Head Injury (GENERAL)

Last updated: January 7, 2022

TBI – traumatic brain injury.

DEFINITIONS, CLASSIFICATIONS

Traumatic brain injury (TBI) - *nondegenerative*, *noncongenital* brain insult from acute external mechanical force, with associated altered state of consciousness, and temporary or permanent impairments of ***cognitive***, ***physical***, ***psychosocial*** functions.

"HEAD INJURY" and "BRAIN INJURY" are not identical, but cannot be easily separated.
N.B. HEAD INJURY may not be associated with neurological deficits!

Scalp injuries
CLOSED – contusion.
OPEN:
1) puncture
2) laceration
3) avulsion

Skull fractures see p. TrH5 >>

Brain injury (TBI)
Communication with outside:
A. **CLOSED**:
a) no scalp injury
b) no skull fracture
c) scalp injury not connected with skull fracture.
- caused by **blunt** objects or **no contact**.

B. **OPEN** – scalp injury connected to skull fracture; *Risk of infection!*
- caused by **blunt** or **sharp** objects.

Penetrating – with dura matter injury;
- caused by ***missile injuries*** (much more common) or ***impalements***.

Location:
A. **Diffuse**:
a) concussion (s. commotio) – mildest TBI with negative imaging.
b) diffuse axonal injury (DAI) – microhemorrhages on imaging.
B. **Focal**:
a) contusions
b) lacerations
c) hematomas (extradural, subdural, subarachnoid, intracerebral)

Cerebrovascular injury

EPIDEMIOLOGY

Brain injury – plague of modern society – despite technological progress (carriages → powerful cars; fist fighting → shotguns), innate man's aggression is not curbed.

INCIDENCE

0.2% per year (in USA, head injury occurs every 7 seconds and death every 5 minutes)

High-risk populations:
1) **young** people (peak 15-24 yrs; second peak > 65 yrs – due to falls)
2) **men** (affected 2-4 times* as often as women; approaches 1:1 as age increases - increased likelihood of TBI caused by falls)
*motor vehicle accidents, contact sports, interpersonal violence, alcohol abuse
3) low-income individuals
4) unmarried individuals
5) members of ethnic minority groups (esp. African Americans, Native Americans)
6) residents of inner cities
7) individuals with history of substance / alcohol abuse
8) individuals with previous TBI

MORBIDITY

- 20-25% brain trauma cases need hospitalization
- major cause of disability!
- 100% severe TBI, 66% moderate TBI → permanent disability.
- 5-10% patients go to long-term care facility.

MORTALITY

- mortality ≈ 10% (higher in persons 15-24 yrs and > 65 yrs).
Major cause of death in young adults!
- 5% of all patients die at site of accident (60% of fatalities occur before patients can be admitted to hospital). also see "Prehospital Management" *below*

N.B. in gunshot TBI, mortality is 90-92% (73-76% are dead at scene; of remaining, 60% die at hospital)

50,000 individuals each year die from head injuries in USA

- according to TBI severity:

1) mild TBI - mortality ≈ 0%
2) moderate TBI - mortality ≈ 2.5-20%
3) severe TBI - mortality ≈ 30-50%

- if patient dies at hospital, average time to death is 2 days after trauma.
- ***TRAUMAS IN GENERAL***:
  - TBI is major determinant of survival in most cases of blunt trauma.
  - TBI contributes significantly for 50-75% of all traumatic deaths.
  - in any traumatic cases, presence of TBI increases fatality rate 3-fold.

ETIOLOGY

1. **Motor vehicle accidents** - most common cause! (≈ 50%) (much more common in *suburban*/*rural areas*)
   - 70% MVA injuries are TBIs.
2. **Falls** - 2nd most common cause (20-30%) (much more common in *elderly* > *children*)
3. **Personal violence** (***assaults***, ***gunshot wounds***, ***child abuse***) - more common cause in *large urban areas*.
   - firearms are 3rd leading cause of TBI (12%; incidence increasing), esp. African American men.
4. **Sports** (esp. football and soccer), **bicycles** – more common in children.

Work-related TBIs - 45-50% all TBIs, esp. military employees (57% are related to transportation).

PATHOPHYSIOLOGY (Primary vs. Secondary Injury)

FINAL NEUROLOGIC STATUS is sum of irreversible damage acquired ***at time of initial injury*** and damage from ***secondary insults***!

- *brain cells do not regenerate* - once brain cell is destroyed, it cannot be replaced; gliotic scar will take its place, but not its function, which is lost forever.

PRIMARY BRAIN INJURY

- occurs at time of trauma: portion of brain sustains ***irreversible damage***, and second portion sustains ***lesser degree of damage*** (recovers over months).

- microscopically - *mechanical cellular disruption*, *microvascular injury*.

I. Diffuse shearing injuries (concussion, diffuse axonal injury)
II. Contusions
III. Lacerations
IV. Tears (of cranial nerves, brainstem, pituitary stalk, etc)

MECHANISMS

Brain is protected by scalp, skull, meninges, CSF!

A. **Contact, s. direct impact injury** (object striking head or head striking object; rarely – head compression) → *scalp* injury, *skull* fracture, *contusions* & *lacerations*.

Injuries tend to be focal

- ***external signs of trauma*** are frequently noted at site of contact.
- skull initially bends inward at point of contact (if force is sufficient, skull fracture can occur) - cranium absorbs some of applied energy, while some energy is transmitted to brain by shock waves that travel and distort / disrupt intracranial contents.
- injury from **compression** requires significant force because skull architecture provides substantial resistance to deformation; if skull ability to absorb force is overcome → multiple linear skull fractures.

Direct impact sets head in motion, resulting in simultaneous **indirect injury** (isolated direct impact injury is rare).

B. **Acceleration-deceleration, s. indirect injury** (cranial contents are set into vigorous motion by forces other than direct contact of skull with another object) → shear, tensile, compressive strains → *hematoma*, *diffuse axonal injury*, injury to *cranial nerves* and *pituitary stalk*.

Injuries tend to be diffuse

- brain is most susceptible to lateral rotation, while tolerating sagittal movements best.
- injury depends on direction of force:
  a) **TRANSLATIONAL forces** (force in AP or true lateral direction - brain's center of gravity is moved in straight line) → damage to *superficial structures* (bridging structures, cortex); as force is increased, deep structures are also affected.
  b) **ROTATIONAL forces** (head is rotated around long axis of body without moving center of gravity of brain – practically impossible) → high shear stress to *deep structures*.
  c) **ANGULAR forces** (combinations of TRANSLATIONAL and ROTATIONAL forces - head pivots on cervical spine) - predominating force determines injury pattern (*any type of TBI* except skull fractures and epidural hematomas).

SECONDARY BRAIN INJURY

- any insults that occur after trauma and worsen neurologic deficits:

N.B. secondary brain injury is main target of TBI treatment!

I. **SYSTEMIC DISORDERS**:

1. **Hypotension**!!! (systolic BP < 90 mmHg doubles mortality!);
   early causes of hypotension - intra- or extracorporeal hemorrhage, cardiac contusion;
   later causes of hypotension - sepsis, pulmonary embolism, GI bleeding.

   N.B. intracranial trauma per se does not cause hypotension!; exceptions:
   1) profound blood loss from *scalp lacerations*.
   2) *infants* (relatively small circulating blood volumes - blood may accumulate without much evidence of increased ICP) - hemorrhage from large *linear skull fracture* into epidural, subperiosteal or subgaleal hematoma, *intracranial bleeding* (esp. in child with hydrocephalus and functioning shunt).
   3) *high cervical* (> C_4) *fractures* with medullary compression [hypotension with bradycardia, nonresponsive to fluid therapy].
   4) *terminal stage*.
2. **Hypoxia**!! (PaO_2 < 60 mmHg doubles mortality!); *causes of hypoxia* - apnea caused by brain stem compression, mechanical airway obstruction (in unconscious patient), chest / pulmonary trauma, intoxication with alcohol / CNS depressants.
3. **Anemia** (hematocrit < 30%)
4. **Fever**

5. **Hypoglycemia**

II. **INTRACRANIAL DISORDERS**:

1. Expanding **intracranial mass** (hematoma, contusions, brain edema & engorgement) → **raised ICP** → decrease in cerebral perfusion pressure, herniation. Cause 50% deaths!
2. **Seizure**
3. **Vasospasm** (due to SAH) → local ischemia.
   N.B. SAH is most common type of traumatic intracranial hemorrhage!

Very dangerous combination: ICP↑ + hypotension

PATHOPHYSIOLOGY (Cerebral Blood Flow, Edema)

TBI disrupts autoregulation & BBB

N.B. injured brain is very sensitive to perfusion fluctuations – autoregulation limits become narrower (e.g. the lower limit for autoregulation may rise from 40 mmHg to 70 mmHg – here is rationale to keep CPP > 60-70 mmHg to prevent ischemia).

AUTOREGULATION

- immediately after trauma, blood vessel lose tone and passively dilate (impaired autoregulation) → *cerebral blood flow*↑ (although metabolic demands and oxygen consumption are diminished) → ICP↑.
- 5-30 min later: postcapillary sphincters and venules constrict but arterioles remain paralyzed (maximally dilated) → *cerebral blood flow*↓ (typically less than half of normal values), *cerebral blood volume*↑ (**brain engorgement**) → ischemia, ICP↑↑.
  - lowest CBF values occur within first 6-12 hours after injury.
  - these changes may exist for several days after injury.
  - it is especially common in children.

  N.B. despite disrupted autoregulation, vasoreactivity to P_{CO2} remains (enables therapeutic hyperventilation)

  Duration of cerebral autoregulation impairment significantly correlates with worse outcomes after severe TBI!

  Preiksaitis et al. Association of Severe Traumatic Brain Injury Patient Outcomes With Duration of Cerebrovascular Autoregulation Impairment Events. Neurosurgery, Volume 79, Issue 1, 1 July 2016, Pages 75–82,

BBB

- mechanical forces and ischemia *disrupt BBB* for several hours (demonstrated by contrast MRI) → **vasogenic brain edema** → ICP↑.
- ischemia (produced by any mechanism) causes **cytotoxic brain edema**.

In TBI, both **vasogenic** and **cytotoxic** brain edema occur!

- brain edema reaches maximum at 48-72 hours.
- brain edema:
  a) ***localized*** (associated with other lesions – hematoma, contusion, infarction)
  b) ***diffuse***
  - on occasion (esp. in children), TBI causes diffuse brain edema within few hours without any focal lesions - due to microvascular disruption and greatly increased CBF.
  - on occasion, malignant edema develops after evacuation of intracranial hematoma (esp. SDH), esp. if patient had hypotension /hypoxia episodes (cause generalized vasoparalysis).

PATHOPHYSIOLOGY (Biochemistry)

- immediately after trauma, bioelectrical brain activity stops → widespread neuron depolarization → release of excitatory neurotransmitters (glutamate, aspartate):
  - excess neuronal firing → K^+ leaves cells, Na^+ accumulates intracellularly → acute neuronal swelling.
  - intracellular Ca^{2+}↑ → generation of oxygen free radicals → membrane damage.
- metabolic activity↑ to restore ionic balance → release of lactate → acidosis.
- excitatory neurotransmitters, lactate, oxygen free radicals are released into bruised / ischemic areas → ***intense inflammatory response*** → further brain edema.

PATHOLOGY, CLINICAL FEATURES

Head injuries and their sequelae are embedded inextricably in medicolegal system - detailed history, review of systems, complete examination, and management steps are essential - documentation should be meticulous!

External signs of trauma (scalp lacerations, abrasions, hematomas, bruising, etc) at site of impact - only confirm that injury has occurred; *not always present* in patient who has sustained serious brain damage!

N.B. as scalp injuries occur at site of impact - carefully explore for foreign bodies or underlying skull fractures.
- in gunshot injuries, carefully document entry and exit wounds, powder burns, and foreign bodies.

- scalp may be injured with or without breach in its surface.
- injured scalp becomes markedly edematous.
- **lacerations** are particularly common, as scalp is readily crushed and split against underlying bone (most scalp lacerations are linear because of skull convexity).
- scalp subcutaneous layer has rich vascular supply → significant blood loss when scalp is lacerated.
- galea is poorly fixated to underlying periosteum → large scalp flaps (scalping or degloving injuries), little resistance to hematoma / abscess formation in subgaleal plane.

N.B. *external bleeding* or *subgaleal blood collections* may cause shock in small infant!

Alteration of consciousness (practically the must symptom for TBI!!!) - inadequate functioning of ***brainstem*** or ***both cortices*** caused by:
a) primary injury (e.g. midbrain or diencephalic hemorrhages, diffuse axonal injury)
b) ischemia (due to ICP↑)
c) hypotension
d) hypoxia
e) hypoglycemia
f) intoxicating substance consumed before injury – may distort entire clinical picture!

- **level** and **duration** (of consciousness alteration) characterize TBI degree. *see below >>*
- LUCID INTERVALS are not unusual (in one study, 25% talked at some point between trauma onset and their deterioration into coma: 81% had focal lesion, 19% had diffuse brain swelling).

Possible **immediate accompaniments of trauma**

1) immediate brief generalized **convulsion** ("impact seizure") - result from transient mechanical and neurochemical changes - most of these patients will not have additional seizures (?*) and do not require long-term anticonvulsants (but require anticonvulsants for first 7 days).
   *other authors state - single seizure at time of injury increases risk of post-traumatic epilepsy 10-fold
2) transient **apnea, flaccidity**, **areflexia**, **dilatation of pupils** (esp. in children).
3) **arterial hypertension**, **cardiac arrest** (in absence of overwhelming brain damage, recovery from arrest is rule).

RESIDUAL EFFECTS (on recovering consciousness)

1. **Dizziness**, **nausea**, **emesis** (common in immediate posttraumatic period, regardless of TBI degree).

2. Slight **blurring of vision** (transient cortical blindness may follow concussion - localized edema or vasospasm in calcarine fissure; usually resolves spontaneously within 24 hours).

3. **Difficulty with concentration**, **mental cloudiness** and **confusion** before full consciousness is restored (this "mental" period is prolonged, roughly proportional to degree of brain injury);
- some patients are **combative** when they regain consciousness.
- behavioral changes (such as agitation) are *most evident at night*.
- ***difficulties with activities of daily living*** may continue for months.

4. **Amnesia** (duration is good indicator of TBI degree):
   1. **Anterograde amnesia** (amnesia for events after trauma) - somewhat of misnomer - ***severe inattention*** in postinjury state primarily prevents retention of new information, ("**posttraumatic confusional state**" is more accurate term).
   2. **Retrograde amnesia** (amnesia for events preceding trauma) – never occurs without anterograde amnesia; may be absent in mild TBI.

- during weeks, improvement occurs in orderly progression from most distant to recent memories (islands of absolute amnesia may remain in severe cases).

HYSTERICAL POSTTRAUMATIC AMNESIA - tendency to recount events that cannot be recalled on later testing, bizarre affect, forgetting one's own name, excessive anterograde deficit.

5. **Headache** (constant generalized or frontal; may be throbbing hemicranial like migraine)
- common for days ÷ months following trauma. H: β-blockers
- persistent severe headache and repeated vomiting in context of normal alertness and no focal neurologic signs are usually benign.

6. **Early post-traumatic SEIZURES** (2.5-7% clinically; 22% by EEG) - develop within 7 days after TBI (50-80% manifest during 1st day as **immediate SEIZURES**) - result from cerebral edema, hemorrhagic lesions (intracerebral, subdural > epidural hematoma), penetrating injury (42% risk of seizures), depressed skull fractures.
- seizures are major threat - increase tissue energy requirements and cerebral blood flow by up to 400% → ICP↑.
- *STATUS EPILEPTICUS* may ensue!
- seizures occurring after 7 days = **late post-traumatic SEIZURES (posttraumatic epilepsy)** *see below*

7. **Focal neurologic signs** – hemiplegia (9%), aphasia (6%), cranial nerve palsies, etc – depend on extent and site of damage to intracranial structures.
- (almost) complete return of motor power and speech is common when cause is compression by hematoma! (vs. laceration → severe residual defects).

Injury to **CRANIAL NERVES**:
a) frequent complication of ***skull base fractures***.
b) torn / stretched by ***brain movement within skull*** (esp. CN1).
c) ***penetrating trauma***.

- occasionally, cranial nerve palsies may not be evident for several days.
- recovery (partial or complete) is rule, but prognosis is worse for CN1 and CN2.

CN1 (in 7% TBI cases) – ***anosmia*** and apparent *loss of taste* (actually loss of perception of aromatic flavors, with elementary tastes retained) occurs in ≈ 10-30% of severe TBI cases (esp. with falls on back of head or anterior fossa fractures) - results from brain displacement → shearing of olfactory filaments at cribriform plate;
Even trivial head injury (to any part of head) can result in anosmia!
– check for CSF rhinorrhea and frontoorbital contusions.
– recovery may last up to 5 years; residual hyposmia is usual.

CN2 (in 5% TBI cases) – fractures of sphenoid bone may transect CN2; closed TBI → partial injuries (blurring of vision, central or paracentral scotomas, sector defects); direct orbital injury → reversible iridoplegia (short-lived blurred vision for close objects).
– indirect optic neuropathy: observation, high-dose steroids, surgery.
– delayed onset of visual loss → surgical decompression.
– prognosis extremely variable (0-100%).

CN3 – injured in uncal herniation.
– aberrant regeneration often occurs (e.g. lid elevation on attempted adduction).

CN4 – fracture of lesser sphenoid wing or stretching near CNS exit site.
– TBI is most common cause of trochlear palsies!
– only ≈ 50-66% recover because of frequent nerve avulsion.
– ***bilateral*** CN4 lesions can occur - if dorsal midbrain and both 4th nerves are impacted in niche of tentorium cerebelli; only ≈ 25% recover.

$CN5_1$, **$CN5_2$** (in facial trauma)
– hyperpathia in nerve distribution may be permanent.

CN6 – most commonly injured oculomotor nerve!

CN7 – petrous fractures (in 30-50% *transverse* temporal bone fractures; in 10-30% *longitudinal* fractures); ***facial palsy*** may be delayed 5-7 days (mechanism - progressive edema within nerve - good prognosis).
– *longitudinal fractures* - spontaneous recovery is usual.
– *transverse fractures* → nerve decompression.

CN8 – petrous fractures (nerve laceration in 80% *transverse* temporal bone fractures) → ***sensorineural hearing loss***, ***vertigo***, positional ***nystagmus*** immediately after injury.
– patients with low- **or** high-frequency hearing loss may have some recovery but those with low- **and** high-frequency loss usually do not recover.
– vertigo due to labyrinth concussion usually resolves within year.

CN9-12 - fracture of occipital condyle; ***COLLET-SICARD syndrome***.

MIDDLE EAR trauma → tympanic perforation, hemotympanum, ossicular disruption → ***conductive hearing loss***.
- most tympanic perforations heal spontaneously. see p. Ear38 >>
- ossicular incongruences → ossiculoplasty (if hearing loss persists > 3 months).

INNER EAR trauma:
1) cochlear concussion → ***sensorineural hearing loss*** (for high-tones).
2) perilymphatic fistula → ***sensorineural hearing loss***.
3) otolith dislodgement → ***benign paroxysmal positional vertigo***.

CONCUSSION

- biomechanically induced alteration of brain function, typically affecting memory and orientation.

Concussion Guidelines: indicators of concussion are documented:
a) **confusion** immediately after the event
b) **impaired balance** within 1 d after injury
c) **slower reaction time** within 2 d after injury
d) **impaired verbal learning and memory** within 2 d of injury.

Concussion Guidelines: clinical and prognostic 5 subtypes (cognitive, ocular-motor, headache/migraine, vestibular, and anxiety/mood) and 2 associated conditions (cervical strain and sleep disturbance).

It's clinical diagnosis:
1) immediate brief (< 6 hours) **loss of consciousness*** (dazed or "star struck"; loss of consciousness is not deep - pupillary reactions and other brainstem functions are intact; extensor plantar responses may be present briefly but not decerebrate posturing).
↓ *± temporary respiratory arrest, loss of reflexes
N.B. true loss of consciousness is not required and it occurs in < 10% of concussion cases!
2) brief **disorientation**
3) **antegrade amnesia** lasting minutes (i.e. amnesia for traumatic event).
4) **dizziness-nausea** (single episode of vomiting), lethargy-irritability.
5) **headache**
6) in severe cases - brief convulsion, autonomic signs (facial pallor, bradycardia → tachycardia, mild hypotension, sluggish pupillary reaction).

Concussion is mild head injury!

Concussion selectively disrupts **attention**!

- wide spectrum of neurologic symptoms may be described but are quickly resolved* - most patients on presentation are neurologically normal (GCS = 15) - diagnosis is usually retrospective!
*patients become normal within few minutes; others may be slightly dazed for few minutes and complain of headaches for ≥ 12 hours.
- concussions are graded:
grade I - confused temporarily but does not display any memory changes.
grade II - brief disorientation and anterograde amnesia of < 5 minutes' duration.
grade III - loss of consciousness for < 5 minutes and retrograde amnesia.
grade IV - loss of consciousness for 5-10 minutes.
grade V - loss of consciousness > 10 minutes.

According to new guidelines, concussion severity is no longer classified at time of event!

The only objective signs of concussion (to rule out malingering) – but only within first 48 hrs:
1. Assymetry of **corneal** reflexes
2. Horizontal **nystagmus** (may be due to alcohol intoxication!)
3. Abnormal **vestibular** reflexes (↑ or ↓, assymetry)

- mechanism of loss of consciousness - functional disconnection* of brain stem from cerebral hemispheres.
transient electrophysiologic dysfunction of RAS in upper midbrain caused by rotation of cerebral hemispheres on relatively fixed brainstem.
higher primates are particularly susceptible to concussion; in contrast, billy goats, rams, woodpeckers can tolerate impact velocity and deceleration 100 times greater than humans.
- mechanism of amnesia is not known.
- ***no immediate or delayed structural brain damage*** - no significant long-term sequelae (except *postconcussion syndrome*).
- **biochemical and ultrastructural changes exist** - depolarization due to excitatory amino acid-mediated ionic fluxes, mitochondrial ATP depletion, local BBB disruption.
- **repeat concussions** have cumulative effects that lead to traumatic encephalopathy.
— having ApoE-4 gene increases risk for chronic problems following concussion.

DIFFUSE AXONAL INJURY (DAI)

- immediate loss of consciousness lasting > 6 hours (i.e. concussion is a mild form of DAI).

Unconsciousness in resuscitated patient despite absence of any *intracranial mass lesion* or history of *hypoxia*

N.B. DAI is almost ubiquitous to all patterns / degrees of TBI

- extensive generalized *shearing or stretching of axons within white matter* – caused by ACCELERATION / DECELERATION injury – rotational or angular forces*, but not translational forces.
*e.g. brain ROTATION within skull
N.B. magnitude of acceleration needed to produce DAI requires head to strike object (increased likelihood that DAI will be accompanied by other intracranial lesions)
- axons are either sheared *at time* of impact or degenerate *soon after*.
  - stretch injury first affects *nodes of Ranvier* (blebbing of nodal axolemma).
  - membrane channels open to admit toxic levels of calcium.
  - numerous swollen and disconnected axons (axonal retraction bulbs) throughout white matter - appear within hours of injury.
- same forces act on vessels → *intracerebral hemorrhages* (micro / macro).
Duret hemorrhages – punctate hemorrhages caused by small penetrating arteriole stretching:
  - also may occur during transtentorial herniation (as secondary injury) – hemorrhages are larger than in DAI.
Subdural hematomas – caused by stretching of bridging subdural veins.
- little cerebral swelling - no ICP↑ (? children may develop diffuse cerebral edema).

Coma lasting 6-24 = **mild DAI** (only axon stretching); 30% patients demonstrate decorticate or decerebrate posturing, but by 24 hours they are following commands.
  - good prognosis (mild or no permanent disabilities, but some patients die).

Coma lasting > 24 hours = **moderate** or **severe DAI** (irreversible axon shearing, hemorrhages).
  - persistent brain stem dysfunction (posturing), autonomic dysfunction (e.g. hypertension, hyperpyrexia).

– poor prognosis (up to persistent vegetative state or death).
N.B. DAI is contributing cause of death in 30-40% cases!

All patients with DAI present identically in coma - no early clinical predictor differentiates mild, moderate, or severe DAI!

Centripetal theory of A.K. OMMAYA and T.A. GENNARELLI (1982) - increases in rotation / acceleration / deceleration force involve progressively deeper (medial) areas of brain:

1) **mild DAI (grade 1)** – lesions only in *subcortical axons* (mainly in parasagittal white matter of cerebral hemispheres).
2) **moderate DAI (grade 2)** – plus lesions in *corpus callosum*.
3) **severe DAI (grade 3)** – plus lesions in dorsolateral quadrants of rostral brain stem (*cerebral peduncle*).

- if patient survives → *wallerian degeneration* (affected areas of white matter are replaced by glial proliferation over several months) → degeneration of involved fiber tracts (delayed neurologic deterioration).

CONTUSION AND LACERATION

- foci of hemorrhagic necrosis (*hemorrhage mixed into tissue**) on brain surface** - result of CONTACT (IMPACT) injury.

*vs. ***HEMATOMA*** - focal collection of blood
**wedge shaped (in cross section) - base in gray matter, taper into white matter

CONTUSION - pia-arachnoid is intact (e.g. in blunt injuries).
LACERATION - pia-arachnoid is torn (e.g. in penetrating injuries).

- blood frequently spreads under pia; if pia is lacerated → SAH.
- contusion is *surrounded by delayed brain edema* (cytotoxic).
- surrounding edema enlarges with time* (contusion "blossoming" - during first 1-2 days; up to 7-10 days) → **mass effect**:
  1) compression of adjacent tissue → ischemia → necrosis → cyst
  2) ICP↑, brain herniation
- contusion is nidus for delayed* hematoma formation (esp. in alcoholics, elderly patients or taking anticoagulants).

*H: routinely repeat CT + careful clinical follow-up

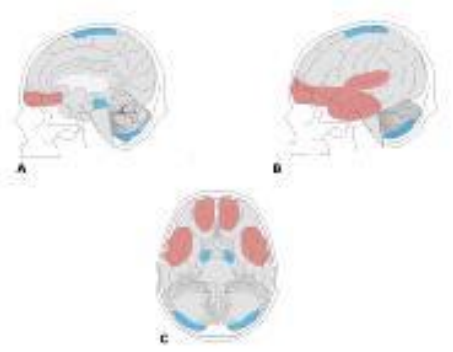
LOCATION of contusions:

1) ***coup contusion*** - at site of impact (direct trauma or during brain *acceleration*):
   a) skull is sufficiently bent inward to strike underlying brain
   b) moving brain abruptly strikes fixed skull
   c) under depressed skull fractures ("fracture contusion")
   d) along tract of missile injuries
2) ***contrecoup contusion*** - in antipolar area, i.e. at point opposite impact (during brain *deceleration*).
   classically, contrecoup contusion occurs when falling head strikes ground:
   backward fall → *contrecoup contusions at frontal and temporal poles;*
   fall on side → *contrecoup contusions at opposite temporal lobe.*
   forward fall *does not cause contrecoup contusions on back of brain because interior surface of skull is smooth at this point!*

- amount of energy dissipated at site of impact determines type of contusion:
  impact from **small hard object** - most of energy is dissipated at impact site → coup contusion.
  impact from **larger object** - less injury at impact site since energy is dissipated at beginning or end of head motion → contrecoup contusion.
- role of skull compliance:
  pediatric compliant skull is easily deformed → coup injury.
  adults - brain is forced against bony protuberances opposite point of impact → countercoup injury.

N.B. whatever site of injury, contusions are most severe in orbital surface of FRONTAL LOBES and anterior & basal portions of TEMPORAL LOBES - brain glides over ridged bony surfaces – orbital roof, sphenoid wing & petrous ridge (***crests of gyri*** are most susceptible to traumatic forces)!
There are more frontal lesions after occipital injury than vice versa!

Gliding contusions - along superior margin of cerebral hemispheres - due to sagittal angular acceleration/deceleration with abrupt stretching and tearing of parasagittal veins, arachnoid membrane, and adjacent cerebrum.
N.B. gliding contusions are result of acceleration/deceleration shear strains (as is diffuse axonal injury) - tend to be bilateral!



Contusion locations in sagittal midline (A), lateral (B), and base (C) views:
red - ***most commonly*** affected areas (orbitofrontal cortex, anterior temporal lobe, and posterior portion of superior temporal gyrus area, with adjacent parietal opercular area);
blue - ***occasionally*** affected areas (lateral midbrain, inferior cerebellum and adjacent tonsil, midline superior cerebral cortex).

HISTOLOGY

- earliest stages - edema and pericapillary hemorrhage.
- next few hours - blood extravasation extends throughout involved tissue, across width of cerebral cortex, and into white matter and subarachnoid spaces.
- evidence of neuronal injury (nucleus pyknosis, cytoplasm eosinophilia, cell disintegration) takes 24 hours to appear (functional brain injury occurs earlier).
- axonal swellings develop in vicinity of damaged neurons or at great distances away.
- usual inflammatory response: neutrophils → macrophages.

HEALING of contusions:

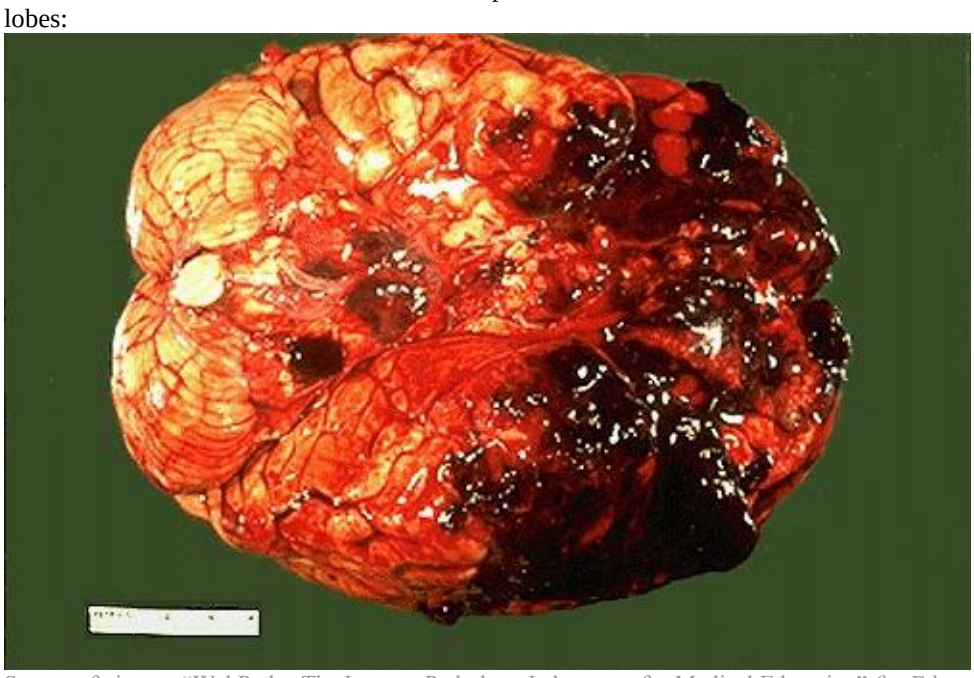
– **superficial lacerations** heal by gliosis with hemosiderin-laden macrophages - small scarred, yellow-brown (hemosiderin-stained) depressions denuded of their meningeal covering (punched-out areas) on surface (*PLAQUES JEUNES*) - source of posttraumatic epilepsy.
– **larger areas of necrosis that extend deep** heal by formation of *MENINGOCEREBRAL CICATRIX* (composed of glia, fibroblasts, and meninges) or larger *CAVITATED LESIONS*.

CLINICAL FEATURES:

1) **focal deficits** (coincide with affected brain region) – manifest after consciousness is regained.
2) **increasing ICP** – manifests as progressive neurologic deterioration.
3) early or late posttraumatic **seizures**

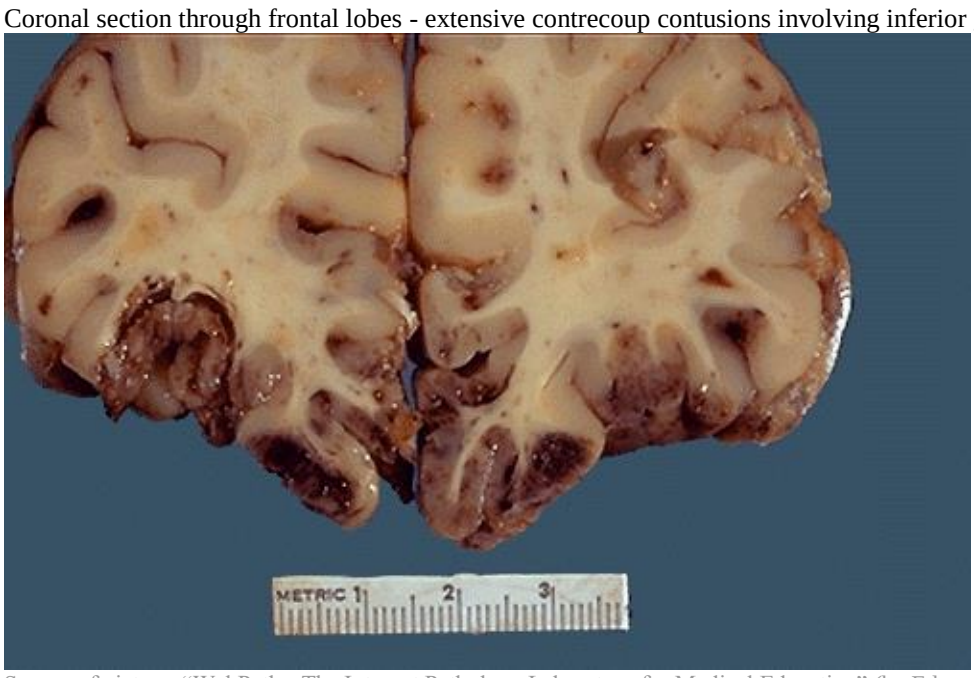
- contusion per se is *clinically silent* if in non-eloquent area (e.g. anterior temporal lobes or inferior frontal lobes); but may manifest latter as expanding mass!
- contusions in brainstem may be *fatal*.

Characteristic location of extensive contrecoup contusions consistent with fall backwards - inferior frontal and temporal lobes:



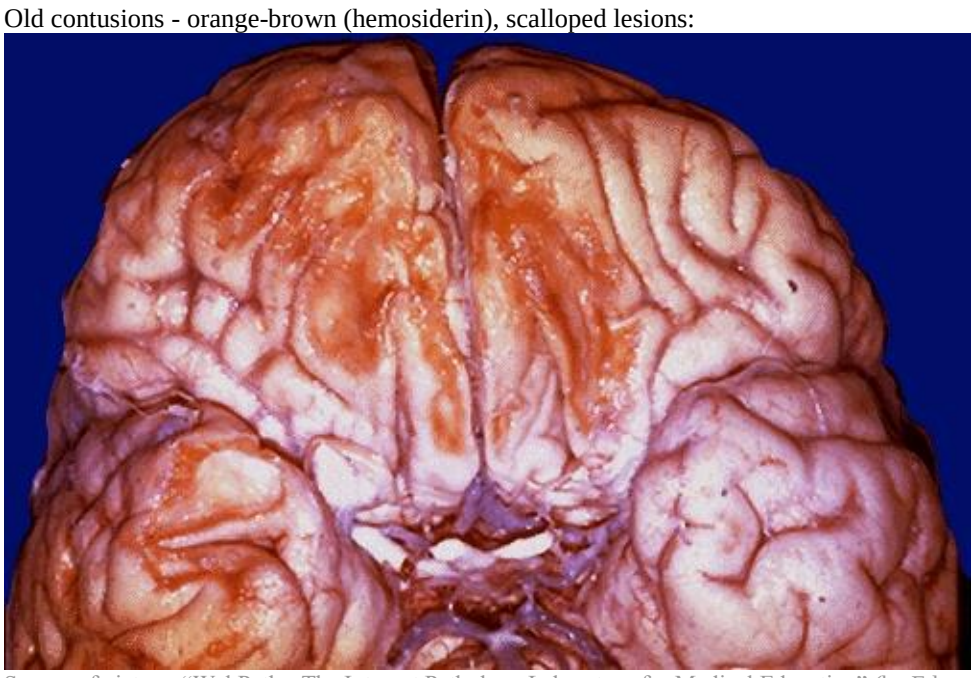
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Coronal section through frontal lobes - extensive contrecoup contusions involving inferior gyri:



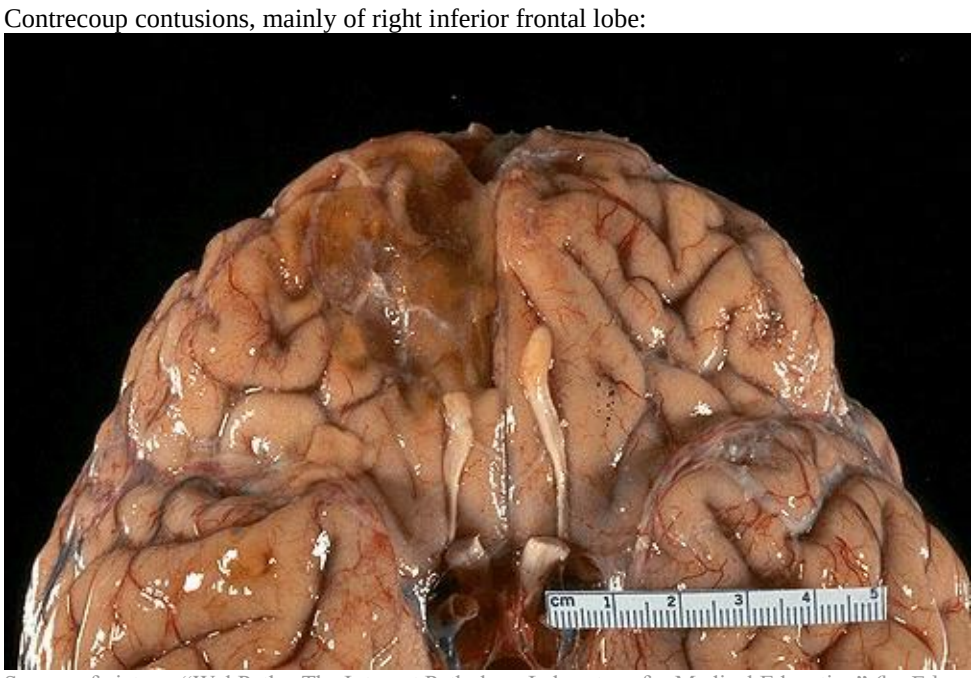
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Old contusions - orange-brown (hemosiderin), scalloped lesions:



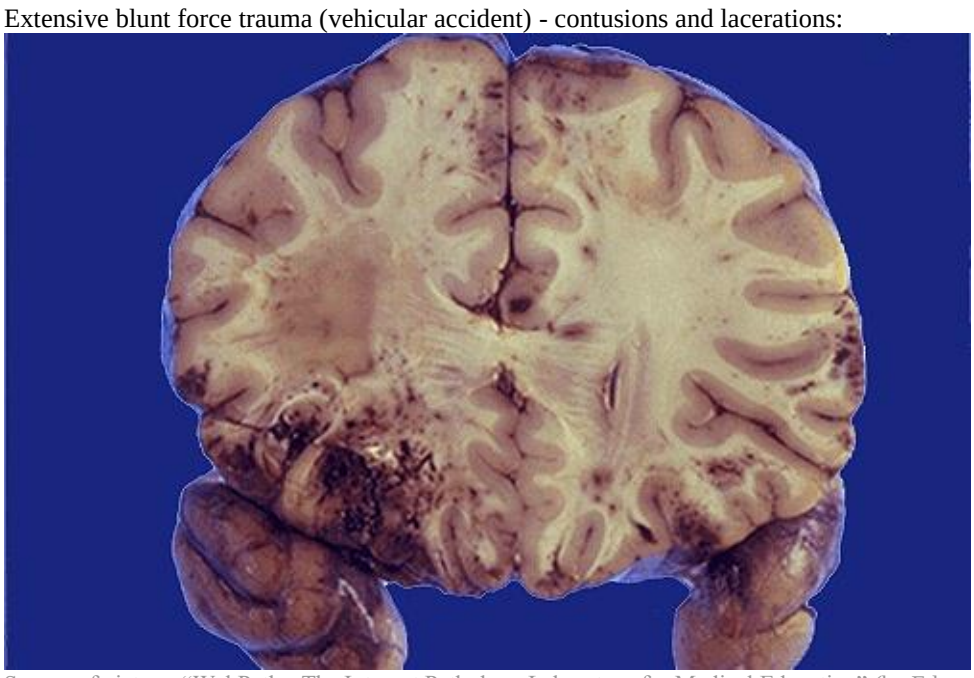
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contrecoup contusions, mainly of right inferior frontal lobe:



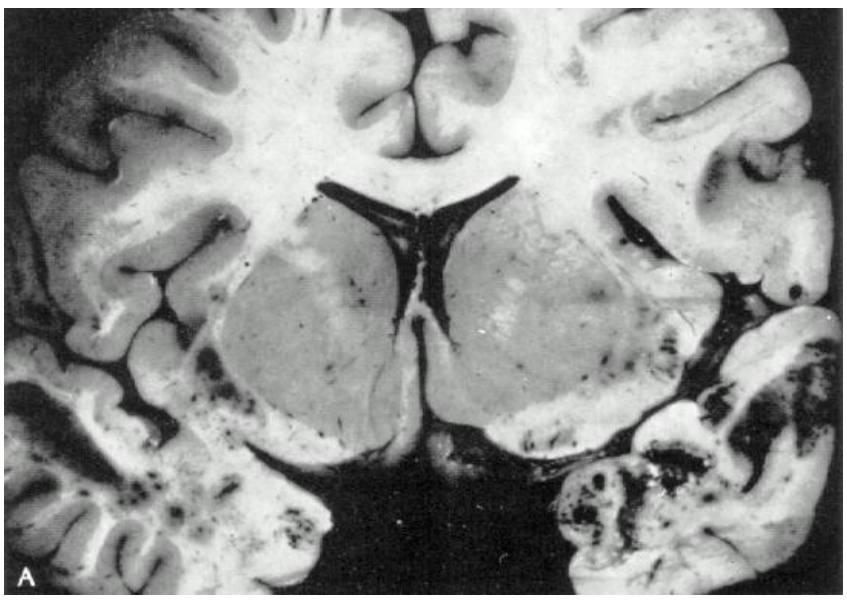
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

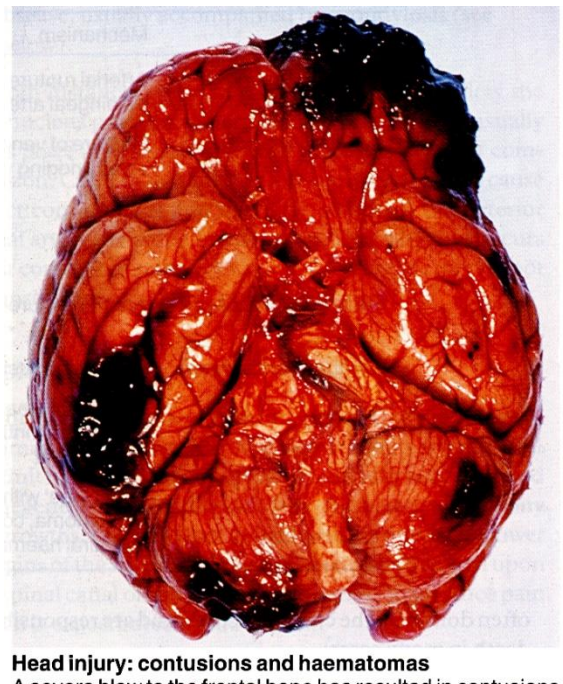
Extensive blunt force trauma (vehicular accident) - contusions and lacerations:



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contusion of temporal poles with fresh hemorrhages:





Head injury: contusions and haematomas
A severe blow to the frontal bone has resulted in contusions and haematomas in the frontal lobes. 'Contre-coup' contusions are present in the parietal lobes, and in the cerebellum.

Source of picture: James C.E. Underwood "General and Systematic Pathology" (1992); Churchill Livingstone; ISBN-13: 978-0443037122 >>

INTRACEREBRAL HEMORRHAGE (TRAUMATIC ICH, tICH)

See below >>

MISSILE (GUNSHOT) INJURY

Wounding capacity of firearm is related to kinetic energy of its missile:

$$\text{Kinetic energy} = \tfrac{1}{2} \times \text{mass} \times \text{velocity}^2$$

Types of injuries:

A. Tangential wounds - caused by impact at oblique angle relative to skull.
   - if missile has high velocity but low energy, it can travel around skull under scalp without passing through skull itself (but at site of impact depressed skull fracture can occur).
   - intracranial damage (primarily cortical contusions) occur at site of initial impact (pressure waves generated by impact).

B. Penetrating injury - projectile breaches cranium but does not exit;
   - low-velocity projectile loses energy as it penetrates skull; projectile may bounce off opposite inner table of skull and ricochet within brain.

C. Perforating injury (worst prognosis!) - projectile passes entirely through head, leaving both entrance and exit wounds.
   - entrance wound is smaller than exit wound.
   - brain damage is accompanied by extensive hemorrhage.

Bullets that penetrate skull do not travel in straight path:

a) *low-velocity* civilian soft bullets - tend to be deflected by intracranial structures (final track is erratic and occasionally bears no relation to exit or entrance site).
   - destabilizing motions include ***yaw*** (deviation of longitudinal axis of bullet from straight line), ***tumbling*** (forward rotation of bullet around its center of mass), ***rotation*** (oscillatory motion of bullet axis around its center of mass).

b) *high-velocity* military metal-jacket bullets - can project straight through tissues and easily fracture bones.

Bullets can damage brain parenchyma through 3 mechanisms:

A. **Direct laceration & crushing** (main mechanism of low-velocity bullets); destroyed tissue is either ejected out of entrance or exit wounds or compressed into walls of missile tract.

B. **Cavitation** (severe in high-velocity bullets) - produced by centrifugal effects of missile.

C. **Percussion shock waves** (last 5-10 msec; severe in high-velocity bullets) - cause stretch injury far from missile path (if shock wave reaches brain stem, cardiovascular and respiratory collapse can occur; shock waves can disrupt vessel walls → traumatic aneurysms).

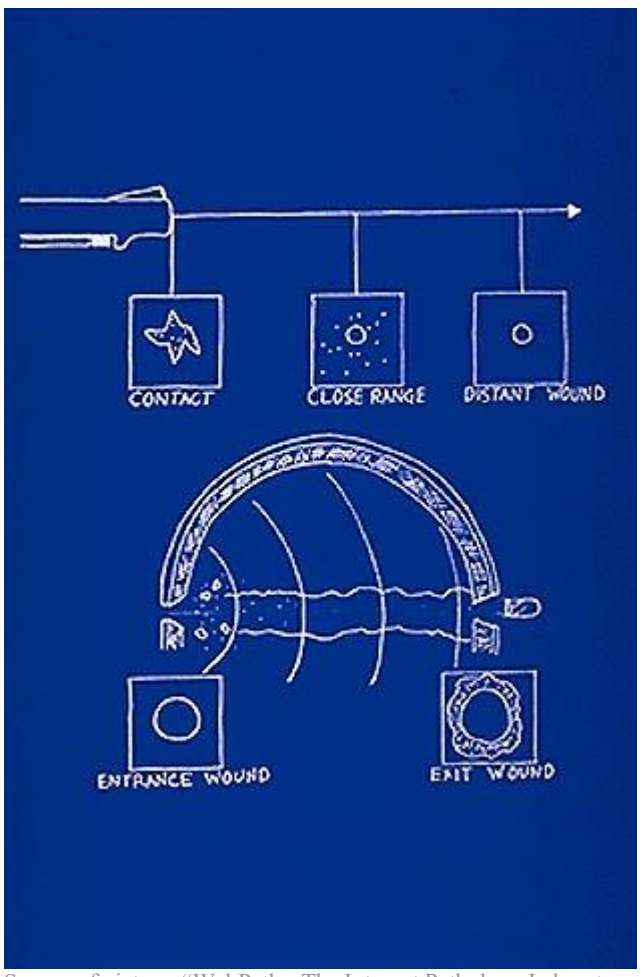
- all these create ***permanent cavity*** (3-4 times larger than missile diameter) and pulsating ***temporary cavity*** (as much as 30 times larger than missile diameter → diffuse damage to brain).

ICP
- rapid increase (up to 100 mmHg) for several minutes → drop (depending on volume of secondary hemorrhage and edema).

CLINICAL FEATURES
- loss of function of brain that is directly injured.
- penetration of *frontal or parietal lobes* by small missiles may not cause loss of consciousness! (good prognosis for survival)

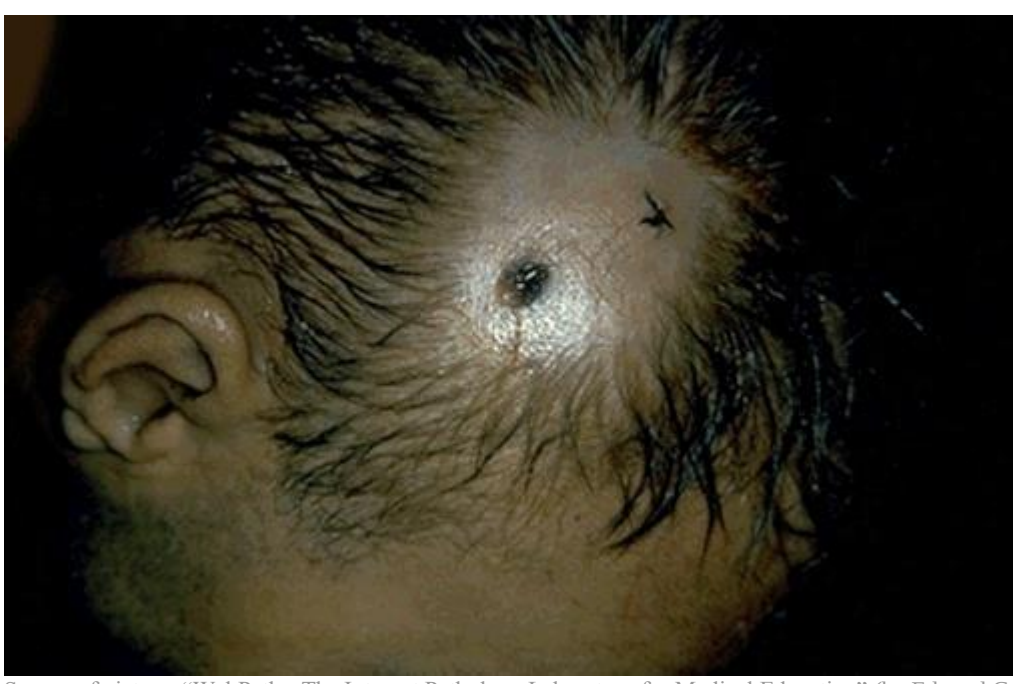
COMPLICATIONS: hemorrhage!!!, infection!!!, post-traumatic epilepsy.
- metal fragments may cause electrolysis, may migrate within intracranial or intraspinal compartments.
- penetrating wounds (incl. GSW) to the head are not associated with C-spine injuries.
- injury to vascular walls (contact or shearing forces) may lead to aneurysm formation (most commonly – pseudoaneurysm – very vulnerable to delayed ruptures).

UPPER - basic differences between skin appearances of **contact**, **close (intermediate)**, and **distant (indeterminate)** range gunshot wound.
LOWER - wounding characteristics in skull:



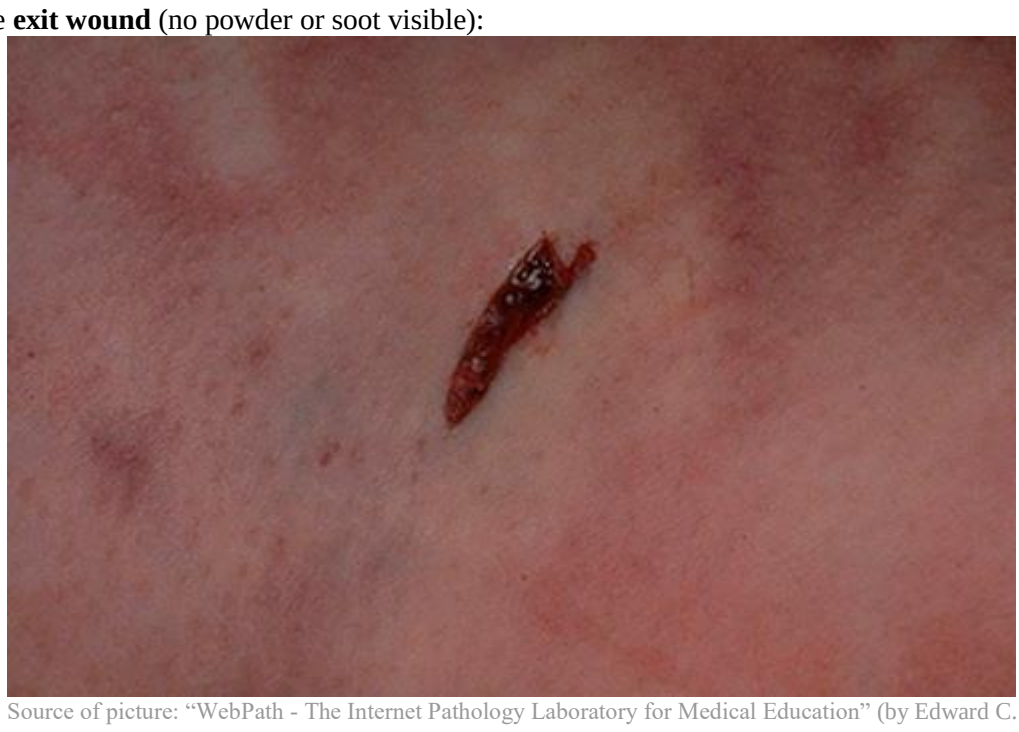
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Entrance wound (at left) and **exit wound** (at right): bullet struck at angle to produce ovoid entrance; exit wounds vary considerably in size and shape because bullet can be deformed in its transit through body (e.g. "hollow-point" bullets are designed to deform so that all their energy will be converted to tissue damage and not exit):



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

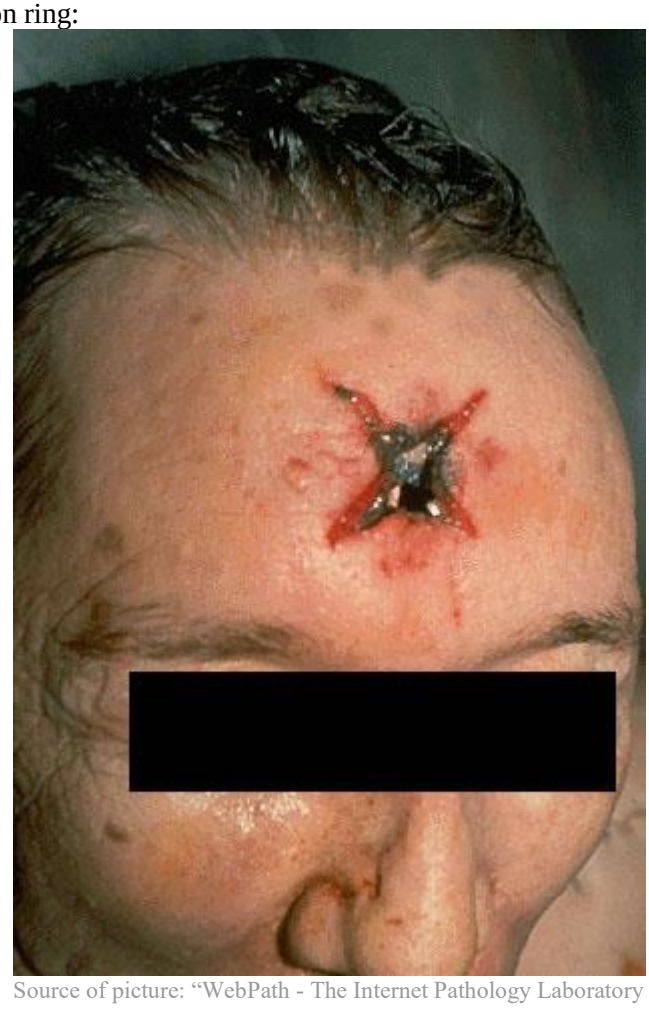
Slit-like **exit wound** (no powder or soot visible):



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contact range gunshots

Contact gunshot entrance wound; since barrel contacts skin, gases released by fired round go into subcutaneous tissue → star-shaped laceration; note also grey-black discoloration from soot, as well as faint abrasion ring:

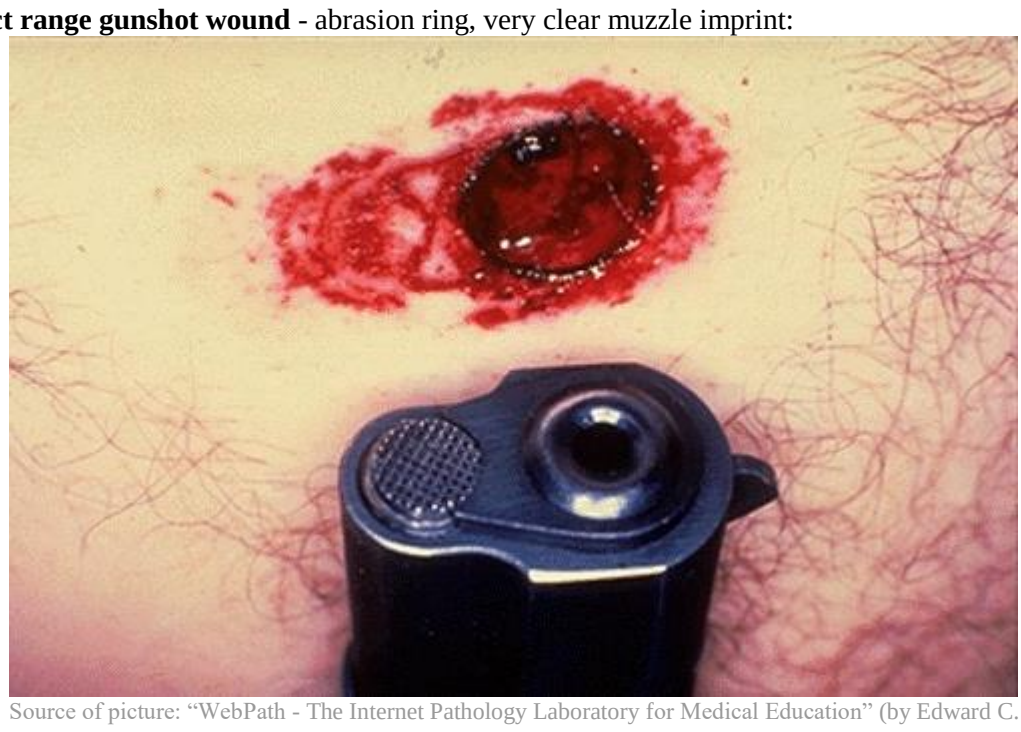


Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contact range gunshot wound - abrasion ring, formed when force of gases entering below skin blow skin surface back against gun muzzle:

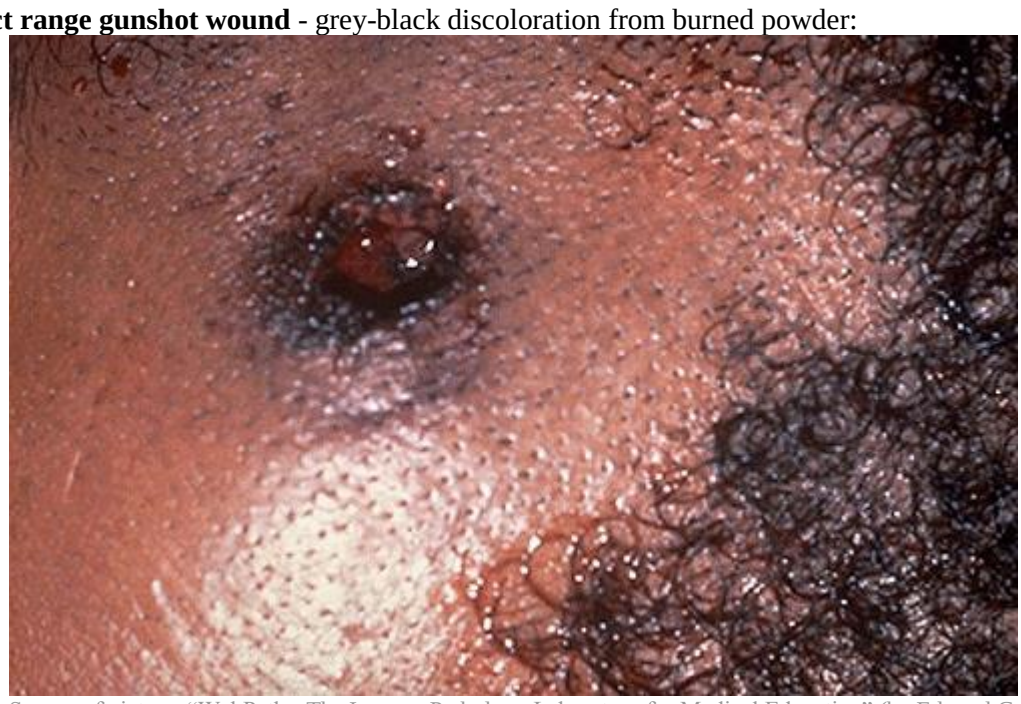
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contact range gunshot wound - abrasion ring, very clear muzzle imprint:



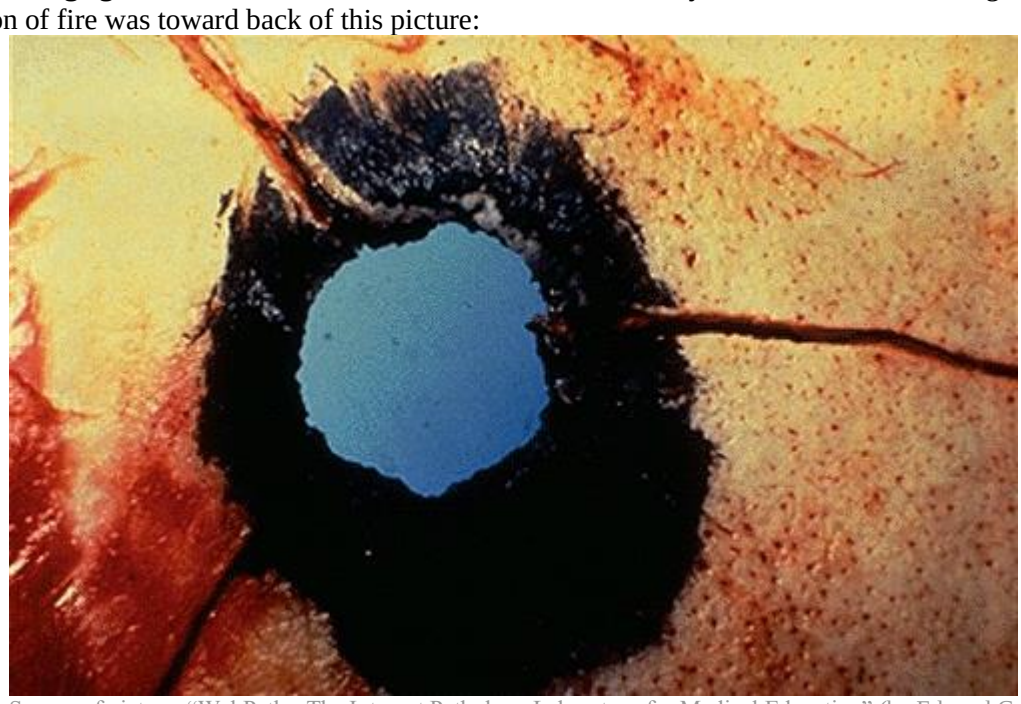
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contact range gunshot wound - grey-black discoloration from burned powder:



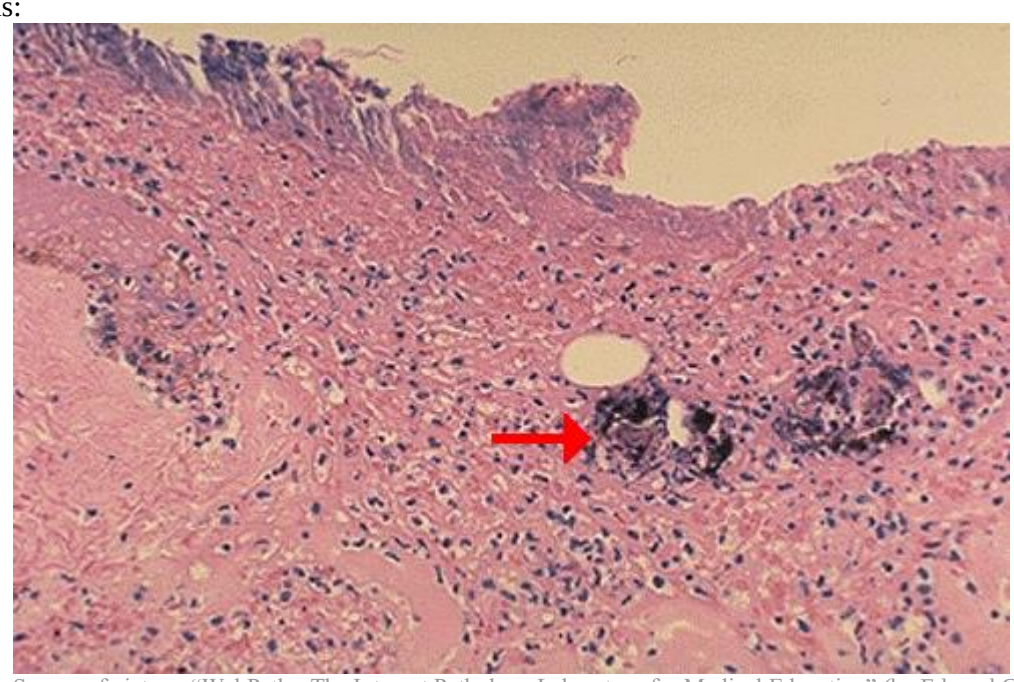
Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Contact range gunshot wound - skull surface demonstrates heavy soot, as well as radiating fracture lines; thus direction of fire was toward back of this picture:



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

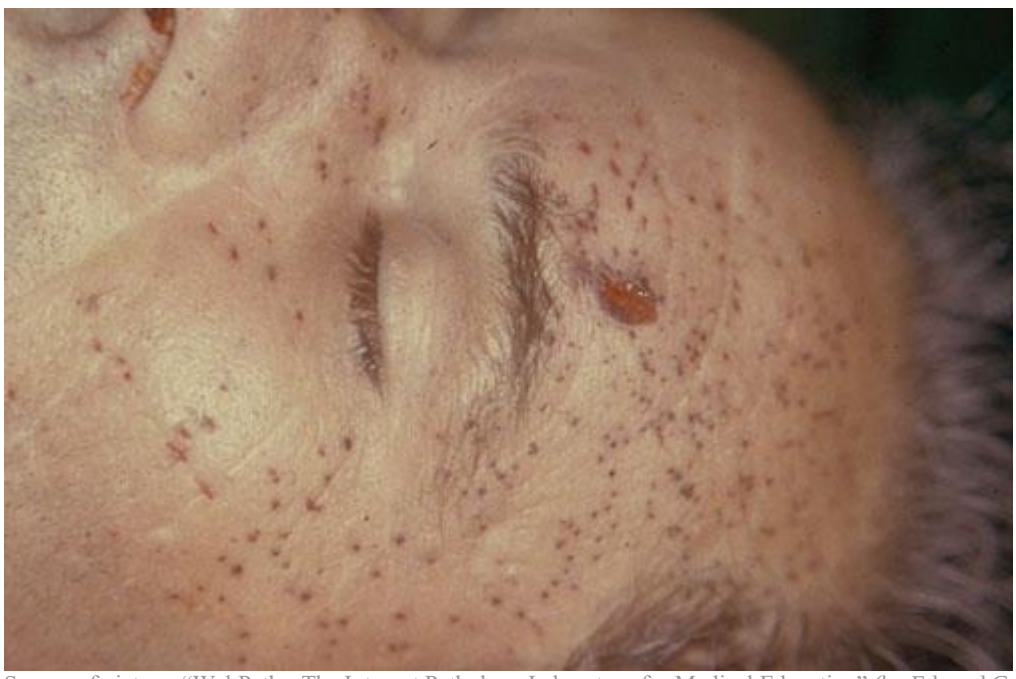
Contact range gunshot wound (entrance wound on skin) - black gunshot residue (*red arrow*) and coagulative necrosis:



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

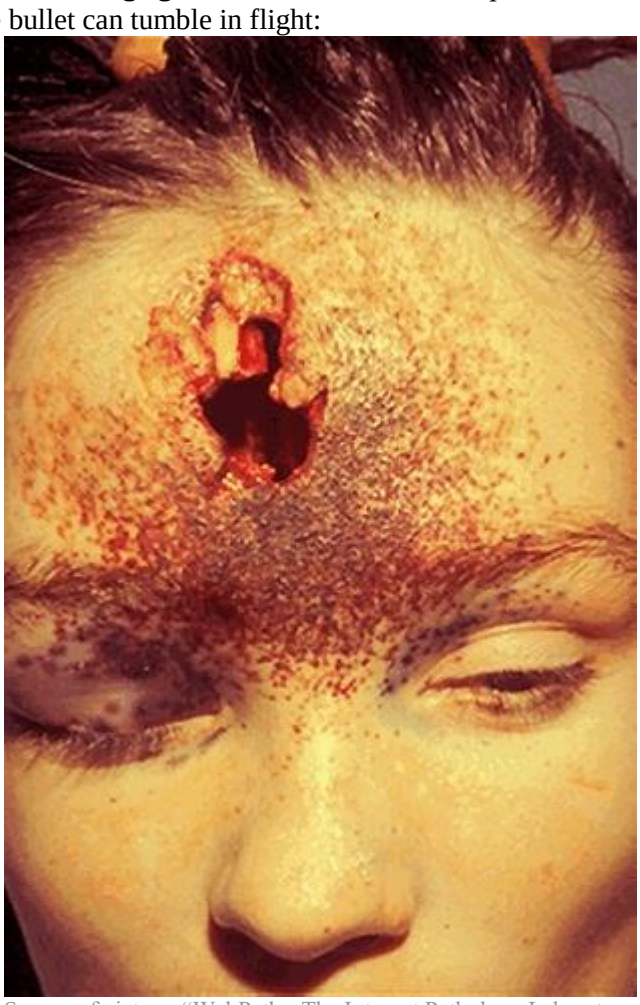
Intermediate range gunshots

Intermediate range gunshot entrance wound - powder "tattooing" around entrance site:



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Intermediate range gunshot entrance wound - powder "tattooing"; actual entrance site is somewhat irregular, because bullet can tumble in flight:



Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

SELF-INFLICTED INJURIES

- injury on dominant side.
- powder burns at entrance site.
- large stellate scalp lacerations (dissection of subgaleal layer by exploding gases).
- if entrance through mouth, injury to hard palate → upper airway compromise.
- careful aim and close range → mortality ≈ 95%.

Suicide is more lethal than homicide!

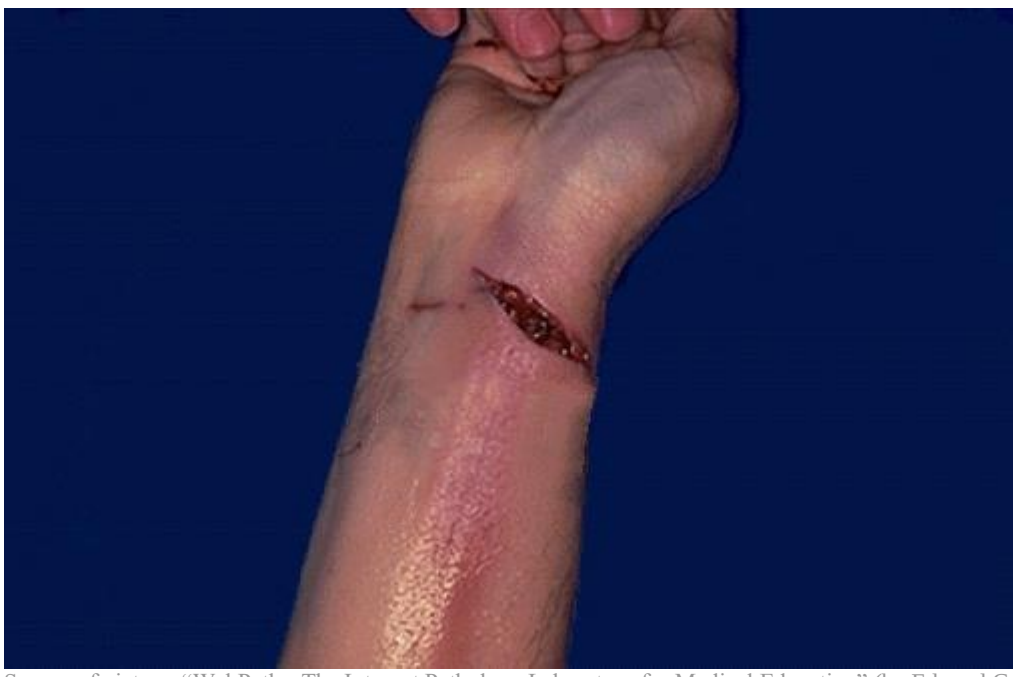
STAB INJURY (IMPALEMENT)

- skull penetration is most common in thin bones of skull:
  1) orbital surfaces
  2) squamous portion of temporal bone – highest mortality (short distance to brainstem and vascular structures)
  3) craniocervical junction
- 2/3 cases on left side!
- knife leaves narrow elongated "slot" fracture (in some cases, no radiological abnormality can be identified).
- **cerebral damage** is largely *restricted to wound tract* (filled with clots).
  N.B. *unlike missile injuries*, no concentric zone of coagulative necrosis caused by dissipated energy is present; *unlike motor vehicle accidents*, no diffuse shearing injury to brain occurs.
- major complications are ***vascular*** (main cause of mortality):
  1) intracerebral hematoma (50%)
  2) subdural hematoma (9%)
  3) contusion (31%)
  4) traumatic aneurysms (risk of rupture - H: early angiography & repair)
  5) carotid-cavernous fistula
  6) stroke (5%)

Mechanism for "defense wounds":

Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

Typical "defense wounds":



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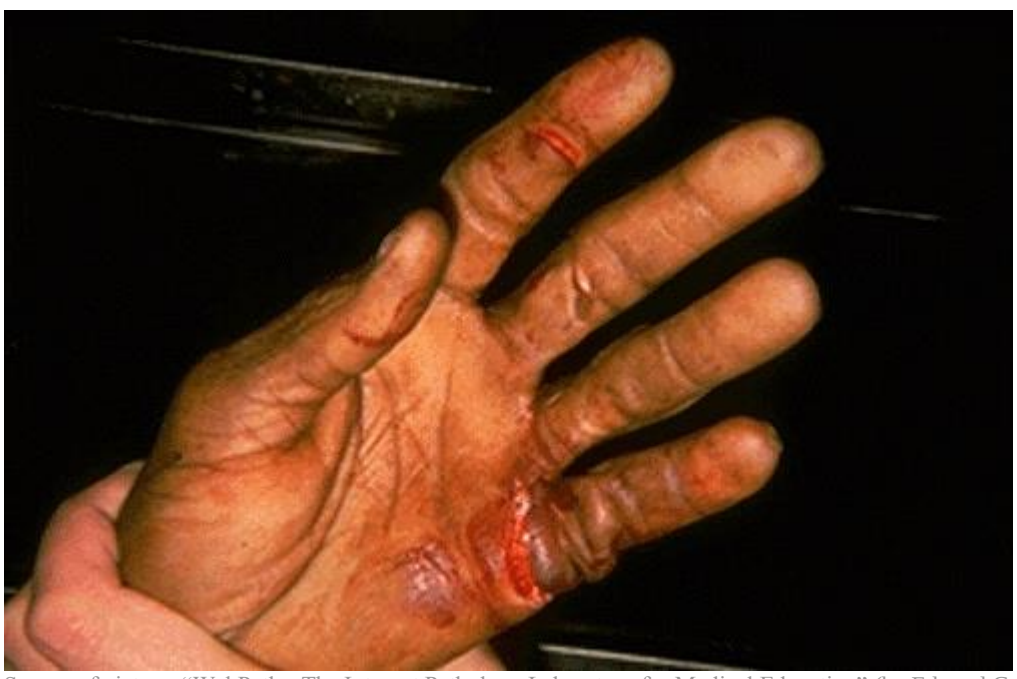


Source of picture: "WebPath - The Internet Pathology Laboratory for Medical Education" (by Edward C. Klatt, MD) >>

COMPRESSION INJURY

- requires *significant force* - skull architecture provides substantial resistance to deformation.
- multiple linear skull fractures (can be depressed if high-energy rapid compression force is applied to small area of skull).

DEGREES OF SEVERITY

- determined by **GCS score** after initial* resuscitation**.

*within 6-48 hours of TBI

**no hypoxia, hypotension, hypothermia, intoxication, sedation

- additional criteria: **duration of loss of consciousness**, **duration of antegrade amnesia**.
- rarely used criteria: number of days to achieve GCS score 15, number of days to achieve GCS motor score 6, length of hospital stay, CT results.

TBI degree	GCS score	CT	Loss of consciousness	Antegrade amnesia	Additional
MILD (s. concussion)	13-15	negative	< 30 min	minutes	length of hospital stay < 48 hours; 3% progress to more serious injuries!*
MODERATE	9-12	negative or positive (10-15% have focal intracranial lesion)	30 min ÷ 6 h	hours	length of hospital stay > 48 hours
SEVERE	≤ 8 (coma)	positive (40% have focal intracranial lesion)	> 6 h	days	

*initial grading of "mild" does not necessarily mean mild outcome

Mortality according to TBI severity → *see above >>*

- patients who reach ED alive:
  75-80% - mild injury (but many patients do not come to ED)
  10-15% - moderate injury
  10% - severe injury (but some patients die at scene of accident or during transport)

N.B. seemingly mild TBI can rapidly degrade* into severe TBI ("speaks and dies") – even mild TBI cases must be ***closely observed in acute period***.

*in 75% cases due to intracranial hematoma formation.

HIGH RISK MILD INJURY	LOW RISK MILD INJURY
A. External signs of trauma B. Skull fracture (or palpable depressed skull fracture) C. Initial GCS 13 D. Loss of consciousness (> 2-5 min) E. Posttraumatic confusion/amnesia (> 20 min) F. Focal neurologic findings G. Asymmetric pupils H. Posttraumatic seizure I. Repeated vomiting or vomiting for > 8 hours after injury J. Persistent severe or progressively worsening headache K. Second ED visit because of persistent symptoms L. Multiple trauma M. Serious painful distracting injuries N. Bleeding disorder/anticoagulation O. Presence of cerebrovascular malformation	A. Currently asymptomatic (incl. fully awake, GCS 15, no focal neurologic findings, normal pupils) B. No other injuries (incl. no evidence of skull fracture) C. No loss of consciousness D. Intact orientation/memory E. Not intoxicated F. Accurate history G. Trivial mechanism H. Injury > 24 hr ago* I. Reliable home observers

P. Intoxication (→ unreliable examination) Q. Mechanism: high-speed motor vehicle accident, fall of > 8 ft R. Unreliable / unknown history of injury S. Suspected child abuse T. Age > 60 or < 2 yrs	

*may miss chronic subdural hematoma

PREHOSPITAL MANAGEMENT

FACIAL INJURIES → see p. TrH25 >>
ANTERIOR NECK INJURIES → see p. TrS21 >>
SPINAL INJURIES → see p. TrS5 >>

TRIAGE principles:
- thoracic, vascular, and abdominal injuries take precedence over head wounds!
- head injuries are more urgent than spinal injuries.
- triage of head injuries: 1. Deteriorating patients (who are not moribund); 2. Stable patients with level of consciousness↓; 3. Stable awake patients

"**GOLDEN HOUR**" – *first hour is very important prognostically* – treat hypoxia & hypotension in the field and en route to the hospital

- 60% fatalities occur before patients can be admitted to hospital (40% at scene and 20% in ER).
- proper management in field can make difference between *normal existence* or *lifetime spent in total paralysis*.
- mortality for military injuries: **4.5**/100 in World War II → **2.5**/100 in Korea → < **1**/100 in Vietnam.
  1. Rapid evacuation is given much of credit! (in civilian injuries - helicopter transport)
  2. Trained teams of rescue workers (not physicians) provide intubation, shock treatment, and other emergency measures.
- importance of ABC - ultimate outcome of brain injury is as much (or more) dependent on early ABC as any other organ.
  even moderate hypotension can convert reversible brain injury to irreversible ischemic brain damage.

Spinal cord injury is present in as many as 10% patients!
Every patient with significant head injury has cervical spine injury until proved otherwise!!!
QUADRIPLEGIA IS FOREVER

1. OXYGENATION

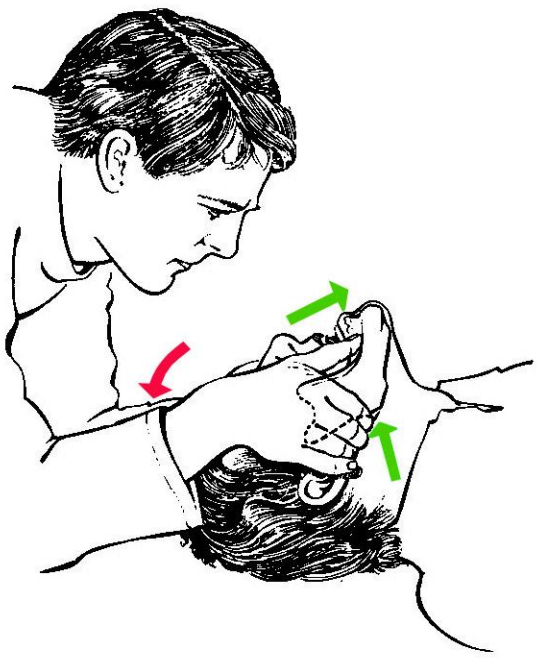
- should be secured immediately.

Only means we can help injured brain in the field – supply oxygen to brain!

- hypoxia – most common cause of prehospital death! see "Secondary Injury" *above*

AIRWAYS

1. ***Clear mouth*** (foreign bodies, vomitus, blood).
2. Do not extend neck! Use ***jaw thrust technique / chin lift maneuver***:



3. ***Airway maintenance***:
   a) **oropharyngeal tube**
   b) early **endotracheal intubation**:
      – everybody in **COMA** (GCS < 8)!
      – everybody with **PENETRATING INJURY** (if physician waits for coma before intubating patient, mortality approaches 100%).
      – extensive **FACIAL INJURIES**
      – **COMBATIVE** patient
      – *nasotracheal intubation* sometimes is preferable (no neck manipulations), but avoid in facial / skull base fractures.
      – for awake patient intubation use RSI (rapid sequence intubation).
        N.B. failure to use paralytic agents, pharyngeal anesthesia, and barbiturate induction → massive ICP elevation!
      – there is some suggestion of increased mortality with prehospital intubation in patients with moderate-to-severe TBI compared with patients intubated in ED (**bag-valve-mask ventilation** with good technique may be of more benefit to brain injured patients than prehospital intubation!).
   c) **cricothyrotomy, tracheostomy, percutaneous transtracheal ventilation**.
   d) **stabilize mandibular fractures** see p. TrH25 >>

BREATHING

a) **spontaneous but insufficient breathing** → 100% oxygen + assisted ventilation with demand valve.

b) **no spontaneous breathing** → ventilation (by positive-pressure ventilation with 100% oxygen).
   – portable ***pulse oximetry*** should verify Sa_{O2} > 96% (provide supplemental oxygen to achieve this level).
   – ***ventilatory rate*** 10-12 breaths per minute (Pa_{CO2} 35-40 mmHg); in *larger patients*, higher ventilatory rates may be required to provide adequate minute ventilation; *neurologic deterioration* + high risk of intracranial mass lesion → higher ventilatory rates (20-25/min, Pa_{CO2} < 35 mmHg) en route to CT / OR.

2. BLOOD CIRCULATION

Injured brain is extremely susceptible to lowered perfusion states!

FLUID RESUSCITATION (*brain injury per se* rarely causes hypotension!!!)

- several large-bore intravenous catheters.
- isotonic (or hypertonic*) saline to aggressively restore SBP to > 100-110 mmHg. see below >>
  *there are studies showing that 250 mL of hypertonic (7.5%) saline bolus in the field improves survival
- avoid volume overload / hypertension! (but fluids should not be withheld in hypotensive patient for fear of increasing cerebral edema and ICP)
- ***autohemotransfusion***: leg elevation + **M**ilitary **A**nti-**S**hock **T**rousers.

MANAGE BLEEDING, OPEN WOUNDS

- **scalp lacerations** may *bleed large volume* into bulky dressing; better prehospital dressing is less bulky, but with firm constant pressure!

  temporary scalp bleeding control → see MANAGEMENT
- **skull fractures** – do not require special care in the field
  - do not impede liquorrhea through fracture lines
  - if brain / nerves exposed – cover with dressing with sterile saline (do not push brain back into cranium) – it is largely devitalized tissue and will be removed during scalp repair.
- do not impede **liquorrhea / bleeding** from nose / ear canal – will lead to intracranial hematoma and infection; H: place absorbent dressing without tamponade
  - epistaxis is safe to tamponade only if no signs of anterior skull base fracture
- life-threatening **dural sinus bleeding** can be slowed by placing patient in *reverse Trendelenburg position* (risk of air embolism!)
- **penetrating objects** should be *left in place* (stabilized with bulky fluffy bandage) - to be removed in operating room.

3. CERVICAL SPINE STABILIZATION

→ see p. TrS5 >>

4. BRIEF NEUROLOGIC STATUS

1. **Level of consciousness** (ideally GCS)
2. **Pupil size and light reactivity** (asymmetry is most important)
3. **Extremity motorics** (asymmetry is most important) - [1]spontaneous movements, [2]following commands, [3]reaction to painful stimuli.

5. TRANSPORTATION

- **rapidly** to trauma center with **CT** and **definitive neurosurgical intervention***.

  *level 1 trauma centers certified by American College of Surgeons (or state trauma certification systems) have trauma surgeon in house 24/7 and neurosurgeon available within 10 minutes of notification.

- patient is ***moved en bloc*** - to avoid displacing spine (or other bones), so that spinal cord (and blood vessels) are not injured.
- transport on left side, HOB elevated 15-30 degrees.
- for transport times longer than 15-20 minutes, ***serial neurologic assessments*** should be documented every 10-15 minutes.
  - most important parameter to monitor – ***level of consciousness*** (along with pulse, BP, breathing)
  - all patients should be placed on ***cardiac monitor*** as they are transported (brainstem compression can cause cardiac dysrhythmias).
- many severely head-injured patients are initially combative / agitated - transporting patient who is fighting against physical restraints may exacerbate physical injury, cause rise in ICP, and interfere with appropriate stabilization and management; H: prehospital ***sedation or paralysis*** (inform ED and trauma teams about it!).

  Morphine and **other depressants** are contraindicated during initial management! (short acting opioid [fentanyl], sedative [propofol], paralytic are fine)
- early ***contact by telephone or radio with trauma center*** - medications given to patient coordinated through neurosurgeons and other health care providers at trauma center.

DIAGNOSTIC EVALUATION

DIAGNOSIS IN LATIN

Morbus traumaticus cerebri, periodus acutus/subacutus, forma levis/mediocris/gravis.

periodus acutus – within 3 months.

Diagnosis is constructed by naming injuries from outside to inside:

1) scalp (e.g. *Vulnus contusum reg. parietalis; Haematoma subaponeuroticum reg. frontalis*)
2) fractures (e.g. *F-ra aperta impressa cominutiva ossis frontalis; F-ra basis cranii fossae mediae; F-ra ossis parietalis*)
3) brain, including complications (e.g. *Syndr. commotionale leve/mediocre/grave; Compressio cerebri. Haematoma epidurale/subdurale; Contusiones multiplices hemispherii sin.; Contusio cerebri lobi occipitalis; Haemorrhagia subarachnoidalis*).
   - state syndrome first, then its cause (*compressio → haematoma*).
   - if there is contusion or hematoma, do not mention concussion.
   - *Ebrietas vulgaris* is mentioned at concurrent conditions.

HISTORY

- patient may be comatose or confused – witnesses & paramedics are of crucial importance!

1. Mechanisms, forces & circumstances of injury.
2. Loss of consciousness – duration, lucid interval, convulsions, apnea, cardiac arrest.
3. After consciousness was regained – amnesia (last thing that can be recalled), vertigo, nausea, vision blurring, headache, other pains.
4. Prior head injuries.
5. Remote or active medicament* / drug / alcohol use - risk of intracranial bleeding, cloud mental status. *esp. present anticoagulant / antiplatelet therapy
6. Premorbid history of headaches, seizures, syncope, TIA & stroke, gait disturbance, psychiatric disease – all these can be the cause of TBI and should be treated!

PHYSICAL EXAMINATION

Examination of patient with decreased level of consciousness → see p. S30 >>

Cervical spine precautions! (10% patients with severe TBI have spinal trauma)
see p. TrS5 >>

*perform during *PRIMARY SURVEY* (identifying life-threatening conditions);

vs. *SECONDARY SURVEY* - detailed examination for identifying all traumatic injuries

1. **ABC***
   Evaluate for hypoxia, hypotension, anemia, and multiple injuries!

2. Monitor **level of consciousness*** – use Glasgow Coma Scale. see p. S30 >>
   - if conscious, assess attention, orientation*
   - GCS score is assessed in field (or by first responder), then reassessed after specific treatment interventions.

   N.B. decrease of even 1-2 points in GCS score indicates significant change in neurologic status → prompt reevaluation!

3. **Signs of trauma**:
   1) **scalp injuries** *see above >>*
   2) **skull fractures** see p. TrH5 >>
   3) **facial trauma** see p. TrH25 >>
   4) **cervical spine** (swelling, pain on palpation, deformity, step-off, malalignment → prompt immobilization) see p. TrS5 >>
   5) ***injuries outside cranium**** should also be searched for at outset, because they are likely to be forgotten if not initially noted.
      *most common in automobile accidents (e.g. **WADDELL triad** - *child pedestrian hit by motor vehicle* - [1]chest-abdomen trauma, [2]leg injury, [3]countercoup head injury).

Neurologic Examination
   a) *awake patient* → detailed neurologic examination.
   b) *uncooperative / comatose patient*:
      1) **pupils*** - size & light response. see below >>
      2) **motor*** - response to painful stimuli, pathologic and deep tendon reflexes.
      3) **brainstem** (for deeply comatose patients) – corneal response, cough, gag, respiratory pattern (overbreathing of ventilator?); optional - oculocephalic (± oculovestibular) tests.

      *asymmetry is most important

4. **Cranial nerves & brainstem**
   - **pupils**!!!* (size and response to light) see p. D1eye >> , p. S30 >>
     N.B. pupils are the only indicator of neurological function in chemically paralyzed patient!
     Don't miss direct orbital trauma!

     Asymmetry - measurement difference of ≥ 1mm.
     Dilated - pupillary size of > 4 mm.
     Fixed – pupillary response < 1 mm to bright light.

     pupillary asymmetry is due to intracranial injury unless proved otherwise.
     unilateral dilated pupil in unconscious patient – CN3 compression (uncal herniation).
     pinpoint pupils - pontine lesions.
     light nonreactive pupils in mid position - midbrain tectum lesions.

   - **eye movements**
     N.B. if voluntary eye movements cannot be assessed → *OCULOCEPHALIC* and *OCULOVESTIBULAR* testing see p. S30 >>
   - **corneal reflex**
   - **facial asymmetry** (e.g. when patient grimaces with noxious stimuli)
   - **gag reflex** - dysphagia (risk of aspiration)
   - **respiratory pattern** see p. 2115 (4-5) >> , p. S30 >>

5. Monitor for **signs of ICP↑**: see p. S50 >>
   1) increasing headache, vomiting
   2) declining mental status (decreasing GCS)
   3) tense fontanelle
   4) Cushing reflex (tachypnea > 20/min*; systolic BP increase > 15 mmHg or widening of pulse pressure, reflex bradycardia < 60/min or change > 10/min)

      *also may indicate pulmonary failure or infection

6. **Motor examination** see p. S30 >>
   N.B. if patient is not alert enough to cooperate with strength testing, motor examination is limited to assessment of ***motor asymmetry, pathologic & deep tendon reflexes***!
   N.B. (occult) extremity trauma can make examination painful or impossible!

7. **Sensory examination** is not reliable in patients who are intoxicated or comatose!

8. **Bedside cognitive testing** (e.g. Mini-Mental State Examination) - to distinguish damaged and spared realms of cognitive functioning; practically never done in acute phase of TBI. see p. D2 >> , p. D3 >>
   - *ability to lay down new memories* (determines duration of antegrade amnesia via serial mental status assessments).

IMAGING - MODALITIES

Presence / absence of cervical spine instability must be determined first! (*lateral cervical spine** and *chest X-rays* are usually obtained in resuscitation room).

*modern approach - *cervical spine CT* (at same time as admission head CT) in all but mildest TBI patients. see p. TrS5 >>

CT	MRI	ANGIOGRAPHY	CRANIOGRAM
ADVANTAGES			
1. Fast, no motion artifacts 2. Patient accessible for monitoring. 3. Defines acute **hemorrhages, mass effects, bony injuries**, hydrocephalus, edema.	Defines contusions and pericontusional edema, posttraumatic ischemic infarction, **brainstem injuries**	Defines **vascular injuries**, injuries to **venous sinuses**	1. Readily available but obsolete 2. May help screen some patients for further imaging studies.
DISADVANTAGES			
1. Artifacts arise from patient movement, foreign bodies. 2. Streak artifacts may obscure brain stem or posterior fossa.	1. Slow (long scanning time), motion artifacts 2. Magnetic field precludes use of monitors and life-support equipment. 3. Not useful for bony injuries. 4. Unsuitable for people with metallic objects.	Requires formal IR procedure so it is done only if CTA is positive.	Does not indicate presence or absence of intracranial injury so it is obsolete study.

American College of Radiology (ACR) Appropriateness Criteria Scales

(1 = least appropriate; 9 = most appropriate; NA = not applicable):

Clinical Situation	Skull X-ray	Cervical X-ray	CT	MRI	MRA	Angio-graphy

mild closed TBI (GCS ≥ 13, no neurologic deficit)	2	2	7	NA	NA	NA
mild closed TBI (focal neurologic deficit)	2	No consensus	9	6	4	NA
moderate ÷ severe closed TBI, stable	4	8	9	6	NA	NA
mild ÷ moderate closed TBI, child < 2 yrs	4	6	9	6	NA	NA
closed TBI, rule out carotid or vertebral artery dissection	NA	5	4	8*	8	6
penetrating TBI, stable, neurologically intact	8	8	8	6	3	6
penetrating TBI, likelihood of vessel injury	8	8	8	6	8	8
depressed skull fracture	8	6	9	6	NA	NA
calvarial fracture	8	6	9	5	NA	NA
penetrating TBI, skull-base fracture	6	6	9	6	6	4
subacute TBI, late neurologic deterioration	NA	NA	8	8	NA	NA
subacute / chronic TBI, stable, normal CT, cognitive and/or neurologic deficit	NA	NA	NA	8	4	NA
chronic TBI, neurologic dysfunction	NA	NA	6	8	4	NA

*5 for gadolinium-enhanced MRI

CT WITHOUT CONTRAST

- diagnostic imaging of choice! – detects skull fractures, contusions, blood, edema.
Contrast is required if intracranial abscesses suspected

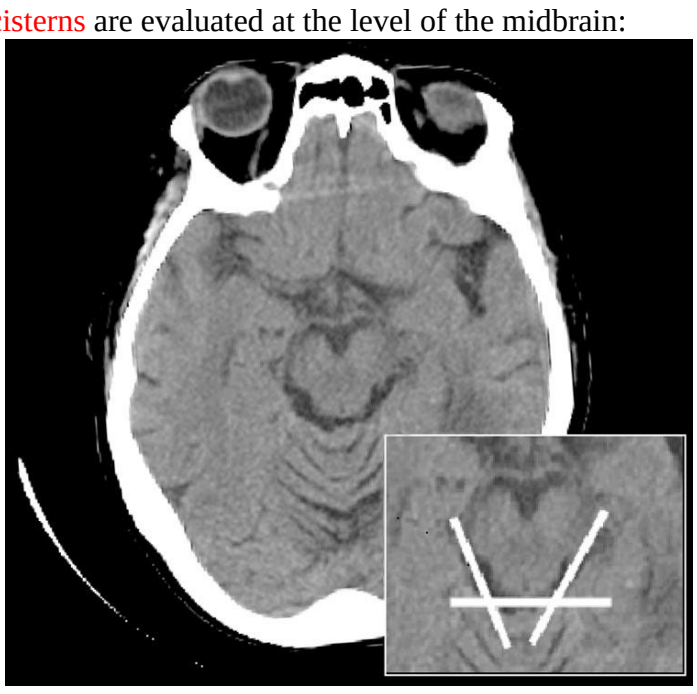
CT is indicated for all patients except LOW-RISK mild TBI;
– for HIGH-RISK mild TBI (without skull fracture), CT may be deferred if patient is hospitalized for observation (any deterioration in neurologic status or any focal signs → CT).

If CT is indicated, skull radiographs are not necessary (CT bony window shows even basilar fractures)

- more severe TBI, greater urgency for CT (exception is when other life-threatening injuries take precedence); e.g. severe TBI (esp. with lateralizing signs) → CT as soon as cardiorespiratory stability is ensured.
N.B. urgency for CT is function of likelihood of surgically correctable ***focal lesion*** (vs. ***diffuse injuries*** - do not benefit from acute neurosurgical intervention - precise anatomic information is not necessary for optimal management).
- *deteriorating patients* should be accompanied by **physician**;
stable but seriously injured patients should be accompanied by experienced ER or trauma **nurse**.
- if abdominal ultrasound or diagnostic peritoneal lavage has not been performed, most comatose victims also have **abdominal CT** and, if thoracic injury is suspected, **chest CT**.
- *patients going to operating room for treatment of other injuries*, must have head CT (because they will not be available for monitoring); if patient is taken immediately to surgery without head CT* → historically: intraoperative **air ventriculogram** (detects large intracranial mass lesions); modern times – patient never goes to OR without head CT (if it is concerning – place ICP monitor so anesthesiologist can follow and treat ICP).
*try to obtain at least single-cut CT through level of lateral ventricles

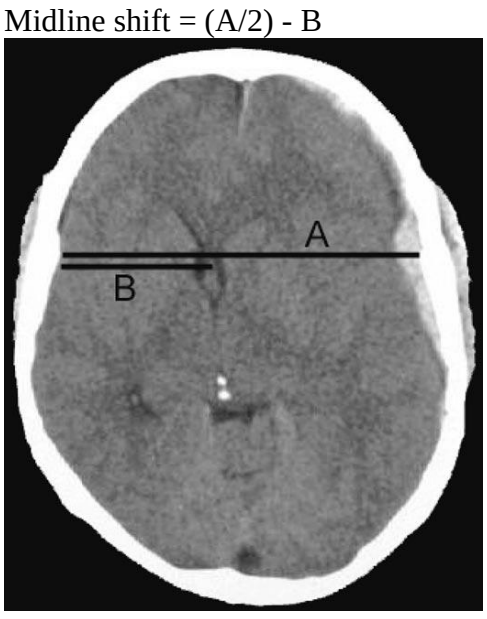
5 most important things to look in CT: mass lesions (hematoma), state of basal cisterns (incl. blood inside), midline shift, ventricular size, depressed fractures

Basal cisterns are evaluated at the level of the midbrain:



Basal cisterns can be: **open** (all limbs open), **partially closed, s. "crowded"** (one or two limbs obliterated), or **completely closed s. "effaced"** (all limbs obliterated).

Midline shift is calculated at the level of the foramen of Monro to the septum pellucidum:
Midline shift = (A/2) - B



Technique
- from *base of occiput* to *top of vertex* in at max. 5-mm increments (modern CTs are done with 1 mm slices).
- three data sets are obtained:
1) ***bone windows*** - bony anatomy of skull.
2) ***tissue windows*** - detailed survey of brain.
3) ***subdural windows*** (optional) - visualization of hemorrhages adjacent to brain (subdural hematomas).

- seriously injured intubated patients should receive neuromuscular blockage during CT study; in severe cases, ***single-cut CT*** through ***level of lateral ventricles*** has high yield for revealing hematomas.

REPEAT CT

Indications for SELECTIVE REPEAT CT:

1. GCS↓ by > 1 point
2. New / aggravated focal signs
3. Persistent severe headache, frequent vomiting
4. Seizure

Indications for SCHEDULED REPEAT CT:

1. Nonoperated intracranial hemorrhages, contusions*
2. Coagulopathies

- CT is repeated within 4-24 hours of initial scan (some contusions and intracranial hematomas are brought to operating room after repeated CT)

*studies do not support SCHEDULED REPEAT CT in patients with intracranial hemorrhage and GCS13-15 and no change in status because imagings do not change management** and outcomes

Abdel Fattah K, Eastman A., Aldy K., et al "A prospective evaluation of the use of routine repeat cranial CT scans in patients with intracranial hemorrhage and GCS score of 13 to 15" Journal of Trauma and Acute Care Surgery

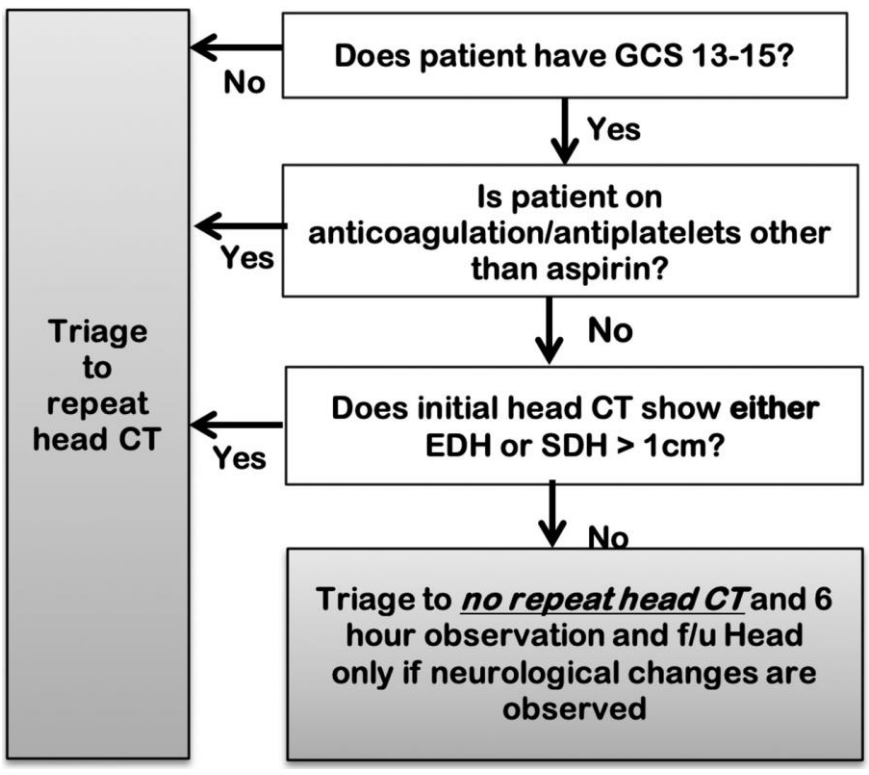
**but may facilitate discharge patient home from ED

Harvard protocol

Martina Stippler et al. Pathway-Based Reduction of Repeat Head Computed Tomography for Patients With Complicated Mild Traumatic Brain Injury: Implementation and Outcomes. Neurosurgery 88:773–778, 2021

Complicated mild TBI (head CT positive for an intracranial traumatic finding + nonfocal neurological examination + GCS 13-15) – if initial presentation is not operative, then ***does not need repeat CT*** (unless patient is on "blood thinners"* or there is EDH or SDH > 1 cm) – can be discharged after clinically stable 6-hr observation in ED:

*except Aspirin



- probability of needing operative intervention is extremely low (< 1%) if the initial CT scan was none operative.
- stable routine follow-up head CT does not protect the patient's condition from deteriorating later!
- traumatic intracranial hemorrhages are associated with 17-20% progression rate but this ***radiographic progression rate does not result in need for neurosurgical intervention***.
- 1 year of implementation - protocol allowed to avoid 71% unnecessary CT scans
  - there were no missed injuries or delays in neurosurgical intervention.
  - none of the patients in no-repeat-CT group underwent delayed surgery.

CT SCALES OF SEVERITY

Marshall Classification of Diffuse Brain Injury

use in prognostication – see below >>

Category	Definition
Diffuse Injury I (no visible pathology)	No visible intracranial pathology seen on CT scan.
Diffuse Injury II	Cisterns are present with midline shift 0-5 mm and/or lesions densities present, no high or mixed density lesion > 25 cc, may include bone fragments and foreign bodies.
Diffuse Injury III (swelling)	Cisterns compressed or absent with midline shift 0-5 mm, no high or mixed density lesion > 25 cc.
Diffuse Injury IV (shift)	Midline shift > 5 mm, no high or mixed density lesion > 25 cc.
Evacuated Mass Lesion	Any lesion surgically evacuated.
Non-Evacuated Mass Lesion	High or mixed density lesion > 25 cc, not surgically evacuated.

Marshall Scoring of TBI

	MLS	Cisterns	High or mixed-density lesion	Notes
I	None	Present	None	No visible pathology on CT scan
II	0-5mm	Present	None	
III	0-5mm	Compressed or absent	None	Swelling
IV	>5mm		None	
V	Any	Any	Any	Any lesion surgically evacuated
VI			>25cm3	Not surgically evacuated

*MLS-midline shift (Heustein Sy)

Grade 1 = **normal** CT scan (9.6% mortality)
Grade 2 = cisterns present, **shift < 5 mm** (13.5% mortality)
Grade 3 = **cisterns** compressed / absent, shift < 5 mm (34% mortality)
Grade 4 = **shift > 5 mm** (56.2% mortality)

Marshall LF, Bowers-Marshall S, Klauber MR et al. A new classification of head injury based on computerized tomography. J Neurosurg 75(Suppl):S14-20, 1991

CT Classification and Outcome on Discharge (Marshall et al. 1991)

	Number of Patients	Unfavorable Outcome (D, VS, SD)	Favorable Outcome (MD + GR)
Diffuse Injury I	52	38%	62%
Diffuse Injury II	177	65	35
Diffuse Injury III	153	84	16
Diffuse Injury IV	32	94	6
Evacuated Mass Lesion	276	77	23
Non-Evacuated Mass Lesion	36	89	11

Rotterdam CT score

- refined Marshall CT classification.
designed to categorize TBI type and severity in adults for prognostic purposes.

Basal cisterns
0: normal
1: compressed
2: absent
Midline shift
0: no shift or ≤ 5mm
1: shift > 5mm
Epidural mass lesion
0: present
1: absent
Intraventricular blood or traumatic SAH
0: absent
1: present
Final score = sum of the scoring items + 1.

Mortality at 6 months post-injury
Score 1: 0%
Score 2: 7%
Score 3: 16%
Score 4: 26%
Score 5: 53%
Score 6: 61%

Helsinki CT score

Mass lesion type(s)
Intracranial subdural hematoma – 2 points
Intracerebral hemorrhage – 2 points
Intracranial epidural hematoma – minus 3 points
Mass lesion size
Hematoma volume > 25 mL – 2 points
Intraventricular hemorrhage
Intraventricular hemorrhage – 3 points
Suprasellar cisterns
Normal – 0 points
Compressed – 1 point
Obliterated – 5 points
Sum score (from -3 to 14) – check prognosis at online calculator >>

Stockholm CT score

tSAH score	SAH in **convexities** (1 if 1–5 mm, 2 if >5 mm) + SAH in **basal cisterns** (1 if 1–5 mm, 2 if >5 mm) + **IVH** (2 if present) (range: 0–6)
Tally	Midline shift (mm)/10 + tSAH score/2 − 1 if epidural hemorrhage + 1 if diffuse axonal injury (basal ganglia, splenium, or brain stem) + 1 if dual-sided subdural hematoma + 1

PLAIN SKULL RADIOGRAPHS

– only rare indications:

N.B. many patients with skull fracture have no neurological sequelae and many with severe intracranial abnormalities have no associated skull fractures!

1) **screening for CT** in **mild TBI** with **signs of skull fracture** on physical examination when **CT is not immediately available** (if skull fracture is confirmed → CT & observation for delayed complications).
N.B. yield of craniography in LOW-RISK mild TBI is very low (even if detected, linear fractures have limited clinical significance in adults – do not change treatment course).
   - ***midline shift of calcified pineal gland*** or ***M-echo signal dislocation*** > 3 mm (in **echoencephaloscopy**) is additional indication to seek for CT.
2) **depressed skull fracture** – use tangential shots to measure the depth of impression.
3) **penetrating injury** – to detect intracranial foreign bodies (small intracranial foreign bodies may be missed unless skull X-ray is taken after minor penetrating injuries).
4) additional indications for **pediatric population**:
   a) **screening for CT** in children < 5 yrs (difficult clinical examination) with minor TBI
   b) suspected **child abuse** (skull radiograph as part of skeletal survey).
   c) suspected **linear skull fracture** (risk of leptomeningeal cyst) - deep scalp lacerations, large scalp hematoma.

NONENHANCED MRI

- most useful in subacute/chronic setting; prognostic use during subsequent care (assists in directing rehabilitation and goals of care);

- *MRI gives superior* (than CT) *depiction of nonsurgical lesions*; some authors now advocate MRI use in neurologically stable patients with moderate-to-severe closed TBI, whereas CT is reserved for neurologically unstable patients.
- specific sequences:
  T2* (either GRE [gradient-recalled echo] or SWI) is most sensitive sequence to detect small *hemorrhages, blood breakdown products*.
  diffusion-weighted images - useful for cerebral *infarctions*;
  FLAIR - useful for *SAH*.

N.B. gadolinium enhancement gives no notable advantage!

Indications:

1. Subacute period of severe TBI - to depict full extent of injury to brain!
2. Suspected contusions not seen on CT (MRI is criterion standard for defining **contusions**!)
3. Persistent symptoms with postconcussive syndrome
4. Suspected posttraumatic ischemic infarction
5. Mental status abnormalities (unexplained by CT; MRI is more sensitive for **diffuse axonal injury**!)
6. **Subacute / chronic subdural hematomas** (MRI is more sensitive than CT but normally CT is just enough).

Contraindication - penetrating injuries with possible (not ruled out with X-ray) intracranial metallic fragments.

ANGIOGRAPHY

- used only when **vascular injury** may be present and when endovascular intervention is anticipated:
  a) penetrating injury (esp. due to impalement) – absolute indication if CTA shows proximity to major vessels!
  b) carotid injuries on CTA with (attributable neurologic deficits from) flow limitation.
  c) skull base fracture near major arteries with unexplained neurologic deficits (esp. temporal bone fractures).
- performed only in patients in stable condition.
- CTA / MRA can obtain similar information.
- formerly (in pre-CT era), angiography was used to diagnose intracranial hematomas.

ULTRASONOGRAPHY

a) intracranial hemorrhage in infants.
b) leptomeningeal cyst (after linear skull fracture) in infants.
c) orbital soft-tissue injury.

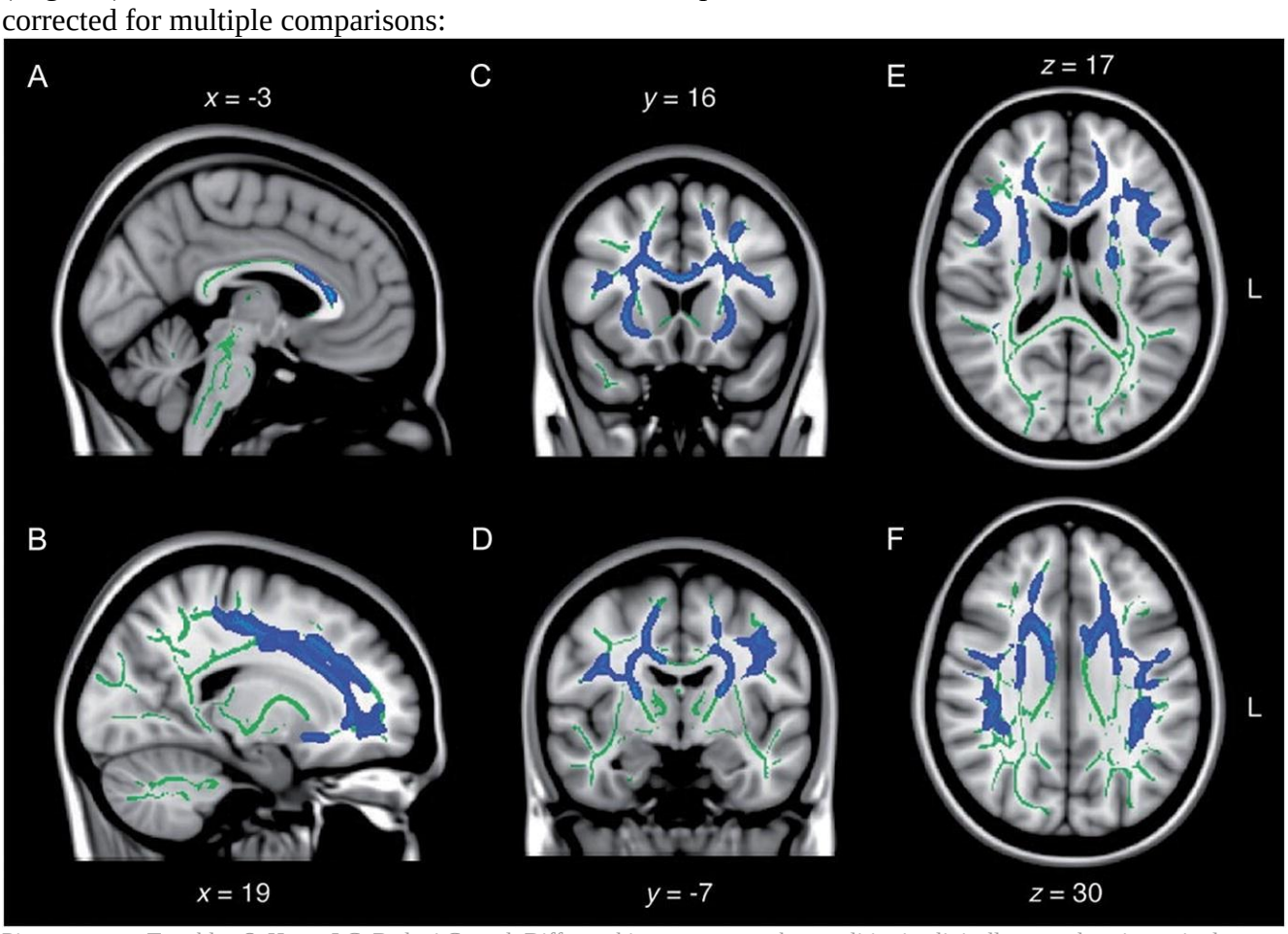
IMAGING - CONDITIONS

CONCUSSION

– normal CT/MRI.

DTI is abnormal!

Diffuse increase in mean diffusivity after remote concussions. Sagittal (A and B), coronal (C and D), and axial (E and F) slices of the tract-based spatial statistics group contrast on mean diffusivity maps (controls vs concussed in blue). The contrasts are overlaid on the mean fractional anisotropy skeleton (in green) and the standard MNI152 T1 1-mm brain template. The results are thresholded at $P \geq .05$, corrected for multiple comparisons:



Picture source: Tremblay S, Henry LC, Bedetti C, et al. Diffuse white matter tract abnormalities in clinically normal ageing retired athletes with a history of sports-related concussions. Brain. 2014;137:(11) 2997-3011.

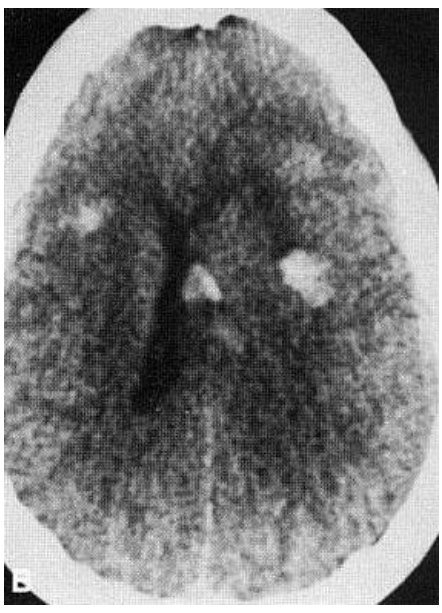
DIFFUSE AXONAL INJURY

– often not visible (microscopic damage).

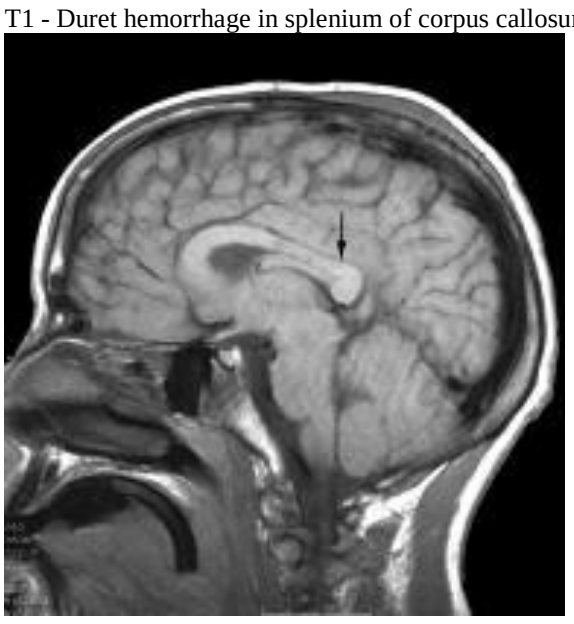
- **CT** - *small petechial hemorrhages in white matter* (most frequently juxtacortical & periventricular, corpus callosum, internal capsule and dorsorostral brainstem) – "tear" hemorrhages;
- DAI can sometimes be superimposed by generalized brain swelling.
- **MRI** is more sensitive (may be positive even when CT is negative; e.g. nonhemorrhagic DAI) - diffuse, small, focal abnormalities limited to white matter tracts.
  SWI is the most sensitive sequence (more sensitive than **GRE**)!
- ***months after injury*** - reduced bulk of white matter with persistent hemosiderin foci.

T2-MRI - foci of hypointense signal representing small shear hemorrhages at gray/white junction (*arrows*):

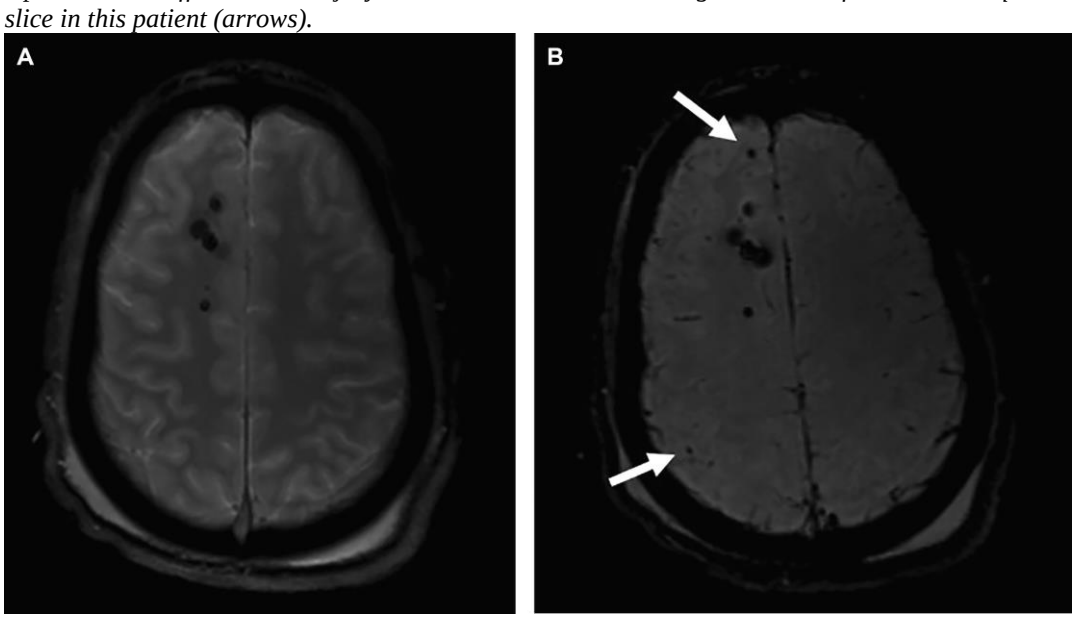
CT - multiple white matter hemorrhages:



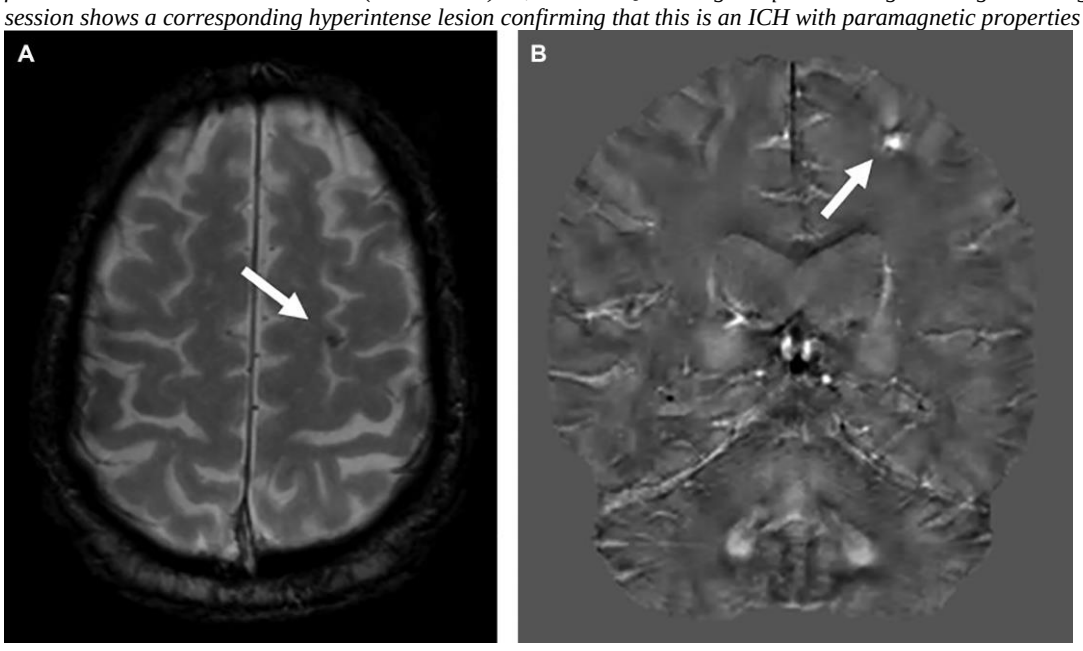
T1 - Duret hemorrhage in splenium of corpus callosum:



SWI is more sensitive for ICH than traditional GRE sequences. **A**, *Standard GRE image shows several small ICH in a patient with diffuse axonal injury.* **B**, *Two additional hemorrhages are identified on SWI sequence at the same slice in this patient (arrows).*



QSM is able to differentiate between ICH and calcification. **A**, *Axial GRE image shows a small hypointense lesion within the left frontal lobe subcortical white matter (white arrow).* **B**, *Coronal QSM image acquired through this region during the same MRI session shows a corresponding hyperintense lesion confirming that this is an ICH with paramagnetic properties (white arrow).*



SCALP INJURIES

- **CT** reliably depicts subgaleal hematomas, elevated and avulsed soft tissues, scalp edema.
- *air within scalp tissue* suggests **scalp laceration** (gas detected several days after trauma - **infection**).

CONTUSION

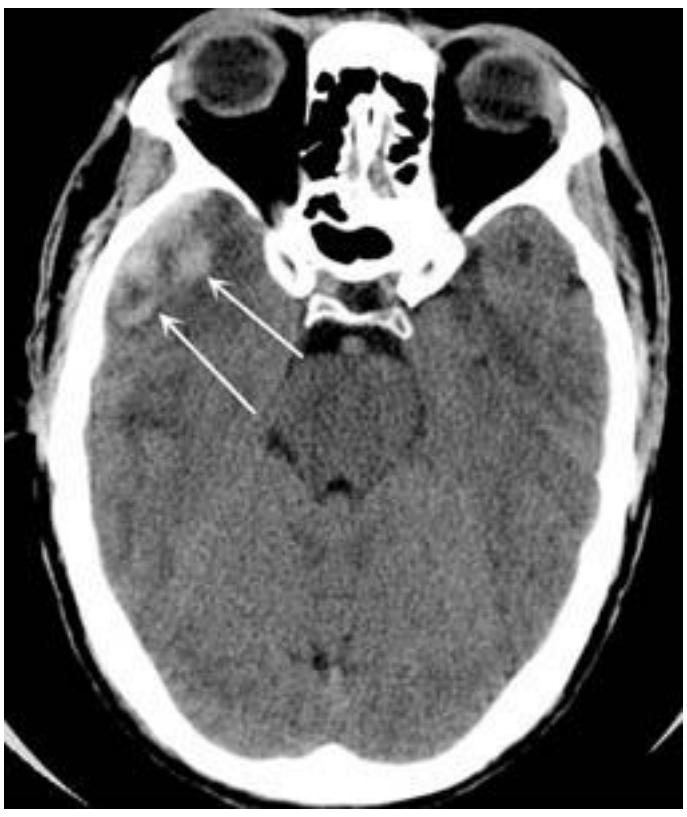
Contusion extends to cortical surface (vs. intracerebral hematoma)

MRI is criterion standard for defining contusions!

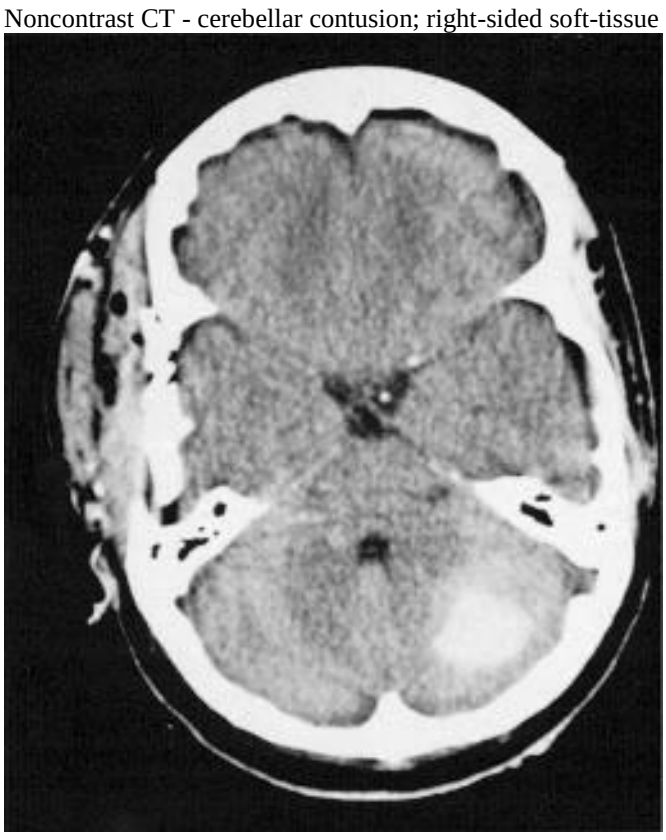
- ***early*** - *inhomogeneous hyperdensity** on CT, hyperintensity on MRI (T1 and T2).
  *initially (< 1-2 hours after TBI), partial volumes between dense microhemorrhages and hypodense edema can render contusions isoattenuating on CT (high initial false-negative rate!); vs. MRI demonstrate contusions from onset!
  - mass effect may distort adjacent sulci and lateral ventricles.
  - some degree of SAH is almost always present.
- ***after several hours*** - *ring of lower density* (edema surrounding contusion; very early - only edema without hemorrhages).
- ***after week*** (blood within contusions has begun to degrade, and MRI becomes more useful) - surrounding ringlike contrast enhancement.

N.B. contusions *progress with time ("blossom")* in size, number, and amount of hemorrhage within contusions – these changes are most evident *over first 24-48 hours* (in 25% cases delayed hemorrhage occurs in areas that were previously free of hemorrhage) – routinely repeat CT!!!

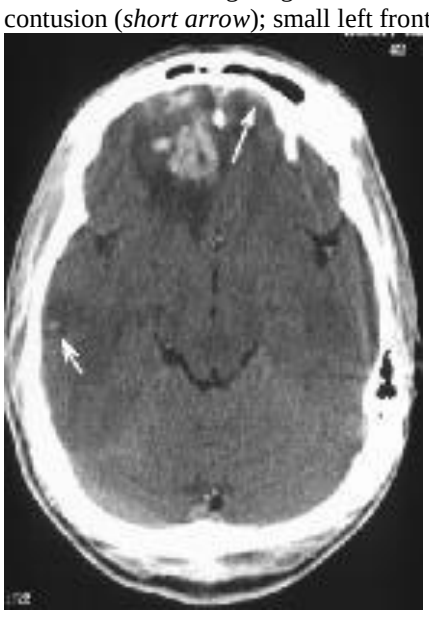
Noncontrast CT - hyperdense region in anterior temporal lobe:



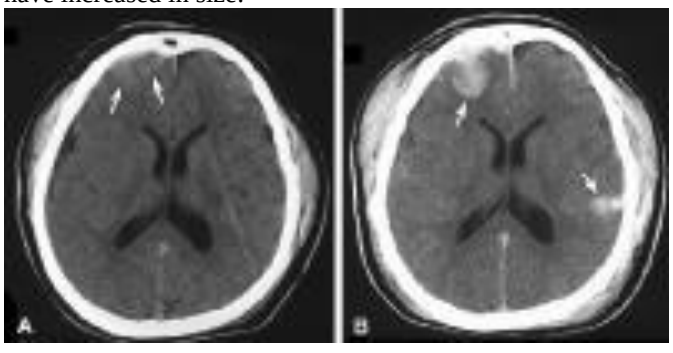
Noncontrast CT - cerebellar contusion; right-sided soft-tissue swelling and bone injury are also obvious:



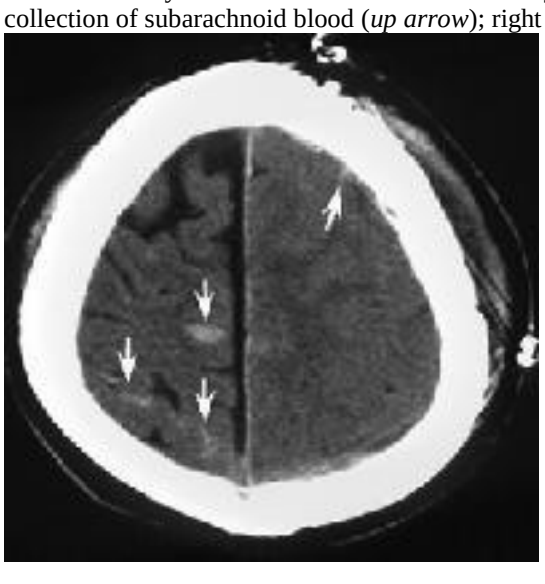
Noncontrast CT - large, right frontal contusion with hemorrhage and surrounding edema; smaller right temporal cortical contusion (*short arrow*); small left frontal subdural hematoma (*long arrow*):



Enlargement of contusion:
A) CT on day 1 - subtle area of slightly hypoattenuating right frontal lobe contusion (*arrows*)
B) CT on day 2 - large, right frontal contusion (*arrow*) and new, large, left temporal contusion (*arrow*); scalp hematomas have increased in size:



CT immediately after blunt trauma to left convexity - severe swelling of entire left cerebral hemisphere with small collection of subarachnoid blood (*up arrow*); right hemisphere shows contrecoup gliding contusions (*down arrows*):



PENETRATING INJURIES

CT – imaging modality of choice: focal areas of increased attenuation (represent parenchymal, intraventricular, subarachnoid, or extracerebral hemorrhage).

- *path of missile* is often obvious from location of hemorrhage and metallic fragments (produce streak artifacts).
- coronal sections may be helpful in patients with skull base or high convexity involvement.

Plain radiographs - can be helpful in assessing bullet trajectory, the presence of large foreign bodies, and the presence of intracranial air; when CT is available, plain radiographs are not essential and are not recommended as a routine.

MRI - not generally recommended in the acute management.

- may help evaluate injuries from penetrating wooden or other nonmagnetic objects.
- in addition to artifact and image distortion, ferromagnetic missiles can also rotate and deflect in response to magnetic torque (literature has not reported any patient suffering additional injury caused by MRI).

Angiography / CTA – when vascular injury is suspected:

a) any patient that goes to OR
b) wound's trajectory passes near Sylvian fissure, supraclinoid carotid, cavernous sinus, or a major venous sinus – facial, orbital, pterional entry sites.
c) unexplained SAH or delayed hematoma.

- pseudoaneurysms may form in ***delayed fashion*** (initial negative CTA/angio does not exclude the risk – repeat CTA in several weeks, esp. before cranioplasty).

OTHER NEUROLOGIC TESTS

EEG - not emergency test!

Most useful role of EEG - diagnosis of **nonconvulsive status epilepticus**!*

*may be detected in ≈ 8% comatose patients when imaging and normal ICP do not explain poor exam

- if taken at some convenient time after admission, it may aid in prognosis:
  at time of injury - *suppression* of electrical cortical activity;
  with recovery - activity returns to normal (often through phase of *generalized slowing and increased voltage*).
  – common feature in all patients (may persist for many weeks) - undue susceptibility of cortical activity to *OVERVENTILATION*.
  – areas of cortical damage may show abnormal activity (slowing and spike activity) for weeks ÷ months – risk of epilepsy!
  N.B. sedative medications may have confounding effect!

  Cortical Spreading Depressions and Depolarizations (CSDs) – may explain a number of phenomena previously difficult to understand (such as non-epileptiform, transient focal neurological deficits and cerebral infarctions); it has been repeatedly demonstrated that they can be treated with KETAMINE!

- bilaterally absent **somatosensory & auditory evoked potentials** predict unfavorable outcome in ≈ 99.5% patients.

Blood tests

i-STAT Alinity (Abbott) - FDA cleared a 15-minute blood test to asses TBIs.

- test measures levels of glial fibrillary acidic protein (GFAP - glial cell damage) and ubiquitin carboxyl-terminal hydrolase L1 (UCH-L1 - specific to neurons) – if both are elevated - 99% predictive value for TBI; 95.8% sensitivity for identifying TBIs.

Lumbar puncture is contraindicated (unless ***meningitis*** is suspected – but LP only after imaging excluded mass lesion = basilar cisterns must be open on CT).

- LP can be therapeutic in SAH.
- evidence has suggested that CSF in basal cisterns is not effectively drained by EVD; **lumbar drain** may be possible – in carefully selected patients– to safely drain CSF and to prevent or attenuate intracranial pressure elevation.

Ophthalmoscopy – signs of ICP↑ (***papilledema***, loss of venous pulsation).

- it has long been held that patients with brain injuries do not get papilledema.

Selhorst JB, Gudeman SK, Butterworth JFt, Harbison JW, Miller JD, Becker DP. Papilledema after acute head injury. Neurosurgery. 1985;16(3):357-363

- TBI patients do get papilledema → renewed interest in the optic nerve sheath diameter as an apparently accurate surrogate measure of ICP.

Transcranial Doppler

- normal average linear blood velocity (LBV) in MCA ≈ 60 cm/s.
- LBV > 100-120 cm/s:
  a) ***hyperemia*** (parallel LBV increase in MCA and ICA) – esp. days 2-4 after TBI
  b) ***vasospasm*** (LBV in MCA exceeds LBV in ICA ≥ 3 times) – usually on days ≥ 5 post TBI
- low LBV (esp. early after TBI) reflects brain hypoperfusion.

GOSLING (PULSATILITY) index = (systolic LBV - diastolic LBV) / mean LBV.

if > 1 – sign of intracranial hypertension

NON-NEUROLOGIC TESTS

Monitor **ECG** - high incidence of supraventricular tachycardia (most common dysrhythmia after TBI), ventricular dysrhythmias, ST-T wave abnormalities, prolonged QT.

Urine toxicology screen and **blood alcohol level** - interpreting patient's mental status.

Glycemia

- *hyperglycemia* correlates with poor outcome.

Serum electrolytes & osmolarity

Osmolarity = 2 × (Na + K) + glycemia + urea

Sodium (alterations occur in 50% comatose patients):

HYPONATREMIA - due to:
a) syndrome of inappropriate antidiuretic hormone (SIADH)
b) cerebral salt wasting (release of natriuretic hormone → urinary Na losses↑ → volume depletion).

- hyponatremia can potentiate brain edema and cause seizures.

HYPERNATREMIA - due to:
a) dehydration
b) diabetes insipidus (urine output↑, urine specific gravity↓)
N.B. MANNITOL can imitate diabetes insipidus by producing high urine output.

Magnesium is depleted in acute phases of both minor and severe TBI.

H: MAGNESIUM SULFATE IV or PO

N.B. magnesium *blocks excitotoxic response* and functions as antioxidant - careful monitoring of magnesium may improve outcome!?

Coagulation studies (PT, aPTT, fibrinogen, platelet counts)

CBC, Hct – monitor in case of bleeding (type and cross match are always obtained with initial orders).

Arterial-venous blood gases – monitor in comatose patients.

- 20-gauge Silastic catheter is inserted with tip in internal jugular bulb, usually on right: arterial jugular venous oxygen content difference can be obtained.

normal venous saturation ≈ 65%;

< 50-55% - global brain ischemia;
> 90% - luxury perfusion (hyperemia).
Maintain ***arterial - jugular venous O_2 content difference*** < 7 vol%.

Volemic indicators (CVP, PCWP) – monitor during treatment of hypotension.

Renal function tests & CK - to exclude rhabdomyolysis if *crush injury* has occurred or *marked rigidity* is present.

Within 4-5 days after admission, comatose patients may have **screening endocrine battery** (incl. cortisol, prolactin, growth hormone, thyroid function) – screening of pituitary injury.

MANAGEMENT

Physicians can do nothing to either *replace lost* neurons or *accelerate restoration* of recovering neurons!

Main goal of TBI management – **prevention, swift recognition and treatment of SECONDARY INSULTS** (i.e. preventing / reversing further brain injury)

N.B. in all neurotrauma cases maintain SBP > 110 mmHg (DAMAGE CONTROL RESUSCITATION)

BRAIN TRAUMA FOUNDATION (BTF) GUIDELINES

Brain Trauma Foundation (BTF) Guidelines for the Management of Severe Head Injury were the first clinical practice guidelines published by any surgical specialty.

- guidelines has been associated with a 50% reduction in mortality + reduced costs of patient care

- can be attributed to eliminating detrimental practices such as *hyperventilation*, administration of *steroids* and *under-resuscitation* due to a fear of brain edema.

DISPO

HOSPITALIZATION

Neurologic deterioration is most common within 24 hrs after TBI

- all patients (except LOW-RISK mild TBI) must be admitted!
  - HIGH-RISK mild TBI patients should be observed for 8-24 hours* ("neuro checks" at 30-60 min intervals - any deterioration in neurologic status or any focal signs → CT).
  - if physician decides that patient with HIGH-RISK mild TBI can be sent home, appropriate ***early follow-up*** should be arranged.

**intoxicated patients* must be observed until clinical sobriety

- all severe TBI and most moderate TBI patients are admitted to ICU.
- <u>if patient is sent home</u>:
  1) patient should be monitored at home* in quiet environment in acute period (12-24 hours) by ***responsible nonintoxicated adult*** who lives with patient (and has ***access to telephone***).

     *do not allow to work, drive, etc
  2) provide ***instructions*** (verbal and written - "head injury check list") describing signs & symptoms of delayed complications of TBI* – patient should be awakened every 2 hours and assessed neurologically.

     *e.g. severe headaches, persistent nausea and vomiting, seizures, confusion or unusual behavior, watery discharge from nose or ear
  3) no ***analgesics*** other than ACETAMINOPHEN or IBUPROFEN should be used.

TRANSFER

<u>Severe TBI patient</u>:
1. **ICP control** - intubation, MANNITOL.
2. **Seizure control** – LEVETIRACETAM (or PHENYTOIN).

N.B. if patient is deteriorating, perform **emergency burr holes** *see below*

ABC

see "Secondary Injury", "Prehospital Management" *above*

AIRWAY, VENTILATION

- all severe TBI patients (or who have penetrating TBI) should be **intubated**: to prevent aspiration, to protect airway and respiratory drive, to allow PRN hyperventilation.

  Rapid sequence induction [RSI] (with adequate sedation and paralysis!!!) is recommended to avoid ICP↑. see p. 3905 >>

  1) *SEDATION* - cerebroprotective agent ETOMIDATE (maintains BP, lowers ICP and brain metabolism, has rapid onset and brief duration);
     THIOPENTAL 3-5 mg/kg is not recommended (lowers BP → secondary brain injury)
  2) LIDOCAINE IV (1-2 mg/kg)
  3) *PARALYSIS* - SUCCINYLCHOLINE IV (1-2 mg/kg)
  4) airway irritation (→ ICP↑) is blunted by MORPHINE or FENTANYL.
- hyperventilation is recommended only as a short temporizing measure for the quick reduction of elevated ICP.
- hyperventilation probably should be avoided during the first 24 hours after injury when cerebral CBF is often critically reduced (hyperoxia induces ischemia).
- if hyperventilation is used, jugular venous oxygen saturation (SjO_2) or brain tissue O_2 partial pressure ($BtpO_2$) measurements are recommended to monitor oxygen delivery.
- pulmonary toilet.
- coma for > 5-10 days → **tracheostomy**.

BLOOD PRESSURE

- to maintain brain perfusion (cerebral perfusion pressure). *see below >>*

End point is **CPP** > 60-70 mmHg.

<u>Goals</u>
1. Systolic BP > 100 mmHg (IV fluids ± vasopressor agents, if necessary)

   Level III recommendation: Maintain SBP ≥ 100 mmHg (for 50-70 years old) or ≥ 110 mmHg (for < 50 or > 70 years old) to decrease mortality and improve outcomes.

   - do not treat hypertension < 160* mmHg until intracranial hypertension is excluded (Cushing reflex is for brain perfusion)

     *< 140 mmHg if ongoing risk of intracranial bleeding

N.B. *albumin worsens outcomes* (albumin extravasates and worsens cerebral edema)

Level II evidence – avoid SBP < 90 mm Hg

single episode of SBP < 90 mm Hg is associated with doubling of mortality in severe TBI (≥ 2 hypotension episodes increase mortality 8-fold)

2. CVP 5-15 cmH_2O
3. PCWP 10-14 mmHg. further see p. S50 >>
4. $Sa_{O2} \geq 94\%$

Level III evidence – avoid PaO2 < 60 mmHg or SaO2 < 90%.

hypoxemia SaO2 ≤ 90% for 11.5-20 min is independent predictor of mortality in severe TBI (p = 0.024)

N.B. fluid restriction is contraindicated in TBI (historical tenet of TBI treatment was fluid restriction, which was believed to limit cerebral edema; but fluid restriction decreases intravascular volume → cardiac output↓ → CBF↓ → cerebral edema)

RESUSCITATION FLUIDS

- NORMAL SALINE is the best resuscitation fluid; HYPERTONIC SALINE is not better* but it is practical in battle field as takes less volume to carry in backpacks of paramedics.

*several studies of prehospital fluids in patients with TBI suggested that **hypertonic solutions** may restore cerebral perfusion, reduce cerebral edema, and modulate the inflammatory response that contributes to neuronal injury, and thus may benefit resuscitation of these patients.
"*Out-of-Hospital Hypertonic Resuscitation Following Severe Traumatic Brain Injury: A Randomized Controlled Trial*" Bulger EM, May S, Brasel KJ, et al JAMA. 2010;304:1455-1464 - largest randomized clinical trial of hypertonic fluid resuscitation following TBI - conclusion: initial fluid resuscitation of patients with severe TBI with either 7.5% saline + 6% dextran 70 or 7.5% saline alone is not superior to NS with respect to 6-month neurologic outcome or survival.

GENERAL MEASURES

REGIMEN, ACTIVITY

General measures for COMATOSE PATIENTS - see p. S30 >>

- neurochecks every 60 mins for 6 hrs, then every hour until stable.
- mobilize after 24 hrs; avoid direct sunlight.

Do not overemphasize severity of injury - unnecessarily prolongs period of invalidism!

- after severe TBI, return to ***active work*** should be deferred for 2-3 months.

NUTRITIONAL SUPPORT

- **early nutritional support** can directly affect TBI outcome.

Level II A recommendation: "Feeding patients to attain basal caloric replacement at least by the 5th day and, at most, by the 7th day post-injury is recommended to decrease mortality".
Level II B recommendation: "Transgastric jejunal* feeding is recommended to reduce the incidence of ventilator-associated pneumonia"

*vs. intragastric (e.g. PEG) feeding

  - waiting 5 days to start enteral nutrition doubles risk of death at 2 weeks (waiting 7 days quadruples risk).
- severe TBI gives 100-500-fold catecholamine surge → stress ulcers (H: PPI), MI.

DVT PROPHYLAXIS

TBI increases risk of DVT significantly and that correlates with TBI severity.

Level III recommendation: LMWH or low-dose unfractionated heparin may be used in combination with mechanical prophylaxis. However, there is an increased risk for expansion of intracranial hemorrhage. In addition to compression stockings, pharmacologic prophylaxis may be considered if the brain injury is stable and the benefit is considered to outweigh the risk of increased intracranial hemorrhage. There is *insufficient evidence to support recommendations* regarding the preferred agent, dose, or timing of pharmacologic prophylaxis for DVT.

- Knudson et al. found that head injury with an Abbreviated Injury Score of ≥ 3, among other factors, was an independent predictor of VTE in trauma patients.
- TBI has been associated with up to 54% incidence of deep venous thrombosis without prophylactic treatment and a 25% incidence in patients with isolated TBI treated with sequential compression devices.
- Ekeh found that DVT occurred in 1/3 of moderate and severe TBI patients with isolated head injuries, having a lower incidence than those patients with concomitant extracranial injuries. Age, subarachnoid hemorrhage, Injury Severity Score >15, and extremity injury were predictors of DVT.
- Reiff et al. demonstrated a 3-4-fold increase in the DVT risk in TBI despite use of mechanical and chemoprophylaxis; VTE risk increases with TBI severity.
- early (< 24 h) initiation of VTE chemoprophylaxis in patients with traumatic intracranial hemorrhage appears to be safe.

Fabio A. Frisoli et al. Early Venous Thromboembolism Chemoprophylaxis After Traumatic Intracranial Hemorrhage. Neurosurgery, nyx164,https://doi.org/10.1093/neuros/nyx164. Published: 18 July 2017
Traumatic intracranial hemorrhage expansion occurred in 18% of patients in the early cohort (prophylaxis within 24 hrs after bleed) compared to 17% in the delayed cohort (> 48 hrs) (P = 0.83).

HEMOGLOBIN

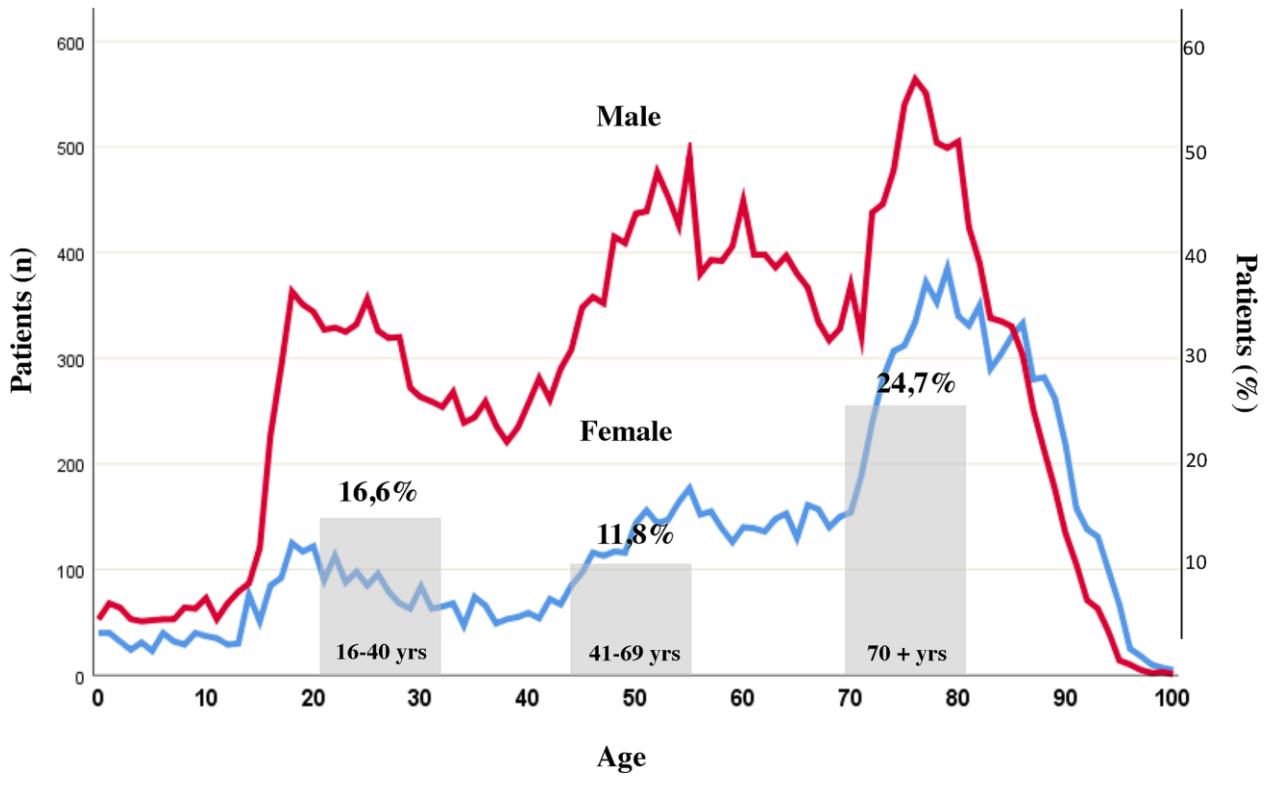
Maintain Hb > 7 g/dL

Robertson CS "Effect of erythropoietin and transfusion threshold on neurological recovery after traumatic brain injury: a randomized clinical trial." JAMA. 2014 Jul 2;312(1):36-47
In patients with closed head injury, neither administration of erythropoietin nor maintaining Hb > 10 g/dL resulted in improved neurological outcome at 6 months (vs. Hb > 7 g/dL).
Transfusion threshold of 10 g/dL was associated with a ↑incidence of thromboembolic events.

COAGULOPATHY

- 20% isolated TBI cases display laboratory coagulopathy upon hospital admission.
- coagulopathy at presentation → 9-fold risk increase in mortality, 30-fold risk increase for poor outcome.
- nature of hemostatic disruptions after TBI remains elusive but current evidence suggests the presence of both a hyper- and hypocoagulable state with possible overlap between phases and states – best to use "global" hemostatic assays (TEG, ROTEM).

Trimodal age distribution of moderate to severe TBI + frequency of coagulopathy upon admission:
first peak until age 18 (driver's license); "testosterone effect" > "young risk-takers"; male > female.
second peak mid-50s ("older risk-takers"; work accidents); male > female
third peak late 70s (mainly falls); incidence in 2 sexes is nearly equal.



NEUROLOGICAL MEASURES

ICP management

- central to intensive care of critically brain injured patient!

N.B. in absence of any obvious signs of increased ICP, *no prophylactic treatment* should be initiated!

MONITORING

Level II B recommendation: management of severe TBI patients using information from ICP monitoring is recommended to reduce in-hospital and 2-week post-injury mortality.
Options (class III) for penetrating TBI: early ICP monitoring is recommended if: unable to assess the neurologic examination accurately / the need to evacuate a mass lesion is unclear / imaging studies (e.g. CT) suggest elevated ICP.

Indications: other indications → see p. S50 >>

A. ***GCS*** > ***8*** + significant mass lesions on CT scan (but often such patients need to go to OR)
B. ***Salvageable patient with GCS*** 3-***8*** (after resuscitation) plus:
   a) abnormal CT scan - ***mass lesions*** (contusions, hematomas) when patient is not taken to operating room for evacuation OR ***diffuse cerebral edema*** (esp. with obliteration of perimesencephalic cisterns – limited residual compliance).
   b) normal CT scan + any two of the following (on admission): SBP < 90 mmHg, age > 40 yrs, unilateral or bilateral motor posturing.

- most academic neurosurgical centers monitor ICP continuously with even moderately severe head injuries.
- even patients taken to operating room frequently have ICP monitors placed at end of operation - later brain swelling may still be a problem even after successful mass evacuation (and even after craniectomy).
- ICP monitor is ***zeroed at midbrain*** level.
- if GCS is < 6, EVD is recommended over intraparenchymal monitor to drain CSF for first 12 hours postinjury (level III recommendation).
- there are studies that do not support ICP monitoring; but from practical standpoint, the ICU staff pays much less attention to brain if ICP monitor is absent.

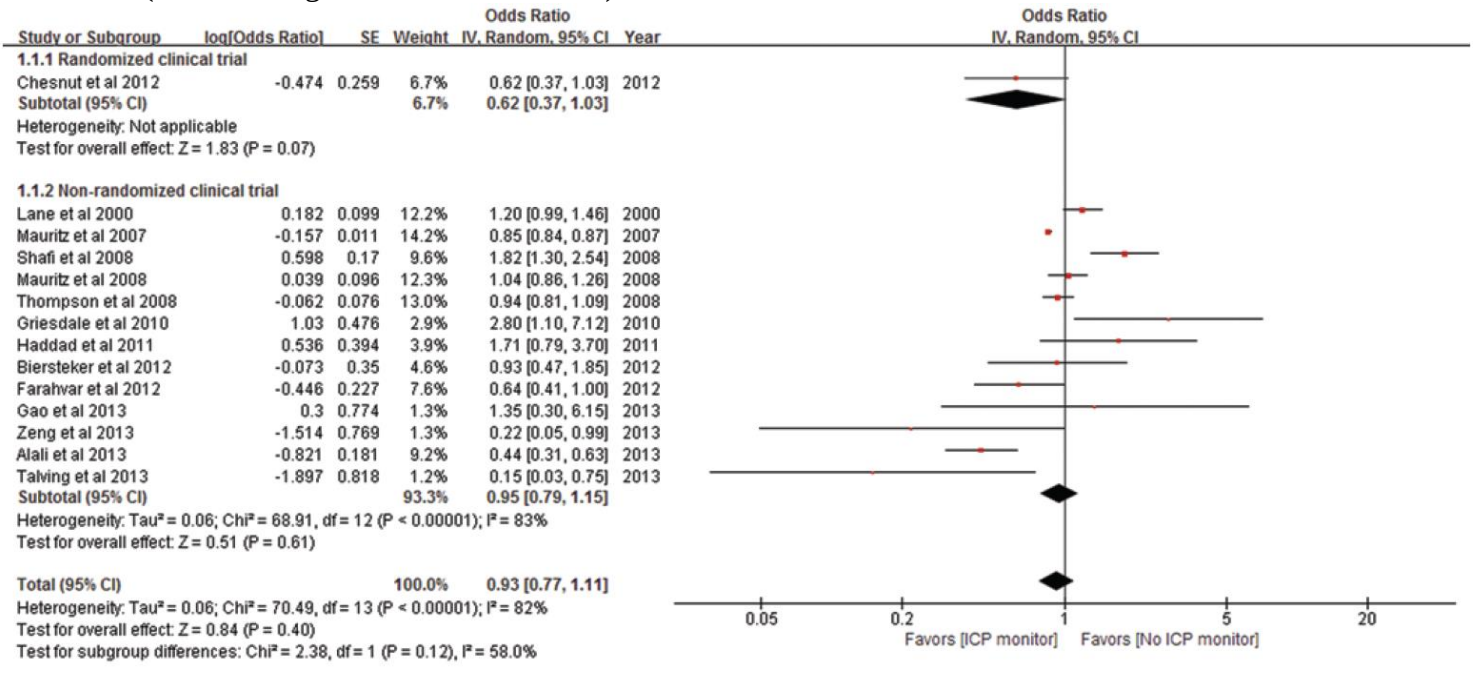
Qiang Yuan "Impact of intracranial pressure monitoring on mortality in patients with traumatic brain injury: a systematic review and meta-analysis" J Neurosurg 122:574–587, 2015

- systematic review and meta-analysis of ICP monitoring studies including 24,792 patients.
- current *clinical evidence does not indicate that ICP monitoring overall is significantly superior to no ICP monitoring in terms of the mortality of TBI patients*. However, studies published after 2012 indicated a lower mortality in patients who underwent ICP monitoring.

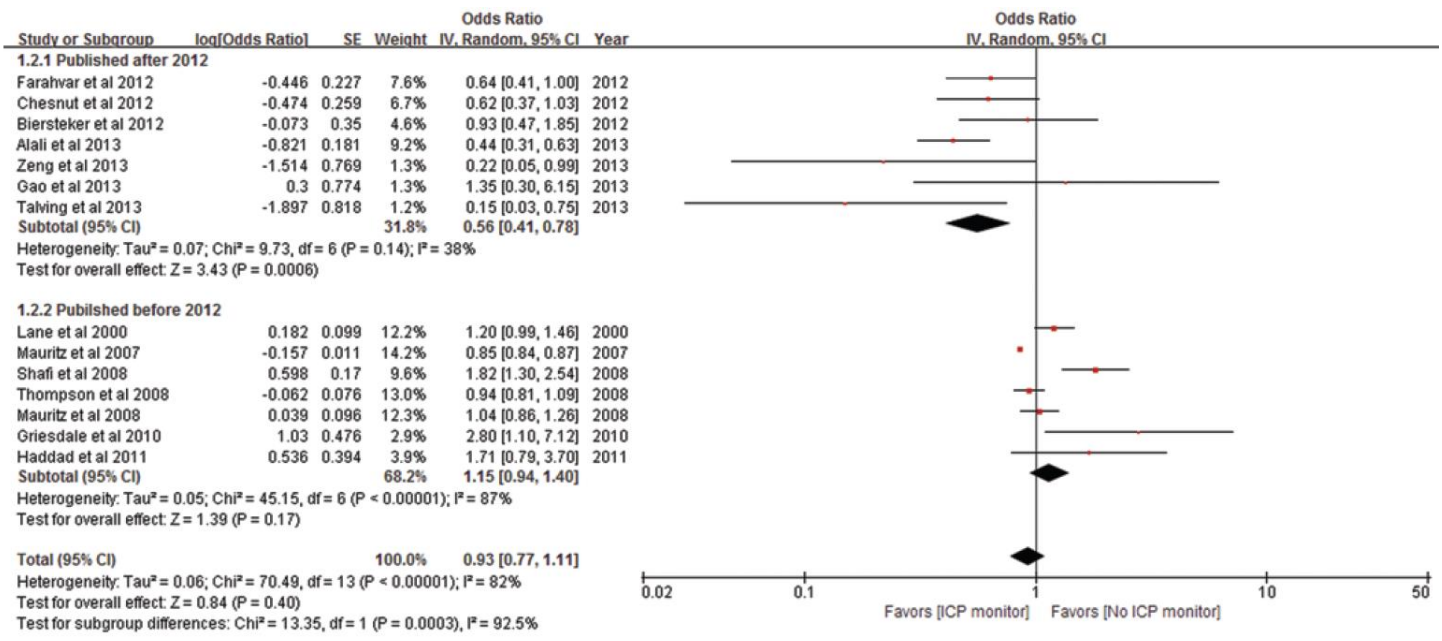
Chesnut RM, Temkin N, Carney N, et al. A trial of intracranial-pressure monitoring in traumatic brain injury. N Engl J Med. Dec 2012;367(26):2471-2481

- high-quality multi-center (South and Central America), Class 1 RCT (N=324)
- ICP monitor vs. close clinical assessment for ICP management.
- **outcomes** for patients managed with information from **clinical assessment do not differ** from those for patients managed with information from the **ICP monitor – no recommendation to use either method preferentially**.
- *ICP monitoring alone is not sufficient to improve outcomes*.

Association between ICP monitoring and mortality in patients with TBI stratified by randomization or not (shown as log [Odds Ratio] with SE). IV = inverse variance.



Association between ICP monitoring and mortality in patients with TBI stratified by publication date (shown as log [Odds Ratio] with SE):



- when ICP remains < 20 mmHg for 24-48 hours without treatment, ICP monitoring is discontinued.

TREATMENT

- ICP > 22* (formerly 25) mmHg for > 15 mins within 1 hour must be treated ASAP (to keep CPP > 70 mmHg) → see p. S50 >>

*> 15 mmHg after decompressive craniectomy (some would also treat > 18 mmHg for patients > 55 yrs or women of any age), > 20 mmHg in European neurointensive care practice

N.B. during periods of autoregulatory loss, no safe ICP limit can be identified!

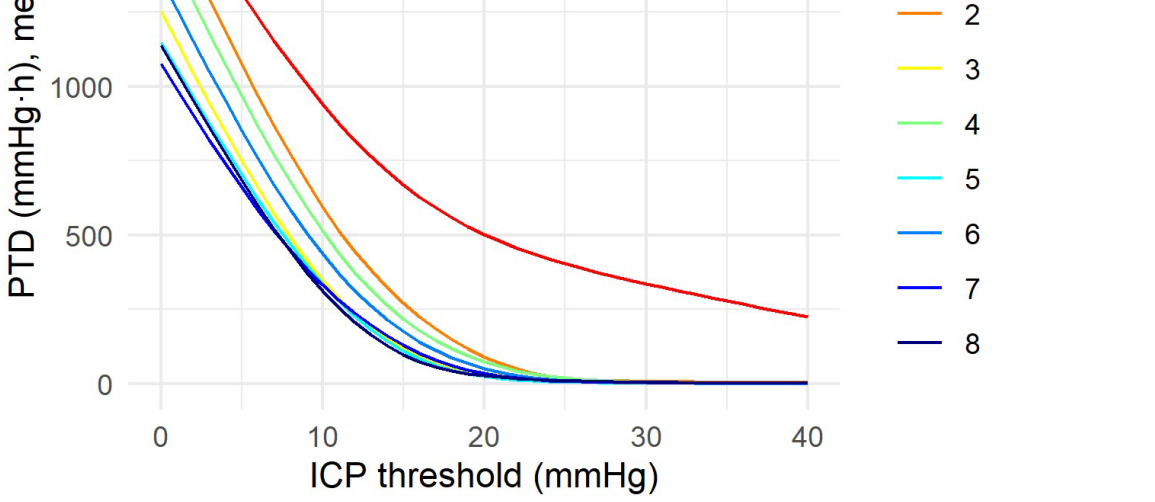
Level II B ***recommendation***: Treating ICP above 22 mm Hg is recommended because values above this level are associated with increased mortality.

Level III ***recommendation***: A combination of ICP values and clinical and brain CT findings may be used to make management decisions.

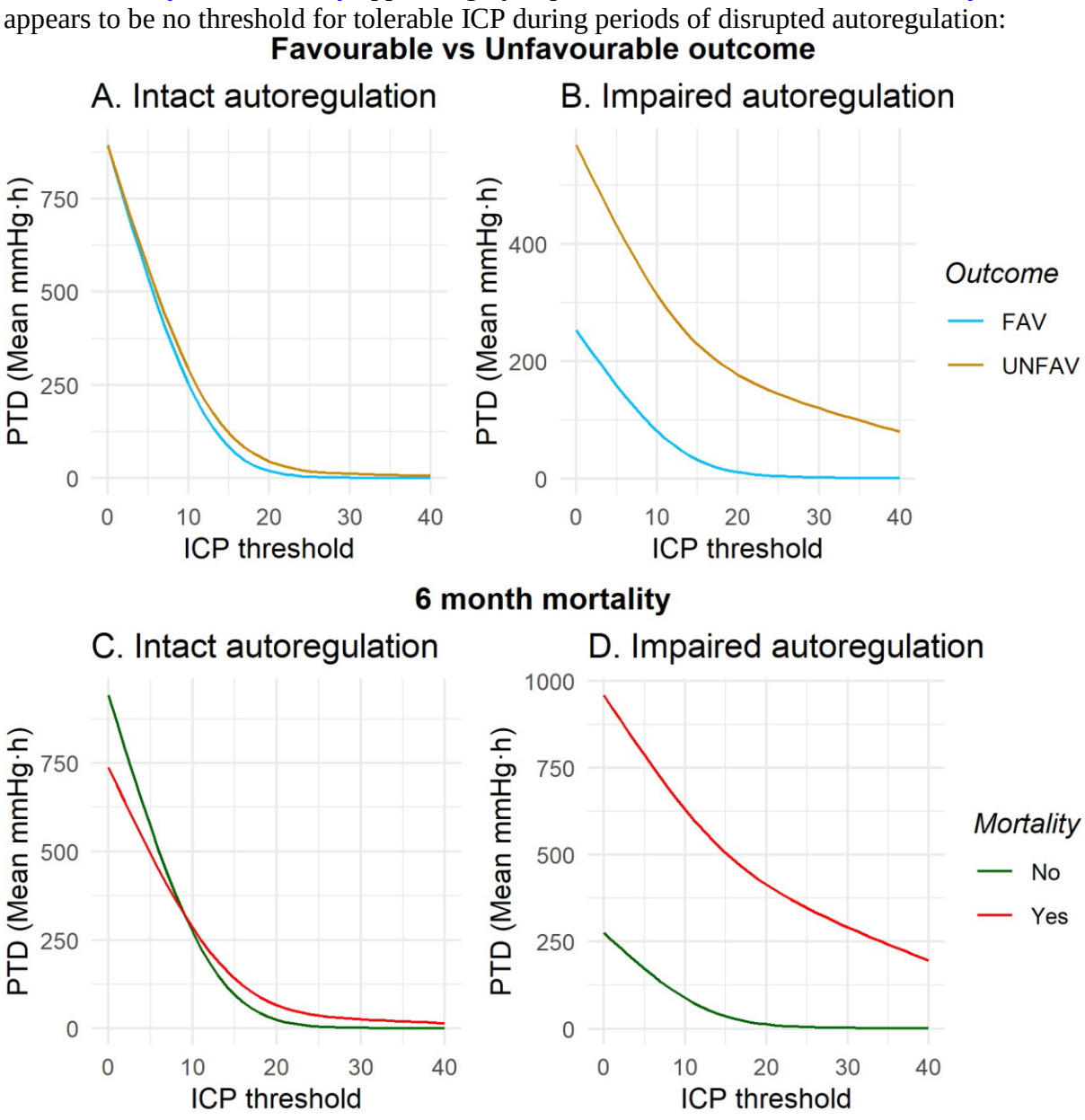
N.B. don't guide management by ICP alone; correlate with clinical exam and CT findings!

Pressure and time dose (PTD) - ICP increase & duration correlate with outcomes:

Åkerlund CAI et al. (2020) Impact of duration and magnitude of raised intracranial pressure on outcome after severe traumatic brain injury: A CENTER-TBI high resolution group study. PLoS ONE 15(12): e0243427. https://doi.org/10.1371/journal. pone.0243427



ICP tolerability / vulnerability appear highly dependent on cerebrovascular reactivity, and there appears to be no threshold for tolerable ICP during periods of disrupted autoregulation:



VENTILATION

- in the absence of cerebral herniation, normal **ventilation** is the goal ($PaCO_2$ goal 35-45 mm Hg).
  - if hyperventilation is used, jugular venous oxygen saturation (SjO_2) or brain tissue O_2 partial pressure ($BtpO_2$) measurements are recommended to monitor oxygen delivery.

Prophylactic hyperventilation vs. normoventilation in severe TBI

In the ***normoventilation*** group, $PaCO_2$ was kept 30–35 mmHg for 5 days.

In the ***hyperventilation*** groups, $PaCO_2$ was kept 24–28 mmHg for 5 days.
Subgroup of hyperventilation received (bolus → sustained IV infusion for 5 days) TROMETHAMINE to examine the effect of loss of CSF buffer during hyperventilation.

	Favourable outcome		Statistical significance
	Normoventilation	Hyperventilation	
3 months	48%	18%	$p < 0.05$
6 months	57%	24%	$p < 0.05$

There were no differences at **12 months** follow-up.
Prolonged prophylactic hyperventilation is deleterious in TBI.
Deleterious effect of sustained hyperventilation could be overcome by THAM.

Muizelaar JP , Marmarou A , Ward JD , Kontos HA , Choi SC , Becker DP , Gruemer H , Young HF . Adverse effects of prolonged hyperventilation in patients with severe traumatic brain injury. J Neurosurg 1991; 75 : 731 – 739

EVD

- two regimens of **EVD**:
  a) continuously monitor ICP and only intermittently drain for ICP elevations ("20 pop down to 10" protocol) – allows closer ICP monitoring; TBI is not hydrocephalus – why to dry continuously?
  b) continuous drainage of CSF with intermittent ICP measurements – prevalent among pediatric experts and may be more effective in lowering ICP.

HYPEROSMOLAR FLUIDS

- restrict MANNITOL use ***prior to ICP monitoring*** to patients with signs of transtentorial herniation or progressive neurological deterioration not attributable to extracranial causes.

Mannitol: **ICP-guided** vs. **empirical**

Smith HP et al. Comparison of mannitol regimens in patients with severe head injury undergoing intracranial pressure monitoring. J Neurosurg 1986; 6 5: 820 – 824

Mean ICP was 5.5 mmHg lower in the empirically treated group compared to the ICP-guided group ($p < 0.05$) but mortality trended to be higher:

	ICP-guided mannitol therapy	Empirical mannitol therapy	Statistical significance
Mortality	35%	42.5%	None

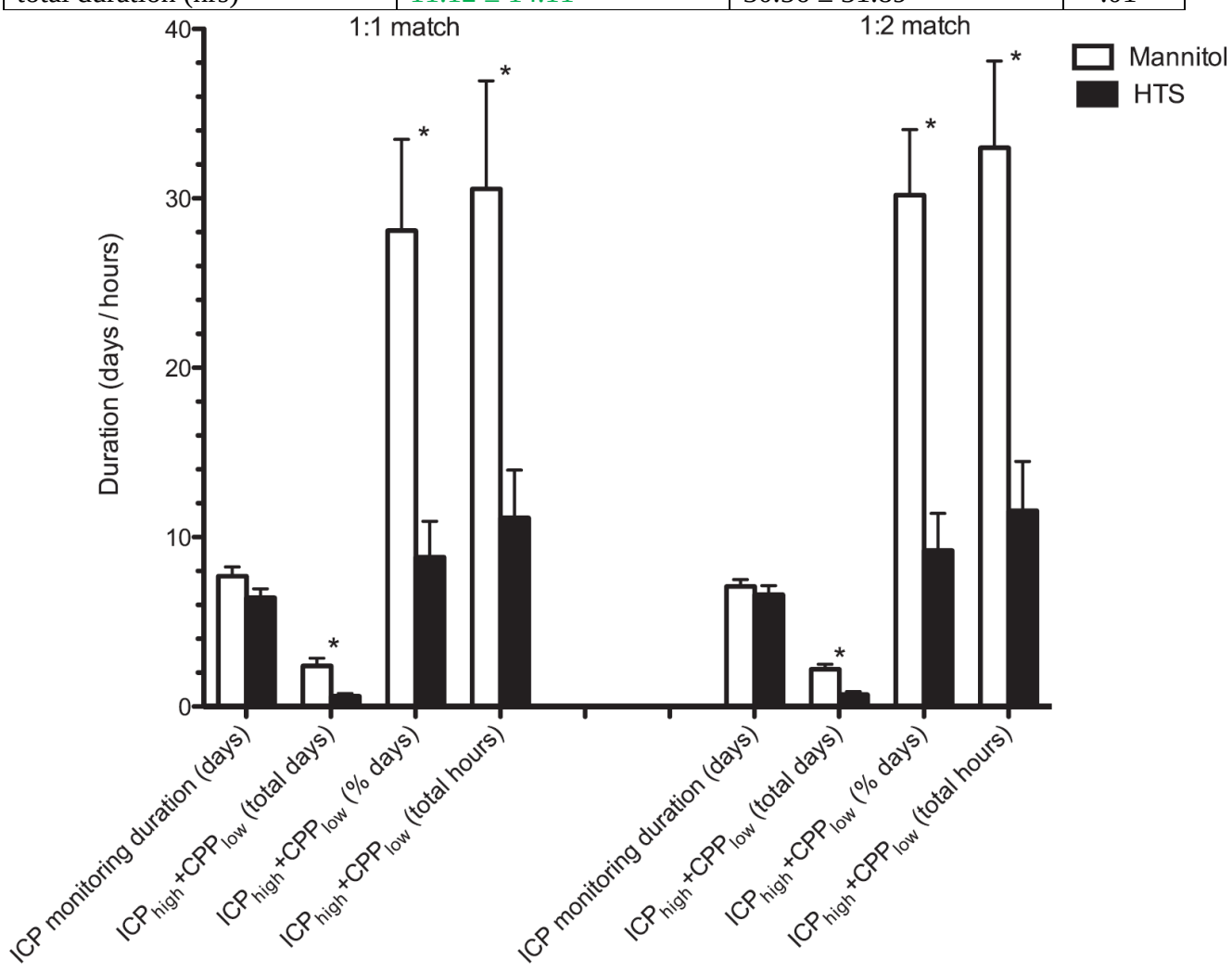
Ideal hyperosmotic agent should simultaneously lower ICP and maintain or improve CPP.
Osmotic agents may lower CPP related to systemic effects on diuresis, intravascular volume, and cardiac output.
N.B. mannitol is a diuretic and HTS is not.
Growing evidence that **hypertonic saline** is better for underresuscitated patient than mannitol!

Hypertonic Saline vs. Mannitol

Mangat HS et al. Hypertonic Saline is Superior to Mannitol for the Combined Effect on Intracranial Pressure and Cerebral Perfusion Pressure Burdens in Patients With Severe Traumatic Brain Injury. Neurosurgery 86:221–230, 2020

- prospectively collected data from the New York State TBI-trac database.
- ***patients received only 1 hyperosmotic agent*** - either mannitol (20%) or HTS (3% bolus) for raised ICP (patients who received both agents were excluded from data analysis to prevent erroneous conclusions).
- patients were matched (1:1 and 1:2) for factors associated with 2-wk mortality: age, GCS score, pupillary reactivity, hypotension, abnormal CT, and craniotomy (extra-axial surgical lesions) → 25 matched pairs for 1:1 comparison and 24 HTS patients matched to 48 mannitol patients in 1:2 comparisons.
- cumulative median osmolar doses in the 2 groups were similar.
- primary endpoint - **combined burden of ICP high (> 25 mm Hg) and CPP low (< 60 mm Hg)**:

Combined burden	HTS	Mannitol	p
total number of days (n)	0.6 ± 0.8	2.4 ± 2.3	< .01
percentage of days vs. total days of ICP monitoring (%)	8.8 ± 10.6%	28.1 ± 26.9%	< .01
total duration (hrs)	11.12 ± 14.11	30.56 ± 31.89	< .01



HTS bolus therapy appears to be superior to mannitol in reduction of the combined burden of intracranial hypertension and associated hypoperfusion in severe TBI.
Comment (Dr. Hawryluk): it is important to replace fluid renal losses after mannitol administration; sometimes the patient's ICP responds better to mannitol than to HTS (mannitol is not naturally found – may have better osmotic gradient).

- Mangat et al. 2014 study (class 2 evidence) indicated that HYPERTONIC SALINE may be more effective than mannitol in lowering ICP but *no difference was found in short-term mortality*.

2 mL/kg of 20 % **mannitol** vs. 2 mL/kg of 7.5 % **hypertonic saline** given when either ICP > 25 mmHg or CPP < 70 mmHg for > 5 min

Vialet R et al. Isovolume hypertonic solutes (sodium chloride or mannitol) in the treatment of refractory posttraumatic intracranial hypertension: 2 mgL/kg 7.5 % saline is more effective than 2 ml/kg 20 % mannitol. Critical Care Medicine 2003; 3 1 : 1683 – 1687

	Hypertonic saline	Mannitol	Statistical significance
Number of episodes ICP >25 mmHg	6.8	13.3	$p < 0.02$
Total duration of episodes	62 min	95 min	$p < 0.04$
Treatment failure	10%	70%	$p < 0.01$

There was ***no significant difference in mortality or GOS*** between the two treatment arms.
N.B. mannitol dose was 0.4 g/kg – lower than we use routinely (1 g/kg)

- pooled data analysis from 3 trials showed continuous HTS therapy was associated with improved survival over bolus HTS therapy.

Asehnoune K, Lasocki S, Seguin P, et al. Association between continuous hyperosmolar therapy and survival in patients with traumatic brain injury - a multicentre prospective cohort study and systematic review. Crit Care. 2017;21(1): 328.

SEDATION

- PROPOFOL is recommended for the control of ICP, but it is not recommended for improvement in mortality or 6-month outcomes (N.B. high-dose propofol can produce significant morbidity)
- high-dose BARBITURATE is recommended to control elevated ICP refractory to maximum standard medical and surgical treatment. protocol – see p. S50 >>

BCT (best conservative treatment) vs. BCT + pentobarbital – for refractory ICP.
Significant positive treatment effect of pentobarbital (p = 0.04)

	BCT	BCT + pentobarbital	Benefit ratio of pentobarbital + BCT:BCT
Control of ICP in all patients (% of patients)	16.7%	32.4%	2:1
Control of ICP in patients with cardiovascular complications prior to randomization (% of patients)	9%	40%	4:1

Eisenberg HM, Frankowski RF, Contant CF, Marshall LF, Walker MD. High-dose barbiturates control elevated intracranial pressure in patients with severe head injury. J Neurosurg 1988; 6 9 : 15 – 23.

Cochrane 2012: "There is *no evidence* that barbiturate therapy in patients with acute severe head injury *improves outcome*. Barbiturate therapy results in a fall in blood pressure in one of four patients. The *hypotensive effect* will offset any ICP lowering effect on cerebral perfusion pressure."

Barbiturates help to control ICP but outcome is unchanged (predetermined by primary injury?)

HYPOTHERMIA (PROPHYLACTIC)

Level II B recommendation: early (within 2.5 hours), short-term (48 hours post-injury) prophylactic hypothermia is not recommended to improve outcomes in diffuse TBI

33 degrees of Celsius reached within 8 hrs after severe TBI:

	Hypothermia	Normothermia	Statistical significance
Poor outcome	57%	57%	None
Death	28%	27%	None

Clifton GL et al. Lack of effect of induction of hypothermia after acute brain injury. N Engl J Med 2001 ; 3 44 : 556 – 563

- robust clinical trials have shown a trend toward worse outcomes with hypothermia!!!! - hypothermia should be used as a last resort!!!

NABIS: H II trial (National Acute Brain Injury Study Hypothermia II)
http://www.medscape.com/viewarticle/735302?src=mpnews&spon=26

- two high-quality **pediatric** trials failed to show benefit and additionally suggested harm related to PROPHYLACTIC hypothermia for TBI. see p. TrH20 >>

HYPOTHERMIA (THERAPEUTIC)

- THERAPEUTIC **hypothermia** (to treat elevated ICP) in severe TBI is effective in decreasing elevated ICP but *does not improve neurological outcome and may increase mortality*!
  - hypothermia bears risks of coagulopathy, immunosuppression, and cardiac dysrhythmia.
  - it is suggested that gradual rewarming can mitigate the inherent risk of rebound intracranial pressure elevation.
  - there has been interest in ***localized cerebral cooling*** in the hopes of obtaining the desired benefits without the systemic side effects.

CPP

MAP by convention is calibrated to the level of the right atrium of the heart.
Central venous pressure (CVP) is also calibrated to the level of the right atrium of the heart; but in TBI ICP is higher than CVP.

CPP = MAP – ICP

Level II B recommendation: recommended target CPP value for survival and favorable outcomes is between 60 and 70 mm Hg. Whether 60 or 70 mmHg is the minimum optimal CPP threshold is unclear and may depend upon the patient's autoregulatory status.

Level III recommendation: avoid aggressive attempts to maintain CPP > 70 mm Hg with fluids and pressors because of the risk of adult respiratory failure (ARDS).

Level III recommendation: CPP below 50 should be avoided.

- Rosner and Daughton (1990) tried CPP augmentation on their patients.

Rosner MJ, Daughton S. Cerebral perfusion pressure management in head injury. J Trauma. 1990;30(8):933-940; discussion 940-931

PRESSURE REACTIVITY INDEX (PRX)

- moving Pearson ***correlation between ICP and arterial blood pressure*** - reflects cerebral vasculature autoregulatory status.

- in patients with intact autoregulation (PRx < 0.3), increasing MAP (CPP) causes vasoconstriction → decreased intracranial blood volume → ICP↓
- in patients with injured autoregulation (PRx > 0.3), increasing MAP causes passive vasodilation → increased intracranial blood volume → ICP↑

N.B. optimal CPP value may need to be tailored to individual patients!

ADVANCED BRAIN OXYGENATION / METABOLIC STATUS MONITORING

The goal of the medical management is to ensure that *nutrient delivery to the brain is optimized through the period of abnormal physiology and brain swelling* - the only way to be assured that this is being achieved is to measure brain metabolites (reassurance that the needs of oxidative metabolism are being met).

OXIMETERS

– monitor brain oxygenation; rationale – sometimes even if ICP is slightly elevated, brain oxygenation remains normal so no need to treat.

Jugular venous oxygen saturation (SjO_2) goal > 50%
Brain tissue oxygenation (pbO2) goal > 20 mmHg

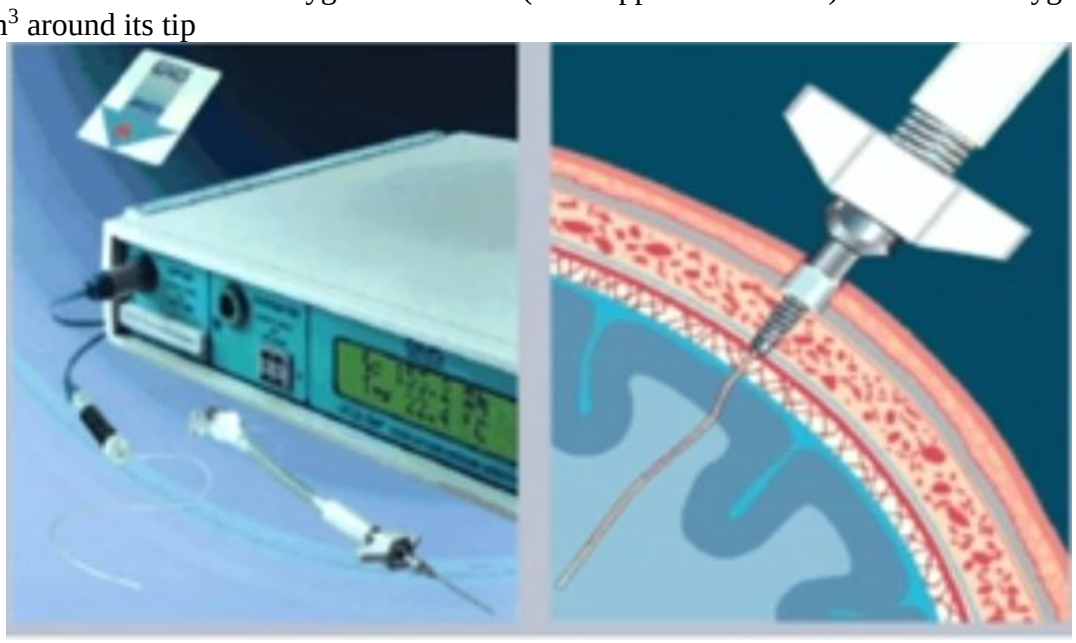
normal brain tissue O_2 partial pressure Pti_{O2} = 25-45 mmHg

1. **Global** – jugular venous oxygen saturation (SjO_2); avoid SjO_2 < 50%

2. **Regional** – brain tissue O_2 partial pressure s. oxygenation ($BtpO_2$ = $PbrO_2$ = $pBtO_2$ = $PbtO_2$ = $PtiO_2$) – indicated for severe TBI. see below for algorithm >>

   - TBI experts worldwide strongly support brain tissue oxygen (PbtO2) monitoring as their first choice for the second parameter (after ICP monitor)

   e.g. Licox Brain Tissue Oxygenation Probe (FDA approved in 2000) – measures oxygenation in mm^3 around its tip



   e.g. "CODMAN Neurotrend Cerebral Tissue Monitoring System" – fiberoptic sensor placed directly in brain tissue monitors local brain tissue Pti_{O2}, Pti_{CO2}, pH, temperature.

   - where to place? – into penumbra; no need to monitor noninjured brain or dead brain areas.

First measure if brain oxygenation falls – increase FiO_2; RBC transfusion and increasing CPP are secondary measures.

Eriksson EA, Barletta JF, Figueroa BE, et al. The first 72 hours of brain tissue oxygenation predicts patient survival with traumatic brain injury. J Trauma Acute Care Surg. May 2012;72(5):1345-1349. PMID: 22673264
Threshold of $BtpO_2$ most predictive of mortality was 29 mmHg

Chang JJ, Youn TS, Benson D, et al. Physiologic and functional outcome correlates of brain tissue hypoxia in traumatic brain injury. Crit Care Med. Jan 2009;37(1):283-290. PMID: 19050612
Threshold of $BtpO_2$ to avoid was 20 mmHg

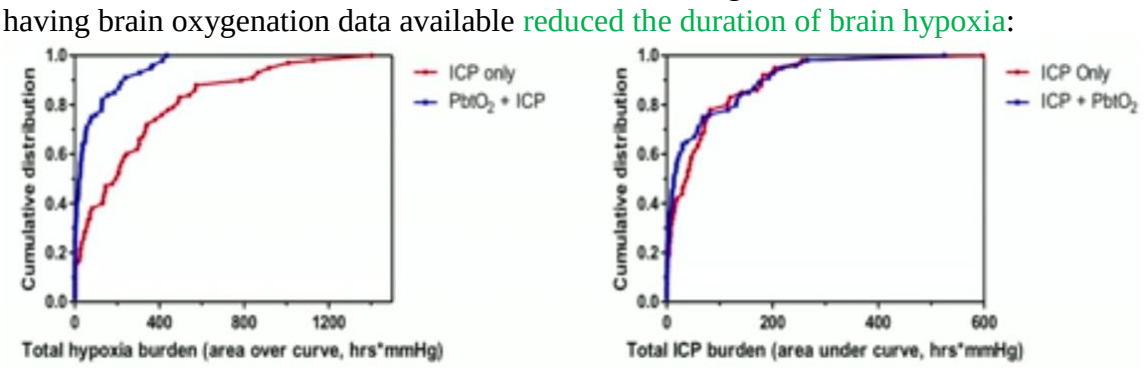
Level III recommendation: Jugular bulb monitoring of arteriovenous oxygen content difference (AVDO2), as a source of information for management decisions, may be considered to reduce mortality and improve outcomes at 3 and 6 months post-injury.

Level III recommendation: Jugular venous saturation (SjO_2) of < 50% may be a threshold to avoid in order to reduce mortality and improve outcomes

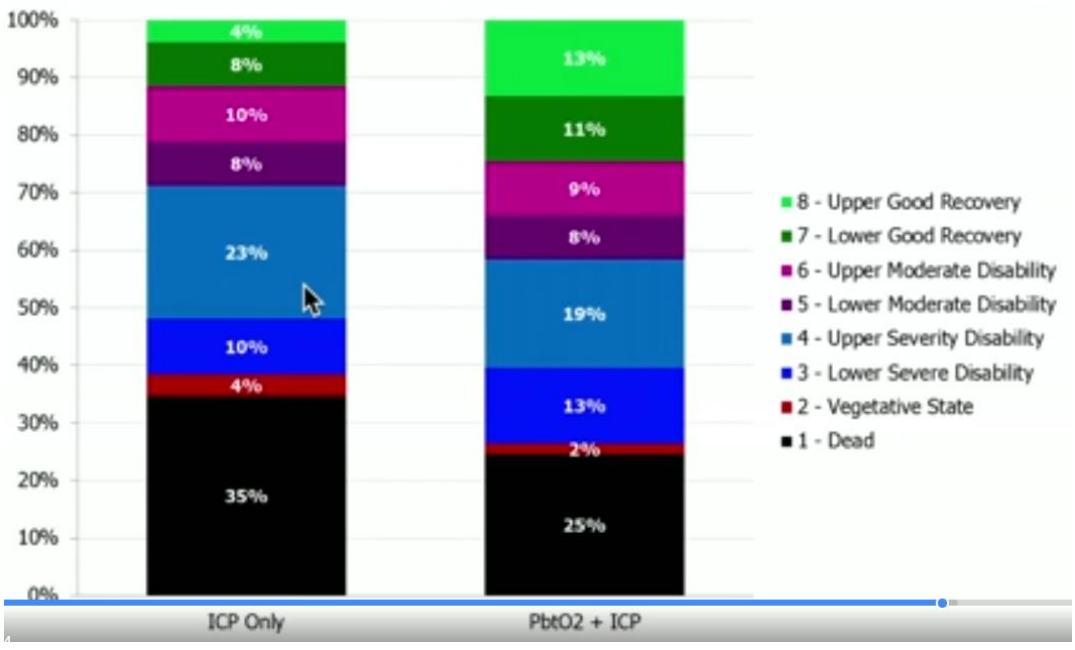
Although patients with desaturations identified with advanced cerebral monitoring have poorer outcomes, ***Level II evidence*** showed no improvement in outcomes for monitored patients.

BOOST-2 trial – ICP monitor alone* vs. ICP monitor plus $BtpO_2$
*brain oxygenation monitor was still placed but the monitor and numbers were hidden from treating staff

- having brain oxygenation data available reduced the duration of brain hypoxia:



- condition at discharge was better in ICP monitor plus $BtpO_2$ group:



TCD

- cerebral autoregulation monitoring.

Sanchez-Porras R, Santos E, Czosnyka M, Zheng Z, Unterberg AW, Sakowitz OW. 'Long' pressure reactivity index (L-PRx) as a measure of autoregulation correlates with outcome in traumatic brain injury patients. Acta Neurochir (Wien). Sep 2012;154(9):1575-1581. PMID: 22743796

There is an association between mortality and L-PRx > 0.2.

MICRODIALYSIS

– monitors cerebral metabolism (e.g. lactate, glutamate)

SEDATION & ANALGESIA

Sedative drugs should be avoided if possible (difficult to monitor level of consciousness + depress respiration) but useful for ICP control.

- restlessness may be combated with small doses of short-acting sedatives (e.g. PROPOFOL, PRECEDEX!!!; historical drug - PARALDEHYDE)
- for agitation **antipsychotics** are useful when used sparingly.
- *periodic withholding of sedation* ("short sedation vacations") - to allow periodic neurologic assessment.
- for analgesia – PARACETAMOL, FIORICET, IBUPROFEN, FENTANYL.

SEIZURE PROPHYLAXIS

- it is prophylaxis of EARLY post-traumatic seizures - anticonvulsant drug is administered routinely in severe TBI and/or cortical irritation but only for 7 days see p. E9 >>
N.B. norepinephrine is seizure suppressant.

ANTIBIOTICS

- prophylactically indicated for:
  a) complicated scalp lacerations
  b) open skull fractures (includes penetrating head injury) – 5 days of triple antibiotics
  c) CSF leak persisting > 7 days

MEDICATIONS NEEDING FURTHER TESTING

BETA-BLOCKERS

- observational studies reveal a significant mortality advantage with β-blockers; however, quality of evidence is very low.

Aziz S. Alali et al. Beta-Blockers and Traumatic Brain Injury. A Systematic Review, Meta-Analysis, and Eastern Association for the Surgery of Trauma Guideline. Annals of Surgery. 2017;266(6):952-961.

FAILED MEDICATIONS

PROGESTERONE – failed in **ProTECT III trial**

TIRILAZAD – no overall benefit on outcome was detected, except in post hoc sub group analysis: men with traumatic SAH had lower mortality.

MAGNESIUM - given within 8 h of moderate to severe TBI does not improve outcome and may even have a detrimental effect:

Outcome	High $MgSO_4$			Low $MgSO_4$		
	$MgSO_4$	Placebo	Stat. Sig.	$MgSO_4$	Placebo	Statistical significance
Mortality	28%	14%	$p = 0.05$	24%	20%	None
Late seizures	17%	13%	$p = 0.05$	9%	6%	None
GOSE	57	54	None	176	174	None

Temkin NR et al. Magnesium sulfate for neuroprotection after traumatic brain injury: a randomised controlled trial. Lancet Neurol 2007; 6 : 29 – 38 .

MINOCYCLINE - a broad-spectrum antibiotic of the tetracycline family that was found to inhibit cytochrome c, thereby inhibiting caspase-mediated apoptosis.

- drug is neuroprotective in different animal models of acute and chronic neurodegeneration, including TBI.
- most human trials showed either small neurological improvements or deleterious neurotoxic effects.

NOT RECOMMENDED MEDICATIONS

1. **Steroids** – increased ICP is due to vasodilation and cytotoxic edema (not due to vasogenic edema); no ***human*** studies demonstrated benefit! (Maxwell et al. showed that glucocorticoids could reduce cerebral edema in an ***animal*** model of TBI by reducing abnormal vascular permeability >>)

Corticosteroid Randomization After Significant Head Injury Trial (MRC CRASH) trial

CRASH trial collaborators. Final results of MRC CRASH, a randomised placebo-controlled trial of intravenous corticosteroid in adults with head injury - outcomes at 6 months. Lancet 2005; 3 65 : 1957 – 1959.

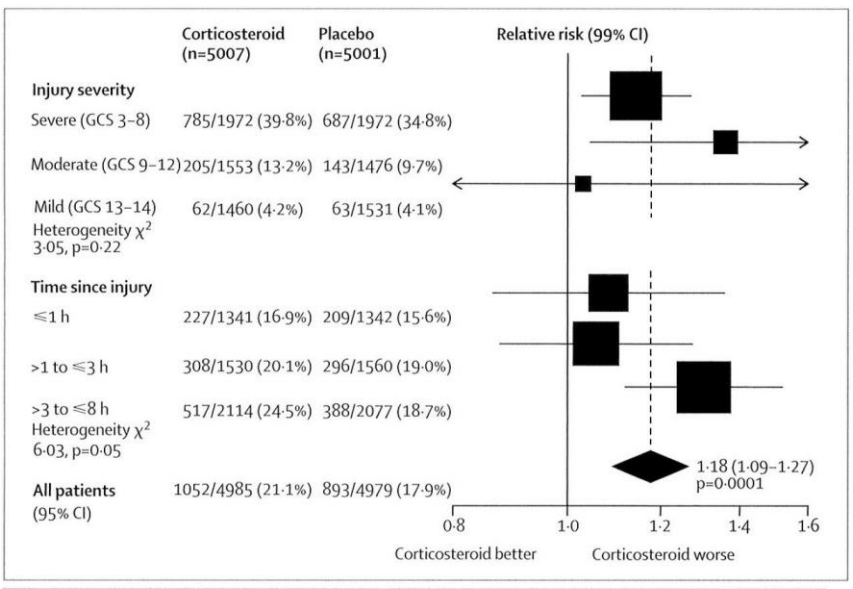
- Level I recommendation (multicenter randomised placebo-controlled trial - 10,008 adult patients, 239 centers in 49 countries worldwide).
- randomized within 8 hours if TBI, GCS ≤ 14
- 48 hours of methylprednisolone (2 gm loading → 0.4 gm/hr) vs placebo.

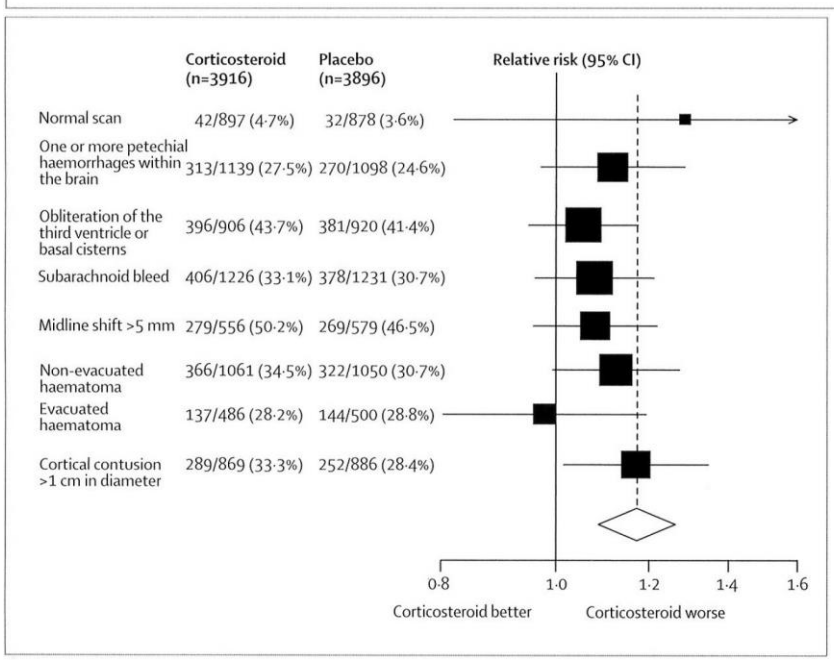
"Steroids are not recommended for improving outcome or reducing ICP. In patients with severe TBI, high-dose methylprednisolone was associated with increased mortality* (RR 1.18, 95%CI 1.09-1.27) and is contraindicated".

*cause unclear but not due to infections or GI bleeding; RR for death 1.15 (p=0.0001).

Outcome		Methyl prednisolone group	Placebo group	Statistical significance
Death within 2 weeks		21.1%	17.9%	$p = 0.001$
Death at 6 months		25.7%	22.3%	$p = 0.0001$
Disability at 6 months	Severe	11.9%	13.6%	None
	Moderate	17.6%	16.9%	None

Death within 2 weeks:





2. **Vasodilators** (aminophylline, pentoxifylline) – decrease seizure threshold, may worsen edema, ↑risk of rebleeds.
3. **Hemostatic agents** (VIT. C, VIT. K, $CaCl_2$)
4. **Hypotonic fluids** IVI (e.g. D5W) – may worsen edema.

SURGERY

See p. Op320 >>

INDICATIONS FOR SURGERY

1. **Scalp lacerations**. see p. Op320 >>
2. Certain **open skull fractures**. see p. TrH5 >>
3. Certain **depressed skull fractures**. see p. TrH5 >>
4. Extra-axial (epidural / subdural) or intra-axial **hematoma** / **hemorrhagic contusion**:
   see p. TrH11 >> , p. TrH13 >>
   a) thickness > 15 mm (EDH) or > 10 mm (SDH)
   b) volume > 30 mL (EDH, SDH) or > 50 mL (IPH)* (esp. in temporal or posterior fossa** locations - these regions do not tolerate additional mass and > 30 mL is a threshold here).
   * more details for IPH >>
   **more details for posterior fossa mass lesions >>
   c) midline shift > 5 mm (shift > 20 mm – mortality approaches 100%).
   d) neurodeficits (e.g. GCS < 9, GCS decrease by ≥ 2 points, focal neurologic signs, refractory ICP > 22 mmHg, effaced / compressed basal cisterns, heterogenous clot on CT [indicates active bleeding]).
   N.B. in general, any neurodeficit due to extra-axial hematoma is indication for surgery!

   These **hematomas** must be evacuated immediately - patients go immediately to OR!

   Other hematomas / contusions are managed nonoperatively with serial CT and close neurological observation in a neurosurgical ICU.

   N.B. early surgery (by CT criteria) has better morbidity* and mortality outcomes vs. delayed surgery (by clinical deterioration criteria)!
   *e.g. ischemic effect of prolonged cortical compression by hematoma
5. **Symptomatic chronic subdural** hematoma. see p. TrH13 >>
6. **Penetrating injuries** (esp. with retained foreign bodies). see p. Op320 >>
7. **(Anticipated) medically refractory intracranial hypertension** → decompressive craniectomy. see p. Op320 >>

- surgical intervention is *not beneficial* in most patients with GCS 3-5 (unless pupils are reactive and CT shows no bihemispheric/multilobar dominant hemispheric injuries).
- historical paradigm: conservatively uncontrollable ICP↑ with rapid patient deterioration in ED (consciousness↓ + asymmetric findings) → think of **brain compression*** → **emergency blind (exploratory) BURR HOLES**. see p. TrH11 >> , p. TrH13 >>
  *esp. if ***skull fracture*** is present – most commonly **epidural hematoma**.

Notes on hematoma size:

- patients with severe *cerebral atrophy* (e.g. elderly) may accommodate large intracranial mass, whereas *young individuals* experience neurological deficits with relatively small intracranial hemorrhages.
- **dynamic nature**: some intracranial hemorrhages *may be actively bleeding* during initial CT - what may appear as relatively small on initial CT scan may actually become quite significant in short period of time!!! – rationale for scheduled repeat head CT (e.g. in 6 hours)

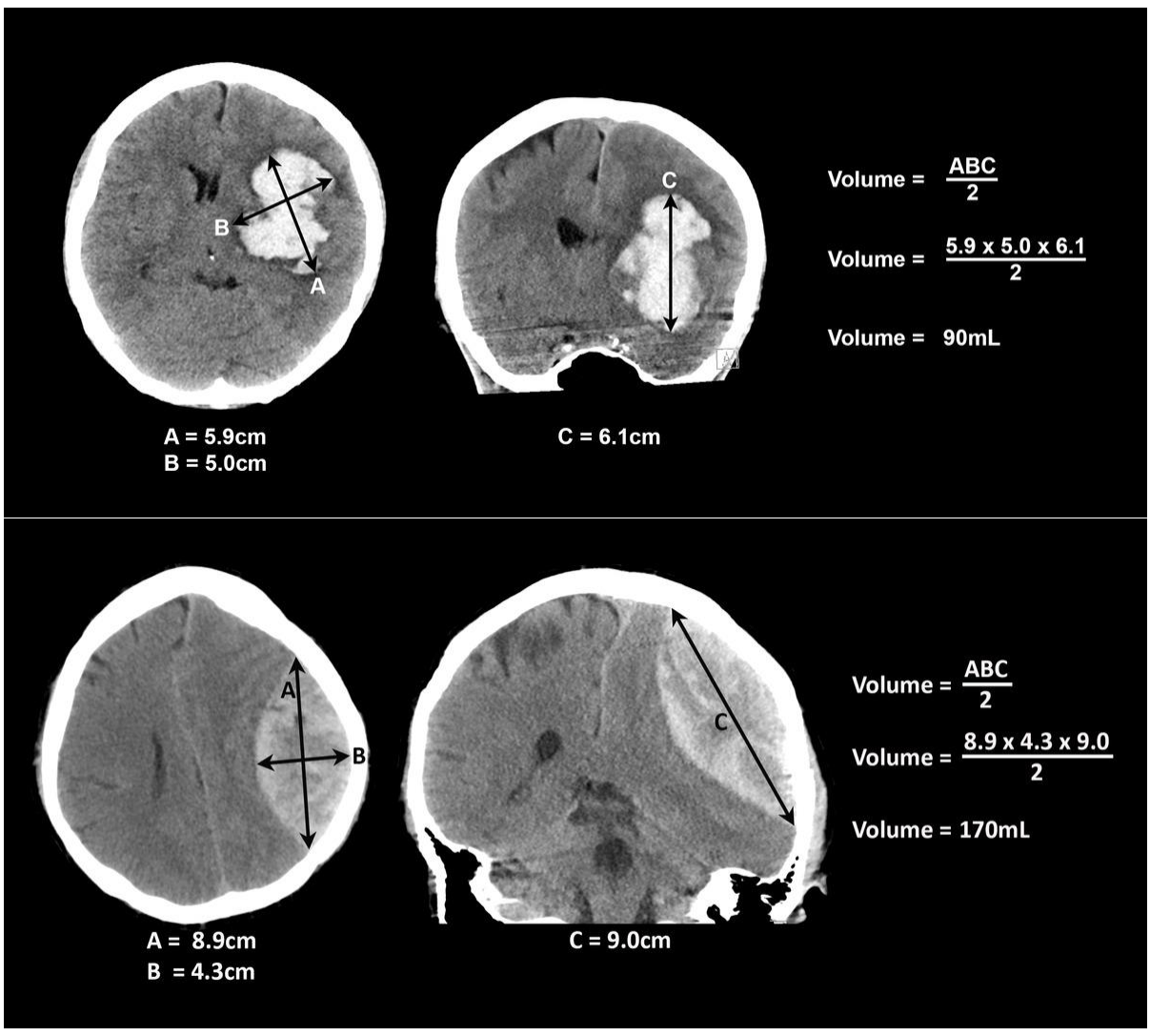
  DTICH (delayed traumatic ICH) – *see below >>*

METHOD TO MEASURE HEMATOMA VOLUME

V = ABC / 2

- identify the CT slice with the largest area of hemorrhage (Slice 1)
- measure the largest diameter, A
- measure the largest diameter 90° to A on the same slice, B.
- count the number of 10-mm slices - compare each slice with slice:
  if the hemorrhage is greater than 75% compared with slice 1, count the slice as 1.
  if the hemorrhage is 25 to 75%, count the slice as 0.5.

if the hemorrhage is less than 25%, do not count the slice.
Add up the total C.



SEATTLE INTERNATIONAL SEVERE TBI CONSENSUS CONFERENCE (SIBICC) – severe TBI management algorithm (2019)

- management algorithms for adult severe traumatic brain injury (sTBI) were omitted in later editions of the Brain Trauma Foundation's sTBI Management Guidelines, as they were not evidence-based.
- 42 experienced, clinically active sTBI specialists from 6 continents comprised the panel (April 5-7, 2019) – to provide consensus-based (class III evidence with > 80% expert agreement) management algorithms with tiered 18 interventions (use of tiers balances benefits and efficacy of intervention against inherent risks).

Adapted thresholds: **ICP** - 22 mmHg, **CPP** - 60 mmHg

TIER-ZERO

Tier Zero (Basic Severe TBI Care - Not ICP Dependent)

Expected Interventions:

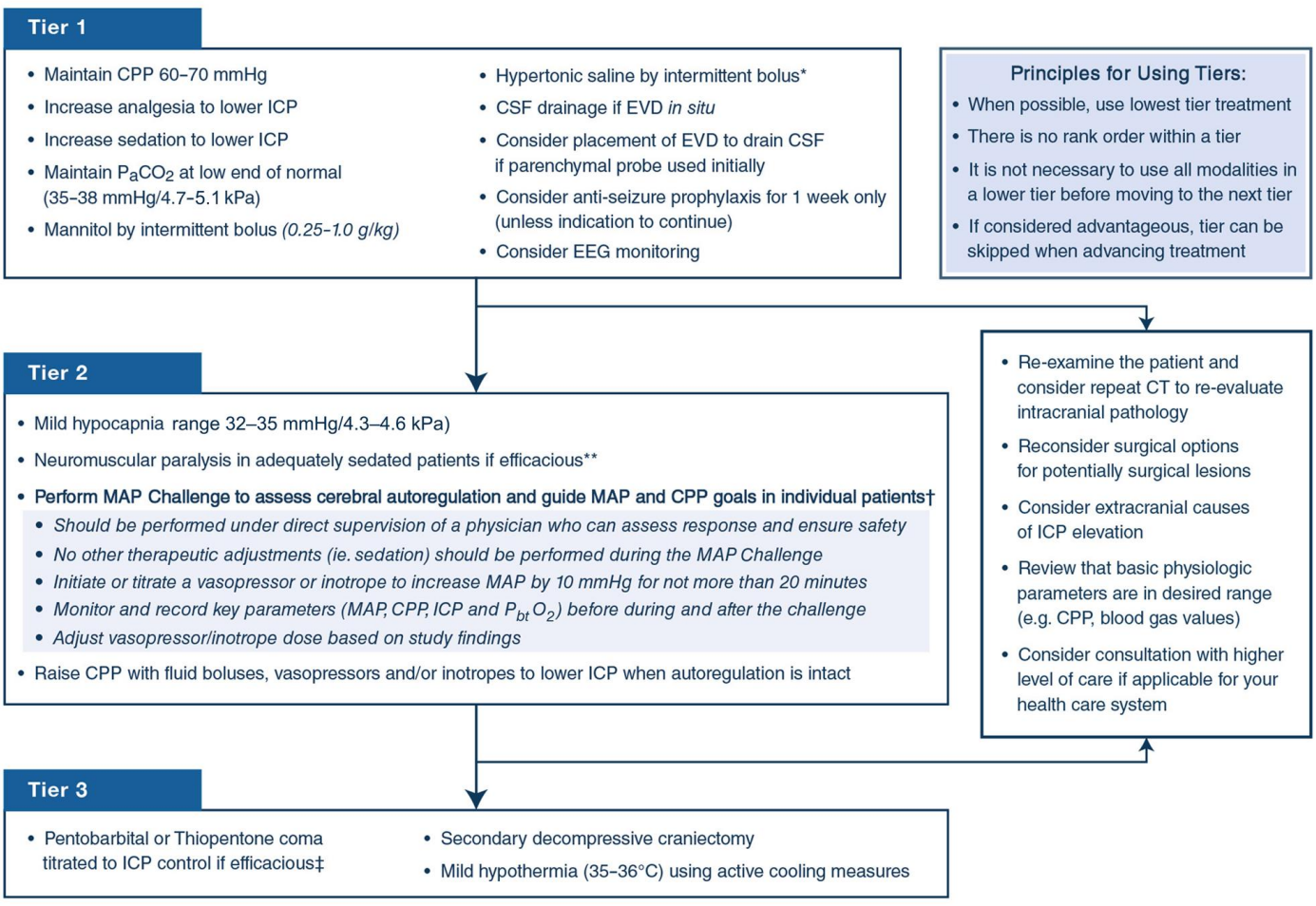
- Admission to ICU
- Endotracheal intubation and mechanical ventilation
- Serial evaluations of neurological status and pupillary reactivity
- Elevate HOB 30-45°
- Analgesia to manage signs of pain (not ICP directed)
- Sedation to prevent agitation, ventilator asynchrony, etc. (not ICP directed)
- Temperature management to prevent fever
  Measure core temperature
  Treat core temperature above 38°C
- Consider anti-seizure medications for 1w only (in the absence of an indication to continue)
- Maintain CPP initially ≥ 60 mmHg
- Maintain Hb > 7g/dL
- Avoid hyponatremia
- Optimize venous return from head (eg. keeping head midline, ensure cervical collars are no too tight)
- Arterial line continuous blood pressure monitoring
- Maintain SpO2 ≥ 94%

Recommended Interventions:

- Insertion of a central line
- End-tidal CO_2 monitoring

- goal of Tier-zero is to establish a stable, neuroprotective physiologic baseline regardless of eventual ICP readings.
- sedatives and analgesics target comfort and ventilator tolerance rather than ICP.
- temperature management targets avoiding fever (> 38 °C).

TIERS 1-3 WHEN ONLY ICP MONITOR IS PRESENT



* We recommend using sodium and osmolality limits of 155 mEq/L and of 320 mEq/L respectively as administration limits for both mannitol and hypertonic saline.
** We recommend a trial dose of neuromuscular paralysis and only proceeding to a continuous infusion when efficacy is demonstrated.
† Rosenthal G. et al 2011
‡ Barbiturate administration should only be continued when a beneficial effect on ICP is demonstrated.
Titrate barbiturate to achieve ICP control but do not exceed the dose which achieves burst suppression.
Hypotension must be avoided when barbiturates are administered.

Tier 1:

2) analgesia & sedation
3) osmotherapy
   - no recommendation for one hypertonic solution over the other.
   - recommendation for using same upper limits for serum sodium and osmolality for both agents
4) CSF drainage
5) normocarbia (35-38)

Tier 2:

1) **neuromuscular blockade**
2) **mild hypocarbia** (32-35) - caution with even mild hyperventilation when brain oxygenation monitoring is not employed!
3) **MAP challenge** – test if static pressure autoregulation (sPAR) is intact* vs disrupted:
   *then use pharmacological MAP augmentation
   - no other active changes in care during challenge.
   - use vasopressor to increase the MAP by 10 mmHg for up to 20 min.
   - observe the MAP, CPP, ICP (and PtbO2) during the challenge.
   - disrupted sPAR will present as a sustained increase in ICP with MAP elevation.
   - adjust the target MAP back to baseline (disrupted sPAR) or to the chosen new, elevated target (intact sPAR).

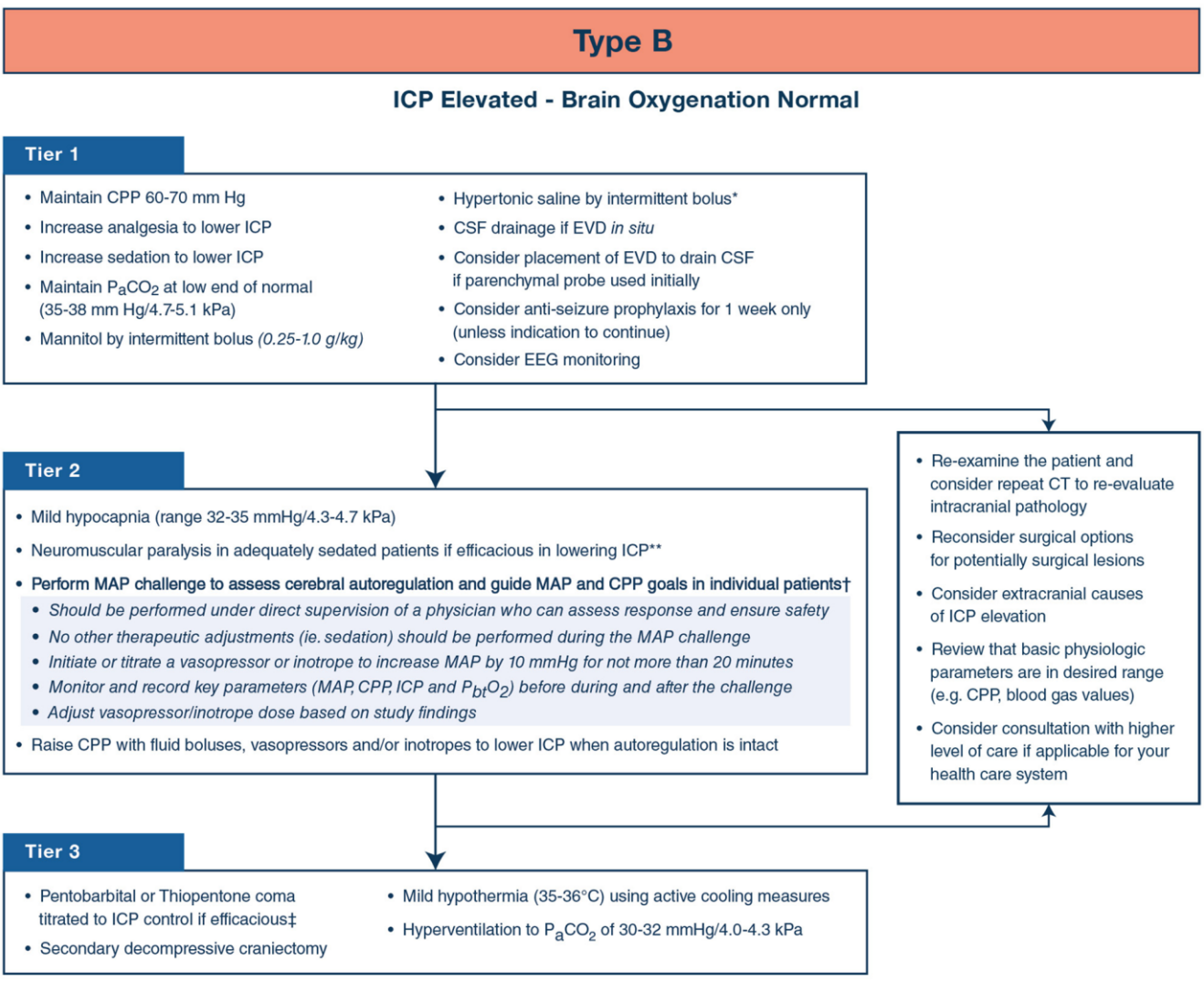
Tier 3: Greatest associated risks!

1) **mild hypothermia** (35–36 °C)
2) **high-dose barbiturate** - based on ICP and EEG response to a test dose.
   - do not increase dose if burst suppression occurs, as further reduction in ICP is not anticipated and toxicity increases (esp. hypotension);
   - endpoint of barbiturate treatment is ICP control not serum levels or EEG response.
3) **decompressive craniectomy**

TIERS 1-3 WITH BOTH ICP AND BRAIN OXYGEN MONITORS

	ICP < 22 mmHg	ICP > 22 mmHg
$P_{bt}O_2$ > 20 mmHg	Type A	Type B
$P_{bt}O_2$ < 20 mmHg	Type C	Type D

Type B (elevated ICP, normal PbtO2)
Tiers 1-3 same as with ICP monitor only, except Tier 3 allows hyperventilation to hypocarbia 30-32



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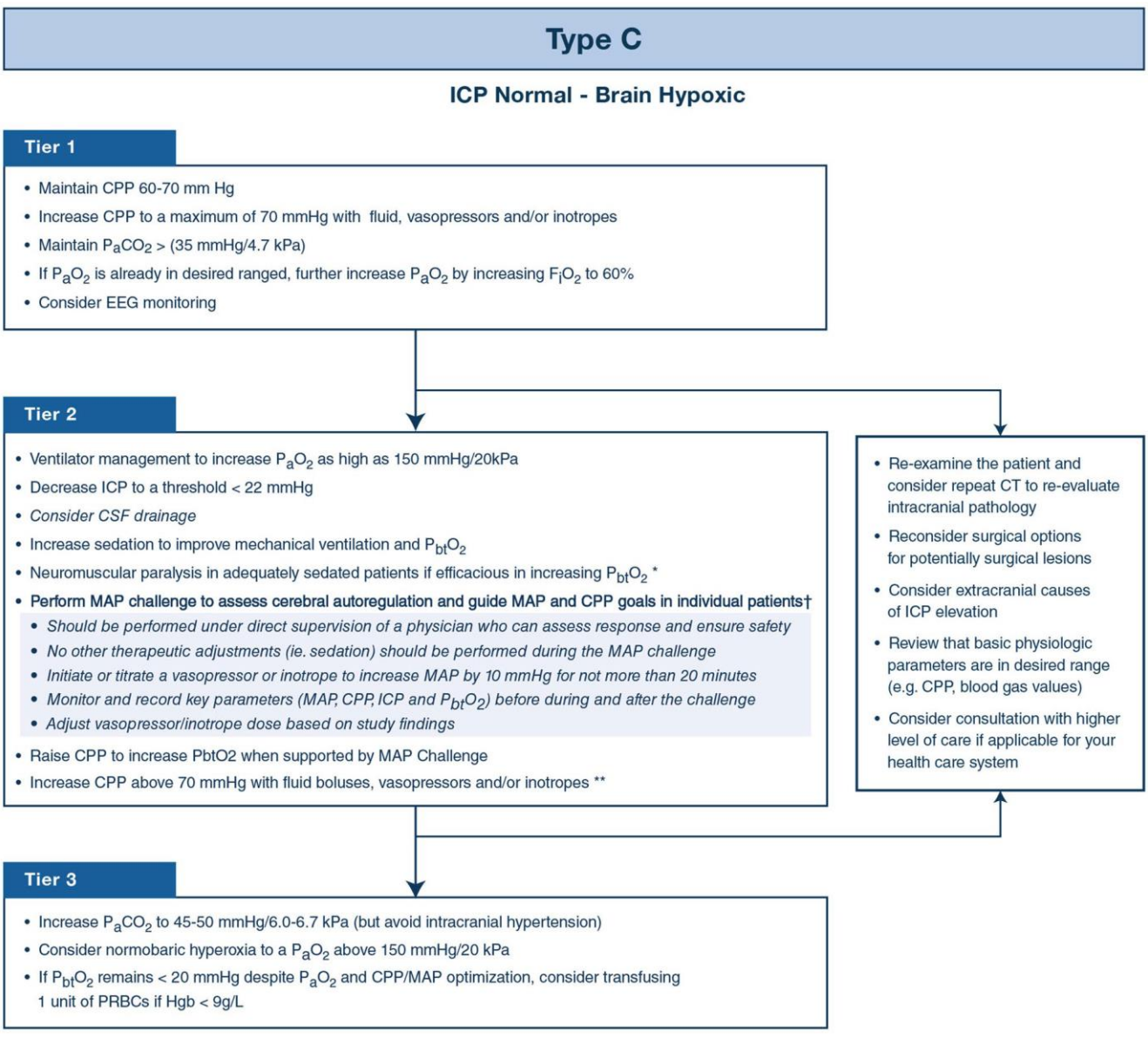
Titrate barbiturate to achieve ICP control but do not exceed the dose which achieves burst suppression.
Hypotension must be avoided when barbiturates are administered.

<u>Type C (normal ICP, low PbtO2)</u> – increasing 4 parameters: CPP, PaO2, PaCO2, Hb + consider ICP target < 22

Tier 1:
1) increase CPP to 70
2) keep normocarbia > 35
3) increase FiO2 to 0.6

Tier 2:
1) increase CPP > 70
2) increase PaO2 to 150

Tier 3:
1) induce hypercarbia 45-50
2) increase PaO2 > 150 (normobaric hyperoxia)
3) if Hb < 9, transfuse 1 unit of pRBC



* We recommend a trial dose of neuromuscular paralysis and only proceeding to a continuous infusion when efficacy is demonstrated.
** Careful monitoring for respiratory complications is required when CPP is raised above 70 mmHg (Robertson et al, 1999)
† Rosenthal G. et al 2011

<u>Type D (high ICP, low PbtO2)</u> – combination of Type B and C, except keep normocarbia (avoid hypocarbia – induces ischemia; avoid hypercarbia – worsens ICP)

Type D

ICP Elevated - Brain Hypoxic

Tier 1

- Maintain CPP 60-70 mm Hg
- Increase CPP to a maximum of 70 mmHg with fluid, vasopressors and/or inotropes
- Increase analgesia to lower ICP/improve ventilation and $P_{bt}O_2$
- Increase sedation to lower ICP/improve ventilation and $P_{bt}O_2$
- Maintain P_aCO_2 > 35 mmHg/4.7 kPa
- Mannitol by intermittent bolus *(0.25-1.0 g/kg)*
- Hypertonic saline by intermittent bolus*
- CSF drainage if EVD *in situ*
- Consider placement of EVD to drain CSF if parenchymal probe used initially
- If P_aO_2 is already in desired range, further increase P_aO_2 by increasing F_IO_2 to 60%
- Consider anti-seizure prophylaxis for 1 week only (unless indication to continue)
- Consider EEG monitoring

Tier 2

- Ventilator management to increase P_aO_2 as high as 150 mmHg/20kPa
- Increase sedation to improve ICP and $P_{bt}O_2$
- Neuromuscular paralysis in adequately sedated patients if efficacious in decreasing ICP or increasing $P_{bt}O_2$ *
- **Perform MAP challenge to assess cerebral autoregulation and guide MAP and CPP goals in individual patients†**
  - *Should be performed under direct supervision of a physician who can assess response and ensure safety*
  - *No other therapeutic adjustments (ie. sedation) should be performed during the MAP challenge*
  - *Initiate or titrate a vasopressor or inotrope to increase MAP by 10 mmHg for not more than 20 minutes*
  - *Monitor and record key parameters (MAP, CPP, ICP and $P_{bt}O_2$) before during and after the challenge*
  - *Adjust vasopressor/inotrope dose based on study findings*
- Raise CPP to decrease ICP and/or increase $P_{bt}O_2$ when supported by MAP Challenge
- Increase CPP above 70 mmHg with fluid boluses, vasopressors and/or inotropes ***

- Re-examine the patient and consider repeat CT to re-evaluate intracranial pathology
- Reconsider surgical options for potentially surgical lesions
- Consider extracranial causes of ICP elevation
- Review that basic physiologic parameters are in desired range (e.g. CPP, blood gas values)
- Consider consultation with higher level of care if applicable for your health care system

Tier 3

- Pentobarbital or Thiopentone coma titrated to ICP control if efficacious‡
- Secondary decompressive craniectomy
- Consider normobaric hyperoxia to a P_aO_2 above 150 mmHg/20 kPa
- If $P_{bt}O_2$ remains < 20 mmHg despite P_aO_2 and CPP/MAP optimization, consider transfusing 1 unit of PRBC if Hgb < 9g/L

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** We recommend a trial dose of neuromuscular paralysis and only proceeding to a continuous infusion when efficacy is demonstrated.
† Rosenthal G. et al 2011
‡ Barbiturate administration should only be continued when a beneficial effect on ICP is demonstrated. Titrate barbiturate to achieve ICP control but do not exceed the dose which achieves burst suppression. Hypotension must be avoided when barbiturates are administered.

CRITICAL NEUROWORSENING

Critical Neuroworsening

A serious deterioration in clinical neurologic status such as:

- Spontaneous decrease in the GCS motor score of ≥ 1 points (compared with the previous examination)
- New decrease in pupillary reactivity
- New pupillary asymmetry or bilateral mydriasis
- New focal motor deficit
- Herniation syndrome or Cushing's Triad which requires an immediate physician response

Response to Critical Neuroworsening

- Emergent evaluation to identify possible cause* of neuroworsening
- If herniation is suspected:
  - empiric treatment
    - hyperventilation**
    - bolus of hypertonic solution
  - consider emergent imaging or other testing
  - rapid escalation of treatment

* Possible causes of neuroworsening include:

- expanding intracranial mass lesion
- cerebral edema
- elevated ICP
- stroke
- electrolyte or other metabolic disturbance
- medical comorbidity
- medication effect
- impaired renal or hepatic function
- systemic hypotension
- seizure or post-ictal state
- hypoxemia/tissue hypoxia
- CNS infection
- infection or sepsis
- substance withdrawal
- dehydration
- hyper or hypothermia

** the hyperventilation $PaCO_2$ limit of 30 mmHg/4.0 kPa does not apply here

TREATMENT NOT RECOMMENDED FOR SEVERE TBI

1. Mannitol by continuous (non-bolus) IV infusion
2. Scheduled infusion of hyperosmolar therapy (e.g. every 4–6 h)
3. Lumbar CSF drainage
4. Furosemide
5. Routine use of steroids
6. Routine use of therapeutic hypothermia < 35 °C (due to systemic complications)
7. Routinely decreasing PaCO2 < 30 mmHg
8. Routinely raising CPP > 90 mmHg
9. High-dose propofol to attempt burst suppression
10. Barbiturates as treatment for low PbtO2 (unless barbiturates are otherwise indicated)
11. Hypothermia as treatment for low PbtO2 (unless hypothermia is otherwise indicated)
12. Hypercarbia in "type D" patients (high ICP + low PbtO2)

SAFETY OF SEDATION HOLIDAY

Condition: ICP "acceptable" for ≥ 24 hours with ongoing treatment.
Factors that matter:

1) duration of "acceptable" ICP
2) amount of treatment that is needed (tiers used)
3) pupils - normal (NP) vs abnormal (AP)
4) GCS motor score
5) Marshall Score on the most recent CT

Goal of sedation holiday – to determine if sedation can be tapered (favorable exam) vs new deficits requiring investigation

Consideration of Sedation Holiday in Patients with ICP Controlled on Tier 1 Therapy and *NO History of Needing Treatment at Higher than Tier 1*									
Marshall Classification of Most Recent CT		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

Consideration of Sedation Holiday in Patients with ICP Controlled on Tier 1 Therapy *with History of Needing Tier 2 or 3 Treatment*									
Marshall Classification of Most Recent CT		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hrs with Tier 1 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

Consideration of Sedation Holiday in Patients with ICP Controlled *on Tier 2 or 3 Therapy*									
Marshall Classification of Most Recent CT		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hrs with Tier 2/3 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hrs with Tier 2/3 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hrs with Tier 2/3 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hrs with Tier 2/3 Treatment	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

SAFETY OF ICP MONITOR REMOVAL

Condition: patient is no longer receiving ICP treatment.
Factors that matter:

1) duration of "acceptable" ICP
2) amount of treatment that was needed (tiers used)
3) pupils - normal (NP) vs abnormal (AP)
4) GCS motor score
5) Marshall CT Head Score

Most experts agree that **72 h of acceptable ICP** is safest; whereas removal at 24 h is recommended only for patients with fairly benign CTs and favorable exams.

Patients with NO intracranial hypertension since monitor insertion

NO INTRACRANIAL HYPERTENSION		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

Patients with intracranial hypertension requiring Tier 1 treatment - now controlled

MILD INTRACRANIAL HYPERTENSION		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

Patients with intracranial hypertension requiring Tier 2-3 treatment - now controlled

MODERATE-SEVERE HYPERTENSION		GCS_M 6		GCS_M 5		GCS_M 4		GCS_M 1-3	
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 24 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 48 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								
		NP	AP	NP	AP	NP	AP	NP	AP
ICP "acceptable" for > 72 hours	DI 1-2								
	EML / DI 1-2								
	DI 3								
	EML / DI III								

REHABILITATION

Guidelines by Texas Head Injury Foundation:

1. Treatment should be adjusted to patient's level of function.
2. Treatment should be consistent, repetitious, and structured.
3. As patient's ability improves, difficulty of task should be increased and degree of structure should be decreased.
4. Results of performance should be consistently provided to patient.
5. Information should be presented via more than one sensory avenue.
6. Information and tasks should be relevant to needs and interests of patient.

Treatment of **spasticity** → see p. Mov3 >>

Aim to physical & cognitive independence! (i.e. rehabilitation is continued until optimum training has been achieved or patient has become independent)

- rehabilitation is creative, cooperative effort of health-care team, patient, and family.
  - family members must be kept informed of progress; they usually wish to learn rehabilitation techniques, and instruction should be provided (family will assume primary responsibility in outpatient therapy).
- rehabilitation should begin as soon as patient is stable.
- relearning old skills / learning methods to compensate for lost skills.

1. **Physical & occupational therapy**
   - functional activities out of bed are begun as quickly as possible!

2. **Cognitive rehabilitation**
   - cognitive enhancing medications (still experimental):
     1) AMANTADINE – efficacy proven by double-blind, placebo-controlled, randomized study – speeds up recovery but final outcome the same.
     2) METHYLPHENIDATE – improved motor outcomes and attention.
     3) DONEPEZIL – improved visual and verbal memory as well as attentional deployment.
     4) LEVODOPA – alerting responses in vegetative or comatose patients.
     5) CITICOLINE – approved in 59 countries for neuroprotection and neurorepair in patients with TBI.

        *Zafonte R et al "Effect of Citicoline on Functional and Cognitive Status Among Patients With Traumatic Brain Injury (Citicoline Brain Injury Treatment Trial (**COBRIT**))* - citicoline is not superior to placebo (no significant differences in survival

or functional and cognitive outcomes in a 180-day evaluation) as acute and postacute therapy among patients with broad range of severity of TBI - worldwide use of citicoline for TBI should now be questioned

NON-NEUROLOGIC COMPLICATIONS

EARLY COMPLICATIONS

I. Pulmonary about respiratory care → see p. S30 >>

1. **PNEUMONIA** (incl. aspiration pneumonia) occurs in 30-50% intubated patients.
2. **ATELECTASIS** - common in all poorly responsive patients;
   H: chest physical therapy, adequate ventilator tidal volumes (incl. PEEP); **pneumonia** can supervene if atelectasis is not treated!
3. **NEUROGENIC PULMONARY EDEMA** (form of ARDS with increase in interstitial and alveolar fluid): suddenly raised ICP → medullary ischemia → *increased sympathetic tone* → sudden shift of intravascular volume from systemic to pulmonary circulation (via hypothalamic influence on pulmonary microvasculature) → alveoli fill with fluid as they would in congestive heart failure, but left ventricular end-diastolic pressure (measured by PCWP) is normal.
   - etiology: acute central nervous system injury (well documented in SAH but prevalent in ICH).
   - clinically: presents abruptly and progresses quickly.
   - radiographically, it is indistinguishable from cardiogenic pulmonary edema.
   - treatment: lower ICP - reverses neurogenic stimulation that causes neurogenic pulmonary edema. Intubation with mechanical ventilator support is often required. Resolution usually occurs within several days.

II. Gastrointestinal about GI care → see p. S30 >>

1. **GI HEMORRHAGE** from gastric stress erosions / ulcers.
   – most patients with severe TBI develop gastric erosions, but only few have clinically significant hemorrhages.
   – GI bleeding usually occurs in first days to 1 week after injury.
   H: prophylaxis & treatment with gastric coating agents (sucralfate), H_2 receptor blockers, frequent antacid administration.
2. **PARALYTIC ILEUS**
3. **BOWEL INCONTINENCE** - caused by underlying constipation, impaired communication and mobility (H: stool softeners, laxatives, rectal suppositories).

III. Cardiologic

- TBI (esp. with intracranial bleeding) can cause primary cardiac dysfunction - variety of **rhythm, rate, conduction abnormalities** - can be life threatening!
- adequate cardiac output is essential to ensure cerebral perfusion!

IV. Hematologic

- large number of patients demonstrate mild **coagulopathy**.
  N.B. multiple contusions detected by first CT scan = ***trauma-related coagulopathy*** that will correct itself within few hours.
- 5-10% (up to 90% patients with severe TBI) have various degrees of **DIC**.
  – DIC can develop within hours after any injury disrupting brain tissue (release of tissue thromboplastin into systemic circulation).
  – DIC increases risk of *delayed intracranial hemorrhage*.
- any coagulation abnormality must be reversed.

V. Urinary:

1. **Urinary tract infections**
2. **Urinary incontinence** – caused by UTI, impaired communication and mobility (i.e. overflow incontinence; H: patient is taken to bathroom and given opportunity to void without instrumentation every 2 hours during day and every 4 hours overnight; if unable to void or unable to evacuate urinary bladder to completion → intermittent catheterization).

LONGER TERM COMPLICATIONS

1. **Deep venous thrombosis**, pulmonary embolism
2. **Decubitus ulcers**
3. **Malnutrition**
4. **Spastic contractures** - can be prevented with aggressive physical therapy.
5. **Heterotopic ossification** (11-76%) - ectopic bone formation in soft tissue surrounding joints or around paralyzed muscles.

- pathophysiology - inappropriate differentiation of mesenchymal cells into osteoblasts; contributing factors - autonomic dysregulation (due to increased vascularity and venous hemostasis), humoral factors, local inflammatory mediators.
- risk factors - posttraumatic coma lasting > 2 weeks, limb spasticity, decreased mobility.
- risk is greatest during first 3-4 months.
- clinically: joint pain, decreased range of motion*, ± low-grade fever & periarticular swelling-warmth-erythema.
  *although ossification does not originate in joints, ankylosis occurs in ≈ 20% cases.
- location (in decreasing order of frequency): hips, knees, elbows, shoulders, hands, spine.
- diagnosis:
  1) serum **alkaline phosphatase**↑ and **ESR**↑ – nonspecific markers in early phases.
  2) **triple-phase bone scanning** – earliest diagnosis!!!
  3) **plain radiography** – lag behind triple-phase bone scan results by 2-3 weeks.
  4) **sonography**.
- prophylaxis – range-of-motion (ROM) exercises; unclear role - NSAIDs, low-dose radiation, bisphosphonates
  use of forceful ROM is somewhat controversial because it is thought to be cause of heterotopic ossification, but data from human studies have not demonstrated this mechanism.
- treatment:
  1) **bisphosphonates** - prevent crystallization of calcium phosphate (but have no effect on mature ectopic bone).
  2) for functional impairment - ***surgical excision*** delayed 12-18 months to allow heterotopic bone to mature (to minimize risk of recurrence).

NEUROLOGIC COMPLICATIONS & SEQUELQE

I. VASCULAR

1. **Cerebral fat embolism** see p. Vas3 >>

2. **Epidural Hematoma** see p. TrH11 >>

3. **Subdural Hematoma** see p. TrH13 >>

4. **Arterial rupture, occlusion, dissection** see p. Vas11 >>

- high mortality - 23-43%.

ICA most commonly injured at skull base
  - manifests as pain, pharyngeal bleed, cranial nerve palsies, distal thrombemboli

VA most commonly during cervical motion that injures vessel intima.
  - causes may be trivial (chiropractic manipulations, violent sports)
  - unilateral VA injury may be asymptomatic (but thrombosis may extend to basilar)

5. **Venous sinus injuries** with overlying skull fractures. see p. Op320 >>
   N.B. posterior fossa / occipital EDH may compress venous sinuses and imitate venous sinus thrombosis on imaging – erroneous heparin administration may cause more harm (e.g. EDH expansion).

6. **Carotid-cavernous fistula** see p. TrH9 >>

7. **SAH** - most common type of traumatic intracranial hemorrhage (some blood extravasation into subarachnoid spaces is to be expected in almost any head injury!; present on CT in 26-53% of severe TBI cases):
   a) tears of subarachnoid vessels (most frequently leptomeningeal vessels at vertex - greatest brain movement at impact).
   b) blood from ventricles (reached subarachnoidal space with CSF flow)

- in most cases, SAH per se is of little clinical importance* (except to indicate that brain has been injured) - no specific treatment is needed.
  *but SAH doubles risk of death (because of associated lesions) >>
- detected by CT in 26-53% cases of severe TBI; repeat CT - to exclude possibility of additional intracranial loculated blood.
  - traumatic SAH is typically located in ***interhemispheric or sylvian fissure***, ***cerebral sulci*** (vs. SAH from ruptured cerebral aneurysm – primarily in basal cisterns).
  - differentiation of *interhemispheric blood* from relatively attenuating *falx cerebri* may be difficult (N.B. blood extends into paramedian sulci).
  - with extensive SAH, brainstem, infundibulum, carotid branches are bathed by blood, and they may appear as filling defects.

  N.B. SAH may render basal cisterns isodense with brain, simulating cisternal compression!
- **traumatic basal SAH** - due to blow to side of chin or jaw in alcohol-induced fistfight - ruptures vertebral artery as it enters cranial cavity (degree of traumatic force required to cause basal SAH is less than reasonably expected).
- complications:
  1) *communicating hydrocephalus*.
  2) *vasospasm* (most intense during 2nd week after TBI) → delayed ischemia, infarction. H: NIMODIPINE

		Delayed Ischemia	
Degree of tSAH	Number	yes	no
small (< 1 mm)	101	3	98
extensive (> 1 mm)	29	7	22
Total	130	10	120

In the patients with symptoms of delayed ischemia, vasospasm was angiographically proven!
Taneda M, Kataoka K, Akai F, et al.: Traumatic subarachnoid hemorrhage and its treatment with Nimodipine. J Neurosurg 85:82-89, 1996

8. **Chronic calcified scalp hematoma** (seen chiefly in older patients prone to repeated head injuries, such as epileptics and recidivist alcoholics); underlying vault may be thickened.

9. **Intraventricular hemorrhage** (1.5-10%) – ruptured subependymal veins.
- intraventricular blood is indicator of severe TBI.
- unclotted blood may layer in most dependent part of ventricles.
- hydrocephaly is a risk (N.B. ventricles may remain small due to compression by brain edema!)

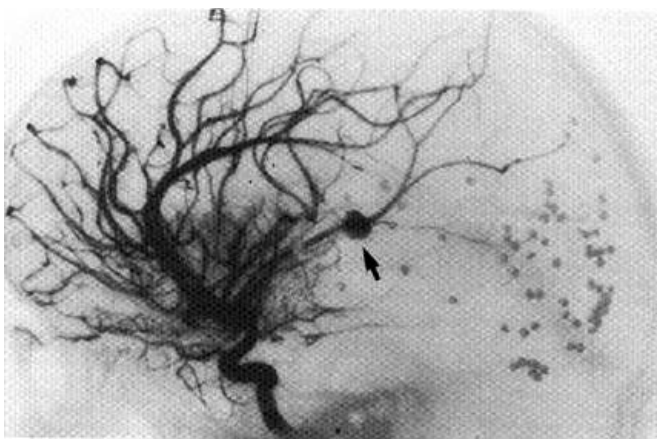
10. **Cerebral thrombosis**

ARTERIAL THROMBOSIS - caused by injury to artery wall.
- thrombosis of contralateral PCA is rare complication of brain distortion by epidural or subdural hematoma.
- thrombosis occasionally develops several days after TBI in elderly patients with cerebral arteriosclerosis (it is difficult to assess role of cerebral trauma in production of these strokes).

VENOUS SINUS THROMBOSIS → severe ICP elevations and venous infarction.
- treatment – anticoagulation (significant risk in those with acute head injuries!); if thrombosis progresses → direct intracranial intravenous thrombolysis / thrombectomy.

11. **Traumatic aneurysms** (< 1%)
- etiology:
  a) ***penetrating vessel injuries*** (stab wounds > gunshot wounds) → **pseudoaneurysms** at distal sites in intracranial circulation (can appear weeks to months after injury).
  see p. Vas25 >>
  b) ***blunt vessel injuries*** → **true aneurysms** (intact adventitia); examples:
     1) head hyperextension and rotation → aneurysm on ICA at skull base;
     2) closed head injury with skull fracture → aneurysm on peripheral intracranial vessel (esp. distal ACA, e.g. pericallosal artery - traumatized at falcine edge).
- present with delayed SAH or intracerebral hematoma.
- diagnosis - angiography - absolutely indicated ASAP in stab injuries! (intracerebral hematoma may harbor and simultaneously obscure traumatic aneurysm)
  - in CT / MRI era, angiography is rarely employed in evaluating head trauma - discovery of traumatic aneurysms is usually delayed until unexpected neurological event occurs.
  - traumatic aneurysms are unrelated to arterial bifurcations.
- treatment (best results if still unruptured) - ***surgical*** or ***endovascular***.
  - ***anticoagulation*** for pseudoaneurysms may minimize thrombus propagation and embolization (controversial).

Acute traumatic arterial aneurysm (carotid angiogram, lateral projection): metallic fragments are seen posteriorly; vessels around them are stretched and narrowed, and rounded collection of contrast medium, representing traumatic aneurysm, is seen (*arrow*), unrelated to arterial bifurcation:



12. **Intracerebral hemorrhage (tICH)** (4-23%); see also p. Vas20 >>

Differences between spontaneous ICH (sICH) and traumatic ICH (tICH):
- tICHs are more likely to be lobar
- tICHs are more likely to be superficial
- tICHs are more likely to have a medium-sized volume (25–65 cc).

- caused by:
  a) ***shearing forces*** that mechanically stretch and tear deep small-caliber arterioles – resulting small petechial hemorrhages subsequently coalesce to form ICH.
     - 85% in frontal and temporal lobes; multiple in 20% cases.
     - on occasion, ICH (ipsi- or contralateral) develops after other intracranial hematoma evacuation
  b) ***penetrating injury*** - occur wherever vessels are interrupted along tract of missile.
- occur with *all degrees* of TBI; linear fracture is found in 40-80% cases.
- most prominent in white matter (vs. contusions).
- reach maximum size by 2-3 days following head injury.

Clinical features:
- 50% of patients sustain loss of consciousness at time of impact; some regain consciousness for lucid interval, and 1/3 have no loss of consciousness at all.
- focal brain injury (similar to contusion or extradural collections).
- brain compression → herniation.

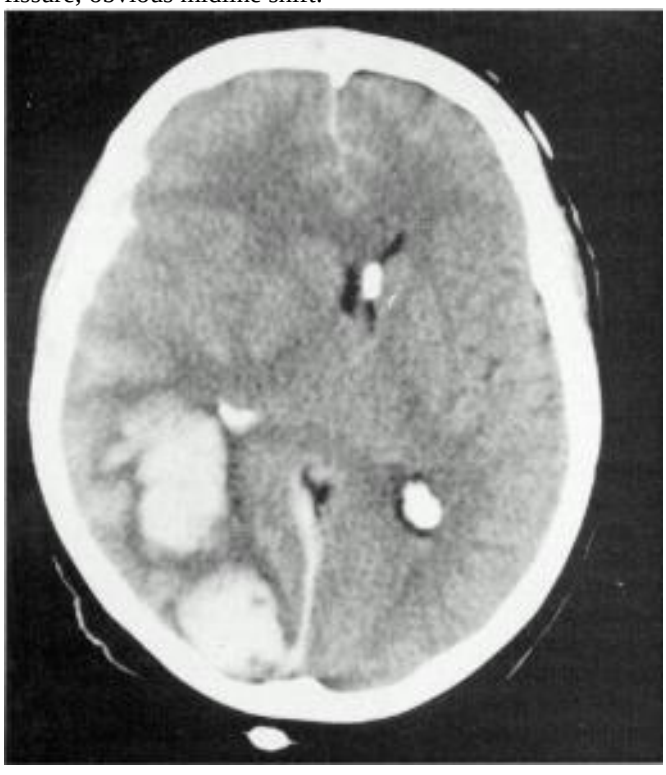
Diagnosis - **CT** (hemorrhagic contusion ÷ large blood collection) - focal area of increased attenuation*, surrounded by low attenuation (edema or contusion); irregular and may have mass effect; over time becomes well demarcated, isoattenuating and then hypoattenuating.

*ICH is made of > 66% clots – appears more homogenous than contusion!

DELAYED HEMORRHAGE (DTICH – DELAYED TRAUMATIC ICH) S. ***BOLLINGER'S SPÄT-APOPLEXIE*** (occurs in 1-7% TBI patients) – ICH that develops in the part of the brain that on the initial CT looked "normal"; may manifest as apoplectic event even after 10 days of asymptomatic interval.

Yamaki et al. (1990): only 84% of all ICHs reached the maximum size within 12 hours from initial CT scan!

Noncontrast CT - occipital and temporal intracerebral hematomas, surrounded by mild edema and hemorrhagic contusion; small interhemispheric subdural hematoma in posterior interhemispheric fissure; obvious midline shift:



Treatment:

a) ***conservative management***
b) ***surgical evacuation*** (for indications – *see above*); see p. Vas20 >>

Pathophysiological pros for early surgical evacuation:
- contused brain does not recover but appears as encephalomalacic brain tissue loss on convalescent phase imaging - removing TICH does not increase tissue loss.
- extravasated blood is believed to be neurotoxic, leading to secondary injury that may be avoided by surgical removal.
- larger TICHs may be associated with an ischaemic penumbra of brain tissue that could be salvaged.
- some TICHs expand to the point at which they cause mass effect with high ICP, resulting in secondary brain injury.

Surgical Trial In Traumatic intraCerebral Haemorrhage (STITCH)

Gregson BA et al. Surgical Trial In Traumatic intraCerebral Haemorrhage (STITCH): a randomised controlled trial of Early Surgery compared with Initial Conservative Treatment. Health Technol Assess 2015;19(70).

- randomized trial: Early Surgery (within 12 hrs) vs. Initial Conservative Treatment (delayed evacuation if it became clinically appropriate); tICH > 10 mL.

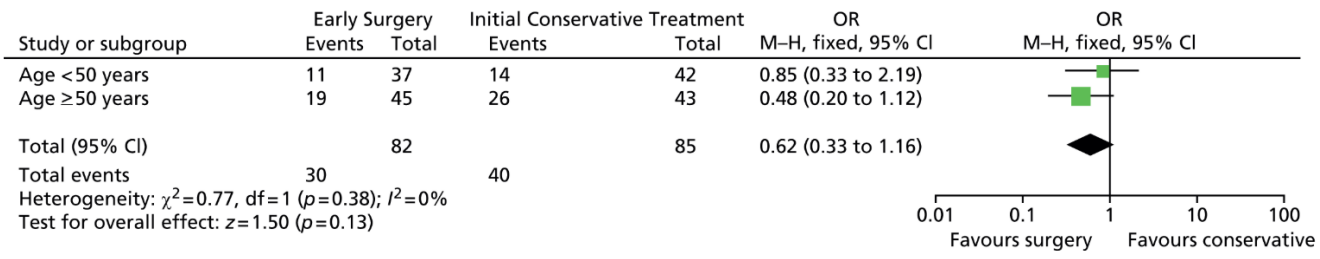
cf. STICH trial – nontraumatic ICH – see p. Vas20 >>

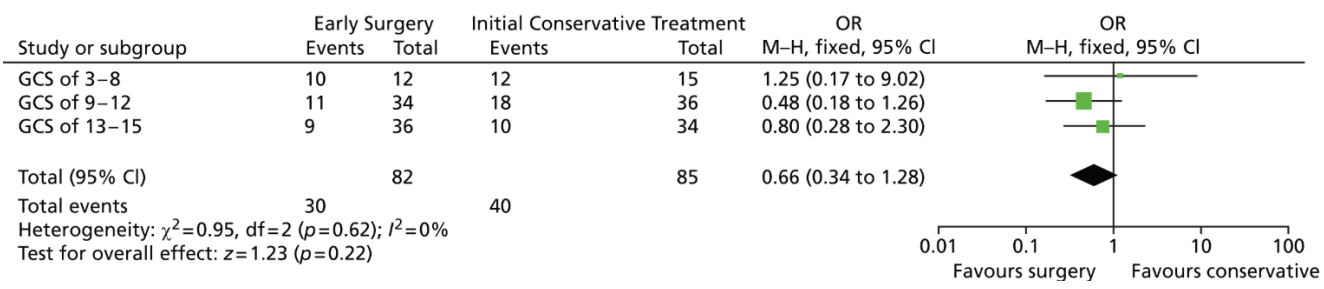
- 170 patients were randomised from 31 centres in 13 countries
- clinical equipoise - only patients for whom the responsible neurosurgeon was uncertain about the benefits of either treatment were eligible.
- 85% of patients had a motor score on the GCS of ≥ 5.
- volume of the largest hematoma was 10-97 ml, with a median of 23 ml.

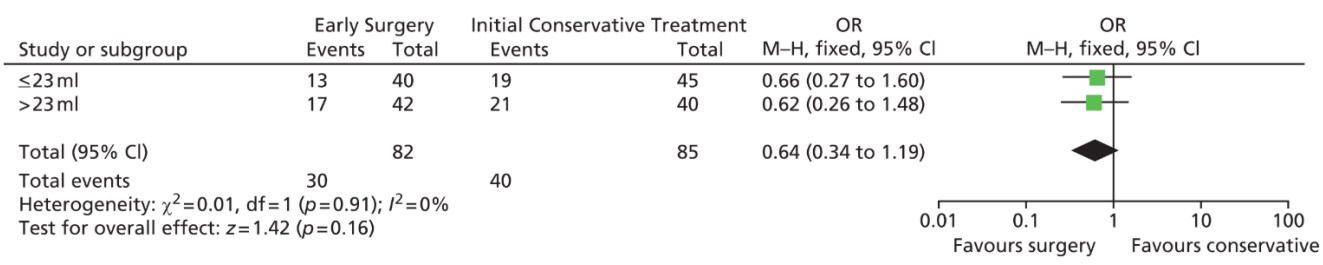
Early Surgery may be a valuable tool in the treatment of tICH, especially if the **GCS is 9-12** – analogy with SDH / EDH management; those with GCS of 13–15 can probably be watched carefully for any deterioration; if GCS has dropped below 8, surgical intervention appears to be less effective.

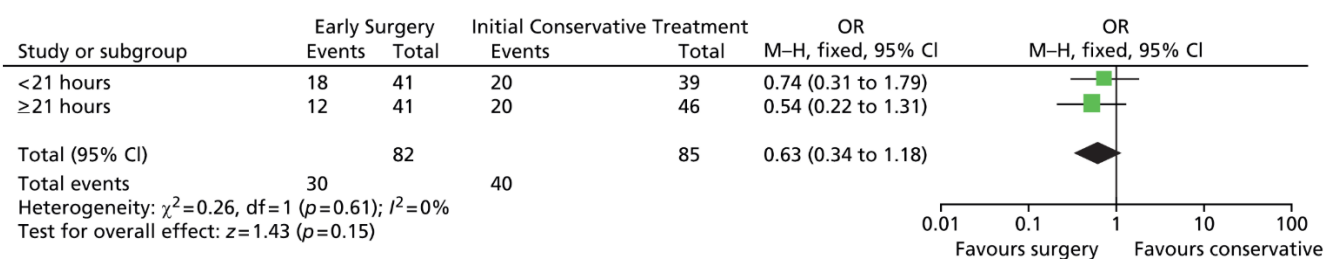
At 6 months:
- Early Surgery patients were 10.5% more likely to have a favorable outcome (absolute benefit), but this difference *did not quite reach statistical significance* because of the reduced sample size (63% vs. 53%, odds ratio 0.65; 95% confidence interval (CI) 0.35 to 1.21; p = 0.17].

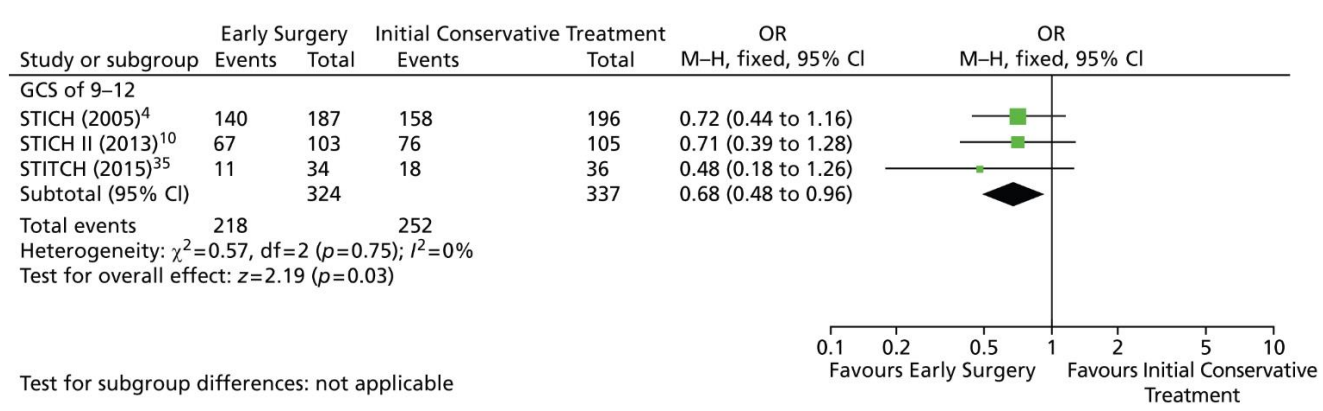
– Mortality was *significantly* lower in the Early Surgery group (15% vs. 33%; absolute difference 18.3%; 95% CI 5.7% to 30.9%; p = 0.006).











Other studies (observational)

Matheisen et al. (1995): patients with an admission GCS of ≥ 6 and a lesion volume of ≥ 20 ml who had surgery without previous neurological deterioration had significantly better outcomes than those who did not have surgery or had surgery after deterioration. None of the patients who had surgery before any deterioration died or was vegetative, as opposed to 39% of those who had surgery after deterioration and 50% of those who did not have surgery.

Mathiesen T, Kakarieka A, and Edner G. Traumatic intracerebral lesions without extracerebral haematoma in 218 patients. Acta Neurochir 1995;137:155-63

Choksey et al. (1993): 38% of patients with a low GCS and a volume of the TICH > 16 ml who had surgery had a poor outcome, compared with 56% of those who did not have surgery.

Choksey M, Crockard HA, and Sandilands M. Acute traumatic intracerebral haematomas: determinants of outcome in a retrospective series of 202 cases. Br J Neurosurg 1993;7:611-22

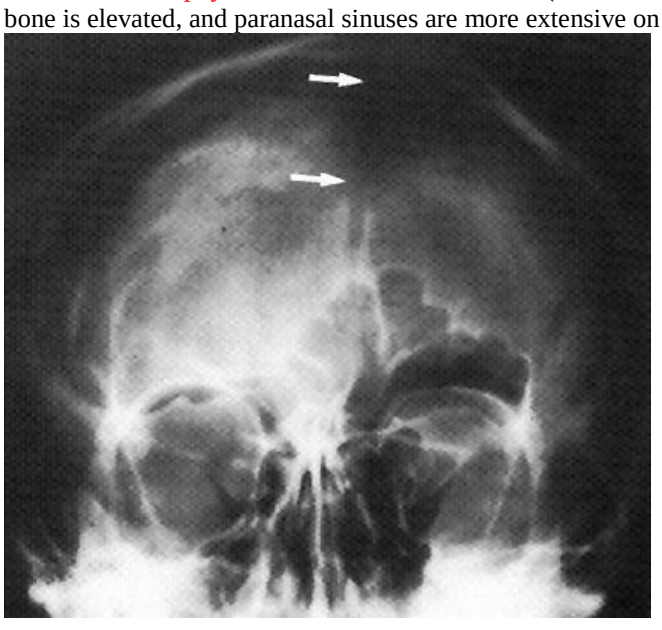
Zumkeller et al. (1992): poor-outcome rate in the operated patients was 29%, compared with 59% in the non-operated group.

Zumkeller M, Hollerhage HG, Proschl M, and Dietz H. The results of surgery for intracerebral hematomas. Neurosurg Rev1992;15:33-6

Contusions, intracerebral hematomas may show remarkable resolution, but more common end results are **focal atrophy** or **encephalomalacia** (extensive softening and cyst formation)

– MRI may show evidence of past hemorrhage (prolongation of T1 and T2).
– injury early in life (vascular damage rather than direct trauma) → **traumatic hemiatrophy** - affects both brain and overlying skull.

Cranial hemiatrophy - left hemicranium is smaller (*arrows* indicate groove for superior sagittal sinus); left petrous bone is elevated, and paranasal sinuses are more extensive on affected left side.



II. INFECTION

- etiology / risk factors:

1) ***penetrating*** injuries.
2) ***skull fractures*** - open depressed fractures, basilar fractures with CSF leak, linear fractures that extend into paranasal sinuses or middle ear.
3) ***iatrogenic*** - ICP monitoring, surgical interventions.

1. Cranial (**osteomyelitis**) see p. Inf7 >>
2. Epidural (**abscess**) see p. Inf5 >>
3. Subdural (**empyema**) see p. Inf5 >>
4. Subarachnoid (**meningitis**) see p. Inf3 >>
5. Intracerebral (**abscess**) see p. Inf5 >>

III. CSF & MENINGES

1. **CSF leaks** (3%, but 5-10% in basal skull fractures) see p. S64 >>

2. **Post-traumatic hydrocephalus** (COMMUNICATING > NONCOMMUNICATING) – due to *SAH*, *intraventricular hemorrhage*. see p. S60 >>
   - unexplained hydrocephalus after acute TBI → prompt thorough examination of posterior fossa (epidural or subdural hematomas may be missed on routine axial CT scans).
   - *normal pressure hydrocephalus* may also occur – diagnosis is difficult: see p. S62 >>
     – 86% severe TBI patients demonstrate some degree of ventriculomegaly on follow-up CT (secondary to diffuse brain atrophy).
     – TBI patients often have memory difficulties and gait abnormalities secondary to head injury.

   N.B. *normal pressure hydrocephalus* presents as neurologic deterioration weeks to months following TBI; high-volume lumbar puncture improves neurologic condition.

3. **Subdural hygroma** see p. TrH15 >>

4. **Leptomeningeal cyst** (s. **growing fracture**) see p. TrH5 >>

5. **Pneumocele** (s. **pneumocephalus**) - air in cranial cavity after *penetrating injury* (air sucked into penetration cavity behind projectile) */ skull fracture involving sinuses*:
   a) *frontal* pneumocele (after fracture of frontal sinus)
   b) *occipital* pneumocele (after fracture through mastoid).
   - ***extradural*** pneumocephalus – no significance; ***intradural*** pneumocephalus – risk of CSF leak.
   - clinically:
     a) asymptomatic
     b) headaches, mental symptoms.

     N.B. signs of ICP↑ do not develop (unless pneumocele becomes infected or filled with CSF).
   - diagnosis – **X-ray**, **CT**: air may not appear for several days after injury (and then only after patients sneeze or blow nose).
   - treatment (rarely indicated per se; if spontaneous air absorption does not occur): dura repair, sinus cranialization.

IV. POST-TRAUMATIC EPILEPSY

see p. E9 >>

V. POST-TRAUMATIC MOVEMENT DISORDERS

see p. Mov22 >>

VI. POSTCONCUSSION (S. POSTTRAUMATIC) SYNDROME

- frequent (30-50%) sequela of MILD head injury.
- rarer in children (but symptoms tend to be more severe).
- diagnosed in DSM-IV as cognitive disorder not otherwise specified.

PATHOPHYSIOLOGY

1. Alterations in excitatory amino acids, catecholamines, cations (≈ similar to migraine)
2. Subtle axonal shearing lesions
3. Microscopic cortical contusions.

Even mild trauma can cause neuronal damage!

CLINICAL FEATURES

- large array of symptoms and signs (of at least 3 months duration):

Syndrome can be extremely debilitating!

1) **headaches** (30-90%):
   – headaches are more frequent and with longer duration in mild rather than severe head injury.
   – **triptans** can abort chronic post-traumatic headaches (PTHs) attributable to mild head trauma.
   – TOPIRAMATE appears to be an effective headache prophylactic therapy in chronic PTH.
   – low doses of **tricyclic antidepressants** appear to have little efficacy.

   a) ***tension-type headaches*** (85% of all post-traumatic headaches); one cause may be temporomandibular joint injury.
   b) ***migraine-like*** (also very common) can develop in hours to weeks after mild TBI.
      – immediately after mild TBI in sports children ÷ young adults may have first-time migraine with aura; this may be triggered multiple times after additional mild head injury - termed *FOOTBALLER'S MIGRAINE*.
   c) ***referred headaches*** from neck injuries (myofascial, intervertebral disc, facet joint injury).
   d) ***greater occipital neuralgia*** from direct blow to nerve or due to suboccipital muscle spasm (superior trapezius, semispinalis capitis). H: local anesthetic nerve blocks (can be combined with injectable corticosteroid).
2) **dizziness** (34-50%) – caused by: labyrinthine concussion, benign positional vertigo, brain stem injury.
3) **nonspecific psychological symptoms** (> 50%) – fatigue (43%), irritability, anxiety, depression, disruption of sleep patterns, loss of concentration and memory (20-40%), light / noise sensitivity (10%), *post-traumatic stress disorder*.
   – neuropsychological testing has documented cognitive impairments (reduction in information processing speed, attention, reaction time, and memory for new information).
4) **blurred vision** (14%) usually caused by convergence insufficiency.
5) **hyposmia** (≈ 5%) caused by damage to olfactory filaments.

- *no direct correlation* between ***TBI severity*** and ***development of PCS*** - symptoms may develop in patients who were only dazed (did not lose consciousness) by injury.
- on objective examination - minimal or no neurologic abnormalities (fixed neurologic deficits are not part of PCS).

DIAGNOSIS

- **neuropsychological testing**!!!

- **MRI** role is not yet defined - *symptoms may appear in absence of any imaging evidence of structural abnormality*!

  N.B. CT / MRI may be warranted to rule out delayed complications of TBI! (e.g. chronic subdural hematoma may mimic PCS)
- **EEG**, **evoked potentials** are also normal.
- when patients have unusual / persistent complaints, consider possible contributions of *personality disorders*, *psychosocial problems*, or *secondary gain** ("*COMPENSATION NEUROSIS*" or malingering).

*N.B. patients with claims in compensation case, however, have similar symptoms that improve with time and similar cognitive test results as those without claims (for many claimants, end of litigation does not mean end of symptoms or return to work - they are not cured by verdict).

TREATMENT

Simple reassurance is often major treatment – inform patient that *cognitive-emotional dysfunction, headaches and other somatic symptoms are not uncommon* and that *most patients improve after 3-6 months*!

1. Supportive **psychotherapy**
2. **Cognitive retraining** *see below (REHABILITATION)*
3. **Physiotherapy**
4. **Antidepressant** and **antianxiety-type** medications.
5. Headaches often respond to:
   a) PROPRANOLOL (30-60 mg/d in three divided doses), or occasionally to **calcium channel blockers**.
   b) TOPIRAMATE appears to be effective
   c) **NSAIDs**
   d) **tricyclic antidepressants**

PROGNOSIS

- symptoms usually last 2-6 months (typically, peak 4-6 weeks following injury), but symptoms may persist for years (some are disabled permanently); risk factors for persistent symptoms:
  1) women
  2) age > 40 years
  3) prior history of head trauma
  4) neurotic symptoms before injury
  5) domestic or financial difficulties.
- 2 years after injury, 20% patients still complain of headaches.
- cognitive deficits usually resolve within 3 months after injury.

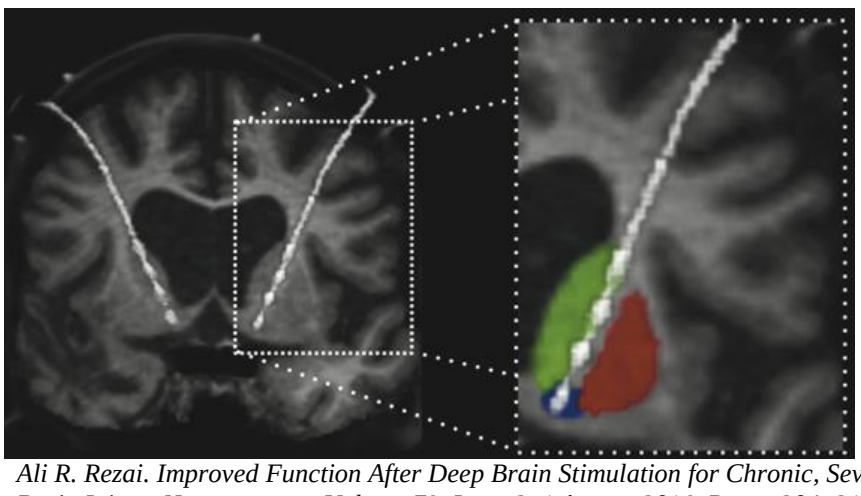
VII. POSTTRAUMATIC PSYCHIATRIC DISORDERS

Serious residual mental problems are found only after severe TBI.

- almost every patient with severe TBI shows mental changes immediately after recovery of consciousness (frequently ***steps to complete recovery*** are semistupor, bewilderment, Korsakoff-like phase, euphoria).

1. Posttraumatic **agitation** / **aggression** is common (≈ 25% patients are found to be aggressive during follow-up period of 5 years).

- associated with frontal injuries, esp. severe TBI
- consistently associated with *depression*, *young age*.
- treatment steps:
  1) first treat / eliminate ***agitating factors***:
     – impaired recognition and inability to communicate are often agitating factors.
     – pain
     – infection
     – electrolyte imbalance
     – adverse effects of drugs (esp. avoid centrally acting drugs).
     – psychosis, insomnia.
  2) ***environmental modifications*** - tools for orientation, minimizing unnecessary stimuli (noisy rooms, bright lights, frequent visitors).
  3) ***drugs***: high-dose β-blockers (particularly PROPRANOLOL), anticonvulsants (e.g. LAMOTRIGINE, DIVALPROEX), antidepressants (particularly SSRIs), AMANTADINE.
     Antipsychotics are controversial - may cause excessive drowsiness, exacerbate cognitive deficits, and inhibit neuronal recovery.
  4) ***restraints*** - use only as last resort to secure patient, staff, and visitor safety
     Physical restraints often exacerbate posttraumatic agitation!
     – less restrictive restraints, such as net-covered beds (e.g. Posey or Vail beds), has become acceptable and popular.
  5) ***DBS*** (placed bilaterally in the nucleus accumbens and anterior limb of the internal capsule to modulate the prefrontal cortex) is promising.
     – DBS lead (inset) is directed through the anterior limb of the internal capsule and striatum, passing between the caudate (green) and putamen (red) with the tip in the nucleus accumbens (blue).



Ali R. Rezai. Improved Function After Deep Brain Stimulation for Chronic, Severe Traumatic Brain Injury. Neurosurgery, Volume 79, Issue 2, 1 August 2016, Pages 204–211,

2. Posttraumatic **depression** - common sequela of TBI (major depression is found in 40-44% hospitalized patients).

- associated with left frontal injuries.
- may lead to cognitive decline, anxiety disorders, substance abuse, dysregulation of emotional expression, aggressive outbursts.
- treatment:
  1) early grief reaction is better treated with supportive therapies
  2) METHYLPHENIDATE
  3) SERTRALINE
  4) AMANTADINE

  N.B. if drugs are used, carefully consider adverse effects (esp. worsening sedation or cognitive impairment).

3. **Psychosis**

- ***transient psychotic episodes*** are not uncommon, but ***long-continued psychosis*** is rare.
- relationship of head injury to subsequent development of psychoses is medicolegal problem (severe TBI may adversely influence preexisting brain pathology and accentuate organic dementia).
- unlikely that TBI could have any direct causal relationship to psychoses that do not have definite structural pathology (e.g. schizophrenia, manic-depressive), but indirect relationship with chemical intermediaries may be postulated.

4. **Personality change** sometimes results from head trauma, even in absence of obvious cognitive changes.

5. **Chronic amnestic disorder** can result from damage to diencephalic / mesiotemporal structures (e.g. mamillary bodies, hippocampus, fornix).

6. **Delayed dementia** after TBI and SCI - could be a consequence of persistent neuroinflammation from CNS-directed autoimmunity (CNS is normally immuniprivileged cf. sympathetic ophthalmia)

PROGNOSIS, OUTCOME

- depends most on nature, site and severity of **brain** damage (than on injury to **skull** or **scalp**).

TBI may result in death, vegetative state, partial recovery, or full return to work.

Hippocratic aphorism: "*No head injury is so serious that it should be despaired of nor so trivial that it can be ignored*."

- adults reach maximum recovery by ≈ 6 months; smaller adjustments continue for perhaps as long as 2 yrs (recovery in children takes even longer).
- *common long-term deficits are* COGNITIVE (recent memory, abstract thinking, rapid information processing, etc).
  N.B. ***neuropsychologic disturbances*** (e.g. postconcussion syndrome) are more common cause of disability in social relations and employment than are specific ***neurologic deficits***!
- **DRIVING INDEPENDENTLY** is of particular importance to most patients.
  – estimating driving ability on basis of ***cognitive testing*** is difficult (although visual spatial skills, reaction times, and awareness of deficits correlate with driving abilities).
  – actual ***road tests*** may be needed.

Moderate TBI

- at 3 months after trauma - 70% are unable to return to work, 90% have memory difficulties, > 90% have persistent headaches.

Severe TBI

- mortality decreased from 50% to 25% over the last decades.
- only 7% have good outcome with moderate disability.
- most are left with at least some residua (small percentage remain in persistent vegetative state); severe cognitive difficulties are rule rather than exception.

5 MOST POWERFUL FACTORS PREDICTING OUTCOME

Notably, of these five major predictors, only the hypotension is amenable to medical manipulation!

1. TBI degree (as measured by ***initial postresuscitation GCS score***) - early predictor of patient's overall outcome!
   Up to 85% patients with GCS 3-4 die 24 h after injury, yet number of patients with poor initial prognosis (incl. absent pupillary light responses) survive, suggesting that *aggressive management is justified in virtually all patients*!

GCS score	Mortality
3	65%
4	45
5	35
6	24
7-13	10-15

If the initial* GCS score is reliably obtained and not tainted by prehospital medications or intubation, approximately 20% of the patients with the worst initial GCS score will survive and 8%-10% will have a functional survival (GOS 4-5).

*the optimal time after injury for determining the initial GCS is the key issue for further research

2. Increasing age – independent predictor of poor outcome!
- the *critical age threshold* for worsening prognosis appears to be above 60 in a review of Class I and II studies (this may be an artifact of the age grouping used by various authors in converting continuous data into categorical data); some studies report outcome as a *continuous function of age without threshold values*.
- **aged brain**:
  1) decreasing capacity for repair after TBI
  2) increasing frequency of intracranial hematomas with the largest intracerebral hematomas observed in the oldest groups.
- **type of injury** that occurs frequently in each age group (e.g. increasing proportion of falls and pedestrian accidents with advancing age).
- **decline in health** as one ages may predispose the aged to systemic complications after TBI.
- children outcome is better than that of adults (patients < 20 yrs are > 3 times more likely to survive than those > 60 yrs).

3. Fixed dilated pupil; see criteria for pupillary exam >>

% Vegetative/Dead (Glasgow Outcome Scale Score [GOS] 1, 2):

First Author	# of Patients	Bilateral Reactive Pupils	Unilateral Unreactive	Bilateral Unreactive
Jennett,[8] 1976	600	42%	—%	95%
Braakman,[4] 1980	305	29	54	90
Heiden,[7] 1983	213	36	—	91
Marshall,[12] 1991	746	32	34	74
	Average	**35**	**44**	**88**

% Good Recovery/Moderate Disability (GOS 4, 5)

First Author	# of Patients	Bilateral Reactive Pupils	Unilateral Reactive	Bilateral Unreactive
Jennett,[8] 1976	600	50%	—%	5%
Heiden,[7] 1983	213	49	—	3
Levin,[10] 1990	259	53	17*	—
	Average	**51**		**4**

*One or both pupils unreactive.

EDH vs. SDH

- in EDH with bilateral fixed pupils mortality is only 56% compared to an average of 88% in SDH

  Phonprasert C, Suwanwela C, Hongsaprabhas C: Extradural hematoma: analysis of 138 cases. J Trauma 20: 679-683, 1980.
  Phuenpathom N, Choomuang M, Ratanalert S: Outcome and outcome prediction in acute subdural hematoma. Surg Neurol 40:22-5, 1993.
- patients operated on for EDH with bilaterally fixed pupils - 18% had a poor outcome (GOS 1-2) vs. 64% in SDH with bilaterally fixed pupils; delay of > 3 hours in evacuating a traumatic intracranial hematoma with bilateral fixed pupils increased the chance of a poor outcome from 40% to 63%.

  Rivas J et al.: Extradural hematoma: analysis of factors influencing the courses of 161 patients. Neurosurg 23:44-51, 1988.
  Sakas DE, Bullock R, Teasdale G: One-year outcome following craniotomy for traumatic hematoma in patients with fixed dilated pupils. J Neurosurg 82:961- 965, 1995.

4. Hypotension - single measurement of SBP < 90 mm Hg.

- hypotension has 67% PPV for poor outcome (79% PPV when combined with hypoxia).
- in one study, logistic regression modeling revealed that ***early hypotension*** (injury ÷ resuscitation) was responsible for a 15-fold excess mortality and ***late hypotension*** (intensive care unit) for an 11-fold excess mortality in severe TBI.

  Chesnut RM, Marshall SB, Piek J, et al.: Early and late systemic hypotension as a frequent and fundamental source of cerebral ischemia following severe brain injury in the Traumatic Coma Data Bank. Acta Neurochirurgica (Suppl) 59:121-5, 1993
- influence of *iatrogenic hypotensive episodes* in patients with severe TBI who had not otherwise been hypotensive - patients with *intraoperative hypotension* had significantly worse neurologic outcomes than those without.

  Pietropaoli JA et al. The deleterious effects of intraoperative hypotension on outcome in patients with severe head injuries. J Trauma 33:403-7, 1992

5. Abnormal head CT (any abnormality noted on CT, consistent with TBI) - *within 12 hours of injury*; present in 68-94% of patients with severe TBI:

   1) **compressed or absent basal cisterns** measured at the midbrain level (i.e. perimesencephalic cisterns) – the strongest independent prognostic factor.
      – mortality when cisterns are absent - 77% (39% when cisterns are compressed; and only 22% when cisterns are open).

        Toutant SM et al.: Absent or compressed basal cisterns on first CT scan: ominous predictors of outcome in severe head injury. J Neurosurg 61:691-694, 1984
      – Teasdale et al. report that the third ventricle usually becomes obliterated before the basal cisterns. vs. in the study by Lang et al. on 118 patients with diffuse traumatic brain swelling, however, no direct relation was seen between the status of the third ventricle and that of the basal cisterns.

   2) **tSAH** (in the basal cisterns, over the convexity) – the second strongest independent prognostic factor.

      Presence of tSAH = 2-fold increase in the risk of dying
      – class I evidence: 69-72% PPV for unfavorable outcome with tSAH in the suprasellar or ambient cisterns (61% PPV with convexital SAH).
      – Fisher's Grade 3 → 62% PPV toward unfavorable outcome; Fisher's Grade 4 → 79% PPV.

   3) **midline shift** at the level of foramen of Monroe.
      – PPV of 70% for mortality with midline shift ≥ 15 mm (class II evidence).
      – PPV of 78% to poor outcome with shift > 5 mm in patients > 45 yrs (class I evidence).
      – prognosis is even worse with midline shift out of proportion to the extent of intracranial hemorrhage.

   4) presence and type of **intracranial lesions**.
      – PPV of 79% to poor outcome (dead/vegetative) in the presence of lesions > 15 ml in patients > 45 (class I evidence).

        Vollmer DG, et al.: Age and outcome following traumatic coma: why do older patients fare worse? J Neurosurg (Suppl)75:37-49, 1991
      – mortality is higher in acute SDH than in EDH.
      – in comparison to diffuse injuries:
        outcome is more favorable in EDH
        outcome is less favorable in acute SDH.
      – hematoma volume is correlated to outcome.

- if CT is normal on admission, outcome is primarily related to concomitant extracranial injuries.
- *the full extent of intracranial pathology may not be disclosed on early CT* (the absence of abnormalities on CT at admission does not preclude the occurrence of raised ICP, and significant new lesions may develop in 40% of patients).

External validation study of different CT scoring systems

Eric Peter Thelin et al. Evaluation of novel computerized tomography scoring systems in human traumatic brain injury: An observational, multicenter study. PLoS Med. 2017 Aug; 14(8): e1002368

- **Stockholm** and Helsinki CT scores were more accurate outcome predictors than the Rotterdam CT score or the Marshall CT classification, with the Stockholm CT score being marginally more accurate than the Helsinki CT score.
- much of the additional information provided by the Stockholm CT score is derived from a more differentiated description of tSAH, suggesting that the amount and location of tSAH plays a larger role in TBI outcome than previously assumed.

see Marshall classification >>
see Rotterdam CT score >>
see Helsinki CT score >>
see Stockholm CT score >>

OTHER PROGNOSTIC FACTORS

1. Penetrating TBI (vs. closed TBI – mortality 2.5 times lower), esp. gunshot TBI.

2. Multiple organ injuries - influence on the outcome of severe TBI is primarily mediated through hypotension.

3. Anticoagulants / antiplatelets - raise risk of intracranial bleeding with even trivial TBI.

Novel oral anticoagulants and trauma

Kobayashi, L et al. Novel oral anticoagulants and trauma: The results of a prospective American Association for the Surgery of Trauma Multi-Institutional Trial. Journal of Trauma and Acute Care Surgery: May 2017 - Volume 82 - Issue 5 - p 827–835

- prospective observational trial across 16 trauma centers, 1,847 patients on antiplatelets / anticoagulants
- ***blunt trauma*** accounted for 99% of patients.
- 50% of patients were on **antiplatelet agents**, 33% on **warfarin**, 10% on **NOAs** (dabigatran, rivaroxaban, or apixaban), and 7% on **combination** therapy or **subcutaneous** agents.
- patients taking NOAs were not at higher risk for ICH on univariate (24% vs. 31%) or multivariate analysis (incidence rate ratio, 0.78; confidence interval 0.61–1.01, p = 0.05).
- compared with all other agents, **aspirin** (90%, 81 mg; 10%, 325 mg) gave the highest rate (35%) and risk (incidence rate ratio, 1.27; confidence interval, 1.13–1.43; p < 0.001) of ICH.
- progression of ICH occurred in 17% of patients and was not different between medication groups.
- mortality was 7% and was not significantly different between medication groups.

4. Presence of even one of *APOE4* alleles - 14-fold greater likelihood of poor outcome.

Geriatric TBI

> 80 yo

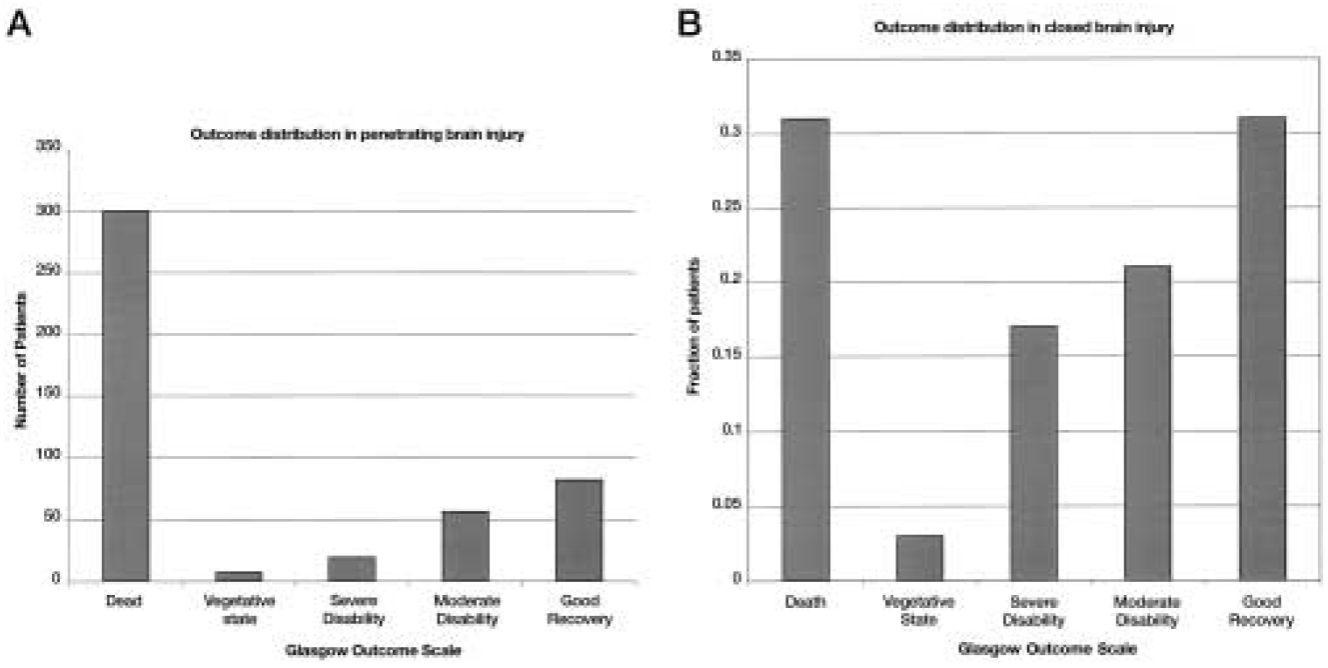
AF Haddad et al. The Morbidity and Mortality of Surgery for Traumatic Brain Injury in Geriatric Patients: A Study of Over 100 000 Patient Cases. Neurosurgery 89:1062–1070, 2021

- patients ≥ 80 yr old with TBI (exclusion - chronic subdural hematomas): 127 129 patients: 121 185 (95.3%) without surgery and 5944 (4.7%) with surgery
- surgery of geriatric TBI is independently associated with increased complications (40.4% vs 20.9%, P < .001), hospital LOS, ICU LOS, ventilator days, reduced discharge to home.
- surgery is not associated with increased mortality.
  - RPA identified an *ED GCS cutoff of 12 (motor component 5)* and injury severity score (ISS) cutoff of 21 as important classifiers of geriatric TBI patients at high risk for mortality following surgery (55.3% vs 16.1% with ED GCS > 12).
- study does not evaluate long-term functional outcome!

Penetrating TBI

Military vs. civilian PBI – see p. Op320 >>

PBI versus TBI outcome distribution (on GOS scale – "J" shape vs. "U" shape):



- among survivors, the percentage of patients with favorable outcome ("moderate disability" plus "good recovery") is equal: 74%, i.e. the main difference in outcome is the difference in mortality

  N.B. in PBI, the outcome distribution differs significantly (from blunt TBI) - overwhelming majority of patients have an unfavorable outcome; mostly, death - ***appropriate outcome measure for PBI is mortality***, not GOS score.

1. **Increasing age** correlates with increased mortality (Class III).
2. **Suicide** correlates with a higher rate of mortality than other causes of PBI (Class II); plus, suicide patients are less likely to receive aggressive resuscitation efforts.

   N.B. patients who recover from attempted suicide frequently report relief over survival and express gratitude to their caregivers!
3. **Perforating** injuries correlate with a poorer outcome when compared with either penetrating or tangential brain injuries (Class III).
4. The effect of **weapon caliber** on outcome, independent of total kinetic energy, was not demonstrated in the published data.
5. **Hypotension** is associated with increased mortality (Class III).
6. **Coagulopathy** is associated with increased mortality, particularly at lower levels of the GCS (Class III).
7. **Respiratory distress** is associated with increased mortality (Class III).
8. In civilian patients, **low GCS** correlates with higher mortality and unfavorable outcome (Class I). In military injuries, fewer patients have a low GCS score; strong correlation also exists between low GCS score and unfavorable outcome in military series (Class III).
9. The presence of **bilateral fixed and dilated pupils** is highly predictive of mortality (Class III).
10. **High ICP** is predictive of higher mortality (Class II). **Cisternal effacement** PBI is associated with increased mortality (Class I). No relation between **midline shift** and outcome has been established (Class I).
11. **Intraventricular hemorrhage** is strongly correlated to increased mortality (Class I) - odds ratio 2.83-96.9; **Subarachnoid hemorrhage** is also correlated to increased mortality (Class I) - odds ratio 1.44-10.6
12. Trajectory:

    Bihemispheric injuries relate to increased mortality (Class II) - odds ratio 1.18-20.05; possible exception may be bifrontal injuries

    Multilobar (> 1 lobe) injuries are strongly associated with mortality (Class III) - odds ratio 3.27-84.4, negative predictive value for mortality 77-98%.

    Perhaps it should be better stated that the presence of unilobar damage is strongly correlated to survival.

    Injuries with **ventricular** involvement have an increased mortality (Class III) - odds ratio 3.35-27.5

SCALES OF OUTCOME

FUNCTIONAL INDEPENDENCE MEASURE (FIM) (one of most widely used measures of function) - level of independence for mobility, self-care, and cognition (all these are often spared in mild TBI - FIM score is inadequate outcome measure for these patients):

Self-care	A. Eating
	B. Grooming
	C. Bathing
	D. Dressing - upper body
	E. Dressing - lower body
	F. Toileting

Sphincter control	G. Bladder management
	H. Bowel management
Transfers	I. Bed, chair, wheelchair
	J. Toilet
	K. Tub, shower
Locomotion	L. Walking, wheelchair
	M. Stairs
Motor subtotal score:	
Communication	N. Comprehension
	O. Expression
Social interaction	P. Expression
	Q. Problem solving
	R. Memory
Cognitive subtotal score:	
TOTAL FIM SCORE:	

GLASGOW OUTCOME SCALE (GOS)

Jennett B , Bond M . Assessment of outcome after severe brain damage. Lancet 1975 ; 1 : 480 – 484

5 – **GOOD RECOVERY** - normal life despite minor deficits

4 - **MODERATE DISABILITY** - disabled but independent; can work in sheltered setting

3 - **SEVERE DISABILITY** - conscious but disabled; dependent on others for daily support

2 - **VEGETATIVE** - no evidence of meaningful response

1 - **DEAD**

GOS can be divided further into:

good outcomes (good, moderate disability, **independent**): 5 and 4
poor outcomes (severe disability, vegetative, dead): 1-3

DISABILITY RATING SCALE (DRS) Rappaport et al. (1982)

CATEGORY	ITEM	INSTRUCTIONS
Arousability, Awareness and Responsivity (i.e. GCS)	Eye Opening	0 = spontaneous 1 = to speech 2 = to pain 3 = none
	Communication Ability	0 = oriented 1 = confused 2 = inappropriate 3 = incomprehensible 4 = none
	Motor Response	0 = obeying 1 = localizing 2 = withdrawing 3 = flexing 4 = extending 5 = none
Cognitive Ability for Self Care Activities	Feeding	0 = complete 1 = partial 2 = minimal 3 = none
	Toileting	0 = complete 1 = partial 2 = minimal 3 = none
	Grooming	0 = complete 1 = partial 2 = minimal 3 = none
Dependence on Others	Level of Functioning	0 = completely independent 1 = independent in special environment 2 = mildly dependent 3 = moderately dependent 4 = markedly dependent 5 = totally dependent
Psychosocial Adaptability	Employability	0 = not restricted 1 = selected jobs 2 = sheltered workshop (non-competitive) 3 = not employable

Disability Categories:

Total DRS Score	Level of Disability
0	None
1	Mild
2-3	Partial
4-6	Moderate
7-11	Moderately Severe
12-16	Severe
17-21	Extremely Severe
22-24	Vegetative State
25-29	Extreme Vegetative State

PREVENTION

Motor vehicle-related TBI:

1) helmets by cyclists
2) automobile seatbelts and child restraints
3) airbags (children < 12 years should ride in back seat of car away from airbag)
4) enforcement of drunk driving laws

SPECIAL ASPECTS

POSTERIOR FOSSA MASS LESIONS

Mostly – **EDH**, **ICH**.

- *parturitional hemorrhages in neonates* primarily (48%) involve posterior fossa.
- patients can undergo rapid life-threatening clinical deterioration - limited size of the posterior fossa → brainstem compression.

Indications for surgery:

a) ICH **diameter > 2.5-3.0 cm**
b) **mass effect on CT** (distortion / dislocation / obliteration of the 4th ventricle; compression of the basal cisterns; obstructive hydrocephalus)
c) **neurological dysfunction / deterioration** referable to the lesion.

Surgical treatment: **suboccipital craniectomy** emergently is the recommended method for evacuation of posterior fossa mass lesions.

ALCOHOL

- advantages - neuroprotection - alcohol use at time of injury decreases likelihood of poor outcome (alcohol impedes excitotoxicity).
- disadvantages:
  1) alcohol raises risk of incurring (repeat) TBI (positive blood alcohol level is detected in 25-60% patients) – risky behavior, coordination↓, motor reaction time↑.
  2) obscured real level of consciousness.
  3) patients often aggressive, asocial.
  4) bleeding risk↑ (thrombocytopathy, coagulopathy, brain atrophy)
  5) cardiorespiratory depression
  6) increased risk of seizures.

LONG-BONE FRACTURES (CONCURRENT WITH TBI)

- femur fractures are common among TBI patients.

TIMING OF INTERNAL FIXATION

- internal fixation with intramedullary nailing is the ideal method of treatment; however, there is no consensus regarding the optimal timing for internal fixation.

EAST guidelines (2014)

Gandhi, Rajesh R et al. Optimal timing of femur fracture stabilization in polytrauma patients: A practice management guideline from the Eastern Association for the Surgery of Trauma. Journal of Trauma and Acute Care Surgery. November 2014, Volume 77 (5), p 787–795

Early vs. late fixation does NOT decrease mortality, infection, or VTE. Early (< 24 hr) fixation is suggested but is conditional and surgical decision should be individualized. The optimal timing remains controversial and guidelines do not replace clinical judgement.

- no significant reduction in mortality was associated with early stabilization (RR of 0.74 [95% CI, 0.50–1.08]), quality of evidence was rated as "low."
- no significant reduction in infection (RR, 0.4; 95% CI, 0.10–1.6) or VTE (RR, 0.63; 95% CI, 0.37–1.07) was associated with early stabilization; quality of evidence was rated "low."
- in the absence of a clear contraindication to surgery or anesthesia, the recommendation of this review, although conditional, should prompt early fixation. However, the ***surgical decision must be individualized to each patient's needs***. Delayed treatment has been associated with a reduction in adverse outcomes in patients with multiple injuries. In addition, delayed stabilization (24–48 hours) may be safer than stabilization within 12 hours for severely injured patients.

  CONCLUSION - in trauma patients with open or closed femur fractures, we suggest early (< 24 hours) open reduction and internal fracture fixation. This recommendation is ***conditional*** because the ***strength of the evidence is low***. Early stabilization of femur fractures shows a trend (statistically insignificant) toward lower risk of infection, mortality, and VTE. Therefore, the panel concludes the desirable effects of early femur fracture stabilization probably outweigh the undesirable effects in most patients.

N.B. 2014 version of guidelines does not comment on the subgroup of patients with TBI.
2000 version of guidelines states: "Level II recommendation: There is no compelling evidence that early long bone stabilization in mild, moderate, or severe TBI either enhances or worsens outcome. The timing of long bone stabilization should be individualized according to the patient's clinical condition."

C. Michael Dunham et al. Practice Management Guidelines for the Optimal Timing of Long Bone Fracture Stabilization in Polytrauma Patients: The EAST Practice Management Guidelines Work Group. 2000 Eastern Association For The Surgery of Trauma.

American College of Surgeons (ACS) Trauma Quality Improvement Program (TQIP) best practices in the management of orthopedic trauma

- management of fractures in patients with TBI represent a particular challenge - early surgical fixation may complicate the acute management of TBI. The goals of acute TBI management are to maintain adequate cerebral perfusion, prevent hypotension, provide adequate oxygenation, avoid hypo- and hypercarbia, and maintain normothermia. Efforts should be made to adhere to each of these goals. Intraoperative monitoring of ICP should be considered to support cerebral perfusion pressure. In the context of a stable ICP and MAP, definitive fixation can be considered in the resuscitated patient, as these patients are less apt to experience transient episodes of hypotension in the operating room. The under-resuscitated patient or those patients whose ICP and CPP have not yet stabilized are best served with damage control procedures or traction.
- **open fractures**: historically, dogma has led orthopedists to treat open fractures with surgical irrigation and debridement within six hours of the injury or risk increased rates of infection -"six hour rule" - disproven in recent years by several high quality studies demonstrating that delaying surgical irrigation and debridement up to 24 hours does not increase infectious complications for open fractures. Based on the best available evidence, the panel does not endorse the "six hour rule."

SPORTS

CHRONIC TRAUMATIC ENCEPHALOPATHY (S. DEMENTIA PUGILISTICA, PUNCH-DRUNK SYNDROME)

- professional boxers are especially at risk (only sport with goal of deliberately injuring brain of opponent).
- cause - repeated head trauma during protracted period.
- clinical features:
  1. **Parkinsonism** and other extrapyramidal features (tremor, ataxia, cerebellar signs).
  2. Progressive **dementia**.
  3. **Behavioral abnormalities** (morbid jealousy, rage reactions).
- manifestations begin 6-40 (average 16) years after starting boxing career.
- pathology: hydrocephalus, thinning of corpus callosum, diffuse axonal injury, hypothalamic anomalies, degeneration of substantia nigra, neurofibrillary tangles (mainly in medial temporal areas), diffuse Aβ-positive plaques (≈ as in Alzheimer disease), scarring of cerebellar folia.
- no therapy is actually effective.
- prevention:
  1) better ***protection for boxers*** (head protection, different gloves)
  2) ***physician must stop match*** when there is evidence of brain injury (i.e. sportsman who sustained concussions, requires physician's statement to return to previous level of involvement). *see below*

MANAGEMENT OF CONCUSSION IN SPORTS

SIDELINE EVALUATION:

Mental status testing:

1. Orientation: Digits backward
   3--1--7
   4--6--8--2
   5--9--3--7--4
2. Months of year in reverse order
3. Memory: names of teams in prior contest
4. President, governor, mayor, recent newsworthy events, three words and three objects at 0 and 5 minutes.
5. Details of contest (plays, moves, strategies, etc.)

Exertional provocative tests:

1. 40 yard sprint
2. 5 push-ups
3. 5 sit-ups
4. 5 knee bends

(any appearance of associated symptoms is abnormal, e.g., headache, dizziness, nausea, unsteadiness, photophobia, blurred or double vision, emotional lability, mental status changes)

Neurologic tests:

1. Pupils: symmetry and reaction

2. Coordination: finger-nose-finger and tandem gait
3. Sensation: finger-nose (eyes closed) and Romberg

GRADING SCALE and GUIDELINES FOR RETURN to competition:

Grade	Features	Actions
Grade 1	no loss of consciousness, confusion without amnesia	remove from contest → examine immediately and q5min for development of amnesia or postconcussive symptoms at rest and with exertion → may return to contest if no amnesia & no symptoms appear for at least 20 minutes.
Grade 2	no loss of consciousness, confusion with amnesia	remove from contest and **disallow return** → examine frequently for signs of evolving intracranial pathologic conditions → reexamine next day.
Grade 3	loss of consciousness	**transport from field by ambulance** (with cervical spine immobilization if indicated) to trauma hospital → emergent thorough neurological evaluation: a) signs of pathologic conditions → hospitalization b) normal findings → instructions to family for overnight observation.

WHEN TO RETURN TO PLAY after removal from contest:

Grade of Concussion	Time Until Return to Play*
Multiple Grade 1 concussions	1 week
Grade 2 concussion	1 week
Multiple Grade 2 concussions	2 weeks
Grade 3 - brief loss of consciousness (seconds)	1 week
Grade 3 - prolonged loss of consciousness (minutes)	2 weeks
Multiple Grade 3 concussions	≥ 1 month (based on decision of physician)

*only after being asymptomatic with normal neurological assessment at rest and with exercise.

BRAINSCOPE'S CONCUSSION INDEX

- EEG-based algorithmic assessment tool for **objective** evaluating severity of concussions.

- diagnostic tool can be used to an athlete's readiness to return to play.
- assessment is done with a disposable headset (10 minute **EEG**) and handheld device (**Neurocognitive Performance Tests** - Simple Reaction Time and Procedural Reaction Time - takes 20 minutes to administer) + **vestibular system testing**.
  - EEG looks for deviations from normal connectivity between brain regions, both between and within hemispheres
- cleared by FDA in late 2019.
- **Concussion Index** (with < 70 points = concussion) had a sensitivity of 86%, specificity of 71%, and negative predictive value of 90%.
- other previously FDA-cleared algorithms are also available on the device including assessing the likelihood of brain bleeds (99% sensitivity) and severity of functional impairment.

SECOND IMPACT SYNDROME

- malignant (fatal) cerebral edema.

- at least 35 cases occurred among US football participants in 1980-1993.
- cause – one minor TBI followed in short order by **second minor TBI** in athletes who are **still symptomatic from first injury**.
- mechanism - impaired cerebral autoregulation → vascular congestion → brain edema → herniation → sudden death.
- prevention - postponed return to play for increasing lengths of time depending on concussion severity. *see above*

BIBLIOGRAPHY for ch. "Head Trauma" → follow this LINK >>