

TBI · Traumatic Brain Injury

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THE STORY IN ONE SENTENCE

The brain gets hurt at the moment of impact, then can get hurt again from swelling and pressure afterward.

“TBI is a knock to the head that bruises or tears the brain. The first job is to stop the bleeding and swelling so the brain does not get hurt a second time.”

Normal anatomy — the body's job

The brain floats inside a hard skull, cushioned by cerebrospinal fluid and fed by a network of tiny blood vessels that bring oxygen and glucose to billions of brain cells.

BODY'S JOB

Brain cells (neurons) send electrical signals to control movement, speech, memory, and every body function. Blood flow is tightly controlled by autoregulation so the brain gets steady oxygen even when blood pressure swings. The skull protects the brain but also traps it in a fixed space.

1. Blood pumps into the brain through arteries in the neck.
2. Tiny vessels spread oxygen and glucose to every brain cell.
3. Cerebrospinal fluid (CSF) surrounds the brain and spinal cord.
4. The skull is a hard, closed box.
5. Autoregulation keeps blood flow steady.

What breaks

A blow to the head tears blood vessels and shears nerve fibers, causing bruising, bleeding, and swelling that raise pressure inside the skull and damage brain cells.

CLINICAL TERM

Traumatic brain injury (TBI) results from direct impact, rapid acceleration-deceleration, or penetrating force that disrupts normal brain structure and function through focal contusions, diffuse axonal injury, intracranial bleeding (hemorrhage), and secondary injury from starved blood flow (ischemia) and swelling (edema).

How the body compensates

The body tries to keep oxygen flowing to the brain by raising blood pressure, shifting CSF and blood out of the skull, and tightening vessels elsewhere—but these tricks only work for a while before pressure overwhelms them.

1. {'step': 'CSF and venous blood get pushed out of the skull.', 'why': 'The brain borrows space by squeezing fluid into the spinal canal and veins, buying a little room before swelling takes over.'}
2. {'step': 'Blood pressure climbs (Cushing response).', 'why': 'When rising ICP squeezes brain vessels and cuts flow, the brainstem signals the heart to pump harder so blood can still get through.'}
3. {'step': 'Heart rate may slow and breathing becomes irregular.', 'why': 'The same brainstem reflex that raises blood pressure also triggers the vagus nerve, slowing the heart, and pressure on respiratory centers disrupts the breathing rhythm.'}
4. {'step': 'Pupils dilate or become unequal.', 'why': 'Herniation stretches or compresses the oculomotor nerve (cranial nerve III), paralyzing the muscle that keeps the pupil small.'}
5. {'step': 'Posturing appears—arms flex or extend stiffly.', 'why': 'Pressure on the brainstem and motor pathways releases abnormal reflex patterns: decorticate (arms bend in) or decerebrate (arms extend, worse sign).'}- 6. {'step': 'These compensations can keep vital signs looking okay for hours.', 'why': 'A patient may seem stable even as ICP climbs, hiding how close they are to herniation—so trending exams and imaging matter more than a single snapshot.'}

Domino effect

1. Impact tears blood vessels and shears axons. — The blow twists or crushes brain tissue, snapping the tiny wires (axons) that carry signals and ripping vessels that feed the brain.
2. Blood leaks and cells start to swell. — Broken vessels spill blood into brain tissue or surrounding spaces, and injured cells lose their pumps, letting water flood in.
3. Intracranial pressure (ICP) rises. — Swelling and blood take up space inside a hard skull that cannot expand, so pressure climbs—like inflating a balloon inside a jar.

4. Cerebral blood flow (perfusion) pressure (CPP) drops. — High ICP squeezes brain arteries from the outside, so even if the heart pumps hard, blood cannot push through and oxygen delivery falls.
5. Brain cells start to die from lack of oxygen (secondary injury). — Without fresh blood, neurons run out of glucose and oxygen within minutes and release toxic chemicals (excitotoxicity) that kill neighbors.
6. The brain tries to compensate: blood pressure climbs, heart rate slows, breathing gets choppy (Cushing's triad). — The brainstem senses the squeeze and fires an emergency reflex to force more blood in, but this only works briefly before ICP wins.
7. If pressure keeps rising, the brain herniates. — Soft tissue gets pushed through skull openings—uncal herniation compresses the brainstem, cutting off signals that control breathing and heart rate.
8. Without urgent treatment, herniation leads to coma, then death. — Once the brainstem is crushed, the body loses control of vital functions and cannot recover, even if the heart is still beating.

Symptoms · what the patient feels, and why

- Headache that won't go away or gets worse: The impact bruises brain tissue and stretches blood vessels, triggering pain signals. Swelling inside the skull (the closed bone box) pushes on pain-sensitive membranes around the brain.
- Confusion or trouble remembering things: The hippocampus (the brain's memory-maker in the inner fold) and the prefrontal cortex (the front part that organizes thinking) get shaken or bruised. Neurons (nerve cells) can't talk to each other smoothly, so new memories don't stick and thoughts get foggy.
- Dizziness or trouble keeping balance: The cerebellum (the balance center at the back base of the brain) and the inner ear's balance sensors get jarred by the blow. Your brain can't match up the signals from your eyes, ears, and muscles, so the room feels like it's spinning or you wobble when you walk.
- Nausea or vomiting: Swelling and pressure inside the skull irritate the vomiting center in the brainstem (the stalk connecting brain to spinal cord). Rising pressure also squeezes structures that trigger the nausea reflex.
- Feeling sleepy or hard to wake up: Injury to the reticular activating system (a network in the brainstem that keeps you alert) dims the brain's wake-up signal. Swelling or bleeding presses on this area, so the person drifts toward sleep and is slow to respond.

- One pupil bigger than the other, or pupils that don't shrink in bright light: Bleeding or swelling pushes the brain downward and pinches the oculomotor nerve (cranial nerve III), which controls pupil size. A squeezed nerve can't tell the pupil to get smaller, so it stays wide open — a sign of dangerous pressure inside the skull.
- Weakness or numbness on one side of the body: A bruise, bleed, or tear in the motor cortex (the strip along the top middle of the brain that sends movement commands) or the corticospinal tract (the highway of nerve fibers running down to the spinal cord) blocks signals to muscles on the opposite side of the body.
- Clear or bloody fluid dripping from the nose or ears: A skull fracture at the base cracks the thin bone separating brain from nose or ear. Cerebrospinal fluid (the clear liquid cushioning the brain) or blood leaks out through the break.
- Seizure (sudden shaking, stiffening, or loss of awareness): Torn or bruised brain tissue disrupts the normal electrical rhythm. Neurons fire all at once in a wild storm instead of in an orderly pattern, causing uncontrolled muscle jerking or a blank stare.
- Trouble speaking or slurred words: Injury to Broca's area (the speech-production zone in the left front of the brain for most people) or the cerebellum (which coordinates the tongue and lip muscles) scrambles the signals needed to form clear words.

Focused exam

- Glasgow Coma Scale score: The GCS tells you how awake and alert the brain is right now. It has three parts: eye opening, talking, and moving. Add the numbers together to get the total score (3 to 15). A score of 8 or less means the brain is so hurt that the person cannot protect their own airway from spit or vomit — you must put in a breathing tube right away. This number is the most important thing you need to know in TBI.
- Pupil size and light reaction: When the brain swells inside the skull, the pressure can push brain tissue down through a hole at the bottom. This squeezes the oculomotor nerve (the nerve that tells the pupil to get smaller when you shine a light). One pupil gets big (blown pupil) and stops reacting to light. This is a sign the brain is about to herniate (squeeze through the hole), which causes death fast. You must act within minutes.
- Neck and spine alignment, tenderness, and movement: Most people with TBI also hit their neck hard. The bones in the neck (cervical spine) can break. If you move a broken neck the wrong way, sharp bone edges can cut the spinal cord and paralyze the person for life. Always treat the neck as broken until you prove it is not — keep the head and neck perfectly still with a collar and board.
- Scalp cuts, bruises, bumps, and dents in the skull: Marks on the head show you where the impact landed. A dent in the skull (depressed skull fracture) or a deep cut that reaches bone means the skull broke. A broken skull tells you the force was very strong, so the brain underneath is probably bruised or bleeding too.

- Breathing pattern and oxygen saturation: When brain pressure rises, the swelling squeezes the brainstem (the bottom part of the brain that controls breathing). The person may breathe too fast, too slow, or in strange patterns. Low oxygen makes brain swelling worse and kills more brain cells. You must give oxygen and sometimes take over breathing with a machine right away.
- Blood pressure and heart rate: The brain needs blood pressure high enough to push blood through swollen, squeezed vessels. You want a mean arterial pressure (MAP) of at least 65 so oxygen-rich blood can still reach the brain. But if blood pressure is too high (over 180 systolic), it can make bleeding inside the brain worse. You must balance these two risks.

Diagnostics · every test answers a question

- Non-contrast head CT scan → Is there bleeding inside the skull, and if so, where and how much? Is the brain being pushed to one side (midline shift)? Are the fluid spaces (ventricles) squeezed shut?
- Arterial blood gas (ABG) → Is the brain getting enough oxygen, and is carbon dioxide being blown off properly?
- Coagulation panel (PT, PTT, INR, platelet count) → Can the blood clot properly, or is there a bleeding problem that will make brain bleeding worse?
- Serum sodium and osmolality → Is the blood thick or thin enough to pull water out of swollen brain tissue?
- Cervical spine CT scan → Is the neck broken?
- Blood alcohol level and urine drug screen → Is confusion from the brain injury, or from alcohol or drugs?

Treatment logic

- Secure the airway and intubate if Glasgow Coma Scale ≤ 8 → A breathing tube (endotracheal tube) keeps the airway open so spit, vomit, or blood cannot get into the lungs and cause pneumonia or block oxygen. The tube also lets you control how much oxygen goes in and how much carbon dioxide comes out, which protects the brain from more swelling.
- Elevate the head of the bed 30 degrees and keep the neck straight in midline → Tilting the head up lets blood and fluid drain out of the skull through the jugular veins (the big veins in the neck), which lowers pressure inside the brain. Keeping the neck straight (not turned or twisted) keeps the jugular veins open so blood can flow out easily.

- Maintain mean arterial pressure (MAP) 65–70 mmHg and oxygen saturation above 90% → The brain needs a MAP of at least 65 to push blood through swollen, squeezed vessels. Oxygen above 90% keeps brain cells alive. If pressure or oxygen drops, more brain cells die and swelling gets worse.
- Emergency surgery (craniotomy) to remove large blood clots or decompress the skull if midline shift > 5 mm or deteriorating exam → Surgery physically takes out the pool of blood or removes part of the skull (decompressive craniectomy) to give the swollen brain more room. This drops pressure inside the skull immediately and can save the person's life.
- Give mannitol 0.25–1 g/kg IV or 3% hypertonic saline bolus for intracranial pressure (ICP) spikes above 22 mmHg → Mannitol and hypertonic saline pull water out of brain tissue into the bloodstream, which shrinks the brain and drops pressure fast (within 15–30 minutes). This buys time while you figure out if the person needs surgery or other treatments.
- Start levetiracetam or phenytoin for seizure prevention in moderate to severe TBI (first 7 days) → Early seizures (in the first week) make brain swelling and pressure much worse because the brain fires wildly and uses up oxygen. An anticonvulsant medicine stops seizures before they start, protecting the brain during the most dangerous time.
- Place external ventricular drain (EVD) or ICP monitor if severe TBI, and keep cerebral blood flow (perfusion) pressure (CPP) 60–70 mmHg → An EVD is a tube placed through the skull into the fluid space (ventricle) inside the brain. It measures pressure in real time and lets you drain fluid to lower pressure when it spikes. CPP (the difference between blood pressure and brain pressure) tells you if blood can still squeeze into the brain. Keeping CPP 60–70 means the brain is still getting fed.

Medications

Mannitol · Osmotic diuretic

Mannitol is a sugar-alcohol that pulls extra water out of swollen brain tissue and into the blood, then flushes it out through the kidneys. When brain tissue swells after a traumatic injury, pressure inside the skull rises and squeezes the brain. Mannitol creates a pull (osmotic gradient) that draws the extra fluid away from the brain and into the bloodstream, lowering the dangerous pressure.

1. Given through an IV, mannitol travels through the bloodstream to the brain.
2. Because mannitol stays in the blood vessels and doesn't cross into brain tissue easily, it creates a strong pull (osmotic force) that draws water out of the swollen brain cells and the space around them.
3. The extra fluid moves into the blood, which lowers the pressure inside the skull (intracranial pressure, or ICP).

4. The kidneys filter the mannitol and the extra water out of the blood, making urine to flush it away.
5. Brain swelling goes down, giving the injured brain more room and better blood flow.

SAFETY WATCH

Can cause sudden drops in blood pressure if given too fast, which reduces blood flow to the injured brain. · Pulls water out of the whole body, so check kidney function and electrolytes (sodium, potassium) regularly. · Do NOT use if the patient already has severe kidney failure or if there is active bleeding inside the brain (hemorrhagic shock), because it can worsen these problems. · Repeated doses can lead to a rebound effect where fluid shifts back into the brain, raising pressure again.

Hypertonic saline (3% sodium chloride) · Osmotic agent

Hypertonic saline is a concentrated salt solution that pulls extra water out of swollen brain tissue by creating a strong salt pull (osmotic gradient). After traumatic brain injury, the brain swells and pressure inside the skull rises. The high-salt IV solution draws water from the swollen brain into the bloodstream, lowering the dangerous pressure and protecting the brain from being crushed.

1. Given through an IV, the concentrated salt solution travels to the brain in the bloodstream.
2. Because the blood now has more salt than the brain tissue, water is pulled from the swollen brain cells and surrounding space into the blood vessels.
3. This reduces brain swelling and lowers intracranial pressure (ICP).
4. The kidneys filter the extra salt and water out of the blood, removing it from the body as urine.
5. Brain tissue has more room, and blood flow to the injured areas improves.

SAFETY WATCH

Can cause the blood sodium level to rise too high (hypernatremia), which can damage brain cells further if not monitored closely. · Check sodium levels in the blood every few hours and adjust the dose carefully. · Can overload the bloodstream with fluid if given too much, especially in patients with heart or kidney problems. · Do NOT stop suddenly—tapering is needed to prevent rebound swelling. · Infuse through a central IV line (a large vein near the heart) because it can irritate and damage smaller veins.

Levetiracetam (Keppra) · Anticonvulsant (anti-seizure medication)

Levetiracetam calms overexcited brain cells to prevent seizures in the first week after a severe traumatic brain injury. When the brain is injured, damaged cells can fire electrical signals

wildly and out of sync, like a short circuit, causing a seizure. Levetiracetam binds to a protein (SV2A) on brain cells that controls how neurons release their chemical messengers, stabilizing the cells so they don't fire too easily.

1. Levetiracetam is absorbed from the gut or given through an IV and travels to the brain.
2. It binds to a protein called SV2A on the surface of brain cells.
3. This binding steadies the release of neurotransmitters (chemical messengers), preventing sudden bursts of electrical activity.
4. The chaotic firing that leads to a seizure is stopped before it can spread.
5. Seizure risk in the critical first week after injury drops, protecting the brain from further damage.

SAFETY WATCH

Can cause mood changes, irritability, or anxiety, especially in patients with a history of depression or psychiatric illness. · May cause dizziness or drowsiness, which can be hard to distinguish from the brain injury itself. · Generally safe for the kidneys and liver, but the dose must be adjusted if kidney function is poor. · Should be given for seven days in severe TBI and then stopped if no seizures occur—long-term use without seizures is not recommended.

Phenytoin (Dilantin) · Anticonvulsant (anti-seizure medication)

Phenytoin stabilizes brain cells by blocking the sodium channels (tiny gates) on neurons that let electrical signals fire. After a traumatic brain injury, damaged brain cells can fire wildly, causing seizures. Phenytoin locks these gates in a closed position after a neuron fires, stopping the cell from firing again too quickly and preventing the chaotic electrical storm of a seizure.

1. Phenytoin is given through an IV or absorbed from the gut and travels to the brain.
2. It finds sodium channels on neurons that have just fired an electrical signal.
3. Phenytoin binds to the channels and holds them shut, preventing the cell from firing again too quickly.
4. This blocks the rapid, repetitive firing that causes a seizure.
5. Seizure risk in the first week after severe brain injury is reduced.

SAFETY WATCH

Must be given slowly through an IV because rapid infusion can cause dangerous drops in blood pressure or irregular heart rhythms (arrhythmias). · Blood levels must be checked regularly because too little won't prevent seizures and too much can cause confusion, dizziness, and trouble walking (ataxia). · Can cause gum overgrowth (gingival hyperplasia) and facial hair growth (hirsutism) with long-term use. · Can irritate veins and cause 'purple glove syndrome' (painful swelling and discoloration at the IV site)—use a central line if possible. · Interacts with many other medications, so the care team must review all drugs the patient is taking.

Propofol · Sedative-hypnotic (GABA-A agonist)

Propofol is a powerful sedative that calms the brain by boosting the effect of GABA (the brain's main calming chemical messenger). After a severe traumatic brain injury, the brain can become overactive, raising pressure inside the skull and causing more damage. Propofol opens GABA receptors (the locks that GABA normally turns) for longer, making brain cells much less excitable. This lowers brain metabolism, reduces oxygen and glucose demand, and helps bring down dangerous intracranial pressure.

1. Propofol is given through an IV and quickly reaches the brain.
2. It binds to GABA-A receptors on brain cells and makes the calming signal (GABA) much stronger.
3. Neurons fire less often, and the brain's overall activity slows down.
4. This lowers the brain's demand for oxygen and glucose, reduces swelling, and decreases intracranial pressure.
5. The sedation also prevents the patient from moving or fighting the ventilator, which can spike brain pressure.

SAFETY WATCH

Lowers blood pressure, which can reduce blood flow to the already injured brain—fluids or vasopressors (drugs that raise blood pressure) may be needed. · Slows breathing and heart rate, so the patient must be on a ventilator and closely monitored. · Long-term or high-dose use (more than 48–72 hours at high rates) can cause propofol infusion syndrome, a rare but deadly condition with heart failure, muscle breakdown, and severe too much acid in the blood (acidosis). · Can raise triglyceride (fat) levels in the blood because propofol is dissolved in a fat emulsion. · Should be stopped gradually to prevent rebound increases in intracranial pressure.

Red flags

- Glasgow Coma Scale score below 9 (deep unconsciousness — the brain is badly hurt and the person can't protect their airway)
- One pupil much bigger than the other or pupils that stay wide and don't react to light (sign of a brain bleed pressing on the nerve)
- Repeated vomiting or vomiting that starts hours after the injury (rising pressure inside the skull)
- Seizure after the head injury (the brain's wiring is misfiring from the damage)
- Clear or pink fluid leaking from nose or ears (skull fracture letting brain fluid escape)

Nursing priorities

1. Check airway patency and oxygen saturation every 15 minutes; prepare intubation equipment at bedside if Glasgow Coma Scale is 8 or below. — The injured brain needs constant oxygen. If Glasgow Coma Scale drops to 8 or less, the patient cannot protect the airway from vomit or tongue blocking the throat, and low oxygen makes brain swelling worse.
2. Assess pupils every hour: measure size in millimeters, check if both are equal, and shine a light to see if they get smaller. — Pupils that stay wide and do not react to light mean a blood clot or swelling is pressing on cranial nerve III (the oculomotor nerve). One blown pupil is a neurosurgical emergency signaling brain herniation (the brain is squeezing downward).
3. Elevate the head of bed to 30 degrees and keep the head and neck in straight midline alignment; avoid neck twisting or flexion. — Jugular veins in the neck drain blood away from the brain. When the neck twists or bends, the veins kink and blood backs up, raising intracranial pressure (ICP, pressure inside the skull). Elevation uses gravity to help drainage.
4. Maintain mean arterial pressure between 65 and 70 mmHg with IV fluids or vasopressors as ordered; avoid blood pressure dropping below MAP 65. — Cerebral blood flow (perfusion) pressure (CPP, the pressure pushing blood into brain tissue) equals MAP minus ICP. If MAP falls, the brain does not get enough blood and oxygen, causing secondary brain injury and cell death.
5. Monitor for and immediately report repeated vomiting, new seizure activity, or worsening drowsiness to the provider. — These are signs of rising intracranial pressure. The skull is a rigid box; bleeding or swelling inside has nowhere to go, so pressure builds and squashes brain tissue. Early recognition allows time for mannitol, hypertonic saline, or emergency craniotomy (surgery to open the skull).

6. Avoid actions that raise intracranial pressure: suctioning longer than 10 seconds, tight cervical collar, coughing, straining, or agitation. — Any Valsalva maneuver (holding breath and pushing), coughing, or fighting the ventilator spikes pressure inside the chest and blocks venous return from the brain, suddenly raising ICP and risking herniation.
7. Keep the environment quiet and dim; cluster care activities so the patient has rest periods between assessments. — Stimulation and noise raise metabolic demand in the injured brain. The brain needs more oxygen when aroused but swelling limits blood flow, creating a mismatch that worsens secondary injury.
8. Have mannitol or 3 percent hypertonic saline ready at bedside if ordered; know the dose and how to give it fast through a large IV. — Mannitol (an osmotic diuretic that pulls fluid from brain tissue into blood vessels) and hypertonic saline shrink brain swelling quickly. Minutes matter when ICP is rising and the patient is herniating; delay causes permanent damage or death.

Sources

- Brain Trauma Foundation Guidelines for Management of Severe TBI, 4th Edition 2016
- CDC Guideline on Diagnosis and Management of Mild Traumatic Brain Injury (2018)
- American College of Emergency Physicians Clinical Policy on Mild TBI
- Cochrane Review on interventions for traumatic brain injury

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