AJR FOCUS ON:

Abusive Head Trauma: A Review of the Evidence Base

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OBJECTIVE. The purpose of this article is to review the constellation of findings of abusive head trauma, which may be accompanied by injuries to the appendicular and axial skeleton, brain and spinal cord, and retina. Additional common features include skin and soft-tissue injury, visceral findings, and evidence of oral trauma.

CONCLUSION. The evidence base for abusive head trauma encompasses diverse disciplines, including diagnostic imaging, pathology, pediatrics, biomechanics, ophthalmology, epidemiology, and orthopedics. When the varied sources of evidence are pieced together and taken in toto, abusive head trauma is often readily differentiated from alternative explanations of an infant's injuries.

Abusive head trauma (AHT), according to the U.S. Centers for Disease Control and Prevention [1], is an injury to the skull or intracranial contents of an infant or child younger than 5 years caused by inflicted blunt impact, violent shaking, or both. The constellation of findings may include injuries to the appendicular and axial skeleton, brain and spinal cord, and retina. Additional common features include skin and soft-tissue injury, visceral findings, and evidence of oral trauma.

History

The recognition of injuries to infants that result from inflicted trauma can be traced to the middle of the 19th century. Auguste Ambroise Tardieu, a French pathologist, characterized injuries to infants and children in Paris that he attributed to trauma at the hands of caretakers. In 1860, Tardieu described injuries to 32 children as resulting from "acts of cruelty and ill treatment"; 24 (75%) of the injuries were at the hands of parents [2]. Burhans and Gerstenberger [3] in 1923 reported on five infants with subdural hematoma (SDH) in four of whom trauma was identified and in four of whom retinal hemorrhage (RH) was identified. Those authors reported that "trauma has been a more constant feature in the history of our cases, although it has not been present in all." Peet and Kahn [4] in 1932 reported on nine infants with SDH, which they indicated was undoubtedly from trauma; eight of the infants had eye findings. In 1946 skeletal injuries associated with chronic subdural collections were described by the pediatric radiologist John Caffey [5]. Caffey reported the association between long bone fractures in children and chronic SDH. Although he recognized that trauma was likely the underlying cause of both, he indicated that "the traumatic episodes and the causal mechanism remain obscure" [5]. In 1953 the British neurosurgeon Norman Guthkelch [6] reported on 18 infants with SDH, 11 of whom were younger than 3 months. Guthkelch reported that 10–15% of the infants had RH and attributed the SDH to birth injuries in 8 of the 16. In 1971 Guthkelch [7] described a series of 23 children with SDH, 22 of whom were younger than 18 months. The causes of SDH in these children were "proved or strongly suspected parental assault." In 1962, Kempe and colleagues [8] set the findings of long bone fractures and SDH into a larger framework: battered child syndrome. They reported that the "findings are quite variable" and could include fractures, SDH, soft-tissue injury, poor hygiene, and malnutrition [8]. In 1974, 28 years after initially describing fractures associated with SDH, Caffey [9] attributed these findings to shaking.

The terminology for the constellation of findings associated with AHT has evolved as understanding of the findings, circumstances, and biomechanics has improved. Even though the findings described by Tardieu

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in the 1880s were similar to those currently seen in AHT, it was Kempe et al. [8] who first coined the term battered child syndrome in 1962. Caffey [9] introduced the terms parent-infant traumatic stress syndrome in 1972 and whiplash shaken infant syndrome in 1974. Since introduced by Caffey in 1972, the term shaken baby syndrome has been frequently used in the medical literature and the general press. In 2009, the American Academy of Pediatrics [10] endorsed a shift in terminology away from the mechanism (shaking) and toward the clinical findings (head trauma). The academy position was that although shaking (rotational injury) can clearly injure an infant, the term abusive head trauma encompasses a broader array of traumatic mechanisms. These include slamming, striking with an object, throwing, and crush forces. The change in nomenclature removes the focus from shaking as a mechanism and places it on the commonality that the head is involved and that the actions causing the trauma are abusive in nature (often referred to as nonaccidental or inflicted).

Epidemiology

The systematic challenges to estimating the precise incidence of AHT include heterogeneity of clinical findings, age-related differences in symptoms and incidence, and different surveillance systems. In addition, many abused infants may not be seen by medical providers [11], and if the infant is seen, the AHT may not be recognized [12]. Despite these challenges, the population incidence estimates are strikingly similar across populations on different continents. Broadly, the incidence of AHT is between 14–40 cases per 100,000 children younger than 1 year [13–18]. The most recent national estimate for the incidence of AHT, for the period 2000–2009, is 39.8 per 100,000 children younger than 1 year [14]. This makes AHT more common than neonatal meningitis. Two high-quality prospective studies in two unrelated large populations showed similar incidence rates. Barlow and Minns [15] conducted weekly contacts with all hospital pediatric departments, pediatric ICUs, and neurosurgical units for all of Scotland for 2 years. They identified 19 cases of AHT, for an annual incidence of 24.6 per 100,000 children younger than 1 year. Keenan and colleagues [16], using a similar surveillance technique for all of North Carolina, reported a rate of 29.7 per 100,000 children younger than 1 year. These rates are remarkably similar to the rate of SDH reported by Jayawant and colleagues [17] in South Wales and southwest England. Those authors retrospectively reviewed inpatient records for 2 years in their region and identified 43 children with SDH—an annual incidence of 21 per 100,000 children younger than 1 year. Talvik and colleagues [13] prospectively evaluated all children admitted to the tertiary care hospitals in Estonia for suspected AHT over a 4-year period and reported an incidence of 40.5 per 100,000 children younger than 1 year. The consistency of the estimates at different times, obtained with different surveillance strategies, and across different populations provides face validity to presence of AHT.

Much of the surveillance of AHT is through hospital discharge (i.e., inpatient) datasets. A report in South Carolina that included both inpatient and emergency department statewide data showed an incidence of 28.9 per 100,000 children younger than 1 year, or one case of AHT for every 3450 infants [19]. The authors noted that 42% of the cases were identified in the emergency department, not among inpatients. Older children with AHT are less likely to be admitted to the hospital for their injuries. Among children with the diagnosis of AHT, 55% of the inpatients were younger than 1 year, whereas only 9% of the emergency department patients were younger than 1 year. This report supports the notion that most of the estimates of AHT (made with inpatient data) are underestimations of the true disease incidence.

There is a slight, but consistent, male predominance among reported victims of AHT [6, 16, 18–21]. The first year of life is the most frequent age for AHT [22], infants younger than 6 months being at particular risk [23]. Although it is common in the first 3–4 months of life, infant crying is regularly reported as an antecedent event of shaking injury [7, 9, 11, 24–27]. Barr and colleagues [28] reported that the age-specific incidence of AHT in California mapped closely the crying curve in infancy. Maternal characteristics associated with increased risk of perpetrating AHT include age younger than 21 years and being unmarried [16]. Children living in households with unrelated adults, compared with a home with two biologic parents, are at 50-fold increased risk of dying of inflicted injuries [29]. Maternal undereducation (< 12 years), maternal age younger than 15 years, and lack of prenatal care have been identified as risk factors for infant homicide, battering being the most common cause [21]. A survey of parents in The Netherlands showed that 5.6% of parents indicated that they smothered, slapped, or shook their infants because of their crying [11]. A survey in North and South Carolina showed that 2.6% of parents reported shaking their children younger than 2 years as a method of discipline [30]. Perpetrators of AHT are more than twice as often men. Fathers are the most common perpetrators of AHT overall [24, 25, 27, 31], followed by mothers' boyfriends and female babysitters [24, 25].

Clinical History

Child victims of AHT often present with findings related to the brain injury. Depending on the circumstances of the injury and the developmental age of the child, those symptoms may be obvious and pronounced or subtle and nonspecific. Infants and younger children may have nonspecific symptoms, such as vomiting, that are misinterpreted, or even missed, by caretakers [12]. The history presented to clinicians evaluating and caring for the child may often be incomplete or even incorrect [12, 25, 26, 32, 33]. Hettler and Greenes [32] found that among children younger than 3 years with intracranial injury, a history that changed was found only in cases of AHT [32]. In children with intracranial injury, the absence of a history of trauma has been repeatedly found to be associated with AHT [22, 23, 32–35]. In addition to the absence of a history of trauma, the history of a short fall (< 3 feet [0.9 m]) resulting in clinically significant intracranial injury has been repeatedly found to be associated with AHT [22, 32]. Infants with AHT present with lower Glasgow Coma Scale scores and higher injury scores than infant victims of accidental injury [20].

Clinical Findings

The findings Tardieu described more than 150 years ago were strikingly similar to injuries seen today: long bone fractures, rib fractures, and brain injuries. The primary findings involve cranial injury (CNS and skull) but can involve the skin (bruising and soft-tissue swelling), skeleton (particularly rib and metaphyseal fractures), eyes (retinal and optic nerve hemorrhage), and neck (cervical spinal and ligamentous injury). Most of the presenting symptoms are associated with CNS injury. Vomiting [18, 25, 36], altered mental status [18, 25, 37, 38], seizure [18, 25, 32, 36–39], and apnea [18, 25, 32, 39] are among the most common. Although debated, the symptoms of AHT are most often reported as immediate (seconds to minutes as opposed to minutes to hours after injury) [24, 25].

Head

The cardinal intracranial finding associated with AHT is SDH [23, 39–41], which is well described as a consequence of trauma. In infants the presence of SDH is strongly associated with AHT [41]. In 1860 Tardieu described "blood on the surface of the brain" child fatalities resulting from abuse [2]. Described for centuries, one of the most common causes of SDH in the pediatric population is birth [18, 42]. If all vaginally born infants were imaged within the first few days of life, approximately one fourth would be found to have a small SDH [43, 44]. These hematomas are universally small and asymptomatic. The best estimate is that birth-related SDH resolves by 4–6 weeks of age. There have been no reported cases of birth-related SDH progressing to chronic SDH or rebleeding. After 4–6 weeks of life, birth can safely be excluded as a cause of SDH. Outside of birth-related SDH, SDH in children is most commonly due to trauma [33, 42]. The presence of an SDH in an infant with an inadequate history has repeatedly had a high association with AHT [22, 34, 39, 40, 41]. The neuroimaging features more commonly associated with accidental head injury include epidural hematoma, intraparenchymal injury, and skull fractures [20, 35, 37, 40, 41].

External

Bruising of victims of AHT is the most common external finding. Although there may be many different patterns and locations of bruising, the most important consideration is the age of the child. Bruising of nonmobile infants is most concerning for AHT [45, 46]. Bruising of the head and neck may also be of particular concern [40, 46]. In general, bruising of otherwise healthy infants is rare [47, 48], and bruising even in fatal AHT is uncommon [7, 49]. In a retrospective review of AHT fatalities, Atwal and colleagues [50] reported 21% had no bruising and 29% had no fresh bruises. Ingham and colleagues [49] reported only 16% of infants who died of AHT had one or more bruises. The absence of bruising on children with fractures is common and well described [51]. In a report by Mathew and colleagues [51], 72% of children with fractures did not have bruises associated with the fractures within 1 week of injury. The authors concluded that absence of bruising cannot be taken to imply either underlying bone disease or an increased possibility of nonaccidental injury.

Skeletal

Skeletal injury, particularly rib fractures and long bone fractures, has repeatedly been found to be associated with AHT in infants [22, 39, 40, 52]. Rib fractures are thought to occur as a result of squeezing around the infant's chest during shaking or slamming and have been described repeatedly as being highly associated with physical abuse, AHT in particular. Although early reports dismissed cardiopulmonary resuscitation (CPR) as a cause of rib fractures, some preliminary data support the hypothesis that the acute anterior rib fractures (CPR-associated rib fractures) described in adults [53] may also occur in infants [54]. There are limited data on whether posterior rib fractures occur as a result of two-thumb CPR [55]. Clearly, the presence of a healing rib fracture (callus formation) would preclude recent chest compressions.

The two most commonly identified long bone fractures in AHT are of the humerus and femur. Diaphyseal fractures of either bone are strongly associated with inflicted trauma (physical abuse) in infancy [52, 56]. With increasing age beyond 1 year (increasing ambulation), accidental mechanisms become more common [57–59].

Eyes

RH is an important component of the constellation of findings associated with AHT [39, 60]. Although not diagnostic in isolation, the presence of RH, along with particular qualitative features of RH, have been strongly associated with AHT [39, 40, 60]. Like SDH, RH has been regularly described as occurring during the birth process and resolves typically within the first month of life [61, 62]. RH has been described in children with other causes of trauma [23], particularly motor vehicle crashes [35, 63] and crush injuries [64, 65], and critical illness [66], but RH from accidental causes typically occurs in a pattern clearly distinct from those associated with AHT [38, 60, 67]. Hemorrhages that extend to the outer margins of the retina (ora serrata retinae), that are extensive (too numerous to count), and that involve multiple layers although not pathognomonic are a particularly precise pattern associated with AHT [34, 36, 38, 60, 68]. It is uncommon, but has been described, for RH to be present in victims of AHT without radiographic signs of intracranial injury at neuroimaging [69]. In addition to RH, retinoschisis (a particular folding of the retina) is also strongly associated with AHT [68, 70] and has been described in crush injuries to the head [64, 65].

Neck

The cervical spine plays a crucial role in the biomechanics of AHT. Compared with older children and adults, infants have disproportionately large heads supported on a weak neck. Hadley and colleagues [71] described a whiplash shake syndrome in 13 infants. They reported that five of the six infant autopsies showed evidence of cervicomedullary junction injury. A separate review of 14 autopsies of infant victims of AHT [72] revealed traumatic axonal damage in the cervical spine in 7 of 11 infants. Brennan and colleagues [73] later found that 71% of infant victims of AHT had primary cervical cord injury. Early imaging studies did not show significant cervical cord findings, but more recent MRI studies clearly show cervical spinal injury (cord or ligament) [74].

Combination of Findings

Although each of the clinical findings has a meaningful association with AHT, it is in combination that dramatic correlations emerge. For example, whereas SDH may have a narrow differential diagnosis by itself, when placed in the context of the clinical history (or lack thereof) and the neurologic, retinal, and skeletal findings, that differential diagnosis evaporates. Maguire and colleagues [39] illustrated this concept most clearly. In a systematic review of the literature, they used patient-level data and found that the probability of AHT in a hypothetical 3-year-old child with an intracranial injury can narrow quite quickly as the findings are combined. The authors collected from the primary authors of six previous publications [18, 22, 32, 36, 38, 75] patient data on children (n = 1053) younger than 3 years with an intracranial injury. Intracranial injury included any combination of subdural hemorrhage, subarachnoid hemorrhage, extradural hemorrhage, intraparenchymal injury, cerebral contusion, diffuse axonal injury, hypoxic ischemic injury, or associated cerebral edema [39]. Using a conservative case definition, the authors evaluated the predictive probability of six clinical findings, both alone and in various combinations. The six clinical variables were any RH, any long bone fracture, any rib fracture, any seizures, any apnea, and any head or neck bruising (Fig. 1). If a 3-year-old child with intracranial injury were to have bruising to the head and neck and a seizure, the probability of AHT would change from the baseline 3% to approximately 46%. If a long bone fracture was also identified, the probability would increase to 92%. If all six of the clinical findings were present, a 3-year-old child with an intracranial injury with head or neck bruising, apnea, seizures, long bone fracture, rib fracture, and RH would have a (reported) 100% probability of having sustained AHT.

In a report on child victims of AHT by Vinchon and colleagues [37], the combination of SDH, severe RH, and the absence of findings of head impact had a sensitivity of 0.24 but a specificity of 1.0. This indicates that the presence of the findings associated with AHT, if present, is quite specific but that their absence is not a good indicator of the absence of abuse.

Secondary Injury

Two phases of injury account for the symptoms and outcomes of AHT. The primary neuronal injury (traumatic axonal injury) results in immediate physical injury to axons [76]. It also results in secondary axotomy, in which injured axons undergo a delayed process that results in neuronal death [77]. Cerebral edema, hypoperfusion, ischemia, oxidative stress, and hypoxia all may contribute to delayed neuronal injury and death. In addition, the presence of SDH is associated with a clinically significant inflammatory response [78]. Cervical spinal injury, which can result in hypoventilation or apnea, may contribute to a worse neurologic outcome by exacerbating the secondary cellular injury.

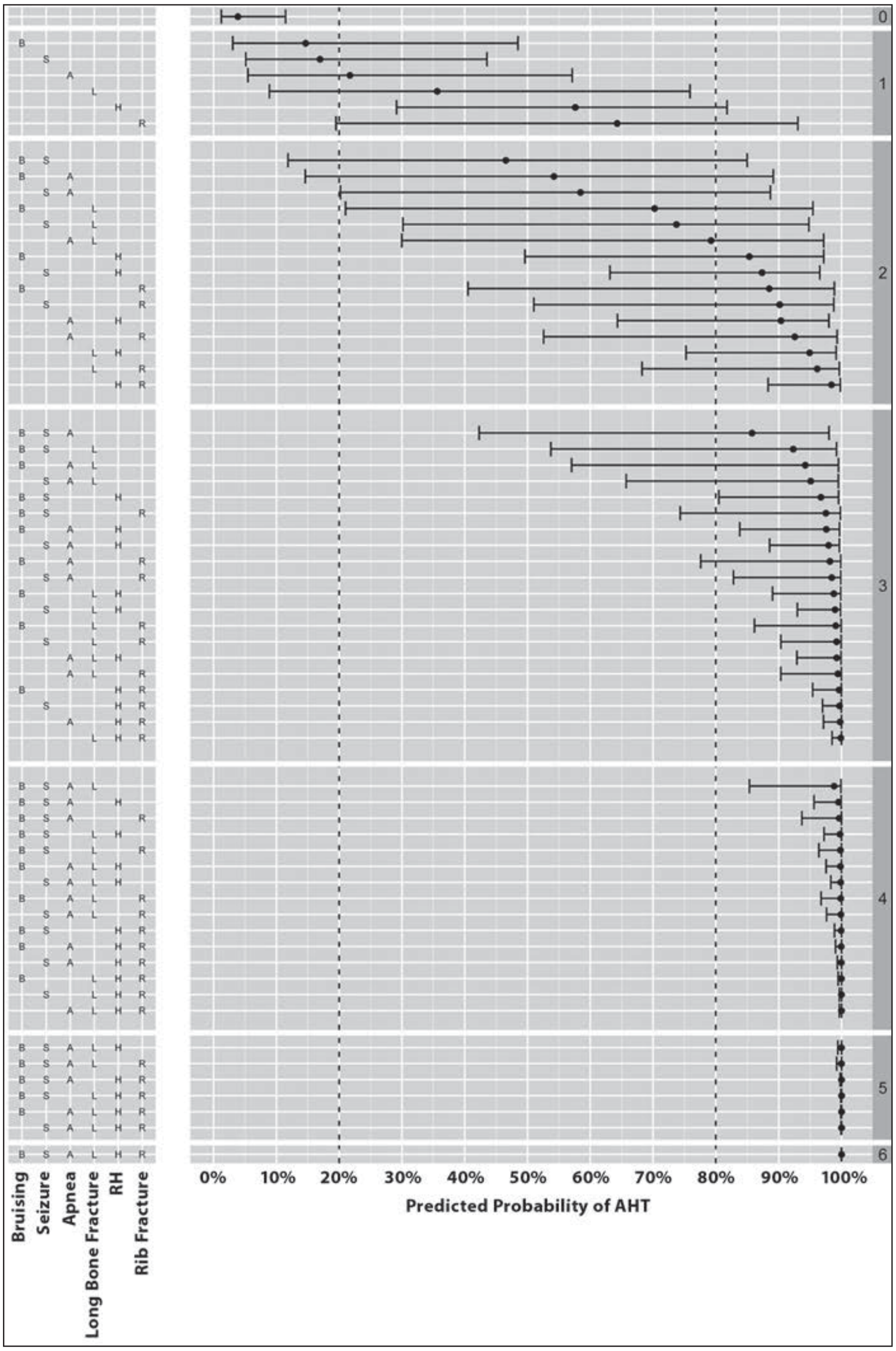

Fig. 1—Graph shows probability that 3-year-old child with intracranial injury has abusive head trauma on basis of additional findings. Numbers at right are numbers of findings. (RH = retinal hemorrhage, AHT = abusive head trauma.) Dashed lines represent hypothetical thresholds for diagnosis or exclusion. (Reprinted with permission from [39])

Outcomes

AHT is the most common cause of traumatic death in infancy [36]. The mortality rate for AHT is greater than that for accidental head injury [23, 79]. It is estimated that 8–25% of infant victims die as a result of their injuries [24, 32, 80]. The survivors have considerable associated morbidity as a result of the injury [17, 32, 36, 81, 82]. In a large retrospective study in Canada [80], only 7% of survivors were identified as having normal neurologic function. Most of those injured had a moderate or greater degree of neurologic disability (60%); 65% had visual impairment; and 12% were in a permanent vegetative state. A prospective study in Switzerland [82] showed that 64% of victims of AHT were disabled and that 36% had a good outcome after 13 months. Barlow and colleagues [83] reported a similar distribution of outcomes in 2005. Using a cross-sectional study design, the authors found that 68% of survivors of AHT had neurologic abnormalities, 36% had severe neurologic difficulties, 16% had moderate difficulties, and 16% had mild difficulties.

Biomechanics

The dangers of shaking an infant are, for many, self-apparent. The growing body of literature in which perpetrators of AHT are asked about the circumstances of the injuries to the child underscores this concept. The literature clearly shows that often in response to frustration, the perpetrator shakes or both shakes and slams the child [25–27, 82]. Because of the clear ethical prohibitions to shaking human infants, much of the biomechanical evidence on the dangers of shaking has been the result of animal research. Although species differences limit broad generalization, a meaningful amount of overlap between humans and other animal species makes animal modeling valuable.

Some of the earliest work to inform the dangers of shaking was primate studies conducted by Ommaya and colleagues [84, 85]. In 1968 they placed sedated rhesus monkeys into a fiberglass chair apparatus (akin to a rocket sled) and delivered an impulse to the chair that resulted in a single whiplash force [85]. Of the 19 monkeys with concussions, 15 had macroscopic SDH. None of the monkeys without concussions (n = 22) had macroscopic SDH. Bonnier and colleagues [86] used a mouse model of shaking without impact and hemorrhagic and traumatic brain lesions and found a 27% fatality rate. The surviving mouse pups had multifocal cystic white matter injury and RH. Finnie and colleagues [87] and Anderson and colleagues [88] used an ovine (lamb) model of shaking alone and found that the shaking caused CNS cellular damage, apnea, and death.

Biofidelic and computer models have been used to study the forces involved in shaking an infant. Although the models are promising, there are a number of challenges to both biofidelic (physical) and computer modeling of AHT. Some of the current issues with the use of model data are that data on the effect of scaling of forces are lacking, infant injury thresholds are unknown, and the materials and structures used in physical models do not completely duplicate infant dynamics [89].

A growing body of literature describes adults admitting to injuring their infants by shaking both with and without head impact [24, 25, 27, 31, 37]. Of particular interest is the report by Adamsbaum and colleagues [27]. This report describes caregiver admissions in France, where plea bargains are not a component of the legal process and thus there is no criminal benefit to admitting to injuring a child. Caregivers who admitted to shaking their infants reported crying as the most important trigger of lashing out at the child, that the shakes were violent, and that most of the shaking injuries did not involve head impact. More than one half of the caregivers reported repeated episodes of shaking. Of the children injured by confessed shaking, 79% had RH, 38% had skeletal injuries, 34% had bruising, and 31% died. Vinchon and colleagues [37] reported on a subsequent cohort of child victims of admitted shaking in France. Their findings were strikingly similar to those of Adamsbaum and colleagues: 85% of victims had RH, 78% had no head impact, and 22% died.

Prevention

Despite many advances in the prevention of child maltreatment in general, there have been limited advances in the prevention of AHT in particular. The most common approach to preventing AHT involves targeting parents immediately after birth. Many of the strategies focus on counseling parents about infant crying and the dangers of shaking a baby. Some of the earliest work in preventing AHT specifically was performed in upstate New York by Dias and colleagues [90]. Using a nonrandomized hospital-based parent education strategy, those authors reported a 47% decrease in the incidence of AHT compared with the rate among historic control subjects. Their strategy involved a one-page pamphlet, an 11-minute video, and nurse support provided to new parents in maternity wards. A similar study in midstate New York showed a 75% decrease in AHT-related injuries [91]. The nonrandomized design of these two studies requires caution in overestimating the efficacy of this strategy. Two randomized trials have shown that perinatal education can improve parental understanding of the dangers of shaking an infant. Barr and colleagues in Vancouver, BC, Canada [92], and Washington state [93] performed a randomized trial of an infant crying educational curriculum (Period of PURPLE Crying). (PURPLE is an acronym for crying characteristics—peak pattern, unexpected timing, resistance to soothing, pain-like look, long bouts, and evening occurrence.) Neither of these trials showed improved caregiver knowledge about infant crying or the dangers of shaking an infant.

Conclusion

A diverse, complicated, international, transdisciplinary, and voluminous evidence base characterizes AHT. When this expansive evidence base is pieced together and taken in toto, AHT can be readily differentiated from alternative explanations of a child's injuries. The debate surrounding AHT is neither scientific nor medical, but legal. Although some authors question the specificity of the clinical findings [94–96], there is near-complete agreement, even among skeptics, that shaking of an infant is dangerous and can be fatal [94, 96, 97]. As in the antivaccine effort, many skeptics of AHT misrepresent or simply misunderstand the breadth of the published medical evidence and introduce this into courtrooms as so-called new science.

The evidence supporting AHT as outlined in this review clearly fits the Bradford Hill criteria for causation [98]. Maguire and colleagues [39] found strength of association for the findings with odds ratios of 10^3 to 10^6 for the combinations of findings (Bradford Hill criterion, strength). The findings of AHT are consistently made by multiple investigators, in multiple countries over a span of more than 100 years (Bradford Hill criterion, consistency). When the findings associated with AHT are combined, there are few, if any, true mimics (Bradford Hill criterion, specificity). The findings associated with AHT occur after a shaking or slamming event as opposed to before (Bradford Hill criterion, temporality). Shaking of an infant out of anger or frustration is readily endorsed both by parents in various countries and by those who have admitted injuring their children (Bradford Hill criterion, plausibility). The findings associated with AHT are clearly traumatic in origin and have consequences similar to those of other traumatic brain injuries (Bradford Hill criterion, coherence). Animal models have shown findings strikingly similar to those in human infants (Bradford Hill criterion, experiment). It is well described that patients may misrepresent their medical histories in an attempt to misdirect the physician to cover for objectionable behavior (e.g., drug-seeking behavior and eating disorders) (Bradford Hill criterion, analogy).

AHT is a devastating neurologic injury that constitutes a tremendous medical, social, emotional, societal, and financial burden. Abuse of any infant is a tragedy, a sign of a greater community shortcoming in which vulnerable children and their parents (for the most part) find themselves in circumstances that result in devastating injury. The features of abuse having been recognized for more than 150 years, great strides have been made in understanding its causes and consequences. This knowledge can and should be leveraged toward improving outcomes among victims of AHT and, ultimately, preventing it.

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