Neuropsychiatric changes following penetrating head injury in children

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Abstract

Background:
Penetrating head injuries demand the prompt attention of a neurosurgeon. While most neurosurgical centers are experienced in the acute management of these injuries, less is known about the long-term neuropsychiatric sequelae of penetrating head trauma. In adults, direct injury to the frontal lobe classically has been associated with mental status changes. However, there is less published data in children.

Case Description:
We report the case of a 12-year-old boy who suffered a penetrating head injury to the frontal lobes secondary to a self-inflicted gunshot wound, and experienced subsequent resolution of pre-existing bipolar disorder and new onset of attention deficit hyperactivity disorder.

Conclusion:
Children with penetrating head injury require close multidisciplinary follow-up in order to monitor, and accordingly implement management strategies, for associated sequelae, including behavioral and neuropsychiatric changes.

Keywords: Behavior, frontal lobe, neuropsychiatry, penetrating head injury, traumatic brain injury

INTRODUCTION

It has been 165 years since Phineas Gage's famous accident – the “American Crowbar Case.”[26] In 1848, an explosion propelled an iron rod entirely through the railroad construction foreman's head, injuring his left frontal lobe.[26] Dr. John Harlow's 1868 report highlighted Gage's resulting psychological and behavioral changes.[20] Formerly “industrious,” “reliable,” “affable,” “a favorite of his peers,” and “happy and tranquil,” he became “fitful, irreverent, indulging at times in the grossest profanity” and “a child in his intellectual capacity and manifestations.”[20] This classic case furthered the understanding of cerebral localization, specifically the view that mental changes could serve as localizing signs for frontal lobe
Penetrating head injury is rare in children and has been the subject of a few case reports. Its exact incidence is unknown. Reports have been published of pediatric penetrating head injury resulting from metal nails and rods, pencils, kitchen utensils, power tools, stab wounds, and gunshot wounds (GSWs). However, there is a paucity of data about the neuropsychiatric impact of these injuries. Here, we report the case of a pubertal boy who showed remarkable neuropsychiatric and behavioral changes, with good functional outcome, after suffering a self-inflicted GSW injuring the frontal lobes.

CASE REPORT

A 12-year-old boy with a 2-year history of bipolar I disorder presented to the hospital with a self-inflicted GSW to the head. This attempted suicide occurred in the context of a major depressive episode. On presentation, the boy's Glasgow Coma Scale (GCS) score was 6. Entry and exit wounds were evident in the left frontal and right temporal regions, respectively. He was fluid resuscitated.

Computed tomography (CT) head revealed bony, soft tissue, and parenchymal injury consistent with a GSW to bilateral frontal lobes. Multiple radiopaque fragments (i.e. shattered bullet) were visualized. Intracranial hemorrhages included an irregularly shaped hematoma across both frontal lobes (bullet trajectory), plus subdural hematomas along the cerebral falx, over the left temporal lobe with extension into a left middle cranial fossa arachnoid cyst, and over the left convexity. There was a leftward midline shift of approximately 5 mm.

The patient was rushed to the operating room (OR) for bifrontal craniectomy. Active bleeding from the right distal middle cerebral artery (MCA) was identified and hemostasis achieved. The hematoma associated with the bullet's tract in the right frontal lobe was drained, the falx cerebri crossed, and the hematoma from the left frontal lobe also evacuated. An external ventricular drain (EVD) was inserted.

The patient had a long and complicated hospital stay, including development of a left hemiplegia. Magnetic resonance imaging (MRI) of the head and magnetic resonance angiogram (MRA) of the circle of Willis done on post-operative day 4 showed multiple areas of restricted diffusion in the right MCA distribution, parasagittal frontal lobes, and left frontal lobe, with scattered areas of hemorrhage. There was an asymmetric decrease in the right internal carotid artery circulation, suggesting vasospasm. Other complications included seizures, cerebral salt wasting, wound dehiscence, cerebrospinal fluid (CSF) leak, cognitive deficits, dysphagia, and speech and language difficulty. By 3-month follow-up, the patient exhibited phenomenal recovery. He spoke with a slow, but deliberate speech. He answered questions appropriately and was able to tell jokes. He was participating in homebound schooling and had taken up tennis. Attempts to wean antiepileptic drugs resulted in clinical seizures; hence, he was maintained on levetiracetam. Four months later, he returned to school in a regular classroom with minimal special education support. He has consistently scored A's and B's in school since making his return.

Approximately 2 years prior to the accident, this boy was seen by the psychiatry service for mood lability, anxiety, depression, psychomotor agitation, indiscretion, irritability, and grandiose ideas. His symptoms were consistent with bipolar I disorder by Diagnostic and Statistical Manual of Mental Disorders (DSM) IV criteria, and he was started on lamotrigine and risperidone, with a good response. By 7 months following the accident, the boy's symptoms of bipolar disorder had regressed completely and he no longer required mood-stabilizing or antipsychotic drugs. His depressive symptoms were maintained in full remission for >8 months on citalopram. However, he demonstrated continued hyperactivity, distractibility, and impulsivity. He would poke, pinch, and bite family members and relatives (behaviors not previously demonstrated) and think it was playful. He would also make threatening statements (i.e. “I am going to kill myself” or “I am going to kill someone”), for example, when angered or being disciplined by his mother. These were impulsive statements that he did not wish to carry out minutes after calming down. On examination, he was distractible, requiring persistent redirection. He was given a diagnosis of attention deficit hyperactivity disorder (ADHD) and started initially on methylphenidate and later switched to...
atomoxetine due to poor tolerance (i.e. side effect of dysphoria). He has demonstrated a good response to therapy. Formal neuropsychological testing was done 6 months following the injury. The patient obtained a full scale IQ score of 93 (average) on the Wechsler Intelligence Scale for Children-IV (WISC-IV). He showed above average verbal comprehension, average working memory, and below average perceptual reasoning and processing speed. Measures of executive function revealed difficulty with inhibition, processing speed, inattention, and alternating attention. The boy's academic functioning was above age-appropriate norms, with the exception of math and reading fluency tasks.

DISCUSSION

There are three critical dimensions to the case we have presented that should be considered:

- **Anatomical** – i.e. the physical element of traumatic brain injury (TBI), frontal lobe damage
- **Psychiatric/behavioral** – i.e. the outward clinical manifestations, including personality changes, regression of bipolar disorder, onset of ADHD, etc
- **Neuropsychological** – the link between the former two, i.e. the changes in neurological/psychological function resulting from physical injury to the frontal lobe, and leading to the behavioral or psychiatric disturbances observed clinically.

**Neuropsychological**

The frontal lobe – in particular, prefrontal cortex – is traditionally considered the control center of executive functions.[31] Executive functions represent a collection of inter-related cognitive processes that allow a person to engage in purposeful, self-serving, goal-directed behavior (e.g. attention, planning, goal setting, reasoning, problem solving, multitasking).[14]

In 2002, Anderson[1] proposed four domains of executive functions in children and adolescents: (1) Attentional control, (2) cognitive flexibility, (3) goal setting, and (4) information processing. “Attentional control” includes the ability to selectively focus attention to specific stimuli, filter irrelevant details, and inhibit instinctive/impulsive responses. “Cognitive flexibility” encompasses working memory and refers to the ability to shift between response sets, learn from mistakes, devise alternative strategies, and simultaneously process multiple sources of information. “Goal setting” includes the ability to develop new concepts and devise strategies toward solving a problem. “Information processing” refers to the speed, efficiency, and fluency of output. Each of these domains shows a unique developmental trajectory through infancy, childhood, and adolescence.[1, 5] The implication is that early insults to the brain may adversely impact executive functions, especially those emerging or maturing at the time of injury.[22] It follows that insults to the brain cause more profound and generalized neuropsychological compromise in younger children.[3] A possible and frequent source of “insult” is TBI.

**Anatomical → neuropsychological**

There is mounting evidence linking childhood TBI with deficits in executive function crossing each of the above domains.[18] Impaired attentional control, including poor response inhibition and deficits in sustained, selective, and shifting attention, is seen in children following TBI.[2] Deficits in working memory,[23] planning,[24] problem solving,[21] and processing speed[7] have also been reported. Such deficits are evident even 5 years post-injury.[11]

**Neuropsychological → psychiatric/behavioral**

In turn, deficits in executive function have been shown to underlie several psychiatric disorders and behavioral disturbances in children. Poor response inhibition, phonetic fluency, planning, processing speed, and working memory are seen in children with ADHD.[32] Bipolar disorder has been correlated with impaired attention, working memory, set shifting, and planning.[32] Deficits in executive function are also seen in pediatric post-traumatic stress disorder,[8] autism spectrum disorders (ASD),[29] fetal alcohol

**Anatomical → psychiatric/behavioral**

It follows from the above discussion that childhood TBI may have important psychobehavioral sequelae. Indeed, a high rate of novel psychiatric disorders is seen in children after head injury, including ADHD, oppositional defiant disorder (ODD), depression, anxiety, post-traumatic stress symptoms, obsessive-compulsive symptoms, and in very rare reports, bipolar disorder.[28,30] Above all, Max and group[27,28] reported personality change to be the most common psychobehavioral disturbance seen after pediatric TBI; in order of frequency of occurrence, this included affective lability, disinhibition, aggression, and apathy. Moreover, victims of childhood TBI often demonstrate maladaptive and aggressive/antisocial behavior and difficulties in socializing.[6]

Most of the available studies on the neuropsychological and behavioral outcomes of childhood TBI, as discussed above, have examined closed (i.e. diffuse) head injuries. Thus, it is difficult to discern the isolated effects of frontal lobe injury from these reports. To that end, there is scant literature on the executive function and behavioral sequelae following penetrating head injury in pediatric patients, and in particular, causing primarily frontal lobe damage.

We have described the case of a 12-year-old boy with a past history of bipolar disorder who suffered a GSW penetrating bilateral frontal lobes. Post-injury neuropsychological testing revealed deficits in attention, response inhibition, and processing speed, with normal working memory and IQ. After the injury, this boy's bipolar disorder resolved and he developed a novel psychiatric diagnosis – ADHD. This boy's bipolar disorder has been in complete remission without treatment for over 1.5 years, and his ADHD is well controlled with stimulant medication. While ADHD is frequently reported after childhood head injury, to our knowledge, this would be the first report of regression of bipolar disorder following pediatric TBI. Nonetheless, an important consideration in the differential diagnosis of our patient is organic personality disorder, termed “Personality Change Due to a General Medical Condition” on DSM-IV. Following TBI, a constellation of changes in enduring patterns of behavior (i.e. personality) may develop with characteristics that resemble borderline personality disorder, including irritability and impulsivity.[17] Indeed, our patient's condition may reflect a “frontal lobe syndrome” resulting from TBI, which again underscores the need for close long-term follow-up in these cases.

The case detailed here is of a child, and the striking neuropsychiatric changes observed clinically may thereby be attributable to early neural and functional plasticity and early vulnerability.[4] The young brain has traditionally been described as having remarkable plasticity to modify neural circuitry and ultimately regain function following insult. A classical example is the lack of significant speech impairment following hemispherectomy for intractable epilepsy in children, irrespective of lateralization, which is attributed to the ability of spared “equipotential” brain to subsume function for the damaged regions.[4] Paradoxically, the immature brain's potential for plasticity and apparent lack of functional specificity might also make it especially vulnerable to injury, since there may be critical disruption of predetermined neurodevelopmental processes in the absence of a “blueprint” to guide recovery.[4] Anderson *et al.*[4] suggested that plasticity and vulnerability lie on a “recovery continuum,” and that a child's outcome following neurological injury in relation to this continuum depends on injury (severity, nature, age) and environmental (family, socio-demographic, interventions) factors.

Postmortem studies have suggested continued maturation of the white matter tracts of the brain into the third decade of life.[9] Aberrant tractography pathways have been demonstrated in children with epilepsy through diffusion tensor imaging (DTI).[10] Hence, it is conceivable that the traumatic frontal lobe injury described in this report, with resultant damage to subcortical white matter tracts, may manifest as changes within another form of pathology, for example epilepsy, or more relevantly in this case, neural circuitry
regulating neuropsychiatric function.

CONCLUSION

Based on our experience reported here, healthcare practitioners should be aware of the below issues in following a patient after penetrating head injury involving the frontal lobes:

- Penetrating injury to the frontal lobe may lead to executive function deficits; hence, neuropsychological testing should form an important component of post-injury follow-up
- These patients should be monitored for behavioral changes and/or the development of novel psychiatric disorders post-injury; if appropriate, a referral to Child Psychiatry should be arranged
- Close psychiatric follow-up and assessment is important, especially in patients with a positive past psychiatric history; these patients may experience complete remission of past, and/or the development of novel, psychiatric diagnoses, necessitating change in management.

Footnotes


REFERENCES


**Figures and Tables**

**Figure 1**

Bullet trajectory. Axial (a) CT head and (b) T2-weighted MRI head revealing bony, soft tissue, and parenchymal injury consistent with a GSW to bilateral frontal lobes, with multiple fragments of shattered bullet

**Figure 2**
(a) Axial T2-weighted MRI head demonstrating an irregularly shaped hematoma across both frontal lobes. (b) MRA circle of Willis revealing an asymmetric decrease in the right internal carotid artery circulation.

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