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TREATMENT OF TRAUMATIC
BRAIN INJURY (TBI)

TRAUMATIC BRAIN INJURY

- Definition: A head injury that disrupts normal brain function
 - Indirect BI occurs without skull contact but with acceleration-deceleration induced damage. (ie. shaken baby syndrome)
 - Direct BI occurs after a significant impact to the head
- Four Types
 - Concussion (most common type)
 - Contusion
 - Penetrating
 - Anoxic
- Leading cause of TBI is falls (1.3M/year; 50%)
- Up to 2.87M US ED visits/year
 - >800,000 children/year are treated in US ERs
 - Ages 0-4 1337.3/100,000
 - Ages 15-19 896.2/100,000
 - Age >75
- 282,000 US hospitalizations/year
- 56,000 US deaths/year
- Survivors often harbor disabilities
- > \$76.5 billion cost to US economy/year

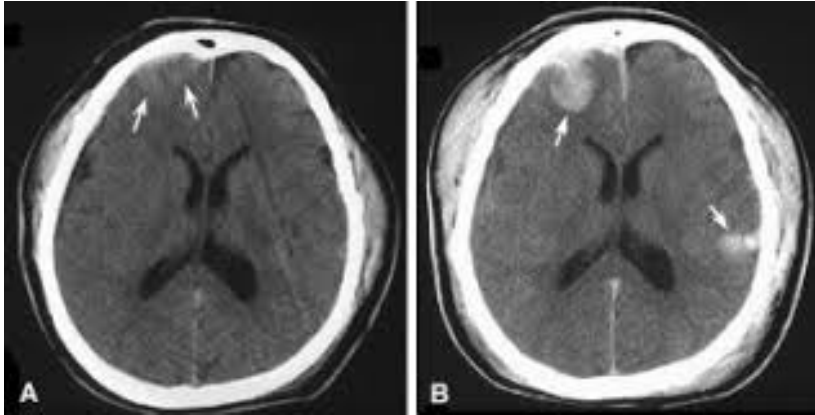
CONCUSSION

- AANS Definition "A mechanical force brain injury resulting in immediate and transient alteration in brain function"
- >3M cases/year in US
 - 19% risk/year from contact sports with 300,000 sports related occurrences/year in US
- Symptoms
 - Confusion
 - Headache
 - Vision disturbance
 - Dizziness/imbalance
 - Nausea/vomiting
 - Amnesia
 - Tinnitus
 - Difficulty concentrating
 - Light sensitivity
 - Loss of smell or taste
 - Insomnia
 - Depression/Irritability
- Medical Care Indicated For
 - Worsening symptoms
 - Focal neurologic findings
 - Continued nausea and vomiting
 - Loss of consciousness
 - Symptoms lasting >10 days
 - Prior concussions

CONTUSION

- A focal region of necrosis and hemorrhage involving the cerebral cortex and subcortical brain tissue that results from external forces to the head which causes the brain to strike internal skull surfaces with subsequent tissue bruising.
- Laceration and shearing leads to bleeding, tissue death and necrosis
- Contusion may be accompanied by inertial forces which cause tissue rotation, torque and stretch which result in diffuse axonal injury (DAI)
 - The importance of these acceleration/deceleration forces is illustrated by the fact that an object falling on a stationary skull may cause less underlying brain damage than the same object striking a mobile skull.
- Cerebral contusions often result in focal neurologic abnormalities that may or may not resolve and can progress towards coma and death.

CONTUSIONS



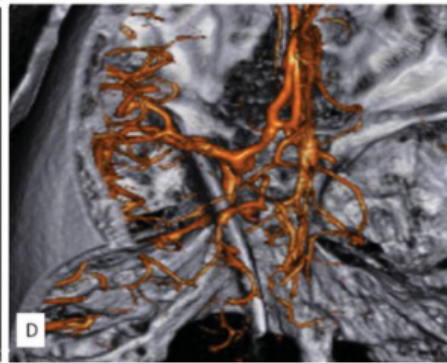
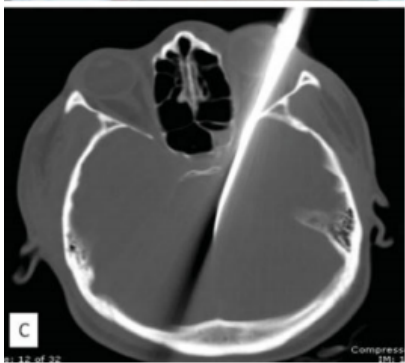
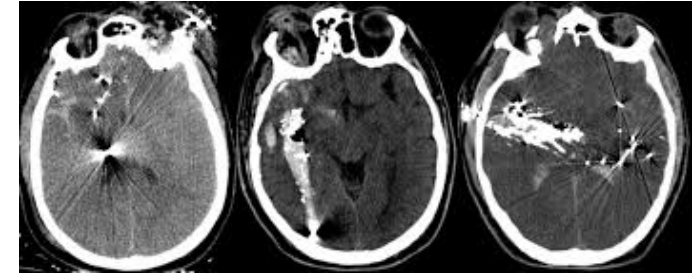
DIFFUSE AXONAL INJURY



PENETRATING INJURY

- A cortical and subcortical brain injury that results from a breach of the scalp, skull, dura, and pial brain surface usually by the head striking a static surface or by a projectile entering the cranial vault.
 - Parenchymal injury may be accompanied by arterial or venous lacerations and hemorrhagic/ischemic stroke
 - Breach of the skull and dura exposes the brain to infectious agents
- Destruction delivered by a high velocity penetrating object can more significantly contribute to tissue damage than does any direct injury imparted by the object itself (ie. GSW)
 - Newton's Second Law of Thermodynamics states that $F=ma$. As a penetrating object changes its velocity over time the magnitude of the change in velocity determines the force imposed on the surrounding tissue . Hence a penetrating rifle round in general causes more damage than a bullet of equal mass ejected by a pistol.
- Examples include
 - Open or closed depressed skull fracture
 - Gunshot
 - Knife
 - Blunt object
 - Farm or industrial implement

PENETRATING INJURY



WHAT IS THE NEUROSURGICAL PHILOSOPHY WHEN MANAGING TBI?

- #1: Little can be done to mitigate damage that has been caused by the initial injury.
- #2: Secondary injuries/insults must be prevented or at least minimized
- #3: The healing milieu must be maximized.

STAGE 1

INITIAL FIELD CARE

Airway – Breathing – Circulation

- Assume patient has spinal fracture and immobilize
- Determine Glasgow Coma Score
- Avoid hypotension to reduce secondary insult to the brain
 - SBP < 90 mmHg associated with 3x worse outcome
 - SBP < 100 mmHg associated with 2x worse outcome
 - SBP < 120 mmHg associated with 1.5x worse outcome
- Avoid hypoxia to reduce secondary insult to the brain
 - PaO₂ < 60 mmHg associated with worse outcomes
 - Intubation (if possible) recommended for GCS < 9, SpO₂ < 90%, airway issues
 - SpO₂ should be kept > 90-93%
 - Avoid hyperventilation which reduces PaCO₂ and in turn reduces CBF and CPP
 - Avoid hypoventilation which increases PaCO₂ and in turn increases CBF and CBV which increases ICP and reduces CPP

STAGE 2

ER CARE

Airway – Breathing – Circulation - Drain

- Trauma management with ATLS protocols
- Intubate as necessary to maintain SpO₂ > 93 mmHg
- Maintain SBP >120 mmHg
- Assume patient has unstable spine fracture and keep immobilized
- Assess for other injuries and obtain appropriate laboratory testing
 - Pupillary exam
 - Visualize tympanic membranes for hemotympanum (evidence for skull base fracture)
 - Evaluate mastoids for Battle Sign and orbits for Raccoon's eyes (evidence skull base fracture)
 - Evaluate cervical spine for palpable step offs and pain
 - Search for hidden scalp lacerations. Irrigate and close quickly to reduce bleeding. Consider abx
 - Palpate skull for step-offs and evidence for underlying depressed fracture
- Determine GCS and/or FOUR Score to document condition, institute algorithms and forecast prognosis
 - Follow GCS/FOUR closely with sequential exams to detect worsening
- Once hemodynamically stable, obtain head CT and cervical spine films

STAGE 3

IMAGING HEAD AND CERVICAL SPINE

- **POTENTIAL CRITICAL FINDINGS**

- Convexity skull fractures (linear; depressed; comminuted; open)
- Skull base fractures/petrous fracture (potential auditory injury)
- Parenchymal contusions (potential for blossoming and increased mass effect)
- Intracranial air (potential for dural laceration and infection)
- Evidence for shear injuries and diffuse axonal injury
- Extra-axial hematomas (epidural/subdural with mass effect or potential mass effect)
- Intraparenchymal hematomas (mass effect or potential developing mass effect)
- Subarachnoid hemorrhage (traumatic; may rarely indicate major arterial injury)
- Air sinus injuries (potential source for infection and CSF leak)
- Orbital fractures (potential for ocular injury, EOM entrapment)
- Ischemic brain tissue (potential evidence for traumatic arterial dissection)
- Intraventricular blood (potential cause for hydrocephalus, fevers)
- Hydrocephalus
- Cervical spine fractures/dislocations (evidence for instability and potential cord injury)
- Cervical soft tissue injuries/retropharyngeal swelling (evidence for cervical instability)

NEUROSURGICAL DECISION TIME

- **Q1:** What is the patient's **GCS**?
- **WHY:** If GCS is <9, placement of **ICP MONITOR** is traditionally indicated due to limited neurologic examination to detect condition decline.

- **Q2:** If ICP monitor is needed, is external ventricular drain (EVD) or parenchymal pressure monitor indicated?
- **WHY:** Patient may benefit from CSF drainage to control ICP and maximize CPP.

- **Q3:** Does patient require **EMERGENT SURGERY** to evacuate a hematoma, remove damaged swollen brain, perform decompressive craniectomy?
- **WHY:** Hematoma may be distorting brain tissue, patient may be a risk for herniation, ICP may be elevated and unresponsive to other therapies.

- **Q4:** Does patient require elevation of depressed skull fracture, repair of dural lacerations?
- **WHY:** Surgery may be needed to reduce risk of infection, manage vascular injuries, reduce ICP.

- **Q5:** Does patient have a **SPINAL INJURY** that requires emergent surgery?
- **WHY:** Spinal instability with or without spinal cord compression may or may not necessitate urgent surgical intervention to reduce risk of new injury or to alleviate current cord compression.

- **Q6:** Does physical examination and imaging suggest a **VASCULAR INJURY** such as an arterial dissection?
- **WHY:** An unrecognized arterial injury can be a cause for early or delayed ischemic stroke.

- **Q7:** What is the patient's overall **PROGNOSIS**?
- **WHY:** Treatment perhaps should be withdrawn due to futility in affecting long term prognosis.

STAGE 4

HOSPITAL MANAGEMENT PROCESS

- The management of TBI combines algorithmic protocols with individualized clinical approaches
- Once the patient is stabilized, TBI is characterized as Severe, Mild or Moderate using scoring systems that help predict short and long-term outcomes.
- Useful TBI scoring systems for adults include:
 - **Glasgow Coma Score (GCS)**
 - **Full Outline of Unresponsiveness Score (FOUR Score)**
 - **IMPACT Score**
 - **CRASH Score**
- Useful TBI scoring systems for individuals under 16 yo:
 - Palchak Rule
 - CATCH Rule
 - Pediatrics BIG Score
 - Pediatric GCS Pediatric Trauma Score

WHY ARE SCORING SYSTEMS IMPORTANT?

- Scores provide an **objective measure** of a patient's condition
- Scores provide **inter-user reliability** for patient examination and severity classification
- Scores provide consistent **comparison over time**
- Scores can be **easily communicated** for offsite decision making and avoids language barriers
- Scoring can direct care by **forecasting outcome**
- Scoring can provide reliable **serial data** for treatment evaluation
- Scoring can provide reliable **patient comparisons** from different sites and over different time periods

GCS (Glasgow Coma Score)

Glasgow Coma Scale		
Response	Scale	Score
Eye Opening Response	Eyes open spontaneously	4 Points
	Eyes open to verbal command, speech, or shout	3 Points
	Eyes open to pain (not applied to face)	2 Points
	No eye opening	1 Point
Verbal Response	Oriented	5 Points
	Confused conversation, but able to answer questions	4 Points
	Inappropriate responses, words discernible	3 Points
	Incomprehensible sounds or speech	2 Points
	No verbal response	1 Point
Motor Response	Obeys commands for movement	6 Points
	Purposeful movement to painful stimulus	5 Points
	Withdraws from pain	4 Points
	Abnormal (spastic) flexion, decorticate posture	3 Points
	Extensor (rigid) response, decerebrate posture	2 Points
	No motor response	1 Point
Minor Brain Injury = 13-15 points; Moderate Brain Injury = 9-12 points; Severe Brain Injury = 3-8 points		

GCS AND OUTCOME

GC S	GOS 1 (%)	GOS 2,3 (%)	GOS 4,5 (%)	GOS 1,2 (%)	GOS 3-5 (%)
3	62-100		5-7	79	21
4	45-90		10-14		
5	35-68		18-29		
6	21-51		50		
7	18-27		69		
8	0-22		77		
3-5	62	15	23		
6-8	20	74	44		
9-15	15-18	76			
3-4				79	21
5-6				45	55
7-9				26	74

GOS		
Score	Functional status	Description
1	Good recovery	Returned to the original functional level and employment with no deficit
2	Moderate disability	Minor neurological deficit that does not interfere with daily functioning or work
3	Severe disability	Significant neurological deficit that interferes with daily activities or prevents return to employment
4	Persistent vegetative state	Coma or severe deficit rendering the patient totally dependent
5	Death	Self-explanatory

FOUR Score (Full Outline of UnResponsiveness)

In comparison to the GCS Evaluation, the FOUR Score eliminates verbal testing and utilizes brainstem and respiratory examination and determines eye function in greater detail. As such it is especially useful in the ICU setting where patients are often mechanically ventilated and unable to verbally respond.

FOUR Score
Eye Response <ul style="list-style-type: none">4= eyelids open or opened, tracking, or blinking to command3= eyelids open but not tracking2= eyelids closed but open to loud voice1= eyelids closed but open to pain0= eyelids remain closed with pain
Motor Response <ul style="list-style-type: none">4= thumbs-up, fist, or peace sign3= localizing to pain2= flexion response to pain1= extension response to pain0= no response to pain or generalized myoclonus status
Brainstem Reflexes <ul style="list-style-type: none">4= pupillary and corneal reflexes present3= one pupil wide and fixed2= pupillary or corneal reflexes absent1= pupillary and corneal reflexes absent0= absent pupillary, corneal, and cough reflex
Respiration <ul style="list-style-type: none">4= not intubated, regular breathing pattern3= not intubated, Cheyne-Stokes breathing pattern2= not intubated, irregular breathing pattern1= intubated, breathes above ventilator rate0= intubated, breathes at ventilator rate or apnea

SCORE RANGE 0-16

FOUR SCORE AND OUTCOMES

For every 1-point increase in FOUR Score, the odds of in hospital mortality were reduced by 15% (even when adjusted for age and sex)

For every 1-point increase in FOUR Score, the odds of poor neurologic outcome (MRS 3-6) were reduced by 18% (even when adjusted for age and sex)

Lowest FOUR Scores better at predicting death than lowest GCS Scores. A GCS Score of 3 can equate to FOUR Score of 0-8. Lowest FOUR Score had 89% mortality while GCS 3 had 71% mortality.

Modified Rankin Scale (MRS)

- 0 No symptoms
 - 1 No significant disability, despite symptoms; able to perform all usual duties and activities
 - 2 Slight disability; unable to perform all previous activities but able to look after own affairs without assistance
 - 3 Moderate disability; requires some help, but able to walk without assistance
 - 4 Moderately severe disability; unable to walk without assistance and unable to attend to own bodily needs without assistance
 - 5 Severe disability; bedridden, incontinent, and requires constant nursing care and attention
 - 6 Death
-

FOUR SCORE AND OUTCOMES

- **SCORE RANGE 0-16**

- <4 predicts early mortality
- <6 predicts delayed mortality
- 7-11 predicts poor outcome
- 11 predicts need for intubation
- Every 1-point increase in total score increases chances of survival by 15% and of good outcome by 18% improved outcome

IMPACT Score

- Predicts 6-month mortality and unfavorable outcomes after moderate to severe traumatic brain injury in TBI patients ≥ 14 yo with GCS ≤ 12 .
- Uses data from first 24 hours of admission
- Best used for isolated head injuries.

IMPACT Scoring

AGE.	_____ years	CT	
		Diffuse injury I.	Y/N
		Diffuse injury II.	Y/N
		Diffuse injury III or IV.	Y/N
		V or VI (evacuated or non-evac mass)	Y/N
		Epidural hematoma.	Y/N
MOTOR		LABS	
Obeys commands.	+6	Hypoxia.	Y/N
Localizes pain.	+5	Hypotension.	Y/N
Withdraws pain	+4	Glucose.	_____ mg/dl
Flexes to pain.	+3	Hemoglobin.	_____ g/dl
Extends to pain.	+2		
No response to pain.	+1		
Unable to test.	0		

CRASH SCALE INJURY PROGNOSIS

- Country
 - Age
 - GCS
 - Pupil response to light
 - Major extra-cranial injury
 - CT findings
-
- PREDICTS 14 DAY MORTALITY AND RISK OF UNFAVORABLE OUTCOME AT 6 MONTHS



LET'S TAKE A PAUSE.

WHERE ARE WE? WHERE ARE WE GOING?

WHAT HAS BEEN ACHIEVED?

- Airway
- Breathing
- Circulation
- Scoring
- Imaging
- Drain
- Spine immobilization/evaluation
- General survey/general lab testing/toxicology
- Surgical decision making and potential surgery
- Consultation with family (if possible)

WHAT NEEDS TO BE DONE?

- Supportive medical care to prevent further insult and provide an opportunity to heal/recover/reorganize/regenerate
- Continually reassess for anatomic changes that require surgical intervention
- Mid and long-term care planning

STAGE 5

MEDICAL MANAGEMENT AND SUPPORT

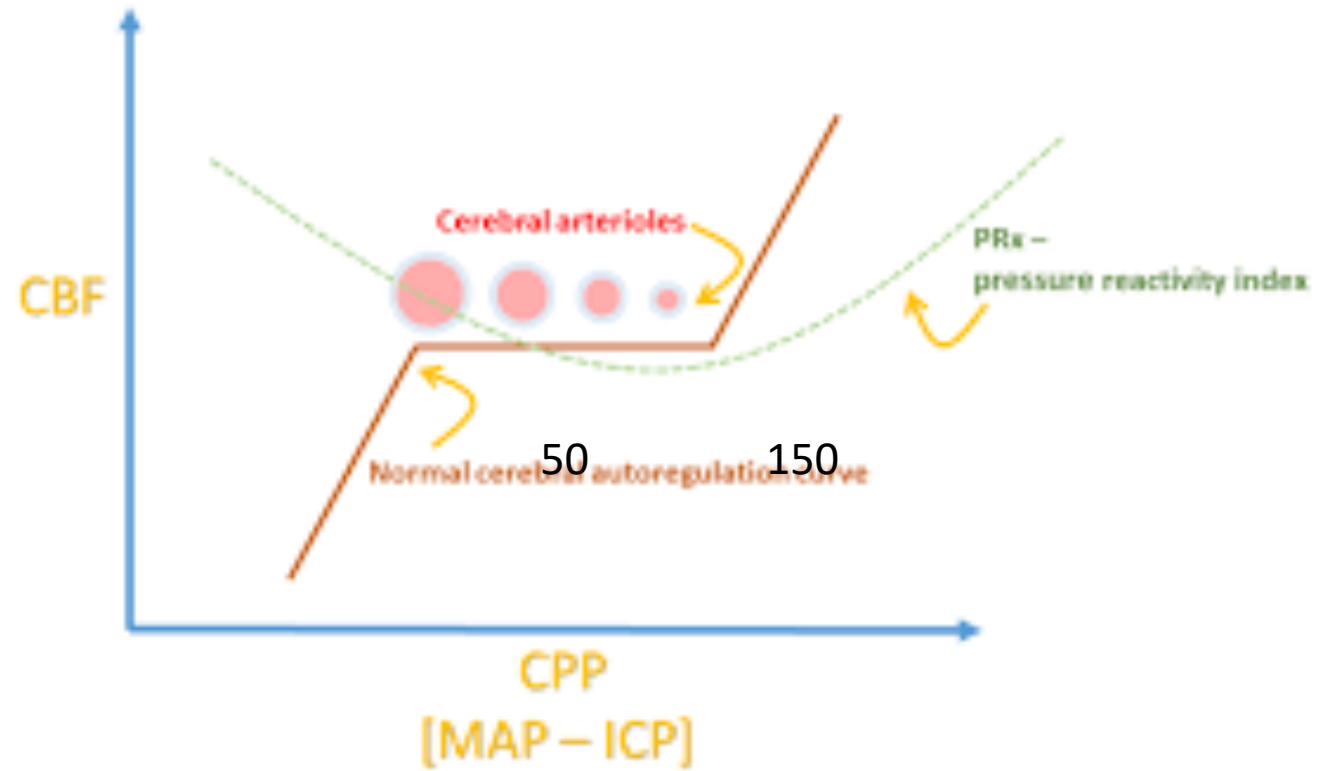
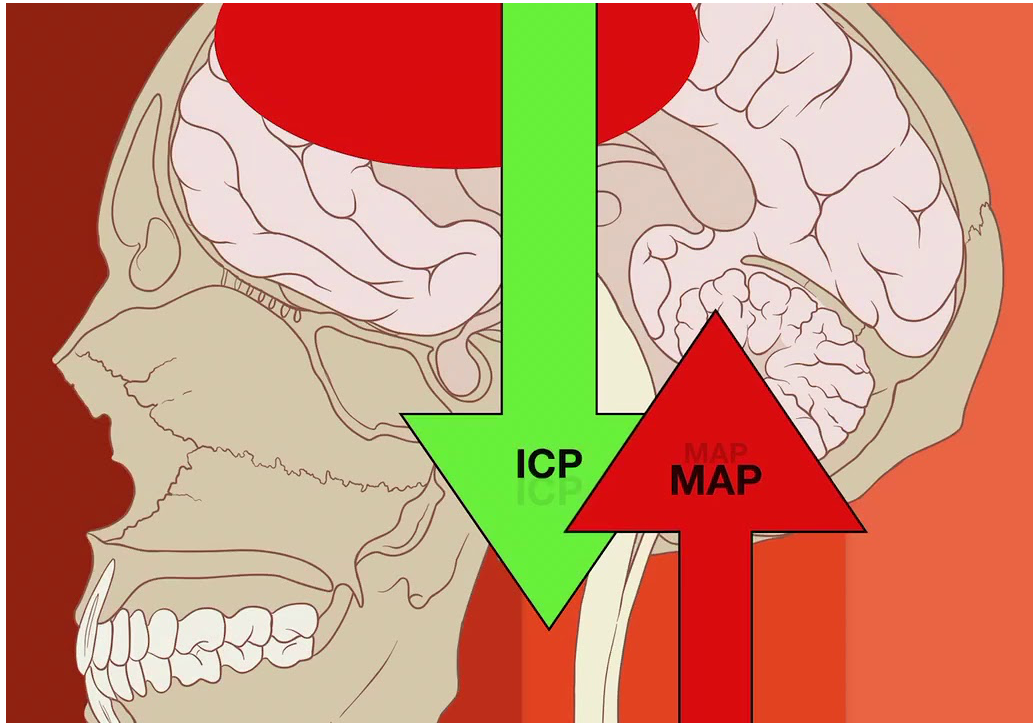
ICU CARE FOR TBI APPEARS COMPLEX, YET IS CONCEPTUALLY SIMPLE

A SINGLE EPISODE OF HYPOXEMIA AND/OR HYPOTENSION WORSENS OUTCOME WHEN GCS \leq 8 (J Trauma 34:216-222, 1993)

- SBP < 90 mmHg associated with 3x worse outcome
- SBP < 100 mmHg associated with 2x worse outcome
- SBP <120 mmHg associated with 1.5x worse outcome

- **1. Avoid brain/spinal cord tissue hypoxia**
 - Maintain oxygen delivery (pulmonary support, Hct, MAP, PaO₂)
 - Prophylactic hyperventilation for GCS \leq 8 yields worse outcomes at 3 and 6 months FU (>2x worse)
- **2. Maintain cerebral perfusion pressure (CPP = MAP – ICP)**
 - Avoid hypotension (fluid management, vasopressors)
 - No clear benefits of albumin or hypertonic saline as compared to isotonic saline
 - Avoid intracranial pressure >25 mmHg (manage swelling and mass effect, CSF volume control, avoid elevated PaCO₂, limit agitation, sedate, paralyze, avoid pyrexia, elevate HOB, surgically intervene)
 - Studies question whether focus on CPP is superior to focus on just ICP in terms of long-term outcomes

A PICTURE IS WORTH MORE THAN WORDS



STAGE 5

MEDICAL MANAGEMENT AND SUPPORT

Identify and correct coagulopathies (33% incidence) to limit hemorrhagic conversion of injured tissue

- Avoid elevated PT, PTT, INR
- Avoid thrombocytopenia
- Administer tranexamic acid within 3h if GCS 8-13 (1g IV over 10 min then 1g over 8h)
 - CRASH-3 Trial showed decreased mortality w/out increased complications

Maintain vigilance for and, if necessary, address new onset or worsening brain swelling, intracranial hemorrhage, hydrocephalus and ischemic stroke using surgical evacuation of blood or brain, decompressive craniectomy, osmotic and diuretic approaches, and/or barbiturate therapy. Barb therapy can reduce ICP but no clear improvement in long term outcome seen. DECRA and RESCUEicp studies support decompressive craniectomy for reducing medically refractory increased ICP, but survival in these patients was often of poor quality.

Maintain vigilance for pyrexia/infections caused by pneumonia, meningitis, abscess, sinusitis, otitis, cholecystitis, pancreatitis, hepatitis, central fevers, DVT, drugs, intraventricular blood, dental infection. Pyrexia may increase metabolism, ICP, CBF, CBV

Protect from and monitor for DVT and PE using heparinoids and mechanical compression. Be suspicious when new cardiac rhythm abnormalities develop and remember the most common ABG with PE is a normal ABG

Nutritional support should begin by day 5 to compensate for hyper-catabolism (90-160% increase over baseline) and maintain intestinal wall integrity. Early nutrition is correlated with decreased morbidity and mortality

Temporary anticonvulsant administration is potentially warranted to reduce incidence of early, but not late, epileptiform activity since severe TBI can be associated with up to 30% incidence of seizure activity. Seizures may increase ICP and increase metabolic activity which can cause secondary brain injury

Kepra vs Dilantin remains unclear. Dilantin use long term (12 months) may impair cognition but improves when stopped.

Avoid hypo- and hyperglycemia (maintain 140-180 mg/dL) since they may contribute to secondary brain injury by causing acidosis, free radical generation and BBB permeability.

Monitor for increased sympathetic activity which can raise cerebral metabolism, ICP, and stress. Consider sympathetic inhibition with catecholamine blockers

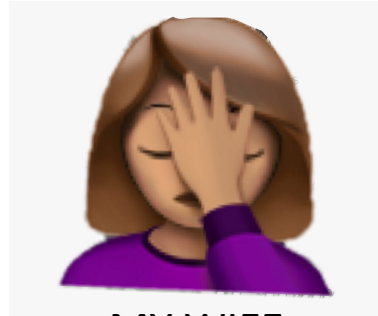
OTHER CONSIDERATIONS

- Tracheostomy
 - Early tracheostomy in TBI ≤ 8 shortens ventilator time but does not appear to reduce pneumonia or death
- Swallowing/dysphagia evaluation
- Parenteral IV nutrition
- Gastric/jejunal nutrition
- Colostomy
- Suprapubic catheter
- DVT prophylaxis
- UE/LE splinting to limit contractures
- PT/OT/Speech Pathology/Cognitive and Physical Rehabilitation
- Pharmacologic manipulation (antidepressants, stimulants)
- Discharge planning
- Family support

DO CURRENT CARE GUIDELINES MAKE A DIFFERENCE?



ME



MY WIFE

Dawes et al. JAMA 2015:965-972

Hospital compliance (14 hospitals) with brain trauma guidelines

10-65% compliance for ICP monitor placement

7-76% compliance for for craniotomy

NO relationship between compliance and mortality.

Studies from 1982 and 2012 show no better outcomes when managing ICP using an invasive monitor as compared to management based on exam and imaging

(Narayan et al.; Chesnut, et al)

MISCELLANEOUS TBI TOPICS

- Can medications enhance recovery in vegetative/near vegetative patients?
 - **Amantadine**
 - Promotes elevation of dopamine levels
 - Increased to 200mg BID over 4 weeks followed by taper off
 - Accelerated improvement over the 4 weeks compared to placebo
 - By 6 weeks both groups were identical
- **Does hypothermia improve outcomes?**
 - GCS 3-8
 - No benefits of hypothermia (3 different studies)

HOW DO WE OPERATIONALIZE OUR KNOWLEDGE ABOUT TBI

- Management has been reviewed. Now that? Consider the following
 - Step 1: Establish a case specific Mission Statement based on understanding the patient's condition and the patient/family's desires.
 - Step 2: Use OODA Loop Analysis to determine immediate and delayed approaches
 - Observe
 - Orient
 - Decide
 - Act

FULFILLING THE MISSION STATEMENT IS PREDICATED ON ACTING ACUTELY
AND SUB ACUTELY

ACUTE OODA in the Field and in the ER

OBSERVE

What is the situation?

ORIENT

What needs to be done ? What is the Mission Statement?

DECIDE

Should what needs to be done, be done to fulfill the Mission Statement?

ACT

Meet the Mission Statement whatever it may be.

FULFILLING THE MISSION STATEMENT IS PREDICATED ON ACTING ACUTELY AND
SUB ACUTELY

SUBACUTE OODA in the ICU

- OBSERVE
 - What is the situation?
- ORIENT
 - What needs to be done? What is the **updated** Mission Statement?
- DECIDE
 - Determine what should be done to meet the **updated** Mission Statement based on the patient's condition, assumed wishes, and prognosis. Prognosis can be estimated using IMPACT and CRASH.
- ACT
 - Do what needs to be done to meet the **updated** Mission Statement.

CLOSING THOUGHTS

WHEN TASKED WITH MANAGING ANY COMPLEX MEDICAL CONDITION
USE ITERATIVE DECISION MAKING TO REMAIN FLEXIBLE TO CHANGING
CONDITIONS AND **AVOID DIGGING IN.**

Establish and focus on the Mission Statement

OODA

Update the Mission Statement

OODA