Abusive Head Trauma in Young Children

A Population-Based Study

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Objective: The objectives of this study were to provide population-based incidence estimate of abusive head trauma (AHT) in children aged 0 to 5 years from inpatient and emergency department (ED) and identify risk characteristics for recognizing high-risk children to improve public health surveillance.

Methods: This was a retrospective cohort study based on children's first encounter in ED or hospital admission with a diagnosis of head trauma (HT), 2000–2010. The relationship between clinical markers and AHT was examined controlling for covariables in the model using Cox hazards regression. Kaplan-Meier incidence probability was plotted, and the number of weeks elapsing from date of birth to the first encounter with HT established the survival time (T).

Results: Twenty-six thousand six hundred eighty-one children had HT, 502 (1.8%) resulted from abuse; 42.4% was captured from ED. Incidence varied from 28.9 (95% confidence interval [CI], 27.9–37.4) in infants to 4.1 (95% CI, 2.4–5.7) in 5-year-olds per 100,000 per year. Adjusted hazard ratio was 20.3 (95% CI, 10.9–38.0) for intracranial bleeding and 11.4 (95% CI, 8.57–15.21) for retinal hemorrhage.

Conclusions: Incidence estimates of AHT are incomplete without including ED. Intracranial bleeding is a cardinal feature of AHT to be considered in case ascertainment to improve public health surveillance.

Key Words: abusive head trauma, abuse, surveillance

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Intentional trauma remains a significant cause of childhood morbidity and mortality. The most recent report from the US Department of Health and Human Services indicates 1740 child fatalities as a result of abuse in 2008 (2.33 per 100,000), with 74.8% occurring in those younger than 3 years.[1] Abusive head trauma (AHT) is the leading type of intentional injury in infants and young children and ranks the third leading cause of serious head injury for children 0 to 14 years old.[2] Reported incidence rates are grossly underestimated because of challenges in establishing the diagnosis of abuse.[3,4] Estimates of incidence rates vary widely depending on the age range of the study population, the source of data, and the case ascertainment criteria used. Most estimates range from 32.2 cases per 100,000 for infants[5] to 3.4 cases per 100,000 children in the second year of age.[6] Although there are limited studies that report incidence of AHT in children through age 5 years, it has been consistently observed that incidence declines significantly with advancing age.[5,7]

Abusive head trauma has very high case fatality rate, and many of the survivors succumb to lifelong disability. Case fatality rate is reported to be as high as 21.4% through age 3 years[8] and up to 53% for children admitted to pediatric intensive care unit (ICU).[7] For survivors, significant deficits in cognitive and behavioral functions have been reported. A prospective study from Scotland with a mean follow-up period of 59 months showed 68% of children with AHT have abnormal developmental findings in follow-up, and 36% developed severe cognitive and behavioral difficulties, making them totally dependent on parents and caregivers.[9] In another study, more children who sustained AHT before age 2 years showed worse cognitive performance compared with those with noninflicted HT.[9] The economic impact of AHT is immense, often costing 2 to 3 times more than HT from other causes.[10,11] The direct cost of care for child maltreatment in the United States was greater than US $24 billion in 2003.[12]

Studies have identified demographic, socioeconomic, and clinical factors associated with AHT in young children. Most studies have shown higher risk of AHT in males than in females,[13–15] blacks than whites,[6,7] and children from families with low income.[5,8,16] Other socioeconomic and environmental factors implicated in child abuse and maltreatment include loss of employment and economic distress in the family,[17,18] natural disasters that result in family displacement,[17] poor social support and family cohesion,[18] and single parenthood. Clinical factors strongly suggestive of AHT include retinal bleeding and detachment,[14,19,20] subdural hematomas,[19–21] and specific fracture patterns.[14,22] Furthermore, a host of child-related factors may exacerbate abuse and maltreatment. Chronic illnesses such as mental retardation, autism spectrum disorder, intractable epilepsy, and emotional and behavioral problems are commonly sighted.[12,23–25]

Although important information has been obtained from the studies published to date, most have had significant limitations such as being limited to children admitted to pediatric ICUs or hospital admissions,[7,13,19,26] narrow age ranges,[6,9,11,27] small sample sizes,[20,28] lack of representativeness of the numerator, or lack of adequately large population base to provide stable incidence estimate.[4,29] This study addresses most of these limitations and builds on the previously gained knowledge. It provides a population-based incidence estimate of AHT using multiyear statewide incidence data of all children aged 0 to 5 years from inpatient and emergency department (ED) sources and identifies salient risk characteristics of AHT that should aid in recognizing high-risk children and improve future safety and public health surveillance. To our knowledge, this is the first population-based incidence estimate of all severity AHT from hospital and ED sources that provides a comprehensive risk

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profile of children with AHT. The study hypothesizes that intracranial bleeding and retinal hemorrhage in children with head trauma (HT) are more likely to be associated with abuse than other causes of injury.

METHODS

Data Sources and Design

This study utilized South Carolina (SC) hospital discharge and ED data sets for 2000–2010. State law mandates all 62 nonfederal hospitals and EDs report uniform, abstracted billing data to the SC State Budget and Control Board. The statewide central nervous system injury surveillance and registry program receive all data pertaining to head and spinal cord injuries with personal identifiers through legal authority—a state law authorizing the surveillance system to receive copies of billing reports with personal identifiers. The contents of the data file are reported elsewhere.[30] The central nervous system surveillance program augments and validates the data through medical chart review and by interviewing a representative sample of patients. Valid E-code completion rate for the period of observation was 94.8%.

Study Design and Population

This is a retrospective cohort study examining demographic, socioeconomic, and clinical characteristics of children aged 0 to 5 years based on their first encounter in ED or hospital admission with a diagnosis of HT between January 1, 2000, and December 31, 2010. A case of HT, also referred to as traumatic brain injury (TBI), was ascertained, using *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*)[31] diagnosis codes 800-801, 803-804, 850-854, and 959.01, consistent with the case definition provided by the Centers for Disease Control and Prevention.[32] We excluded children coded as late effects of intracranial injury (907.0) and repeat encounters with the same diagnosis. This study was approved by the Medical University of South Carolina institutional review board.

Definitions

The main outcome of interest was HT resulting from abuse. External cause of injury codes (E-code) of child abuse, beating, assault, and/or when the HT is corroborated with a diagnosis of child maltreatment syndrome (shaken baby syndrome) were used to diagnose AHT. The case ascertainment *ICD-9-CM* codes utilized to identify AHT are included in Table 1A. Independent variables of interest were socioeconomic and clinical characteristics. Insurance type was used as a proxy measure of socioeconomic status and was categorized as "indigent care" if primary payer was Medicaid, medically indigent assistance program (MIAP), or "uninsured." All other insurance categories were grouped as "commercial/Medicare."

Intracranial hemorrhage[19,20,33–35] and retinal bleeding or detachment[14,15,28,36,37] have been noted as probable markers of AHT in young children. Given the codes pertaining to retinal bleeding, detachment, and splitting are outside the range of *ICD-9-CM* codes designated for trauma (800–959) and could occur without a traumatic event, they were only considered traumatic in the presence of probable diagnosis of AHT. To determine the association of these lesions with AHT and evaluate their usefulness for public health surveillance, the diagnosis codes of HT were categorized as (*a*) intracranial hemorrhage (ICH), (*b*) cerebral contusion/concussion and open intracranial wound, (*c*) skull fractures with or without intracranial injuries, and (*d*) intracranial injury of unspecified nature or unspecified head injury. Diagnosis codes pertaining to intraocular lesion were categorized as (*a*) retinal bleeding and (*b*) retinal detachment as shown in Table 1B.

TABLE 1. Case Ascertainment *ICD-9-CM* Codes of AHT (A), TBI and Intraocular Lesions (B), and Selected Stressful Childhood Conditions (C)

Condition	*ICD-9-CM*
A. Descriptors of abuse in children with HT	
1. Child abuse and maltreatment syndrome	995.50, 995.54, 995.55,995.59
2. Child beating, abuse, assault (E-code)	E960.0, E967, E968.1, E968.2, E968.8, E968.9
B. Clinical descriptors of type of TBI and intraocular lesions	
1. Intracranial hemorrhage	852, 853
2. Cerebral contusion/ concussion and open intracranial wound	850, 851, 854.1
3. Skull fractures with or without intracranial injuries	800, 801, 803, 804
4. Intracranial injury of unspecified nature or unspecified head injury	854.0, 959.01
5. Retinal bleeding	361.30, 361.33, 361.81, 361.89, 361.30, 361.33, 361.81, 361.89, 362.40, 362.81
6. Retinal detachment	361.0, 361.8, 361.9
7. Injury to optic nerve and visual cortex	950.0–950.3
C. Selected childhood illnesses stressful to parents/caregivers	
1. Excess crying	780.91, 780.92, 780.95
2. Autistic disorder	299.0, 299.9
3. Circadian rhythm sleep disturbance	327.3
4. Attention-deficit/ hyperactivity disorder	314
5. Infantile cerebral palsy	343
6. Epilepsy and seizure disorders	345, 780.39
7. Mental retardation	318,319

We identified a selected number of childhood illnesses, shown in Table 1C, that have been cited in the literature as stressful to parents and caregivers possibly associated with increased rates of abuse.[12,24,38–41] They were identified from the primary or secondary diagnoses field assigned at the time of HT diagnosis and were grouped as "present" or "absent." Injury severity was determined by translating *ICD-9-CM* diagnosis codes into Abbreviated Injury Scale (AIS) using ICDMAP-90 software.[42] The AIS is an anatomic measure of injury severity in an ordinal scale—from 1 (minor) to 6 (critical/unsurvivable)—classifying injuries according to life threat.[43] It was categorized as mild (AIS 2), moderate (AIS 3), and severe (AIS 4-6). To account for the effect of multiple injuries, we counted the number of injuries of AIS 2 and higher to body regions other than the head and categorized them as "multiple" or "head only."

We grouped all 62 nonfederal hospitals in the state as "hospital with pediatrics specialty care," if the hospital has multispecialty in pediatrics with pediatric ICU; otherwise, the hospital was defined as "general hospital." Place of residence was dichotomized as "rural" or "urban" based on the Office of Management and Budget metropolitan statistical area designation.[44]

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TABLE 2. Characteristics of Children With AHT by Source of Patient Care

Characteristics	Source of Patient Care: Hospital Inpatient (n = 289), n (%)	ED (n = 213), n (%)	Total (n = 502), n (%)	*P*
Diagnosis ascertainment				<0.001
Child maltreatment syndrome (CMS)	40 (13.9)	7 (3.3)	47 (9.4)	
Child beating/abuse (E-code)	83 (28.7)	31 (14.6)	114 (22.6)	
Both CMS and E-code	166 (57.4)	175 (82.2)	341 (68.0)	
Type of brain injury				<0.001
Intracranial (IC) hemorrhage	226 (78.2)	12 (5.6)	238 (47.4)	
Skull fracture	34 (11.8)	17 (8.0)	51 (10.2)	
Contusion/concussion	16 (5.5)	99 (46.5)	115 (22.9)	
Unspecified IC or head injury	13 (4.5)	85 (39.9)	98 (19.5)	
Retinal bleeding or detachment				<0.001
Yes	120 (41.5)	3 (1.4)	123 (24.5)	
No	169 (58.5)	210 (98.6)	379 (75.5)	
Age of child, y				<0.001
0–1	160 (55.4)	19 (8.9)	179 (35.7)	
1–2	78 (30.0)	57 (26.8)	135 (26.9)	
2–3	24 (8.3)	61 (28.6)	85 (16.9)	
3–4	15 (5.2)	33 (15.5)	48 (9.6)	
4–5	6 (2.1)	25 (11.7)	31 (6.2)	
5–6	6 (2.1)	18 (8.5)	24 (4.8)	
Place of residence				<0.001
Rural	113 (39.1)	159 (74.6)	272 (54.2)	
Urban	176 (60.9)	54 (25.4)	230 (45.8)	

Race was defined as "white" or "black" regardless of ethnicity. Black race is composed of 95.3% African Americans and 4.7% other races. The remaining variables were defined as noted in Table 3.

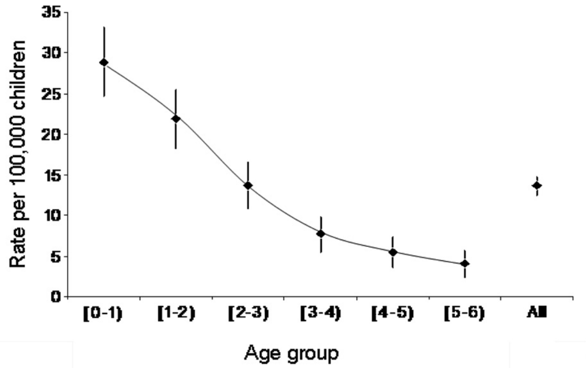
Statistical Analysis

Data analyses relied on SAS software package (SAS V9.03, Cary, NC).[45] Descriptive statistics—*t* test for continuous variables and χ^2 tests for proportions—were used to compare group characteristics. Age-specific incidence rate of AHT was calculated by dividing the accrued number of events over the 11 years by the population estimate[46] at the midpoint of the interval under the assumption of a stable closed population. The result was then annualized for each age, and a confidence interval (CI) was constructed by treating the rate as Poisson random variable according to the following formula.

$$95\%\,\mathrm{CI} = R_i\left(Z_{(1-\alpha/2)} \times \sqrt{\frac{R_i}{n_i}}\right);$$

where R_i is age−specific rate and n_i age−specific population

The relationship between the dependent variable (AHT) and independent variables was examined as a function of time using Cox proportional hazards regression averaged over the entire time of follow-up. The number of weeks elapsing from date of birth to the first encounter with HT established the survival time (T). The model assumes the hazard ratio (HR) comparing any 2 specifications of predictors is constant over time. This assumption was tested with the goodness-of-fit χ^2 test, which compares the observed and expected survival probabilities, and by graphical means using the log-log Kaplan-Meier (KM) curves.[47] Variables with bivariate association $P \leq 0.20$ were included in the multivariable model. Multicolinearity among covariables was evaluated by assessing deviations of regression coefficients and their SEs in the fitted univariate and multivariate models.[48] Covariables were entered simultaneously into the model. Kaplan-Meier survival curves graphically presented the incidence probability of AHT as a function of injury type. It was plotted as 1-survival probability as proposed by Penman and Johnson.[49] A log-rank test validated the homogeneity of survival curves across injury type strata.[50] $P < 0.05$ and HRs that excluded 1 in the confidence limits were considered significant.



Events	179	135	85	48	31	24	502
Population	56,211	56,164	56,630	56,996	54,846	53,684	334,231
Rate/Year	28.9	21.9	13.7	7.7	5.1	4.1	13.7
95% CI	24.7–37.7	18.2–25.5	10.8–16.6	5.5–9.8	3.3–6.9	2.4–5.7	12.5–14.8

FIGURE 1. Annualized incidence rate of abusive HT with 95% CI. SC 2000–2010.

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RESULTS

During the 11 years reviewed, 28,660 children with HT, aged 0 to 5 years, were evaluated, of which 502 (1.8%) resulted from abuse. Table 2 shows 289 (57.6%) of the children with AHT were identified among those admitted to hospitals and 213 (42.4%) among those treated and released or transferred from the ED. Sixty-eight percent of the children with AHT were identified with the combined use of child maltreatment syndrome and child-beating E-codes, 22.6% with child-beating E-codes, and 9.4% with child maltreatment syndrome E-codes.

TABLE 3. Demographic and Clinical Characteristics of TBI Patients by Abuse Status

	TBI			
Characteristics	**Total (n = 28,660), n (%)**	**Abuse (n = 502), n (%)**	***P***	**Other (n = 28,158), n (%)**
Age of child				<0.001
[0–1)	3136 (10.9)	179 (35.7)	2957 (10.5)	
[1–2)	7332 (25.6)	135 (26.9)	7197 (25.6)	
[2–3)	6268 (21.9)	85 (16.9)	6183 (21.9)	
[3–4)	4774 (16.7)	48 (9.6)	4726 (16.7)	
[4–5)	3812 (13.3)	31 (6.2)	3781 (13.4)	
[5–6)	3338 (11.7)	24 (4.8)	3314 (11.8)	
Age, mean (SD), wk	123.5 (80.2)	79.5 (69.2)	124.4 (80.1)	<0.001*
Race, sex				<0.001
Black, male	6622 (23.1)	158 (31.5)	6464 (22.9)	
Black, female	4447 (15.5)	90 (17.9)	4357 (15.5)	
White, male	9972 (34.8)	168 (33.5)	9804 (34.8)	
White, female	7619 (26.6)	86 (17.3)	7533 (26.8)	
Poverty status				<0.001
Indigent care	16,899 (59.0)	406 (80.9)	16,493 (58.6)	
Nonindigent care	11,761 (41.0)	96 (19.1)	11,665 (41.4)	
Type of brain injury				<0.001
Intracranial (IC) hemorrhage	1395 (4.9)	238 (47.4)	1157 (4.1)	
Skull fracture	1446 (5.1)	51 (10.2)	1395 (5.0)	
Contusion/concussion	4456 (15.6)	115 (22.9)	4341 (15.4)	
Unspecified IC or head injury	21,363 (74.4)	98 (19.5)	21,253 (75.5)	
Retinal bleeding or detachment				<0.001
Yes	162 (0.6)	123 (24.5)	39 (0.1)	
No	28,489 (99.4)	379 (75.5)	28,159 (99.9)	
TBI severity (AIS-head)				<0.001
Severe (AIS 4-6)	1243 (4.3)	220 (45.8)	1023 (3.6)	
Moderate (AIS 3)	824 (2.9)	47 (9.4)	777 (2.8)	
Mild (AIS 2)	26,593 (92.8)	235 (46.8)	26,358 (93.6)	
Concomitant injuries				<0.001
Multiple	2550 (8.9)	221 (44.0)	2329 (8.3)	
Head only	26,110 (91.1)	281 (56.0)	25,829 (91.7)	
Stressful child illness				<0.001
Present	150 (0.5)	13 (2.6)	137 (0.5)	
Absent	26,510 (99.5)	489 (97.4)	28,021 (99.5)	
Hospital type				<0.001
Pediatric specialty center	7271 (25.4)	247 (49.2)	7024 (24.9)	
General hospital	21,389 (74.6)	255 (50.8)	21,134 (75.1)	
Discharge disposition				<0.001
Deceased	135 (0.5)	43 (8.6)	92 (0.3)	
Transferred elsewhere	1556 (5.4)	76 (15.1)	1480 (5.3)	
Home	26,969 (94.1)	383 (76.3)	26,586 (94.4)	
Place of residence				<0.001
Rural	11,713 (40.9)	272 (53.2)	11,441 (40.6)	
Urban	16,947 (59.1)	230 (46.8)	16,717 (59.4)	
Median inpatient days	2	5	2	
Median acute care charge, US %	6096	15,657	5505	

*Two-sample *t* test with unequal variances.

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Significant differences exist between children with AHT identified from inpatient sources and those identified from ED sources. Patients identified from inpatient sources tended to have more significant injuries and to be younger; 78.2% of inpatients had ICH (compared with 5.6% of outpatients), 41.5% had retinal hemorrhages (as compared with 1.4% of outpatients), and 85.4% were younger than 2 years (as compared with 35.7% of outpatients).

Figure 1 shows annualized incidence rate of AHT by age. The population incidence rate per 100,000 children aged 0 to 5 years was 13.7 (95% confidence interval [CI], 12.5–14.8). The highest rate was noted in infants with a rate of 28.9 (95% CI, 24.7–37.7). This translates to 1 AHT for every 3450 infants. Incidence rate continued to decline with advancing age (linear trend $P < 0.001$). Sharper decline occurred before age 3 years, suggesting vulnerability of the very young. There was wide disparity by race based on the overall crude incidence rate of AHT, 41.2 and 24.2 per 100,000 per year for black and white children, respectively.

Significant differences were noted between children with AHT and other HT in all covariables included in the analyses (Table 3). The mean age of AHT children was 45 weeks less than other HT ($P < 0.001$). Blacks represented 38.4% of the children with HT but 49.4% of AHT. Whereas hospitals with pediatric specialty center evaluated only 24.9% children with HT, they identified 49.2% of all identified AHT ($P < 0.001$). Children with indigent insurance represented 58.6% of children with HT but 80.9% of AHT ($P < 0.001$). The most profound difference, however, was noted in the type of injury sustained. Children with AHT had a significantly higher proportion of ICH, were more likely to die, tended to have severe and multiple injuries, and resided in rural counties (all $P < 0.001$).

The distribution of the salient clinical features of AHT noted in our study—types of retinal and cranial injuries—is shown in Table 4. Significantly higher proportion of infants and toddlers (0–24 months) with AHT had retinal bleeding, intracranial hemorrhage, skull fracture, and cerebral contusion/concussion than children with AHT older than 24 months ($P < 0.05$). Retinal detachment was noted only in infants and toddlers with AHT. However, retinal bleeding and the various types of cranial injuries were also noted in the children with non-AHT but with lesser intensity than what was observed in AHT. The preponderance of these injuries in the 0 to 24 months remained significantly higher regardless of abuse ($P < 0.01$).

Table 5 shows adjusted risk characteristics of AHT. Intracranial hemorrhage and skull fractures were strongly associated clinical indicators of AHT with HRs of 20.31 and 7.36, respectively ($P < 0.001$). Retinal bleeding was the second strongest clinical indicator with HR of 11.42 ($P < 0.001$). Children with indigent insurance had 2.58 times higher risk of AHT compared with those with other types of insurance ($P < 0.001$). Furthermore, AHT was significantly associated with multiple injuries (HR, 2.28; $P < 0.001$) and residency in rural counties (HR, 1.58; $P < 0.001$). Black boys had significantly elevated HRs compared with white girls ($P < 0.01$). The presence of parentally stressful childhood comorbidities appears to trend toward an increased risk of AHT.

Figure 2 is a graphic depiction of the KM curve, indicating the cumulative incidence probability of AHT across type of injury strata over the course of time between birth and the event of HT. The curves indicate the increasing probability of AHT as a function of the types of lesion sustained at a given point in the child's age without accounting for other competing risk factors. For instance, for children presenting with a clinical evidence of ICH, the incidence probability of abuse at the 52nd week of age is 16%, ignoring all other competing intrinsic risk factors of hemorrhage. In the figure presented, the cumulative incidence probability of AHT sharply increased with ICH and was relatively flat for unspecified head injury. This suggests that establishing a diagnosis of AHT is a lot harder for children presenting with milder severity such as concussion-contusion or unspecified HT requiring more corroborating evidence to establish the diagnosis of abuse.

DISCUSSION

This is the first study to report incidence rates and risk profile of AHT utilizing a comprehensive statewide data set. Results showed that AHT is a significant public health problem with an incidence rate of 13.7 per 100,000 per year in SC. Despite lack of directly comparable studies of AHT through age 5 years, incidence estimate of AHT in infants is comparable with other studies,[5,6,13,51] with 1 infant per 3450 experiencing brain insult before his/her first birthday. Our findings also identified risk characteristics that may help identify those patients most at risk for AHT. Brain injury type, retinal hemorrhage, indigent insurance, concomitant injuries, and place of residence are salient characteristics that can help stratify the risk of AHT.

TABLE 4. Distribution of Retinal and Cranial Injury by Age and Abuse Status

	AHT			Other HT		
Type of Lesion	**Age 0–2 (n = 314), n (%)**	**Age 3–5 (n = 188), n (%)**	**P**	**Age 0–2 (n = 10,154), n (%)**	**Age 3–5 (n = 18,004), n (%)**	**P**
Retinal injury						
Detachment	4 (1.27)	0 (0.00)	0.152†	0 (0.00)	0 (0.00)	0.999*†
Bleeding	88 (28.03)	36 (19.15)	0.021	26 (0.26)	8 (0.04)	<0.001
None	222 (70.70)	152 (80.85)	Reference	10,128 (99.74)	17,996 (99.96)	Reference
Cranial injury						
Hemorrhage	147 (46.82)	94 (50.00)	<0.001	509 (5.01)	536 (2.98)	<0.001
Skull fracture	30 (9.55)	5 (2.66)	<0.001	615 (6.06)	619 (3.44)	<0.001
Contusion/concussion	81 (25.80)	10 (5.32)	<0.001	1176 (11.58)	3617 (20.09)	<0.001
Other/unspecified	56 (17.83)	79 (42.02)	Reference	7854 (77.35)	13,232 (73.49)	Reference

*Fisher exact test.

†When cell count is 0 in 50% of the cells, 1 was added to each cell to stabilize the estimate.

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TABLE 5. Adjusted Hazard Ratios of AHT in Children Aged 0–5 Years

Characteristics	Adjusted HR (95% Confidence Limit)	*P*
Race, sex		
Black, male	1.50 (1.15–1.97)	0.003
Black, female	1.21 (0.89–1.64)	0.222
White, male	1.26 (0.96–1.63)	0.092
White, female	Referent	
Poverty status		
Indigent care	2.58 (2.05–3.26)	<0.001
Nonindigent care	Referent	
Type of brain injury		
Intracranial hemorrhage	20.31 (10.86–38.00)	<0.001
Skull fracture	7.36 (4.81–11.95)	<0.001
Contusion/concussion	3.69 (2.78–4.89)	<0.001
Unspecified intracranial or head injury	Referent	
Retinal bleeding or detachment		
Yes	11.42 (8.57–15.21)	<0.001
No	Referent	
TBI severity (AIS-head)		
Severe (AIS 4-6)	1.11 (0.62–2.01)	0.724
Moderate (AIS 3)	0.62 (0.36–1.05)	0.075
Mild (AIS 2)	Referent	
Concomitant injuries		
Multiple	2.28 (1.88–2.77)	<0.001
Head only	Referent	
Stressful child illness		
Present	1.45 (0.80–2.61)	0.222
Absent	Referent	
Hospital type		
Pediatric specialty center	1.05 (0.82–1.41)	0.703
General hospital	Referent	
Discharge disposition		
Deceased	0.79 (0.55–1.13)	0.194
Transferred elsewhere	1.07 (0.82–1.41)	0.607
Home	Referent	
Place of residence		
Rural	1.58 (1.32–1.90)	<0.001
Urban	Referent	

Previous studies have been limited by the venue used to capture cases and methods used for case identification. We sought to overcome these limitations with the use of E-codes for child abuse and child maltreatment from a comprehensive statewide database. Other researchers have described limitations of E-code. Ellingson et al[5] using the 2003 Kids' Inpatient Database analysis of AHT showed that the combined use of child abuse E-code and child maltreatment syndrome diagnosis code captured 67.8%, whereas E-code alone captured only 19.4%. More recently, Leventhal et al[52] demonstrated the enhancing effect of the combined use of child abuse E-code and child maltreatment syndrome diagnosis code to identify and to track the trend of serious injuries due to physical abuse of children. Duhaime et al[19] further illustrate the gross underestimation of AHT with E-code. Of the 100 severe head injuries hospitalized to 3 teaching hospitals, only 2 (8.3%) of the 24 clinically confirmed AHT were admitted to have been caused by assault. Given the legal ramifications of such admissions, E-code will be of limited use to capture significant number of AHT for surveillance activities.

We believe that our estimates are more reliable because our database included both ED patients and inpatients and because we utilized more stringent ascertainment criteria. In our study, 42.4% of AHT was captured through ED surveillance. Case ascertainment bias due to failure to account for all data sources is a common limitation in surveillance of injuries and diseases.[53] Although most of the children with AHT identified from ED had less-severe injuries, they often represent vulnerable groups from underserved rural communities that might be subject to more abuse. However, there may be differential detection bias of less-severe AHT in the ED among children from indigent and unstable families who tend to use the ED as the primary venue of care. Clinicians in the ED have a heightened index of suspicion of child abuse. This theoretically reduces the probability of missing cases that are likely to be intentionally inflicted. Thus, there may be increased detection of AHT in this subgroup of the population while at the same time providing the opportunity to capture the less-severe types of abuse more likely to be missed among hospitalized children as noted by the study of Jenny et al.[54] Furthermore, our study also confirmed our hypothesis that ICH and retinal bleeding are strongly associated clinical markers of AHT. These clinical conditions have been consistently noted with AHT.[14,17,19,20,35,55] Our study supports the use of these injury patterns in future surveillance of AHT.

Although a large portion of AHT is severe, mild or moderate cases are common and more challenging to identify. These less obvious cases are very important to identify because, when missed, these children are at risk for repeat and, potentially, escalating abuse. We posit, therefore, that future surveillance for AHT should not focus solely on ICU patients but also include patients managed primarily in the ED. This is supported by work published previously by Runyan et al[3] that stressed the value of collecting information from multiple venues of care including ED.

The presence of ICH is highly predictive of AHT (HR of 20.31). This is consistent with other studies.[5,17,29,56–58] In previous studies, subdural hemorrhage was present in 90% to 95% of the autopsies[56,57] and in 55% to 94% of survivors of abuse.[17,58] Because of this increased frequency, ICH in children should prompt thorough investigation for abuse.[59] It may even be safe to assume children with ICH as potential abuse cases until proven otherwise unless there is a plausible mechanism of injury. The steep incidence probability KM plot with ICH through 75 weeks suggests the likelihood of AHT peaks in young children. Intracranial hemorrhage can be safely considered a cardinal feature of AHT in young children and therefore a valuable tool in the broader surveillance for AHT in population studies.

The relationship between indigent insurance and AHT is unsettling but not unexpected. A study from Pennsylvania showed Medicaid was the primary payer for 47% of AHT children,[7] and hospital discharge data from Kids Database indicate an increasing incidence of AHT with Medicaid.[5] Other studies showed children who are most likely to be abused are from low-income and poor neighborhoods,[13,17,59] where substandard living conditions and poverty-related stress are common. Our finding, however, does not support that parents and caregivers of children with indigent insurance are likely to be abusive. Poverty is an ecological marker of abuse and not an intrinsic behavioral attribute of poor parents. Similarly, the high HR of AHT noted in rural underserved communities could largely be explained by poverty.

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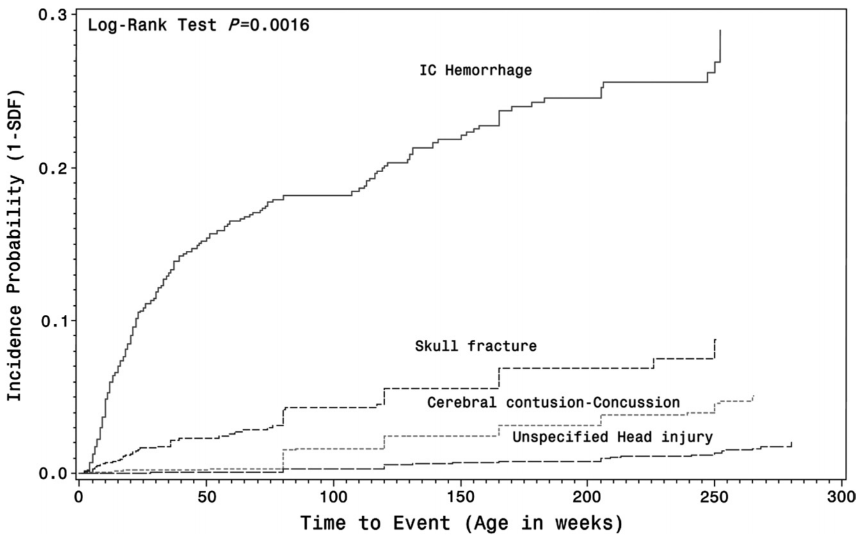

FIGURE 2. Kaplan-Meier plot of the incidence probability of AHT by type of brain injury.

The increased HR with concomitant injuries is supported by other studies.[20,22] Rib fracture is the most common injury, with 73% positive predictive value.[14] Multiple wounds and old scars are cardinal signs of prior abuse that should be taken seriously.[27] Although not reported in comparable studies, it has been shown that children with disabling illnesses or conditions requiring regular care are prone to abuse.[12,24,38–40,60] Although this phenomenon is intuitive, it was surprising to find no previous study that measured the extent to which stressful childhood illnesses are associated with AHT.

Although the strong bivariate association noted by hospital type was attenuated when adjusted, the likelihood of establishing a diagnosis of AHT is higher in pediatric specialty centers than in general hospitals. Trokel et al[27] observed that infants admitted to children's hospitals had a 2.7-fold increased odds of having a child abuse diagnosis compared with those admitted to general hospitals. Of note, nearly all studies describing the cardinal clinical features of AHT were based in children's hospitals. This suggests a special emphasis on child maltreatment in this type of institution.[8,14,16,58] Establishing a diagnosis of AHT requires a high index of suspicion, an experienced care provider, and an appreciation of subtle characteristics that make abuse more likely. This is perhaps the reason why a diagnosis of AHT is more likely to be made in a children's hospital setting.

In our study, joint analysis of sex and race show small racial effect, yielding comparable HRs among black boys, white boys, and black girls in reference to white girls as noted from overlapping CIs. This suggests that risk of AHT is less racially related and more likely explained by indigence. However, this stands contrary to studies that showed high risk with blacks.[6,7,61] A likely explanation for this discordant finding is residual confounding and detection bias. Previous studies did not adjust for socioeconomic status and relied on clinical reports where ascertainment bias toward black is high.[26,62–64]

Our study has several strengths. To our knowledge, it is the first study that quantified the incidence rate of AHT in a statewide population using both hospital discharge and ED visits. Estimation of risk associated with important sociodemographic and clinical variables and the analytical method that relied on time-to-event are important strengths. Furthermore, our data came from a population-based surveillance registry spanning 11 years from a state that has large underserved black population with the third highest infant mortality rate in the United States. Despite these strengths, there are several limitations worth noting. First, analysis is based on administrative data designed primarily for billing purposes. Although, the data set has 1 primary and 9 secondary diagnoses, it is possible that diagnoses with low reimbursement may have not been included, which would have contributed to underestimation of the rates reported.

Second, our case identification process would miss fatal cases of AHT that did not reach the hospital or ED, and therefore the overall rates are underestimations. Third, retinal injuries and ICH are frequently noted among children with AHT. These clinical pictures are factors that raise the suspicion for a diagnosis of abuse leading to circularity of cause-effect relationships positing fallacy in temporality of the association, particularly among low-income and minority parents/caregivers. However, our analysis indicates that there are many children diagnosed with AHT without retinal injuries and ICH, suggesting that these conditions were not the sole criteria to establish the diagnosis of abuse. Fourth, there is wide variability in skill set and diagnostic resources among hospitals in our state. It is possible that the accuracy of the fourth and fifth digit of the diagnosis codes from underresourced hospitals might be less reliable. However, earlier analyses support the reliability of this data system.[65] Fifth, ascertainment of AHT relied on child abuse and child maltreatment *ICD-9-CM* codes without validation against a more reliable source. However, our incidence estimates compare well with previous studies, making this limitation less significant.

CONCLUSIONS

Abusive head trauma remains a significant public health problem in young children. This study demonstrates the viability of improved population-based surveillance with a statewide data set including both ED and inpatient encounters. By using expanded cases, ascertainment criteria capture rate was improved. High-risk groups include children with indigent insurance, multiple injuries, and children from rural underserved communities. Intracranial hemorrhage and retinal hemorrhage are the most frequently encountered clinical indicators of AHT. Consideration of these clinical markers as ancillary criteria for case ascertainment in public health surveillance is invaluable. Enhancing diagnostic capabilities and awareness of AHT in

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general and underresourced hospitals and encouraging a multidisciplinary approach in clinical investigations are critical steps to identify AHT and improve public health surveillance for AHT.

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