57 Rehabilitation and Outcome of Head Injuries

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Traumatic injury is the leading cause of death in children and adolescents,[1,2] and pediatric traumatic brain injury (TBI) accounts for approximately 40 to 50% of injury deaths.[3] Despite efforts at prevention, pediatric head injury remains a significant public health problem in the United States. Of children who survive severe head injury, 50% experience neurologic deficits affecting multiple areas of function.[4] Although pediatric brain injury was once considered more benign than injury during adulthood,[5] studies indicate that younger children may be more at risk for impairment than older children, particularly if the head injury is severe.[6,7] Thus, it is easy to understand why research on the outcome and rehabilitation of children with brain injury continues to receive a great deal of attention by a variety of health care professionals.

57.1 General Considerations Affecting Outcome

57.1.1 Severity of Injury

Not surprisingly, evidence clearly indicates that children sustaining severe injuries have the worst prognosis. Many of these children exhibit long-term deficits in a number of cognitive, psychosocial, and adaptive domains.[8,9] A unique study of adults who were injured during their preschool years demonstrates the far-reaching effects of severe injury incurred in early childhood.[10] Of the 39 children followed to adulthood, 15 required special school placements for either physical (21%) or mental (18%) disabilities. Despite the fact that the remaining 59% attended "typical" schools and more than two-thirds of this group demonstrated a low-normal or higher IQ, only 23% were able to work full time. This finding suggests that either personality changes or behavior problems, or both, interfered with their functioning as adults. Other studies have indicated that individuals sustaining moderate to severe injuries are more likely to exhibit long-term reductions in quality of life and deficits in a broad range of social skills.[9,11]

57.1.2 Preexisting Conditions

Although the information on this topic is somewhat limited, a study by Donders and Strom[12] indicated that children with preexisting learning disabilities exhibited a greater than expected drop in intellectual functioning following a moderate to severe head injury when compared with a group that had no history of preexisting learning difficulties. Another case series, by Schmidt and colleagues,[13] indicated that children with a history of low birth weight demonstrated an attenuated pattern of recovery in terms of verbal memory, academic performance, and adaptive skills when compared with a control group of normal birth weight matched for age, sex, injury severity, and socioeconomic status. Importantly, these groups demonstrated very similar patterns of test performance at baseline, and differences emerged only over time, suggesting a difference in the trajectory of recovery rather than a preexisting difference in performance between the two groups.

57.1.3 Age of the Child

Current conceptualizations of pediatric head injury suggest that younger age at injury is associated with a less favorable prognosis. In light of this new understanding of the developmental consequences of TBI in children, it is particularly important to consider age at injury in the discussion of outcome. For example, findings from a longitudinal study of very young children (i.e., 4 months to 7 years old at the time of injury) demonstrated not only minimal recovery 6 months after injury but also a reduction in the acquisition of new skills after severe injury.[14] Another study of children ranging in age from 2½ to 16 years at the time of injury found older age at injury predicts better adaptive function for up to 5 years after injury, particularly in the absence of premorbid learning problems.[15] These findings highlight important differences between adult and child outcome research. In children, injury occurs to a developing brain. Thus, Taylor and Alden strongly recommend that the age-related effects of injury and subsequent recovery be investigated with consideration of age at injury, time since the insult, and age at testing. Age and time since insult may take on even more significance when the neuropsychiatric symptoms associated with injury to the frontal systems, such as those commonly seen in children with moderate to severe injury,[16,17] are the focus of investigation. For example, Levin et al found that younger and older children with *similar* levels of severity and times since injury showed *different* patterns of executive deficits. The differences in injury pattern and recovery of function might be accounted for, at least in part, by the developmental stage of the brain at the time of insult.

57.1.4 Resources of the Family

A child's recovery from head injury may be affected by both neuropsychiatric (e.g., Glasgow Coma Scale [GCS] score, duration of loss of consciousness, de novo psychiatric problems, neurologic status) and what Max et al[18] termed the psychosocial disadvantage factor (e.g., family dysfunction, family psychiatric history, lower socioeconomic status). Noting the adverse impact of pediatric TBI on families, Wade et al, Taylor et al, and Yeates et al completed a series of studies that demonstrated the complicated interactions between premorbid and postinjury family functioning and outcome after TBI in school-aged children.[19–23] In their 1997 study, this research group showed that perceived family burden and psychological distress are related to recovery in children with head injury.[20] Family function before the traumatic injury influenced both behavior and cognitive outcome. These findings were extended in 2004 with a controlled study that was one of the first to demonstrate the importance of family environment in the postacute period. Based on their previous finding indicating the influence of preinjury family function on later recovery, the investigators controlled for family factors when they assessed outcome. Measures of postinjury family environment (i.e., family economic burden, parental psychological distress, and family dysfunction) were associated with 1-year outcome, with behavior and school function most affected in severely injured children. Further studies by this group have found that the family system continues to influence recovery from brain injury for as long as 4 years after injury.[21–23] Less than optimal family circumstances exacerbated the adverse effects of TBI on overall behavior, social outcome, and academic skills, but not on cognitive status as measured by neuropsychological tests. However, a series of more recent investigations by Schmidt and colleagues indicates that family socioeconomic status, especially a family's access to financial resources, influences a child's trajectory of recovery in tasks of basic emotion processing.[24,25] Interestingly, these investigators also demonstrated that many of these effects were more significant in younger children.

The research regarding the influence of family function is not equivocal. Others suggest that the family disorganization frequently noted after pediatric head injury is not necessarily related to dysfunction that was present before the injury occurred.[26] Schwartz et al[27] investigated the relationship between behavior problems and family function 4 years after injury. Children with TBI who met the criteria for clinically significant postinjury behavior problems were compared with children who had head injury and displayed no such problems. This comparison indicated that although the clinically involved children were more socially disadvantaged, family dysfunction developed only late in the recovery course. Comparison groups did not differ at either preinjury or early (i.e., within the first year after injury) time points, a finding suggesting that negative family outcomes emerged after the head injury.

57.1.5 Mild Injuries

Of the more than 1 million TBIs that occur each year in the United States, mild TBIs are by far the most common, representing at least 79% of all TBIs.[28] In recent years, there have been growing concerns regarding the consequences of very mild head injuries (i.e., concussions).[29] Concerns have been most notable regarding repetitive mild injuries. Although research continues on the long-term sequelae of these repeated concussive events, some initial data suggest that individuals sustaining three or more mild concussions exhibit long-term decreases in verbal memory skills.[30] As many of these mild injuries occur during the course of athletic competition, a major focus of clinical management in these cases is determining when an athlete should return to play. The use of computerized testing for baseline measurement of an athlete's neurocognitive abilities, followed by regularly repeated assessments after a concussion, has gained popularity as a way of guiding and making more informed decisions regarding return to play.[31–33] Although the use of computerized testing as a sole means of making these decisions has not been universally accepted (see Echemendia et al[34] and Mayers and Redick[35]), it remains a common practice. A major concern with relying exclusively on computerized baseline testing to inform return-to-play decisions is the concern that athletes may attempt to invalidate their baseline performance by intentionally "faking bad" during these evaluations. There is some evidence to suggest that postinjury computerized batteries, if interpreted with regard to population-based means (as opposed to baseline scores), may continue to provide a valid assessment of postconcussive cognitive symptoms.[34,36]

57.2 Assessing Neurobehavioral Consequences in the Acute Period

Comprehensive neuropsychological testing is rarely completed in the inpatient setting because the acute consequences of TBI obscure the accuracy of measurement as a consequence of baseline effects. One important exception might be the application of the Children's Orientation and Amnesia Test (COAT),[37] a standardized assessment of posttraumatic amnesia. The COAT can be administered serially and is an appropriate component of any inpatient evaluation conducted following a pediatric TBI. Posttraumatic amnesia has been found to be a potent predictor of later recovery from TBI and as such provides useful information for both the neurosurgeon and other rehabilitation providers.

57.2.1 Functional Skills

Assessing functional living (i.e., adaptive skills) following a mild or moderate injury is an important aspect of monitoring recovery, guiding return to play in the case of sports-related injuries or return to school in the case of other, more serious injuries, and helping both clinicians and parents understand when more in-depth evaluation is necessary. Adaptive abilities are those needed to function independently at an age-appropriate level.[38] A current challenge in the outcome field is to develop appropriate measures of functional outcome for children. Adaptive abilities or functional outcome in the broadest sense is frequently measured with the Glasgow Outcome Scale (GOS).[39] In children, the GOS score depends on return to school as a measure of successful outcome. A child's return to school, however, does not have the same significance as an adult's return to work because legal mandates require schools to attempt to educate all children.[40] In addition, the broad GOS categories lack sensitivity,[41] particularly when used in a pediatric population, because they fail to consider how the demands on children change across different developmental levels.

A revised version of the GOS, the GOS-Extended (GOS-E),[42] has promise for evaluating outcomes in pediatric populations but lacks developmental specificity. In a recent study, Beers and colleagues[43] modified the GOS-E to create a more developmentally appropriate measure, the GOS-E Pediatric Version (GOS-E Peds). These investigators reported that the GOS-E Peds had good predictive, criterion, and discriminant validity at 3 and 6 months within a sample of children sustaining mild to severe TBIs. The authors argued that the GOS-E Peds would be an appropriate measure to use in future studies assessing outcomes following pediatric head injuries, although few studies have employed this measure to date.

Although not without problems, a more sensitive indicator than the GOS of adaptive competence in children is the Vineland Adaptive Behavior Scales (VABS).[44] This norm-referenced instrument has the advantage of using a semistructured interview with the parent to measure adaptive skills across the domains of communication, daily living, and social domains and appears to be sensitive to the changes associated with TBI.[45] Using serial VABS data, Fletcher et al[46] showed that age-specific adaptive behavior declined in the year following severe head injury but not after mild to moderate injury. Levin et al[47] found that functional outcome on the VABS was inversely related to the depth of a brain lesion on magnetic resonance (MR) imaging at follow-up. The VABS is also useful for evaluating premorbid function, particularly in younger children,[48] and in assessing isolated aspects of adaptive behavior, such as socialization, in the later recovery period. A recent study by Rivara et al[49] in which the VABS was used indicated that children with moderate or severe TBI exhibited decreases in the ability to participate in age-appropriate activities, communication, and self-care skills, none of which returned to baseline levels at 24 months after injury. Interestingly, these investigators also observed decreases in quality of life at 2 years after injury in children sustaining a complicated mild TBI (i.e., a mild injury with evidence of findings on neuroimaging), suggesting that, at least in some individuals, these injuries may not be as benign as suspected. Other evidence indicates that injury severity and preinjury factors, such as behavioral functioning, adaptive skills, and family environment, can play a role in long-term functional outcomes, even more than 10 years after injury.[50–53]

57.3 Neuropsychiatric Manifestations during the Period of Active Recovery

Some of the most common neurobehavioral sequelae within the period of active recovery (i.e., the initial 2 years after injury) from closed head injuries involve deficits in processing speed, memory (especially working memory), behavior regulation, and attention. These difficulties can result in significant behavioral disruption, difficulties in returning to grade-level academic work, and problems with activities of daily living. If deficits in neurocognitive functioning are still evident after the initial postacute period (i.e., the period following the resolution of posttraumatic amnesia and following participation in intensive inpatient or outpatient rehabilitation), referral to a pediatric neuropsychologist for a comprehensive evaluation of cognitive domains is recommended. Specifically, this assessment should be completed before a child resumes full-time academic work. Although a pediatric neuropsychological evaluation is most critical for children who sustained a severe injury, often children with moderate injuries who recover relatively quickly and who typically have little or no need for long-term rehabilitation can also benefit from this kind of thorough postinjury assessment. There are several important factors to consider before a referral for a pediatric neuropsychological evaluation:

- Can the child reliably respond to simple commands and complete basic motor tasks when asked to do so?
- Does the child have sufficient energy to sustain attention and effort for at least 2 to 3 hours of testing?
- Are the child's language and motor skills sufficiently recovered so as to make testing within these domains possible and interpretable? Of note, although continued deficits in either or both of these domains do not explicitly rule out the possibility of neuropsychological testing, deficits do suggest that referrals should be made to practitioners with specialized experience and training in the assessment of postacute pediatric TBI.

57.4 Areas of Comprehensive Assessment

A comprehensive neuropsychological evaluation involves assessment across neurocognitive domains, including intellectual ability, academic skills, receptive and expressive language skills, visual and verbal memory skills, visual-motor and fine-motor deficits, behavioral and emotional functioning, and attention and executive skills.

Intellectual testing is an important component of pediatric neuropsychological evaluations because it establishes a child's current abilities and provides a baseline level of performance, which is useful in tracking a child's development as he or she matures and as moves farther and farther away from the actual injury. Academic skills are also an important component of an assessment because these skills are frequently robust and may be more resistant to deterioration following a severe injury. As a result, academic performance can help to estimate a child's premorbid abilities. Importantly, because children are continuing to acquire new academic skills, they remain at long-term risk for significant academic delays secondary to a failure to make developmentally appropriate progress. Findings in these two areas are often elaborated on by the identification of a child's strengths, and weaknesses in the cognitive domains discussed in the subsequent sections.

Language skills can be divided into receptive (i.e., the understanding of language) and expressive (i.e., the use of language) skills. Both types of assessment should be conducted in a thorough evaluation in order to determine if additional referrals for outpatient speech and language therapy services are necessary. Language assessment is also an important component of a pediatric neuropsychological evaluation because difficulties with language can often contribute to or exacerbate behavioral and social deficits.

Memory problems, especially difficulties with working memory, are some of the most common problems following a closed head injury. Working memory is the ability to keep information in mind and use it for a specific purpose. For example, working memory is required when someone gives you directions on how to get to a specific room in a building you have never visited before. Because working memory is mediated by structures within the frontal lobe, specifically the left dorsal–lateral prefrontal cortex, it is extremely vulnerable to TBI. Deficits in working memory can lead to problems with everyday behaviors, such as compliance with medication. Although working memory problems are common after TBI, long-term verbal and visual memory difficulties can also arise because these functions are largely mediated by temporal structures, such as the hippocampus, which are structurally and metabolically vulnerable.

Problems with processing speed and motor control are frequent following pediatric TBI. Deficits in these domains can lead to problems in efficiently carrying out academic and adaptive tasks. Measures of processing speed are some of the most sensitive to neurologic dysfunction and should be incorporated in any thorough assessment of neurocognitive skills.

Executive deficits are also very common following pediatric TBI and are related to many of the behavioral difficulties discussed below. Executive functions are a wide range of neurocognitive skills and include the following: initiation of activity (i.e., the ability to begin meaningful motor or cognitive tasks); sustaining (i.e., the ability to persist in cognitive or motor tasks that have been initiated); shifting (i.e., the ability to change focus when necessary in order to change strategy or carry out another procedure); and inhibiting (i.e., the ability to withhold a response and/or regulate action as is appropriate for the situation). Because many of these abilities are mediated through structures in the frontal lobes, they are exceptionally vulnerable to closed head injuries. Moreover, because of their protracted development, children may not fully express the extent of the damage they have sustained until the demands on these skills increase as they grow older.

Although traumatic head injury often results in physical impairment, more problematic consequences involve the individual's cognition, emotional function, and behavior. These cognitive, emotional, and psychosocial deficits are frequently referred to as the neuropsychiatric sequelae of brain injury and are a significant cause of disability. Personality and behavior changes following closed head injuries are common manifestations of moderate and severe injuries. Often, these changes in behavioral functioning result in a diagnosis of a novel-onset psychiatric disorder. In a series of investigations, Max and colleagues[54–56] demonstrated that upward of 45% of all children sustaining a TBI exhibited novel-onset psychiatric disorders at 3 months after injury. Furthermore, these investigators showed that from 60 to 80% of children sustaining a severe TBI exhibited signs of novel-onset psychiatric disorders.[54,56] Max et al also suggested that severity of injury, lifetime psychiatric disorder, family psychiatric history, preinjury family function, socioeconomic status, and preinjury intellectual function contributed to, but could not account for, the increase in novel psychiatric diagnoses following injury. A recent follow-up to these initial investigations indicated that nearly half of all children sustaining a TBI exhibited a novel-onset psychiatric diagnosis at 3 months after injury and that personality change and externalizing disorders occurred significantly more frequently in the TBI group than in the orthopedic control group.

57.5 Late Effects of Pediatric Traumatic Brain Injury

As the devastating consequences of TBI in childhood have become better understood, more studies have undertaken what has become known as research into the late effects of TBI. This body of research provides important information for neurosurgeons because it informs them regarding the cognitive prognosis after TBI. This is particularly important for children, who by definition will continue to engage in challenging cognitive pursuits for years after injury. It has been our experience that neurosurgeons, who provide the first line of treatment after TBI, are sought out by families for treatment recommendations sometimes years after the acute injury period, when heretofore unappreciated cognitive problems become more apparent.

57.5.1 Intellectual Abilities

An apparently intact intellectual level frequently obscures other cognitive challenges and thus is not a reliable indicator of recovery following pediatric TBI. Nonetheless, studies using IQ as an outcome variable can yield some general findings as to overall patterns of recovery. A recent investigation by Crowe and colleagues[57] suggested that children sustaining a TBI in middle childhood actually had worse outcomes than did children sustaining injuries in early or late childhood. The investigators suggested that this result might reflect a window of vulnerability in brain maturation occurring during middle childhood. In another study, this group demonstrated significant decreases in intellectual functioning, assessed between the ages of 4 and 6 years, in children who sustained a severe TBI before the age of 3 years.[58] Ewing-Cobbs and collaborators[59] reported a similar finding when they observed continued deficits in intellectual functioning in children who had sustained a severe TBI before the age of 6 years and were followed for 5 years after injury. Conversely, Anderson and colleagues[60] showed that as a group, survivors of childhood TBI did not exhibit significant decreases in terms of intellectual abilities 10 years after injury, although these investigators cautioned that survivors of severe TBI had a less benign course. A recent study of adult survivors of pediatric TBI indicated relatively intact intellectual functioning, although significant decreases in IQ and quality of life were noted in those individuals who had sustained severe injuries.[61] Head-injured children who have IQ scores within the normal range can, nonetheless, exhibit a variety of problems, some of them long term. For example, a study of children age 9 to 18 years injured approximately 4 years earlier demonstrated that IQ was not correlated with problem-solving skills within a social context.[62,63] Another study noted that children with normal IQ scores exhibited subtle language differences in the classroom.[64]

57.5.2 Motor and Visual-Motor Skills

Motor problems are perhaps the most easily recognized sequelae of head injury and are observed to some degree in nearly all children after moderate to severe head injury. Early work by Levin and Eisenberg identified deficits on tests of stereognosis, finger localization, and graphesthesia in approximately 25% of children with severe head injuries.[65] Others have shown that children with severe injuries are most affected when balance and speed of performance are essential to successful task completion. In a recent investigation, Sutton and colleagues[66] found that children with TBI exhibited significant decrements on a measure of visual-motor integration skills when compared with a population of children who had attention-deficit/hyperactivity disorder (ADHD). A series of investigations by Caeyenberghs and collaborators indicated not only that children with TBI exhibit a variety of motor impairments, including difficulties with manual dexterity, hand–eye coordination, and postural control, but also that many of these motor anomalies are associated with changes to white matter tracts (see Caeyenberghs et al[67–70]). Residual motor deficits have long-lasting functional significance in recreational activities and, later, in the workplace. A 1996 study[71] described strength, agility, and coordination problems that limited children's participation in sports. Emanuelson et al[72] described fine-motor deficits severe enough to affect vocational outcome for as long as 7 years after severe injury during childhood or adolescence.

57.5.3 Speech and Language

Severe oral-motor disturbances, including dysarthria and dysphagia, are rare throughout the entire spectrum of pediatric TBI; however, Morgan et al indicated that these conditions are significantly more common following severe injury (upward of 75% of survivors of severe pediatric TBI) and can have profound effects upon recovery.[73] Spontaneous mutism and classic aphasic syndromes, including dyscalculia, dysgraphia, and expressive aphasia, are commonly observed in the acute recovery phase, although these effects are usually not long term.[74] On the other hand, researchers have shown that communication problems are often present in children who do not demonstrate aphasia and that these deficits can persist, particularly after severe head injury.[75] These linguistic impairments can include increased latency in naming objects, reduced verbal fluency, problems in writing to dictation, difficulty copying sentences, problems with written expression, particularly production speed and complexity, and slower-than-normal spontaneous speech.[74]

Expressive and Receptive Language

Residual communication deficits after childhood head injury are common[10,14,62] and can occur after head injury of any degree of severity. Research suggests that deficits noted after severe injury persist for years and substantially impact quality of life.[10,15,16] A controlled study of youngsters aged 3 through 7 years at the time of head injury identified no differences between groups with respect to intellectual ability, adaptive competence, or behavior when the children were compared with healthy, appropriately matched peers. However, small but significant differences persisted for 2½ years after injury on a verbal test that required the comprehension and integration of complex material and on a verbal fluency task.[17] Another longitudinal study of children injured between the ages of 5 and 15 years found that severe head injury adversely affected verbal fluency for as long as 5 years after injury. In comparison with children who had milder injury, their rate of language development was slower and did not reach the level predicted for their age. In addition, children injured at a younger age had a slower rate of recovery than did children who were injured when they were older.[14] Hanten et al[76] found continued deficits in expressive language abilities during a 2-year follow-up of children with moderate to severe TBIs when they were compared with children who had sustained only mild injuries. However, participants within all three groups exhibited a similar trajectory of improvement. Results also indicated that younger children demonstrated more deficits regardless of injury severity and that children from higher socioeconomic levels demonstrated a faster rate of recovery of skills.

Long-term difficulties (i.e., 1 year or more after injury) have been observed in more foundational language tasks, such as confrontation naming and phonologic word retrieval.[77] Language disruption following pediatric TBI has also been demonstrated with functional brain imaging techniques. A 2007 investigation showed changes in activation patterns within language-related cortical areas in a group of children who had sustained a closed head injury when they were compared with normal controls.[18] Interestingly, these alterations were correlated with performance on neuropsychological measures of linguistic abilities, and changes occurred even though many of the participants with TBI exhibited relatively few structural lesions on conventional MR imaging.

Pragmatic Language

Impairment of pragmatic language may be observed in children after head injury.[15] Pragmatic language, or discourse, is defined as language, either narrative or conversational, that is used to communicate with others and to meet the speaker's needs. Literature suggests the sparing of language capacity in young children who have undergone hemispherectomy, and the effect of head injury on developing linguistic skills is of particular interest.[35] Dennis and Barnes found that after severe head injury, children were most deficient in tasks that required understanding inference and intentions—abilities that have a significant impact on classroom performance.[20] Chapman and collaborators[21] found deficits in discourse skills in children who had sustained either a mild or severe TBI when they were compared with uninjured peers. The investigators also demonstrated that working memory skills were correlated with discourse performance. Deficits in pragmatic language are also associated with social outcome, and these issues can become more salient as children mature.[63]

57.5.4 Memory and Learning

Memory impairments are perhaps the most commonly discussed sequelae of brain injury in children. Deficits in *explicit memory*, which is the conscious recollection of previous experience (i.e., free recall, cued recall, and recognition), that occur after head injury in school-aged children are well characterized elsewhere.[22,23,26,27,75,78] Anderson et al[48] are one of the few research groups to study the recovery of memory in young children, probably because the memory tests available for this age group are limited. Their research demonstrated that in the acute recovery period, younger children across the spectrum of injury severity exhibited memory problems. Although a more robust relationship between memory impairment and injury severity developed over time, there was also evidence that memory and learning actually *deteriorated* or failed to progress in some youngsters with moderate to severe injury. In a subsequent investigation, Anderson and Catroppa[79] demonstrated that children with severe TBI injured during middle childhood exhibited long-term deficits in complex verbal memory abilities assessed at 5 years after injury. These authors also observed persistent deficits in verbal and visual memory skills in children sustaining a severe TBI and indicated that these deficits were associated with academic performance.[80] In a unique investigation, Salorio and colleagues[81] reported that performance on a verbal learning task at 1 year after injury was strongly related to the volume of brain lesions outside the frontotemporal areas. The authors speculated that these results were indicative of diffuse axonal injuries that disrupted connections important for memory encoding, consolidation, and retrieval processes.

It is also important to consider how head injury affects prospective memory. In contrast to the recall of events from the past, *prospective memory* is the recall of intentions to be performed at a future time.[82] Prospective memory is described as event-based (i.e., there is an external cue such as a timer), time-based (i.e., a scheduled appointment), or activity-based (i.e., a specific action is to be performed either before or after another event). Activity-based prospective memory is the only task that does not require the interruption of ongoing activities. As these examples illustrate, prospective memory supports adaptive behavior, such as completing errands, keeping appointments, or following instructions at a future time. Research shows that prospective memory develops early in life, being reported in children as young as 2 years. In one of the first studies in this area, researchers evaluated prospective memory in a sample of children 5 years after severe TBI.[82] Performing a challenging mental task for less than 15 minutes resulted in prospective memory failures in more than 90% of the severely head-injured group. Furthermore, prospective memory deficiency remained even after a reminder had been provided. Difficulties in prospective memory were related to everyday problems, including maintaining the intention to complete a task in the face of ongoing attentional and task demands. Simple reminders or cues did not improve performance, suggesting that different strategies are needed to improve functioning. In a series of more recent investigations, McCauley and collaborators demonstrated that the prospective memory skills of children with TBI can be improved in tasks with a high incentive value (e.g., a large versus a small monetary reward).[83–85] However, these investigators cautioned that although the group with severe TBI exhibited some improvements, their performance within the high-motivation condition continued to fall short of that of the control group under the low-motivation condition, suggesting persistent and significant deficits in prospective memory skills in children sustaining a severe TBI.[83]

Recent investigations have also addressed *implicit memory* after childhood brain injury. Implicit memory occurs and can be demonstrated without deliberate awareness. Two examples include priming (i.e., the facilitation of learning that occurs by prior exposure to a stimulus) and procedural learning (e.g., skiing or maze learning). For a review of this literature, see Schacter et al.[20] Shum et al[86] used a visual priming task to study implicit memory in a group of children aged 8 through 14 years with severe head injury and in healthy controls. The children were shown picture fragments and later the complete pictures intermixed with a group of novel pictures. Both groups showed an equal priming effect despite group differences on an explicit memory task. Noting the possibility of dissociation between various types of implicit memory, the investigators compared a group of moderately to severely head-injured children with a group of healthy controls on a measure of procedural memory.[87] No significant differences between groups were identified on either a rotary pursuit task or a mirror-reading task. However, in a recent investigation, Lah and colleagues[88] found that children sustaining a TBI before the age of 6 years exhibited deficits on measures of implicit as well as explicit memory when compared with either children injured later in childhood or uninjured controls. Given these mixed findings, future studies that evaluate different types of implicit memory skills following pediatric TBI occurring at various ages appear warranted.

57.5.5 Attention and Executive Function

Because trauma commonly affects the macrostructure and microstructure of frontal brain regions either directly or indirectly,[89] a marked trend in recent outcome research is to delineate more clearly the deficits associated with injury to these frontal brain regions. Frontal lobe injury, in particular, accounts for deficits in higher-order attentional skills, problem solving, planning, judgment, and information processing, as well as the personality changes frequently observed in children with TBI. These higher-level abilities, grouped under the rubric of executive function, serve to manage and coordinate both cognition and behavior.[90] The long-term impact of the disruption of executive skills that occurs during childhood remains poorly understood.[91] However, the assessment of executive abilities in the near term after traumatic head injury provides the critical information necessary to plan subsequent interventions.

In a review of the extant literature on attention deficits following pediatric TBI, Ginstfeldt and Emanuelson[92] suggested that divided attention and sustained attention appear most vulnerable to closed head injury, whereas simple attention span is more robust to disruption. These authors also indicate that most of the significant gains in attention skills can be expected within the first year after injury, with many individuals experiencing persistent deficits into adulthood. Interestingly, a study by Thaler and colleagues[93] observed differences between component aspects of attention skills in children following TBI and children diagnosed with ADHD. These authors indicated that children sustaining a TBI exhibited difficulties in the domains of focus and encoding, whereas children with primary ADHD exhibited difficulties in the domains of sustaining and encoding. These and other findings (see Anderson et al,[94] Kramer et al,[95] Levin et al,[96] and Sinopoli et al[97]) suggest that children with attention problems secondary to TBI exhibit a neurocognitive and symptom profile that differentiates them from children with a diagnosis of idiopathic ADHD. In a 2011 investigation,[98] Catroppa and colleagues indicated that at 10 years after injury, attentional skills were not normally developed in a group of children who had sustained severe head injuries before the age of 6 years.[99] This investigation indicated that attention abilities developing early and more complex attentional skills developing later appeared most vulnerable to an injury sustained in the preschool period.

Working memory is an aspect of memory subsumed by the frontal brain regions that has recently received scrutiny in the pediatric outcome literature. Working memory is of limited capacity and is age-dependent. Through processes of storing, monitoring, and manipulating information, working memory mediates the development of many complex cognitive processes and academic skills.[100] Noting the vulnerability of the prefrontal regions to closed head injury and the structure of the frontal lobes, Levin et al[89] investigated the impact of head injury on working memory in children. The investigators used a working memory test that allowed adjustment of the memory load (the n-back task) and evaluated children across the spectrum of injury severity at 3, 6, 12, and 24 months after injury. Children who sustained severe injury showed a decline in working memory between 1 and 2 years after injury, whereas less severely injured patients continued to demonstrate age-appropriate gains. In a recent investigation, Gorman and colleagues[101] demonstrated deficits in visual and verbal working memory skills following pediatric TBI. This study also indicated that these difficulties were not secondary to other executive dysfunctions (e.g., problems with inhibitory control).[102]

Research is beginning to elaborate on the impact of metacognition on the executive abilities of children who have experienced severe head injury. According to information-processing theory,[103] metacognition refers to self-regulatory activities that monitor performance effectiveness and adjust strategies to enhance performance. With respect to memory ability, metacognitive management (i.e., employment of effective memory-enhancing strategies) usually begins to develop at the age of 6 years. Hanten et al[104] investigated metacognitive judgment in nine 7- to 13-year-old children, seven of whom had documented frontal injury. In this controlled study, children were asked to make two predictions: (1) how easy it would be to memorize each word in a 15-word list and (2) how many words from the list would be recalled after a 2-hour delay. Interestingly, the head-injured group showed no significant difference in learning when compared with the control group. In contrast, the head-injured group evidenced significant impairment in both predictions of task ease and performance level during the recall task. A study by Crowther et al[105] also demonstrated that children with moderate or severe TBI exhibited changes in their learning strategies and meta-memory judgments over a 2-year follow-up interval when compared with children who had sustained only a mild injury. Interestingly, although children with moderate or severe TBI demonstrated a faster rate of improvement in their performance during the first 12 months after injury, their scores peaked at this time point and then gradually began to diverge from those of children in the mild injury group between 12 and 24 months after injury.

A recent investigation by Wilson et al[106] indicated that adolescents who had sustained a TBI reported significantly fewer metacognitive, but not behavioral executive, deficits than their their parents did. The number of their reports was also decreased when they were evaluated against the self-reports of uninjured aged-matched peers. The authors suggest these findings are indicative of deficits in self-awareness and understanding of limitations within the TBI group. Taken together, these findings suggest that children who sustain a significant head injury can exhibit a general metacognitive deficit when asked to assess their own level of skill, the difficulty of a task, or the cognitive demands necessary for successful task completion. Finally, the pattern of results observed in the study of Crowther et al[107] suggests that children with moderate or severe injuries may make significant gains in meta-memory judgments in the first year after injury but may evidence a lag in age-appropriate maturational processes after this initial burst of recovery.

The impact of executive deficits is not limited to performance on working memory or meta-memory tasks. Aspects of social problem solving and behavioral regulation have been shown to be associated with the severity of injury to the frontal brain regions.[108,109] Janusz and colleagues[64] investigated social problem-solving skills with a developmental model of social reasoning. The relationship between developmental level and social outcome was compared in three injury groups: severe head injury, mild head injury, and orthopedic injury. Findings indicated that children with severe head injury defined social dilemmas and generated alternative solutions at the same developmental level as the control children. However, the *quality* of their solutions was poorer—that is, they described lower-level strategies as the "best" solution and used lower-level reasoning to evaluate the effectiveness of their strategies. In a similar investigation, Ganesalingam et al[110] demonstrated that the social problem-solving difficulties of children with TBI were associated with deficits in self-regulation as assessed by performance measures and parent and teacher reports. A study by Levin et al[111] demonstrated that measures of cognitive control (e.g., working memory and inhibition) were positively related to social outcomes at 12 months after injury as assessed by the VABS. This study also showed that the relationship was stronger in children from lower socioeconomic backgrounds, suggesting an interaction between socioeconomic status and postinjury social outcomes.

Problem Behaviors

Behavioral changes within the 2-year recovery period are now well characterized in the outcome literature. Research in the 1980s and early 1990s established that premorbid psychiatric disturbances and severity of trauma were the best predictors of postinjury behavior problems. A significant number of children developed new behavior problems after head injury. Cole and colleagues[112] demonstrated that increases in aggressive behavior are very common following pediatric TBI. Furthermore, children with preexisting attention problems and anxiety as well as children with higher levels of disability were at the greatest risk for developing symptoms of aggression at 1 year after injury. A follow-up investigation by Gerring et al[42] demonstrated that the prevalence of preinjury conduct disorder in children sustaining a TBI was higher than that in an age-matched and demographically matched population, but the TBI group also displayed a significantly higher rate of conduct disorder and disruptive behavior symptoms at 1 year after injury in comparison with uninjured, matched controls. A recent investigation by Max et al[113] indicated that approximately 50% of children sustaining a moderate to severe head injury developed symptoms of a novel psychiatric diagnosis at 3 months after injury. This was compared with 13% of orthopedically injured controls and was not accounted for by preinjury functioning, family psychiatric history, or environmental factors.

Noting that behavior problems often persist well past the 2-year recovery period, recent work has attempted to characterize the behavior problems in children with head injury that fail to resolve[63,64,114,115] or even worsen over time.[108,109] A controlled study by Taylor et al[62] investigated behavior over a 4-year period by comparing children who had moderate or severe head injury with an orthopedic control group. The level of behavior problems did not change as a function of time (i.e., short-term vs. long-term follow-up), suggesting the stability of these sequelae. Children in both the severe- and the moderate-injury groups showed poorer competence (i.e., school performance, activities, and social function) and everyday communication skills in comparison with the children who had orthopedic injuries. As the authors noted, a portion of children with moderate and severe injuries exhibited behavior problems for as long as 4 years after injury. These were exacerbated by family environments characterized by limited resources and poor overall functioning.

Academic Skills

Numerous studies have documented changes in academic functioning following pediatric TBI. Taylor and colleagues[116] examined school readiness skills in a group of children who had sustained a TBI before 6 years of age. Results indicated that children within the severe TBI group exhibited decrements in school readiness skills at a 6-month follow-up. Performance was predicted by injury-related variables and to some degree was moderated by environmental factors. A study by Ewing-Cobbs et al[117] found that children who had sustained a TBI showed significant improvement in terms of academic skills performance over a 2-year follow-up interval; however, children in the severe TBI group continued to demonstrate marked deficits across academic domains. Children who were younger at the time of injury exhibited a decelerating rate of improvement in academic skills when compared with children who sustained similar injuries at an older age. In another investigation, Ewing-Cobbs et al[118] demonstrated that children who had sustained a TBI before 6 years of age continued to exhibit academic deficits at a mean of 5 years after injury. This study also found that 50% of children in the TBI group had either failed an academic grade or required a primary placement in a special education classroom. Hanten and colleagues[76] demonstrated impairments in reading comprehension scores in children with severe TBI when compared with children sustaining either mild or moderate head injuries. Interestingly, this study indicated that lower-level reading skills, including reading rate, accuracy, and decoding skills, did not differ between children with mild, moderate, or severe TBI. Similar to the Ewing-Cobbs investigations, this study found that children injured at an earlier age experienced more difficulties in reading comprehension skills regardless of their age at the time of assessment.

Written language skills also appear to be affected by the severity of injury and age at injury. In one study of children and adolescents, written language was more impaired in the children in the sample who were between the ages of 5 to 10 years, an effect not seen in naming, expressive, and receptive language skills.[119] Because written language skills show the most rapid development between the ages of 6 and 8, this finding lends support to the idea that developing abilities are those most vulnerable to disruption by brain injury.

57.6 Treatment and Rehabilitation

Although the acute outcome of children with head injury is necessarily of primary interest to the readers of this text, the treatment of the longer-term consequences of head injury is also relevant. Previously, we have discussed chronic difficulties with attention, organization, information processing, working memory, and problem solving that directly influence learning. These cognitive deficits often lead to academic delays, significant behavioral disturbances, difficulties with socialization, family discord, and long-term problems with vocational attainment, all of which are appropriate targets for intervention.

57.6.1 Pharmacologic Treatment of Frontal Lobe Symptoms

Despite the vital influence that attention, monitoring, and organization have on learning, there continues to be a dearth of information regarding effective pharmacologic interventions directed at the specific cortical systems that subsume those cognitive functions and are perturbed by closed head injuries.[120] Amantadine hydrochloride (AMH), a dopamine agonist, has a long history of use in the pediatric population, although few empiric investigations have been conducted of its effectiveness in pediatric patients with TBI. Beers and colleagues completed a small pilot investigation examining the ability of AMH to improve outcome in pediatric patients following TBI.[121] Children with a history of head injury who were experiencing clinically significant symptoms of executive dysfunction were randomized to treatment or to a usual and customary care condition. Neuropsychological assessment was completed at baseline and immediately after the 12-week treatment phase. Among the children who received AMH, the side effects were generally mild and remitted after the first week. Results indicated that children in the medication group evidenced statistically significant improvement in comparison with children in the usual care group in parent-reported measures of executive skills and promising trends in laboratory measures of executive abilities. These results are tempered by the lack of a placebo-controlled design. Small sample size also limits the ability to ascertain the important effects of age, gender, and injury level on response to AMH. A more recent pilot study by Scott et al[122] indicated that ziprasidone may reduce symptoms of agitation and aggression in the acute stage of recovery after pediatric TBI. For a thorough review of the medication management options for pediatric patients with TBI, please see Pangilinan et al.[123]

57.6.2 Cognitive Rehabilitation

As discussed throughout this chapter, impairments of cognition and behavior after traumatic head injury often persist long after neurologic symptoms have remitted.[124] Thus, although children with severe head injury usually receive inpatient rehabilitation services, longer-term services at home and sometimes at school are often needed. This rehabilitation is optimally completed by an interdisciplinary team of physical therapists, occupational therapists, speech pathologists, psychologists, educators, and parents, with the specific goal of the child's successful reintegration at home and in school.[125] Children with brain injury frequently benefit from secondary interventions that they complete with parents and the schools. Unfortunately, few empiric studies have assessed the efficacy of any of these interventions.

Rehabilitation Programs

Understanding a child's pattern of cognitive and behavioral strengths and weaknesses is a critical component of successful cognitive rehabilitation programs. With this information in hand, rehabilitation specialists use a variety of techniques, with the common goal of establishing new patterns of cognitive activity by reinforcing or re-establishing previous patterns of behavior, using compensatory cognitive mechanisms to replace impaired abilities, providing external compensatory mechanisms, such as personal orthoses or increased structure and support, and providing therapeutic interventions that enable individuals to come to terms with their limitations, thereby improving their overall quality of life.[124] For a review of the approaches to cognitive rehabilitation and behavioral management used in pediatric TBI interventions, see Catroppa and Anderson,[126] Semrud-Clikeman,[127] and Ylvisaker et al.[128,129]

Acknowledging the lack of efficacy studies in the pediatric literature and the ever-present problem of maintenance and generalization with extant techniques, Ylvisaker and Feeney[125] and Park and Ingles[130] propose what they term “context-sensitive” rehabilitation. One goal for such intervention techniques is to prevent predicted behavioral deterioration and social skills deficits from occurring in the longer term after brain injury. This approach recognizes that the effects of pediatric TBI on foundational skills like attention and executive functioning will in turn have profound effects on other cognitive domains as well as on the implementation and eventual success of rehabilitation programs. Intervention techniques, chosen on an individualized basis, might include those that are impairment-oriented (e.g., empirically validated retraining exercises), activity-oriented (e.g., *compensatory* strategies that allow the individual to participate in an activity with a support that reduces the disability without changing the underlying cognitive impairment), and participation-oriented (e.g., environmental modifications encompassing both the concrete environment and the psychosocial environment).

Efficacy studies of these context-sensitive rehabilitation procedures are limited. Two studies are of particular interest because they involved children. Feeney and Ylvisaker[131] evaluated a context-sensitive support-oriented behavioral and cognitive intervention to improve the behavioral self-regulation of two children who had experienced brain injury 1 to 2 years earlier. Both children had sustained severe frontal injuries, and upon return to the classroom they exhibited serious cognitive and behavioral problems. The rehabilitation intervention, which included behavioral supports, cognitive supports, and specific routines to support deficient executive skills, was highly individualized and completed in the classroom. After the initial intervention had been completed, a maintenance program was continued at school and completed at home. Both children achieved acceptable levels of behavioral control within approximately 1 month. Training was provided to ensure that environmental modification and successful instructional techniques continued over the next school year. These highly individualized and labor-intensive procedures resulted in positive results not only at 1-year follow-up but also for as long as 9 years after the initial injury.

Other, less labor-intensive cognitive interventions have also demonstrated some effectiveness. In a small pilot study of a Web-based cognitive rehabilitation intervention, Wade and collaborators[132] found evidence of improvements in self-reported executive abilities in a group of adolescents after TBI when they were compared with an education-only group that had similar characteristics.

Family Interventions

In accordance with the growing body of research noting that a child’s recovery from head injury is correlated with family function, many hospitals and rehabilitation programs now offer support services for parents. These groups provide a venue in which parents can express feelings and resolve emotional problems within the family. Evidence suggests that parenting interventions can be very beneficial in improving family functioning and in promoting functional recovery in children following a TBI.[133] In a recent case study, Cohen and colleagues[134] demonstrated the effectiveness of parent–child interaction therapy in reducing externalizing behavior problems and improving parent adjustment in an 11-year-old boy who had sustained a TBI. Interestingly, this case study successfully employed a therapeutic approach typically used in much younger children, suggesting that a flexible approach can be employed in the design of intervention programs for children and families coping with a TBI.

Some pilot programs have also begun to use Web-based curricula to facilitate the delivery of family and cognitive interventions. Although the evidence base is small, these pilot programs have shown promise for improving parent coping and family functioning in general, and in effecting modest gains in cognitive skills in children with a TBI.[135–137] For a review and a discussion of guidelines for family interventions following pediatric TBI, see Cole et al.[138]

School-Based Interventions

Almost all children who survive a TBI return to the classroom.[139] Because children experiencing the longer-term sequelae are now understood to have an educational disability, modifications and specialized instructional techniques have come under increased scrutiny.[140] Interventions provided in the school setting can include assistive technologies,[141] curricular and classroom modifications, and specialized “pull-out” services (i.e., individual physical, occupational, and speech and language therapies). The provision of these educational modifications and services is based on an individualized educational plan that identifies appropriate learning criteria, specific instructional procedures and modifications, and the learning environment that best meets the needs of the individual child. The most successful individualized educational plans provide for a comprehensive assessment of the student’s strengths and weaknesses as well as for staff education regarding TBI.[142] Interestingly, educators are beginning to recognize the degree of developmental disruption caused by dysexecutive symptoms and emphasize the remediation of executive skills with programs that address learning strategies[143] and social skills.[144] (See Szekeres and Meserve[140] for an extended discussion of these techniques.)

57.7 Summary and Conclusion

Head injury is the most frequent cause of acquired brain insult in children, with an incidence of approximately 100 hospitalizations per 100,000 persons. In contrast to the excellent recovery reported in most children sustaining mild head injury, those with moderate to severe head injury show adverse effects in the development in cognitive, language, motor, adaptive, and psychosocial domains. Apart from the severity of injury, age less than 5 years and an adverse family environment are related to persistent sequelae of head injury.

Within the cognitive domain, intellectual ability as measured by conventional standardized tests frequently shows a trend toward recovery after severe head injury and eventually approximates the normal range in most children. However, deficits in explicit memory and learning, attention, and executive functions, such as planning and self-regulation, frequently persist despite the apparent recovery of intellectual ability. Although language deficits can be pervasive during the initial phases of recovery from severe head injury, pragmatic skills, including the organization and processing of narrative discourse, are among the most persistent communication deficits. Residual problems with learning and explicit memory, which frequently persist despite initial improvement, contribute to reduced academic achievement in children following moderate to severe head injury. In contrast, retention of overlearned skills and implicit learning are relatively preserved. Executive functions as measured by laboratory tasks, such as planning, metacognitive measures, such as estimating one's learning and retention, and self-regulation of behavior in daily activities as rated by parents and teachers are frequently impaired for long intervals after moderate to severe head injury. Information processing speed tends to slow after moderate to severe head injury and detracts from performance in various domains. Similarly, slowing of motor speed is a frequent sequela of moderate to severe injury. Importantly, more recent studies have reported unexpected late declines in cognitive skills, such as working memory and attention. Adaptive functioning in relation to age expectation can also decline following severe head injury. The integration of cognitive skills with social processing, as in social problem-solving tasks, appears to be a useful approach to elucidating the sequelae of severe head injury and holds potential for the development of effective behavior intervention. To date, researchers have proposed such interventions to mitigate disability after head injury in children, but evidence for their efficacy is generally limited to case reports and group studies that lack randomized, placebo-controlled designs. However, initial studies of both pharmacologic and cognitive interventions have reported positive results that serve to encourage clinical trials.

Pearls

- The assessment of outcome depends on a careful consideration of preinjury risk factors. In children, brain injury occurs to a developing brain. Recovery is correlated with preinjury factors that continue to influence development after brain injury, as well as with injury- and family-related factors that can affect recovery in various areas of functioning. Children may recover to their preinjury level but fail to maintain the same rate of development that they had before the injury occurred.
- The emotional, behavioral, and cognitive deficits associated with pediatric brain injury often do not stabilize after the usual 2-year recovery period. It is not unusual to identify new deficits as a child matures. This may surprise parents, who expect further recovery as opposed to increased problems as the child matures.
- The functional significance of injury to the frontal brain regions has received increased scrutiny over the past decade. The impact that impairment of higher-order attentional skills, problem solving, planning, and judgment (i.e., the executive deficits) has on social, educational, and personality function is increasingly appreciated.
- A comprehensive neuropsychological evaluation completed at 1 year after injury can help track recovery. In addition, because of the changing pattern of deficits that can occur through childhood, follow-up evaluations at regular intervals serve to refine treatment planning and educational interventions.
- Although the new cognitive rehabilitation programs and educational interventions developed to address deficient executive abilities appear promising, efficacy studies are lacking.

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