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Abusive Head Trauma in the Era of Evidence and AI: Re-thinking the Triad

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Abstract

Abusive head trauma (AHT) is one of the most challenging and consequential diagnoses in pediatric and forensic medicine. The classic triad of subdural hemorrhage, retinal hemorrhage, and encephalopathy has long been considered a key indicator of inflicted injury in infants. However, growing evidence has questioned the specificity of this triad and the assumption that it can be attributed to a single mechanism, particularly violent shaking. Concerns have also been raised regarding circular reasoning, diagnostic bias, and inadequate consideration of alternative medical conditions. This article critically re-examines the triad within the broader framework of AHT. It reviews current controversies regarding biomechanics and causation. It also highlights the importance of careful differential diagnosis. Possible alternative explanations include birth-related hemorrhage, accidental trauma, bleeding disorders, infections, metabolic diseases, vascular anomalies, and cerebral venous sinus thrombosis. It also discusses the value of structured clinical prediction tools, such as PredAHT and PediBIRN, and considers the emerging role of artificial intelligence in risk assessment and hemorrhage detection. A multidisciplinary, evidence-based, and bias-aware approach remains essential in suspected AHT cases.

Keywords: *Abusive head trauma; shaken baby syndrome; triad; subdural hemorrhage; retinal hemorrhage; artificial intelligence; forensic medicine.*

INTRODUCTION

Child abuse and neglect is a public health and forensic medicine problem that encompasses physical and/or emotional maltreatment, sexual abuse, neglect/negligent care, and forms of exploitation directed at individuals under 18 years of age. It causes actual or potential harm to the child's health, life, development, or dignity and most often occurs within a relationship of responsibility–trust–power [1]. Although the true burden cannot be fully quantified because a substantial proportion of these cases may remain concealed. There are differences in definitions and reporting, a very high number of children worldwide are exposed to violence and/or neglect each year; some estimates indicate "up to 1 billion" children in the 2–17 year age group [2]. In clinical practice, factors that increase suspicion of abuse can be summarized as inconsistency between history and findings, delayed presentation for medical care, multiple injuries at different stages of healing, unexplained bruises/burns, suspicious fracture patterns, intraoral injuries, and accompanying signs of neglect [3].

One of the most devastating subcategories of physical abuse is abusive head trauma (AHT) associated with severe morbidity and mortality, particularly during infancy. AHT is defined as "injury to the skull and/or intracranial contents in a young child (in most studies, <5 years) resulting from intentional blunt impact, violent shaking, or a combination of both" [3]. AHT is among the leading causes of fatal head trauma, especially in children under 2 years of age and contributes substantially to the burden of severe/fatal traumatic brain injury [4].

The principal challenge that complicates recognition of AHT is presenting complaints. Nonspecific and overt external signs of trauma do not always accompany the condition. In infants, symptoms such as irritability, lethargy, recurrent vomiting, feeding difficulty, apnea, seizures, altered level of consciousness, and a bulging fontanelle may be present. The history provided by the caregiver may not explain the trauma. For this reason, clinicians have relied more heavily on certain clusters of findings in diagnostic reasoning [5].

The co-occurrence of subdural hemorrhage, retinal hemorrhage, and encephalopathy, referred to in infants as the "triad". For many years, Shaken Baby Syndrome (SBS) has been strongly associated with violent shaking when identified in the absence of a clear accidental history and was used as an important basis in favor of abuse. Since the 1970s, the concept of SBS has appeared in medical literature. However, beginning in the 2000s, critiques became more prominent, arguing that the triad cannot be attributed to a single specific mechanism and that important methodological limitations exist in the way the evidence has been generated. Within these debates, hypotheses suggest that severe hypoxia may contribute to the findings through brain edema and vascular injury [6].

The clinical and forensic implications of diagnostic uncertainty are bidirectional: False negative and false positive. A false-negative assessment may increase the risk of recurrent abuse and fatal outcomes, whereas a false-positive assessment may lead to innocent caregivers facing criminal proceedings and to unnecessary separation of the child from the family. Therefore, the goal in evaluating AHT is to adopt a multidisciplinary approach that strengthens not only sensitivity but also specificity [3].

In 2009, the American Academy of Pediatrics recommended use of the more comprehensive and less mechanism-reductionist term "abusive head trauma (AHT)," nothing that the term "SBS" implies a mechanistic assumption [7]. Although this approach permits the evaluation of shaking, impact and combined mechanisms within a broader conceptual framework, some scholars contend that it may obscure ongoing scientific debate regarding the "triad" and risk conflating distinct etiological processes [5].

The Conflict Named "Shaken Baby Syndrome Hypothesis and the Triad"

According to this model, the triad reflects the biomechanical consequences of violent shaking. Sudden angular acceleration leads to stretching and tearing of bridging veins, resulting in subdural hemorrhage, whereas vitreoretinal traction produces multilayered retinal hemorrhages. Encephalopathy represents the clinical manifestation of diffuse axonal injury, cerebral edema, and secondary hypoxic–ischemic processes [4]. In certain forensic contexts, it was used to support causal inference. [5].

First, it remains unclear whether the triad occurs exclusively after traumatic shaking. Subdural and retinal hemorrhages may occur during the birth process, in the perinatal period, or in certain medical conditions [8]. Within this framework, the proposed "unified hypothesis" posits that the triad may reflect secondary hypoxic–ischemic processes rather than primary trauma [6].

If the triad does not in every case reflect a specific trauma mechanism, then causal inference may be open to re-evaluation in some cases previously classified as SBS. This possibility has important implications, particularly in the forensic context, in terms of the standard of evidence and the approach of expert witnesses [5].

Within current terminology, abusive head trauma (AHT) encompasses not only shaking but also mechanisms such as throwing the child, impact against a rigid surface, and blunt force trauma. Shaking and impact frequently co-occur, producing a biomechanical injury profile distinct from isolated shaking [4]. The central issue is whether a specific cluster of findings can distinguish intentional shaking from alternative etiologies with high specificity.

Circular Reasoning and Diagnostic Biases

One approach to reduce the diagnostic bias is the use of clinical decision/prediction rules. These tools do not aim to establish an "automatic diagnosis", they implicate a detailed abuse evaluation with transparence and reproducibility by combining high-risk indicators within a predefined algorithm [9].

In this context, one of the most frequently cited examples is PredAHT. PredAHT is a model that calculates the probability of AHT in children <3 years of age with intracranial injury, using combinations of six clinical features: apnea, seizures, retinal hemorrhage, rib fracture, long-bone fracture, and head/neck bruising. In particular, the presence of an additional finding accompanying a rib fracture or retinal hemorrhage, or the coexistence of any three of the six findings, has been associated with a high probability of AHT (estimated probability >85%) [10].

PediBIRN-4 is a four-variable clinical decision rule intended for screening in children <3 years of age with acute head injury. These four variables include clinically significant respiratory compromise, bruising of the ears/neck/torso, bilateral or interhemispheric subdural hemorrhage or fluid collection, and skull fractures other than an isolated, unilateral, nondiastatic linear parietal fracture [11]. In PICU validation data, PediBIRN-4 demonstrated a sensitivity of approximately 96%; thus, it serves as a screening approach designed to reduce missed cases [11, 12].

In contrast, PediBIRN-7 provides a patient-level probability of AHT after a comprehensive abuse evaluation, including skeletal survey and ophthalmologic assessment. It incorporates seven key variables covering respiratory compromise, specific bruising patterns, characteristic intracranial and skeletal findings, severe retinal pathology, and radiologic evidence of hypoxic–ischemic brain injury. [11]. In a recent validation study, PediBIRN-7 demonstrated a sensitivity of 0.74, specificity 0.77, and ROC-AUC 0.83 relative to definitional criteria [13]. However, tools such as PredAHT and the PediBIRN family do not replace clinical judgment. Structuring high-risk indicators strengthens within-team standardization by making the assessment threshold explicit and reduces the risk of bias-driven automatic labeling [10,12,13].

Biomechanical Limits of Shaking Trauma

In infants, the head is proportionally large and heavy and the neck has weak musculature. It can move uncontrollably in a flexion–extension pattern during shaking. The classical view posits that abrupt acceleration–deceleration generates rotational motion within the cranial vault, which may strain bridging veins and lead to tearing. Because this mechanism cannot be directly evaluated in humans for ethical reasons, modeling studies have examined it using different approaches, and consensus remains limited [14].

Experimental studies have demonstrated that the maximum angular acceleration generated by shaking alone remains below proposed injury thresholds. The table summarizes the scenarios illustrated in the figure and the corresponding maximum head acceleration (g) values derived from the graph (Table 1):

Table 1: *Approximate Peak Head Acceleration Values Across Different Injury Scenarios in Relation to Injury Reference Value (IRV) Thresholds* [15,16]

Scenario / Data Group	Condition (Graph Definition)	Maximum Peak Head Acceleration (Approx., g)	IRV* = 51 g	IRV* = 87 g
Shaking	Shaking maneuver	~10–15 g	Below	Below
Horizontal fall – occipital impact	30 cm	~65–70 g	Above	Below / Near
Horizontal fall – occipital impact	60 cm	~95–100 g	Above	Above
Horizontal fall – occipital impact	90 cm	~140–150 g	Above	Above
Horizontal fall – occipital impact	120 cm	~165–175 g	Above	Above
Horizontal fall – occipital impact	150 cm	~200–210 g	Above	Above
Motor vehicle crash – no head injury	“No head injury” group	~25–50 g	Mostly below	Below
Motor vehicle crash – severe/fatal injury	With skull fracture/hemorrhage	~105–200 g	Above	Above
Professional football – concussion	“Concussion” reference	~90–100 g	Above	Around / Above

Values are derived from Instrumented Child Restraint Air Bag Interaction (CRABI) dummy experiments and reflect linear (not rotational) head acceleration; thus, they provide a comparative magnitude overview rather than proof of a specific injury mechanism. Shaking generated low peak accelerations (~10–15 g), whereas short-distance occipital falls (≥30 cm) exceeded IRV reference lines (51 g) and higher falls (≥60 cm) surpassed 87 g, approaching ranges reported in sports concussion and severe motor vehicle crashes [15,16].

Evidence suggests that concomitant head impact may contribute in shaking cases. In a subset of clinical cases, the infant may have experienced both shaking and impact against a rigid surface. Although similar biomechanical processes may also occur in accidental falls, in witnessed low-height falls (<1–2 m) subdural hemorrhages tend to be more limited [17,18].

The status of cervical structures remains controversial. Multiple studies suggest that severe shaking may cause injury to the neck muscles and connective tissues. Cervical examination and imaging remain normal in a substantial proportion of cases. Published reports indicate that this finding challenges a shaking mechanism [19].

Alternative Differential Diagnoses

The table provides a systematic screening for potential medical mimics in infants presenting with the "triad."

Alternative diagnosis/condition
Birth-related hemorrhages (vacuum/forceps delivery; perinatal Subdural hematoma (SDH)/ Retinal hemorrhage (RH) [21,22]
Accidental trauma (falls/impact; high-energy accidents) [23]
Bleeding diathesis (hemophilia, von Willebrand disease, platelet function disorders, etc.) [24]
Vitamin K deficiency bleeding (VKDB) [25]
Cerebral vascular anomalies (AVM, aneurysm, etc.) [20]
Infections (bacterial meningitis; subdural effusion/empyema) [26,27]
Metabolic/genetic: Glutaric aciduria type I [28]
Metabolic/genetic: Menkes disease and other fragility disorders [29]
Cerebral venous sinus thrombosis (CVST) [30,31]
Other controversial or low–level evidence explanations (drowning–hypoxia, severe vomiting/coughing, etc) [20]
BESS/benign external hydrocephalus [20]
The conditions listed above may also coexist with abusive head trauma (AHT). Therefore, no single entry in this table, when considered in isolation, either definitively excludes or conclusively proves abuse [20–31].

Diagnostic Approach in Suspected Abusive Head Trauma (AHT): toward Future

The diagnosis of abusive head trauma (AHT) does not rely on a single pathognomonic finding but emerges from a multidisciplinary clinical evaluation in which historical, physical, radiologic, laboratory, and contextual factors are synthesized. The aim is twofold: to protect the child while simultaneously minimizing false-positive labeling [32].

Abusive head trauma sits at the crossroads of emergency care, radiology, and the courtroom, where uncertainty has consequences in both directions. Decades of debate around the triad highlight a central lesson: no single finding, test, or mechanistic inference can carry the full burden of causality. The next advance in AHT assessment is therefore unlikely to arise from the mere accumulation of data, but from the structured integration of clinical evolution, imaging findings, laboratory signals, and social context within transparent and auditable decision frameworks. In this context, artificial intelligence can make time-critical evidence more visible and consistent if bias control, explainability, multicenter validation and forensic reliability are treated as core requirements, not afterthoughts [32].

Operationally, this transformation is already emerging through holistic decision models that integrate multilayered clinical, radiological, laboratory, and contextual data. Algorithms based on artificial intelligence capable of automatically detecting and prioritizing intracranial hemorrhage on emergent cranial CT may shorten reporting times and accelerate diagnostic pathways in time-critical cases [33]. Deep learning models can estimate the probability of retinal hemorrhage by analyzing radiomorphological patterns of the globes on pediatric CT. In settings with limited ophthalmologic access, such tools may help guide timely referral for urgent fundus examination [34].

Beyond image analysis, machine learning–based risk prediction systems can integrate clinical documentation, demographic data, laboratory findings, and imaging results. By processing these variables together, they may help detect cases that might otherwise be overlooked through quantitative estimation of AHT probability. For these systems to be clinically and forensically acceptable, they must rely on bias-controlled datasets. They should ensure algorithmic transparency and explainability, while demonstrating reproducibility through multicenter validation [35].

Ultimately, the goal is not to replace human expertise but to support it. The future lies in decision-support systems grounded in standardized reporting, explainable AI, ethical oversight, and traceable decision pathways that strengthen both evidentiary consistency and accountability [32].

CONCLUSION

Abusive head trauma remains one of the most consequential diagnoses in pediatrics and forensic medicine precisely because its classic markers can be compelling yet not mechanistically definitive. The triad (subdural hemorrhage, retinal hemorrhage, and encephalopathy) should be understood as a high-risk signal since overlapping clinical contexts, alternative medical conditions, and ongoing biomechanical uncertainties limit any one-to-one inference from findings to mechanism. The most defensible approach, therefore, is a structured, multidisciplinary synthesis of history, examination, neuroimaging, ophthalmologic assessment, skeletal survey, laboratory evaluation, and differential diagnosis supported by transparent clinical prediction tools to reduce circular reasoning and bias while simultaneously minimizing both missed abuse and unjust labeling.

Looking forward, progress in AHT assessment will be driven less by "more testing" than by smarter integration of evidence into auditable decision pathways. Artificial intelligence can strengthen this architecture by accelerating recognition of time-critical intracranial hemorrhage, guiding prioritization of specialist evaluations, and supporting risk estimation through multimodal models so long as these systems are trained on bias-controlled datasets and meet standards of explainability, multicenter validation, and forensic defensibility. In this future, AI should function as a disciplined lens that clarifies and standardizes evidence, not as an automated adjudicator; accountability must remain human, and the goal must remain constant: protecting the child while ensuring that conclusions can withstand both clinical scrutiny and courtroom standards.

REFERENCES

1. World Health Organization. Child maltreatment [Internet]. Geneva: WHO; 2023 [cited 2026 Feb 12]. Available from: https://www.who.int/news-room/fact-sheets/detail/child-maltreatment
2. World Health Organization. Violence against children [Internet]. Geneva: WHO; 2023 [cited 2026 Feb 12]. Available from: https://www.who.int/news-room/fact-sheets/detail/violence-against-children
3. Parks SE, Annest JL, Hill HA, Karch DL. Pediatric abusive head trauma: recommended definitions for public health surveillance and research. Atlanta (GA): Centers for Disease Control and Prevention; 2012.
4. Choudhary AK, Servaes S, Slovis TL, Palasis S, Hedlund GL, Narang SK, et al. Consensus statement on abusive head trauma in infants and young children. Pediatr Radiol. 2018;48(8):1048–65.
5. Vinchon M. The triad and abusive head trauma: current controversies and review of the literature. Forensic Sci Med Pathol. 2020;16(3):413–25.
6. Geddes JF, Tasker RC, Hackshaw AK, Nickols CD, Adams GGW, Whitwell HL. Dural haemorrhage and hypoxic brain injury in inflicted head injury: a neuropathological study. Neuropathol Appl Neurobiol. 2003;29(1):14–22.
7. Christian CW; Committee on Child Abuse and Neglect, American Academy of Pediatrics. Abusive head trauma in infants and children. Pediatrics. 2009;123(5):1409–11.
8. Wright JN. CNS injuries in abusive head trauma. AJR Am J Roentgenol. 2017;208(5):991–1001.
9. Kea B, Hall MK, Wang R. Recognising bias in studies of diagnostic tests part 2: interpreting and verifying the index test. Emerg Med J. 2019;36(8):501–505. doi:10.1136/emermed-2019-208447.
10. Maguire SA, Kemp AM, Lumb RC, Farewell DM. Estimating the probability of abusive head trauma: a pooled analysis. Pediatrics. 2011;128(3):e550–e564. doi:10.1542/peds.2010-2949.
11. Hymel KP, Armijo-Garcia V, Foster R, et al; Pediatric Brain Injury Research Network (PediBIRN) Investigators. Validation of a clinical prediction rule for pediatric abusive head trauma. Pediatrics. 2014;134(6):e1537–e1544. doi:10.1542/peds.2014-1329.
12. Hymel KP, Karst W, Marinello M, et al. Screening for pediatric abusive head trauma: Are three variables enough? Child Abuse Negl. 2022;125:105518. doi:10.1016/j.chiabu.2022.105518.
13. Hymel KP, Carroll CL, Frazier TN, et al. Validation of the PediBIRN-7 clinical prediction rule for pediatric abusive head trauma. Child Abuse Negl. 2024;152:106799. doi:10.1016/j.chiabu.2024.106799.
14. Duhaime AC, Gennarelli TA, Thibault LE, Bruce DA, Margulies SS, Wiser R. The shaken baby syndrome: a clinical, pathological, and biomechanical study. J Neurosurg. 1987;66(3):409–415.
15. Mertz HJ, Prasad P, Irwin AL. Injury risk curves for children and adults in frontal and rear collisions. In: Proceedings of the 37th Stapp Car Crash Conference. Warrendale (PA): SAE International; 1993. p. 13-30.
16. Klinich KD, Hulbert GM, Schneider LW. Estimating infant head injury criteria and impact response using crash reconstruction and pediatric cadaver data. In: Proceedings of the 46th Stapp Car Crash Conference. Warrendale (PA): SAE International; 2002. p. 165-194.

17. Prange MT, Coats B, Duhaime AC, Margulies SS. Anthropomorphic simulations of falls, shakes, and inflicted impacts in infants. J Neurosurg. 2003;99(1 Suppl):143-150.

18. Coats B, Margulies SS. Potential for head injuries in infants from low-height falls: laboratory investigation. J Neurosurg Pediatr. 2008;2(5):321-330.

19. Bandak FA. Shaken baby syndrome: a biomechanics analysis of injury mechanisms. Forensic Sci Int. 2005;151(1):71-79.

20. Mankad K, et al. The neuroimaging mimics of abusive head trauma. *Eur J Paediatr Neurol*. 2019 Jan;23(1):19-30. doi:10.1016/j.ejpn.2018.11.006.

21. Rooks VJ, Eaton JP, Ruess L, Petermann GW, Keck-Wherley J, Pedersen RC. Prevalence and evolution of intracranial hemorrhage in asymptomatic term infants. *AJNR Am J Neuroradiol*. 2008 Jun;29(6):1082-1089. doi:10.3174/ajnr.A1004

22. Watts P, Maguire S, Kwok T, Talabani B, Mann M, Wiener J, et al. Newborn retinal hemorrhages: a systematic review. *J AAPOS*. 2013 Feb;17(1):70-78. doi:10.1016/j.jaapos.2012.07.012.

23. Chadwick DL, Bertocci G, Castillo E, Frasier L, Guenther E, Hansen K, et al. Annual risk of death resulting from short falls among young children: less than 1 in 1 million. *Pediatrics*. 2008 Jun;121(6):1213-1224. doi:10.1542/peds.2007-2281.

24. Anderst JD, Carpenter SL, Abshire TC. Evaluation for bleeding disorders in suspected child abuse. *Pediatrics*. 2022 Oct 1;150(4):e2022059276. doi:10.1542/peds.2022-059276.

25. Shearer MJ. Vitamin K deficiency bleeding (VKDB) in early infancy. *Blood Rev*. 2009 Mar;23(2):49-59. doi:10.1016/j.blre.2008.06.001.

26. Wong AM, et al. Diffusion-weighted MR imaging of subdural empyemas in children. *AJNR Am J Neuroradiol*. 2004 Jun;25(6):1016-1021.

27. Zainel A, et al. Bacterial meningitis in children: neurological complications, associated risk factors, and prevention. *Microorganisms*. 2021 Mar 5;9(3):535.

28. Vester MEM, Bilo RAC, Karst WA, Daams JG, Duijst WLJM, van Rijn RR. Subdural hematomas: glutaric aciduria type 1 or abusive head trauma? A systematic review. *Forensic Sci Med Pathol*. 2015 Sep;11(3):405-415. doi:10.1007/s12024-015-9698-0.

29. Arita JH, et al. Menkes disease as a differential diagnosis of child abuse. *Arq Neuropsiquiatr*. 2009 Oct;67(4):1027-1030.

30. Krasnokutsky MV. Cerebral venous thrombosis: a potential mimic of primary traumatic brain injury in infants. *AJR Am J Roentgenol*. 2011 Sep;197(3):W503-W507.

31. Anderst J, Carpenter S, Frazier T, Appavu B, Noetzel M, Beslow LA, et al. Subdural hemorrhage in a cohort with cerebral sinovenous thrombosis: application to abusive head trauma. *Child Abuse Negl*. 2021 Jul;117:105119. doi:10.1016/j.chiabu.2021.105119

32. Narang SK, Haney S, Duhaime AC, Martin J, Binenbaum G, de Alba Campomanes AG, et al. Abusive Head Trauma in Infants and Children: Technical Report. *Pediatrics*. 2025 Mar 1;155(3):e2024070457. doi:10.1542/peds.2024-070457.

33. Arbabshirani MR, Fornwalt BK, Mongelluzzo GJ, et al. Advanced machine learning in action: identification of intracranial hemorrhage on computed tomography scans of the head with clinical workflow integration. *npj Digit Med*. 2018;1:9. doi:10.1038/s41746-017-0015-z.

34. Gunturkun F, Bakir-Batu B, Siddiqui A, et al. Development of a Deep Learning Model for Retinal Hemorrhage Detection on Head Computed Tomography in Young Children. *JAMA Netw Open*. 2023;6(6):e2319420. doi:10.1001/jamanetworkopen.2023.19420.

35. Jadhav P, et al. Application of a Machine Learning Algorithm in Prediction of Abusive Head Trauma in Children. *J Pediatr Surg*. 2024 Jan;59(1):80-85. doi:10.1016/j.jpedsurg.2023.09.027.