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Pediatric Traumatic Brain Injury, Before, During, After A Pediatric Physiatrist Point of View

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INTRODUCTION

Pediatric traumatic brain injury is a very common medical problem encountered by pediatric physiatrists and for some children a difficult recovery. The rehabilitation of this is equally difficult. The incidence of traumatic brain injuries in the pediatric age group is 200/100,000 per year.[1] The majority are minor brain injury by definition from the Glasgow Coma Scale. The scale is poor in describing the rehabilitation outcome of a child with severe or moderate brain injury.[2,3,4,5] For mild brain injury there are many articles published that show difficulties in some children and young adults though many individuals who have these injuries never receive care or input.

I will focus this article on severe brain injury which has significant changes in function that are at times present in mild and moderate brain injury, but in a lesser amount. In order to present a more focused picture the article will be about the rehabilitative outcome of mostly diffuse brain injury. This will eliminate the non-accidental injury which at times is a repetitive brain injury as well as infectious, tumor or degenerative injuries. I will at times introduce thoughts on penetrating injury though this can present different in outcome then diffuse axonal injury. The overall concept of the paper is to review thoughts regarding TBI in children and young adults with my viewpoint based on evidence based medicine and experience.

Pediatrics is the care of the newborn, infant, preschooler, child, and young adult. This span of maturation is very important in the area of pediatric rehabilitation and outcome. It is one of the cornerstones on evaluation of the patient with a traumatic brain injury in the pediatric age groups.

The newborn at birth has an immature brain. There is development of the brain in the areas of neuromuscular, neurocognitive, and neurobehavioral realms over the childhood and early adult years. This development occurs in an organized manner based on genetics and environmental influences.[6] At birth, the brain is immature with maturation occurring from occipital to frontal at specific times through childhood, puberty, and ending in the mid-twenties. A severe traumatic brain injury interrupts this development causing axonogenesis, neurogenesis, axonal death, along with a cascade of biochemical changes. These new connections that develop after a brain injury permanently alter the maturation process of the brain. This alteration will change the *before* developmental path which is influenced *during* the acute hospitalization and rehabilitation time, giving an indication of the *after* outcome.

Before TBI

Maturation of the brain occurs in a predictable manner. Its developmental milestones have a wide variance of normal especially for the newborn through preschool years. The child who

doesn't sit unsupported by six months is not at risk of delay in that this has an accepted range. The child, who develops hand dominance at 6 months of age or asymmetrical movement of the body, does indicate an altered pattern needing assessment.

The pediatric acquisition of skills from newborn to adult continues into early adulthood. The young child's development is most easily noted in movement but also overtime in neurocognitive and behavioral manners. This acquisition of skills and maturation of the brain allows for future productivity in society, understanding the social norms, as well as obtaining vocation, knowledge, caring, and the concept of a functional adult.

There are milestones of development that are important to the acquisition that have been noted in pediatrics that are "explosions of function". The easiest for the parents to see, is the explosion of movement going from a totally dependent newborn to a walking and later running child in a rather short time period. The accepted concept of falling in toddlers to the development of mature gait around 6 years of age assures a steady increasing in gross motor function. The acquisition of hand skills such as an infant trying to grasp an object with both hands to transferring the object from hand to hand allows not only movement but neurocognitive and neurobehavioral play. These play situations and maturation of the brain in language, movement, and behavior allows the child to enter into their workplace and develop a place in their growing community, the school. School and learning are the jobs of children which help develop the brain through its maturation stages to reach the child's productive functional adult level. The work load of the school, as well as community interactions, develops the brains function and cellular development.

Therefore, struggles in acquisition of skills such as aggressive behavior to others, lack of imaginative play, slow in acquisition of language or learning; forms a baseline for the child's community. When stressed in these areas or other developmental milestones, it allows for increase resource utilization to improve development and function. The hope is to assist in the development of the child's maturing brain. During times of greatest acquisition of skills, resources are used to maximize function. Examples of this are the 0-3 age programs for children at risk or the neonatal follow-up clinics for newborn "graduates" from the NICU that have "red flags" requiring additional services.

These acquisition of skills, are like the adult, who has baseline knowledge of carpentry, the skills of a professional athlete, or the social awareness of a leader. They form who the child is at that specific time. If a traumatic brain injury occurs along the timeline of acquisition then there is disruption in the child, family, their community, and workplace. Unlike a child who has a paralyzing spinal cord injury the maturation of the brain in traumatic brain injury is permanently altered. A child with prolonged coma will walk independently in the vast majority with 10% limited in ambulation and only 17% in a dependent state. [7] Despite this ability to regain gross motor function, fine motor hand function in moderate and severe injury is slower and less refined.8 The neurocognitive and neurobehavioral abilities of those children with severe injury, as in moderate brain injury, fall further behind their development curve after the injury.[2,12] They begin having difficulty in the workplace of the school, the social setting of the home, and their community.[2, 8-26]

Therefore the concept of allostasis becomes evident to the caregiver, family, and at times the community. Allostasis in this regards is how the child's continuous process of development is affected by the acute traumatic brain injury's stress (load) in the development and acquisition of skills.[2, 13] From a pediatric rehabilitation point of view, knowing the before function of the child is necessary in order to develop the rehabilitative plan or life care plan of that child.

During the Traumatic Brain Injury

There are few measurements that give clues to outcome of the child entering this phase of care and assessment. The vast majorities of adults if in coma for prolonged time, will remain totally dependent without ambulation. 70% of children in a prolonged coma state will ambulate.[7] At 12 weeks of coma 38 % of the children still will be ambulators according to Brink et al.[7] In the early literature this was attributed to plasticity of the brain. Now with maturation and better understanding of development of the brain with its axonogenesis, neurogenesis, and cellular development, the better outcome in children is believed to be due to the continuous process of maturation of the brain.[2,6] Maturation of the brain occurs throughout the pediatric years into early adulthood allowing for acquiring of skills needed in the adult life.[6]

Therefore, evaluating the child in the acute setting concepts such as GCS, Rancho Scale, posttraumatic amnesia, delay in access to care, or anoxia with secondary injuries to the brain only give rough approximation of the rehabilitative outcome of the child/young adult. Their ability to ambulate as stated above can give false security to the family. Clinical studies have demonstrated a gross ability to define functional outcome though hard to apply to an individual person at times.[32,33,34,35]

Medical complications such as heterotrophic ossification are aggressively evaluated. In this differential deep vein thrombosis, a rare occurrence in the pediatric ages during rehabilitation, needs to be considered especially with risk factors i.e. fracture, central line use or local infection.[1,2,28] Entities such as precocious puberty or SIADH can occur and are complex medical problems consistent with severe brain injury involving the pituitary. These and other medical complications need to be evaluated and cared for but rarely influence the functional outcome of the child in regards to their brain injury rehabilitation. They may highlight the severity of injury but not functional outcome over time. These medical complications will require assistance and resource utilization based on medical knowledge of multiple specialists.

The presence of early seizures unlike the adult age group does not indicate future anticonvulsant needs. Children rarely have seizures complications in diffuse axonal injury and observation is better than exposure of anticonvulsants on the recovery of the immature brain. Penetrating head injuries have a higher incidence of seizures as well as intracranial bleeds with the needs for surgical intervention being higher in the penetrating injury. Therefore the presence of a penetrating injury may indicate the need for anticonvulsants and follow up with neurology. Even with penetrating injuries the frequency of long term anticonvulsant needs is low in the pediatric head injury population with the majority of seizure focuses resolving over time as noted in EEG serial assessments after TBI.

One clinical thought I always remember is that as a female child ages the hormonal influxes during menses will lower seizure threshold at times causing a re-evaluation of treatment needs and medical assessment, especially if her injury was penetrating or had a component of hemiparesis in the early recovery time.

Autonomic dysfunction known as the hyperdynamic state or other names has been seen to affect outcome. Brink et al., stated the presence of increased blood pressure, heart rate, sweating and posturing did affect the functional outcome of children at Rancho.[7] In a paper presented in 1989 by myself at the American Academy of Physical Medicine and Rehabilitation out of the 189 patients from 1983 to 1989 at the Rehabilitation Institute of Chicago, treatment with propranolol decreased the symptoms permitting interventional rehabilitation to go forward. While not assessing the functional outcome, in this retrospective evaluation, it did seem to permit faster calming permitting rehab intervention to continue with

better than anticipated outcome. This state only presented itself in severe diffuse TBI of any cause, occurring during the rehab time period and not in the acute hospital time. Clifton et al. stated, that when blood pressure was greater than 20 mmHg above the normal it lead to a poorer outcome from TBI.[29] They demonstrated the use of propranolol was successful while hydralizine was not. Also noted were increased blood concentrations of chatecolamines during this time period. I have noted this on my own patients overtime where the chatecolamines were four to five times higher than normal. It is difficult to state that this affects the outcome directly, especially since the assessment and treatment directed at the biochemical abnormalities of brain injury in children is in its early years. The presence of autonomic dysfunction though supported by Brink and others, as well as my experience, does influence their rehabilitation.

Another factor that will influence rehabilitation is hypotonia. I have not seen this addressed in the literature but if a child is hypotonic in the acute setting then the rehabilitation goals should be lower. It is much like hypotonic cerebral palsy where the lack of spasticity or normal tone may indicate a poor functional outcome.

During Rehabilitation

During the rehabilitation time, if possible during the acute hospitalization, the collection of pre-injury information to form the developmental baseline is the cornerstone of the rehab team plan. This along with the stresses (load) that may pre-exist in the child for example, attention deficit, family history of psychiatric challenges, history of slow acquisition of milestone, or the thought of pre-existing sensory integrative dysfunction are important. It is hard to collect this in the preschool ages due to the broad spectrum for normal. The knowledge is obtained by the whole team working in a transdisciplinary manner to gather from as many sources as possible i.e. school, pre-school., family, day care, or church. The more input usually the better with the family being an integral partner in the collection. This allows for the concept of allostasis from the injury. It also allow for a starting point or baseline, bringing the family members and their community into the treatment "family" team.

During the rehab time the child's plan hopefully will focus from position and movement to attention deficits, spontaneity of ideas, imaginative play, acquisition of past academic and language as well as behavioral assessment. The neurocognitive and neurobehavioral components are collected by the pediatric rehab team by stressing these components to see the abilities of the child. The team conference in pediatric rehabilitation reports the standards of recovery and functional measurement i.e. wee fim, pedi or others. But more importantly it documents where the child falters or stumbles in acquisition of past skills or regaining skills in their milestone of maturation specific to their age.

This is the most important point of pediatric rehabilitation, in my opinion, since the goals of the team are to teach the family their child's strengths and weakness. This knowledge will allow for development of the Individual Educational Plan (IEP) of the school or the child's work place to assure success and identifying future rehabilitations needs. The rehab team should point out the significant functional challenges i.e. lack of safety awareness, inability to focus, time to cognitive fatigue, and type of memory challenges. This permits the school, which entered the rehab team early after admission or through strong communications, appropriate placement allowing for continued gains and successes with less family/child stress.

Therefore, the pediatric rehab team teaches the family, respectfully and honestly, what has happened and likely to continue, hopefully for the best, but with appropriate "realistic optimism." The family must have input into this process since the most important factor in

the family's opinion is cognition and behavior after the traumatic brain injury. In pediatric rehabilitation the team's effort is to educate the family, school, and community of the child/young adult's ability, permitting an understanding of the specific needs of the patient. This idea of appropriate knowledge also has its timeline and being diligent in teaching and repeating these concepts is important so the family also understands the timeline of maturation with the influence of the TBI in re-directing its development.

Therefore, especially in the younger child who will have the greatest deficits over time due to greater maturation lags in multiple areas, returning to the rehab team after discharge in an outpatient setting is an important point to the outcome of the child. The pediatric rehab plan continues to follow-up allowing for modification of the plan through the maturation stages. The team, which includes the school, uses school experience for assisting in upgrading and evaluating academic areas. Outside the school's interventions, the other rehab needs are addressed. This is especially at points of maturation explosion i.e. puberty, which requires a transdiscplinary team evaluation frequently dependent on the age and resources available. It also allows for the assessment of function and possible use of medications to assist in the deficits. This requires strong working knowledge of the person's functional challenges, maturation stage, and family education in order to achieve functional improvement with various medications. [1,29, 30,31,32]

During this time as well as throughout this journey the family is the center of care. It can assure success or failure of the child. Assisting the family in the "loss of the child" and getting to "know" their child is paramount for the team. This means assisting other siblings if needed as well as the parents. This can be challenging since they may be tired or possibly not see the challenges. At times unfortunately, the family can be a complication as well. All these factors are part of the pediatric rehab team assessment and life care plan. It requires a strong consistent team delivering one message over time in many different ways with different team leaders as needed throughout this maturation process. The physicians continue to see the child for medical complications over time though the rehabilitation outcome is based on the neuromuscular, neurocognitive, and neurobehavioral more frequently since these challenges many times are more devastating than the medical challenges in pediatric traumatic brain injury.

Medications during the acute hospitalization need to be reviewed with those that may hamper rehabilitation outcome being discontinued when possible i.e. anticonvulsants, benzodiapene, muscle relaxants, and others·[1,29,30,31] Neurocognitive and neurobehavioral milestones are stressed by confusion, aggression, lack of motivations, or other complications of brain injury which directly affect the outcome of the TBI rehabilitation.[14,15,16,17,18] Many medications used in the acute hospitalization may interfere with this rehabilitation process.

The use of medications for these challenges is in its infancy of understanding, especially in the developing child, being directed mostly by the experience of the provider.[30,31,32] The effect of medications used in a mature adult brain may influence negatively the developing brain. Knowing the normal development of a child in cognition and behavior is important in order to judge the "cost/benefit" of using medications that may assist in memory, cognition, or behavior. In the rehabilitation plan or life care plan as the child ages, introduction of these medications in a "start slow" manner especially as the child lags in develop can influence specific deficits.[1,30,31,32] The life care plan or rehab plan should be able to identify the type of challenges that medications maybe able to address over the maturation cycle using neuropsychological testing, school/family functional level during times of greatest change/development. The pediatric rehab team also should be able to show how the

neuropsychological results have been "tested" in the "real world" with the successes or challenges noted. Clinical studies can assist this experienced knowledge of the child's function by identifying the areas of injury that may match this functional loss.[34,35,36] This transdiscplinary approach allows for a greater understanding of the child throughout the maturation cycle into adulthood. Knowledge of the child's outcome in this manner permits the rehabilitation plan/life care plan to extend into adulthood were it can be applied over time in a clear manner for the family and the community.

SUMMARY

Plasticity of the pediatric brain after traumatic brain injury is the influence of the injury on the maturation cycle. This cycle is dynamic changing from birth into adulthood. Rehabilitation planning takes into account this maturation using the transdisciplinary team to maximize outcome. Medication is used to maximize function with utilization geared to the child's maturation, starting slowly and adjusting over time. The life care plan can include these steps based on the solid foundation of pre-injury function, medical/rehabilitation team assessment, family (school) performance (function), knowledge of the maturation of the brain and future function as an adult with traumatic brain injury.

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