



Abusive head injury in the very young: outcomes from a Singapore children's hospital

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Abstract

Purpose Abusive head trauma (AHT) is a serious problem in children. The aims of this study are to identify risk factors that correlate with outcomes for those requiring neurosurgical intervention for very young children with AHT, assessment of variables associated with outcomes, and corroboration of our results with literature.

Methods This is an ethics-approved, retrospective study. Inclusion criteria consisted of patients aged 2 years old or less with a diagnosis of AHT managed by the Neurosurgical Service, KK Women's and Children's Hospital. Demographical and clinical variables are incorporated in the statistical analyses. Logistic regression was applied to statistically significant variables for the risk prediction model.

Results From 2000 to 2020, 24 patients required surgery for AHT. Timepoint was set at 12 months post-diagnosis. Univariate analyses demonstrated that patients with mild TBI were likely to have a favourable GOS-E Peds ($p = 0.01$), whereas radiological presence of cerebral oedema ($p < .001$), development of scar epilepsy ($p = 0.021$), and progression to cerebral palsy ($p = 0.001$) were associated with unfavourable GOS-E Peds.

Conclusion This is the first study focused on neurosurgical outcomes for very young children with AHT in Singapore. We advocate multidisciplinary efforts to improve outcomes for this devastating condition.

Keywords Abusive head injury · Non-accidental head injury · Paediatric head injury

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Introduction

Abusive head trauma (AHT) is a very serious problem in young children globally [1]. Despite certain preconceptions, affected patients can be found in all sections of society, encompassing all socioeconomic strata [2]. Epidemiological studies show that AHT tend to affect children below 2 years old. In contrast, children with accidental injury tend to be much older [3]. Brain injuries in affected patients have been demonstrated to permanently hinder neurological, behavioural, and cognitive development [4]. Neurosurgical interventions are more frequently required in AHT compared to accidental head injuries in the paediatric population, with significantly worse outcomes [1, 5, 6]. Although there have been reports on AHT from various countries in Southeast Asia, there has been no previous study focused on the outcomes of clinical and neurosurgical interventions childhood AHT in our local context [7–11]. As part of Singapore's largest children's hospital, the Neurosurgical Service at KK Women's and Children's Hospital is no stranger to the

difficulties of managing children with AHT. The primary aim of this study was to identify risk factors that correlate with patient outcomes for those requiring neurosurgical intervention for their AHT. Secondary aims include, firstly, to assess if selected variables can be used to predict for outcomes in our local cohort and, next, corroborate our results with published literature.

Methods

Study design

This is an ethics-approved, retrospective study conducted in Singapore's largest children hospital, KK Women's and Children's Hospital (SingHealth CIRB Reference: 2020/2632). Patients less than 2 years old with a diagnosis of AHT that require intervention by the Neurosurgical Service, KKH, are included. Patients above the age of 2 years do not require neurosurgical intervention and with incomplete medical information are excluded. In addition, head injury patients with known bleeding disorders and/or on long-term anti-coagulation medication are also excluded.

Overview of management approach to patients

All patients with suspected non-accidental trauma are routinely referred to the Paediatric Medical Team for evaluation. Presently, a workflow is implemented to allow detection of victims of AHT from the Children's Emergency and Outpatient Clinics. Briefly, this assessment includes detailed haematological and metabolic blood investigations, a thorough skeletal X-ray survey, and eye examination by the ophthalmologist. To make the diagnosis of RH more stringent in its association with AHT, we define RH to be haemorrhages that are found in within multiple deep retinal layers, associated with retinal detachment and blood products of varying ages [5, 12, 13]. Concurrently, hospital medical social workers are also engaged to identify any familial or social red flags experienced by the patient. Red flags include clinical findings consistent with healed or ongoing non-accidental injury, unreliable history from caregivers, and previous incidents of child abuse within the same family. These will trigger a referral to the Child Protection Officer and the Ministry of Family and Social Development who will step timely to take over the remainder of the investigations. During the patient's admission, dedicated multi-disciplinary meetings are held to provide perspectives from each specialty, in order to come to a consensus on the best care plan for individual patients. Discharge from hospital is only allowed if the home environment is deemed safe for the patient. Alternatively, foster families may be engaged if the former is not available.

Patient demographics and variables of interest

All traumatic brain injury (TBI) patients are screened from the hospital databases using the International Classification of Diseases diagnosis codes. Individual patient information is either obtained from electronic data or hard copy notes. Imaging details for each patient are obtained from the radiology archives and assessed for completeness. Based on the Glasgow Coma Scale, we divided the patients into 'Mild TBI' (GCS 13 to 15), 'Moderate TBI' (GCS 9 to 12), and 'Severe TBI' (GCS 3 to 8) [14]. Next, we used the Glasgow Outcome Score-Extended Paediatric Version (GOS-E Peds) for interval assessment of functional outcome. This is a qualitative outcome score that has been specifically validated for children and has been demonstrated to be sensitive to severity of TBI and its sequelae over time [15]. Specifically for this study, scores of GOS-E Peds 1 to 4 are grouped under 'Favourable' and scores of 5 to 8 are deemed as 'Unfavourable'. Decision for the cut-off at GOS-E Peds of 5 and above was based on the functional status that these patients still require supervision and have dependency on their caregivers. Following that, we defined the outcome of 'Development of Scar Epilepsy' as recurrent seizures following AHT whereby there is persistent convulsive episodes or fits related to irreversible cerebral damage, requiring regular anti-epileptic medication. Finally, we defined 'Progression to Cerebral Palsy' as acquired brain injury to the growing cerebral cortex secondary to AHT, resulting in impaired motor ability to move, and maintain balance and posture. A summary flowchart is depicted in Fig. 1.

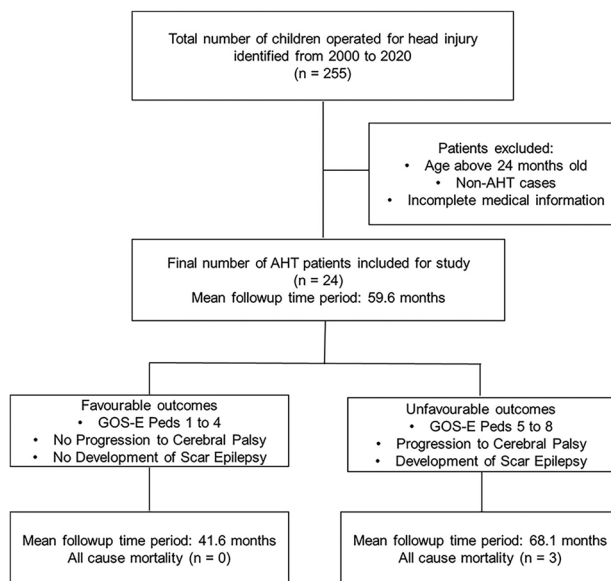


Fig. 1 Schematic overview of study workflow

Data analysis

Statistical analyses were generated using SPSS version 27 (Statistical Package for the Social Sciences Statistics, Version 27.0; IBM, New York). The Pearson chi-square test or Fisher's exact test is used to compare categorical variables, as appropriate. The Wilcoxon-signed ranked test is used to compare continuous variables. A one-way ANOVA is used where there are 3 or more groups of data within a single variable. Odds ratios (ORs) and 95% confidence intervals (CIs) for patient variables are used to compare against the following: the primary outcome of interest, GOS-E Peds (Favourable versus Unfavourable); and secondary outcomes of interest, 'Progression to cerebral palsy' and 'Development of scar epilepsy', via univariate logistic regression analyses. The timepoint of 12 months is used for the 3 selected outcomes. A *p*-value of < 0.05 is considered statistically significant for this study.

Literature review

To identify articles pertinent to paediatric AHT, a systematic search of publications in the English language using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines is performed in PubMed, Google Scholar, and Web of Science [16]. As the nomenclature used in medical literature for NAHI varies broadly, the following keywords used in the search included 'non-accidental head injury', 'battered child syndrome', 'shaken baby syndrome', 'abusive head trauma', and 'inflicted head trauma'. Results are individually examined and counter-checked amongst one another for duplicates. For this study, we are particularly interested in articles reporting on the outcomes of AHT patients in children aged 2 years old and below. Articles focused on adult populations, traumatic head injury secondary to accidental causes, non-accidental injury not involving the head; and publications without full-text access, and/or without English translation of their content, are excluded. Reference lists from selected articles are also checked to obtain as complete information as possible.

Results

Overview of patient demographics and clinical findings in study population

From 01 January 2000 to 31 December 2020, a total of 255 paediatric patients required emergency surgery for head injury. In this cohort, there were 24 confirmed cases of AHT (9.4%) aged 24 months and below (mean age in

months 8.75 ± 7.46). There were 19 males (79.2%) and 5 females (20.8%), who comprised of 11 Chinese, 11 Malay, 1 Indian, and 1 other ethnicity. Three patients had siblings with a previous history of non-accidental injury (12.5%). In most of the cases, the perpetrator of the AHT was identified as the patient's biological parent ($n = 11$; 45.8%), the remaining being the babysitter ($n = 7$; 29.2%) and unknown/inconclusive ($n = 6$; 25.0%). Upon admission, 7 patients had mild TBI (29.2%), 8 had moderate TBI (33.3%), and 9 had severe TBI (37.5%). Nineteen patients had witnessed seizures requiring anti-epileptic medication (79.2%). Concurrently, 3 patients had clinical evidence of co-existing visceral and/or long bone injuries (12.5%). Here, we included injuries that were either diagnosed at the time of admission or healed injuries that were discovered as part of the overall investigation. Retinal haemorrhages (RH) were found in 18 patients (75%) during formal ophthalmological examination. The average length of hospital stay per patient was 43 days (mean 46.91 days; range 0 to 187 days). Clinical, social, radiological and functional variables of interest examined in this study are summarized in Table 1.

Radiological features and neurosurgical procedures

Neuroimaging findings of importance included SDH ($n = 22$; 91.7%), ICH ($n = 1$; 4.2%), skull fracture ($n = 7$; 29.2%), and cerebral oedema ($n = 13$; 54.2%). There was no case of extradural hematoma in our cohort. Fifteen patients had radiological evidence of intracranial injury to both hemispheres (62%). Sixteen of the patients required 1 neurosurgical intervention only (45.8%), while the rest required more than 1 intracranial-type surgery as a direct consequence of their AHT ($n = 8$; 33.3%). There were no post-operative complications from their neurosurgical interventions. Surgeries not involving the brain, such as limb fracture fixation, percutaneous endoscopic gastrostomy, and management of lacerations/burns, were not included in our analysis. Types of neurosurgical interventions included insertion of intracranial monitor probe ($n = 2$; 8.3%), external ventricular drain ($n = 3$; 12.5%), subdural drain ($n = 4$; 16.7%), burr hole drainage ($n = 8$; 33.3%), and decompressive craniectomy ($n = 7$; 29.2%). Three patients (12.5%) passed away in the Children's Intensive Care Unit (CICU) during their post-operative period after their first neurosurgical procedure (mean number of days 6 ± 4.24). Upon their demise, these patients were referred to the coroner who confirmed death to be due to the severity of head injury. In our cohort, 7 patients underwent more than 1 neurosurgical procedure related to sequelae from their AHT (29.2%). Two patients needed a total of 3 surgeries each, where the remaining 5 had 2 surgeries each. One patient presented with diffuse cerebral oedema

Table 1 Patient demographics and variables. (Note: *values are *n* (%), otherwise stated)

Parameter	Value (%)
Age (months)	8.8 ± 7.5 (mean ± SD)
0 to 12 months	20 (83.3)
13 to 24 months	4 (16.7)
Gender	
Male	19 (79.2)
Female	5 (20.8)
Ethnicity	
Chinese	11 (45.8)
Malay	11 (45.8)
Indian	1 (4.2)
Others	1 (4.2)
Siblings with history of non-accidental injury	3 (12.5)
Perpetrator	
Biological parent	11 (45.8)
Nanny	7 (29.2)
Unknown	6 (25.0)
Follow-up duration (months)	1337.5; 59.6 ± 56.0 (total; mean ± SD)
Length of stay in hospital (days)	43.7 ± 43.3 (mean ± SD)
Up to 30 days	14 (58.3)
More than 30 days	10 (41.7)
Severity of TBI	
Mild (GCS 13 to 15)	7 (29.2)
Moderate (GCS 9 to 12)	8 (33.3)
Severe (GCS 3 to 8)	9 (37.5)
Seizures at initial presentation	19 (79.2)
Neuroimaging features	
Cerebral oedema	13 (54.2)
Bilateral hemispheres involved	15 (62.5)
SDH	22 (91.7)
ICH	1 (4.2)
Skull fracture	7 (29.2)
Presence of other associated non-accidental injuries	
Retinal haemorrhage	18 (75.0)
Visceral and/or skeletal injury	3 (12.5)
Number of neurosurgical procedures	
1 surgery only	16 (66.7)
More than 1 surgery needed in relation to AHT	8 (33.3)
Primary outcome of interest (at 12 months)	
GOS-E Peds 1 to 4 (Favourable)	13 (52.4)
GOS-E Peds 5 to 8 (Unfavourable)	11 (45.8)
Secondary outcomes (at 12 months)	
Progression to cerebral palsy	7 (29.2)
Development of scar epilepsy	13 (54.2)

and was managed medically with an intracranial monitor probe insertion. However, he developed scar epilepsy that became progressively refractory to multiple anti-epileptic medications. A corpus callosotomy was finally performed when the patient was 16 years old for seizure control and to

improve quality of life. Five patients developed interval brain parenchyma atrophy and associated subdural collections after their AHT. Here, 4 patients underwent subdural peritoneal shunts to relieve the ongoing mass effect from the subdural collections. Autologous bone cranioplasty procedure

Table 2 Detailed list of patients who underwent more than 1 surgery

Patient number	First surgery performed	Second surgery (time after first surgery)	Third surgery (time after second surgery)
1	Intracranial monitor probe insertion	Corpus callosotomy (16 years)	-
11	Left subdural drain insertion	Left subdural peritoneal shunt (6 months)	-
13	Left subdural drain insertion	Left subdural peritoneal shunt (9 months)	-
15	Left decompressive craniectomy	Left autologous bone cranioplasty (3 months)	Left synthetic implant cranioplasty (24 months)
16	Right decompressive craniectomy	Right autologous bone cranioplasty (1 month)	-
20	Bilateral burr hole drainage of SDH	Left subdural peritoneal shunt (3 months)	-
21	Right craniotomy and evacuation of subdural haematoma	Bilateral burr hole drainage of subdural collection (2 months)	R subdural peritoneal shunt (1 month)

was done for 2 patients who had previous decompressive craniectomies for their initial AHT injuries. Nonetheless, 1 of them presented with bone resorption of their autologous bone graft, associated with a growing skull defect. Decision was made for a pre-formed synthetic implant to replace the previous cranioplasty (Table 2).

Patient outcomes of interest

The following outcomes of interest were set at a timepoint of 12 months: 'GOS-E Peds', 'Progression to cerebral palsy', and 'Development of scar epilepsy'. Univariate analyses demonstrated that patients with mild TBI were more likely to have a favourable GOS-E Peds ($p = 0.01$), whereas radiological presence of cerebral oedema ($p < 0.001$), Development of scar epilepsy ($p = 0.021$), and Progression to cerebral palsy ($p = 0.001$) were associated with an unfavourable GOS-E Peds (Table 3). Further subgroup analyses showed that cerebral oedema was also statistically significant for the outcomes of Development to scar epilepsy ($p < 0.001$) and Progression to cerebral palsy ($p = 0.006$), respectively (Tables 4 and 5). As there were 0 counts for some of the variables, multivariate analysis was not performed.

Literature review findings

A total of 56 publications from January 1992 to February 2020 pertinent to our study were identified. Specific to this study, there were 25 studies that featured reviews, epidemiology, treatment modalities, and/or long-term disease outcomes for paediatric AHT. Decision was made to exclude publications that included accidental head injury and/or focused on injury to other body parts as part of their study population. In addition, we included selected papers on pathophysiology of childhood head injury to facilitate meaningful discussion. Otherwise, all relevant publications are referenced in this study accordingly (Fig. 2).

Discussion

Abusive head injury is a common cause of childhood death in non-accidental trauma [17]. For affected patients, AHT often results in debilitating long-term neurological deficits and sometimes death [18]. Associated risk factors include young age of parents, complex family situations, low socioeconomic status, minority racial backgrounds, and disability or prematurity of the child [19–21]. Although some authors have reported a male predominance in victims of child abuse [22] and a simultaneous prevalence of abuse amongst minority populations [23], there are studies which demonstrate otherwise [1]. Separately, there are heavy treatment costs and numerous other indirect financial burdens that result from AHT. These include adverse long-term neurological and psychological sequelae. Sadly, these effects are likely to incur large expenses beyond childhood, especially due to the need for chronic medications and neurorehabilitation therapy [24]. Despite increased global awareness of non-accidental injury faced by children, the literature reports that only a limited number of hospitals routinely use standardised protocols when evaluating abuse [25].

In Singapore, the lead agency against child abuse is the Child Protection Service of the Ministry of Social and Family Development [2]. In 2020, there are a total of 1313 such cases, whereby 677 are alleged physical abuse investigations [26]. Furthermore, there is an average 14.3% rise per annum of such cases in the past 5 years [26]. Although prohibited in several Western countries, domestic corporal punishment (that is, physical punishment where pain is inflicted for discipline) is still lawful in Singapore [2]. Here, most children are still brought up according to the traditional Asian cultures in our country, especially with regard to physical punishment, emotional expression, and care of children. Although a detailed discussion of childrearing in our local context is beyond the scope of this paper, it should be emphasised that our society condemns violence to children, and excessive physical punishment is very much frowned upon. Nonetheless, we are aware that the question is what level of

Table 3 Univariate analysis of patient demographics and variables for the primary outcome of interest GOS-E Peds. Bold values indicate statistical significance (i.e., *p*-value <0.05)

Variable	Overall (%)	Favourable GOS-E Peds (1 to 4)	Unfavourable GOS-E Peds (5 to 8)	Unadjusted OR (95% CI)	<i>p</i> -value
Total number of patients	24 (100)	13 (54.2)	11 (45.8)		
Demographics					
Age in months; mean ± SD	8.75 ± 5.5	7.85 ± 7.32	9.81 ± 7.83		0.531
Male	19 (79.2)	11 (57.9)	8 (42.1)		0.475
Chinese	11 (45.8)	7 (63.6)	4 (36.4)		0.430
Perpetrator (parent)	11 (45.8)	5 (45.5)	6 (54.5)		0.252
Siblings with history of AHT	3 (12.5)	1 (33.3)	2 (66.7)	2.7 (0.21–34.2)	0.576
Length of hospital stay in days; mean ± SD	43 ± 46.91	52.3 ± 56.04	34.6 ± 36.49		0.414
Follow-up duration in months; mean ± SD	59.6 ± 56.0	41.6 ± 43.1	68.1 ± 72.2		0.299
Number of surgeries; mean ± SD	1.38 ± 0.65	1.39 ± 0.65	1.36 ± 0.65		0.939
Clinical presentation at admission					
Mild TBI (GCS 13 to 15)	7 (29.2)	7 (100.0)	0 (0.0)	1.0	0.01
Moderate TBI (GCS 9 to 12)	8 (33.3)	3 (37.5)	5 (62.5)	2.8 (1.5–5.4) [^]	-
Severe (GCS 3 to 8)	9 (37.5)	3 (33.3)	6 (66.7)		-
Seizures at initial presentation	19 (79.2)	10 (52.6)	9 (47.4)	1.4 (0.19–10.0)	1.00
Neuroimaging findings					
Cerebral oedema	13 (54.2)	2 (15.4)	11 (84.6)	6.5 (1.8–23.2) [^]	<0.001
Bilateral hemisphere involvement [#]	15 (62.5)	9 (60.0)	6 (33.3)		0.675
SDH	22 (91.7)	12 (54.5)	10 (45.5)		0.902
ICH [#]	1 (4.2)	1 (100.0)	0 (0.0)		0.347
Skull fracture	7 (29.2)	3 (42.9)	4 (57.1)	1.9 (0.32–11.3)	0.66
Associated injuries					
Retinal haemorrhages [#]	18 (75.0)	11 (61.1)	7 (38.7)		0.357
Visceral and/or skeletal injury	3 (12.5)	1 (33.3)	2 (66.7)	2.7 (0.21–34.1)	0.576
Number of neurosurgical procedures[#]					
1 surgery only	17 (70.8)	9 (52.9)	8 (47.1)		0.851
> 1 surgery	7 (29.2)	4 (57.1)	3 (42.9)		-
Secondary outcomes of interest (at 12 months)					
Development of scar epilepsy	11 (45.8)	3 (27.3)	8 (72.7)		0.021
Progression to cerebral palsy	7 (29.2)	0 (0.0)	7 (100.0)		0.001

[#]negative relationship; OR not presented; [^]zero counts; relative risk (RR) presented instead

punishment will be deemed as ‘excessive’ [27]. Under such circumstances, it may be challenging to differentiate between reasonable corporal punishment versus child abuse, particularly in the clinical setting.

Clinical manifestations of AHT vary with age, mechanism, and specific types of injuries [28]. Affected patients may present with variable neurological signs, or occasionally with occult injury as part of a child abuse evaluation for extracranial injuries [29]. In addition, taking a reliable history in the setting of suspected AHT is challenging, leading to the difficulty in categorising head trauma as ‘non-accidental’ outside of a caregiver’s confession [30]. Under such circumstances, AHT is an extremely difficult diagnosis to make [12]. Mortality rates from AHT range from 3.7 to

38% in the literature [1, 3, 31, 32]. This is congruent with our study, whereby we had a 12.5% death rate.

Reports confirm that the most frequent injuries sustained involve the head and neck [11], and most AHT occurs in children younger than 2 years old [9, 33]. This age group is especially vulnerable as they are still non-verbal and of much smaller physical stature. For them, certain injuries tend to be more common in the setting of AHT. For example, multi-layered retinal haemorrhages (RH) have been cited to occur in 60 to 85% of AHT patients [34]. This is especially so in the setting of AHT whereby specificity of severe RH has been reported to be up to 100% [35]. These findings concur with our study whereby 75% of our patients had RH. Next, very young patients may sustain significant head trauma

Table 4 Subgroup univariate analysis of selected patient demographics and variables for presence of scar epilepsy as an outcome. Bold values indicate statistical significance (i.e., p -value <0.05)

Variable	Overall (%)	No scar epilepsy	Development of scar epilepsy	Unadjusted OR (95% CI)	p -value
Total number of patients	24 (100)	13 (54.2)	11 (45.8)		
Clinical presentation at admission					
Mild TBI (GCS 13 to 15)	7 (29.2)	6 (85.7)	1 (14.3)	1.0	0.156
Moderate TBI (GCS 9 to 12)	8 (33.3)	3 (37.5)	5 (62.5)	8.4 (0.84–87.8)	-
Severe (GCS 3 to 8)	9 (37.5)	4 (44.4)	5 (55.6)		-
Seizures at initial presentation	19 (79.2)	8 (42.1)	12 (57.9)	2.3 (0.48–4.1) [^]	0.612
Neuroimaging findings					
Cerebral oedema	13 (54.2)	5 (38.5)	6 (61.5)	4.3 (0.75–24.2) [^]	<0.001
Bilateral hemisphere involvement [#]	15 (62.5)	8 (53.3)	7 (46.7)		0.916
SDH	22 (91.7)	12 (54.5)	10 (45.5)		0.902
ICH [#]	1 (4.2)	1 (100.0)	0 (0.0)		0.347
Skull fracture	7 (29.2)	4 (57.1)	3 (42.9)		0.608
Associated injuries					
Retinal haemorrhages [#]	18 (75.0)	13 (72.2)	5 (27.8)		0.795
Visceral and/or skeletal injury	3 (12.5)	2 (66.7)	1 (33.3)		0.642
Number of neurosurgical procedures[#]					
1 surgery only	17 (70.8)	9 (52.9)	8 (47.1)		0.608
> 1 surgery	7 (29.2)	4 (57.1)	3 (42.9)		-

[#]negative relationship; OR not presented; [^]zero counts; relative risk (RR) presented instead

without evidence of scalp injury. The thin, pliable skull of these young infants transmits force more diffusely than the more rigid skull of the older child. The subdural space of

the young infant is narrower and less tolerant of a space-occupying lesion. It has been recommended that infants with unexplained subdural hematoma (SDH) undergo further

Table 5 Subgroup univariate analysis of selected patient demographics and variables for progression to cerebral palsy as an outcome instead. Bold values indicate statistical significance (i.e., p -value <0.05)

Variable	Overall (%)	No progression to cerebral palsy	Progression to cerebral palsy	Unadjusted OR (95% CI)	p -value
Total number of patients	24 (100)	17 (70.8)	7 (29.2)		
Clinical presentation at admission					
Mild TBI (GCS 13 to 15)	7 (29.2)	7 (100)	0 (0.0)	1.0	0.072
Moderate TBI (GCS 9 to 12)	8 (33.3)	6 (75.0)	2 (25.0)	1.3 (0.89–2.0) [^]	
Severe (GCS 3 to 8)	9 (37.5)	4 (44.4)	5 (55.6)	2.3 (0.93–4.7) [^]	
Seizures at initial presentation	19 (79.2)	13 (68.4)	6 (31.6)	2.3 (0.18–28.1) [^]	0.612
Neuroimaging findings					
Cerebral oedema	13 (54.2)	6 (46.2)	7 (53.8)	2.6 (1.1–6.5) [^]	0.006
Bilateral hemisphere involvement [#]	15 (62.5)	11 (73.3)	4 (26.7)		0.507
SDH	22 (91.7)	16 (72.7)	5 (37.3)		0.902
ICH [#]	1 (4.2)	1 (100.0)	0 (0.0)		0.512
Skull fracture	7 (29.2)	4 (57.1)	3 (42.9)	4.0 (0.43–37.3)	0.374
Associated injuries					
Retinal haemorrhages [#]	18 (75.0)	13 (72.2)	5 (27.8)		0.795
Visceral and/or skeletal injury	3 (12.5)	2 (66.7)	1 (33.3)	1.2 (0.10–16.5)	0.865
Number of neurosurgical procedures[#]					
1 surgery only	17 (70.8)	12 (70.6)	5 (29.4)		0.967
> 1 surgery	7 (29.2)	5 (71.4)	2 (28.6)		

[#]negative relationship; OR not presented; [^]zero counts; relative risk (RR) presented

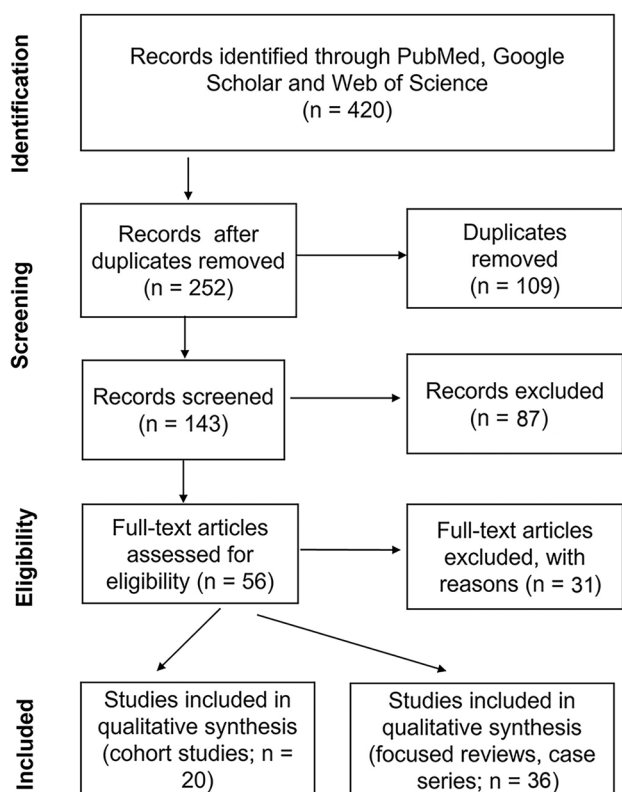


Fig. 2 PRISMA flow diagram of the literature search pertinent to study

investigation for AHT [29]. For AHT, the most common intracranial lesions are SDH in the parafalcine, tentorial, and occipital convexity regions, associated with focal or diffuse areas of parenchymal hypodensity on CT scan [36]. These also concur with our patients, whereby more than 90% of them have radiological evidence of SDH. Although SDH is commonly seen in AHT, we emphasise caution to exclude other unrelated causes for similar radiological findings in this age group [37]. One such consideration is the condition of benign enlargement of subarachnoid spaces of infancy (BESSI). This is a self-limiting condition that has been postulated to be secondary to immature arachnoid villi impairing CSF absorption [38, 39]. Nonetheless, physicians who encounter a young child with BESSI and SDH should not reflexively determine that BESSI is the cause of the SDH and thus forgo an abuse evaluation [37]. This is especially so if there are features of macrocephaly, raised intracranial pressure [40], or concurrent injuries associated with child abuse [37, 41]. In our study, all patients were assessed thoroughly to ensure that these red flags, neurological symptoms, and clinico-social factors are present before concluding the diagnosis of AHT (Fig. 3).

Following that, the incidence of malignant cerebral oedema is higher in AHT patients when compared to those suffering from accidental trauma, leading to increased frequency of neurosurgical interventions [1]. This is because

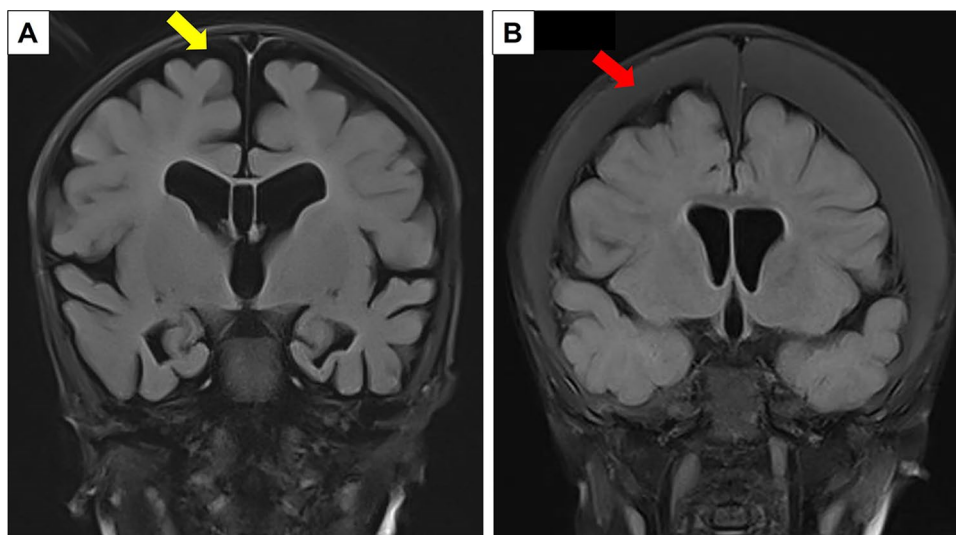


Fig. 3 Comparison of representative coronal T2-weighted fluid-attenuated inversion recovery (FLAIR) with fat suppression images of 2 different 7-month-old patients with BESSI (A) and AHT patient (B). Of note, the patient with BESSI (A) has enlarged subdural and subarachnoid spaces (represented by the yellow arrow), without evidence of blood products or cortical effacement. This contrasts with the AHT patient (B) who pre-

sented with signs of raised ICP and bilateral RH. The red arrow depicts bilateralsubdural collection, suggestive of subacute-chronic blood products, causing local mass effect on the underlying cerebral cortex. This patient underwent burr hole drainage that confirmed a subacute subdural hematoma under pressure

the unmyelinated infant brain with its higher water content is more susceptible to rapid life-threatening, diffuse brain swelling during injury [28]. Diffuse cerebral swelling is usually seen 24 to 48 h following trauma and may occur more frequently in children than adults due to impaired autoregulation of perfusion and possibly an increased inflammatory response. Paediatric patients also generally have lower mean arterial pressures which result in greater likelihood for hypoperfusion and subsequent infarction [34]. Our study demonstrates that the presence of cerebral oedema on initial scans shows a strong correlation with higher GOS-E Peds scores (45.8%). This is likely so because diffuse insults such as cerebral oedema from TBI often result in hypoxic–ischemic encephalopathy, often irreversibly damaging the growing brain [42]. Consequently, these patients are at high risk of limited recovery and correspondingly poor outcomes [43]. This phenomenon is reflected in our own cohort, whereby cerebral oedema significantly correlates to and is predictive for patients progressing to cerebral palsy and development of scar epilepsy. Studies observe that scar epilepsy has significant impact on quality of life for both patient and their caregivers [44]. Consistent with previous publications that report poorer outcomes for AHT patients [1, 28, 45, 46], our study shows that cerebral oedema significantly correlates to and is associated with patients progressing to cerebral palsy (29.2%) and development of scar epilepsy (54.2%).

From a neurosurgical perspective, this study has also highlighted the necessity of continued follow-up by our unit. In our series, we had 29.2% of patients that required additional neurosurgical interventions due to secondary neurological sequelae from their initial AHT. At the time of this writing, large-scale studies focused on long-term outcomes of children with AHT are limited [47, 48]. Nonetheless, existing literature strongly suggests that affected patients remain vulnerable to neurological, cognitive, and psychological disabilities throughout their lives [47–49]. Therefore, it is essential that clinicians review them regularly in the long term and step in to coordinate for their other biopsychosocial needs, as required.

Study critique and future work

For this study, we acknowledge that there are noteworthy limitations. First and foremost, this is a retrospective cohort with a modest population conducted at a single institution. Hence, additional variables and subgroup analyses at a deeper level are omitted as part of the statistical interrogation as the numbers are not meaningful. Separately, we believe that there will be AHT cases inevitably missed out over this 20-year period, likely due to underreporting of cases or limited awareness of this diagnosis in the early years.

As part of the ongoing work, our institution has adopted a multi-disciplinary approach to managing these complex patients. This workflow is constantly evolving to ensure that we are congruent with the latest evidence-based medicine and public health efforts. Prospectively, we endeavour to include long-term neuropsychological and functionality assessments of these patients as they continue to grow to adulthood. To optimise the neurorehabilitation potential in these children, the challenge is to identify interventions tailored specifically to the developing brain, which will minimise secondary effects of the initial brain insult from AHT and reduce neurocognitive morbidity [42]

Conclusion

Abusive head trauma is a devastating condition associated with long-term neurological sequelae and burdensome healthcare costs. The authors therein present our neurosurgical experience for very young children diagnosed with AHT, and their outcomes. We advocate increased awareness in clinicians, strong multi-disciplinary teamwork, and collaborations with like-minded international groups, for management of affected children.

Declarations

Conflict of interest All the authors certify that this manuscript is a unique submission and is not being considered for publication, in part or in full, with any other source in any medium. All authors made substantial contributions to the manuscript and approved its final version. We report no competing interests, funding, financial support or industrial affiliations received for the writing of this article. Also, we declare no conflict of interest concerning the material or methods used in this paper.

References

1. Adamo MA, Drazin D, Smith C, Waldman JB (2009) Comparison of accidental and nonaccidental traumatic brain injuries in infants and toddlers: demographics, neurosurgical interventions, and outcomes. *J Neurosurg Pediatr* 4:414–419
2. Wong PY, How CH, Wong PC (2013) PILL series. Management of child abuse. *Singapore Med J* 54:533–536; quiz 537
3. Jayawant S, Parr J (2007) Outcome following subdural haemorrhages in infancy. *Arch Dis Child* 92:343–347
4. Barlow KM, Thomson E, Johnson D, Minns RA (2005) Late neurologic and cognitive sequelae of inflicted traumatic brain injury in infancy. *Pediatrics* 116:e174–185
5. Duhaime AC, Christian CW, Rorke LB, Zimmerman RA (1998) Nonaccidental head injury in infants—the “shaken-baby syndrome.” *N Engl J Med* 338:1822–1829
6. Haviland J, Russell RI (1997) Outcome after severe non-accidental head injury. *Arch Dis Child* 77:504–507

7. Thalayasingam M, Veerakumarasivam A, Kulanthayan S, Khairuddin F, Cheah IG (2012) Clinical clues for head injuries amongst Malaysian infants: accidental or non-accidental? *Injury* 43:2083–2087
8. Golden N, Maliawan S (2005) Clinical analysis of non-accidental head injury in infants. *J Clin Neurosci* 12:235–239
9. Nooraudah AR, Mohd Sham K, Zahari N, Fauziah K (2004) Non-accidental fatal head injury in small children—a clinico-pathological correlation. *Med J Malaysia* 59:160–165
10. Hafiz MZ, Saffari MH (2011) Characteristic differences in neuroimaging and physical findings between non-accidental and accidental traumatic brain injury in young children. A local experience in general hospital of Kuala Lumpur. *Med J Malaysia* 66:95–100
11. Chew YR, Cheng MH, Goh MC, Shen L, Wong PC, Ganapathy S (2018) Five-year review of patients presenting with non-accidental injury to a Children's Emergency Unit in Singapore. *Ann Acad Med Singap* 47:413–419
12. Togioka BM, Arnold MA, Bathurst MA, Ziegfeld SM, Nabaweesi R, Colombani PM, Chang DC, Abdullah F (2009) Retinal hemorrhages and shaken baby syndrome: an evidence-based review. *J Emerg Med* 37:98–106
13. Billmire ME, Myers PA (1985) Serious head injury in infants: accident or abuse? *Pediatrics* 75:340–342
14. Carney N, Totten AM, O'Reilly C, Hawryluk GWJ, Bell MJ, Bratton SL, Chestnut R, Odette AH, Kisooson N, Rubiano AM, Shutter L, Tasker RC, Vavilala MS, Wilberger JW, Wright DW, Ghajar J. Brain Trauma Foundation: Guidelines for the management of severe traumatic brain injury. https://braintrauma.org/uploads/03/12/Guidelines_for_Management_of_Severe_TBI_4th_Edition.pdf. Accessed 10 Nov 2021
15. Beers SR, Wisniewski SR, Garcia-Filion P, Tian Y, Hahner T, Berger RP, Bell MJ, Adelson PD (2012) Validity of a pediatric version of the Glasgow Outcome Scale-Extended. *J Neurotrauma* 29:1126–1139
16. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol* 62:e1–34
17. Sato Y, Moritani T (2013) Nonaccidental head injury: evidence-based neuroimaging. In: Medina LS, Sanelli PC, Jarvik JG (eds) *Evidence-based neuroimaging diagnosis and treatment: improving the quality of neuroimaging in patient care*. Springer, New York, New York, NY, pp 385–400
18. Barlow K, Thompson E, Johnson D, Minns RA (2004) The neurological outcome of non-accidental head injury. *Pediatr Rehabil* 7:195–203
19. Klein M, Stern L (1971) Low birth weight and the battered child syndrome. *Am J Dis Child* 122:15–18
20. Sills JA, Thomas LJ, Rosenbloom L (1977) Non-accidental injury: a two-year study in central Liverpool. *Dev Med Child Neurol* 19:26–33
21. Keenan HT, Runyan DK, Marshall SW, Nocera MA, Merten DF, Sinal SH (2003) A population-based study of inflicted traumatic brain injury in young children. *JAMA, J Am Med Assoc* 290:621–626
22. Barlow KM, Minns RA (2000) Annual incidence of shaken impact syndrome in young children. *Lancet* 356:1571–1572
23. Kesler H, Dias MS, Shaffer M, Rottmund C, Cappos K, Thomas NJ (2008) Demographics of abusive head trauma in the Commonwealth of Pennsylvania. *J Neurosurg Pediatr* 1:351–356
24. Bogumil DDA, Demeter NE, Kay Imagawa K, Upperman JS, Burke RV (2017) Prevalence of nonaccidental trauma among children at American College of Surgeons-verified pediatric trauma centers. *J Trauma Acute Care Surg* 83:862–866
25. Naik-Mathuria B, Akinkuotu A, Wesson D (2015) Role of the surgeon in non-accidental trauma. *Pediatr Surg Int* 31:605–610
26. <https://www.msf.gov.sg/research-and-data/Research-and-Statistics/Pages/Child-Abuse-Investigations.aspx>. Accessed 10 May 2021
27. Loh CY (1990) Hospitalization and parental styles as factors affecting infant attachment behaviour. National University of Singapore. <https://scholarbank.nus.edu.sg/handle/10635/166476>. Accessed 04 May 2022
28. Duhaime AC, Christian CW (2019) Abusive head trauma: evidence, obfuscation, and informed management. *J Neurosurg Pediatr* 24:481–488
29. Christian CW, Committee on Child A, Neglect AAoP, (2015) The evaluation of suspected child physical abuse. *Pediatrics* 135:e1337–1354
30. Lee AC (2008) Bruises, blood coagulation tests and the battered child syndrome. *Singapore Med J* 49:445–449; quiz 450
31. Newton AW, Vandeven AM (2005) Update on child maltreatment with a special focus on shaken baby syndrome. *Curr Opin Pediatr* 17:246–251
32. Duhaime AC, Alario AJ, Lewander WJ, Schut L, Sutton LN, Seidl TS, Nudelman S, Budenz D, Hertle R, Tsiaras W et al (1992) Head injury in very young children: mechanisms, injury types, and ophthalmologic findings in 100 hospitalized patients younger than 2 years of age. *Pediatrics* 90:179–185
33. Jayawant S, Rawlinson A, Gibbon F, Price J, Schulte J, Sharples P, Sibert JR, Kemp AM (1998) Subdural haemorrhages in infants: population based study. *BMJ* 317:1558–1561
34. Paul AR, Adamo MA (2014) Non-accidental trauma in pediatric patients: a review of epidemiology, pathophysiology, diagnosis and treatment. *Transl Pediatr* 3:195–207
35. Dashti SR, Decker DD, Razzaq A, Cohen AR (1999) Current patterns of inflicted head injury in children. *Pediatr Neurosurg* 31:302–306
36. Ewing-Cobbs L, Kramer L, Prasad M, Canales DN, Louis PT, Fletcher JM, Vollero H, Landry SH, Cheung K (1998) Neuroimaging, physical, and developmental findings after inflicted and noninflicted traumatic brain injury in young children. *Pediatrics* 102:300–307
37. Hansen JB, Frazier T, Moffatt M, Zinkus T, Anderst JD (2018) Evaluations for abuse in young children with subdural hemorrhages: findings based on symptom severity and benign enlargement of the subarachnoid spaces. *J Neurosurg Pediatr* 21:31–37
38. Zahl SM, Egge A, Helseth E, Wester K (2011) Benign external hydrocephalus: a review, with emphasis on management. *Neurosurg Rev* 34:417–432
39. Nickel RE, Gallenstein JS (1987) Developmental prognosis for infants with benign enlargement of the subarachnoid spaces. *Dev Med Child Neurol* 29:181–186
40. Kuruvilla LC (2014) Benign enlargement of sub-arachnoid spaces in infancy. *J Pediatr Neurosci* 9:129–131
41. Kumar R (2006) External hydrocephalus in small children. *Childs Nerv Syst* 22:1237–1241
42. Anderson V, Spencer-Smith M, Wood A (2011) Do children really recover better? Neurobehavioural plasticity after early brain insult. *Brain* 134:2197–2221
43. Giza CC, Prins ML (2006) Is being plastic fantastic? Mechanisms of altered plasticity after developmental traumatic brain injury. *Dev Neurosci* 28:364–379
44. Berto P (2002) Quality of life in patients with epilepsy and impact of treatments. *Pharmacoeconomics* 20:1039–1059
45. Iqbal O'Meara AM, Sequeira J, Miller Ferguson N (2020) Advances and future directions of diagnosis and management of pediatric abusive head trauma: a review of the literature. *Front Neurol* 11:118
46. Narang S, Clarke J (2014) Abusive head trauma: past, present, and future. *J Child Neurol* 29:1747–1756

47. Lind K, Toure H, Brugel D, Meyer P, Laurent-Vannier A, Chevignard M (2016) Extended follow-up of neurological, cognitive, behavioral and academic outcomes after severe abusive head trauma. *Child Abuse Negl* 51:358–367
48. Nuno M, Ugiliweneza B, Zepeda V, Anderson JE, Coulter K, Magana JN, Drazin D, Boakye M (2018) Long-term impact of abusive head trauma in young children. *Child Abuse Negl* 85:39–46
49. Manfield J, Oakley K, Macey JA, Waugh MC (2021) Understanding the five-year outcomes of abusive head trauma in children: a retrospective cohort study. *Dev Neurorehabil* 24:361–367

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