Current Concepts

Nonaccidental Head Injury in Infants — The "Shaken-Baby Syndrome"

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TRAUMA is the most common cause of death in childhood, and inflicted head injury is the most common cause of traumatic death in infancy.[1-3] Beginning with the classic descriptions of Kempe et al.[4] and Caffey[5] and with subsequent clinical, biomechanical, and radiologic studies, the diagnostic features of nonaccidental head injury in infants and toddlers have become widely recognized. This review outlines the mechanisms, typical features, differential diagnosis, and acute management of the most frequently encountered form of infantile inflicted head injury, the so-called shaken-baby syndrome.

BIOMECHANICS AND TERMINOLOGY

The names applied to the syndromes of inflicted head injury in infancy reflect the evolving and sometimes controversial understanding of the actions necessary to cause the types of injuries seen, such as shaking an infant held by the arms or trunk or forcefully striking an infant's head against a surface. Although there is considerable controversy, the available evidence suggests that it is the sudden deceleration associated with the forceful striking of the head against a surface that is responsible for most, if not all, severe, inflicted brain injuries. Because the histories given when infants with such injuries present for medical attention are often vague or unreliable, the events must be inferred from knowledge of the causative forces in witnessed cases of accidental trauma and experimental models of injury. Studies of the biomechanics of brain injury have established that forces applied to the head that result in a rotation of the brain about its center of gravity cause diffuse brain injuries. It is this type of movement that is responsible for the diffuse axonal injury and subdural hematoma seen, for example, in cases of motor vehicle accidents that result in severe disability or death. In contrast, forces that result in a translation, or straight-line, movement of the center of gravity are generally less injurious to the brain, with the effects largely determined by the specific focal contact forces.[6] The type and severity of the injury are determined both by the type of deceleration and by its magnitude. In infants and young children, household falls causing head injuries mainly involve low-velocity translational forces; rotational (or angular) deceleration is distinctly uncommon.[3]

The term "whiplash shaken-baby syndrome" was coined by Caffey to explain the constellation of infantile subdural and subarachnoid hemorrhage, traction-type metaphyseal fractures, and retinal hemorrhages and was based on evidence that angular (rotational) deceleration is associated with cerebral concussion and subdural hematoma.[7-10] Because the type but not the magnitude of deceleration was addressed in early reports of the syndrome, it was postulated that injuries could be inflicted unwittingly by caretakers through generally acceptable child care practices. More recent biomechanical studies of these injuries show that the magnitude of angular deceleration is 50 times as great when the head of an infant model held by the trunk forcefully strikes a surface as when shaking alone occurs, and it only reaches injury thresholds calculated for infants at the moment of impact. When the surface is soft, the force of the impact is widely dissipated and may not be associated with visible signs of surface trauma, even though the brain itself decelerates rapidly.[11] It is the sudden angular deceleration experienced by the brain and cerebral vessels, not the specific contact forces applied to the surface of the head, that results in the intracranial injury. This angular force is distinct from the forces generated in most cases of accidental trauma in infants. The majority of abused infants in fact have clinical, radiologic, or autopsy evidence of blunt impact to the head.[11-13] Thus, the term "shaking–impact syndrome" may reflect more accurately than "shaken-baby syndrome" the usual mechanism responsible for these injuries.[14] Whether shaking alone can cause the constellation of findings associated with the syndrome is still debated, but most investigators agree that trivial forces, such as those involving routine play, infant swings, or falls from a low height are insufficient to cause the syndrome. Instead, these injuries appear to result from major rotational forces, which clearly exceed those encountered in normal child-care activities.[3,13,15-19]

EPIDEMIOLOGY

The shaking–impact syndrome is largely restricted to children under three years of age, with the majority of cases occurring during the first year of

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life.[11,20,21] In a prospective study of consecutively admitted children under two years of age who had head injuries, 24 percent of the injuries resulted from inflicted trauma; among infants with severe injuries, the proportion was even higher.[2,3,22] Frequently, such children have evidence of previous abuse.[13] At our institution, more traumatic deaths result from child abuse involving head injuries than from any other single cause.

Risk factors for nonaccidental injuries in children include young parents, unstable family situations, low socioeconomic status, and disability or prematurity of the child.[23,24] Starling et al. found that the perpetrators were, in descending order of frequency, fathers, boyfriends, female babysitters, and mothers.[25]

HISTORY, PHYSICAL EXAMINATION, AND LABORATORY FINDINGS

With inflicted head injuries, an accurate history is rarely provided at presentation. The information most commonly reported involves the child's symptoms or a history of blunt impact to the head, usually of a minor nature.[11,20] A history of shaking is obtained in a minority of cases.[11-13,20] The history may be vague or may vary with time, or a mechanism of injury that is incompatible with the developmental capacity of the child may be described.

Common symptoms include lethargy, irritability, seizures, increased or decreased tone, impaired consciousness, vomiting, poor feeding, breathing abnormalities, and apnea. Milder neurologic findings include lethargy, irritability, and meningismus. Approximately half of all patients with the shaking–impact syndrome have severe impairment, are unresponsive, have opisthotonos, or are moribund.[12] The fontanelle may be full. Seizures are reported in 40 to 70 percent of patients.[20,26]

Retinal hemorrhages, best seen with the use of mydriatic agents, are found in 65 to 95 percent of patients.[2,20,21,27,28] The hemorrhages may be unilateral or bilateral, and retinal folds or detachments may be seen. The exact biomechanical forces necessary to cause retinal hemorrhages are unknown, but several mechanisms have been postulated, including increased retinal venous pressure, extravasation of subarachnoid blood, and traction of retinal vessels at the vitreoretinal interface due to angular deceleration.[29,30] Although strongly associated with inflicted head injury, retinal hemorrhages are not specific for the diagnosis, nor can they be dated with precision. Such hemorrhages have been reported in some cases of accidental trauma (especially subdural hematoma) and, in rare cases, after resuscitation; they can also occur with papilledema.[3,27,31,32] Retinal hemorrhages are seen in up to 40 percent of vaginally delivered newborns but resolve by one month of age.[33] Nontraumatic causes include subarachnoid hemorrhage, sepsis, coagulopathy, galactosemia, severe hypertension, and other rare conditions.[34-37] The diagnosis of inflicted head injury cannot rest on the finding of retinal hemorrhage alone, but the finding of severe bilateral retinal hemorrhage with retinal folds or detachments is particularly suggestive of the diagnosis.

General physical findings may include bruising, swelling, a pattern of cutaneous marks, and burns. In some patients no extracranial injuries are detected. Some cutaneous injuries become visible only after admission. In some patients, soft-tissue injuries, including scalp hemorrhages, are noted only at autopsy.[11,13]

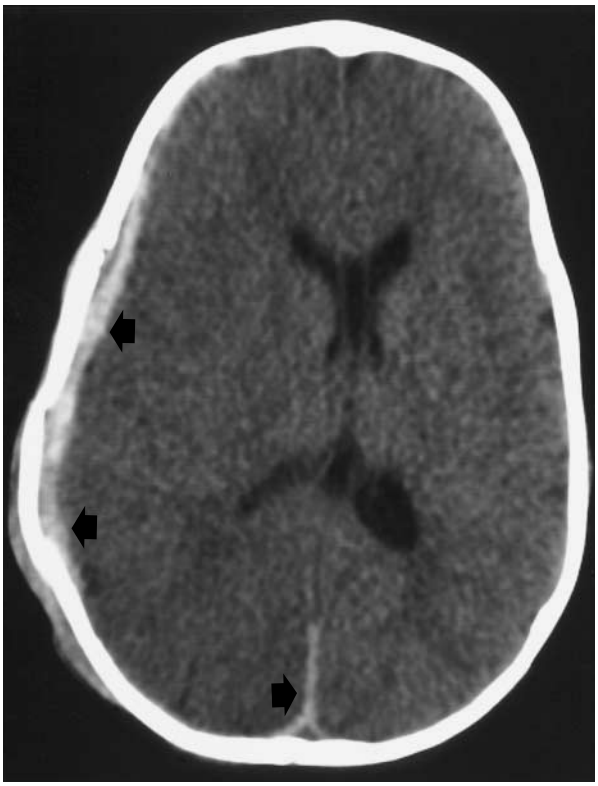
Lumbar puncture, typically performed as part of an evaluation for sepsis in infants with nonspecific findings, reveals bloody fluid. Hemoglobin values may be decreased.[21] Elevated coagulation factors do not necessarily indicate a primary coagulopathy but may reflect the underlying brain injury.[38]

RADIOLOGIC FINDINGS

Computed tomographic (CT) scanning is the mainstay of the diagnosis of the shaking–impact syndrome. Subdural or subarachnoid hemorrhage can nearly always be detected on CT scans, although the more subtle findings may be missed by less experienced observers. Hemorrhages most often appear as unilateral or bilateral high-density collections of fresh blood that are thin but extensive; a particular propensity for the interhemispheric fissure, especially posteriorly, is well documented.[39,40]

A peculiar and poorly understood CT finding that is uniquely associated with subdural hematoma in infancy is extensive loss of gray–white differentiation and diffuse hypodensity. This finding can be unilateral or bilateral. The basal ganglia and posterior fossa structures are relatively spared and thus appear hyperdense as compared with the surrounding cerebrum, which is abnormally hypodense ("reversal sign").[41] In unilateral cases, an additional wedge-shaped area of hypodensity in the contralateral frontal lobe, probably reflecting subfalcine herniation, is usually noted (Fig. 1B). Diffuse hypodensity is not always apparent on the initial CT scan (Fig. 1A) but appears within the first few days in infants with severe neurologic symptoms (i.e., unresponsiveness).[42] This finding is not specific for abuse, but since abuse is the most common cause of subdural hematoma in infancy, it is seen most often in association with abuse.

Magnetic resonance imaging (MRI) is useful in detecting and characterizing small extraaxial hemorrhages in infants with equivocal CT findings. The identification of parenchymal contusions on MRI scans may also be helpful in differentiating the shaking–impact syndrome from the rare case of spontaneous subarachnoid hemorrhage (Fig. 2).[43] Soft-tissue swelling may be noted on CT scans, MRI scans, or plain skull films. Plain films are superior to CT



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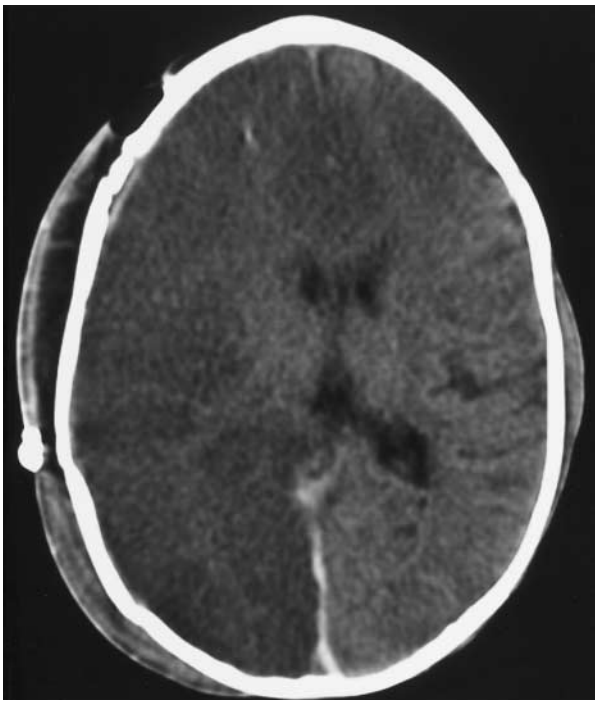

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Figure 1. Axial Cranial CT Scans in an Eight-Month-Old Unresponsive Boy Found at Home.

A skeletal survey showed fractures of the skull, multiple ribs, arms, and legs. The initial CT scan (Panel A), obtained without the administration of contrast material, shows a right-convexity subdural hematoma extending onto the posterior falx cerebri (arrows). There is mass effect with a midline shift. A scan obtained 24 hours after surgical evacuation of the hematoma (Panel B) shows hypodensity throughout the right cerebral hemisphere, involving both the cortex and the white matter. The contralateral anterior frontal lobe is also characterized by decreased density. Blood remains visible along the falx cerebri.

scans for the detection of skull fractures, which are found most commonly in the occipital or parietooccipital regions. Multiple or complex skull fractures have been associated with abuse.[40,44,45]

A skeletal survey is essential in the evaluation of a child for the shaking–impact syndrome, since extracranial abnormalities are detected in 30 to 70 percent of abused children with head injuries.[40,46] A wide variety of skeletal injuries have been described. Although none are strictly pathognomonic of abuse, multiple posterior or lateral rib fractures and metaphyseal fractures are characteristic. In some patients, delayed repeated films or radionuclide bone scans are necessary to detect sites of subtle injury.[47,48]

Some infants with previous inflicted injuries present with chronic subdural hematomas, although data from studies of such infants are scarce. In Parent's series, 44 percent of infants with chronic subdural hematomas were thought to have sustained previous inflicted injuries.[49] The diagnosis in this population rests largely on the finding of unexplained skeletal or other injuries indicative of abuse. Treatment of symptomatic chronic subdural hematoma usually includes surgical drainage or shunting.

INITIAL MANAGEMENT, CLINICAL COURSE, AND OUTCOME

The initial treatment of infants with markedly impaired consciousness includes intubation, ventilation, fluid resuscitation, and anticonvulsant therapy. Surgical evacuation should be considered in the case of a large acute hematoma.[50,51] The value of aggressive management of intracranial hypertension has been questioned on the basis of outcome studies, which show that infants who present with poor prognostic indicators, especially bilateral diffuse hypodensity on CT scans, have dismal outcomes regardless of treatment. Less severely injured infants are treated with anticonvulsant agents and closely observed; recovery is variable in such cases.[26,52]

In infants who succumb, the cause of death is uncontrollable intracranial hypertension. Remarkable cortical and white-matter atrophy is seen consistently on follow-up neuroradiologic studies (Fig. 3) in

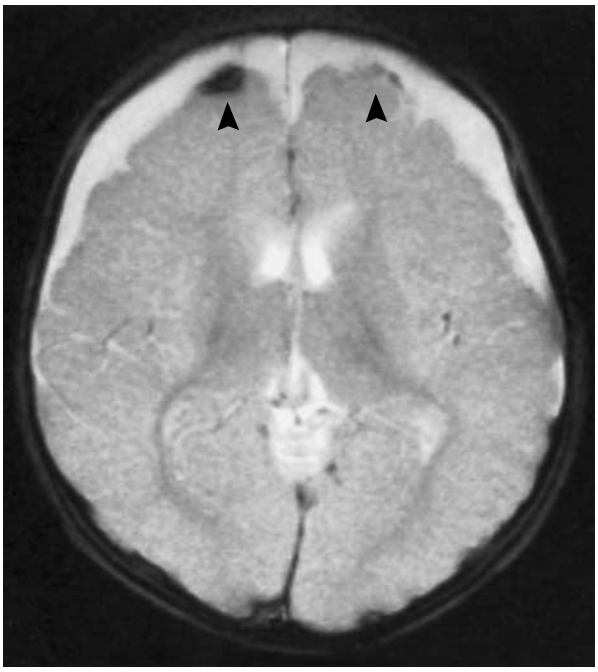

Figure 2. T_2-Weighted Axial Cranial MRI Scan in a Four-Month-Old Girl Reported to Have Fallen from a Low Height.

Gradient-echo imaging was used with the technique of the fast low-angle shot (FLASH) to demonstrate blood products. Areas of acute hemorrhage on both frontal cortical surfaces can be seen (arrowheads), along with proteinaceous extraaxial collections. This infant also had multiple rib fractures.

survivors with diffuse hypodensity during the acute period.

TIMING OF THE INJURY

Since the history is often unreliable in cases of the shaking–impact syndrome, information about the timing of the injury must be extrapolated from data on accidental trauma. Acute subdural hematoma associated with severe neurologic compromise, brain swelling, or death occurs in the setting of a clear injury involving a major mechanical force and is followed by the immediate or rapid onset of neurologic symptoms.[53] In a series of 95 children who died from accidental head injuries, all but 1 of the children had an immediate decrease in the level of consciousness; the exception was a patient with an expanding epidural hematoma.[54] This type of injury, generated by contact forces to the skull and dura, is usually not associated with a serious primary brain injury and is rarely associated with child abuse.[18] Other reports of delayed deterioration after pediatric head injury have primarily involved the onset of seizures, followed by recovery.[55] On the basis of these data, it can be discerned that there is no evidence of a prolonged interval of lucidity between the injury and the onset of symptoms in children with acute subdural hematoma and brain swelling — the injuries also seen in severe cases of the shaking–impact syndrome (i.e., those associated with coma or death). Thus, an alert, well-appearing child has not already sustained a devastating acute injury that will become clinically obvious hours to days later.

The timing of the traumatic event is more difficult to establish in patients with mild neurologic injuries and is determined on the basis of general physical and radiologic findings. These methods can indicate only a general time frame.

A separate issue concerns the possibility of a subclinical injury that is later exacerbated by a relatively minor second mechanical trauma. Such rare events have been reported in older children and adults, usually in the setting of acute subarachnoid and subdural hemorrhage and brain swelling related to recurrent impact to the head involving well-documented concussive forces during sports activities.[56,57] This pattern of injury, with a clear time line and rapid, well-described acute deterioration, stands in sharp contrast to the vague histories of previous episodes of trivial trauma that are sometimes suggested as possibly causative in the shaking–impact syndrome. There is no evidence that traumatic acute subdural hematoma, particularly that leading to death, occurs in otherwise healthy infants in an occult or subclinical manner.

AUTOPSY FINDINGS

Although there are some variations, pathological findings in infants who have been shaken and battered are remarkably consistent. Evidence of external injury has been found in up to 85 percent of such infants and is most often located in the head and neck. Scalp trauma is sometimes visible only after the hair has been shaved. Autopsy detects fractures in 25 percent of affected infants.[58] Fractures involving the skull are most common in the posterior parietal bone or occipital bone or both.

Subdural hemorrhage, usually localized at the parieto-occipital convexity or posterior interhemispheric fissure, is the most consistent autopsy finding in shaking–impact syndrome.[11,21] Such hemorrhages typically range from 2 to 15 ml in volume and almost never cause death because of direct mass effect.[58] In most fatal cases, the hemorrhage is acute and involves liquid blood or a small clot resembling currant jelly.

With fatal injuries, estimates of the time at which the injury occurred rely on clinical, radiologic, and postmortem findings. Hirsch has provided guidelines for determining the age of a subdural hematoma on the basis of its gross features and microscopical characteristics.[59] Various factors limit the reliability of these methods; for example, reduced cerebral blood flow may impede the cellular re-

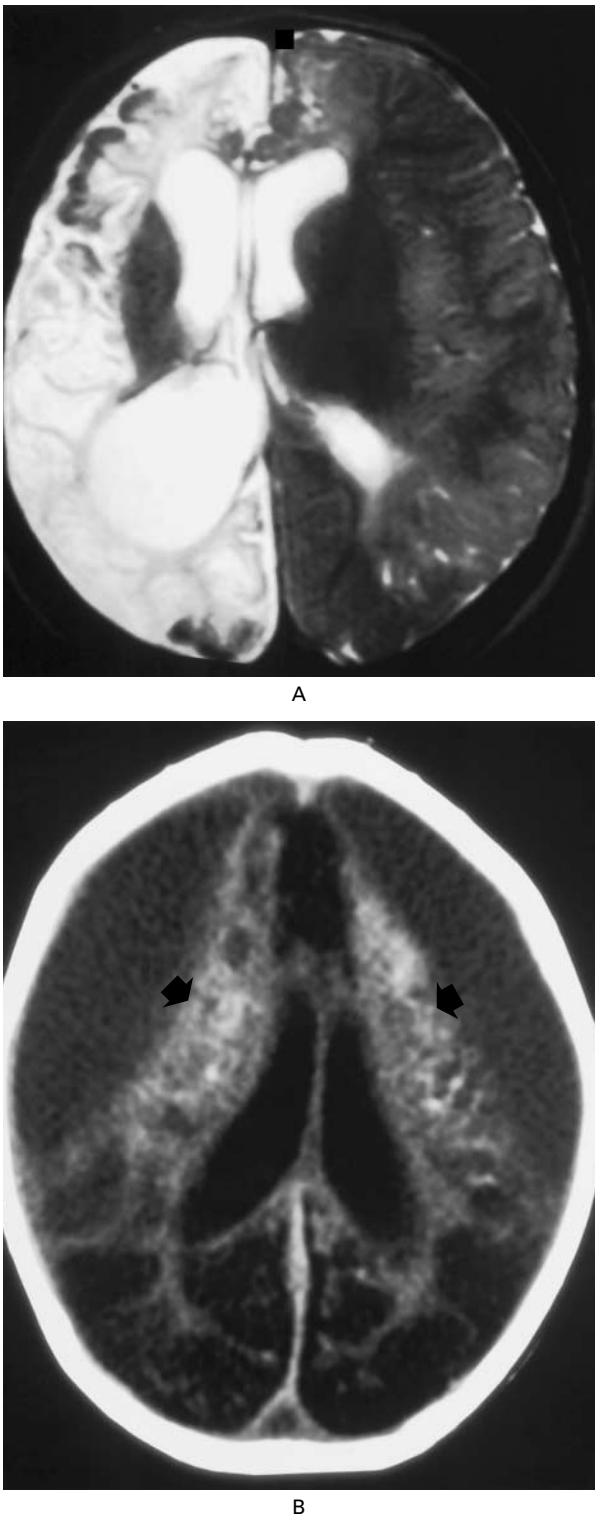

Figure 3. Follow-up Brain Images in Two Infants Injured at Four Months of Age.

A T_2-weighted axial MRI scan in one infant (Panel A) shows severe encephalomalacia involving the entire right cerebral hemisphere, with subcortical cystic changes. The ventricles are enlarged because of atrophy. The left frontal lobe is atrophic, whereas the basal ganglia and the remainder of the left hemisphere are relatively spared. An axial CT scan in the other infant (Panel B) shows bilateral diffuse encephalomalacia involving the supratentorial cortical and subcortical regions, with cysts and calcifications. The markedly atrophic brain (arrows) is surrounded by proteinaceous subdural fluid.

sponse. Iron staining must be performed to detect hemosiderin, if previous or old hemorrhage is suspected. Most infants who die within a few days after presentation have no evidence of organization of the hematoma.

Superficial contusions are most frequent in the olfactory bulbs and tracts and underlying gyrus rectus.[58] Of greater mechanical importance are gliding contusions, tears of the corpus callosum, and diffuse axonal injury, which result from extreme rotational force.[60-62] Occasionally, the ventricular wall, the vein of Galen, or even the vertebral artery may be torn. The rostral brain stem may be damaged as a consequence of the forces of angular deceleration.[63] Cerebral edema is common in infants who survive for hours or days, and necrosis is often observed.

Acute hemorrhage along the sheath of the optic nerve is typically most obvious at the junction of the nerve and the globe. Retinal hemorrhages occupy any or all layers of the retina and may be preretinal or subretinal as well. Occasionally, large vitreous hemorrhages are present.[58,64,65]

Careful dissection of the cervical region is essential. The prosector must remove the brain and spinal cord in continuity, since the most common site of cervical injury is C1 to C4. Tissue sampling for microscopical study should include typical sites of diffuse axonal injury, with the realization that gross hemorrhage may be absent. The exact time course for the development of axonal retraction balls during the initial hours after injury is a matter of debate.[66-68]

Some affected infants survive with intellectual and neurologic deficits (including blindness) for weeks, months, or years after the injury. The findings in these cases include well-demarcated cavities, primarily in the frontal lobes, representing the residua of the gliding contusions; more widespread cystic or noncystic gray-matter damage; scars in the centrum ovale, corpus callosum, or both; and chronic retinal damage with secondary optic-nerve degeneration.

PATHOPHYSIOLOGIC FACTORS

The causes of the severe brain swelling and subsequent extreme tissue loss in infants with the shaking–impact syndrome who survive are incompletely

understood and are unique to this age group. Most accidental subdural hematomas in infants are caused by motor vehicle collisions or falls from substantial heights, but in these cases, both diffuse brain swelling and fatal outcomes have been reported.[3,19,27,69]

Johnson et al. have suggested that when crying infants are shaken until apnea renders them silent, hypoxia is the primary pathophysiologic event.[26] However, the finding of unilateral hypodensity in one third of cases suggests that global hypoxia is not the only factor, nor does the pattern of delayed atrophy match that seen in survivors of isolated hypoxic injury from other causes. Cervical trauma has been reported on the basis of autopsy findings in cases of inflicted head injuries, although clinical signs of spinal cord injury are rare.[21,70] Vessel occlusion, perhaps resulting from concomitant strangulation, has been suggested to explain the cases of more unilateral tissue loss.[71] However, this explanation is rarely borne out by the findings on MRI angiography or autopsy.[58]

The most consistent finding in cases of the shaking–impact syndrome is the presence of subdural and subarachnoid blood. Hemorrhage therefore is both a marker for the threshold of force required to cause the injury and a likely pathophysiologic contributor to the resultant brain damage. It thus appears that some combination of mechanical trauma, hemorrhage, hypoxia, and possibly seizure activity overwhelms the compensatory mechanisms of the immature brain, resulting in massive swelling and widespread neuronal loss. A further understanding of these processes will require more scrutiny and better experimental models.[72-75]

DIFFERENTIAL DIAGNOSIS

No other medical condition fully mimics all the features of the shaking–impact syndrome. Several patterns of clinical and radiographic findings allow a definitive diagnosis. These include a history of trivial or no trauma, acute subdural hemorrhage, and unexplained extracranial bony injuries or clearly inflicted soft-tissue injuries; and a definite history of no possibility of trauma with clear physical or radiologic evidence of head impact with subdural hemorrhage. Although not necessary for the diagnosis, the findings of retinal hemorrhages or multiple fractures in different stages of healing make the diagnosis more certain.[3,76] It is clear that some suspicious cases will have insufficient findings with which to make a firm diagnosis. An algorithm has been developed to help differentiate injuries that can be assumed to be inflicted from those that are suspicious, for the purpose of classifying cases in clinical research. The results with this algorithm are closely correlated with the determinations of the child-abuse team at our institution.[3]

The single most common diagnosis mimicking nonaccidental trauma is accidental injury. Small epidural hemorrhages and traumatic subarachnoid hemorrhages can be mistaken for subdural hematomas; MRI may be helpful in these instances.[77] Accidental subdural hemorrhages have been reported in infants after motor vehicle collisions or falls involving substantial angular deceleration.[19,27,69,77] Infants with enlarged extraaxial spaces, such as may be seen in some cases of shunted hydrocephalus, appear to be at increased risk for subdural or subarachnoid hemorrhage with lesser degrees of trauma.[78] In cases of accidental head injury, the history is clear and consistent, the infant's symptoms reflect the forces described, and no unexplained skeletal injuries are identified.

A variety of coagulopathies are associated with intracranial hemorrhage in infants, including hemophilia and hypoprothrombinemia caused by vitamin K deficiency.[79,80] These disorders are suggested by the clinical history, physical findings, and laboratory tests. Transient prolongation of the prothrombin time and disseminated intravascular coagulopathy have been associated with the presence of parenchymal brain injury in infants with accidental trauma and in those with inflicted trauma.[38,81] Recommended screening tests include assessment of the platelet count, prothrombin time, activated partial-thromboplastin time, and bleeding time; abnormal values merit further evaluation.

Osteogenesis imperfecta is a rare inherited disorder of connective tissue that results from an abnormal quantity or quality of type I collagen. This disorder is usually readily distinguished from injuries caused by child abuse, although the physical features of osteogenesis imperfecta may be subtle. In addition to fractures, suggestive findings include blue sclerae, hearing impairment, dentinogenesis imperfecta, hypermobility of the joints, bruising, short stature, radiographic evidence of wormian bones, osteopenia, bowing and angulation of healed fractures, and progressive scoliosis. Although uncertainty about the diagnosis is usually related to unexplained skeletal injuries, subdural hemorrhage is a rare complication of the disease.[82] Fractures associated with osteogenesis imperfecta usually involve the diaphyses of long bones, but rib fractures, fractures of varying ages, and in rare cases, metaphyseal fractures can occur.[83,84] Biochemical analysis of cultured skin fibroblasts is diagnostic in approximately 85 percent of patients with the disease.[85] Clinical and radiographic evaluation by an experienced examiner is usually sufficient to distinguish osteogenesis imperfecta from injuries caused by child abuse, with biochemical testing reserved for cases in which the diagnosis is uncertain.[84]

Glutaric aciduria type I is a metabolic disorder caused by a defect of glutaryl–coenzyme A dehydrogenase. The onset of clinical symptoms may be acute or insidious, and the findings may include developmental delay, hypotonia, dyskinesia, cortical at-

rophy, and subdural collections.[86] Skeletal injuries and retinal hemorrhages have not been described as part of the disease. Urinary screening for this disorder should be considered in infants with appropriate clinical findings.

CONCLUSIONS

The shaking–impact syndrome is a common, serious injury resulting from major mechanical forces. If the history and the physical and radiologic findings are suggestive of this diagnosis, the patient should be admitted to the hospital for treatment. A thorough, unbiased evaluation is essential. If abuse is suspected, the law requires that the appropriate child-welfare and law-enforcement agencies be notified. Caretakers should be informed, in a nonaccusatory manner, that the diagnosis is suspected and that investigative procedures will be necessary for the welfare of the child. The medical record has great legal importance, and careful documentation will later benefit the physician, who may be subpoenaed to testify in court.

The future safety of a child with the shaking–impact syndrome rests on the physician's ability to recognize its characteristic features. Effective prevention strategies must be guided by an improved understanding of the pathophysiology and causes of this common disorder.

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