Overview

Definition

Traumatic brain injury (TBI) is a nondegenerative, noncongenital insult to the brain from an external mechanical force, possibly leading to permanent or temporary impairment of cognitive, physical, and psychosocial functions, with an associated diminished or altered state of consciousness.

The definition of TBI has not been consistent and tends to vary according to specialties and circumstances. Often, the term brain injury is used synonymously with head injury, which may not be associated with neurologic deficits. The definition also has been problematic with variations in inclusion criteria.

For excellent patient education resources, see eMedicineHealth's patient education article Concussion.

Glasgow Coma Scale

The Glasgow Coma Scale (GCS) defines the severity of a TBI within 48 hours of injury.

Eye opening

- Spontaneous = 4
- To speech = 3
- To painful stimulation = 2
- No response = 1

Motor response

- Follows commands = 6
- Makes localizing movements to pain = 5
- Makes withdrawal movements to pain = 4
- Flexor (decorticate) posturing to pain = 3
- Extensor (decerebrate) posturing to pain = 2
- No response = 1
**Verbal response**

- Oriented to person, place, and date = 5
- Convereses but is disoriented = 4
- Says inappropriate words = 3
- Says incomprehensible sounds = 2
- No response = 1

The severity of TBI according to the GCS score (within 48 h) is as follows:

- Severe TBI = 3-8
- Moderate TBI = 9-12
- Mild TBI = 13-15

**Ranchos Los Amigos Scale of Cognitive Functioning**

The severity of deficit in cognitive functioning can be defined by the Ranchos Los Amigos Scale.

- level I = No response
- level II = Generalized response
- level III = Localized response
- level IV = Confused-agitated
- level V = Confused-inappropriate
- level VI = Confused-appropriate
- level VII = Automatic-appropriate
- level VIII = Purposeful-appropriate

**TBI defined by the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine**

The Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine defines mild head injury as "a traumatically induced physiologic disruption of brain function, as manifested by one of the following:

- Any period of loss of consciousness (LOC),
- Any loss of memory for events immediately before or after the accident,
- Any alteration in mental state at the time of the accident,
- Focal neurologic deficits, which may or may not be transient."

The other criteria for defining mild TBI include the following:

- GCS score greater than 12
- No abnormalities on computed tomography (CT) scan
- No operative lesions
- Length of hospital stay less than 48 hours
The following criteria define moderate TBI:

- Length of stay at least 48 hours
- GCS score of 9-12 or higher
- Operative intracranial lesion
- Abnormal CT scan findings

**The National Institutes of Health Traumatic Coma Data Bank**

The National Institutes of Health (NIH) sponsored the Traumatic Coma Data Bank (TCDB).[1] The TCDB revealed that severe TBI is indicated when the GCS score is below 9 within 48 hours of the injury.

**Simplified Motor Score (SMS)**

The SMS is a 3-point scale developed to address the perceived limitations of the GCS, such as its complexity and poor interrater reliability. The points are as follows:

- Obeys commands = 2 points
- Localizes pain = 1 point
- Withdraws to pain or worse = 0 points

A study by Thompson et al determined that in an out-of-hospital setting, the SMS was similar to the GCS score for predicting TBI outcomes.[2]

**Epidemiology**

Inconsistency in the definition and classification of traumatic brain injury (TBI), along with discrepancies in data collection, has made the epidemiology of TBI difficult to describe accurately.

Problems with TBI data collection include the fact many patients with mild TBI may not present to the hospital, and the ones who do present may be discharged at the emergency department (ED) without adequate documentation. Severe TBI with associated death at the scene of the accident or during transport to a hospital also may not be accounted for completely in data collection for TBI epidemiologic studies.

Differences in diagnostic tools and admission criteria also may affect the above-defined severity classifications. In the past, the use of roentgenograms to help diagnose skull fractures after head injury did not show much of any concurrent intracranial lesions. These lesions were difficult to diagnose until the advent of CT scanning, which is now the diagnostic imaging of choice in TBI cases.[3, 4]

Other confounding variables in determining the epidemiology of TBI exist. The use of different definitions that may not clearly define the type of injury (see Synonyms, Key Words, and Related Terms) makes the epidemiology of TBI difficult to describe. Another variable is the difference in findings from diagnostic imaging at different time intervals (eg, when early
epidural hematoma is present, the CT scan may be normal, but if the scan is later repeated, it may show evidence of pathology.\textsuperscript{[3, 5]}

TBI accounts for approximately 40\% of all deaths from acute injuries in the United States. Annually, 200,000 victims of TBI need hospitalization, and 1.74 million persons sustain mild TBI requiring an office visit or temporary disability for at least 1 day.

The financial cost is estimated at approximately $4 billion per year. This estimate includes the loss of potential income of the patient and of relatives (who may need to become caregivers), the cost of acute care, and other medical expenses, such as continuous ambulatory and rehabilitation care.

**Mortality rate**

Approximately 52,000 US deaths per year result from TBI. Local factors in the United States may influence this mortality rate; it is lowest in the Midwest and Northeast and is highest in the South.

The mortality rate for deaths outside of the hospital is approximately 17 per 100,000 people; it is approximately 6 per 100,000 people for patients who are hospitalized.

The initial GCS score and, therefore, the severity of the TBI help to predict the likelihood of death from the injury. The mortality rate is high in severe TBI and is low in moderate TBI. In a TCDB study, the mortality rate in severe TBI was about 33\%; in another study, in Central Virginia, the mortality rate in moderate TBI was found to be 2.5\%.

Among children aged 0-14 years, an estimated 475,000 TBIs occur each year.\textsuperscript{[6]} Rates are higher among children aged 0-4 years. Death and hospitalization rates are highest among black children aged 0-9 years, compared with whites, in TBIs related to motor vehicle accidents (MVAs).

**Prevalence and incidence**

The prevalence (ie, the existing cases at any given time) of TBI is not well documented, because most cases (ie, mild TBI) are not fatal, and patients may not have been hospitalized. Estimates often are based on existing disabilities.

Estimates by the National Institutes of Health Consensus Development Panel on Rehabilitation of Persons with TBI showed that 2.5-6.5 million Americans live with TBI-related disabilities.

A National Health Interview Survey estimated that annually, 1.9 million persons sustain a skull fracture or intracranial injury, with such trauma making up approximately 1\% of all injuries.

That incidence of mild TBI is about 131 cases per 100,000 people, the incidence of moderate TBI is about 15 cases per 100,000 people, and the incidence of severe TBI is approximately 14 cases per 100,000 people. The inclusion of prehospital deaths increases the last figure to 21 cases per 100,000 people.

Differences in rates in various parts of the United States may be attributable to differences in the methods of case verification and in the cause of injury.
High-risk populations

Some particular segments of the populace are at increased risk of sustaining a TBI, including the following:

- Young people
- Low-income individuals
- Unmarried individuals
- Members of ethnic minority groups
- Residents of inner cities
- Men
- Individuals with a history of substance abuse
- Individuals who have suffered a previous TBI

Sex

Men are approximately twice as likely as women to sustain a TBI. This ratio approaches parity as age increases because of the increased likelihood of TBI caused by falls, for which males and females have similar risks in later life.

The male-to-female mortality rate for TBI is 3.4:1. However, the cause-specific ratio for firearm-related injuries is 6:1, while that for injuries related to MVAs is 2.4:1.

Age

Injury is the leading cause of death among Americans younger than 45 years; TBI is the major cause of death related to injury.

The risk of TBI peaks when individuals are aged 15-30 years. The risk is highest for individuals aged 15-24 years. Peak age is similar for males and females. Twenty percent of TBIs occur in the pediatric age group (ie, birth to 17 y).

The highest mortality rate (32.8 cases per 100,000 people) is found in persons aged 15-24 years. The mortality rate in patients who are elderly (65 y or older) is about 31.4 individuals per 100,000 people.

Mechanism of injury

Common causes of fatal injuries vary according to gender, age, race, and geographical location. Such causes are as follows:

- MVAs are the leading cause of TBI in the general population, especially among whites in the United States. MVAs account for approximately 50% of all TBIs. In the United Kingdom, MVAs are the third most common cause of TBI, after falls and assaults.
• Falls are the second leading cause of TBI. Falls account for 20-30% of all TBIs. In individuals aged 75 years or older, falls are the most common cause of TBI. Very young persons also commonly sustain TBI due to falls.
• Firearms are the third leading cause of TBI (12% of all TBIs) and are a leading cause of TBI among individuals aged 25-34 years. Gunshot-related, fatal TBIs are higher among men than among women and are more prevalent among African Americans than they are among whites.
• Work-related TBIs constitute an estimated 45-50% of all TBIs. Incidence varies from 37 cases per 100,000 people for military employees (57% are related to transportation) to 15 cases per 100,000 people for civilians (50% are because of falls).
• While the incidence of TBIs from major causes decreased significantly following the introduction of safety measures (eg, seatbelts, helmets), the rate of TBI from gunshots has increased.
• Alcohol is a major factor in many TBIs and often is associated with the leading causes of TBI.

Prevention

The use of helmets by cyclists has led to fewer TBIs, and the cases that do occur are less severe than they were in prehelmet days. Automobile seatbelts and child restraints also have been associated with reduced TBI morbidity and mortality rates. No data currently address the effects of air bag use on TBI mortality and morbidity rates.

Trends

The incidence of TBI has been decreasing because of the introduction of preventive measures and as a result of better enforcement of drunk driving laws. The length of stay in acute hospitals and rehabilitation facilities has been declining because of the increased demand for facilities and because of the resources that are available in the community for patients who are discharged early.

Update on mild TBI

The National Hospital Ambulatory Medical Care Survey, published in February 2005, looked at mild TBI in the United States from 1998-2000. The survey found that the average rate of mild TBI was 503.1 cases per 100,000 population, with peaks among males at 590 cases per 100,000 population, among Native Americans at 1026 cases per 100,000 population, among persons younger than 5 years at 1115.2 cases per 100,000 population, and in the Midwest region of the United States at 578.4 cases per 100,000 population. Sports and bicycles account for about 26.4% of mild TBIs among children aged 5-14 years.
Pathophysiology: Primary Injury

Overview

Traumatic brain injury (TBI) is the result of an external mechanical force applied to the cranium and the intracranial contents, leading to temporary or permanent impairments, functional disability, or psychosocial maladjustment.\textsuperscript{10, 11} TBI can manifest clinically from concussion to coma and death. Injuries are divided into 2 subcategories: (1) primary injury, which occurs at the moment of trauma, and (2) secondary injury, which occurs immediately after trauma and produces effects that may continue for a long time. This section focuses on primary injury, while the next section focuses on secondary injury.

The physical mechanisms of brain injury are classified using the following categories:

- Impact loading - Collision of the head with a solid object at a tangible speed
- Impulsive loading - Sudden motion without significant physical contact
- Static or quasistatic loading - Loading in which the effect of speed of occurrence may not be significant

Impact loading causes TBI through a combination of contact forces and inertial forces. Inertial force ensues when the head is set in motion with or without any contact force, leading to acceleration of the head. Contact force occurs when impact injury is delivered to the head at rest. Static or quasistatic loading is rare and occurs when a slowly moving object traps the head against a fixed rigid structure and gradually squeezes the skull, causing many comminuted fractures that may be enough to deform the brain and lead to fatal injury.

Contact or inertial forces may strain the brain tissue beyond its structural tolerance, leading to injury. Strain is the amount of tissue deformation caused by an applied mechanical force. The 3 basic types of tissue deformation are as follows:

- Compressive - Tissue compression
- Tensile - Tissue stretching
- Shear - Tissue distortion produced when tissue slides over other tissue

Types of Primary Injuries

Primary injuries can manifest as focal injuries (eg, skull fractures, intracranial hematomas, lacerations, contusions, penetrating wounds), or they can be diffuse (as in diffuse axonal injury).

Skull fractures

- Skull fractures can be vault fractures or basilar fractures.
- Hematoma, cranial nerve damage, and increased brain injury may be associated with skull fractures.
- Vault fractures tend to be linear and may extend into the sinuses. Injuries also can be stellate, closed, or open fractures. Closed fractures do not permit communication with the
outside environment, while the open fractures do. Fractures are defined as depressed or nondepressed, depending on whether or not the fragments are displaced inwardly. A simple fracture is defined as having 1 bone fragment; a compound fracture exists when there are 2 or more bone fragments.

- Basal skull fractures often are caused by dissipated force and may be associated with injuries to the cranial nerves and discharges from the ear, nose, and throat.

**Auditory/vestibular dysfunction**

Impact force to the temporal region may not cause a fracture but may lead to possible conductive or sensorineural hearing loss.

Conductive hearing loss results from a defect in the conduction of sound, which may occur as a result of tympanic perforation, hemotympanum, or ossicular (ie, malleus, incus, stapes) disruption. Sensorineural hearing loss may be secondary to defect in the inner ear (eg, acute cochlear concussion, perilymphatic fistula).

Benign paroxysmal positional vertigo can occur when calcium carbonate crystals become dislodged from the macula of the utricle and move into the posterior semicircular canal. In such cases, vertigo can provoked by any sudden change in head position. The diagnostic test for this condition is the Dix-Hallpike maneuver.

**Intracranial hemorrhages**

Several types of intracranial hemorrhages can occur, including the following:

- Epidural hematoma occurs from impact loading to the skull with associated laceration of the dural arteries or veins, often by fractured bones and sometimes by diploic veins in the skull's marrow. More often, a tear in the middle meningeal artery causes this type of hematoma. When hematoma occurs from laceration of an artery, blood collection can cause rapid neurologic deterioration.
- Subdural hematoma tends to occur in patients with injuries to the cortical veins or pial artery in severe TBI. The associated mortality rate is high, approximately 60-80%.
- **Intracerebral hemorrhages** occur within the cerebral parenchyma secondary to lacerations or to contusion of the brain, with injury to larger, deeper cerebral vessels occurring with extensive cortical contusion.
- Intraventricular hemorrhage tends to occur in the presence of very severe TBI and is, therefore, associated with an unfavorable prognosis.
- Subarachnoid hemorrhage may occur in cases of TBI in a manner other than secondary to ruptured aneurysms, being caused instead by lacerations of the superficial microvessels in the subarachnoid space. If not associated with another brain pathology, this type of hemorrhage could be benign. Traumatic subarachnoid hemorrhage may lead to a communicating hydrocephalus if blood products obstruct the arachnoid villi or in the event of a noncommunicating hydrocephalus secondary to a blood clot obstructing the third or fourth ventricle.
Coup and contrecoup contusions

A combination of vascular and tissue damage leads to cerebral contusion.\[12\]

Coup contusions occur at the area of direct impact to the skull and occur because of the creation of negative pressure when the skull, distorted at the site of impact, returns to its normal shape.

Contrecoup contusions are similar to coup contusions but are located opposite the site of direct impact. Cavitation in the brain, from negative pressure due to translational acceleration impacts from inertial loading, may cause contrecoup contusions as the skull and dura matter start to accelerate before the brain on initial impact.

The amount of energy dissipated at the site of direct impact determines whether the ensuing contusion is of the coup or contrecoup type. Most of the energy of impact from a small, hard object tends to dissipate at the impact site, leading to a coup contusion. In contrast, impact from a larger object causes less injury at the impact site, because energy is dissipated at the beginning or end of the head motion, leading to a contrecoup contusion.

Concussions

Concussion is caused by deformity of the deep structures of the brain, leading to widespread neurologic dysfunction that can result in impaired consciousness or coma. Concussion is considered a mild form of diffuse axonal injury.

Diffuse axonal injury

Diffuse axonal injury is characterized by extensive, generalized damage to the white matter of the brain. Strains of the tentorium and falx during high-speed acceleration/deceleration produced by lateral motions of the head may cause the injuries. Diffuse axonal injury also could occur as a result of ischemia.\[5\] In addition, primary blast exposure can lead to some axonal injury, which can be detected using diffusion tensor imaging (DTI).\[13\]

Neuropathologic findings in patients with diffuse axonal injury were graded by Gennarelli and colleagues, as follows\[14\]:

- Grade 1 - Axonal injury mainly in parasagittal white matter of the cerebral hemispheres
- Grade 2 - As in Grade 1, plus lesions in the corpus callosum
- Grade 3 - As in Grade 2, plus a focal lesion in the cerebral peduncle

Penetrating head injuries

Gunshot wounds and missile/nonmissile projectiles cause many penetrating head injuries. The energy dissipated on entry is equal to \(1/2 \text{ mass} \times \text{velocity squared}\). Therefore, high velocity missiles tend to cause the most profound damage.
Pathophysiology: Secondary Injury

Secondary types of traumatic brain injury (TBI) are attributable to further cellular damage from the effects of primary injuries. Secondary injuries may develop over a period of hours or days following the initial traumatic assault.

Secondary brain injury is mediated through the following neurochemical mediators:\(^{[15]}\):

**Excitatory amino acids**

Excitatory amino acids (EAAs), including glutamate and aspartate, are significantly elevated after a TBI.\(^{[16]}\)

EAAs can cause cell swelling, vacuolization, and neuronal death.

EAAs can cause an influx of chloride and sodium, leading to acute neuronal swelling. EAAs can also cause an influx of calcium, which is linked to delayed damage. Along with N-methyl-D-aspartate receptor agonists, which also contribute to increased calcium influx, EAAs may decrease high-energy phosphate stores (adenosine 5'-triphosphate, or ATP) or increase free radical production.

EAAs can cause astrocytic swellings via volume-activated anion channels (VRACs). Tamoxifen is a potent inhibitor of VRACs and potentially could be of therapeutic value.

**Endogenous opioid peptides**

These may contribute to the exacerbation of neurologic damage by modulating the presynaptic release of EAA neurotransmitters.

Activation of the muscarinic cholinergic systems in the rostral pons mediates behavioral suppression, which often is observed in TBI, as well as LOC.

Heightened metabolism in the injured brain is stimulated by an increase in the circulating levels of catecholamines from TBI-induced stimulation of the sympathoadrenomedullary axis and serotonergic system (with associated depression in glucose utilization\(^{[17]}\)), contributing to further brain injury.

Other biochemical processes leading to a greater severity of injury include an increase in extracellular potassium, leading to edema; an increase in cytokines, contributing to inflammation; and a decrease in intracellular magnesium, contributing to calcium influx.

Based on the effect on astrocytes, which are the cells that exhibit hypertrophic and hyperplastic responses to central nervous system (CNS) injury, increased production of protein kinase B/Akt with activation of P2 purinergic receptors has been implicated in neuronal survival in TBIs.\(^{[18]}\)
**Increased intracranial pressure (ICP)**

The severity of a TBI tends to increase due to heightened ICP, especially if the pressure exceeds 40 mm Hg. Increased pressure also can lead to cerebral hypoxia, cerebral ischemia, cerebral edema, hydrocephalus, and brain herniation.

**Cerebral edema**

Edema may be caused by the effects of the above-mentioned neurochemical transmitters and by increased ICP. Disruption of the blood-brain barrier, with impairment of vasomotor autoregulation leading to dilatation of cerebral blood vessels, also contributes.

**Hydrocephalus**

The communicating type of hydrocephalus is more common in TBI than is the noncommunicating type. The communicating type frequently results from the presence of blood products that cause obstruction of the flow of the cerebral spinal fluid (CSF) in the subarachnoid space and the absorption of CSF through the arachnoid villi. The noncommunicating type of hydrocephalus is often caused by blood clot obstruction of blood flow at the interventricular foramen, third ventricle, cerebral aqueduct, or fourth ventricle.

**Brain herniation**

Supratentorial herniation is attributable to direct mechanical compression by an accumulating mass or to increased intracranial pressure.\[^{19}\] The following types of supratentorial herniation are recognized:

- **Subfalcine herniation** - The cingulate gyrus of the frontal lobe is pushed beneath the falx cerebri when an expanding mass lesion causes a medial shift of the ipsilateral hemisphere. This is the most common type of herniation.
- **Central transtentorial herniation** - This type of injury is characterized by the displacement of the basal nuclei and cerebral hemispheres downward while the diencephalon and adjacent midbrain are pushed through the tentorial notch.
- **Uncal herniation** - This type of injury involves the displacement of the medial edge of the uncus and the hippocampal gyrus medially and over the ipsilateral edge of the tentorium cerebelli foramen, causing compression of the midbrain; the ipsilateral or contralateral third nerve may be stretched or compressed.
- **Cerebellar herniation** - This injury is marked by an infratentorial herniation in which the tonsil of the cerebellum is pushed through the foramen magnum and compresses the medulla, leading to bradycardia and respiratory arrest.
References


