Post-Concussion Syndrome-Children

Forensic Science Newsletter

William A. Cox, M.D., FCAP

www.forensicjournals.com

September 1, 2016

Neuropathology

In this Forensic Science Newsletter we will discuss **post-concussion syndrome in children**, its definition, general information, clinical presentation, neuroanatomy as related to the clinical presentation, other injury factors associated with post-concussion syndrome, treatment, pathophysiology and epidemiology.

Definition

Post-concussion syndrome is a name given to symptoms that develop following a concussion, which persist for an unusually long time. Most concussions in children resolve in 7-10 days. Typically, most children and adolescent athletes return to their normal activities within two weeks. As stated in the previous article "Post-concussion-Syndrome-Adults," it is a disorder with complicated origins, confusing and conflicting findings reference symptom duration, absence of objective neurologic findings, inconsistent presentation and poorly understood etiology. When it comes to post-concussion syndrome in children there are statements made in the literature that it is virtually unknown in children. However, other literature states approximately 20-50% develop symptoms of post-concussion syndrome.
The symptoms of post-concussion syndrome in children include tiredness, headache, memory loss, dizziness, irritability, poor attention, depression, difficulty in concentration, sleep problems, and personality changes. In post-concussion syndrome in children as is true in adults, the symptoms last for at least one month. Typically, post-concussion syndrome symptoms resolve in 2-3 months, with subtle symptoms lasting longer. There is no upper limit for how long symptoms can last. Some patients will have symptoms for several years.

General Information

Post-concussion syndrome symptoms can be seen in mild traumatic injuries other than mild traumatic brain injury, however, **post-concussion syndrome symptoms are more pronounced in children with mild traumatic brain injury.**
Although, children who sustain a concussion (mild traumatic brain injury) have a more favorable outcome reference to cognitive, achievement, and behavior issues as compared to those who sustain moderate to severe traumatic brain injury, they can

show adverse effects as manifested by **cognitive and somatic symptoms** and **emotional and behavioral symptoms**. Children who experience a mild traumatic brain injury are at an increased risk for the development of cognitive and behavioral problems as well as post-concussion syndrome symptoms. These symptoms are especially prone to occur immediately after mild traumatic brain injury in children. They include: headaches, dizziness, fatigue, depressed or anxious mood, sleep disturbance, light sensitivity, forgetfulness, and concentration difficulties. Most of these symptoms resolve within a few months of the injury. **Persistent post-concussion syndrome symptoms occur only in a minority of children with mild traumatic brain injury**.

Although, emotional and behavioral problems following mild traumatic brain injury are believed to be due to the traumatic brain injury, there is a school of thought, which suggest that those children who develop such emotional and behavioral problems following a traumatic brain injury have evidence of a predilection for, or have shown, pre-injury evidence of emotional and behavioral problems. Thus, the thought is in some children, the mild traumatic brain injury exacerbates the predilection for, or the pre-injury evidence of emotional and behavioral problems.

There are also other risk factors in both adults and children for the development of post-concussion syndrome symptoms following a mild traumatic brain injury, which include: lose of conscious, initial disorientation, longer period of post-traumatic amnesia, traumatic brain injury-related abnormalities in neuroimaging, motor vehicular related trauma, hospitalization, younger age at injury, limited social support, dysfunction within the family, lower IQ, pre-injury behavior and learning problems, and involvement of litigation. **Knowledge of such risk factors would greatly aid the clinician in their clinical evaluation of the patient, whether adult or pediatric, as well as subsequent treatment.**

As occurs in post-concussion syndrome in adults, adding to the confusion of getting a clear picture of mild traumatic brain injury is the use of alternate terms for mild traumatic brain injury, including: “minor head injury,” mild closed head injury,” and “concussion.”

Clinical Presentation of Post-Concussion Syndrome Symptoms in Children

There are two distinct groups of post-concussion syndrome symptoms in children in contradistinction to adults. In children there are **cognitive** and **somatic symptoms** and **emotional** and **behavioral symptoms**. What is also of interest is how these two distinct groups of symptoms present themselves in children following a traumatic brain injury who developed post-concussion syndrome symptoms. For example, there is a distinct decline over time of those who developed cognitive and somatic symptoms of post-concussion syndrome but an increase over time in emotional and behavioral post-concussion syndrome symptoms.

Cognitive symptoms include: negative or distorted thinking, difficulty concentrating, distractibility, forgetfulness, reduced reaction time, loss of short term or long-term

memory, indecisiveness, poor motor coordination, identity confusion, impaired judgement

Cognitive dysfunction is represented by impairment of cognitive function, which rises to the level the person has difficulty in functioning in society in a normal manner.

Foundation of cognitive disorders in general are caused by a variety of factors: hormonal imbalances in the womb, genetic predisposition and environmental factors. Common environmental causes are a lack of proper nutrients and interaction during vulnerable stages of cognitive development, especially during infancy. Other common causes are substance abuse and **physical injury**. When an area of the brain that determines cognitive function is damaged, either by excessive use of drugs, alcohol or from **physical trauma**, the resulting neurophysiological changes can result in **cognitive dysfunction.** The areas of the brain which play a significant role in cognition will be discussed under **neuroanatomy as related to clinical presentation**.

Somatic symptoms-physically felt symptoms include: headache and head pain and muscle tension; metallic taste in mouth; clenching and grinding teeth and jaw pain; chest pain and tightness and palpitations; lump in throat or trouble swallowing; urinary incontinence; breathing difficulties; tingling or skin sensations; stomach and digestive discomfort; sexual pain or inability.

The study of somatic symptoms seen in post-concussion syndrome has shown they are very similar to those seen in **Post-Traumatic Stress Disorder**.

Foundation of **somatic symptoms**: There is dysregulation in autonomic nervous system; limbic instability and alterations in both the hypothalamic-pituitary-adrenal and sympatho-adrenal medullary axes, which in turn affect neuroendocrine and immune functions, and causes central nervous system effects resulting in pseudo-neurological symptoms and disorders of sleep-wake regulation, which result in further autonomic nervous system dysregulation.

Emotional and **behavioral symptoms** following a traumatic brain injury the person may experience significant emotions and behavioral changes, which include: verbal outbursts, physical outbursts, poor judgement and disinhibition, impulsive behavior, negativity, intolerance, apathy, egocentricity, rigidity and inflexibility, risky behavior, lack of empathy, lack of motivation or initiative and depression or anxiety. Some patients will experience **mood swings** following a mild traumatic brain injury. They may have difficulty in controlling their emotions. The patient may feel they are on an emotional roller-coaster. Often there is no specific event that triggers the sudden emotional response. This may be confusing to family members who may think they accidentally did something that upset the person. In some cases the person will show sudden episodes of crying or laughing. Such emotional expressions may have nothing to do with the way the person feels. Usually, the person cannot control these emotional problems. They may make inappropriate comments to friends or strangers not realizing

they are off color. They can also show the opposite personality change in that they may become muted or seemingly emotionless, which is called “flat affect.”

Foundation of **emotional** and **behavioral symptoms**: behavioral deficits are often seen in traumatic injury to the hippocampus and medial temporal lobe structures as well as the frontal lobe.

Mood swings are associated with altered connections between emotion generating and emotion regulating systems. For example, with depression there are heightened intrinsic connectivity in visceromotor emotion generators including subgenual anterior cingulate cortex and thalamus and reduced dorsolateral prefrontal cortex metabolic activity at rest and in response to emotional stimuli. They also show greater and sustained activity in the amygdala to emotional cues.

Anxiety is a reflection of uncontrolled feelings of apprehension and persistent worry or concern. There is strong evidence to suggest the foundation of anxiety is due to a functional decline or a biological change in emotion-relevant neural circuits. This includes findings of hypo-metabolism in the medial temporal lobe, superior temporal gyrus and the insula. Functional MRI studies have shown that patients with anxiety disorders have higher activity in the amygdala, insula, anterior cingulate cortex, and ventromedial prefrontal cortex in response to negative emotional cues. Analysis of intrinsic connectivity in patients with anxiety have shown heightened intrinsic connectivity between the amygdala and anterior cingulate cortex and other emotion generating structures and decreased coupling between emotion generators (i.e., amygdala) and regions that promote emotional control including the orbitofrontal and dorsolateral prefrontal cortex. Structural neuroimaging has shown a smaller volume in the left middle and superior temporal gyri and pregenual anterior cingulate cortex in anxiety disorders broadly. Neuroimaging studies have also shown larger volume in the central nucleus of the amygdala in those with generalized anxiety disorders. Those with panic disorders have smaller volumes in the temporal lobes and bilateral amygdala, but normal hippocampal volume.

Disinhibition refers to the presence of unwanted actions, thoughts, and feelings. As control systems that are involved in self-monitoring, impulse control, and emotion regulation fail, behavior becomes dysregulated, inappropriate, and error-prone. From a social standpoint, these deficits lead to poor maintenance of social boundaries and violations of social norms.

Behavioral, cognitive and emotional control all rely on a network that has centers in the ventrolateral prefrontal cortex and orbitofrontal cortex with connections to the dorsal anterior insula, anterior mid-cingulate cortex, dorsolateral prefrontal cortex, medial frontal cortex, frontal pole, and lateral parietal cortex.

Neuroanatomy as related to the Clinical presentation of Post-Concussion Syndrome, Children and Adults

There are six components of the brain: **frontal lobes, parietal lobes, occipital lobe, temporal lobes, cerebellum** and the **brainstem**.

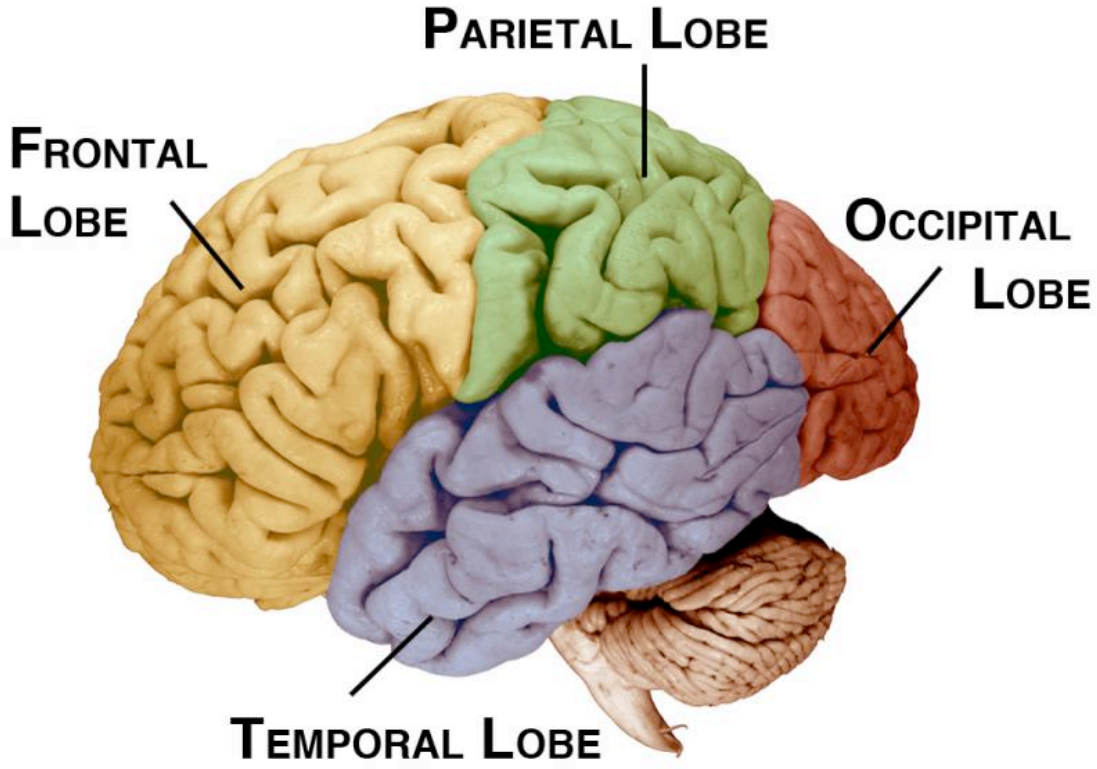

Fig. 1 This illustration shows the four lobes of the brain, with the cerebellum and brainstem being unlabeled. The frontal lobe is in the most anterior portion of the cerebral cortex (in front of the central sulcus); it is involved in reasoning, planning, parts of speech, movement, emotions, and problem-solving. (serendip.brynmawr.edu)

The five components, which play a significant role in cognition are the frontal lobe, parietal lobe, temporal lobe, cerebellum and brainstem.

Frontal lobes link and integrates all components of behavior at the highest level. It is involved in planning, organizing, problem solving, selective attention, personality and a variety of "higher **cognitive functions**" including behavior and emotions, social adjustment and impulse control. Injury to parts of the frontal lobes may cause an inability to move part of the body or the whole side of the body. Speech may become halting, disorganized or be stopped except for single explosive words. Personality may change. Social rules of behavior may be disregarded. Executive function, planning, abstract reasoning, impulse control, sustained attention and insight are all located here. Because of its frontal position in the head, the frontal lobe is highly susceptible to injury.

The **functions** of the frontal lobe include: initiation, problem solving, judgement, inhibition of behavior, planning and anticipation, self-monitoring, motor planning, personality and emotions, awareness of abilities and limitations, organizations, attention and concentration, mental flexibility and speaking (expressive language).

Problems associated with frontal lobe dysfunction include those involving emotion (i.e., depression, anxiety, personality changes, aggression, acting out, and social inappropriateness).

Parietal lobes are divided into two functional regions. One involves sensation and perception and the other is concerned with integrating sensory input, primarily with the visual system. The first function integrates sensory information to form a single perception (cognition). The second function constructs a spatial coordinating system to represent the world around us. Individuals with damage to the parietal lobes show striking deficits, such as abnormalities in body image and spatial relations.

Traumatic brain injury involving the area between the parietal and temporal lobes can cause deficits in memory and personality. Left parietal-temporal lesions can effect verbal memory and the ability to recall strings of digits. The right parietal-temporal lobe is concerned with nonverbal memory.

Right parietal-temporal lobe lesions can produce significant changes in personality.

Temporal lobes perceive and recognize verbal material. It is among the most frequently injured parts of the brain during head injuries. One of the common manifestations of injury to the temporal lobe is the person may have difficulty screening out distractions. Injury to the upper temporal area can cause someone to misunderstand what is said. They may make sounds like words but which are not recognizable as words at all. They may also misunderstand body language. Emotional changes such as unexplained panic or unexpected panic or unexpected tearfulness may be noted. Left temporal area includes speech, naming and verbal memory. The right temporal area includes musical abilities, foreign languages, visual memory, and comprehension of the environment.

Functions of the temporal lobe include: memory, hearing, understanding the language (receptive language), organization and sequencing and musical awareness.

Problems associated with temporal lobe dysfunction include: thinking (i.e., memory and reasoning) and language (i.e., communication, expression and understanding).

Cerebellum receives information from the sensory system, the spinal cord, and other parts of the brain and then regulates motor movements. The cerebellum coordinates voluntary movements such as posture, balance, coordination, and speech, resulting in smooth and balanced muscular activity.

The cerebellum is considered a motor structure, because cerebellar damage leads to impairments in motor control and posture and because the majority of the cerebellum's outputs are to parts of the motor system. Motor commands are not initiated in the cerebellum; rather, the cerebellum modifies the motor commands of the descending pathways to make movements more adaptive and accurate. **What most do not realize the cerebellum is also involved in cognition.** The cerebellum is involved in the following functions:

Maintenance of balance and posture: The cerebellum is important for making postural adjustments to maintain balance. A person with cerebellar damage will show evidence of 'balance disorders.'

Coordination of voluntary movements: Most movements are composed of a number of different muscle groups acting together in a coordinated fashion. One major function of the cerebellum is to coordinate the timing and force of these different muscle groups to produce fluid limb or body movements.

Motor learning: The cerebellum plays a major role in adapting and fine-tuning motor programs to make accurate movements through a trial-and-error process (e.g., learning to hit a baseball).

Cognitive functions: Although the cerebellum is most understood for its contributions to motor control, it is also involved in certain cognitive functions, such as language.

Damage to the cerebellum produces movement disorders. Typically, the person will show uncoordinated voluntary movements and problems maintaing balance and posture.

The **brainstem** plays a vital role in basic attention, arousal, and consciousness. All information to and from our body passes through the brainstem on the way to and from our brain. Like the frontal and temporal lobes, the brainstem is located in an area near bony protrusions making it vulnerable to damage during trauma.

Functions of the brainstem include: breathing; heart rate; swallowing; reflexes to seeing and hearing (startling response); controls sweating, blood pressure, digestion, temperature (autonomic nervous system); affects level of alertness; ability to sleep; and sense of balance (vestibular function).

Problems associated with dysfunction of the brainstem include: decreased vital capacity in breathing, which is important for speech; swallowing food and water (dysphasia); difficulty with organization and perception of the environment; problems with balance and movement; dizziness and nausea (vertigo); and sleeping difficulties (insomnia and sleep apnea).

Other Injury Factors Associated with Post-Concussion Syndrome in Children with mild Traumatic Brain Injury

Loss of consciousness is associated with a higher incidence of cognitive post-concussion syndrome. **Motor vehicular related trauma** is associated with a higher incidence of post-concussion syndrome. **Motor vehicular related trauma** also predicts a marginal higher incidence of **emotional post-concussion syndrome symptoms. Hospitalizations** are marginally associated with a higher incidence of **cognitive post-concussion syndrome symptoms.**

There are two **non-injury characteristics**, which moderate the effects of **injury related** factors in post-concussion syndrome: they are **age** and **social economic status**. **Age** at injury moderates the effects of CT scan abnormalities and **emotional post-concussion syndrome symptoms**. **The younger the age the greater the emotional post-concussion syndrome symptoms.**

Social economic status moderates both the effects of **non-head injury** of **somatic post-concussion syndrome symptoms**, as well as the effect of parenchymal contusions or hemorrhages on MRIs of those with **cognitive post-concussion syndrome symptoms**.

There have been a number of studies, which have shown post-concussion syndrome symptoms are related both to the **injury characteristics**, as well as **non-injury factors**. For example, the greater the number of **pre-injury symptoms** is associated with a corresponding number of post-concussion syndrome symptoms.

Younger age and **female sex** were also associated with a greater number of post-concussion syndrome symptoms.

Lower **social economic status** and **female sex** were associated with higher incidence of **somatic post-concussion syndrome symptoms**.

There are particular types of injury patterns, which suggest a greater incidence of brain insult and a greater number of post-concussion syndrome symptoms with mild traumatic brain injury. These include loss of consciousness, acute CT scan abnormality, parenchymal brain lesions on MRIs, hospitalization, motor vehicular related trauma, and injuries to body regions other than the head.

Other clinical evaluation studies have shown both neurological and psychological factors contribute to post-concussion syndrome symptoms in children with mild traumatic brain injury. For example, it has been shown physical discomfort or difficulties in adjusting to the effects of injury, contribute to post-concussion syndrome symptoms developing after mild traumatic brain injury. What further complicates this picture is evidence of neurological disruption can cause functional issues, which add to the post-concussion syndrome picture.

Treatment

The best therapy for post-concussion syndrome is rest, both physical and mental. From a physical standpoint, strenuous activity must be significantly decreased. **Under no circumstances are the athletes to return to sports**. Once the child or adults symptoms have cleared they can begin to workout, however, they must do so in incremental steps, using the pyramid concept. Should the post-concussion syndrome symptoms return they must stop and wait until the symptoms abate before continuing with their rehabilitation.

What is also essential is all activities, which are intellectually stimulating must also cease, as well as any activity that can exacerbate post-concussion syndrome symptoms. For a child, as well as an adult, this includes any situation in which there are crowds, noise, and bright lights. What is meant by this is the child and adult should refrain from going to the mall, sporting events, movies, playing video games, texting, sending and receiving emails and as stated above, any physical exertion.

What must be kept in mind is eventually, all post-concussion syndrome patients recover.

There will be an occasional child, as well as adults, which may experience depression with suicide ideation. Such patients are to be taken seriously and monitored closely.

What must be avoided at all cost is the child or adult experiencing another traumatic brain injury, mild, moderate or severe, while they still are experiencing symptoms of post-concussion syndrome symptoms. Such an eventuality can lead to the child's or adult's death.

Pathophysiology

Recently, researchers investigating the underlying mechanisms of post-concussion syndrome have suspected activation of the immune inflammatory response (immunoexcitotoxicity) may be the underlying pathophysiologic mechanism that occurs in those patients who go on to develop post-concussion syndrome symptoms, most especially prolonged symptoms. The activation of the immune inflammatory response involves an interaction between immune receptors within the central nervous system (CNS) and excitatory glutamate receptors. This interaction triggers a series of events, such as extensive reactive oxygen species and reactive nitrogen species generation, accumulation of lipid peroxidation products and prostaglandin activation, which then leads to dendritic retraction, synaptic injury, damage to microtubules, and mitochondrial suppression. For a more in depth review of this subject please click on the following link "Post-concussion-Syndrome-Adults," and read pages 3-11.

Epidemiology

Traumatic brain injury in children between the ages of birth to 14 years account for approximately 39,000 hospitalizations and 484,000 emergency department visits yearly in the United States.
The causation of these emergency room visits in this age group are usually due to falls and motor vehicular accidents. Most of these patients who are seen in the emergency room for traumatic brain injury in this age group are not hospitalized, 80-90%. Of those children in this age group who are hospitalized over 80% are diagnosed with **mild traumatic brain injury**.

Summary

Post-concussion syndrome symptoms can be seen in mild traumatic injuries other than mild traumatic brain injury, however, post-concussion syndrome symptoms are more pronounced in children with mild traumatic brain injury. There is also evidence different patterns of post-concussion syndrome symptoms change over time post injury in children. There are also indicators in those with mild traumatic brain injury, which are associated with more severe post-concussion syndrome symptoms, such as: motor vehicular related injuries, loss of consciousness, hospitalization, acute CT scan abnormalities, parenchymal abnormalities on MRIs and accompanying non-head injury. There is also a relationship between the effects of mild traumatic brain injury on post-concussion syndrome being moderated by such factors as age at injury and social economic status.

The recent research into the mechanisms underlying post-concussion syndrome following traumatic brain injury, including mild traumatic brain injury, have suggested the evolution within the brain of a central pathological mechanism, which involves activation of an immune inflammatory response as the primary pathophysiologic process responsible for post-concussion syndrome. This inflammatory response involves a process called **immunoexcitotoxicity**, which plays a key role not only in post-concussion syndrome but many neurodegenerative diseases including **chronic traumatic encephalopathy.**

Understanding the various pathways involved in immunoexcitotoxicity leading to post-concussion syndrome, as well as many neurodegenerative diseases including chronic traumatic encephalopathy, will allow us to develop nonpharmacological and pharmacological agents to interrupt these pathways and thus prevent the often tragic consequences of immunoexcitotoxicity.

There are now several books available for your review on the website, www.forensicjournals.com. These books are entitled “Traumatic Injuries to the Head, Vertebrae, Spinal Cord and Peripheral Nerves of the Newborn During Birth,” “Nonsexual and Sexual Traumatic Injuries of the Perineum, External Genital Organs and the Breasts: Adult, Elderly and Pediatric,” and “Traumatic Injuries of the Organs of the Pelvis: Adult and Pediatric.”