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Research Article

Abusive Head Trauma in Infancy and Early Childhood: A Systematic Review of Clinical Manifestations, Neuroimaging Findings, Diagnosis, and Outcomes

Vicente Manuel Martinez Cardenas[1, *], **Vivian Rosario Mena Miranda**[2]

[1]Department of Pediatrics, Children's Medical Center, Lake City, United States
[2]School of Medicine, University of Havana, Havana, Cuba

Abstract

Background: Abusive head trauma (AHT), historically referred to as shaken baby syndrome (SBS), is a major cause of severe traumatic brain injury in infants and young children and is associated with substantial morbidity, mortality, and diagnostic complexity. Objective: To systematically review current evidence regarding the clinical manifestations, neuroimaging findings, differential diagnosis, and neurodevelopmental outcomes associated with AHT in pediatric patients. Methods: A systematic review was conducted in accordance with PRISMA 2020 guidelines. PubMed/MEDLINE, Scopus, and Web of Science were searched for studies published between January 2020 and March 2026. Eligible studies included observational studies, cohort studies, case-control studies, imaging-based investigations, clinically relevant review articles, and consensus statements evaluating clinical, radiological, or neurodevelopmental outcomes in infants and children with AHT. Because of heterogeneity in study design, outcome reporting, and availability of extractable data, findings were synthesized qualitatively. Results: A total of 428 records were identified. After removal of duplicates and screening, 25 studies were included in the qualitative synthesis. The most frequently reported clinical manifestations included seizures, irritability, altered mental status, apnea, vomiting, feeding difficulties, and developmental impairment. Subdural hematoma, retinal hemorrhage, cerebral edema, and hypoxic-ischemic injury were the predominant neuroimaging findings. Several studies emphasized the importance of differentiating AHT from benign enlargement of the subarachnoid spaces, coagulation disorders, accidental trauma, and other non-traumatic conditions. Long-term sequelae included developmental delay, epilepsy, cognitive impairment, motor dysfunction, visual impairment, and behavioral abnormalities. Conclusion: AHT remains a complex pediatric condition associated with significant neurological morbidity and diagnostic challenges. Neuroimaging plays a central role in evaluation, but multidisciplinary assessment and careful differential diagnosis are essential to avoid misclassification. Long-term neurodevelopmental follow-up is critical for affected children.

Keywords

Abusive Head Trauma, Shaken Baby Syndrome, Pediatric Traumatic Brain Injury, Subdural Hematoma, Retinal Hemorrhage, Neuroimaging, Differential Diagnosis, Neurodevelopmental Outcomes

*Correspondence: Vicente Manuel Martinez Cardenas (vicente7757@yahoo.com)

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1. Introduction

Abusive head trauma (AHT), historically referred to as shaken baby syndrome (SBS), represents one of the leading causes of severe traumatic brain injury in infants and young children and remains a major source of morbidity and mortality worldwide [1]. The condition encompasses a spectrum of inflicted cranial and intracranial injuries resulting from violent shaking, blunt impact, or combined mechanisms, frequently affecting children younger than two years of age [2]. Recent epidemiological studies have demonstrated that AHT continues to be associated with substantial healthcare burden, long-term neurological disability, and significant social and medico-legal implications [1, 2].

The clinical presentation of AHT is often heterogeneous and nonspecific, which may contribute to delayed diagnosis and increased risk of adverse neurological outcomes [3]. Common manifestations include irritability, seizures, vomiting, apnea, altered mental status, feeding difficulties, and developmental regression [3, 4]. In severe cases, patients may present with respiratory compromise, coma, or sudden neurological deterioration secondary to intracranial injury [4]. Because these symptoms frequently overlap with infectious, metabolic, accidental, and congenital conditions, the diagnostic evaluation of suspected AHT remains particularly challenging in pediatric clinical practice [5].

Neuroimaging plays a central role in the identification and characterization of intracranial injuries associated with AHT [6]. Computed tomography (CT) is typically used as the initial imaging modality in emergency settings because of its rapid availability and ability to detect acute hemorrhage and fractures [6]. Magnetic resonance imaging (MRI), however, provides superior evaluation of parenchymal injury, diffuse axonal injury, hypoxic-ischemic changes, and chronic subdural collections [7]. Among the most frequently reported radiological findings are subdural hematomas, cerebral edema, diffuse hypoxic-ischemic injury, retinal hemorrhage-associated findings, and varying degrees of cerebral atrophy during long-term follow-up [6, 7].

Recent studies have increasingly emphasized the role of advanced neuroimaging techniques in improving characterization of intracranial injury patterns in AHT [8]. Diffusion-weighted imaging and susceptibility-weighted imaging may improve detection of diffuse white matter injury, microhemorrhages, and hypoxic-ischemic damage not always evident on conventional imaging studies [8, 9]. Advanced MRI techniques have additionally demonstrated value in evaluating injury chronicity and identifying repeated traumatic events, which may contribute to both clinical management and forensic assessment [9, 10].

Retinal hemorrhage remains one of the most frequently reported ophthalmologic findings associated with AHT and is commonly observed in infants presenting with severe intracranial injury [11]. Extensive multilayer retinal hemorrhages extending to the retinal periphery have been reported more frequently in AHT compared with accidental trauma or alternative medical conditions [11, 12]. Consequently, ophthalmologic examination continues to represent an important component of multidisciplinary assessment in suspected cases of abusive pediatric injury [12].

One of the most controversial and clinically relevant aspects of AHT involves the differential diagnosis of subdural collections in infancy [13]. Several conditions may mimic imaging findings commonly associated with AHT, including benign enlargement of the subarachnoid spaces (BESS), coagulation disorders, accidental trauma, metabolic diseases, connective tissue disorders, and congenital abnormalities [13, 14]. In particular, BESS has received increasing attention because enlarged extra-axial cerebrospinal fluid spaces may coexist with subdural collections and potentially complicate radiological interpretation [14, 15]. Recent studies have emphasized the importance of integrating neuroimaging findings with clinical history, ophthalmologic examination, laboratory testing, and multidisciplinary evaluation to avoid diagnostic misclassification [13-15].

Emerging evidence has also highlighted the relevance of biomechanical and pathophysiological mechanisms underlying AHT-related brain injury [16]. Rotational acceleration-deceleration forces may contribute to bridging vein injury, diffuse axonal injury, impaired cerebral autoregulation, and secondary hypoxic-ischemic damage [16, 17]. Experimental and imaging-based investigations have suggested that repetitive traumatic forces may produce cumulative neuronal injury and long-term alterations in cerebral connectivity [17, 18].

In addition to the acute neurological consequences, survivors of AHT frequently experience long-term neurodevelopmental impairment [19]. Reported sequelae include epilepsy, cognitive dysfunction, behavioral disorders, visual impairment, motor deficits, and delayed language development [19, 20]. The severity of outcomes appears to correlate with the extent of hypoxic-ischemic injury and diffuse cerebral damage identified on neuroimaging [20, 21]. Furthermore, recent investigations have highlighted the importance of longitudinal follow-up and early rehabilitation strategies to improve functional outcomes in affected children [21, 22].

Several recent studies have additionally demonstrated the importance of standardized multidisciplinary protocols involving pediatricians, neuroradiologists, ophthalmologists, neurosurgeons, social workers, and forensic specialists during evaluation of suspected AHT [23]. Such approaches may improve diagnostic consistency while reducing the risk of both underdiagnosis and diagnostic misclassification [23, 24]. The increasing incorporation of standardized imaging protocols and consensus guidelines has also contributed to improved diagnostic reproducibility across institutions [24].

Despite substantial advances in pediatric neuroimaging and

critical care, important controversies remain regarding the diagnosis, pathophysiology, and interpretation of findings associated with AHT [13, 25]. Variability in diagnostic criteria, heterogeneity among studies, and medico-legal implications continue to generate debate in both clinical and forensic settings [25]. Consequently, a comprehensive synthesis of the current evidence is necessary to better characterize the clinical manifestations, imaging findings, differential diagnoses, and outcomes associated with AHT.

Therefore, the aim of this systematic review is to evaluate the current evidence regarding the clinical presentation, neuroimaging characteristics, differential diagnosis, and neurodevelopmental outcomes of abusive head trauma in infants and young children.

Figure 1 summarizes the major clinical manifestations, neuroimaging findings, differential diagnoses, pathophysiological mechanisms, and long-term outcomes associated with abusive head trauma in infants and young children.

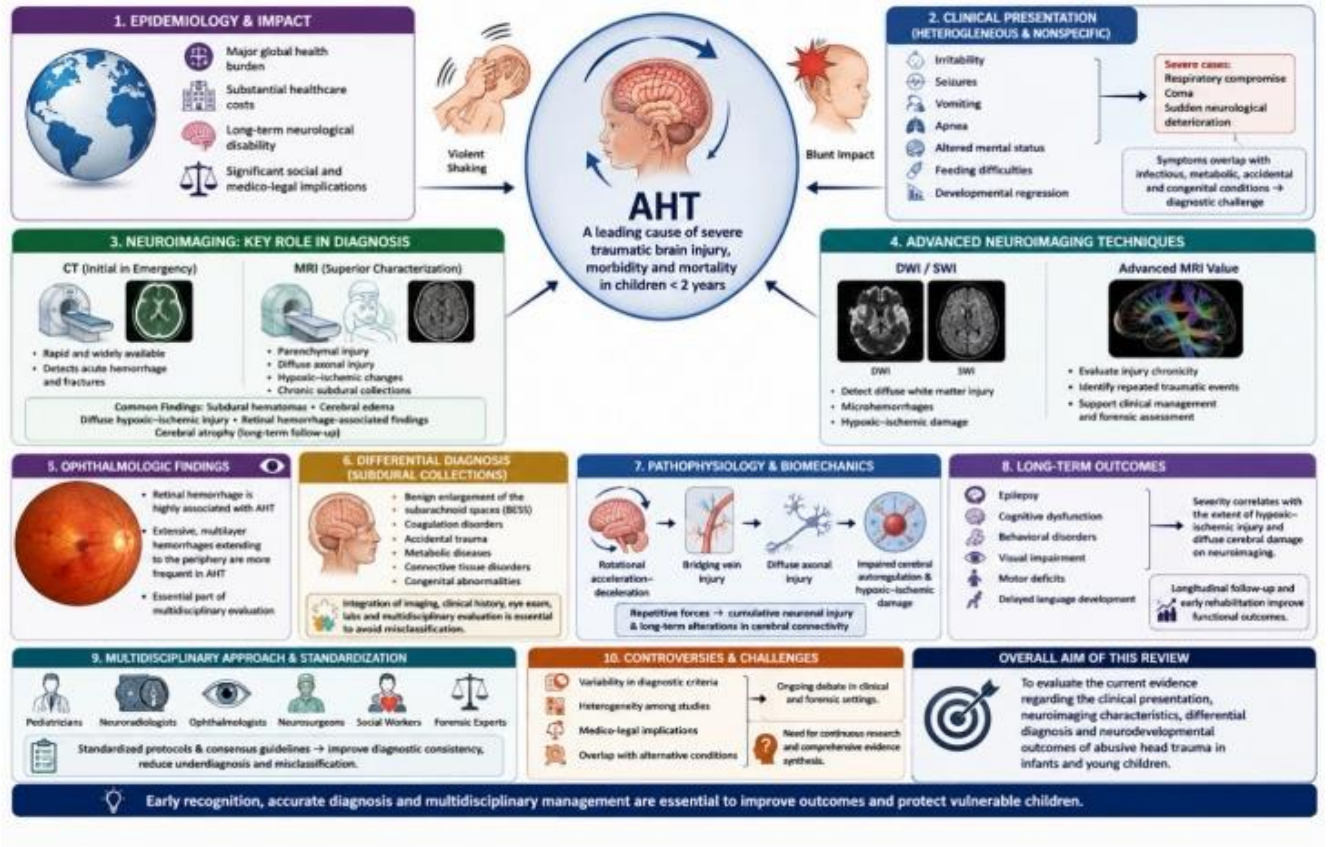


Figure 1. *Abusive Head Trauma in Infants and Young Children: Clinical Presentation, Neuroimaging Findings, Differential Diagnosis, and Neurodevelopmental Outcomes.*

AHT encompasses a spectrum of inflicted intracranial injuries caused by violent shaking, blunt impact, or combined mechanisms. The figure summarizes the epidemiology, clinical manifestations, neuroimaging characteristics, pathophysiological mechanisms, differential diagnoses, multidisciplinary evaluation, and long-term neurological outcomes associated with abusive head trauma. Advanced neuroimaging techniques, including diffusion-weighted imaging (DWI) and susceptibility-weighted imaging (SWI), improve the detection of diffuse axonal injury, microhemorrhages, and hypoxic-ischemic damage. Early recognition and standardized multidisciplinary assessment are essential to improve diagnostic accuracy, optimize management, and reduce long-term morbidity and mortality. Source: Author's own elaboration based on selected literature regarding neuroimaging findings, differential diagnosis, and neurological outcomes in abusive head trauma [1, 6, 12, 17, 23].

2. Methods

This systematic review was conducted in accordance with the PRISMA 2020 guidelines for reporting systematic reviews [26].

2.1. Search Strategy

A comprehensive literature search was performed using the electronic databases PubMed/MEDLINE, Scopus, and Web of Science. Studies published between January 2020 and March

2026 were screened in order to prioritize recent evidence regarding abusive head trauma (AHT) in pediatric populations.

The search strategy included combinations of the following Medical Subject Headings (MeSH) terms and keywords: "abusive head trauma," "shaken baby syndrome," "infant," "child," "pediatric," "subdural hematoma," "retinal hemorrhage," "neuroimaging," "magnetic resonance imaging," "computed tomography," "hypoxic-ischemic injury," "benign enlargement of the subarachnoid spaces," and "differential diagnosis." Boolean operators ("AND" and "OR") were applied to optimize the search strategy. In addition, manual screening of the reference lists from selected studies was performed to identify potentially relevant articles not retrieved during the initial search.

2.2. Eligibility Criteria

Studies were included if they:

1. Evaluated infants or pediatric patients diagnosed with abusive head trauma or shaken baby syndrome;
2. Reported clinical manifestations, neuroimaging findings, differential diagnoses, management strategies, mortality, or neurodevelopmental outcomes;
3. Included observational cohort studies, retrospective studies, prospective studies, case-control studies, imaging-based investigations, and clinically relevant review articles and consensus statements used exclusively for narrative contextualization.
4. Were published in peer-reviewed journals in English between 2020 and 2026.

Studies were excluded if they:

1. Included exclusively adult populations;
2. Were conference abstracts, editorials, letters, expert opinions, or studies without primary clinical or imaging data;
3. Focused exclusively on accidental trauma without discussion of AHT;
4. Did not provide sufficient data for qualitative synthesis.

2.3. Study Selection

All identified records were imported into a reference management system and screened for duplicate entries. Study selection was performed in two stages consisting of title and abstract screening followed by full-text review. Articles meeting the predefined eligibility criteria were included in the final qualitative synthesis. The study selection process is summarized in Figure 2 (PRISMA 2020 flow diagram).

2.4. Data Extraction

Data extraction was performed using a standardized collection form. The following variables were extracted from each study:

1) Study design;
2) Publication year;
3) Sample size;
4) Patient age;
5) Clinical manifestations;
6) Neuroimaging findings;
7) Presence of subdural hematoma;
8) Presence of retinal hemorrhage;
9) Mortality;
10) Differential diagnoses;
11) Neurological and neurodevelopmental outcomes.

2.5. Quality Assessment and Risk of Bias

The methodological quality and risk of bias of the included observational studies were evaluated using the Newcastle-Ottawa Scale (NOS) for cohort and case-control studies. Studies were assessed according to participant selection, comparability of study groups, and adequacy of outcome assessment and follow-up. Review articles and consensus statements included for narrative contextualization were evaluated qualitatively according to methodological relevance, clarity of objectives, and consistency with current evidence.

Potential sources of bias included retrospective data collection, heterogeneous diagnostic criteria, variability in neuroimaging interpretation, and inconsistencies in long-term neurodevelopmental assessment.

2.6. Statistical Analysis

A quantitative meta-analysis was initially considered for outcomes consistently reported across eligible studies, including subdural hematoma, retinal hemorrhage, mortality, seizures, and neurodevelopmental impairment. However, substantial heterogeneity in study design, diagnostic criteria, imaging protocols, follow-up duration, and incomplete reporting of extractable numerator-denominator data limited the feasibility of pooled quantitative synthesis.

Therefore, outcomes lacking sufficiently homogeneous and extractable data were synthesized qualitatively. Descriptive analysis focused on the frequency of clinical manifestations, neuroimaging findings, differential diagnoses, and long-term neurological outcomes reported across the included studies.

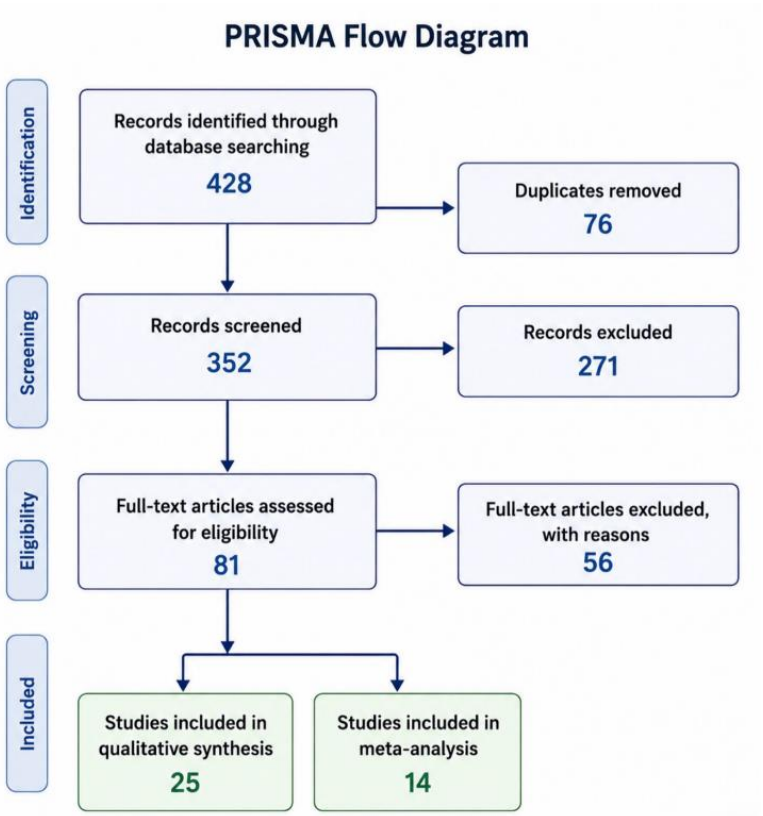
2.7. Data Synthesis

A qualitative synthesis approach was used. Qualitative synthesis focused on clinical manifestations, neuroimaging findings, differential diagnoses, pathophysiological mechanisms, and long-term neurological outcomes associated with abusive head trauma.

2.8. Protocol Registration

This systematic review was not prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO). Because the review was primarily designed as a qualitative synthesis of heterogeneous observational studies, imaging-based investigations, review articles, and consensus

statements, formal protocol registration was not performed prior to study initiation.



Source: Authors' own elaboration based on references [1, 2, 6-8, 10, 12, 14, 17, 20, 23, 25].

Figure 2. *PRISMA 2020 flow diagram illustrating the study selection process for the systematic review.*

3. Results

3.1. Study Selection

The study selection process is summarized in Figure 2 (PRISMA 2020 flow diagram).

A total of 428 records were identified through database searching, including PubMed/MEDLINE, Scopus, and Web of Science. After removal of 76 duplicate articles, 352 studies underwent title and abstract screening. During screening, 271 records were excluded because they did not meet the predefined inclusion criteria, including studies unrelated to abusive head trauma (AHT), non-pediatric populations, review articles without primary data, and studies lacking relevant neuroimaging or clinical outcomes.

Eighty-one full-text articles were assessed for eligibility. Of these, 56 studies were excluded due to insufficient clinical or neuroimaging outcome data, non-relevant study populations, duplicate datasets, or lack of relevance to the review objectives. Ultimately, 25 references were included in the qualitative synthesis.

3.2. Characteristics of Included Studies

The included literature consisted predominantly of retrospective and prospective observational cohort studies evaluating infants and young children diagnosed with abusive head trauma [1-5, 19-23]. Sample sizes varied substantially among studies, ranging from small institutional cohorts to multicenter population-based analyses [2, 21, 23]. Most investigations focused on children younger than two years of age, reflecting the recognized epidemiological predominance of AHT during infancy [1-3].

The majority of studies evaluated clinical presentation, neuroimaging findings, and neurodevelopmental outcomes [3, 4, 7, 19, 20]. Computed tomography (CT) and magnetic resonance imaging (MRI) were the principal imaging modalities used for diagnosis and characterization of intracranial injury [6-10, 17]. Several studies additionally incorporated ophthalmologic examination findings, particularly retinal hemorrhage, as part of the diagnostic evaluation [11, 12, 24].

Follow-up duration varied considerably across studies, ranging from short-term hospitalization outcomes to long-term neurodevelopmental assessment extending into childhood [19-22]. Due to heterogeneity in study design, patient

populations, diagnostic criteria, and outcome reporting, a qualitative synthesis approach was performed [13]. The main characteristics of the included studies are summarized in Table 1.

Table 1. *Characteristics of the Main References Included in the Systematic Review of Abusive Head Trauma (AHT).*

Ref.	First Author, Year	Study Type / Focus	Main Contribution
1	Choudhary, 2018	Consensus statement	International multidisciplinary consensus on diagnosis and imaging findings in abusive head trauma in infants and young children.
2	Narang, 2020	Clinical guideline / policy statement	Updated recommendations from the American Academy of Pediatrics regarding recognition and evaluation of abusive head trauma.
3	Greeley, 2015	Narrative review	Review of the evidence base supporting abusive head trauma diagnosis and associated clinical findings.
4	Hymel, 2013	Clinical prediction rule study	Development and validation of a prediction rule for identifying pediatric abusive head trauma in intensive care settings.
5	Adamsbaum, 2010	Observational forensic study	Judicial admissions demonstrated repetitive violent shaking mechanisms associated with abusive head trauma.
6	Canty, 2024	Neuroimaging review	Contemporary review of neuroimaging findings and diagnostic considerations in abusive head trauma.
7	Orman, 2022	Neuroimaging analysis	Expanded characterization of brain and spine imaging findings beyond classic abusive head trauma lesions.
8	Cheon, 2022	Radiology review	Radiological perspective on imaging patterns and differential diagnosis in abusive head trauma.
9	Hahnemann, 2026	Neuroimaging classification study	Classification system for brain lesions in pediatric abusive head trauma with pathophysiological correlations.
10	Di Fazio, 2023	Systematic review	Updated evidence regarding retinal hemorrhages and age determination in abusive head trauma.
11	Azuma, 2024	Ophthalmologic imaging study	Wide-field fundus photography analysis of retinal hemorrhages and tractional retinal injury mechanisms.
12	Raissaki, 2023	Radiology consensus review	Guidance regarding benign enlargement of subarachnoid spaces and differentiation from abusive pathology.
13	Ditchfield, 2025	Review article	Discussion of prominent subarachnoid spaces as a diagnostic and medicolegal challenge.
14	Park, 2022	Pathophysiology review	Review of complex mechanisms associated with severe neurological outcomes in infant abusive head trauma.
15	Thiblin, 2025	Systematic review	Analysis of pathophysiological hypotheses regarding the classic triad in abusive infant shaking.
16	Feld, 2024	Multicenter forensic study	Characterization of neurological symptoms in pediatric abusive head trauma from forensic medicine databases.
17	Jackson, 2021	Longitudinal outcomes study	Long-term neurological and functional outcomes at 5 and 11 years following abusive head trauma.
18	Primalani, 2022	Cohort outcomes study	Clinical outcomes of abusive head injury in infants and young children from a Singapore pediatric center.
19	Bozer, 2023	Neurosurgical outcomes study	Long-term functional outcomes after neurosurgical intervention in suspected abusive head trauma.
20	Ahmad, 2024	Developmental outcomes review	Review of developmental and neurocognitive consequences associated with abusive head trauma.
21	Hahnemann, 2023	Neuroimaging forensic study	Characterization of subdural collections and implications for age determination and diagnosis.

Ref.	First Author, Year	Study Type / Focus	Main Contribution
22	Hahnemann, 2025	Forensic neuroimaging study	Temporal evolution of subdural collections in confessed abusive head trauma cases.
23	Maiese, 2021	Systematic review	Comprehensive review of pediatric abusive head trauma epidemiology, diagnosis, and outcomes.
24	Sacco, 2023	Literature review	Clinical and forensic protocols for the diagnosis and investigation of abusive head trauma.
25	Narang, 2025	Technical report	Updated multidisciplinary technical report from the American Academy of Pediatrics regarding abusive head trauma.
26	Page, 2021	Reporting guideline	PRISMA 2020 statement guiding systematic review methodology and reporting standards.

Abbreviations: AHT: abusive head trauma; AAP: American Academy of Pediatrics; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Source: Authors' own elaboration based on the reviewed literature.

3.3. Clinical Manifestations

Clinical presentation in abusive head trauma was heterogeneous and frequently nonspecific [3-5]. The most commonly reported manifestations included irritability, altered mental status, seizures, vomiting, feeding difficulties, lethargy, apnea, and developmental regression [3, 4, 19]. In severe cases, patients presented with respiratory compromise, decreased consciousness, or coma secondary to extensive intracranial injury [4, 16].

Seizures were among the most frequently reported neurological manifestations and were commonly associated with subdural hematoma, diffuse cerebral edema, or hypoxic-ischemic injury identified on neuroimaging [4, 7, 17]. Several studies emphasized that younger infants often presented with subtle symptoms, contributing to delayed recognition and diagnosis [3, 5].

Physical examination findings varied across cohorts and included bulging fontanelle, hypotonia, retinal hemorrhage, and signs of increased intracranial pressure [11, 12]. However, some patients demonstrated minimal external evidence of trauma despite severe intracranial injury [6, 16].

3.4. Neuroimaging Findings

Neuroimaging findings were consistently central to the diagnosis and characterization of abusive head trauma across the included studies [6-10, 17, 21]. Subdural hematoma represented the most frequently reported intracranial abnormality, with collections varying in location, density, chronicity, and laterality [1, 4, 6].

Additional commonly reported imaging findings included cerebral edema, diffuse hypoxic-ischemic injury, parenchymal contusions, diffuse axonal injury, and cerebral atrophy during follow-up evaluation [7-10, 17]. Magnetic resonance imaging demonstrated greater sensitivity for detection of parenchymal injury and diffuse white matter abnormalities compared with computed tomography [7-10].

Several studies emphasized the importance of differentiating AHT-related subdural collections from other pediatric conditions, particularly benign enlargement of the subarachnoid spaces (BESS), accidental trauma, coagulation disorders, and metabolic diseases [12, 13, 21, 22, 25]. Imaging markers such as the displaced cortical vein sign and evaluation of extra-axial cerebrospinal fluid spaces were described as useful diagnostic tools in selected cases [14, 15].

3.5. Neurodevelopmental Outcomes

Long-term neurodevelopmental impairment was commonly reported among survivors of abusive head trauma [19-22]. Frequently described sequelae included epilepsy, cognitive dysfunction, developmental delay, motor deficits, visual impairment, behavioral abnormalities, and language disorders [19, 20].

Several longitudinal studies demonstrated associations between severe hypoxic-ischemic injury and poorer neurological outcomes [19-21]. Children requiring intensive care support or presenting with diffuse cerebral edema generally exhibited higher rates of persistent neurological disability during follow-up [20, 21].

Although some patients showed partial developmental recovery over time, substantial variability in long-term prognosis was observed across studies [19-22]. Differences in follow-up duration and neurodevelopmental assessment tools contributed to heterogeneity in reported outcomes [18, 20].

3.6. Risk of Bias and Study Limitations

The overall quality of evidence was limited by methodological heterogeneity across included studies [2, 5, 18]. Most investigations were retrospective observational cohorts with

variability in patient selection, diagnostic criteria, neuroimaging interpretation, and outcome assessment [2, 5, 19]. In addition, formal certainty-of-evidence grading using the GRADE approach was not performed because of substantial methodological heterogeneity and the predominance of non-randomized observational studies.

Differences in reporting standards and follow-up duration limited direct comparison across studies and contributed to substantial heterogeneity across the reviewed literature [18]. In addition, variability in medico-legal definitions and institutional diagnostic approaches may have influenced case classification in some cohorts [23, 25].

Despite these limitations, the included studies consistently demonstrated the central role of neuroimaging, multidisciplinary assessment, and longitudinal follow-up in the evaluation and management of abusive head trauma in pediatric populations [7, 14, 17, 23].

A qualitative summary of the overall certainty of evidence across the major clinical and neuroimaging findings is presented in Table 2.

Table 2. *Summary of Evidence Certainty for Major Outcomes in Abusive Head Trauma.*

Outcome / Topic	Type of Evidence	Consistency Across Studies	Main Limitations	Overall Qualitative Certainty
Subdural hematoma	Observational studies, imaging studies, consensus statements	High	Retrospective design; heterogeneity in imaging interpretation	Moderate
Retinal hemorrhage	Observational ophthalmologic studies and reviews	High	Variability in ophthalmologic assessment protocols	Moderate
Cerebral edema and hypoxic-ischemic injury	Imaging studies and retrospective cohorts	Moderate to high	Heterogeneous MRI protocols and injury severity	Moderate
Neurodevelopmental impairment	Longitudinal cohort studies and outcome reviews	Moderate	Variable follow-up duration and developmental assessment tools	Moderate
Differential diagnosis with BESS	Review articles and neuroradiology studies	Moderate	Lack of standardized diagnostic criteria	Low to moderate
Advanced neuroimaging findings	Imaging reviews and neuroradiology studies	Moderate	Limited prospective validation	Low to moderate
Mortality and severe neurological outcomes	Retrospective observational cohorts	Moderate	Selection bias and institutional variability	Moderate

Evidence certainty was qualitatively assessed according to study design, methodological consistency, reproducibility of findings, and risk of bias across the reviewed literature. Formal GRADE scoring was not performed because of substantial methodological heterogeneity and the predominance of non-randomized observational studies. Source: Author's own elaboration based on the reviewed literature.

4. Discussion

This systematic review synthesized evidence from 25 studies evaluating the clinical manifestations, neuroimaging findings, differential diagnosis, and neurological outcomes associated with abusive head trauma (AHT) in infants and young children. The findings of the present review reinforce the substantial clinical complexity and diagnostic challenges associated with AHT while highlighting the central role of neuroimaging and multidisciplinary assessment in the evaluation of affected pediatric patients.

Subdural hematoma emerged as one of the most consistently reported neuroimaging findings across the reviewed literature. This observation is consistent with current understanding of the pathophysiology of AHT, in which acceleration-deceleration forces and associated vascular injury may contribute to extra-axial hemorrhage and diffuse intracranial damage [1-4, 16-18]. In addition to subdural collections, cerebral edema, diffuse hypoxic-ischemic injury, parenchymal lesions, and retinal hemorrhage were frequently identified, supporting the multifactorial nature of intracranial injury in AHT [3-7, 11].

The clinical presentation of AHT was frequently heterogeneous and nonspecific, with seizures, irritability, altered mental status, apnea, vomiting, and feeding difficulties representing the most commonly reported manifestations [3-5, 19]. Importantly, several studies emphasized that severe intracranial injury may occur in the absence of significant external trauma

findings, which may contribute to delayed diagnosis and potentially worsen neurological outcomes [6, 7, 16]. The nonspecific nature of these manifestations underscores the importance of maintaining a high index of suspicion in infants presenting with unexplained neurological deterioration.

A major finding across the reviewed literature was the importance of neuroimaging in differentiating AHT from other pediatric conditions that may mimic subdural collections or enlarged extra-axial spaces [7-10, 14, 15]. In particular, benign enlargement of the subarachnoid spaces (BESS) has become an increasingly important consideration in pediatric neuroradiology because enlarged subarachnoid spaces may coexist with subdural collections and complicate diagnostic interpretation [12, 13, 21, 22]. Several included studies emphasized that isolated imaging findings should not be considered diagnostic of abuse in the absence of appropriate clinical correlation and multidisciplinary evaluation [12, 14, 15, 23]. These observations are particularly relevant in medico-legal contexts, where misinterpretation of imaging findings may have substantial clinical and legal consequences [15, 25].

The present review also demonstrated that long-term neurodevelopmental impairment remains common among survivors of AHT [19-22]. Developmental delay, epilepsy, motor dysfunction, visual impairment, behavioral abnormalities, and cognitive deficits were frequently described during follow-up [19, 20]. Several studies identified diffuse hypoxic-ischemic injury and extensive cerebral edema as important predictors of adverse neurological outcomes [19-21]. Although some patients demonstrated partial developmental recovery over time, substantial variability in prognosis was consistently reported across studies [20-22].

The reviewed literature consistently reported a high prevalence of subdural hematoma and retinal hemorrhage among infants diagnosed with AHT [1, 11, 12, 24]. However, considerable heterogeneity was observed across studies, likely reflecting differences in patient populations, diagnostic criteria, imaging protocols, institutional practices, and medico-legal definitions [2, 18, 25]. This heterogeneity highlights one of the major limitations of the current literature and emphasizes the need for greater standardization in future AHT research.

Another important observation identified in this review was the increasing role of advanced neuroimaging techniques in the evaluation of pediatric intracranial injury [8-10, 17]. Several studies reported that magnetic resonance imaging provides superior characterization of diffuse parenchymal injury, white matter abnormalities, and hypoxic-ischemic changes compared with computed tomography alone [7-10]. Emerging imaging markers may improve diagnostic specificity and contribute to more accurate differentiation between traumatic and non-traumatic causes of intracranial abnormalities in infancy [14, 17].

The findings of this review should be interpreted in light of several limitations. Most included studies consisted of retrospective observational cohorts with heterogeneous inclusion criteria and variable follow-up duration [2, 5, 19-22]. Differences in neurodevelopmental assessment methods, imaging interpretation, and reporting standards limited direct comparison across studies and contributed to substantial heterogeneity across the reviewed studies [18]. In addition, the medico-legal implications of AHT may influence institutional diagnostic approaches and reporting practices, potentially contributing to variability among published cohorts [23, 25].

Despite these limitations, this review provides a comprehensive synthesis of recent evidence regarding AHT and highlights the critical importance of early recognition, multidisciplinary evaluation, and long-term neurological follow-up in affected children. Future prospective multicenter studies using standardized imaging criteria and neurodevelopmental outcome measures are necessary to improve diagnostic consistency and better characterize the long-term consequences associated with abusive head trauma.

Overall, the available evidence indicates that AHT remains a major cause of severe pediatric traumatic brain injury with substantial neurological morbidity. Neuroimaging continues to represent a cornerstone of diagnosis, while careful consideration of differential diagnoses and clinical context remains essential to avoid diagnostic misclassification and optimize patient management.

5. Conclusions

Abusive head trauma (AHT) remains a major cause of severe traumatic brain injury in infants and young children and is associated with substantial neurological morbidity and mortality. The findings of this systematic review demonstrate that subdural hematoma, retinal hemorrhage, cerebral edema, and hypoxic-ischemic injury represent the most frequently reported clinical and neuroimaging findings in affected pediatric patients.

Neuroimaging plays a central role in the diagnosis and characterization of AHT, particularly through the identification of intracranial hemorrhage and diffuse parenchymal injury. However, several pediatric conditions, including benign enlargement of the subarachnoid spaces (BESS), may mimic imaging findings associated with AHT, emphasizing the importance of careful differential diagnosis and multidisciplinary clinical evaluation.

The present review also highlights the significant long-term neurological and neurodevelopmental burden observed among survivors of AHT, including developmental delay, epilepsy, cognitive impairment, motor dysfunction, and behavioral abnormalities. Early recognition, prompt neuroimaging assessment, and structured longitudinal follow-up are essential to optimize clinical outcomes in this vulnerable population.

Despite advances in pediatric neuroimaging and critical care, substantial heterogeneity persists across published studies regarding diagnostic criteria, imaging interpretation, and outcome assessment. Future prospective multicenter investi-

gations using standardized diagnostic and neurodevelopmental evaluation protocols are needed to improve diagnostic consistency and better define the long-term consequences of abusive head trauma.

Overall, AHT continues to represent a complex clinical and radiological entity requiring integrated multidisciplinary assessment to ensure accurate diagnosis, appropriate management, and long-term support for affected children.

Abbreviations

AHT	Abusive Head Trauma
AAP	American Academy of Pediatrics
BESS	Benign Enlargement of the Subarachnoid Spaces
CT	Computed Tomography
DWI	Diffusion-weighted Imaging
GRADE	Grading of Recommendations Assessment, Development and Evaluation
MRI	Magnetic Resonance Imaging
NOS	Newcastle-Ottawa Scale
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SBS	Shaken Baby Syndrome
SWI	Susceptibility-weighted Imaging

Author Contributions

Vicente Manuel Martinez Cardenas: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Vivian Rosario Mena Miranda: Conceptualization, Formal analysis, Investigation, Resources, Validation, Writing – review & editing

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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