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Neuropathology

Mild Traumatic Brain Injury (Concussion) in Infants, Toddlers, Children and Adolescents

In the Forensic Science Newsletter of May 15, we discussed Mild Traumatic Brain Injury (Concussion) in adults. In this issue of the Forensic Science Newsletter we are going to discuss mild TBI (concussion) in infants, toddlers, children and adolescents.

General Information

According to the Centers for Disease Control and Prevention, there are approximately four million sports and recreation related concussions per year, with many more occurring but not recognized or reported. When you consider the age group of fourteen to twenty-four years, the second leading cause of traumatic brain injury are sports, the first being motor vehicular accidents. Research done by the New York Times has shown at least fifty youth football players have died or acquired serious head injuries since 1997. Another study estimated the chances of a young athlete in a contact sport experiencing a concussion is 20% each year.
Historically, as stated above, most concussions were thought to be due to falls or motor vehicular accidents. However, since the New York Times study, more recent studies of children and adolescents indicate most concussions occur during sporting events, with the greatest risk during competitions. Although there is no definitive data on whether males or females are at greater risk of concussions, different mechanisms of injury have been suggested. Males seem prone to concussion through player-to-player contact, whereas concussions in females tend to be caused by contact with the playing surface or equipment.

Before continuing, we will define what constitutes an **infant**, **toddler**, **child**, and an **adolescent**.
An **infant** is defined as a young child between the ages of one month and one year. A **newborn** is an infant who is between birth and one month of age. Some classify an infant as a child whose age is between birth and one year, whereas others define an infant as a child whose age is between birth and two years.
A **toddler** is defined as a child between one and three years.

A **child** is technically an individual between birth and **puberty (adolescents),** who is between the ages of three and the beginning of puberty for that child, which typically occurs in girls, between 8-12 years-of-age and in boys, beginning about the age of 9½-years-of-age.
Puberty is the biologic process in which a child becomes an adult. The term **'adolescents'** defines this process, which typically spans the ages of 8 to 12 when considering girls and boys together, and 20 years.

As a brief review, concussion is the mildest form of TBI. It typically represents a disturbance in brain function caused by direct or indirect force to the head. Historically, it is represented as a functional rather than a structural injury that results from shear stress to the brain parenchyma caused by rotational or angular forces or as the result of direct impact to the head. It is important to remember, direct impact to the head is not required to produce a concussion. Also, loss of consciousness is not required to make a diagnosis of concussion. Although historically, it has been represented as a functional rather than a structural injury to the brain, recent studies using newer imaging techniques, such as Diffusion Tensor Imaging (DTI), have shown microstructural axonal disruption in concussion.
The most recent concussion consensus statement, developed by a collaboration of six major professional associations concerned about sports medicine issues in this country, defines concussion as follows:

Concussion or mild TBI is a pathophysiological process affecting the brain induced by direct or indirect biomechanical forces. Common features include the following:

1. Rapid onset of usually short-lived neurological impairment, which typically resolves spontaneously.
2. Acute clinical symptoms that usually reflect a functional disturbance rather than structural injury (Note recent findings with DTI).
3. A range of clinical symptoms that may or may not involve loss of consciousness.
4. Routine neuroimaging studies are typically normal (CT scan & MRI).

Mild TBI constitutes about 90% of childhood head trauma. Despite its very high prevalence, only 3-5% of children with mild TBI have evidence of gross intracranial pathology and less than 1% require emergency neurosurgical intervention.

Infants and Toddlers

Concussion (mild TBI) in an infant can be very difficult to recognize. It is important to remember, infants less than one year of age suffer a different pattern of injuries when it comes to head trauma, which is believed to be related to the developmental state of the anatomy of their head. In infants the skull is highly deformable due primarily to unfused cranial sutures; they have a high head-to-body ratio; an elastic spinal column with immature joints; reduced neck muscle tone; and a relatively unmyelinated brain, which lends the infants brain to being more easily injured. Children with severe head injuries are more prone than adults to have intracranial hypertension (80% v. 40%-50%). They

are also more prone to malignant brain edema, which is due to brain hyperemia occurring shortly after the injury and is distinct from cytotoxic edema, which may develop later. Children also have a lower incidence of mass lesions than adults (30% v. 40%-50%).
Cervical spine injuries are rare in children under 12-years-of-age due to the greater mobility and elasticity of the cervical spine. However, an injury should be suspected in any child who has significant head or facial trauma, is unconscious or complains of neck pain. In children with unexplained refractory shock the possibility of spinal cord injury with spinal shock should be considered. **Spinal cord injury should not be diagnosed or ruled out on the basis of radiographic evaluation alone, since in up to 67% of children with such an injury no radiographic abnormality is demonstrated. Also, interpretation of the cervical spine radiograph is more difficult in the child than in the adult since several variants of normal are commonly confused with the effects of trauma. Clinically, a child with a cervical spinal cord injury will usually have transient paresthesia, numbness or paralysis after injury.**

Typically, a concussion or acute head trauma, in an infant, toddler, child or adolescent, is either an accidental injury (non-intentional) or a non-accidental injury (intentional, [child abuse]).
An accidental, non-intentional injury, may occur due to the dropping of the infant while holding it, motor vehicular accident, etc. When it comes to falls, age and fall height influence the types of head injuries seen; infants sustain skull fractures more commonly than toddlers, and low-level falls (less than 3 feet [1 meter]) can cause intracranial injury without soft tissue injury or skull fractures, occurring in 6% of infants and 16% of toddlers.
In a large UK-based study, which analyzed data from 11,466 infants less than 6 months old, in which they documented 3357 accidental falls in 2554 infants. Most falls resulted in no injury and serious injury was rare.
A non-accidental, intentional injury comes under the category of child abuse of which one example would be Abusive Head Trauma (AHT) with a concussion being an example of its mildest form.

AHT may be caused by a direct blow to the head and face, asphyxia or shaking. It is important to remember, the poor neck muscle tone and relatively large head (high head-to-body ratio) make them vulnerable to acceleration-deceleration forces associated with shaking. There are two other forces an infants head can be subjected to one of which is linear and the other rotational. A linear force is one in which the freely movable head of an infant is subjected to a blow to the front or back of the head, resulting in anterior-posterior or posterior-anterior movement of the brain. A linear force applied to the side of an infants head results in a side-to-side movement of the brain. However, as stated above, direct impact to the head is not required to produce a concussion. The most damaging force that can be applied to an infants head, as well as that of a toddler, child, adolescent and adults head is a force that is applied to the head tangentially or off-center, which causes the brain to rotate within the head. Such forces have a greater propensity to create shear within the parenchyma of the brain, which disrupt neural membranes then a linear force due to direct impact. The disruption of neural

membranes allows potassium efflux into the extracellular space. Resultant intracellular increases of calcium and excitatory amino acids is followed by further potassium efflux, which in turn causes suppression of neuronal activity. What is of interest is as sodium potassium pumps restore balance there is increased energy requirement, however, cerebral blood flow is decreased indicating a disruption in autonomic regulation, which can persist for several weeks. **It is during this time the brain is very vulnerable to additional injury. This is one of the reasons why you never allow an athlete, whether that be a child, adolescent or an adult, to return to play until neurologically it is deemed safe.**

Clinical Symptoms and Signs in Infants and Toddlers

In an infant it may be difficult to recognize a brain injury has occurred for often they lack external signs of injury even with serious intracranial trauma. The signs and symptoms of concussion typically present immediately after injury, but may be delayed several hours. The signs and symptoms usually last less than 72 hours, and most concussions resolve spontaneously within 7-10 days. Recovery may be prolonged in children, adolescents and those with previous concussions.
The signs and symptoms are often nonspecific manifesting as lethargy, vomiting (without diarrhea), crying inconsolably, refusing to eat, cannot be comforted, unusual long periods of being quiet and excessive sleepiness.

After an injury the infant may show a temporary loss of the most recently attained developmental skills. For example, if the injury occurred at 3-4 months, the infant who was able to rollover, no longer does. If the injury occurred at 6 months, the infant who was babbling and able to sit independently is no longer babbling or able to sit independently. If an infant begins to cry when placed in a particular position then one needs to consider the possibility of vertigo or dizziness has developed from that injury. Should vertigo or dizziness develop from an injury, then that position should be avoided for a few weeks. In most cases, the infant will return to normal over the next several weeks. During this time, the infant should be kept in as normal a routine as possible giving more time for naps and sleep.

Should the infant or toddler manifest a loss of consciousness or amnesia greater than 5 minutes (some use 1 minute), persistent dizziness, mental status changes, bulging anterior fontanelle, seizures, focal neurologic deficits, a depressed skull fracture, signs of a basilar skull fracture, drug or alcohol consumption and the child is under 2-years-of-age then the infant or toddler should immediately have CT imaging. In a preverbal child who manifest these signs and symptoms AHT should also be strongly suspected.

Although this newsletter is concerned with mTBI (concussion) in infants, toddlers, children and adolescents, there is a component of AHT, which needs to be explored due to its importance when assessing infants, toddlers, and children who have sustained suspicious mTBI and that is **retinal hemorrhages**. It is true, retinal hemorrhages can be found in other conditions, however, hemorrhages which are multiple, involve more

than one layer of the retina, extend to the periphery and from the optic nerve to the ora serrata, are suspicious for child abuse.

Traumatic retinoschisis also raises a strong suspicion for child abuse. Retinoschisis is characterized by abnormal splitting of the retina's sensory layers within the macula resulting in a loss of visual function. The retina, which consists of multiple layers of interconnected nerve and pigment cells, is separated into distinct layers in retinoschisis, which results in a loss of vision in the corresponding visual field. In many respects, retinoschisis is a form of macular degeneration. **There is a widely held view that traumatic retinoschisis, as is true of retinal folds, are seen in no other condition other than AHT.**

Retinal folds involve only the sensory retina. They most commonly develop when a tractional force is exerted upon a focal area of the retina. Causes include distortion of the sensory retina due to mechanical force and or vascular occlusion, idiopathic epiretinal membranes, chorioretinal scars and fibrovascular proliferation associated with retinal detachment or diabetic retinopathy.

There have been recent reports both traumatic retinoschisis and retinal folds can be associated with predominantly static crush injuries. **Some use this finding as support for the argument there may be no retinal signs seen exclusively in non-accidental injury.**

Indications for Computed Tomography Scan in Children Under Three years of Age (Infants and Toddlers) in Minor Head Trauma

In an article written in the Journal Trauma. 2001 Aug; 51(2):231-8, the authors concluded a normal neurologic exam and maintenance of consciousness does not preclude significant rates of intracranial injury in pediatric patients. They went on to state that neither loss of consciousness or mild altered mentation is a sensitive indicator with which to select patients for CT scanning. They found skull fractures and superficial craniofacial injury were also unreliable. It was their position that even in those children who have sustained mTBI, it is incumbent upon the medical facilities treating these children to have a liberal policy of CT scanning even though the child may show normal neurologic status.

In a more recent article entitled "Indications of Brain Computed Tomography Scan in Children Younger than 3 years of age with Minor Head Trauma," published in Emergency Medicine International. 2014, they reached a different conclusion. It was their position a child who has sustained AHT with a Glasgow Coma Scale less than 13, with focal neurological deficits, and deteriorating consciousness should receive a CT scan. However, for a child who has sustained a concussion (mTBI) there is no clear agreement about doing a CT scan. What further complicates this issue is neurological examination in children is difficult, especially in newborns, infants and toddlers.

It was their position that definitive indications for CT scanning after head trauma were deteriorating clinical course, focal neurological deficit, abnormal mental status, evidence of skull fracture, loss of consciousness and persistent vomiting (more than 3 episodes) and the presence of a coagulopathy. Barring these indications, ordering CT scans were considered clinically questionable.

In this study they found 93.7% of CT scans of children under 3-years-of-age with mTBI were not necessary. The most common reason given for why these CT scans were ordered was fear of malpractice litigation. The second most important factor was the request of the family.
An interesting point was raised in this paper and that was the exposure of these children to radiation. **Children, especially those under 2-years-of-age are considerably more sensitive to radiation then adults, which is due to their rapidly dividing cells due to their growth. They went on to point out, a single head CT exposes a child to 200-600 times as much radiation as a typical posterior-anterior and lateral chest x-ray.**

Children and Adolescents

Concussion in children under the age of 6 or 7 can be difficult to recognize due to their short term memory and brief attention spans, which are normal for these ages. With older children and adolescents short term memory and attention span issues or changes are more revealing. For example, adolescents may manifest confusion and word-finding problems.
Confusion in children and adolescents may be associated with the following symptoms and signs:

1. Brief (less than 20 minutes) loss of consciousness.
2. Confusion, being dazed or stunned, or seeing stars.
3. Headache.
4. Nausea.
5. Emotional lability (cry or laugh unexpectedly).
6. Anxiety or depression.
7. Sleep disturbance.
8. Fatigue and vertigo.

It is important to note studies have shown a brief loss of consciousness in not associated with prolonged recovery. They have also shown convulsions immediately after injury are benign. However, the significance of amnesia is less clear. Recent studies suggest prolonged headache (more than 60 hours), fatigue, tiredness, fogginess or the presence of more than 3 symptoms at presentation, such as loss of consciousness for more than 60 seconds, amnesia, previous concussion, age younger than 18, comorbid conditions, mediations (psychotropic drugs and anticoagulants), may be associated with prolonged recovery.

Most children and adolescents with concussions recover fully but data suggest longer recovery periods than in adults, usually 7-10 days longer. **What is very important to remember is you never allow same-day return to play as previously stated on page 3.** It is important you institute longer asymptomatic rest periods before initiating graded return-to-play protocol.

On occasion, mTBI in children and adolescents may be followed by some perplexing and worrisome clinical phenomena, some of which are insignificant, whereas others are more serious and indicative of a pathologic process other than concussion. What is of importance is when these occur, neurologic or neurosurgical evaluation is mandatory.

Drowsiness, Headache, and Confusion: These symptoms occur most frequently in children, who, minutes to hours after a concussion, seem not to be themselves. They often lie down, are drowsy, complain of a headache and may vomit. Such symptoms suggest the presence of an intracranial hemorrhage. There may be evidence of focal cerebral cortical edema on MRI near the point of impact. Of these symptoms and signs, vomiting is associated with an increase incidence of skull fracture, as well as intracranial hemorrhage. Typically, these symptoms abate after a few hours suggesting their benign nature. However, if these symptoms occur it is strongly suggested a CT scan or MRI be accomplished.

Transient Paraplegia, Blindness, and Migrainous Phenomena: Following a fall or blow to the top of the head, both legs may become temporarily weak and numb, which on occasion may be associated with what appears to be bilateral Babinski signs and sometimes with sphincter incontinence.

Babinski sign is an extension of the large toe with the other toes fanning out when the sole of the foot is rubbed with a blunt instrument. This sign can indicate upper motor neuron disease with damage to the corticospinal tract of the spinal cord and brain in children, adolescents and adults. **However, in infants the Babinski sign is a normal finding in that it represents a primitive reflex.**

If the impact was to the back of the head, the occipital region, the child, adolescent or adult, may experience temporary blindness. Usually, the symptoms disappear after a few hours. One of the explanations for these transient symptoms is a direct localizing concussive effect, caused either by the indentation of the skull or by impact on these parts of the brain against the inner table of the skull. Another explanation for the transient paraplegia is a concussion to the cervical portion of the spinal cord as briefly discussed on page 3. The blindness and paraplegia are usually followed by a throbbing headache.

On occasion an athlete after sustaining a mTBI, such as a concussion, will experience transient migrainous visual phenomena, aphasia or hemiparesis, which is followed by a headache. There is a thought that all of these phenomena are due to an attack of migraine induced by a blow to the head.

Migraine is characterized by periodic, typically unilateral, often pulsatile headaches that begin in childhood, adolescence or early adult life and recur with diminishing frequency during advancing years. The presentation of migraine in children is different from that in adolescents and adults. Instead of complaining of a headache, the child may appear limp and pale and complain of abdominal pain; vomiting is more frequent than in adults, and there may be a slight fever. Another variant in children is the episodic vertigo and staggering gait (paroxysmal disequilibrium) followed by headache. There are some children who present with bouts of fever or transient disturbances in mood and abdominal pain, the so called abdominal migraine. Some children may experience

attacks of hemiplegia, without headache, first on one side then on the other, every few weeks. Typically, recovery is complete.
An interesting phenomena that can occur following mTBI is transient global amnesia. Typically, this phenomena last between 2-24 hours. It should be pointed out this phenomena is very similar to posttraumatic amnesia.

Delayed Hemiplegia: The primary causes of delayed hemiplegia are late evolving epidural or subdural hematoma and, in more severe injuries, an intracerebral hemorrhage. The majority of these cases are associated with a decrease level of consciousness from the outset, although, there are exceptions.

After reviewing this newsletter, should you desire to consult with me regarding the issues discussed please click on the following consulting page link.

I would also like to bring to your attention there is one book available for purchase "Traumatic Injuries to the Head, Vertebrae, Spinal Cord and Peripheral Nerves of the Newborn During Birth." A second book, "Nonsexual and Sexual Traumatic Injuries of the Perineum, External Genital Organs and the Breasts: Adult, Elderly and Pediatric," will become available shortly. These books can be seen by clicking on the link 'White Papers."