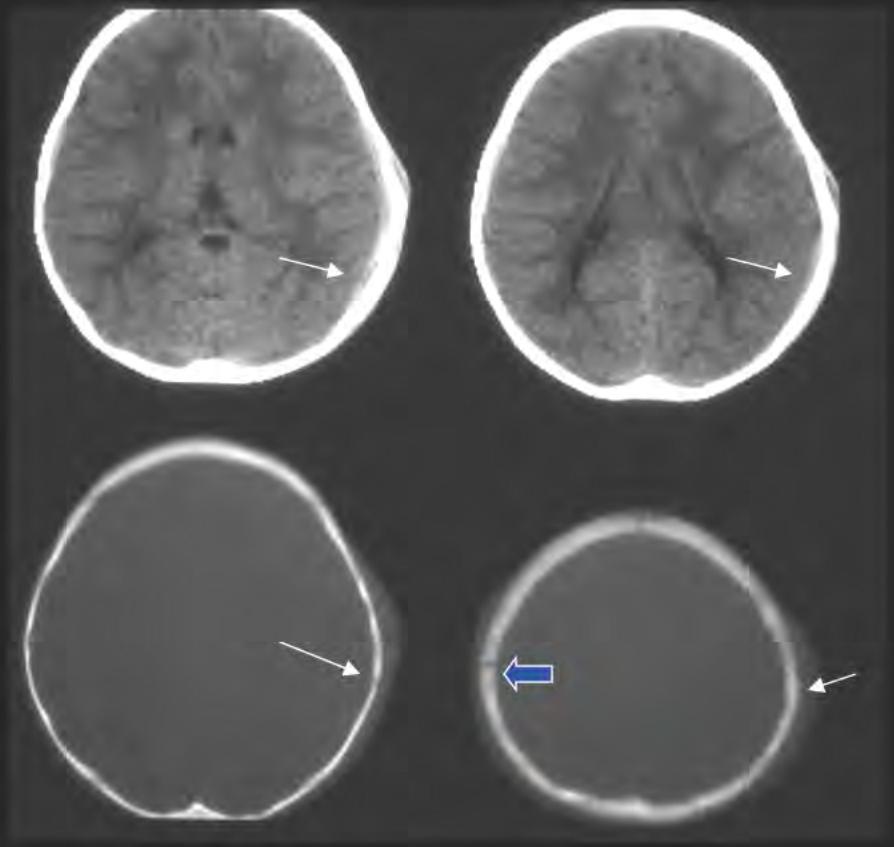
Hyperacute right SDH = NAI (Myth?)

Tearing of Brain & Veins



Barnes P, Robson C. CT findings in hyperacute nonaccidental brain injury. Pediatr Radiol 2000; 30:74-81.
Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

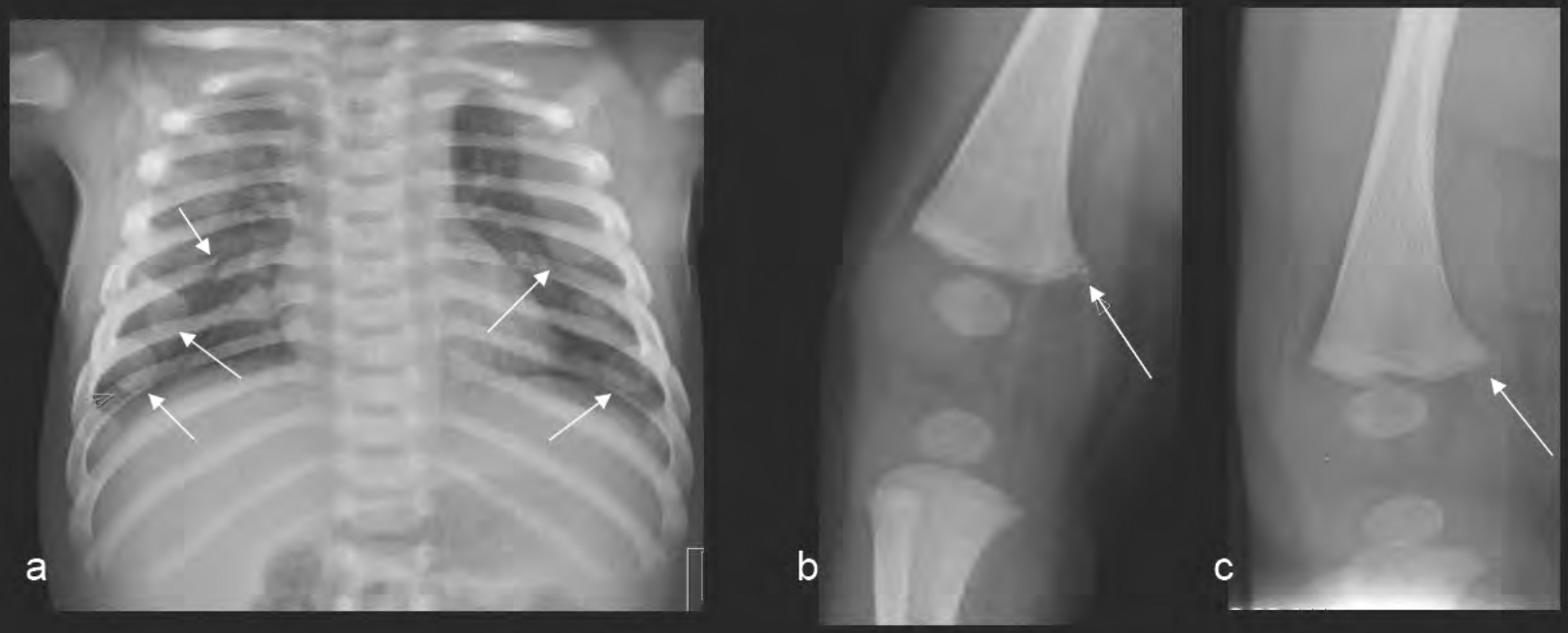
Multiple Skull Fractures of Varying Age + SDH = Abuse (Myth?)



Kleinman P, Barnes P. Head trauma. In: Kleinman P,ed. Diagnostic Imaging of Child Abuse. 2nd edition. New York, Mosby Year Book;1998:285-342.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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)?



Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries).

Keller K, Barnes P. Rickets vs. abuse – the evidence: Reply. Pediatr Radiol 2009;39:1130.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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**

- Caffey J. Multiple fractures in the long bones of infants suffering from chronic subdural hematoma. Am J Roentgenol 1946; 56: 163-173.
- Kempe C, Silverman F, et al. The battered child syndrome JAMA 1962; 181: 17-24.
- Guthkelch A. Infantile subdural haematoma and its relationship to whiplash injuries. BMJ 1971; 2: 430-431.
- Caffey J. On the theory and practice of shaking infants. Am J Dis Child 1972; 124: 161-169.
- 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.
- Ommaya A. Whiplash injury and brain damage. JAMA 1968; 204: 75-79.
- Duhaime A, Gennerelli T, Thibault L, et al. The shaken baby syndrome. A clinical, pathological, and biomechanical study. J Neurosurg 1987; 66:409-415.
- Ommaya A, Goldsmith W, Thibault L. Biomechanics and neuropathology of adult and paediatric head injury. British J Neurosurg 2002; 16: 220-242.
- Prange MT et al. Anthropomorhic simulations of falls, shakes, and inflicted impacts in infants. J. Neurosurg. 2003;99:143-150.
- Goldsmith W, Plunkett J. Biomechanical analysis of the causes of traumatic brain injury in infants and children. Am J Forensic Med Pathol 2004;25:89-100.
- Cory CZ, Jones MD. Can shaking alone cause fatal brain injury? A biomechanical assessment of the Duhaime shaken baby syndrome model. Med Sci Law 2003; 43: 317.
- Ommaya A, Goldsmith W, Thibault L. Biomechanics and neuropathology of adult and paediatric head injury. British J Neurosurg 2002; 16: 220-242.
- Bandak FA. Shaken baby syndrome: a biomechanics analysis of injury mechanisms. Forensic Sci Int. 2005; 151:71-79.
- Ouyang J, Zhu Q, Zhao W, Xu Y, Chen W, Zhong S.Biomechanical assessment of the pediatric cervical spine under bending and tensile loading. Spine. 2005;30(24):E716-23.
- 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 S151).
- Prange M, Newberry W, Moore T et al. Inertial neck injuries in children involved in frontal collisions. Society of Automotive Engineers SAE International 2007 -01-1170.
- Coats B, Margulies S. Potential for head injuries in infants from low-height falls. J Neurosurg Pediatrics 2008;2:321-330.
- Pierce MC, Bertocci G. Injury biomechanics and child abuse. Annu. Rev. Biomed. Eng. 2008;10:85-106.
- Roth S, Raul J-S, Ludes B, Willinger R. Finite element analysis of impact and shaking inflicted to a child. Int J Legal Med 2006.
- Lloyd J, Willey E, Galaznik J, Lee III W, Luttner S. Biomechanical evaluation of head kinematics during infant shaking versus pediatric activities of daily living. J Forensic Biomechanics Vol. 2 (2011), Article ID F110601, 9 pages, doi:10.4303/jfb/F110601

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. On the theory and practice of shaking infants. Am J Dis Child 1972;124:161.
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.
Uscinski R. Shaken baby syndrome: fundamental questions. Brit J Neurosurg 2002;16:217-219.

Guthkelch 1971 Infant SDH Whiplash Injury

"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]

Guthkeld. Infantile subdural hematoma and its relationship to whiplash injuries. Brit Med J 1971;2:430.

Uscinski R. Shaken baby syndrome: fundamental questions. Brit J Neurosurg 2002;16:217-219.

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.

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

Uscinski R. Shaken baby syndrome: fundamental questions. Brit J Neurosurg 2002;16:217-219.

Duhaime et al 1987 SBS

1month 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"

Duhaime A, **Gennerelli T, Thibault L, et al**. The shaken baby syndrome. A clinical, pathological, and biomechanical study. J Neurosurg 1987; 66:409-415.
Uscinski R. Shaken baby syndrome: fundamental questions. Brit J Neurosurg 2002;16:217-219.

Prange 2003 Falls, Shakes, Impacts

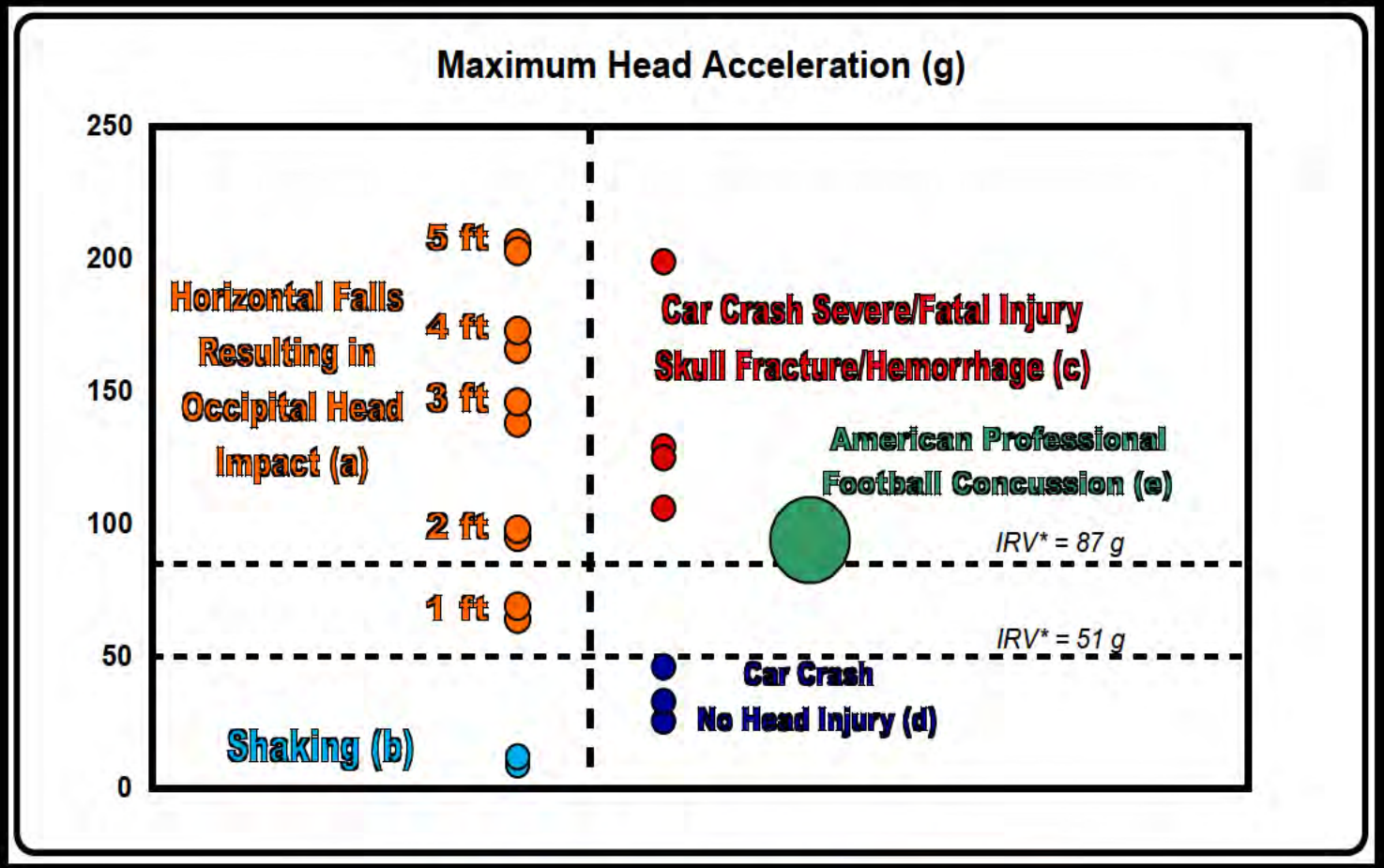
1.5 month old infant model subjected to minor falls, shakes, inflicted impacts.

"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 maximun change in angular velocity of the head experienced during shaking and inflicted impact against unencased foam is sufficient to cause SDHs or TAIs in an infant".

Prange, Coats, Duhaime, Margulis. Anthropomorhic simulations of falls, shakes, and inflicted impacts in infants.
J. Neurosurg. 2003;99:143-150



Chris Van Ee Ph.D. Design Research Engineering (www.dreng.com);

Mertz H, Anthropomorphic Test Devices, Chapter 4, pg 84, Accidental Injury: Biomechanics and Prevention, 2nd Edition, Editors: Melvin J, Nahum A, Springer, 2002. Child Restraint Air Bag Interaction (CRABI).

Klinich JD, Hulbert G, Schneider LW, Estimating Infant Head Injury Criteria and Impact Response Using Crash Reconstruction and Finite Element Modeling, Society of Automotive Engineers Paper # 2002-22-0009, 2002. CRABI 12 (a,b); CRABI 6 (c,d); Injury Reference Values (IRV).

Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF. Concussion in professional football: reconstruction of game impacts and injuries (e). Neurosurgery. 2003 Oct;53(4):799-812

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."*

Ommaya A, Goldsmith W, Thibault L. Biomechanics and neuropathology of adult and paediatric head injury. British J Neurosurg 2002; 16: 220-242.

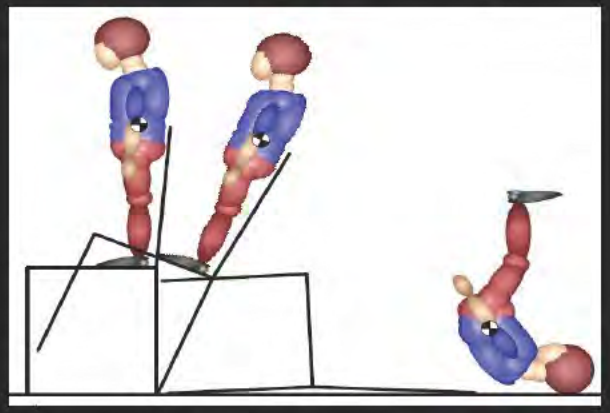
*"Head acceleration and velocity levels commonly reported for **SBS** generate forces that are far too great for the infant neck to withstand without injury . . and can potentially cause severe, if not lethal, **spinal cord or brain stem injury** . . at levels well below those reported for the SBS."*

Bandak. Shaken baby syndrome: a biomechanics analysis of injury mechanism. Forensic Sci Int 2005;151:71 (plus commentaries & replies).

Biomechanics Evidence Base
Conclusions & Recommendations

- **Shaking** may ***theoretically*** cause brain injury if associated with **cervical spinal cord 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!!

2 yM SCIWORA: Partial High Cervical Cord Transection, SAH, SDH, RH, and Hypoxic-Ischemic Brain Injury (CT, Path, Biomech).



Barnes P, Krasnokutsky M, Monson K, Ophoven J. Traumatic spinal cord injury: accidental versus nonaccidental injury. Semin Pediatr Neurol 2008;15:178-184.

Evidence Base
Head Injury in NAI
Neuropathology

- Geddes et al. Neuropathology of Inflicted Head Injury in Children. I. Pattern of Brain Injury. Brain 2001; 124: 1290-1298.
- Geddes et al. Neuropathology of Inflicted Head Injury in Children. II. Microscopic Brain injury in Infants. Brain 2001; 124: 1299-1306.
- Geddes J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropathology and Applied Neurobiology 2003; 29: 14-22.
- Geddes J, Whitwell H. Inflicted head injury in infants. Forensic Science International 2004;146:83-88.
- Punt J, Bonshek, R, Jaspan T, et al. The 'unified hypothesis' of Geddes et al. is not supported by the data. Pediatric Rehabilitation 2004;7:173-184.
- Minns R. Shaken baby syndrome: theoretical and evidential controversies. J R Coll Physicians Edinb 2005;35:5-15.
- Byard R, Blumbergs P, Rutty G, et al. Lack of evidence for a causal relationship between hypoxic-ischemic encephalopathy and subdural hemorrhage in fetal life, infancy, and early childhood. Ped Develop Pathol 2007;10:348-350.
- Hauser R, Jankowski Z, Gos T, Krzyżanowski M. Hemorrhages in head tissues during the asphyxiation process. Forens Sc Int 2001; 124:235-236.
- Kibayashi K, Shojo H and Sumida T. Dural hemorrhage of the tentorium on postmortem cranial tomographic scans in children. Forensic Sci Int 2005;
- 154:206-9.
- Cohen M, Cox P, Kiho L, et al. "Lack of evidence for a causal relationship between hypoxic ischemic encephalopathy and subdural hemorrhage in fetal life, infancy and early childhood". Byard et al. A response. Ped Develop Pathol 2007;10 :500-501.
- Cohen M, Scheimberg I. Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol 2009;12:169-176.
- Koto T, Takubo K, Ishida S, et al. Hypoxia disrupts the barrier function of neural blood vessels through changes in the expression of claudin –5 endothelial cells. Am J Pathol 2007; 170:446 1389-1397.
- Emerson M, Pieramici D, Stoessel K, et al. Incidence and rate of disappearance of retinal hemorrhage in newborns. Ophthalmology 2001;108: 36-39.
- Squier W. Shaken baby syndrome: the quest for evidence. Develop Med Child Neurol 2008;50:10-14.

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 et al. Neuropathology of Inflicted Head Injury in Children. I. Pattern of Brain Injury. Brain 2001; 124: 1290-1298.
Geddes et al. Neuropathology of Inflicted Head Injury in Children. II. Microscopic Brain injury in Infants. Brain 2001; 124: 1299-1306.

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 J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropathology and Applied Neurobiology 2003; 29: 14-22.

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

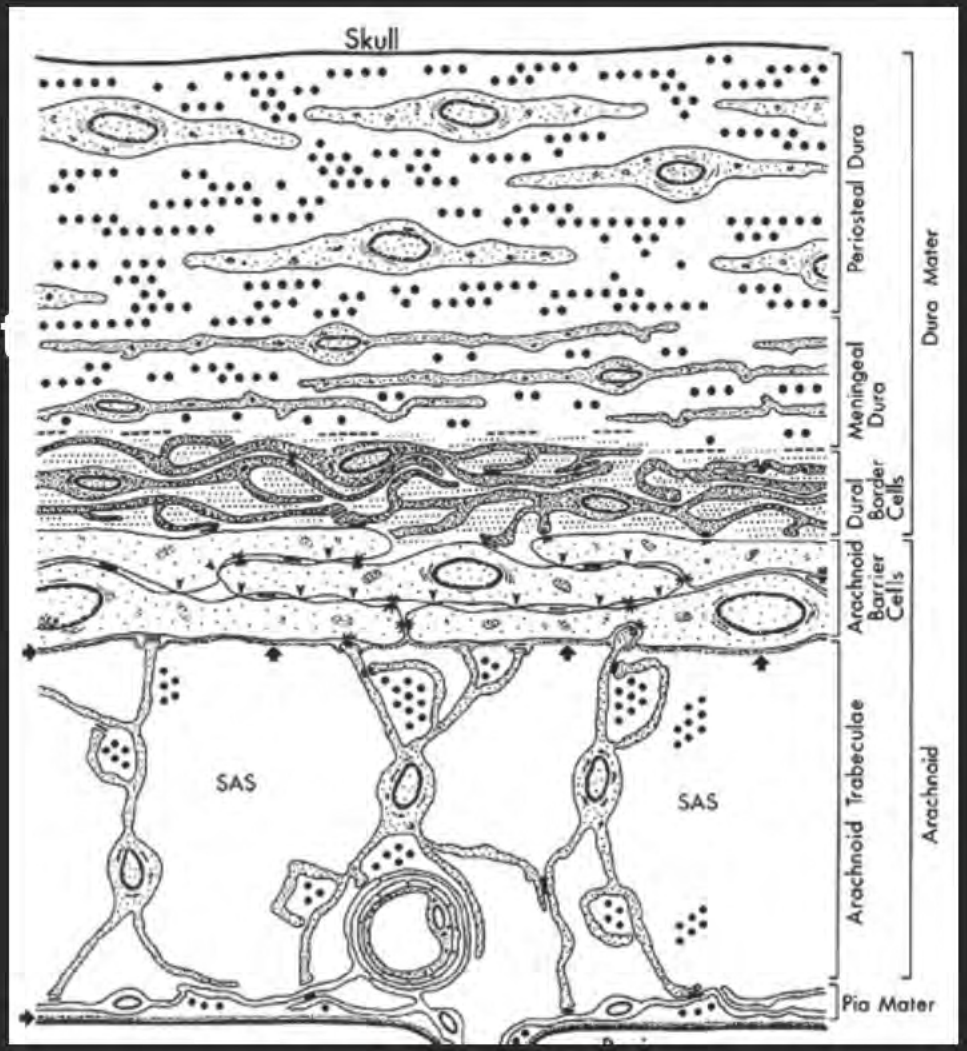
- Common Features: severe hypoxia-ischemia, infection, cerebral venous hypertension, arterial hypertension, brain swelling, venous immaturity / fragility and increased permeability.
- Result: intracranial venous dural hemorrhage [+ retinal hemorrhage].
- Also, hypoperfusion followed by reperfusion, especially via dural arterial supply with dural hemorrhage (no blood-brain-barrier).
- Coagulopathy.
- "**The Unified Hypothesis**" (i.e. the **Cascade**).

Geddes J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropathology and Applied Neurobiology 2003; 29: 14-22.

Cohen M, Scheimberg I. Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol 2009;12:169-176.

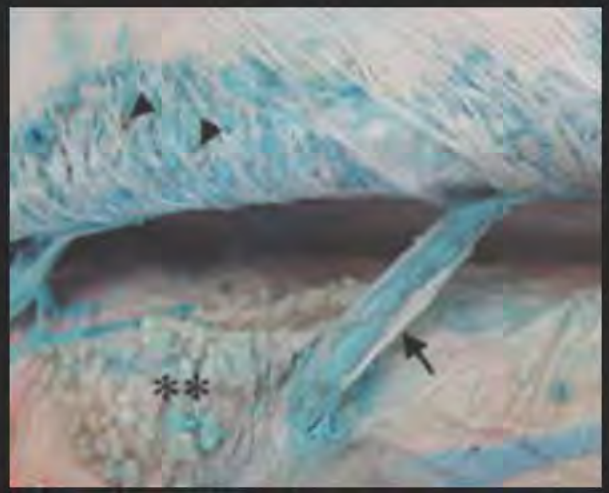
Dural Border Cell Layer/Subdural Compartment & Dural Vascular Plexus

- 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



Dural Venous Plexus (arrowheads) & Bridging Vein (arrow).

Dural Hemorrhages

Mack J, Squier W, Eastman J. Anatomy and development of the meninges: implications for subdural collections and cerebrospinal fluid circulation. Pediatr Radiology 2009;39:200-210.

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

Sguier W. Shaken baby syndrome: the quest for evidence. Develop Med Child Neurol 2008;50:10-14.

Geddes J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropathology and Applied Neurobiology 2003; 29: 14-22.

Cohen M, Scheimberg I. Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol Pediatr Develop Pathol 2009;12:169-176.

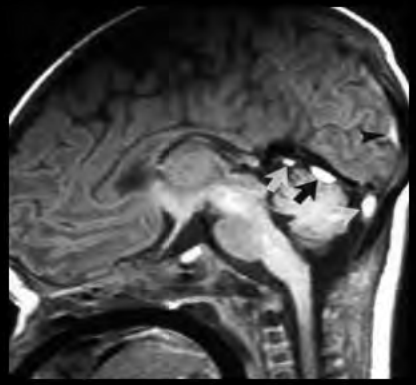
Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18:53-74.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Dural Vascular Plexus Hemorrhage / Hygroma (DH)

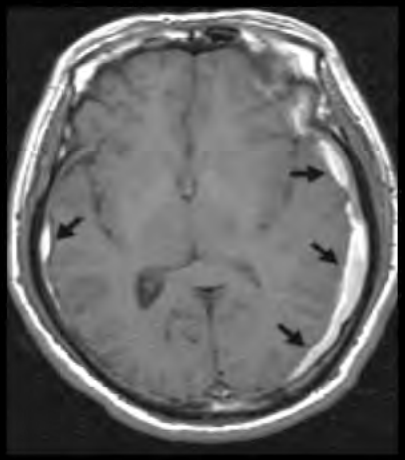
Julie Mack, Hershey Medical Center

Fetal



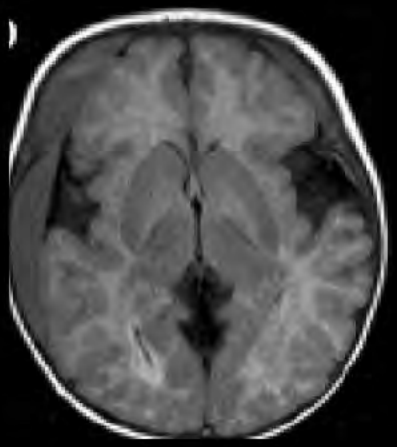
Neonatal

BECC



Spontaneous Intracranial Hypotension

Osteogenesis Imperfecta



GA1

Acute Life Threatening Event
ALTE

- DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

- Apnea – Central, Obstructive, Mixed.

Differential Diagnosis of ALTE

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

Gastrointestinal (33%)

- Gastroesophageal reflux
- Gastroenteritis
- Esophageal dysfunction
- Colic
- Surgical abdomen
- Dysphagic Choking

Differential Diagnosis of ALTE

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

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

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

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

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

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

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;52:1127-1146.

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

DeWolfe CC. Apparent life-threatening event: a review. Pediatr Clin N Am 2005;

52:1127.

Geddes J, Talbert D. Paroxysmal coughing, subdural, and retinal bleeding: a computer modeling approach. Neuropathol Appl Neurobiol 2006;32:625-634.

Talbert D. The sutured skull and intracranial bleeding in infants. Med. Hypotheses. 2006; 66:691-694.

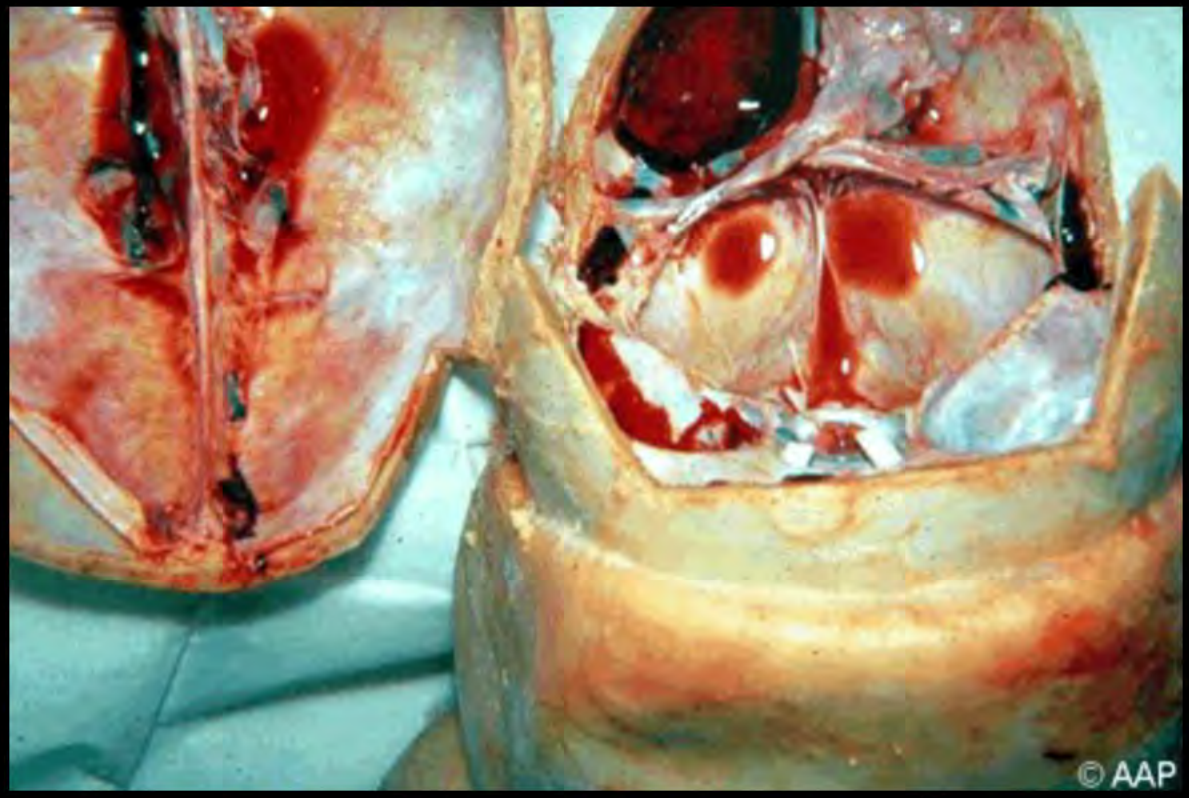
American Academy of Pediatrics red book online. Pertussis. http://www.aapredbook.aappublications.org/cgi/content/full/2003/1/3.9 2003:472 (accessed July 2005).

Mohan P. Aspiration in infants and children. Pediatr Rev 2002;23:330-1.

CDC National Immunization Program. General pertussis information http://www.cdc.gov/doc.do/id/0900f3ec80228696 2000:2 (accessed May 2006).

Page M, Jeffery H. The role of gastro-oesophageal reflux in the aetiology of SIDS. Early Hum Dev 2000;59:127-49.

DH + RH in Pertussis

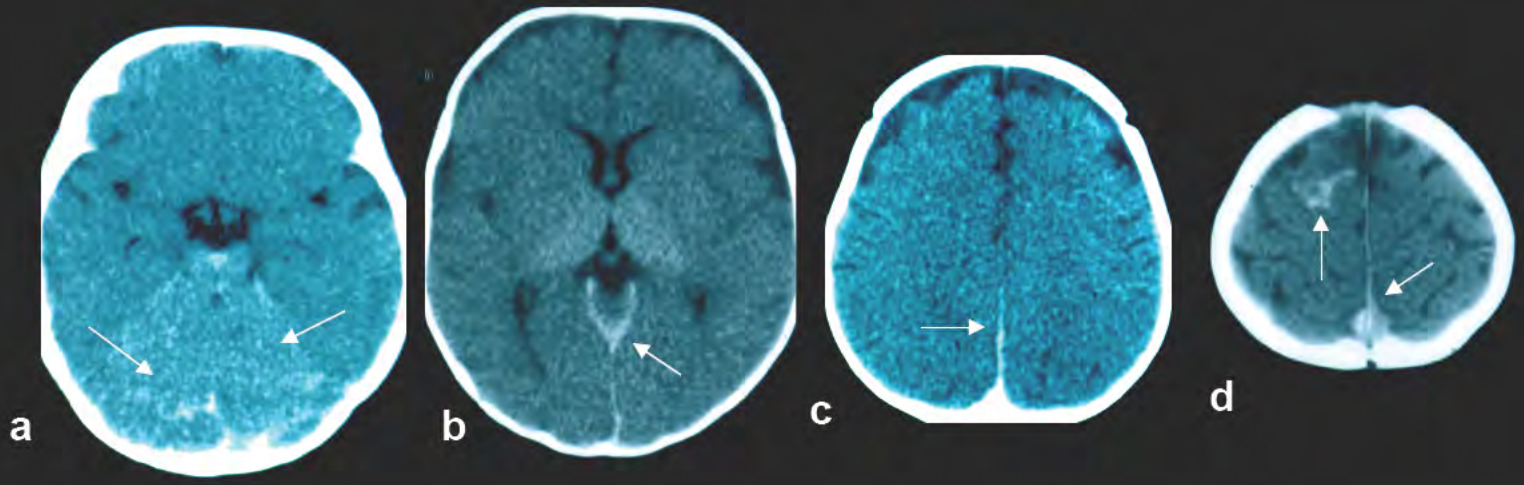


American Academy of Pediatrics *Red Book Online: Pertussis.* 2003 (see also **The Centres for Disease Control & Prevention website**)

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]



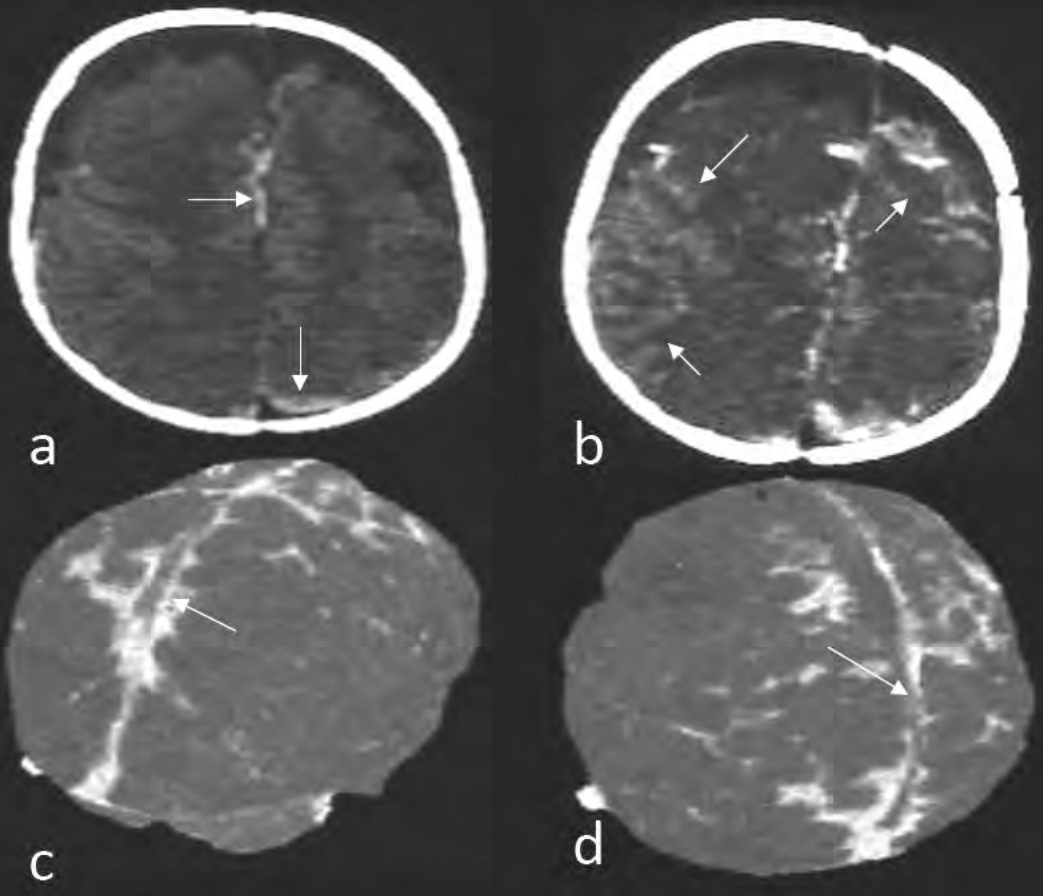
Barnes P, Galaznik J, Krasnokutsky M, et al. CT in Infant Dysphagic Choking Acute Life Threatening Event (ALTE – a mimic of child abuse). Society for Pediatric Radiology, Scottsdale AZ, May 2008.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Dural Hemorrhage & Hypoxia-Ischemia

- **Geddes et al**. Neuropathology of Inflicted Head Injury in Children. I. Pattern of Brain Injury. Brain 2001; 124: 1290-1298.
- **Geddes et al**. Neuropathology of Inflicted Head Injury in Children. II. Microscopic Brain injury in Infants. Brain 2001; 124: 1299-1306.
- **Geddes J et al**. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropathology and Applied Neurobiology 2003; 29: 14-22.
- **Geddes J, Whitwell H.** Inflicted head injury in infants. Forensic Science International 2004;146:83-88.
- **Cohen M, Scheimberg I.** Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol 2008 Nov. 13:1 [Epub ahead of print].
- **Mack J, Squier W, Eastman J.** Anatomy and development of the meninges: implications for subdural collections and CSF Circulation. Pediatr Radiol March 2009.
- **Croft P, Reichard R.** Microscopic examination of grossly unremarkable pediatric dura mater. Am J Forensic Med Pathol 2009;30:10-13.
- **Koto T, Takubo K, Ishida S, et al**. Hypoxia disrupts the barrier function of neural blood vessels through changes in the expression of claudin –5 endothelial cells. Am J Pathol 2007; 170:446 1389-1397.

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).

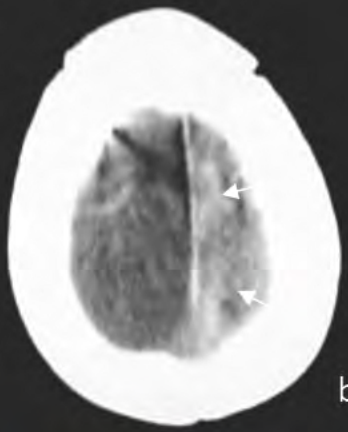
Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Krasnokutsky MV. Cerebral venous thrombosis. A potential mimic of primary traumatic brain injury in infants. AJR 2011; 197: W503-507.

Mimic - Venous Thrombosis

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

a



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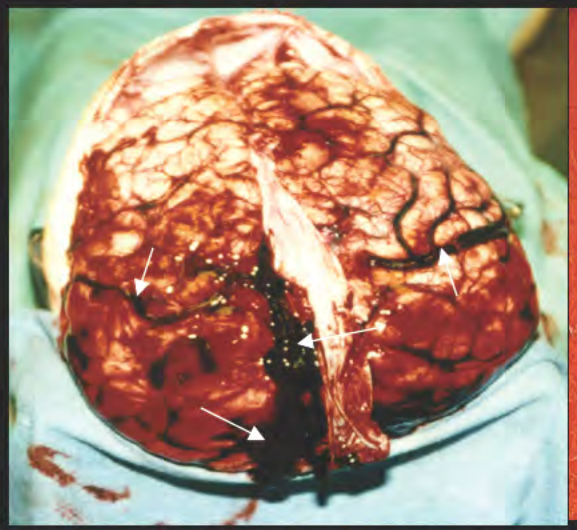
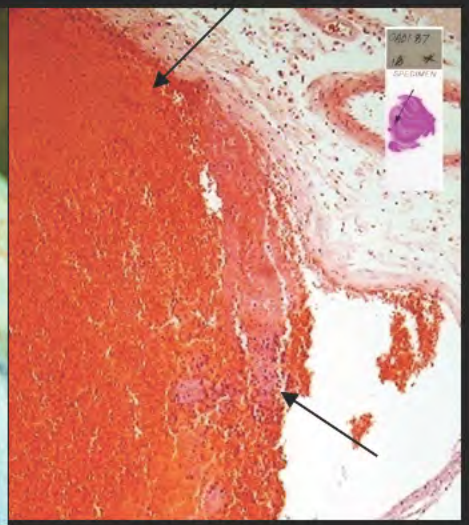


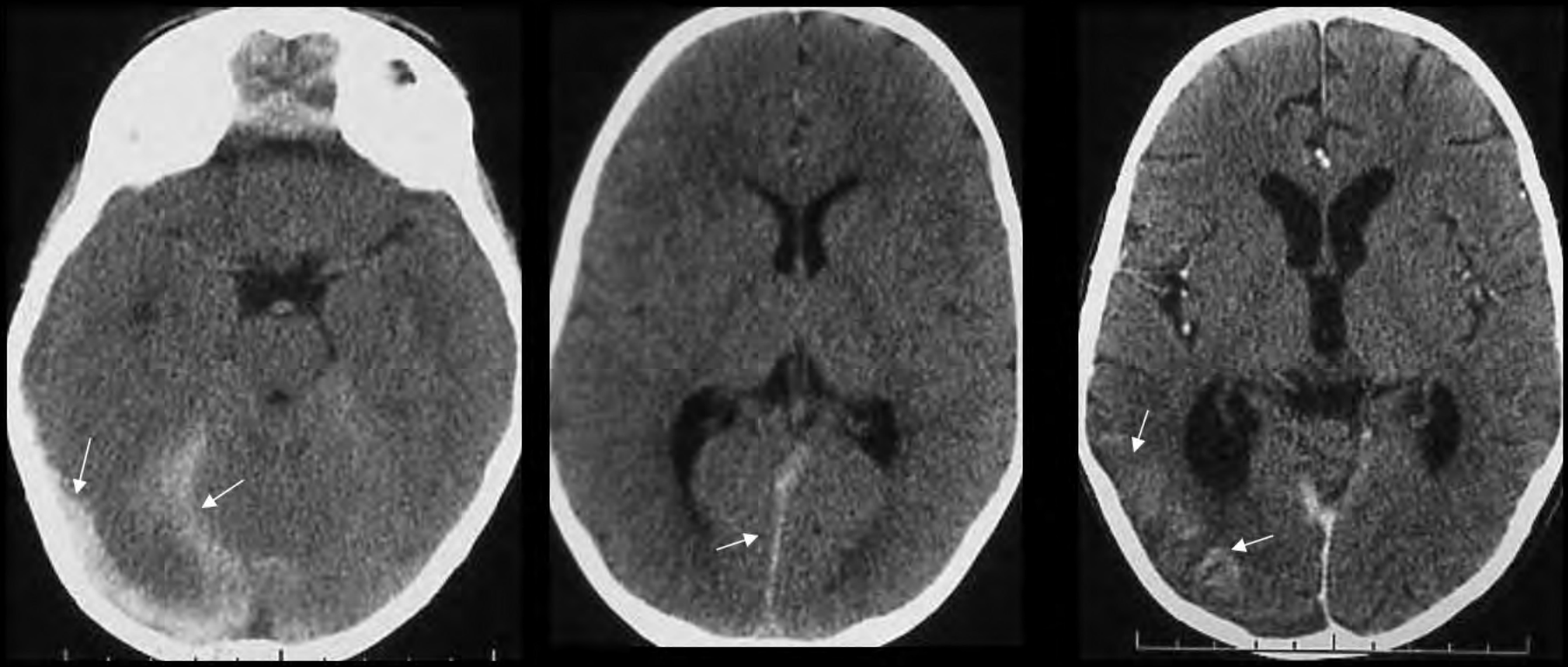
c



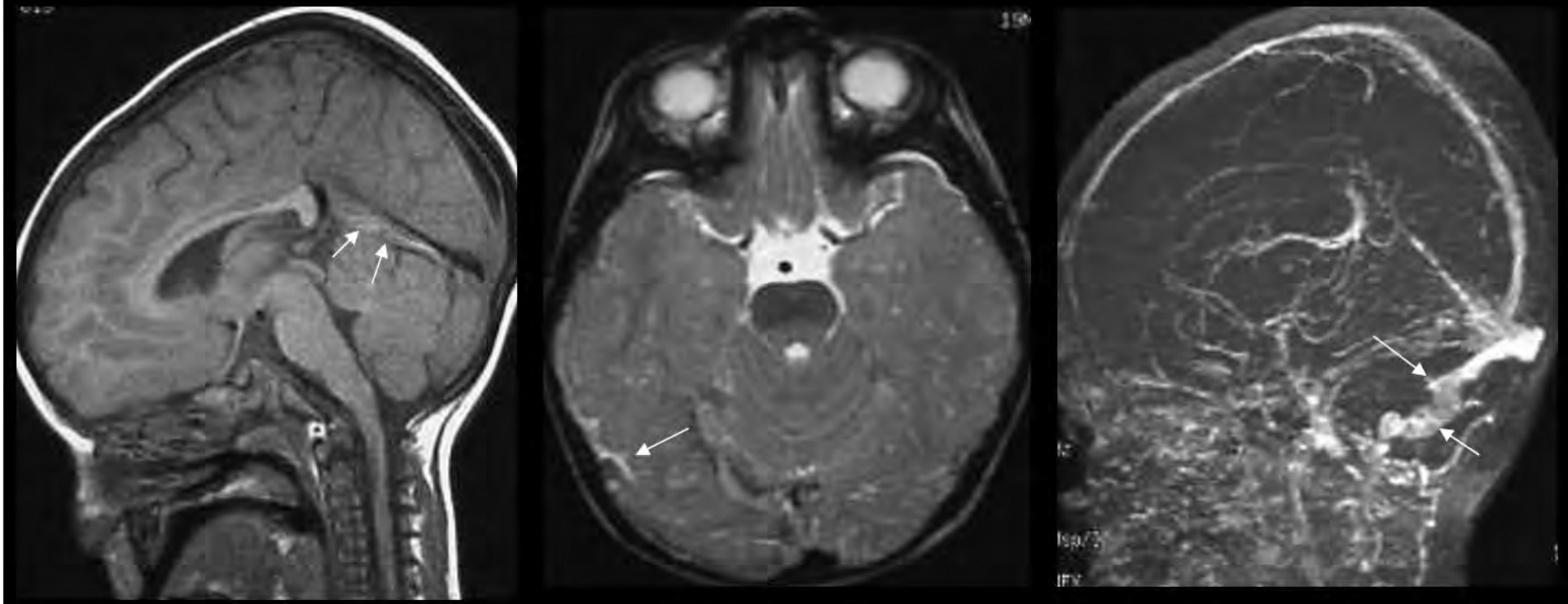
d

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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).

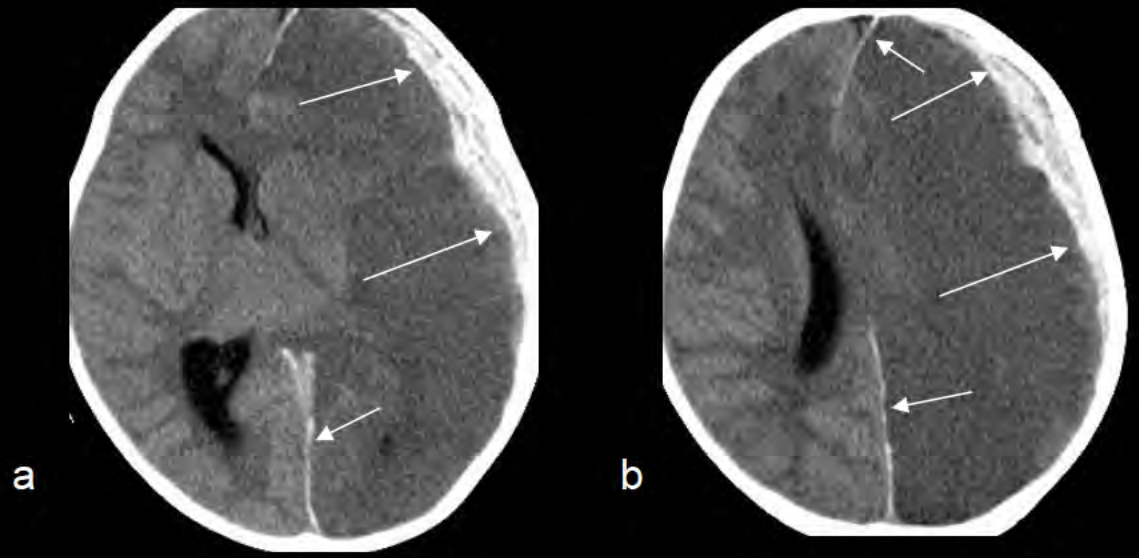


DeVeber G et al. Cerebral Sinovenous Thrombosis. N Engl J Med 2001;345:417-423.

- 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.

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.

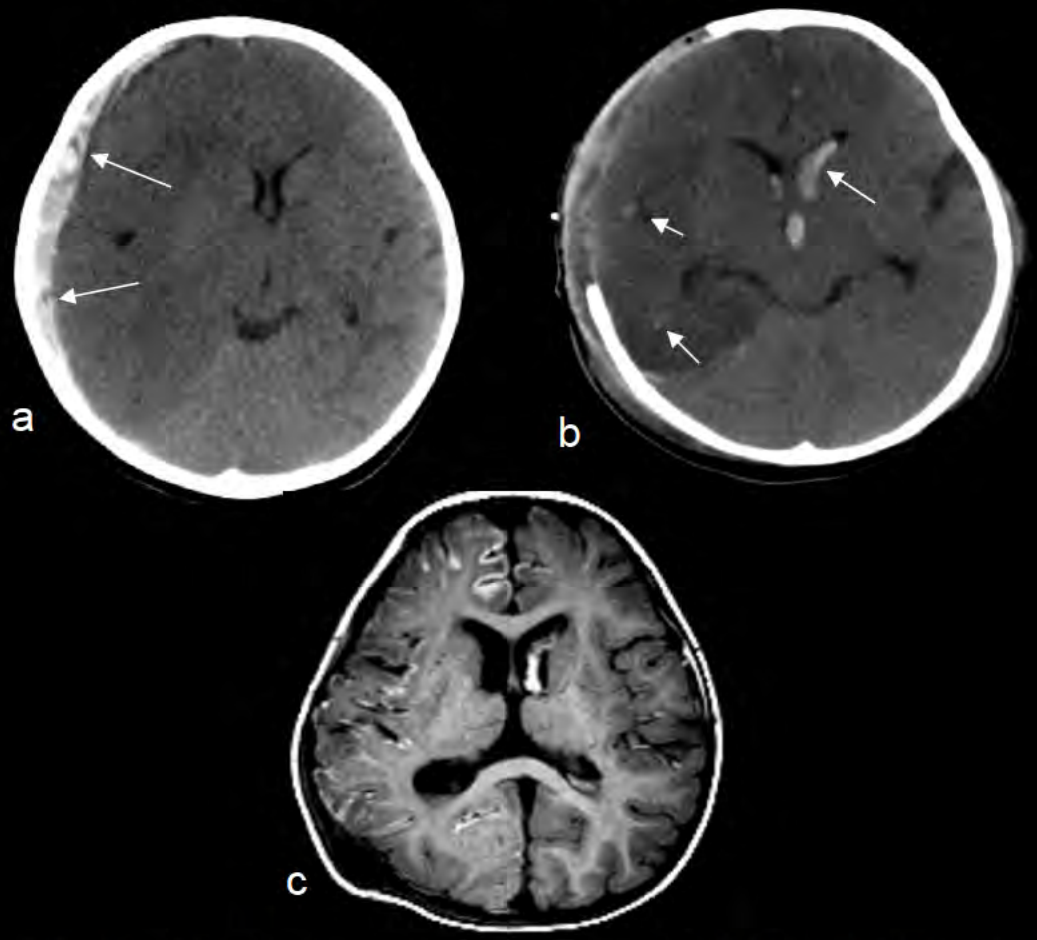


[Courtesy - Shaku Teas, MD, Forensic Pathologist, Chicago, IL]

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Mimic - Coagulopathy

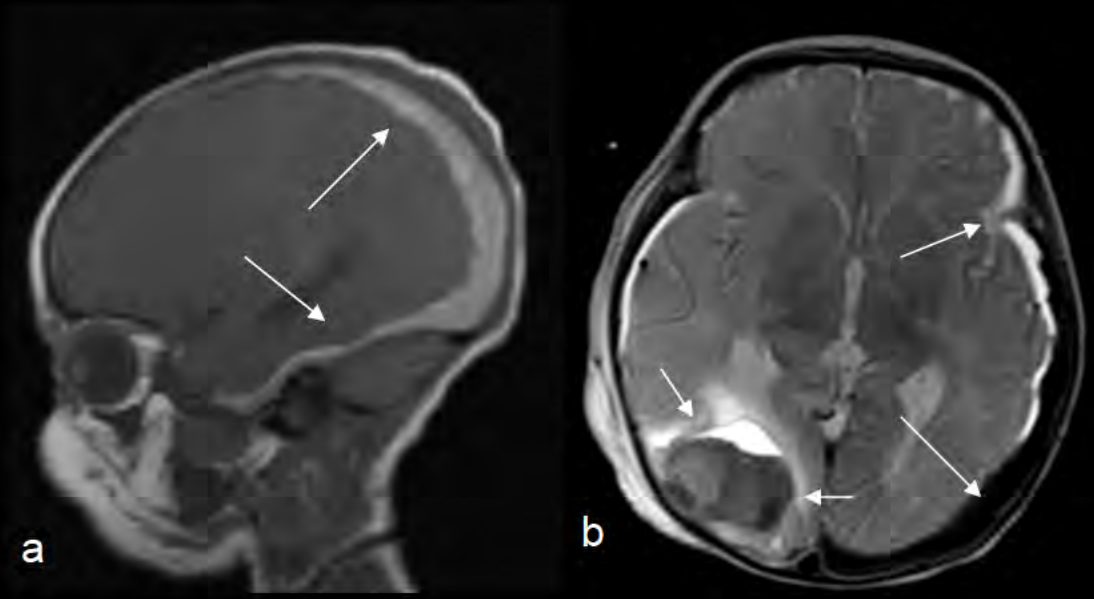
9mF with Triad & alleged NAI; also, recent fall & coagulopathy (later confirmed platelet disorder). Initial CT (a) shows mixed-density right SDH with right cerebral edema. Postoperative CT 5 days later shows other cerebral & intraventricular hemorrhages. T1 MRI (c) 11 days postoperatively shows evolving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



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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.



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Hematologic Disorders

Liesner R, Hann I, Khair K. Nonaccidental injury and the haematologist: the cause and investigation of easy bruising. Blood Coagul Fibrinolysis 2004;15 (suppl 1): S41-S48.

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.

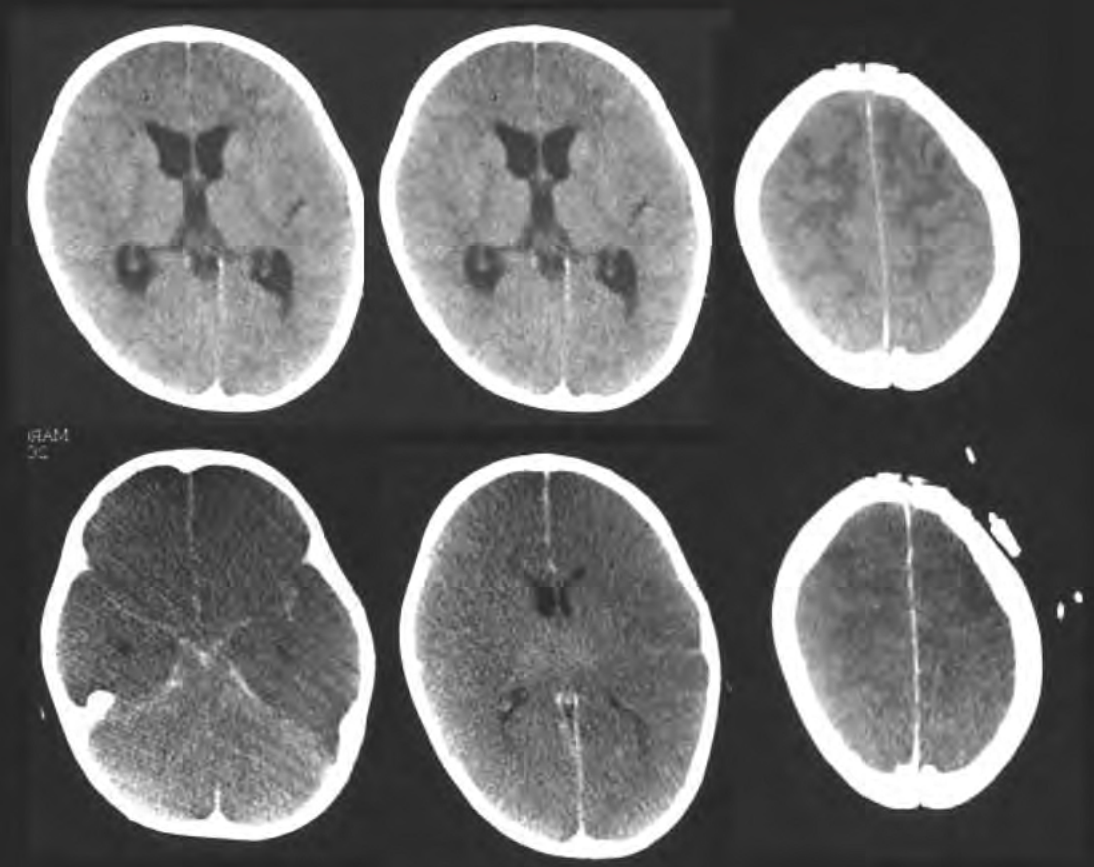
Furthermore, artefact is a frequent problem, and many cases present with a negative family history of bleeding.

Crucial to eliminate coagulation factor deficiencies (including factor XI and factor XIII), vWD, platelet disorders (including thrombocytopenia and leukaemia), and rare conditions such as Æ2-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

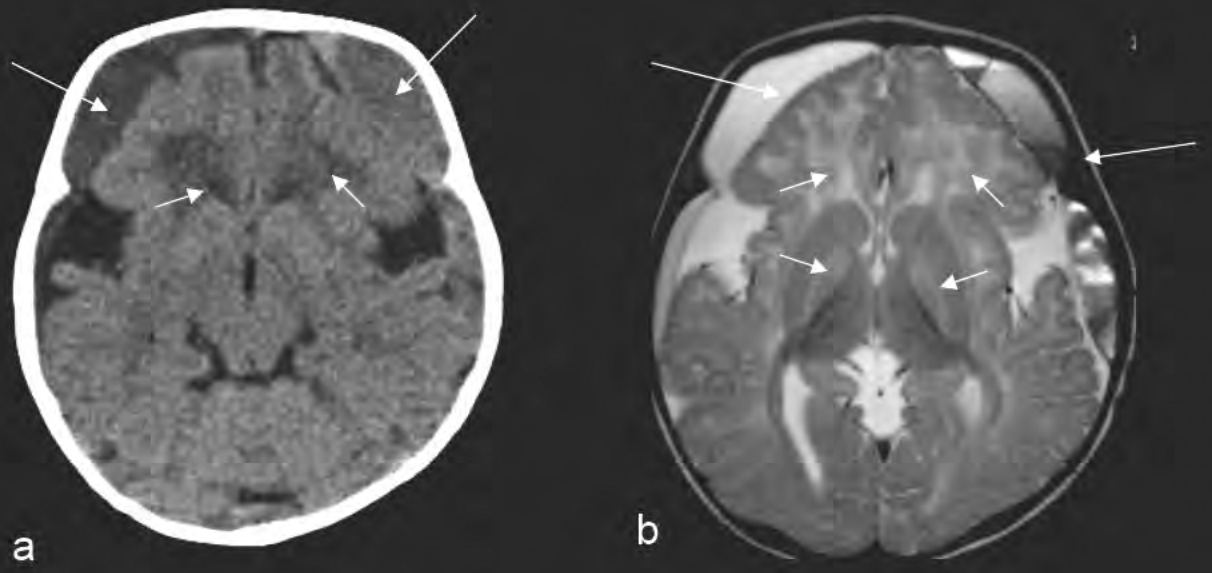
Delayed Edema + Herniation



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

Mimic - Metabolic Disorder

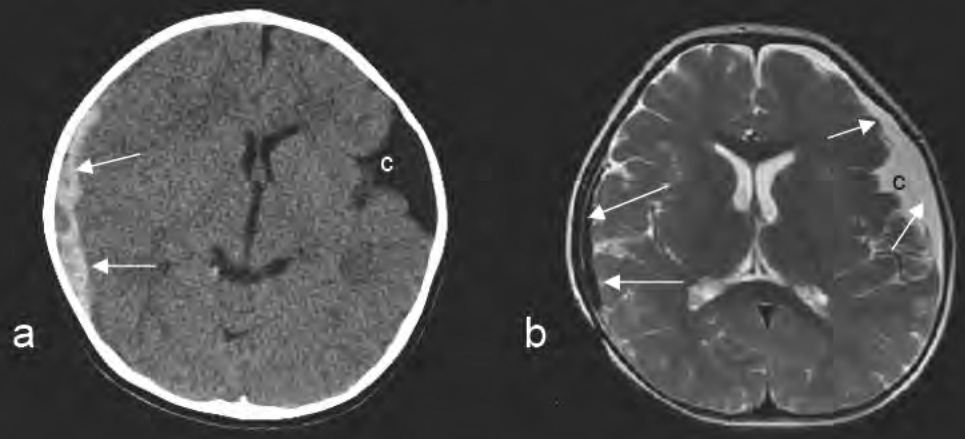
12m infant with triad & alleged NAI. Glutaric Acidopathy Type 1. CT (a) & T2 MRI (b) show bilateral SDH of varying age (long arrows), wide sylvian fissures, plus basal ganglia and cerebral white matter abnormalities (short arrows).



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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).



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am. Jan. 2011.

Over-the-Counter Cold Medications — Postmortem Findings in Infants and the Relationship to Cause of Death

Marinette L et al. J Analytical Toxicology 2005;29:738-743.

- 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.

Shaken Baby Syndrome
or
Vaccine-Induced Encephalitis

Harold Buttram, MD
Christina England

Multiple Vaccinations and the Shaken Baby Syndrome

F. Edward Yazbak, MD, FAAP
The Doctor's Corner
National Vaccine Information Center

- 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

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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.

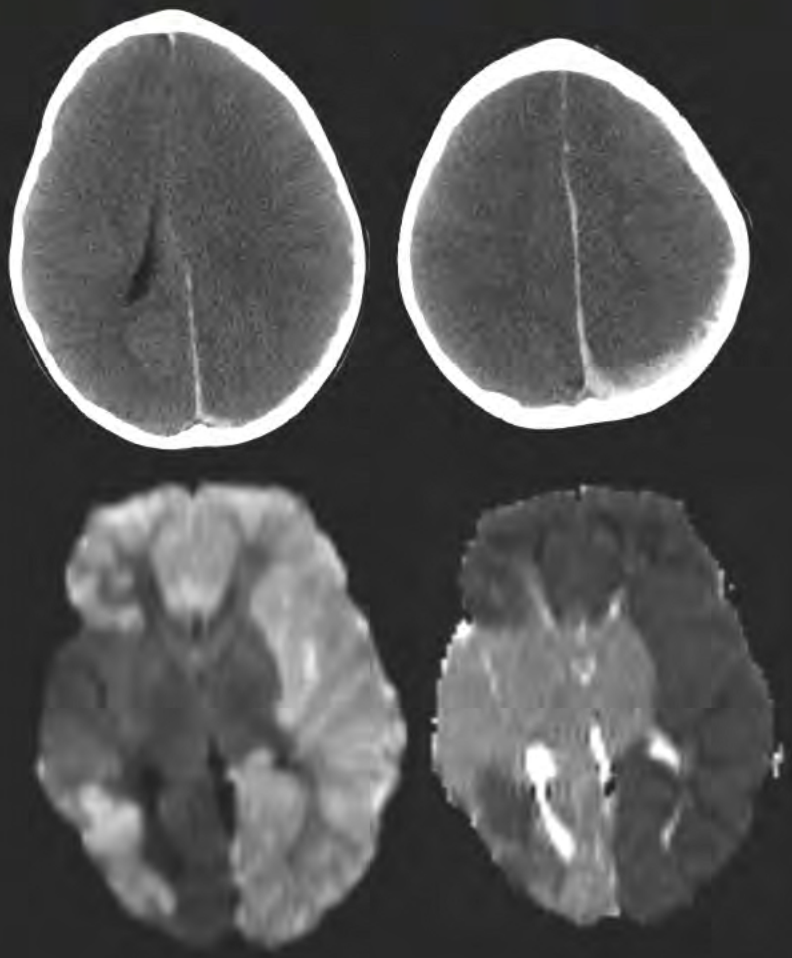
Bruce D, Alavi A, Bilaniuk L, et al. Diffuse cerebral swelling following head injuries in children: the syndrome of "malignant brain edema." J Neurosurg 1981;54:170-178.

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.

Steinbok P, Singhal A, Poskitt K, Cochrane D. Early hypodensity on CT scan of the brain in accidental pediatric head injury. Neurosurgery 2007;60:689-695

Mimic - Short Fall + Malignant Edema with SDH



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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

- Azais M, Echenne B. Idiopathic pericerebral effusions of infancy (external hydrocephalus). Annales Pediatr (Paris) 1992;39:550-558.
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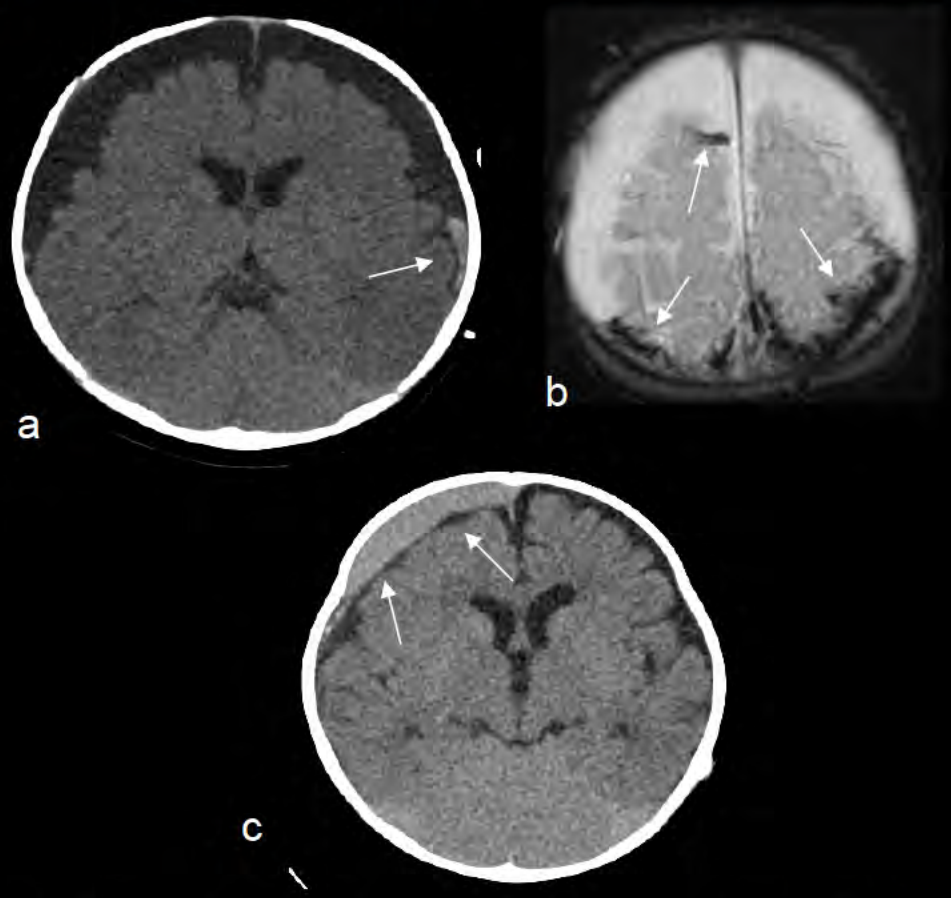
- Hellbusch L. Benign extracerebral fluid collections in infancy: clinical presentation and long-term follow-up. J Neurosurg 2007;107:119-117.
- Vinchon M, et al. Subdural hematoma in infants: can it occur spontaneously?: Data from a prospecitve series and critical review. Child Nerv Syst 2010; ePub.
- Ghosh P, Ghosh D. Subdural hematoma in infants without accidental or nonaccidental injury: benign external hydrocephalus, a risk factor. Clin Pediatr online 16 May 2011; DOI: 10.1177/0009922811406435.

Mimic - BECC + Hemorrhage

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-dranage (c) shows rehemorrhage (arrows). Diagnosis: BECC or chronic SDHG with rehemorrhage?



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Evidence Base for SDH with Rebleed

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- Trenchs V, Curcoy A, Navarro R, Pou J. Subdural haematomas and physical abuse in the first two years of life. Pediatr Neurosurg 2007;43:352-357.
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Evidence Base SDH - Rebleed
Birth Factors

- Holden K et al. Cranial MRI of normal term neonates: a pilot study. J Child Neurol 1999;14:708-710 (50%).
- Chamnanvanakij S, Rollins N, Perlman J. Subdural hematoma in term infants. Pediatr Neurol 2002;26:301-304.
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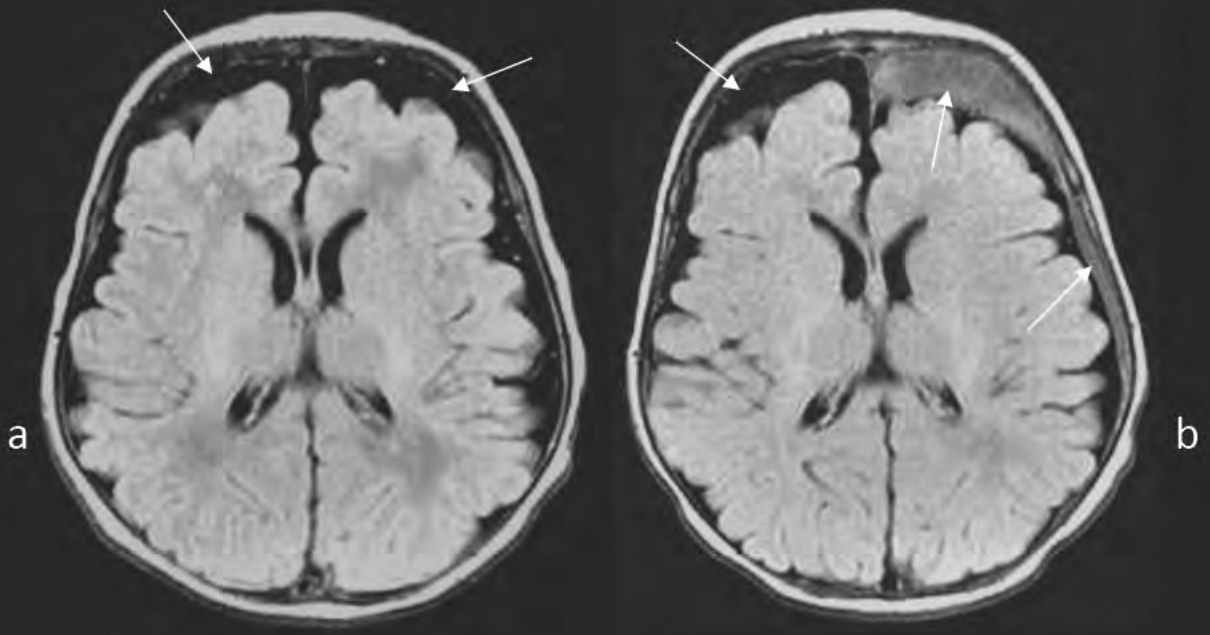
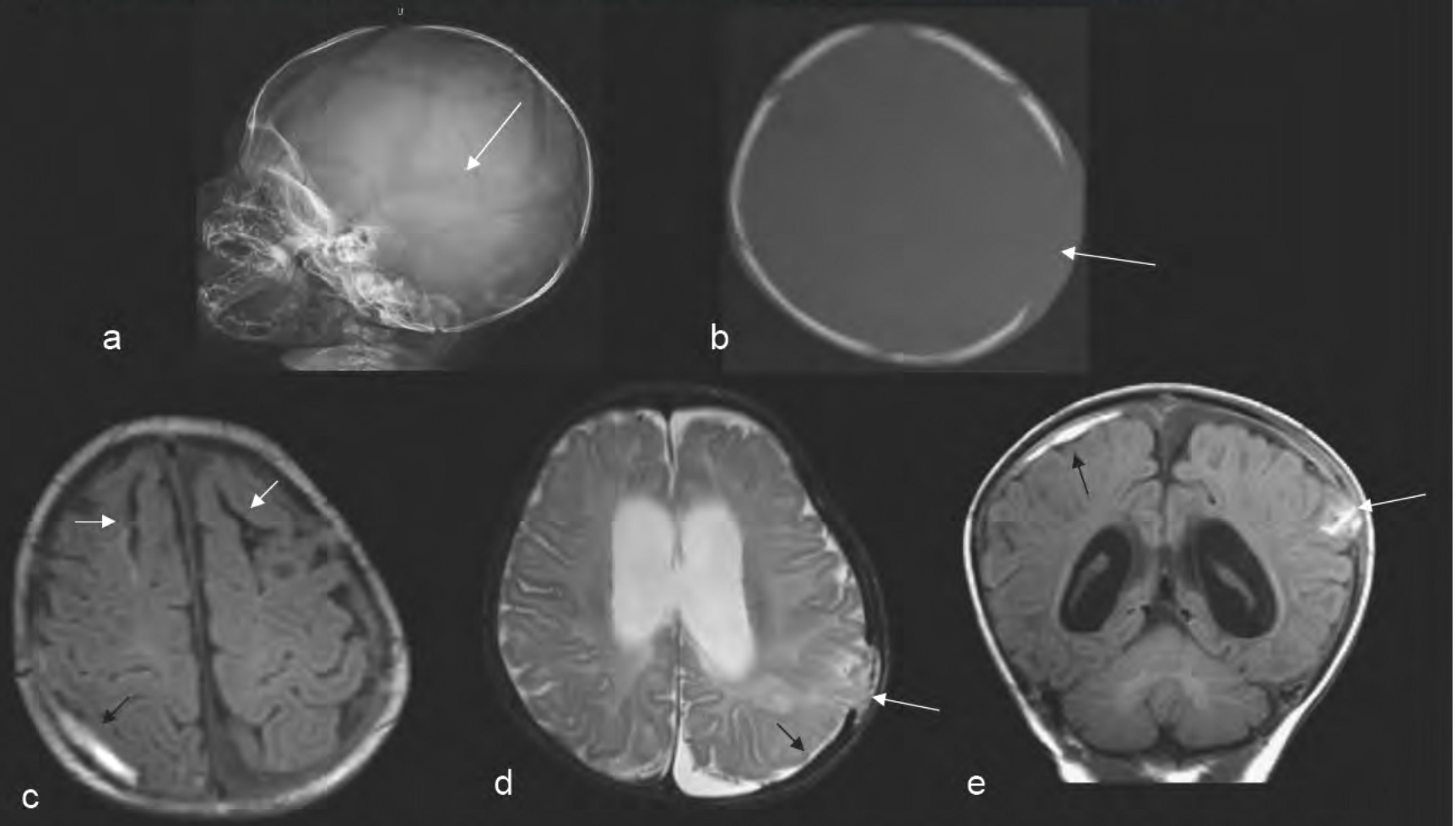
Mimic - BECC vs. SD Hygroma at birth (a) with SDH - rehemorrhage one month later (b).



Rooks V, Eaton J, Ruess L et al. Prevalence and evolution of intracranial hemorrhage in asymptomatic term infants. AJNR, April 2008 (46%).

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).



Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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.

Head Injury in NAI - Prosecution

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

Evidence-Based Challenges

- **Aoki N, Masuzawa H**. Infantile acute subdural hematoma: J Neurosurgery 1984; 61: 273-280.
- **Kirshner R, Stein R**. The mistaken diagnosis of child abuse. A form of medical abuse? Am J Dis Child 1985; 139: 873-875.
- **Tongue A.** The ophthalmologists role in diagnosing child abuse. Ophthalmology 1991;98;1009-1010.
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- **Gardner H.** Correlation between retinal abnormalities and intracranial abnormalities in the shaken baby syndrome. Am J Ophthalmology 2003; 135: 745-746.
- **Gilles E et al**. Retinal hemorrhage asymmetry in inflicted head injury: a clue to pathogenesis? J Pediatr 2003;143:494-499.
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Head Injury in NAI - Prosecution
Retinal Hemorrhage only occurs in SBS / NAI.
Evidence-Based Challenges

- **Lantz P, et al.** Perimacular retinal folds from childhood head trauma: evidence-based case report. BMJ 2004; 328: 754-756.
- **Aryan H et al.** Retinal hemorrhage and pediatric brain injury: etiology and review of the literature. J Clin Neuroscience 2005; 12:624-631.
- **Lueder G et al.** Perimacular retinal folds simulating nonaccidental injury in an infant. Arch Ophthalmol 2006;124:1782-1783.
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- **Binenaum G, et al.** An animal model to study retinal hemorrhages in nonimpact brain injury. J AAPOS 2007;11:84-85.
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- **Emerson M et al.** Ocular autopsy and histopathologic features of child abuse. Ophthalmology 2007;114:1384-1394.
- **Gardner H**. Retinal folds. Arch Ophthalmology 2007;125:1142.

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.
- Brown. AAPOS 2007. Dog shaking / killing of 2 kittens, 1 rabbit with no eye findings at autopsy.
- 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.

Galaznik J. Eye findings and allegations of shaking and non-accidental injury: post-publication peer review (8 August 2007). Pediatrics 2007;19:1232-1241.

Galaznik J. Shaken baby syndrome: letter to the editor. Developmental Medicine & Child Neurology 2008;50: 317-319.

CT & MRI in Alleged NAI Limitations

- **Tung GA et al**. Comparison of Accidental and Nonaccidental Traumatic Head Injury in Children on Noncontrast Computed Tomography. Pediatrics. 2006 Aug;118(2):626-33.
- **Vinchon M et al**. Imaging of head injuries in infants: temporal correlates and forensic implication for the diagnosis of child abuse. J Neurosurg (Pediatrics 2) 2004; 101: 44-52.
- **Zuerrer M et al**. MR imaging of intracranial hemorrhage in neonates and infants at 2.35 Tesla. Neuroradiology 1991;33:223-229.
- **Wells R, Sty J**. Traumatic low attenuation subdural fluid collections in children younger than 3 years. Arch Pediatr Adolesc Med 2003; 157:1005-1010.
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- **Barnes P**. Imaging of the CNS in Suspected or Alleged NAI. ASPNR Gyrations Newsletter 2007; 2: 5-7 <www.aspnr.org>
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Timing of Hemorrhage (Thrombosis) CT Limitations

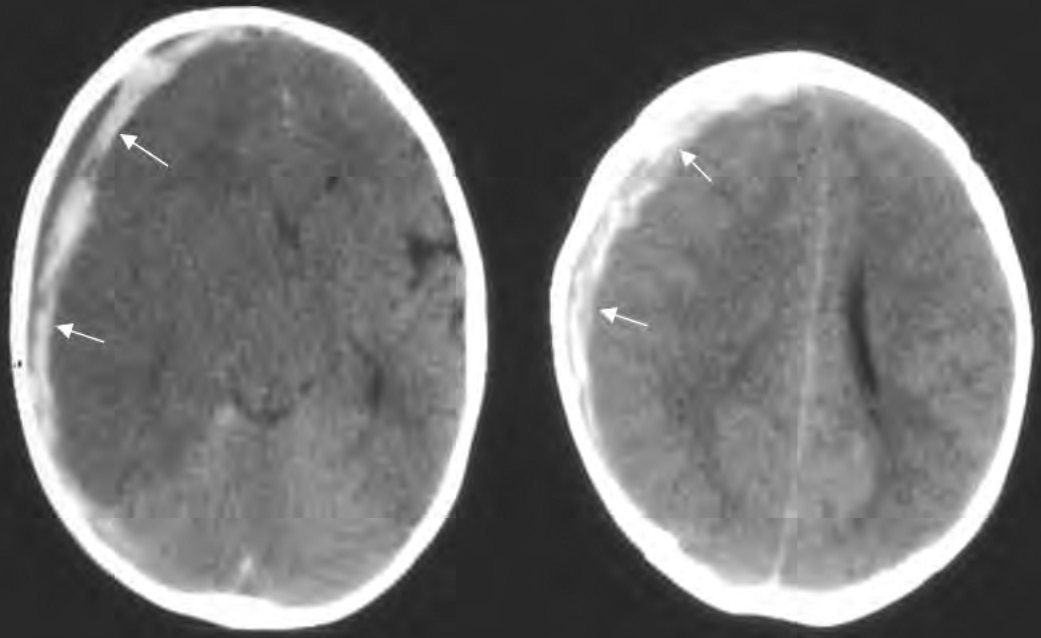
- High density (i.e. clotted, acute to subacute) 3 hr. to 7-10 days;
- Not differentiate hemorrhage v. thrombosis (e.g. venous)
- Iso-Hypodense (i.e. nonclotted):
  - Hyperacute (<3 hrs.)
  - Chronic (> 7-10 days)
  - BECC or subdural hygroma (acute or chronic)
- Blood levels unusual in acute stage except 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.

Tung GA et al. Comparison of Accidental and Nonaccidental Traumatic Head Injury in Children on Noncontrast Computed Tomography. Pediatrics. 2006 Aug;118(2):626-33.

Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18:53.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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



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Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am, Jan. 2011.

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** (3-7days): 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).

Vinchon M et al. Imaging of head injuries in infants: temporal correlates and forensic implication for the diagnosis of child abuse. J Neurosurg (Pediatrics 2) 2004; 101: 44-52.

Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18:53.

Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. Pediatr Radiol 2009;39:586-590.

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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.

Vinchon M et al. Imaging of head injuries in infants: temporal correlates and forensic implication for the diagnosis of child abuse. J Neurosurg (Pediatrics 2) 2004; 101: 44-52.

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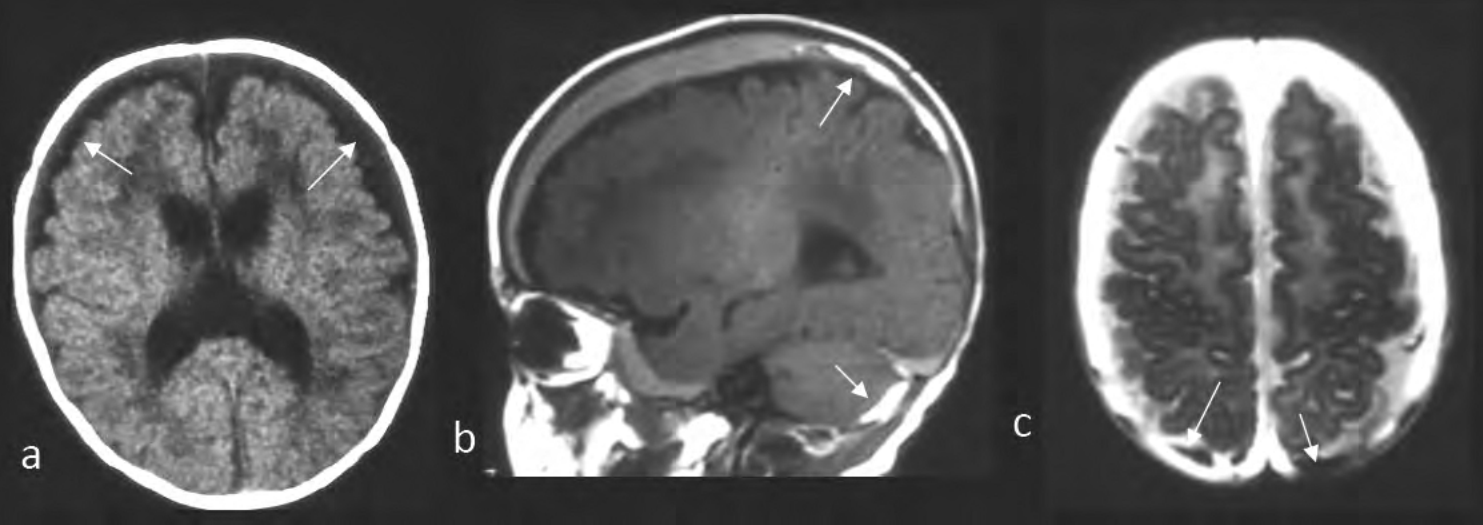
Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. Pediatr Radiol 2009;39:586-590.

Barnes P. Imaging of NAI and the Mimics: Issues & Controversies in the Era of Evidence-Based Medicine. Radiol Clin N Am Jan. 2011.

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↑

Evidence-Based Update Brain Imaging in Nonaccidental Injury and the Mimics

Blood, Brain, & Bones

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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."

Geddes J et al. Dural Haemorrhage in Non-traumatic Infant Deaths: Does it Explain the Bleeding in 'Shaken Baby Syndrome'? Neuropath and Applied Neurobiol 2003; 29: 14-22)
Cohen M, Scheimberg I. Evidence of intradural and subdural hemorrhage in the perinatal and neonatal period in the context of hypoxic ischemic encephalopathy. Pediatr Develop Pathol 2008 Nov. 13:1 [Epub ahead of print].
Sguier W. Shaken baby syndrome: the quest for evidence. Develop Med Child Neurol 2008;50:10-14.
Barnes P, Krasnokutsky M. Imaging of the CNS in Suspected or Alleged NAI. Topics Magn Res Imag 2007:18 53-74.
Sirotnak A. Medical disorders that mimic abusive head trauma. In Frasier L et al, Abusive Head Trauma in Infants and Children, GW Medical Publishing, St. Louis, 2006, 191-226.
Kellogg N et al. [AAP COCAN]. Evaluation of suspected child abuse. Pediatrics 2007; 119: 1232-1241.

NAI – Bones
Skeletal Fragility Disorders

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

Jenny C et al. [AAP COCAN]. Evaluating infants and young children with multiple fractures. Pediatrics 2006;118: 1299-1303.

Bishop N et al. Unexplained fractures in infancy: looking for fragile bones. Arch Dis Child 2007;92:251-256.

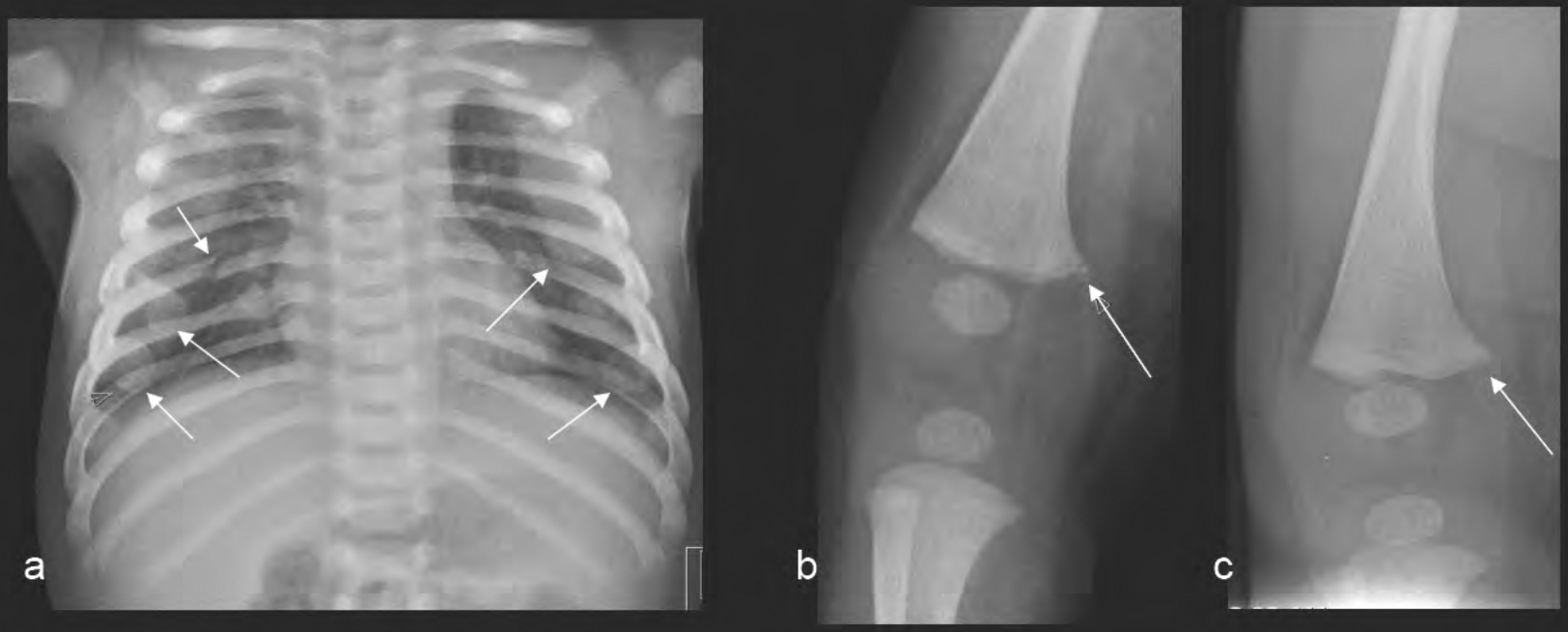
Kellogg N et al. [AAP COCAN]. Evaluation of suspected child abuse. Pediatrics 2007; 119: 1232-1241.

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Kemp AM, Dustan F, Harrison S, et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ 2008; 337: 1-8.

Keller K, Barnes P. Rickets vs. abuse – the evidence: Reply. Pediatr Radiol 2009;39:1130.

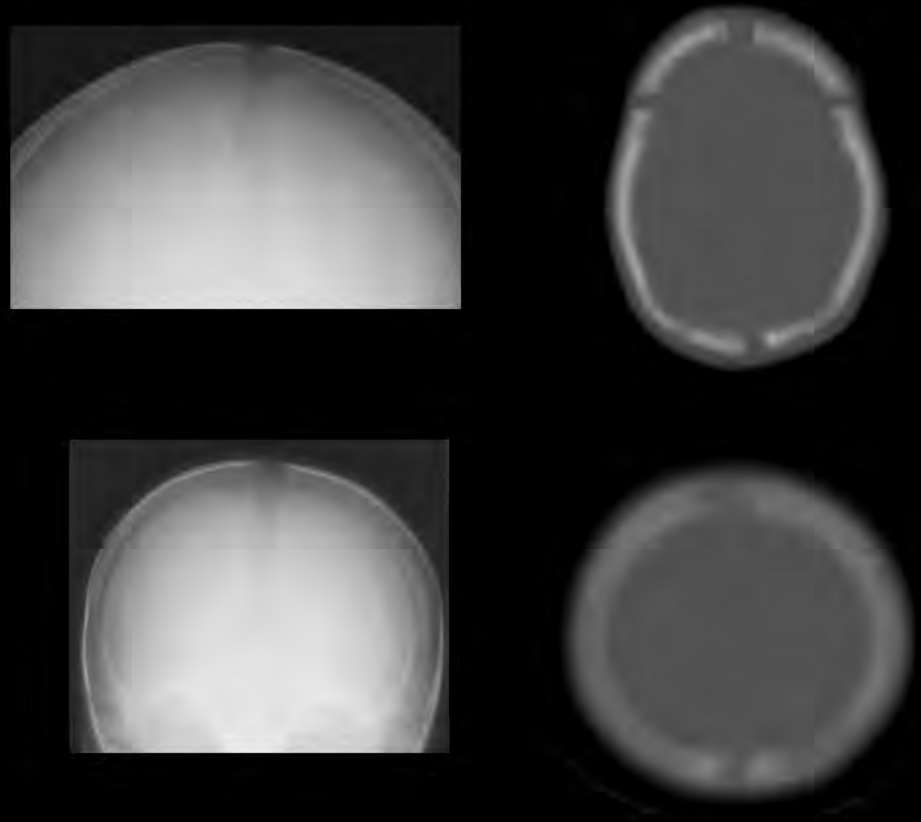
3m infant with alleged NAI; also, “history” consistent with congenital rickets. Chest film (a) shows bilateral recent and old, healing rib fractures (pseudofractures? rachitic rosary? - arrows). Knee films before (b) & after (c) vitamin D supplementation show “healing” CML (arrows)?



Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries).

Keller K, Barnes P. Rickets vs. abuse – the evidence: Reply. Pediatr Radiol 2009;39:1130.

Radiographic Findings
Congenital Rickets
Skull



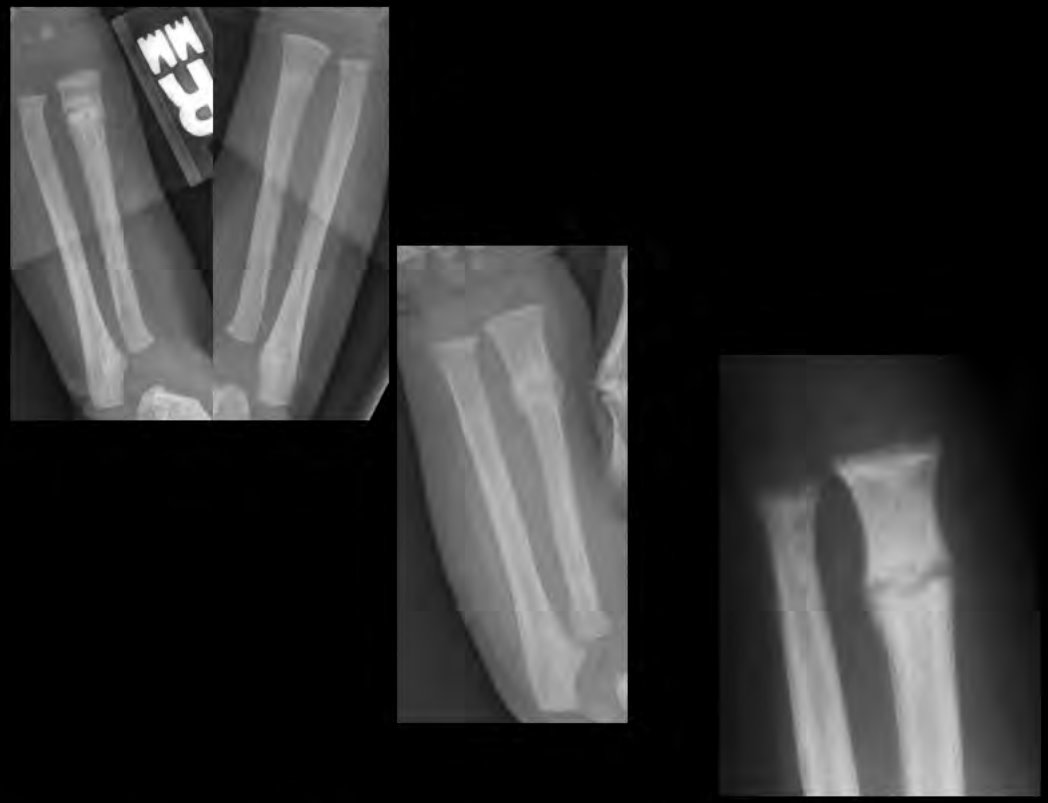
Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

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

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Radiographic Findings of Congenital Rickets

Looser's Zones + Metaphyseal Changes (2m, 4m, 15m)



Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Radiographic Findings of Congenital Rickets

Wrist Changes Pre & Post Vitamin D Therapy

Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

Radiographic Findings of Congenital Rickets

Lower Extremity (distal tibial tilt)

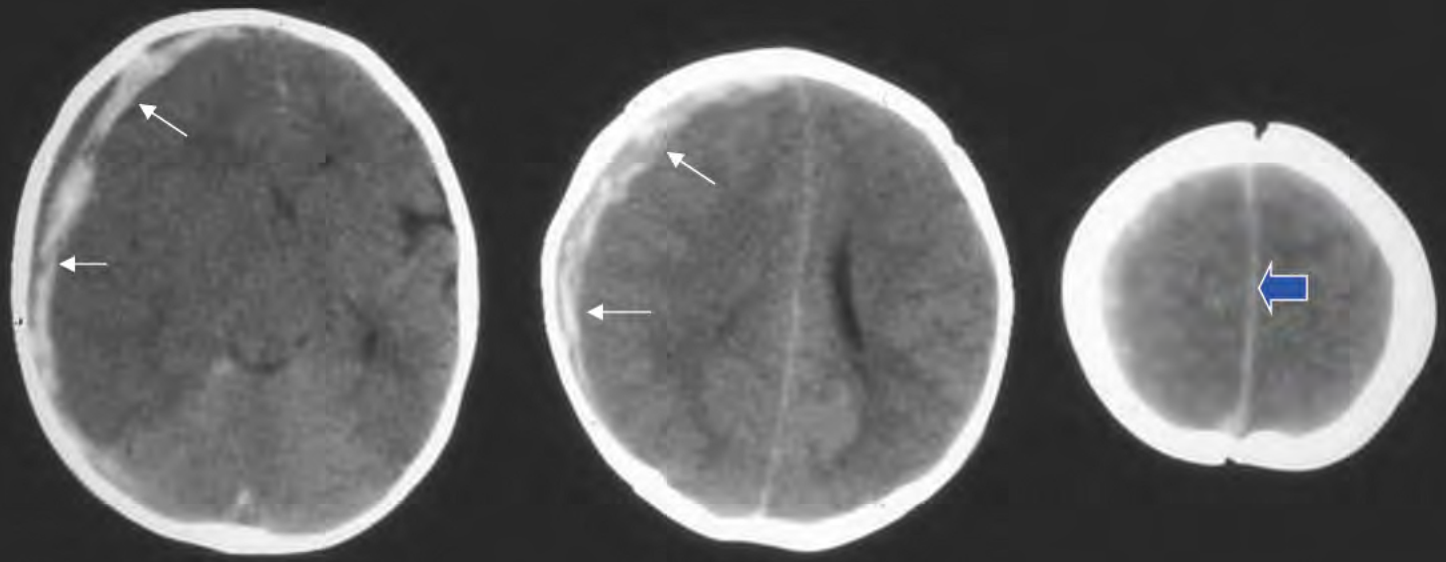
Keller K, Barnes P. Rickets vs. abuse: a national and international epidemic. Pediatr Radiol 2008;38:1210-1216 (plus commentaries & reply).

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.
- ER: Child unresponsive, posturing, bag ventilation. Pupils fixed, dilated. Extensive RH / macular folds. No signs of trauma; .No spontan. movements, increased tone.
- 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 Survery - 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).



(Barnes P, Robson C. CT findings in hyperacute nonaccidental brain injury. Pediatr Radiol 2000; 30:74-81)

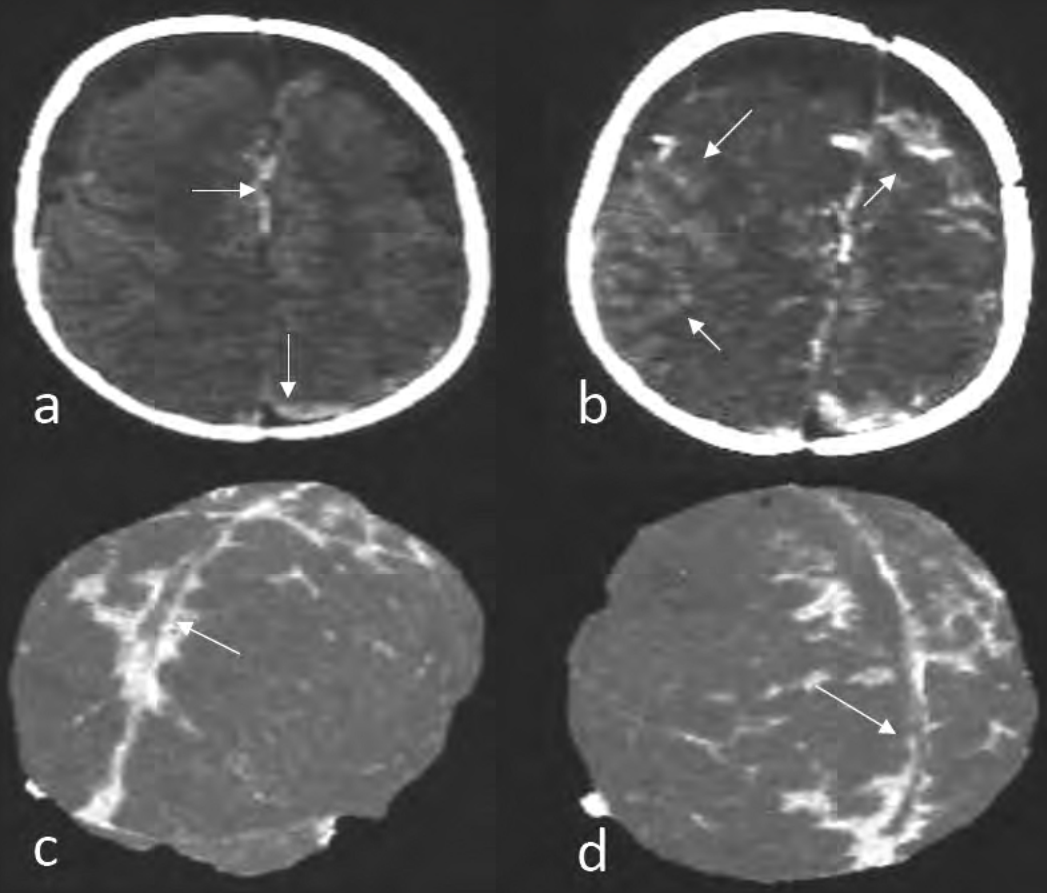
Case # 2

- 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;
- Manslaughter conviction ((Forensic Pediatrician, Forensic Pathologist, Ped. Radiologist).
- 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)

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