Abusive Head Trauma: Epidemiology, Pathogenesis, Diagnosis and Outcome

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Abstract

While accidental trauma is the most common cause of death in childhood, abusive head trauma is the most common cause of traumatic death in infancy. The incidence of abusive head trauma in the United States is estimated to be 15 per 1000 children each year, though this may be an underestimation. Nearly 25% of children under 2 years of age who are hospitalized for head trauma have been abused. There are several clinical and radiological features that are helpful in distinguishing accidental from abusive head trauma in young infants, such as retinal hemorrhages, which are present in 60% to 95% of patients with abusive head trauma. Computed tomographic scanning (CT) is the most rapid, reliable tool in the diagnosis of abusive head trauma. Acute subdural and subarrachnoid hemorrhage, the most common brain injuries seen in children with abusive head trauma, can be readily appreciated on CT by experienced clinicians. Long-term outcome of survivors of abusive head trauma tends to be poor, and is dependent on the severity of symptoms on initial presentation. Such clinical features are helpful in distinguishing accidental from abusive head trauma in young children.

Abusive Head Trauma

Introduction

Child abuse has been documented in the United States for over a century. The first well-publicized case of child abuse in the United States occurred in New York in 1874 (Ten Bensel, Rheinberger & Radbill, 1997). According to accounts from various contemporary sources, a young girl named Mary Ellen had been systematically and severely beaten by her stepmother. When a Methodist missionary, Mrs. Wheeler, was unsuccessful in interceding on the child's behalf, she turned to the founder of the New York Society for the Prevention of Cruelty to Animals (NYSPCA), Henry Bergh. Through the efforts of Mr. Bergh and the NYSPCA, the parental rights of Mary Ellen's stepmother were terminated, and Mrs. Wheeler then adopted Mary Ellen. One year later, Mr. Bergh founded the New York Society for the Prevention of Cruelty to Children. Nearly one hundred years later, in 1962, Henry Kempe and colleagues, published "The Battered Child Syndrome," which contained the results of a survey of law enforcement/protection professionals who noted large numbers of alleged child beatings by caregivers (Kempe, Silverman, Stele, Drogemuller, & Silver, 1962).

Despite the vast amount of literature regarding the detection, evaluation and prevention of child abuse that has been published since Kempe's landmark article, the maltreatment of children continues to be a significant problem in the United States. Solving this problem requires cooperation among many professional disciplines. Dr. Richard Krugman, a pioneer in the field of child maltreatment evaluation, nicely summarized this sentiment in the following statement:

> When I was an intern, I learned that child abuse is not just a medical problem, a social problem or a legal problem. It is ultimately a child's problem, and solving it requires that all professionals work together for that child and family. (1991, p. 3)

While trauma is the most common cause of death in childhood, abusive head trauma is the most common cause of traumatic death in infancy. The yearly incidence of abusive head trauma in the United States is estimated to be 15 per 1000 children, though this may be an underestimation. Nearly 25% of children under two years of age who are hospitalized for head trauma have been abused (Duhaime & Partington, 2002).

Since the 1940's, the features of abusive head trauma, also known as *shaken baby* or *shaking-impact* syndrome, have been well established. In 1946, Robert Salinger, a pediatrician, first characterized the original "battered babies" (Caffey, 1974). He described an infant nurse who confessed to killing three infants who were in her care and injuring many more in her care. She would become angry and frustrated over an infant's crying and proceeded to grab the child about the chest or between the shoulders and elbows and shake them violently until the infant ceased to cry. Autopsies on two of these infants revealed diffuse subdural hemorrhage over both cerebral hemispheres.

The biomechanical forces necessary to cause this spectrum of injuries have only recently been explained. In 1972, Caffey described the "Whiplash Shaken Infant Syndrome", which suggested that the pathogenesis of such injuries as subdural hemorrhage and retinal hemorrhage was rotational deceleration forces of the head. Such forces cause the dura to slide along the surface of the brain, rupturing the vessels in the subdural space. Similarly, the vitreous humor slides along the surface of the retina, disrupting the vessels that course between the layers of the retina, resulting in diffuse retinal hemorrhage (Annable, 1994).

There has been some disagreement among those who care for children with abusive head trauma as to whether shaking alone is a sufficient cause, or whether both shaking and impact are necessary to cause this spectrum of injuries. Duhaime and colleagues in 1987 and Prange and colleagues in 2003 constructed biomechanical infant models and demonstrated that the forces necessary to cause concussion and subdural hemorrhage were generated only when these models were shaken and impacted on a fixed, hard surface, and not during shaking alone or during falls less than 1.5 meters (Duhaime et al., 1987; Prange, Coats, Duhaime, & Margulies, 2003). Such evidence of impact injury to the head may not be apparent on initial examination, and may be recognized only when the scalp is shaved or the galea exposed at surgery (Duhaime, Christian, Rorke, & Zimmerman, 1998). Other investigators have suggested that vigorous, violent shaking alone generates the force necessary to cause these injuries. Gilliland and Folberg (1996) reviewed the autopsies of children who died from abusive head trauma and found that 9% did not have any evidence of focal injury to the scalp, skull or dura.

Evaluating through Caregiver History

Caregivers who inflict these injuries are sometimes unaware that they had injured the child. However, a competent observer would realize that such caregiver actions would inherently be injurious to the child. Infants and children are often shaken because of a caregiver's unrealistic expectations of the infant or child or as a disproportionate response to increasing levels of frustration. In some instances, it may be difficult to determine if the caregiver's intent was to inflict harm or to simply to stop the infant or child from crying. Recent studies have demonstrated that perpetrators who injure children in this manner are most likely to be, in descending order, fathers, male paramours, female babysitters and mothers (Starling & Holdern, 2000).

The histories provided by caregivers may be vague, such as "I found him like this when he awoke from a nap." There may be a suggestion of or reference to a remote, poorly defined event, such as "He may have fallen off the couch yesterday" or to a minor fall, such as "She fell and hit her head on the ground" or "He hit himself in the head with a toy". There is much literature to support the concept that household falls or falls down stairs rarely result in life threatening brain injury (Joffe & Ludwig, 1988; Helfer, Storis & Black, 1977; Duhaime, Alario, et al., 1992), except if a space-occupying lesion, such as an epidural or large intracranial hemorrhage, is present.

Evaluation through Physical examination

Children with abusive head trauma can have a wide spectrum of symptoms and signs. Children with milder injuries may have only irritability, vomiting, poor feeding or sleepiness. These are symptoms overlap with those a myriad of common pediatric illnesses, and thus these children might not be recognized as having sustained an inflicted head injury. Children with severe injuries often present with more ominous symptoms and signs, such as apnea, unresponsiveness, seizures or cardiopulmonary arrest. The highest incidence of such injury is in children under six months of age, due to their proportionally larger head, weak neck muscles and poor head control, though varying degrees of injury can be seen in children up to two years of age (Duhaime, Christian, Rorke, & Zimmerman, 1998). Older, but physically smaller, children with developmental delays can also suffer from these injuries.

The observation that the diagnosis of abusive head trauma may be overlooked in children with milder symptoms was supported by a study by Jenny and colleagues in 1999 (Jenny, Hymel, Ritzen, Reinert & Hay, 1999). These investigators reviewed the medical records of 173 children less than three years of age with inflicted head trauma. They found that although 54 of these children (31%) had had a medical evaluation shortly after sustaining inflicted head trauma, the clinician failed to recognize that the child had been injured in this manner. The children who were most likely to have the diagnosis of abusive head trauma "missed" were very young (less than 6 months old), Caucasian infants who came from families where both parents lived in the home. This group of infants did not have respiratory compromise or seizures, and were more likely to have only irritability or vomiting.

On physical examination, there may not be obvious signs of trauma to the head, neck or chest. Scalp contusions may be seen only when the head is

shaved or when the scalp is exposed during craniotomy (Duhaime, Christian, Rorke, & Zimmerman, 1998). The extent of brain injury largely determines the signs and symptoms a child may have. There may be focal neurological signs, such as hypertonicity or flaccidity, gaze palsies, or unequal pupils. The child may be irritable or unresponsive to pain. Focal or generalized seizures may be apparent. Cardiopulmonary arrest may be due to significant brain injury, either from direct deceleration injury to the brainstem and upper cervical cord or from subsequent hypoxia and ischemia from cerebral edema (Duhaime, Christian, Rorke, & Zimmerman, 1998).

Retinal hemorrhages are present in 60% to 95% of patients with abusive head trauma (Annable, 1994; Duhaime, Christian, Rorke, & Zimmerman, 1998). They may sometimes be discovered on direct ophthalmoscopy without mydriatics, but often the true extent of hemorrhaging may be appreciated only with dilated, indirect ophthalmoscopy. Typically, the retinal hemorrhages seen in those children with abusive head trauma are multiple and often extend to the periphery (Krugman, 1991; Caffey, 1974). They can occur in multiple layers of the retina, most often in the nerve fiber and ganglion cell layers, and appear to be flame-shaped. Intraretinal and preretinal hemorrhages are more often dot-, blot- or boat-shaped hemorrhages (Annable, 1994). Retinal hemorrhages may either be unilateral or bilateral. Retinoschesis, internal splitting of the retina, macular folding, and vitreous hemorrhage are other retinal abnormalities often associated with abusive head trauma (Annable, 1994; Duhaime, Christian, Rorke, & Zimmerman, 1998).

On occasion, retinal hemorrhage may be seen in head injuries associated with accidental mechanisms. A recent case series by Christian and colleagues (1999) documented three cases of accidental falls and found that retinal hemorrhages were present on the same side as the subdural hemorrhage (Christian, Taylor, Hertle, & Duhaime, 1999). However, the retinal hemorrhages noted in this case series were isolated to the posterior pole of the retina, did not cover a significant surface area of the retina, did not extend to the periphery and were not accompanied by retinal folds or detachment. Similarly, Schloff et al. (2002) found that up to 8% of children with intracranial hemorrhage from accidental causes or neurosurgical procedures may have retinal hemorrhages. In contrast, retinal hemorrhages seen in abusive head trauma are diffuse and extend to the periphery of the retina. When such hemorrhage is associated with retinal folding or detachment or retinoschesis, the condition is highly suggestive of abusive injury. Finally, Bechtel and colleagues (2004) performed a prospective study of hospitalized children with inflicted and accidental head injury. Retinal hemorrhage was recognized in 10% of children with accidental head trauma and the majority of these were unilateral (Odom et al., 1997). In contrast, 60% of those with abusive head trauma had retinal hemorrhages that extended to the periphery, and these involved the preretinal layer and covered the macula (Odom et al., 1997). When retinal injury is suspected in cases of inflicted childhood neurotrauma, it is important that a dilated examination by an ophthalmologist be obtained, as important injury may be missed when such an examination is done by someone other than an ophthalmologist (Levin, 1990; Morad, et al., 2003).

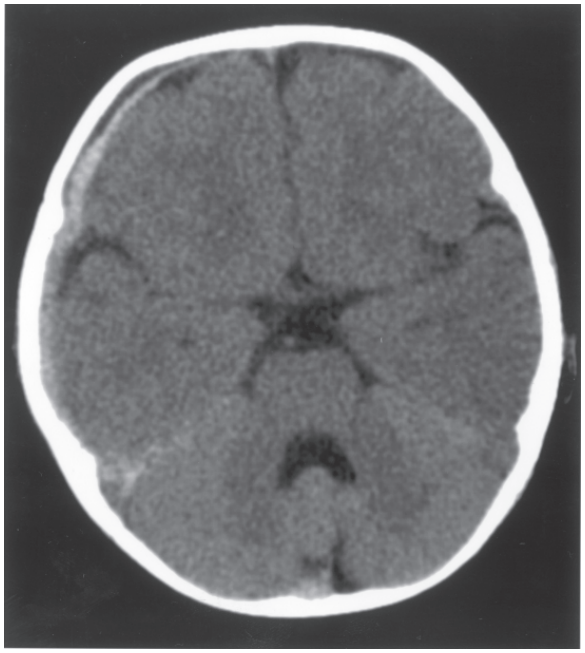
Cardiopulmonary resuscitation typically does not cause retinal hemorrhages. Odom and colleagues (1997) performed dilated indirect ophthalmoscopy on hospitalized children who had undergone at least one minute of closed chest compressions during cardiopulmonary resuscitation. Of the 43 patients studied, only one patient had retinal hemorrhages, which were few in number. This patient also had evidence of activated coagulation at the time of the ophthalmoscopic examination. Retinal hemorrhage may be seen in up to 30% of infants shortly after birth, but typically resolves after 6 weeks of age (Barnes & Robson, 2000; Feldman, 1997).

Evaluation through Radiography

Computed tomographic scanning (CT) is the most rapid, reliable tool in the diagnosis of abusive head trauma. Acute subdural and subarrachnoid hemorrhage, the most common brain injuries seen in children with abusive head trauma, can be readily appreciated on CT by experienced clinicians (See Figure 1). Typically, a subdural hemorrhage will be thin and extensive, but can occasionally be large enough to cause mass effect (Smith, 1997). There is a high propensity for subdural hemorrhage to involve the interhemispheric fissure, but also can involve the convexities, and can be unilateral or bilateral (Duhaime, et al, 1987; Schloff et al., 2002). Subarachnoid hemorrhages are usually multifocal and can be most often seen along the falx or the tentorium (Duhaime, Christian, Moss & Seidl, 1996). Skull fractures as well can be detected by CT scan and when present suggest impact of the head onto a fixed, hard surface. Skull fractures are most often linear, but can be stellate or diastastic as well.

Children with more severe deceleration injury to the brain may have evidence of diffuse cerebral edema

Figure 1



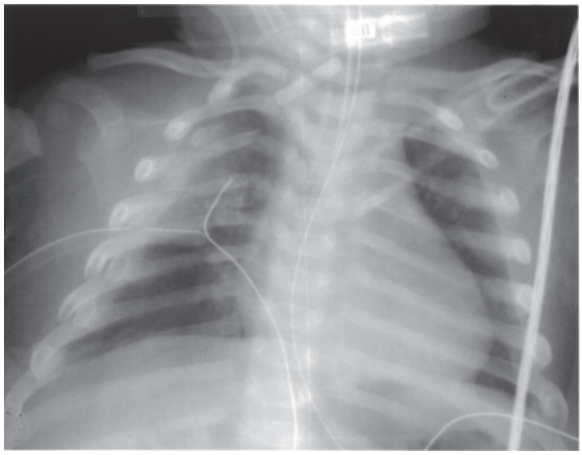
Acute subdural and subarachnoid hemorrhage in a three-month-old infant.

and diffuse axonal injury. This may appear as a reversal of the differentiation between the gray-and white matter, also known as the "reversal sign" (Smith, 1997). The gray matter will therefore appear less dense than the deeper gray matter structures of the basal ganglia and brain stem, as well as the white matter. Diffuse axonal injury arises from shearing injuries to the structures along the gray-white matter interface. Acute, punctate hemorrhage may be present along the gray-white matter junction of the gyri, the corpus callosum or the basal ganglia (Smith, 1997).

Magnetic resonance imaging (MRI) may be useful to detect small extra-axial fluid collections not appreciated on CT scans, to reveal diffuse axonal injury and to narrow the window of time in which the injury occurred (Smith, 1997; Duhaime, Christian, Moss & Seidl, 1996). MRI can be difficult to obtain in children requiring mechanical ventilation and inotropic support, and thus should be considered as an adjunct to CT scans.

Other hallmarks of shaking injury include posterior and anterolateral rib fractures and metaphyseal fractures. When children present with acute brain injury due to shaking, these injuries may occasionally be detected on plain radiographs at the time of initial presentation to the Emergency Department. At the time of the acute injury, such fractures may not have overlying tenderness, edema or crepitus, and there may not be loss of function of the involved extremity. Despite the high frequency of rib fractures in abuse, clinically significant injury to the lungs and heart is uncommon. When there is underlying injury, pneumothoraces or pulmonary contusions may be present (See Figure 2). In cases when rib fractures are not initially detected by plain radiography, they may only be detected with skeletal scintigraphy, but this can be difficult to obtain in children who have significant brain injury that requires mechanical ventilation and inotropic support. Plain radiography obtained within 10 days of initial presentation may be the only modality to demonstrate these fractures in this sicker group of patients with abusive head trauma (Havilland & Ross, 1997). When these fractures are present with the previously described CNS and retinal findings, this constellation of injuries is pathognomic for abusive head trauma. Despite the high frequency of rib fractures in abuse, clinically significant injury to the lungs and heart is uncommon. When there is underlying injury, pneumothraces or pulmonary contusions may also be present.

Figure 2



Acute bilateral posterior rib fractures of the 1st through 4th ribs in a four-month-old infant. As a result of displacement of the rib fractures, there was also a right pneumothorax.

Outcomes for Survivors of Abusive Head Trauma

Long-term outcome for survivors of abusive head trauma tends to be poor, and is dependent on the severity of symptoms at initial presentation (Ewing-Cobbs et al., 1998; Gilles & Neslon, 1998; Hanigan, Peterson, & Njus, 1987; Feldman, 1992). The overall mortality from such injuries can be as high as 25% (Ewing-Cobbs et al., 1998). Children who present with apnea, seizures and coma are more likely to have long-term neurologic sequelae as developmental delay, seizures and static encephalopathy. Children with

inflicted head injury tend to have a significantly worse neurological outcome as compared to children with accidental traumatic brain injury (Hanigan, Peterson, & Njus, 1987). It is important that these children receive long-term follow-up, as some survivors with milder injury may display deficits such as attention and memory problems, only when they begin school (Hymel et al., 1998). In addition, behavioral difficulties and speech and language abnormalities may manifest in the second or third year of life, and persist into adolescence and adulthood (Hymel et al., 1998).

Tin Ear Syndrome

Cutaneous injury to the ear, ipsilateral brain injury and retinal hemorrhage have been described in children who have been physically abused (Duhaime et al, 1996; Ewing-Cobbs et al., 1998; Gilles & Neslon, 1998). This constellation of injuries has been referred to as the tin ear" syndrome. When children are struck on the side of the head with an object, such as the hand, the impact to the ear can cause the apex of the helix to fold onto itself and be compressed against the side of the head during the blow (Gilles & Neslon, 1998). This results in a rim of petechiae along either the inner or outer aspect of the helix. It has been postulated that when the head is struck in this manner, it undergoes rotational acceleration. That force is thought to cause the ipsilateral subdural hemorrhage, cerebral edema, and hemorrhagic retinopathy (Ewing-Cobbs et al., 1998).

Closed head trauma that may be confused with abusive head trauma

Some children who have contact injuries to the head, either from short vertical falls or blows to the head, may sustain either epidural hemorrhage, subdural hemorrhage or cerebral contusion. When there is a contact injury to the head, the point of impact causes the inner table of the skull to bend inward, putting it under compression, which may injure blood vessels with in the epidural or subdural space, as well as the parenchyma of the brain itself (Barlow, Thomson, Johnson & Minns, 2005). These focal injuries may be accompanied by a skull fracture as well. At the same time of this inbending of the skull, there is also simultaneous outbending of the skull around the site of impact (Barlow, et al., 2005). This puts the outer table of the skull under tension, and a skull fracture may result, either proximate to or remote from the site of impact. As the skulls of infants are somewhat more elastic, the tension on the outer table of the skull as it bends outward from an impact site may not always result in a fracture (Barlow, et al., 2005). These children typically do not present with significant alterations in mental status, unless the EDH or SDH is large enough to cause mass effect and focal cerebral edema. (Barlow, et al., 2005). In contrast to children who have head injury due to shaking, the outcome of children with subdural hemorrhage due to impact injury is typically good, as most often the hemorrhage is not extensive and spontaneously resolves within 48 hours after injury, with few neurological sequelae (Hanigan, Peterson, & Njus, 1987).

Prevention of Abusive Head Trauma

Many agree that a systematic approach to informing parents and caregivers about the dangers of shaking infants and the environment in which shaking may occur is a necessary part of any education and prevention program. In 1992, Showers evaluated an inflicted childhood neurotrauma education program in an urban county in Ohio. Over a one-year period, this program disseminated information about the dangers of shaking infants to 15,000 parents of newborns. Evaluations were completed by only 21% of this cohort. Of the parents who responded, 75% stated that they found the information useful, and 49% indicated that they would be less likely to shake an infant (Showers, 1992). More recently, Dias and colleagues evaluated a hospital-based education program in Buffalo, New York. As part of this education program, parents of newborns in participating hospitals viewed a videotape (*Portrait of a Promise: Preventing Shaken Baby Syndrome*; Midwest Children's Resource Center, St. Paul, MN) and signed a written statement that they would not shake their infant in the future. The incidence of abusive head trauma in this county was reduced by 47% during the five-year implementation of this program. No similar decrease in the number of cases of abusive head trauma was seen in an adjacent Pennsylvania county during this same period (Dias et al., 2005). Further study is needed to determine if the effectiveness of such educational programs can be replicated in other geographically and ethnically diverse populations.

Summary

Abusive head trauma is a frequent cause of infant morbidity and mortality. The hallmarks of abusive head trauma include subdural and subarachnoid hemorrhage and retinal hemorrhages. The type of retinal hemorrhage seen in abusive head trauma is unique and can be distinguished from that of accidental head injury and from other medical causes. The neurological outcome for children with abusive head trauma is typically worse than that of children with accidental head trauma. This is especially so if

an infant presents with apnea or cardiopulmonary arrest. Such features are helpful in distinguishing accidental from abusive head trauma in young infants. Efforts at educating parents about the harmful sequelae of shaking so as to prevent brain injury need to be carried out in geographically diverse populations.

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