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Patrick Barnes  
*Stanford Hospital & Clinics*

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## CHILD ABUSE—NONACCIDENTAL INJURY (NAI) AND ABUSIVE HEAD TRAUMA (AHT)—MEDICAL IMAGING: ISSUES AND CONTROVERSIES IN THE ERA OF EVIDENCE-BASED MEDICINE

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Dr. Patrick Barnes

I'm a pediatric radiologist and a pediatric neuroradiologist. So, my work is in radiologic imaging. Imaging technology started being used many years ago to help detect child abuse using x-rays used to look at the bones including the skull and make the diagnosis. Doctors would then look in the eyes and see retinal hemorrhages. Then maybe a neurosurgeon would come along and drain a subdural hematoma. In later years, we started using more advanced imaging techniques such as CT and MRI. And then somehow imaging became a gold standard, without a basic science foundation (e.g. neuropathology, biomechanics) which is part of our problem in distinguishing nonaccidental injury (NAI) from accidental injury or from medical conditions that “mimic” NAI.

Over the past few decades, there's been a building movement to relook at Shaken Baby Syndrome (SBS) and child abuse in general. The diagnosis of SBS was based on the “triad” of subdural hemorrhage, retinal hemorrhage, and brain injury.<sup>1</sup> The triad was considered pathognomonic of SBS particularly when the caretaker history was considered inconsistent with the degree or extent of the injury. And occasionally, there were also fractures present (the tetrad).<sup>2</sup> However, the diagnostic criteria have evolved over time in the response to challenges to the triad doctrine.<sup>3</sup>

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1. Brian Harding, R. Anthony Risdon & Henry F. Krous, *Shaken Baby Syndrome: Pathological Diagnosis Rests on the Combined Triad, Not on Individual Injuries*, 328 *BMJ* 720, 720–21 (2004).

2. See, e.g., Am. Acad. of Pediatrics, Comm. on Child Abuse and Neglect, *Shaken Baby Syndrome: Rotational Cranial Injuries—Technical Report* 108 *PEDIATRICS* 206, 207, 208 (2001) (stressing importance of checking for fractures).

3. See, e.g., Sandeep Narang, *A Daubert Analysis of Abusive Head Trauma/Shaken Baby Syndrome*, 11 *HOUS. J. HEALTH L. & POL'Y*, 505, 523–35 (2011) (discussing the history of AHT, or Shaken Baby Syndrome); *Committee Report to the Attorney General: Shaken Baby Death Review*, MINISTRY OF THE ATTORNEY GENERAL (Mar. 4, 2011), <https://www.attorneygeneral.jus.gov.on.ca/english/about/pubs/sbdr/sbdr.html> (noting that the evolution of medical science necessitates a review of pediatric head injury cases that resulted in criminal convictions); see generally Keith A. Findley et al., *Shaken Baby Syndrome, Abusive Head Trauma, and Actual Innocence: Getting it Right*, 12 *HOUS. J. HEALTH L. & POL'Y* 209 (2012); see generally DEBORAH TUERKHEIMER, *FLAWED CONVICTIONS: “SHAKEN BABY SYNDROME” AND THE INERTIA OF INJUSTICE* (1st ed. 2014). Press. New York. 2014.

During the first twenty years of my career, the triad was assumed to be due to nothing but abuse.<sup>4</sup> I never questioned it. I marched in step, because I grew up in the authoritarian era, in which the older leaders and teachers told me this is the way it is. And it took me a while to grow up and start questioning these assumptions.

The traditional literature started with Caffey,<sup>5</sup> Kempe, Silverman,<sup>6</sup> and Guthkelch.<sup>7</sup> It started out as Battered Child Syndrome, then it became Shaken Baby Syndrome.

We get all of these numbers, all of this reporting from all of these jurisdictions, yet there are no standardized definitions. According to kidsdata.org, within the state of California, where I practice, there has been a decreased number of allegations and only sixteen percent of those allegations substantiated during that period of time.<sup>8</sup> How come? Well, maybe public awareness prevention programs as well as changes in how cases are investigated. Maybe there's been some progress.

First of all, since I'm an imaging specialist, I'm telling you up front that imaging has been considered a gold standard for diagnosing Shaken Baby Syndrome, but the real gold standards are neuropathology, biomechanics, and other areas of science. In fact, imaging cannot reliably distinguish non-accidental injury from accidental injury or from predisposing or complicating medical conditions, period.<sup>9</sup>

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4. Harding et al., *supra* note 1, at 720–21; see, e.g., Am. Acad. of Pediatrics, Comm. on Child Abuse and Neglect, *Shaken Baby Syndrome: Inflicted Cerebral Trauma*, 92 PEDIATRICS 872, 872 (1993) (defining shaken baby syndrome as a serious form of child maltreatment); see generally Cindy W. Christian, Robert Block & Comm. on Child Abuse and Neglect, *Abusive Head Trauma in Infants and Children*, 123 PEDIATRICS 1409 (2009) (discussing ways that abuse—even beyond shaking—can cause head trauma in children); Nancy D. Kellogg & Comm. on Child Abuse and Neglect, *Evaluation of Suspected Child Physical Abuse*, 119 PEDIATRICS 1233 (2007) (providing guidance to clinicians about evaluating suspected physical abuse in children).

5. See generally John Caffey, *Multiple Fractures in the Long Bones of Infants Suffering from Chronic Subdural Hematoma*, 56 AM. J. ROENTGENOLOGY 163 (1946); see generally John Caffey, *On the Theory and Practice of Shaking Infants*, 124 AM. J. DISEASES CHILD. 161 (1972) [hereinafter Caffey, *Theory and Practice*].

6. See generally C. Henry Kempe, Frederick N. Silverman, Brandt F. Steele, William Droegemueller & Henry K. Silver, *The Battered-Child Syndrome*, 181 J. AMER. MED. ASS'N. 17 (1962).

7. See generally Arthur Norman Guthkelch, *Infantile Subdural Haematoma and Its Relationship to Whiplash Injuries*, 2 BRIT. MED. J. 430 (1971).

8. Summary: *Child Abuse and Neglect*, KIDSDATA.ORG, <http://www.kidsdata.org/topic/2/child-abuse-and-neglect/summary> (last visited Feb. 2, 2017).

9. See Patrick D. Barnes & Michael Krasnokutsky, *Imaging of the Central Nervous System in Suspected or Alleged Nonaccidental Injury, Including the Mimics*, 18 TOPICS MAGNETIC RESONANCE IMAGING 53, 54–56 (2007) (discussing challenges in identifying a medical diagnosis based on a causative event (e.g. shaking) from imaging); Andrew P. Sirotiak, *Medical Disorders that Mimic Abusive Head Trauma*, in ABUSIVE HEAD TRAUMA IN INFANTS AND CHILDREN: A MEDICAL,

There is a differential diagnosis for the triad. When we were going back and looking at the medical records of these children, a lot of them were already ill. Even though it was a sick child, they just “knew” the child had been shaken and had these injuries. We also started doing more post-mortem correlations with the imaging and found features of conditions other than trauma.

And I’m saying the same thing regarding the skeletal injury: imaging can’t distinguish skeletal injury due to non-accidental trauma from that due to accidental injury or from those due to predisposing or medical conditions, including the bone fragility disorders.<sup>10</sup> There is a differential diagnosis for the bone abnormalities, and that differential diagnosis has been reported as far back as you can go in both the child abuse literature and the bone health literature.<sup>11</sup>

And there’s building literature on other causes of the elements of the triad and the tetrad. In 2008, Dr. Kathy Keller, a pediatrician (and my wife), and I thought a lot of these cases look like rickets.<sup>12</sup> And since then, there has been a lot more literature on this.<sup>13</sup> A

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LEGAL, AND FORENSIC REFERENCE 232–46 (2006); see Gilbert Vezina, *Assessment of the Nature and Age of Subdural Collections in Nonaccidental Head Injury with CT and MRI*, 39 PEDIATRIC RADIOLOGY 586, 590 (2009) (noting radiology and clinical challenges in evaluating head injury in suspected child abuse cases); see generally Patrick D. Barnes, *Imaging of Nonaccidental Injury and the Mimics: Issues and Controversies in the Era of Evidence-Based Medicine*, 49 RADIOLOGIC CLINICS N. AM. 205 (2011) [hereinafter Barnes, *Issues and Controversies*] (discussing critiques to the triad by evidence-based medical and legal principles); C.C. Meltzer et al., *Guidelines for the Ethical Use of Neuroimages in Medical Testimony: Report of a Multidisciplinary Consensus Conference*, 35 AMER. J. NEURORADIOLOGY 632 (2014) (presenting guidelines to consider amidst growing concern over potential misuse of neuroradiologic imaging data in legal cases).

10. See generally David M. Ayoub et al., *A Critical Review of the Classical Metaphysical Lesion: Traumatic or Metabolic?*, 202 AMER. J. ROENTGENOLOGY 185 (2014); Nick Bishop, Alan Sprigg & Ann Dalton, *Unexplained Fractures in Infancy: Looking for Fragile Bones*, 92 ARCHIVES DISEASE CHILDHOOD 251 (2007); Emalee G. Flaherty et al., *Evaluating Children with Fractures for Child Physical Abuse*, 133 PEDIATRICS e477 (2014); Carole Jenny & Comm. on Child Abuse and Neglect, *Evaluating Infants and Young Children with Multiple Fractures*, 118 PEDIATRICS 1299 (2006); Kathy A. Keller & Patrick D. Barnes, *Rickets vs. Abuse: A National and International Epidemic*, 38 PEDIATRIC RADIOLOGY 1210 (2008); Kathy A. Keller & Patrick D. Barnes, *Reply Regarding Rickets vs. Abuse: The Evidence*, 39 PEDIATRIC RADIOLOGY 1130 (2009); Nancy D. Kellogg & Comm. on Child Abuse and Neglect, *Evaluation of Suspected Child Physical Abuse*, 119 PEDIATRICS 1233 (2007); Alison M. Kemp et al., *Patterns of Skeletal Fractures in Child Abuse: Systematic Review*, 337 BMJ 859 (2008).

11. See generally Bishop et al., *supra* note 10; Flaherty et al., *supra* note 10; Kemp et al., *supra* note 10; Paul K. Kleinman, *Problems in the Diagnosis of Metaphysical Fractures*, 38 PEDIATRIC RADIOLOGY 388 (2008); Amaka Offia, Rick R. van Rijn, Jeanette Mercedes Perez-Rossello & Paul K. Kleinman, *Skeletal Imaging of Child Abuse (Non-Accidental Injury)*, 39 PEDIATRIC RADIOLOGY 461 (2009); Alan Sprigg, *Temporary Brittle Bone Disease Versus Suspected Non-Accidental Skeletal Injury*, 96 ARCHIVES DISEASE CHILDHOOD 411 (2011).

12. Keller & Barnes, *supra* note 10, at 1211.

13. See, e.g., Samantha Schilling et al., *Vitamin D Status in Abused and Nonabused Children Younger than 2 Years Old with Fractures*, 127 PEDIATRICS 835, 840 (2011); Sprigg, *supra* note 11, at 412–13.

new form of rickets with which we were not previously familiar arises in a Vitamin-D-deficient mother, and then gets passed on to the fetus, and then to the neonate and infant. The obstetrician looks after the mother and the fetus. Then the fetus is born at preterm or term and handed off to the neonatologist, who then hands the neonate off to the pediatrician. So what often gets lost in those transitions?

There was a classic case in the U.K. recently involving a brain injury and skeletal injury in a child who died. There were classic skeletal findings, especially skull and ribs, all pointing to rickets. And all of the younger doctors missed it. But a couple of older doctors in town picked it up and said, “You missed a serious case of Vitamin D deficiency rickets where all the imbalances set the baby up for death.” Interestingly, the post-mortem description of the bones perfectly described rickets, yet the pathologist concluded that there were classic lesions of abuse.<sup>14</sup> The same thing appears to happen with other birth injuries and other neonatal bone fragility disorders.<sup>15</sup>

I began looking at the science more carefully after being a prosecution expert in the Nanny Case in 1997,<sup>16</sup> and I’ve concluded that the triad is not specific for NAI, whether one, two, or all three of the components of the triad are present.<sup>17</sup> I’ve also learned that bone fractures, including the so-called classic metaphyseal lesion (CML) where the growing end of the bone is allegedly twisted or pulled, is not classic for NAI. In fact, rickets can have a similar or

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14. Clare Dyer, *Prosecution of Parents over Baby’s Death Raises Controversy over Diagnosing Child Abuse*, 344 *BMJ* e2932, e2932 (2012).

15. See, e.g., Bruce W. Hollis & Carol L. Wagner, *Vitamin D and Pregnancy: Skeletal Effects, Nonskeletal Effects and Birth Outcomes*, 92 *CALCIFIED TISSUE INTERNATIONAL* 128, 133, 136 (2013) (suggesting that increasing Vitamin D intake during pregnancy will improve birth outcomes and reduce skeletal problems); Junko Yorifuji et al., *Craniotables in Normal Neonates: The Earliest Sign of Subclinical Vitamin Deficiency*, 93 *J. CLINICAL ENDOCRINOLOGY & METABOLISM* 1784, 1786–88 (2008) (presenting results that suggest softening of the skull bones is associated with vitamin D deficiency in utero).

16. Patrick D. Barnes & Caroline D. Robson, *CT Findings in Hyperacute Nonaccidental Brain Injury*, 30 *PEDIATRIC RADIOLOGY* 74, 76–78 (2000) (discussing case report of a 19-year-old au pair who was convicted of manslaughter after accused of child abuse when 8-month old boy was unresponsive).

17. Andrew P. Sirotnak, *Medical Disorders that Mimic Abusive Head Trauma*, in *ABUSIVE HEAD TRAUMA IN INFANTS AND CHILDREN: A MEDICAL, LEGAL, AND FORENSIC REFERENCE* 191–92 (Lori Frasier et al., eds. 2006); see also J.F. Geddes et al., *Dural Haemorrhage in Non-Traumatic Infant Deaths: Does it Explain the Bleeding in “Shaken Baby Syndrome”?*, 29 *NEUROPATHOLOGY & APPLIED NEUROBIOLOGY* 14, 19–21 (2003) [hereinafter Geddes et al., *Dural Haemorrhage*] (suggesting that subdural bleeding in some infant head injuries is not traumatic); Waney Squier, *Shaken Baby Syndrome: The Quest for Evidence*, 50 *DEVELOPMENTAL MEDICINE & CHILD NEUROLOGY* 10, 12–13 (2008) (presenting evidence challenging the triad).

identical appearance. Furthermore, I've learned that imaging cannot provide precise causation or timing of injury whether involving the head or skeletal structures.

And so what my role has been, when I came from Boston Children's Hospital and was part of the child abuse team there, and before that in Oklahoma, and now in California, was to implement recommendations from the Centers for Disease Control, the American College of Radiology, the American Academy of Pediatrics, and other organizations. That means producing a differential diagnosis, following a multidisciplinary approach, performing better child and family protective evaluation and management, reframing the definitions of neglect or abuse for prevention, and reducing the cost-shifting from the medical and social systems to the criminal justice system.<sup>18</sup>

So this is the more compassionate and collaborative approach I've been hoping to build with my child abuse team while working with child abuse pediatricians and other child and family professionals. I have spent a lot of time in family court and criminal court. I would really like to see a lot of these cases decriminalized and handled in child protection hearings rather than going to criminal court, but I recognize that some cases do need to go to criminal court.

The traditional medical diagnosis of child abuse is subject to mandatory reporting in all states, so a physician must report if child abuse is suspected. And I do that. When I see those radiologic images from the emergency room or from the intensive care unit, I call and say, this could be trauma. It may be accidental; it may be non-accidental. There are other medical causes that can produce these imaging findings, so let's make sure we do the parallel work up. First, we start with our very good social workers, and report our concerns to local child protective services. So let's work up that aspect while protecting the child. Let's be sure, however, that we do a thorough medical workup for the mimics of abuse.

The SBS theory started out in the U.S. in the early twentieth century by assuming that shaking could cause tearing of blood vessels in the eyes, resulting in retinal hemorrhage, and tearing of blood vessels about the brain, leading to subdural hemorrhage plus brain injury.

Then an interesting thing happened in the mid-to-late part of that century. Someone in Canada decided that we really needed a

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18. Centers for Disease Control and Prevention, *Nonfatal Maltreatment of Infants—United States, October 2005–September 2006*, 57 MORBIDITY AND MORTALITY WKLY REP. 336 (2008), <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5713a2.htm>.

system in medicine that is based on science.<sup>19</sup> What all our teachers had taught us until that time about health and medicine, including child abuse, didn't seem to be systematically based upon a lot of science. A system was subsequently implemented using quality of evidence ratings based upon scientific methodology and biostatistical significance for establishing and publishing standards and guidelines in medicine. The weakest rating, Class IV, indicates a diagnosis or treatment strategy, for example, based on non-scientific consensus, or expert opinion alone.

But when you look at the Shaken Baby Syndrome literature, particularly prior to 2000, very few publications have ratings above Class IV.<sup>20</sup> Class I or Class II is required to be a standard or guideline. Expert opinion alone, Class IV, would never make it. And what about the exculpatory polygraphs, the acquittals, and the post-conviction exonerations? And what about the over-reliance on confessions to support the medicine behind Shaken Baby Syndrome?

In response to the evidence-based medicine challenge to the traditional diagnosis of child abuse, some child abuse pediatricians have claimed or adopted an experience-based standard. In the United States, Canada, and others of our peer nations, an evidence-based standard is required along for the informed consent from our patients.

Evidence-based medicine is what really woke me up after the initial twenty years of my professional experience, when I realized what I was doing during that time. Having been raised in a Christian home, I began to rethink the Ten Commandments and the Constitution of the United States. Most all faiths and laws agree that there are some things you shouldn't do, including "Thou shall not bear false witness against thy neighbor." Was I doing that during those earlier years? Are we still doing that?

In criminal cases, constitutionally, we always talk about due process, innocent until proven guilty beyond reasonable doubt, clear and convincing evidence—a lot of stuff that we doctors don't know or think about much. The burden of proof is on the prosecution.

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19. See generally Michael S. Pollanen et al., *Fatal Child Abuse-Maltreatment Syndrome: A Retrospective Study in Ontario, Canada, 1990-1995*, 126 FORENSIC SCI. INT'L 101 (2002) (suggesting a new triad for shaken baby syndrome, the "Ontario triad," that includes subdural hemorrhage, retinal hemorrhage and no signs of impact).

20. Mark Donohoe, *Evidence-Based Medicine and Shaken Baby Syndrome Part I: Literature Review, 1966-1998*, 24 AM. J. FORENSIC MED. & PATHOLOGY 239, 241 (2003); see also Jan Leestma, *Case Analysis of Brain-Injured Admittedly Shaken Infants: 54 Cases, 1969-2001*, 26 AM. J. FORENSIC MED. & PATHOLOGY 199, 204 (2005) (finding that only 11 cases of admittedly shaken babies showed no sign of cranial impact).

But look what's happened in these SBS cases: the burden has shifted to the defendant to prove the prosecution's expert theory wrong. I was that prosecution expert for twenty years. Barry Scheck asked me in the Nanny Case, "Dr. Barnes, you're so sure this is abuse. Were you there?" And to this day, I still think about that cross examination. No, I wasn't there. How did I know what was going on?

The SBS theory held that if you have the triad, that's abuse, just that simple. Or even just two of the triad. Shaking an otherwise healthy child can cause subdural hematoma. We just assumed all of these kids were otherwise well before the shaking event. So I started going back and looking at their past histories, all the way back to birth, particularly for children under six months of age. And I often saw that this child had never been well. I also learned that short falls can cause the triad.

Another piece of the dogma was there's no such thing as a lucid interval. If you're abused, you're immediately symptomatic. So that's an easy case for blaming the last caretaker in a successful prosecution. It turns out, however, that when it comes to imaging, there's a lot of overlap between accidental and non-accidental injury, and there are different types of injuries we might see that have old bleeding and then new bleeding. The Nanny Case is an example of that. But we were taught that when you have injuries that look like they're of different timing, that just means that there was more than one inflicted injury.

The Nanny Case was my awakening after marching in lockstep for the prior twenty years. When I looked at the experts who testified for the other side, I was shocked at the quality of their credentials and testimony, yet I had no idea what they were saying and where it came from. I testified that all the injuries to the baby happened at the same time. Before I testified, I had told the prosecutor, "You know, some of this could be old. Some of it could be new." And she said, "You can't say that. To nail the nanny, you've got to say it happened within hours before the initial CT scan."

I published an article about the Nanny Case in which I characterized it as a child abuse case.<sup>21</sup> The jury found the nanny guilty of second-degree murder. But then the judge reduced the verdict to manslaughter and gave her time served and sent her home to the U.K. There was all of this controversy after the trial, and I was then

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21. Barnes & Robson, *supra* note 16, at 76–78 (discussing case report of a 19-year-old au pair who was convicted of manslaughter after accused of child abuse when 8-month old boy was unresponsive).



asked by one of jurors to participate in some discussions of the evidence. I said, "Sure, I'd be glad to participate. Get both sides at Harvard where this guy was from and let's do it." That never happened. Then I was subsequently asked to review an SBS defense case, the Baby Scoon Case from New York. The imaging showed that the baby has multiple strokes in the brain." This was a premature baby, who was very ill at the time. The father was an anesthesiologist, and the mother was a social worker, as I recall. I looked at CT scans, which included one of the first CT venograms ever done on an infant and I said, "These are strokes due to venous thrombosis." This baby must have had meningitis or some infection, which was also apparent on the autopsy according to a neuropathologist.

There's a lot of talk about the short falls, and how high the fall would have to be to produce the symptoms of the triad. This is something that Dr. Chris Van Ee, along with other biomechanical scientists, talk about all the time. So there's been this building literature all along that was telling us, that the science on SBS versus impact trauma was unsettled. It's never been scientifically proven that only shaking, and not short falls, can produce the injuries of the triad.

Dr. Caffey put forward the Shaken Baby Syndrome hypothesis,<sup>22</sup> largely citing Dr. Guthkelch,<sup>23</sup> but recognized that the evidence was largely circumstantial. He then recommended that we should establish child abuse centers, get a lot of money, and do some research.<sup>24</sup> But not much, if any, scientific research has actually been done. And Dr. Guthkelch was, in turn, citing Dr. Ommaya.<sup>25</sup> Dr. Ommaya's research showed that you have to achieve forces above forty Gs to get any part of the triad, and that you probably would have a neck injury with it.<sup>26</sup> Evidently, neither Dr. Caffey nor Dr. Guthkelch realized that humans may not be capable of generating such forces by shaking only.

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22. Caffey, *Theory and Practice*, *supra* note 5, at 168–69.

23. *Id.* at 163.

24. *Id.* at 169.

25. *Id.* at 430, 431.

26. See Ayub K. Ommaya, Fred Faas & Philip Yarnell, *Whiplash Injury and Brain Damage*, 4 J. AM. MEDICAL ASS'N 285, 286–89 (1968) (observing in an experimental study of subhuman primates—mostly rhesus monkeys—that cerebral concussion and gross hemorrhages and contusions on the surface of the brain and upper cervical cord can be produced by rotational displacement of the head without significant direct head impact).

Then Dr. Duhaime, a well-respected pediatric neurosurgeon, and her research team published a study<sup>27</sup> using an infant biomechanical model and correlating the results with the findings of a separate autopsy series of infant victims of SBS. According to current evidence-based medicine standards, this was the highest rated series published in that era. She had football players from the University of Pennsylvania shake the baby models. But none of them could generate the forces to achieve the injury thresholds achieved by Ommaya. When the baby model was dropped or impacted, the resulting forces reached or exceeded injury thresholds.<sup>28</sup> Also the autopsy series showed that a lot of these babies had signs of impact along with massive swelling in the brain.

Others came along and published on this issue and more doubt was raised regarding SBS. Biomechanical scientists, such as Dr. Faris Bandak, have shown that since the neck is the weak link between the body and the head, if you're shaking a baby that violently, you would expect to break the neck first.<sup>29</sup>

The biomechanical literature raised reasonable doubt about the SBS, such that shaking theoretically could cause the triad, but there needs to be some associated neck injury or impact. Also, short distance falls can produce forces above the threshold for the triad.

So what I often worry about are the stories that we hear in many cases in which a caretaker drops a young infant head first on to the floor. The head leads the body and impacts first, which can then turn or twist the neck where it connects to the head near the breathing centers of upper spinal cord and lower brainstem. So then the baby stops breathing and brain injury can occur due to oxygen deprivation. I'm not one who says shaking can't cause the triad. I'm not one who says you can shake your baby without harm.

We published a paper in which the baby stopped breathing from a short fall that had resulted in asphyxiation and that's what made

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27. See generally Ann-Christine Duhaime et al., *The Shaken Baby Syndrome: A Clinical, Pathological, and Biomechanical Study*, 66 J. NEUROSURGERY 409 (1987).

28. See *id.* at 412–13 (noting that on average, impact accelerations exceeded shake accelerations by a factor of nearly fifty times).

29. See Faris A. Bandak, *Shaken Baby Syndrome: A Biomechanics Analysis of Injury Mechanisms*, 151 FORENSIC SCI. INT'L 71, 76–79 (2005) (finding that an infant head subjected to the levels of rotational velocity and acceleration required in the shaken baby syndrome literature would result in forces on the infant neck that far exceed the cervical spine's limits). See also John Lloyd et al., *Biomechanical Evaluation of Head Kinematics during Infant Shaking versus Pediatric Activities of Daily Living*, 2 J. FORENSIC BIOMECHANICS 1 (2011); J.F. Luck et al., *Tensile Mechanical Properties of the Pediatric Human Osteoligamentous Cervical Spine*, 39 J. BIOMECHANICS S151 (2006); Jun Ouyang et al., *Biomechanical Assessment of the Pediatric Cervical Spine under Bending and Tensile Loading*, 30 SPINE E716 (2005); Mary Clyde Pierce & Gina Bertocci, *Injury Biomechanics and Child Abuse*, 10 ANN. REV. BIOMEDICAL ENGINEERING 85 (2008).

that brain turn black on the CT scan.<sup>30</sup> White areas of small hemorrhages were also present between the brain and the skull, as well as a thin white stripe of hemorrhage along the middle between the right and left sides of the brain. We used to say that this injury pattern on CT was always due to Shaken Baby Syndrome. I used to say that shaking causes the injury pattern by tearing of brain and tearing of the blood vessels around the brain and in the eyes. I used to say this pattern of injury on the CT scan could only be due to SBS and nothing else. Well, I was wrong. The doctors didn't believe that this baby's triad and CT abnormalities were due to the reported fall. The autopsy clearly showed a head impact and injury to the infant's neck including a tearing of the upper spinal cord next to the brain stem where the breathing center is located.<sup>31</sup> If a child goes too long without oxygen but undergoes resuscitation, then the result can be asphyxic brain injury with associated hemorrhages about the brain and in the eyes.

Then came along a series of neuropathology reports, starting with Dr. Geddes, a well-respected neuropathologist in the United Kingdom.<sup>32</sup> She reviewed the neuropathology of a series of "known" SBS cases. What she found was unexpected and surprising. Most of these babies presented with apnea, an acute life-threatening event (ALTE), where the infant stops breathing.<sup>33</sup> She also found older injury in nearly half of them,<sup>34</sup> including subdural collections that may have dated back to birth. And most of the brain injury she observed wasn't representative of traumatic tearing of the brain tissue. In fact, most of the injury was due to a lack of oxygen and blood flow. Also, many infants had sites of impact injury.<sup>35</sup> Could many of these cases represent dropped or accidentally impacted infants rather than SBS?

Dr. Geddes also did a control study of infants with no known history of trauma but who appeared to be resuscitated Sudden Infant Death Syndrome (SIDS) victims.<sup>36</sup> In other words, these are cases where there wasn't a crib death because somebody found the baby and resuscitated the baby. What else did she find that could

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30. Patrick D. Barnes et al., *Traumatic Spinal Cord Injury: Accidental versus Nonaccidental Injury*, 15 SEMINARS PEDIATRIC NEUROLOGY 178, 178-79 (2008).

31. *Id.* at 180.

32. See generally J.F. Geddes et al., *Neuropathology of Inflicted Head Injury in Children: I. Patterns of Brain Damage*, 124 BRAIN 1290 (2001) [hereinafter Geddes et al., *Patterns*] (reporting findings from the brains of 37 infants who died of head injuries and 14 control infants who died of other causes).

33. *Id.* at 1291.

34. *Id.* at 1291-93.

35. *Id.* at 1291.

36. Geddes et al., *Dural Haemorrhage*, *supra* note 17.

cause the triad? She observed findings of infection, hypoxia-ischemia (deprivation of oxygen), along with combined etiologies which you might expect to find in a near-SIDS group.<sup>37</sup> She also included some SIDS cases in her study.<sup>38</sup> She also reported some cases thought to be consistent with SBS.<sup>39</sup> From her observations she proposed a unified hypothesis for causation of the triad whether due to accidental or non-accidental trauma or resulting from a medical condition.<sup>40</sup>

As a result of Dr. Geddes's published works, other scholars such as Mack, Squier, and Eastman began a critical review of the anatomy and physiology of the meninges, the linings between the brain and the skull, including a re-examination of the mechanisms of how subdural collections occur.<sup>41</sup> It was previously thought that subdural hemorrhage in SBS resulted from traumatic tearing of the veins extending from the brain surface into the overlying meninges. However, it turns out that in many cases of subdural hemorrhage, evidence of bridging vein rupture can't be demonstrated.<sup>42</sup> Often, only diffuse small hemorrhages are observed within the membranes (i.e., intradural), especially when encountered in the immature brain of the infant.

We now know that there are causes of subdural, or intradural, hemorrhage in these infants other than trauma or abuse. And there was a very important paper written by Dr. DeWolfe<sup>43</sup> reviewing the common causes of infant acute life-threatening events (ALTE—apnea, seizure) that may often occur in homes or other daycare settings. Some infants are born with, or develop, feeding and swallowing problems such as reflux or regurgitation of stomach contents which can cause choking, particularly in preterms.<sup>44</sup> Other common causes of infant ALTE include seizures, meningitis, or birth or post-birth injury.<sup>45</sup> Respiratory and other viral infections

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37. *Id.* at 14.

38. *Id.*

39. *Id.* at 18.

40. *Id.* at 19–21.

41. See generally Julie Mack, Waney Squier & James T. Eastman, *Anatomy and Development of the Meninges: Implications for Subdural Collections and CSF Circulation*, 39 *PEDIATRIC RADIOLOGY* 200 (2009) (describing how nontraumatic conditions can be associated with subdural hemorrhage and explaining the role of the dura in homeostasis of the central nervous system).

42. *Id.* at 204.

43. See generally Craig C. DeWolfe, *Apparent Life-Threatening Event: A Review*, 52 *PEDIATRIC CLINICS N. AMER.* 1127 (2005) (reviewing literature regarding an “apparent life-threatening event” or complex of symptoms that present expectantly in an infant and cannot easily be characterized by a health care provider).

44. *Id.* at 1139–40.

45. *Id.* at 1133–35, 1139–40.

may be the cause of ALTE and result in the triad.<sup>46</sup> Heart and vascular disease may be the source.<sup>47</sup> Yes, maltreatment can also be a cause.<sup>48</sup>

So we then started looking into choking babies, and there is some research on that.<sup>49</sup> Some of the original articles are about choking associated with whooping cough, or pertussis, including with the triad.<sup>50</sup> So then, here is a series of cases, some of which were managed by the innocence projects.<sup>51</sup> There is the Audrey Edmunds case where we, on imaging, found features of hypoxia-ischemia from a baby who stopped breathing, a baby who also had evidence of old hemorrhage, maybe from birth. Dural/subdural hemorrhage can be caused just by a lack of oxygen (hypoxia) or a lack of blood flow (ischemia) without any shaking or other forms of abuse. Lots of research has been done<sup>52</sup> to support what Dr. Geddes<sup>53</sup> had originally hypothesized, although she and others continue to be under attack by SBS-proponents.<sup>54</sup>

Other mimics of abuse that may present as an ALTE with the triad include venous thrombosis, particularly in infants recently ill with vomiting and diarrhea, and often associated with infection.<sup>55</sup>

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46. *Id.* at 1128, 1131, 1133–35, 1139.

47. *Id.* at 1133.

48. *Id.*

49. See generally J.F. Geddes & D.G. Talbert, *Paroxysmal Coughing, Subdural and Retinal Bleeding: A Computer Modelling Approach*, 32 NEUROPATHOLOGY & APPLIED NEUROBIOLOGY 625 (2006) (finding that coughing can cause bleeding and noting that unexplained haemorrhages attributed to “shaking” may be due to a rare complication of pertussis); Parvathi Mohan, *Aspiration in Infants and Children*, 23 PEDIATRICS REV. 330 (2002) (discussing various conditions in which aspiration may occur in children); Megan Page & Heather Jeffery, *The Role of Gastro-Oesophageal Reflex in the Aetiology of SIDS*, 59 EARLY HUM. DEV. 127 (2000) (examining how reflex apnea can cause death during sleep).

50. See generally Geddes & Talbert, *supra* note 49 (finding that coughing can cause bleeding and noting that unexplained hemorrhages attributed to “shaking” may be due to a rare complication of pertussis).

51. See, e.g., Barnes, *Issues and Controversies*, *supra* note 9, at 220 (presenting case studies of infants whose injuries were suspected as nonaccidental).

52. See, e.g., Marta C. Cohen & Irene Scheimberg, *Evidence of Occurrence of Intradural and Subdural Hemorrhage in the Perinatal and Neonatal Period in the Context of Hypoxic Ischemic Encephalopathy: An Observational Study from Two Referral Institutions in the United Kingdom*, 12 PEDIATRIC AND DEVELOPMENTAL PATHOLOGY 169 (2009); Geddes et al., *supra* note 17, at 19–21; Irene Scheimberg et al., *Nontraumatic Intradural and Subdural Hemorrhage and Hypoxic Ischemic Encephalopathy in Fetuses, Infants, and Children up to Three Years of Age: Analysis of Two Audits of 636 Cases from Two Referral Centers in the United Kingdom*, 16 PEDIATRIC & DEVELOPMENTAL PATHOLOGY 149 (2013); Mack et al., *supra* note 41; Patrick Kelly et al., *Subdural Hemorrhage and Hypoxia in Infants with Congenital Heart Disease*, 134 PEDIATRICS E773 (2014).

53. See generally Geddes et al., *Patterns*, *supra* note 32.

54. See generally Duhaimé et al., *supra* note 27.

55. See, e.g., Michael V. Krasnokutsky, *Cerebral Venous Thrombosis: A Potential Mimic of Primary Traumatic Brain Injury in Infants*, 197 AM. J. ROENTGENOLOGY W503, W504-05 (2011) (presenting cases of patients with whose symptoms mimicked brain trauma).

Venous thrombosis may occur with trauma, particularly in the presence of a skull fracture.<sup>56</sup> Vascular malformations as well as bleeding and clotting disorders must be excluded, along with meningitis, metabolic disorders, benign extracerebral collections of infancy and arachnoid cysts, and inappropriate cold medications.<sup>57</sup>

So neuropathology and biomechanics provide evidence that raises doubt about the triad only being caused by abuse. Then there is the evidence about short falls and the literature showing that there can be a lucid interval after a head injury.<sup>58</sup> Both sides now agree there can be a lucid interval—the baby doesn't have to be immediately ill. The interval could last for hours or even until the next day. The triad can be produced accidentally, non-accidentally, or from a medical cause. So you've got to work these cases up all the way back to birth and before, particularly when the baby is under six months of age. Malignant brain edema from accidental trauma, as well as abuse, can cause the triad.<sup>59</sup> We also know that some babies are born with large collections between the brain and the skull that can predispose the child to subdural hemorrhage, and there is now a lot of literature on this.<sup>60</sup> We know that such

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56. See, e.g., Gabrielle deVeber et al., *Cerebral Sinovenous Thrombosis in Children*, 345 N. ENG. J. MED. 417, 418–21 (2001) (discussing observations of 160 children with sinovenous thrombosis); Nomazulu Dlamini, Lori Billingham & Fenella J. Kirham, *Cerebral Venous Sinus (Sinovenous) Thrombosis in Children*, 21 NEUROSURGERY CLINICS N. AMER. 511, 518–19 (2011) (noting clinical presentations of sinovenous thrombosis and that prothrombotic disorders may be risk factors for CSVT in children); Michael V. Krasnokutsky, *Cerebral Venous Thrombosis: A Potential Mimic of Primary Traumatic Brain Injury in Infants*, 197 AM. J. ROENTGENOLOGY W503, W504-05 (2011) (presenting cases of patients with whose symptoms mimicked brain trauma).

57. Barnes, *Issues and Controversies*, *supra* note 9, at 209; Laureen Marinetti et al., *Over-the-Counter Cold Medications: Postmortem Findings in Infants and the Relationship to Cause of Death*, 29 J. ANALYTICAL TOXICOLOGY 738, 742–43 (2005).

58. See, e.g., A.C. Duhaime et al., *Head Injury in Very Young Children: Mechanisms, Injury Types, and Ophthalmologic Findings in 100 Hospitalized Patients Younger than 2 Years of Age*, 90 PEDIATRICS 179, 181–84 (1992); Susan R. Durham & Ann-Christine Duhaime, *Maturation-Dependent Response of the Immature Brain to Experimental Subdural Hematoma*, 24 J. NEUROTRAUMA 5, 9–13 (2007); M. Oehmichen, C. Meissner & K-S. Saternus, *Fall or Shaken: Traumatic Brain Injury in Children Caused by Falls or Abuse at Home—A review on Biomechanics and Diagnosis*, 36 NEUROPEDIATRICS 240, 241–44 (2005); R.A. Williams, *Injuries in Infants and Small Children Resulting from Witnessed and Corroborated Free Falls*, 31 J. TRAUMA 1350, 1351 (1991).

59. See generally D.A. Bruce et al., *Diffuse Cerebral Swelling Following Head Injuries In Children: The Syndrome of "Malignant Brain Edema,"* 54 J. NEUROSURGERY 170 (1981) (discussing findings from 63 children with CTs suggesting head injuries); see also Paul Steinbok et al., *Early Hypodensity on Computed Tomographic Scan of the Brain in an Accidental Pediatric Head Injury*, 60 NEUROSURGERY 689 (2007) (noting in a retrospective review that all five patients with diffuse cerebral hemispheric hypodensities on early CT scans presented severe head injuries and immediate, unremitting coma before brain death).

60. See, e.g., John Amodio et al., *Spontaneous Development of Bilateral Subdural Hematomas in an Infant with Benign Infantile Hydrocephalus: Color Doppler Assessment of Vessels Traversing Extra-Axial Spaces*, 35 PEDIATRIC RADIOLOGY 1113, 114–16 (2005); Joseph H. Piatt, *A Pitfall in the*

collections can re-bleed, and we know that bleeding at birth can form chronic collections even if not a high percentage of the time.<sup>61</sup> And those can sometimes occur from minor trauma or normal handling, and sometimes from abuse. And what did we learn from some of our earlier MRI studies on development, birth factors? Up to fifty percent of babies who had normal labor and delivery had bleeding.<sup>62</sup> And some of those re-bleed.<sup>63</sup>

There are a number of mimics of abuse. In fact, I'm getting to the point where we should stop calling them mimics. These are actual, legitimate, evidence-based medicine causes of the triad.

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*Diagnosis of Child Abuse: External Hydrocephalus, Subdural Hematoma, and Retinal Hemorrhages*, 7 NEUROSURGICAL FOCUS E5, E8-9 (1999); Thomas Pittman, *Significance of a Subdural Hematoma in a Child with External Hydrocephalus*, 39 PEDIATRIC NEUROSURGERY 57, 57-58 (2003).

61. See, e.g., Owen Dyer, *Brain Haemorrhage in Babies May Not Indicate Violent Abuse*, 326 BMJ 616, 616 (2003); Kent Hymel, Carole Jenny & Robert W. Block, *Intracranial Hemorrhage and Rebleeding in Suspected Victims of Abusive Head Trauma: Addressing the Forensic Controversies*, 7 CHILD MALTREATMENT 329, 344 (2002); Eva Lai Wah Fung et al., *Unexplained Subdural Hematoma in Young Children: Is it Always Child Abuse?*, 44 PEDIATRICS INT'L 37, 38-41 (2002).

62. See V.J. Rooks et al., *Prevalence and Evolution of Intracranial Hemorrhage in Asymptomatic Term Infants*, 29 AM. J. NEURORADIOLOGY 1082 (2008) (finding that forty-six of 101 asymptomatic neonates had subdural hemorrhage).

63. Barnes, *Issues and Controversies*, *supra* note 9, at 206.