BRAIN BENDERS

Concussion Pathophysiology & Anesthetic Impacts

Daniel King, DNP, MNA, APRN, CRNA, CPPS, CNE

Associate Professor, Rosalind Franklin University of Medicine and Science; Owner, DreamLion Anesthesia, Chicago, IL

LEARNING OUTCOMES

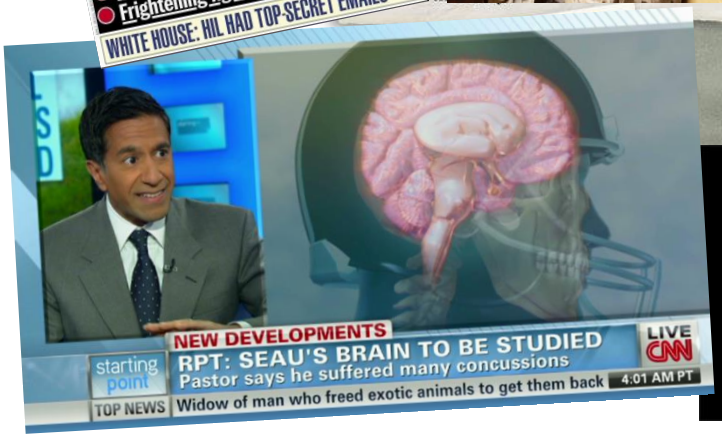
The learner will…

1. Identify patient populations at highest risk for diagnosed and undiagnosed concussions.

2. Be able to describe nervous system dysfunction and cellular pathophysiological changes associated with concussion injury.

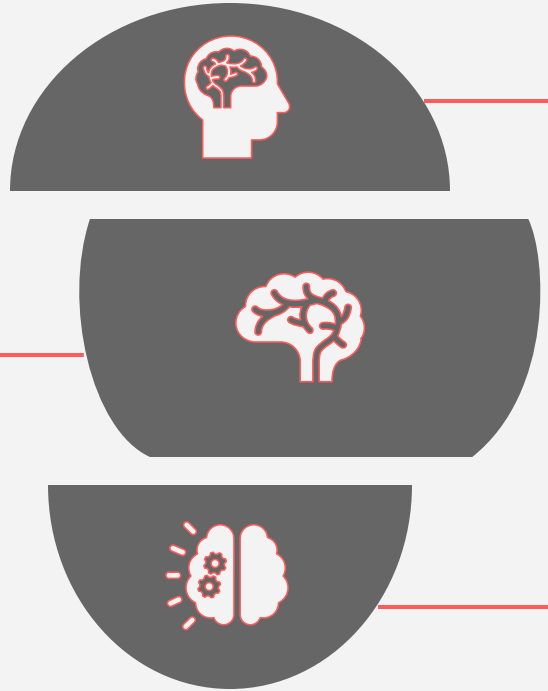
3. Implement best evidence-based practice techniques for optimizing anesthetic outcomes in patients who have sustained a concussion.

CONCUSSIONS: A GAME CHANGER



TRIPPED UP ON TERMINOLOGY

TRAUMATIC BRAIN INJURY (TBI)



MILD TRAUMATIC BRAIN INJURY (mTBI)

CONCUSSION

CDC DEFINITION

"A concussion is a type of traumatic brain injury—or TBI—caused by a bump, blow, or jolt to the head or by a hit to the body that causes the head and brain to move rapidly back and forth."

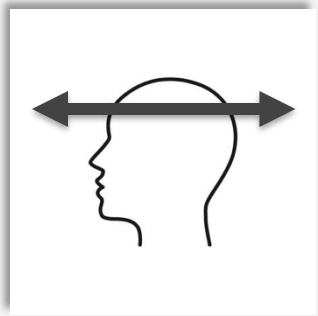
NIH DEFINITION

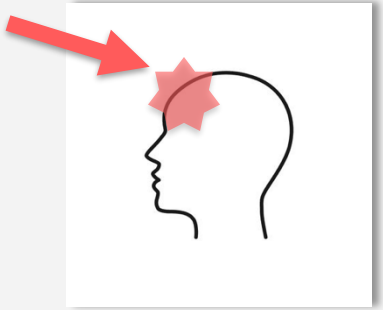
“Traumatic brain injury (TBI), a form of acquired brain injury, occurs when a sudden trauma causes damage to the brain. TBI can result when the head suddenly and violently hits an object, or when an object pierces the skull and enters brain tissue. Symptoms of a TBI can be mild, moderate, or severe, depending on the extent of the damage to the brain. A person with a mild TBI may remain conscious or may experience a loss of consciousness for a few seconds or minutes. Other symptoms of mild TBI include headache, confusion, lightheadedness, dizziness, blurred vision or tired eyes, ringing in the ears, bad taste in the mouth, fatigue or lethargy, a change in sleep patterns, behavioral or mood changes, and trouble with memory, concentration, attention, or thinking. A person with a moderate or severe TBI may show these same symptoms but may also have a headache that gets worse or does not go away, repeated vomiting or nausea, convulsions or seizures, an inability to awaken from sleep, dilation of one or both pupils of the eyes, slurred speech, weakness or numbness in the extremities, loss of coordination, and increased confusion, restlessness, or agitation.”

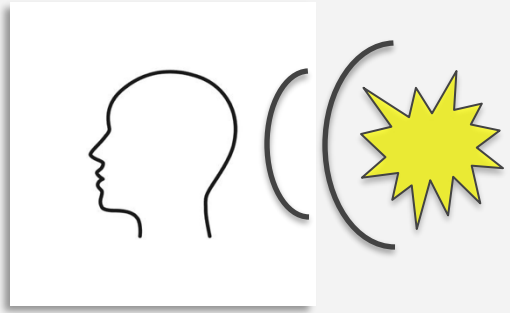
ACRM DEFINITION

"A patient with mild traumatic brain injury is a person who has had a traumatically induced physiological disruption of brain function, as manifested by at least one of the following: 1. any period of loss of consciousness; 2. any loss of memory for events immediately before or after the accident; 3. any alteration in mental state at the time of the accident (eg, feeling dazed, disoriented, or confused); and 4. focal neurological deficit(s) that may or may not be transient; but where the severity of the injury does not exceed the following: • loss of consciousness of approximately 30 minutes or less; • after 30 minutes, an initial Glasgow Coma Scale (GCS) of 13-15; and • posttraumatic amnesia (PTA) not greater than 24 hours."

WHAT IS A CONCUSSION?







A concussion **is a form of a traumatic brain injury**.

Results from **acceleration/deceleration forces** on the brain.

Can result in many physical manifestations.

Images by Sports Illustrated and BaltimoreRavens.com

FORCE OF A CONCUSSION

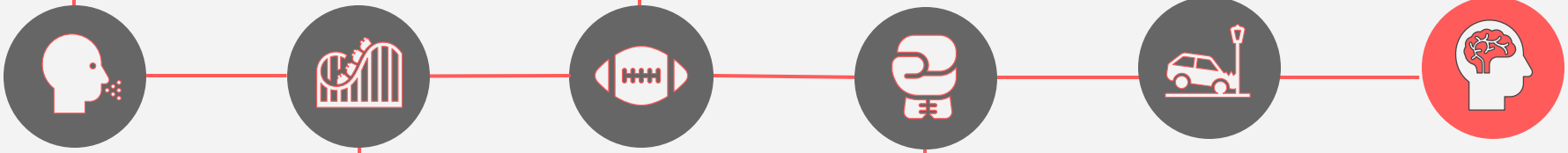
3.5 Gs
Sneeze

4-6 Gs
Rollercoaster plunge

< 30 Gs
Football tackle

58 Gs
Heavyweight boxer punch

60 Gs
Motor vehicle crash



CONCUSSION 70-120 Gs
5500-10,000 rads/s²

SPORT CONCUSSION ASSESSMENT TOOL

SYMPTOMS

- Headache **(#1, 93%)**
- “Pressure in head”
- Neck pain
- Nausea or vomiting
- Dizziness
- Blurred vision
- Balance problems **(#2, 75%)**
- Sensitivity to light
- Sensitivity to noise
- Feeling slowed down
- Feeling like “in a fog”
- “Don’t feel right”
- Difficulty concentrating **(#3, 67%)**
- Difficulty remembering
- Fatigue or low injury
- Confusion
- Drowsiness
- Trouble falling asleep
- More emotional
- Irritability
- Sadness
- Nervous or anxious

1.6-3.8 million

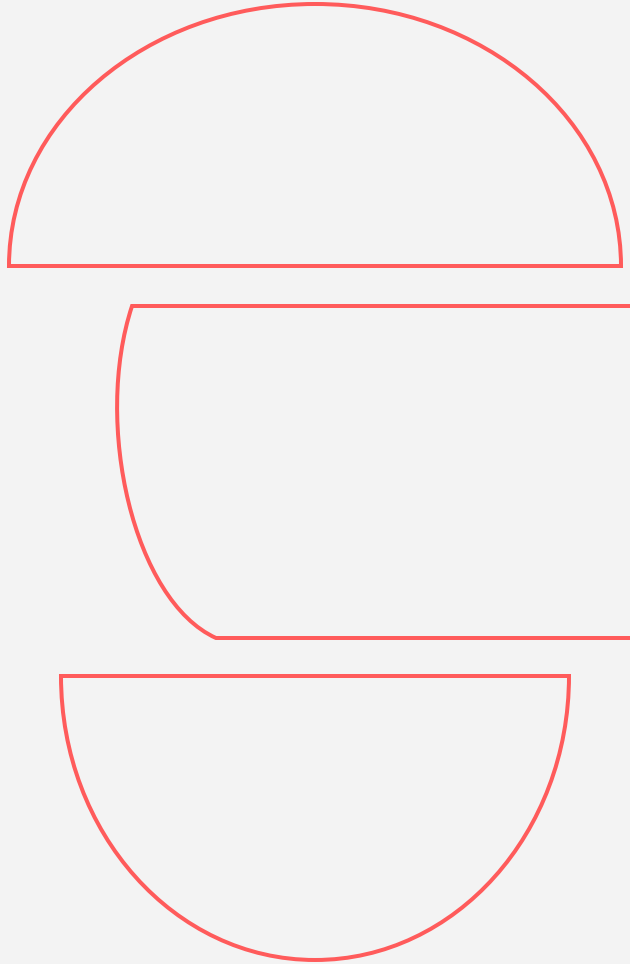
Sports-related concussions per year

2.4 million

Emergency department (ED) visits

281,000

Hospitalizations

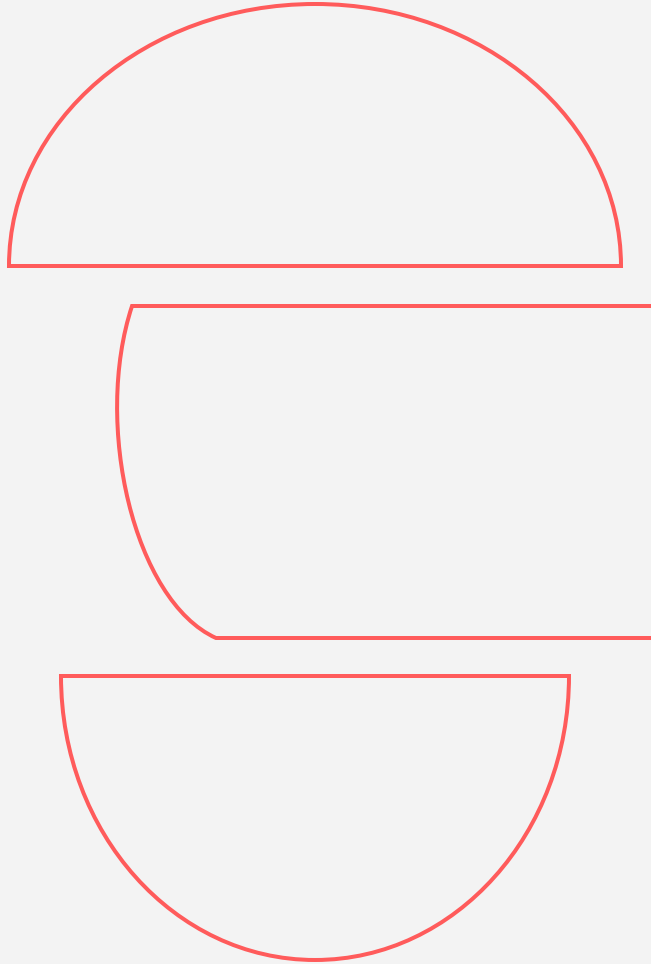


> 75-95%

of all TBIs are mild (mTBI)

$17,000,000,000

Cost per year



WHICH group is at highest risk?

CHILDREN

0-4 years

ADOLESCENTS

15-19 years

ELDERLY

> 75 years

♂ Male gender is most common

Anesthesia after concussion is **common** and occurs **quickly**.

- Over 10 years, 1,038 concussed patients underwent 1,820 diagnostic and surgical procedures requiring anesthesia
- 15% of concussed patients received anesthesia within 1 year of their injury (44% within 1 month, 33% within 1 week)
- Sports injury was NOT the most common mechanism

(Abcejo et al, 2017;2022)

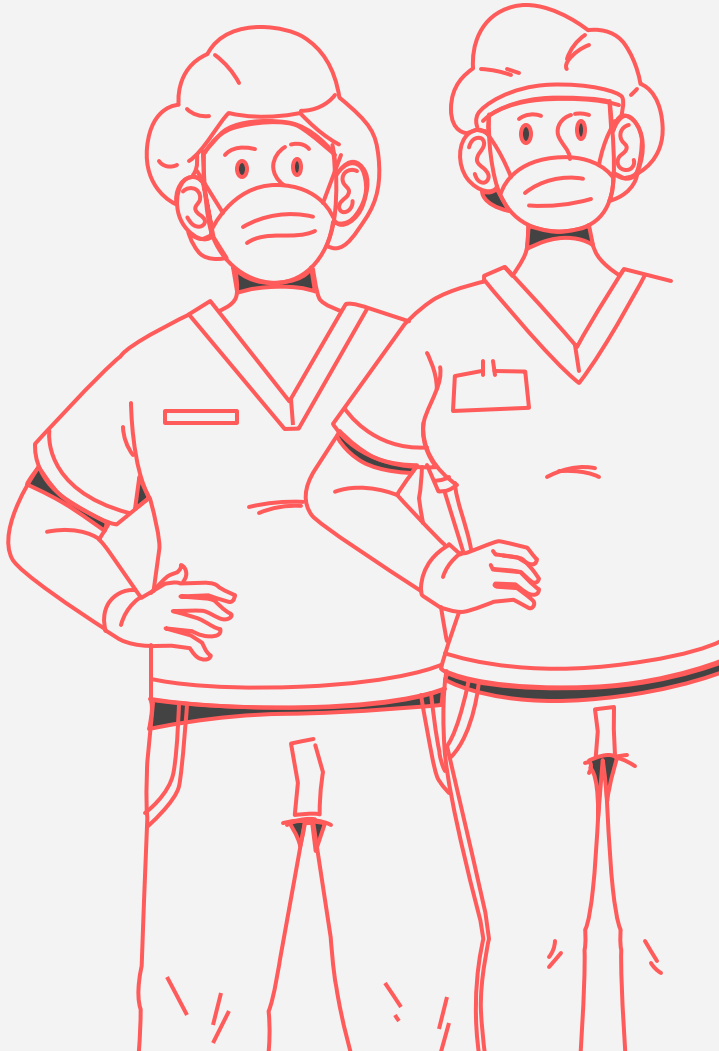
Mechanism of Injury

1. **Motor Vehicle Crash (n=375)**
2. Fall (n=367)
3. Sports (n=209)
4. Assault (n=87)

Type of Surgery

1. **Orthopedic (53%)**
2. General (21%)
3. Spine (7%)
4. Radiology (7%)
5. ENT/oral (7%)

(Abcejo et al, 2017; 2022)

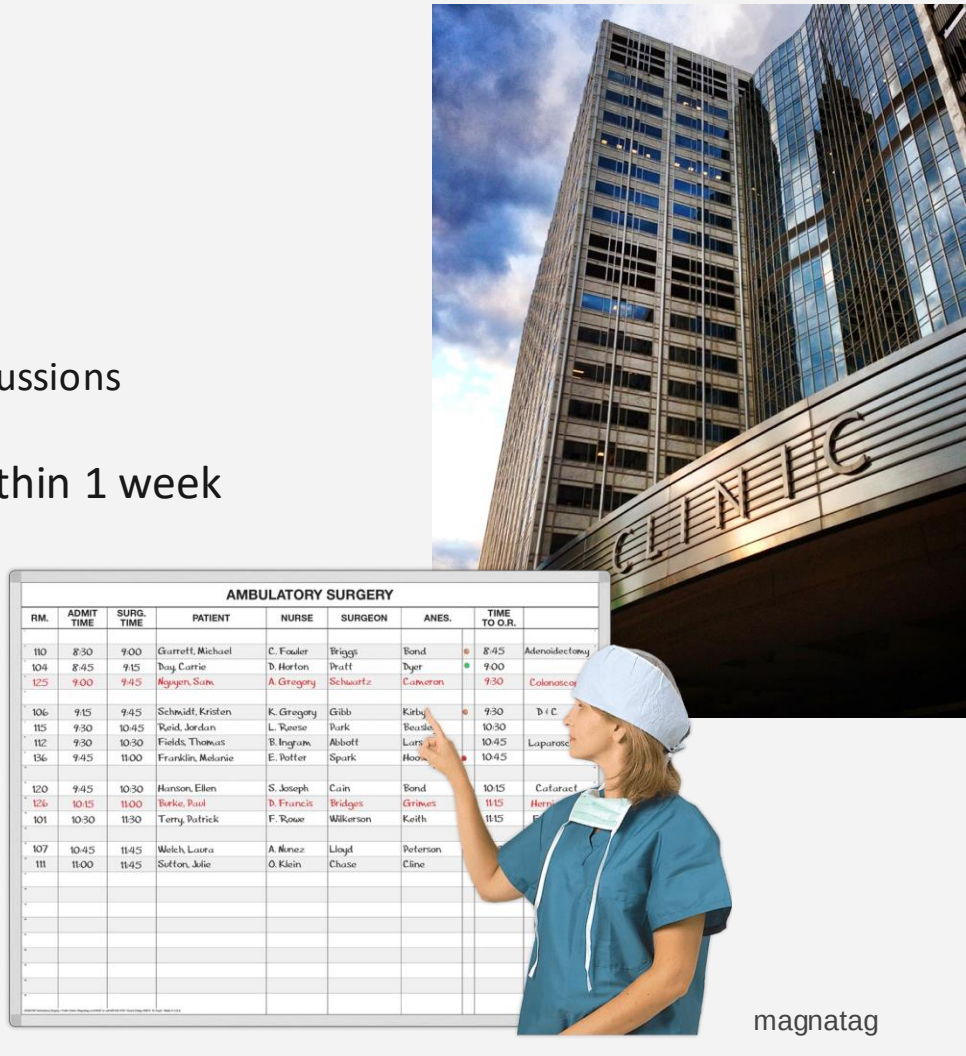


TIMING

(Abcejo et al, 2017; 2022)

- 67% diagnosed on the day of injury
  - Delay in diagnosis for 1/3
  - Most delays were in sports-related concussions
- Many underwent elective procedures within 1 week of injury
  - i.e., tooth extractions, cataracts
- Others underwent surgery for trauma ***before*** diagnosis established

In this time period, the patient may be vulnerable to *secondary* brain injury



WHAT ABOUT KIDS?

3,046 pediatric patients with TBI

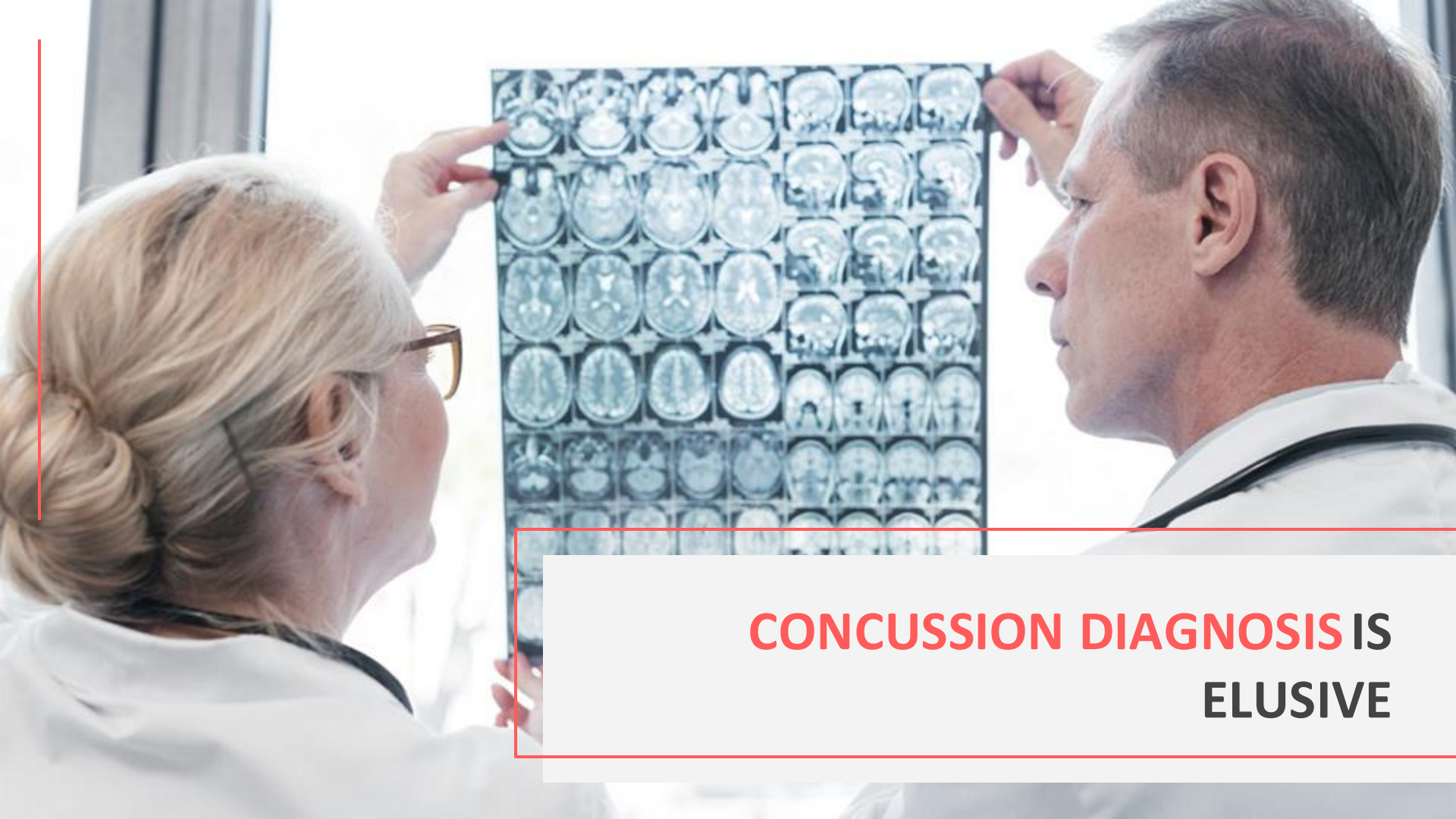
- Mild TBI (mTBI), or concussion, represented 87.1% of all injuries

Mechanism of Injury

1. **Falls/interpersonal contact (47.4%)**
2. Roller sports (26.4%)
3. Skiing/snowboarding (10.4%)
4. Water sports (1.7%)

(Yue et al, 2016)

https://elizabethsandelmd.com/insights/coma-and-other-disorders-of-consciousness/



CONCUSSION DIAGNOSIS IS ELUSIVE

Concussion Diagnosis is Elusive

- CT and MRI scans continue to be relied upon despite **LOW** evidence for use
- Many tools (SCAT, PCSS, GSC, SAC) have been devised but utility decreases after the immediate injury subsides
- Concussions are *dynamic* and we need tools that dynamically measure them

https://us.medical.canon/products/computed-tomography/aquilion-precision/

Constellation of Diagnostic Tools

Functional MRI (fMRI)*
Diffusion tensor imaging (DTI)
Magnetic resonance spectroscopy (MRS)
Cerebral blood flow (CBF)*
Electrophysiology
Heart rate*
Measure of exercise performance
Fluid biomarkers*
Transcranial magnetic stimulation (TMS)

BOLD MRI

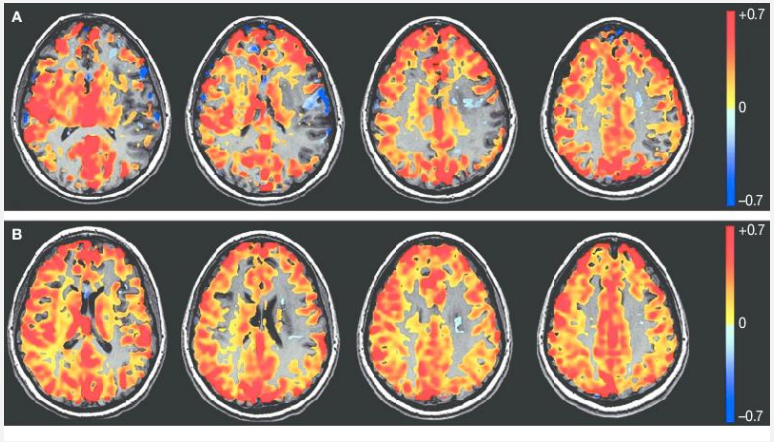
Blood **O**xygen **L**evel-**D**ependent Magnetic Resonance Imaging

More useful than CT for concussion dx

Relies on contrast drawn by venous deoxyhemoglobin

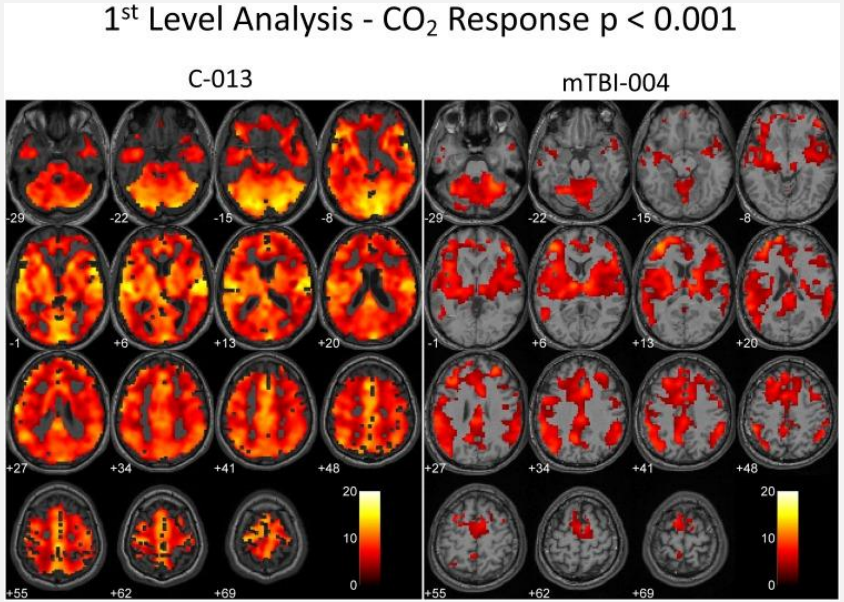
Allows for real time observation of:

- Cerebral blood flow patterns
- Glucose metabolism
- Energy expenditure
- Other neuronal cell activities



BOLD MRI: Abnormal Cerebrovascular Changes

- In **CO_2 stress test** of control, symptomatic and asymptomatic concussed patients:
  - Concussed patients had quantifiably abnormal cerebrovascular responses to periods of hyper/hypocapnia
- In follow up studies, cerebrovascular resistance remains in post-concussion athletes → headaches
- Blood flow responds ***dramatically*** to alterations in ET tensions commonly seen in anesthesia → delirium/POCD



(Original Mutch, et al. 2014); Update: Mutch et al. Brain BOLD MRI O_2 and CO_2 stress testing: implications for perioperative neurocognitive disorder following surgery. *Crit Care*. 2020;24(1):76.

Altered Vascular Responsiveness

Bishop et al, 2017:

Concussed hockey players vs. controls underwent squat/stand maneuvers

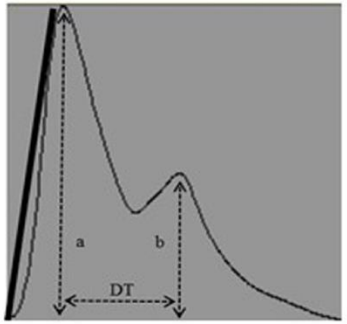
- Less HR variability
- Less change in SBP
- Postural baroreflexes were impaired for concussed participants
- ? Altered vascular myogenic and vagal tone (frontal cortex)

Reflects autonomic nervous system impairment after concussion!

Following study findings (Memmini, et al 2021)

- > 1 previous concussion places risk for **long-term dysautonomia**

Memmini, et al. Long-Term Influence of Concussion on Cardio-Autonomic Function in Adolescent Hockey Players. *J Athl Train*. 2021;56(2):141-147.



	SysSlope (mmHg/s)		RI (%)		SI (m/s)		DT (ms)	
	Rest	First 60	Rest	First 60	Rest	First 60	Rest	First 60
	48 Hrs							
Control	458 ± 236*	486 ± 222*	74 ± 13	74 ± 11	5.8 ± 0.5	6.0 ± 0.7	312 ± 28	299 ± 15
Concussion	408 ± 132	370 ± 101	79 ± 4	78 ± 4	6.0 ± 0.5	6.2 ± 0.5	288 ± 16	302 ± 31
	Week 1							
Control	435 ± 132†	434 ± 133†	77 ± 7	76 ± 6	5.9 ± 0.4	5.9 ± 0.5	307 ± 20	299 ± 15
Concussion	419 ± 167	401 ± 119	77 ± 6	79 ± 4	6.0 ± 0.6	5.9 ± 0.6	301 ± 19	309 ± 21

FIGURE 2 | Finger arterial pulse contour characteristics of groups by condition and visit. The Systolic slope (SysSlope; black line, left panel) is calculated from the rate of rise (change in pressure/change in time) of the systolic upstroke. The reflection index (RI) is calculated as b/a. The stiffness index (SI) is calculated as body height/DT. Data are presented as group mean ± SD in table (right panel). *Control vs. concussion: $p < 0.0001$; †control vs. concussion: $p < 0.01$.

(Original: La Fountaine et al, 2016); Update La Fountaine, et al. Use of Mayer wave activity to demonstrate aberrant cardiovascular autonomic control following sports concussion injury. *Ann N Y Acad Sci.* 2022;1507(1):121-132)

Investigation of arterial pulse waveforms in concussed vs control patients at 48 hrs. and 1-week post-concussion. Measurements recorded at rest and during isometric hand grip tests.

Findings:

- Transient **increase** in peripheral artery stiffness
- Paradoxical **decline** in cardiac stroke volume
- Compensatory **increase** in heart rate

Resolution of findings within 1 week of injury

Biomarkers:
A Simple Blood Test?

S100β

GFAP- glial fibrillary acidic protein

NSE- neuron specific enolase

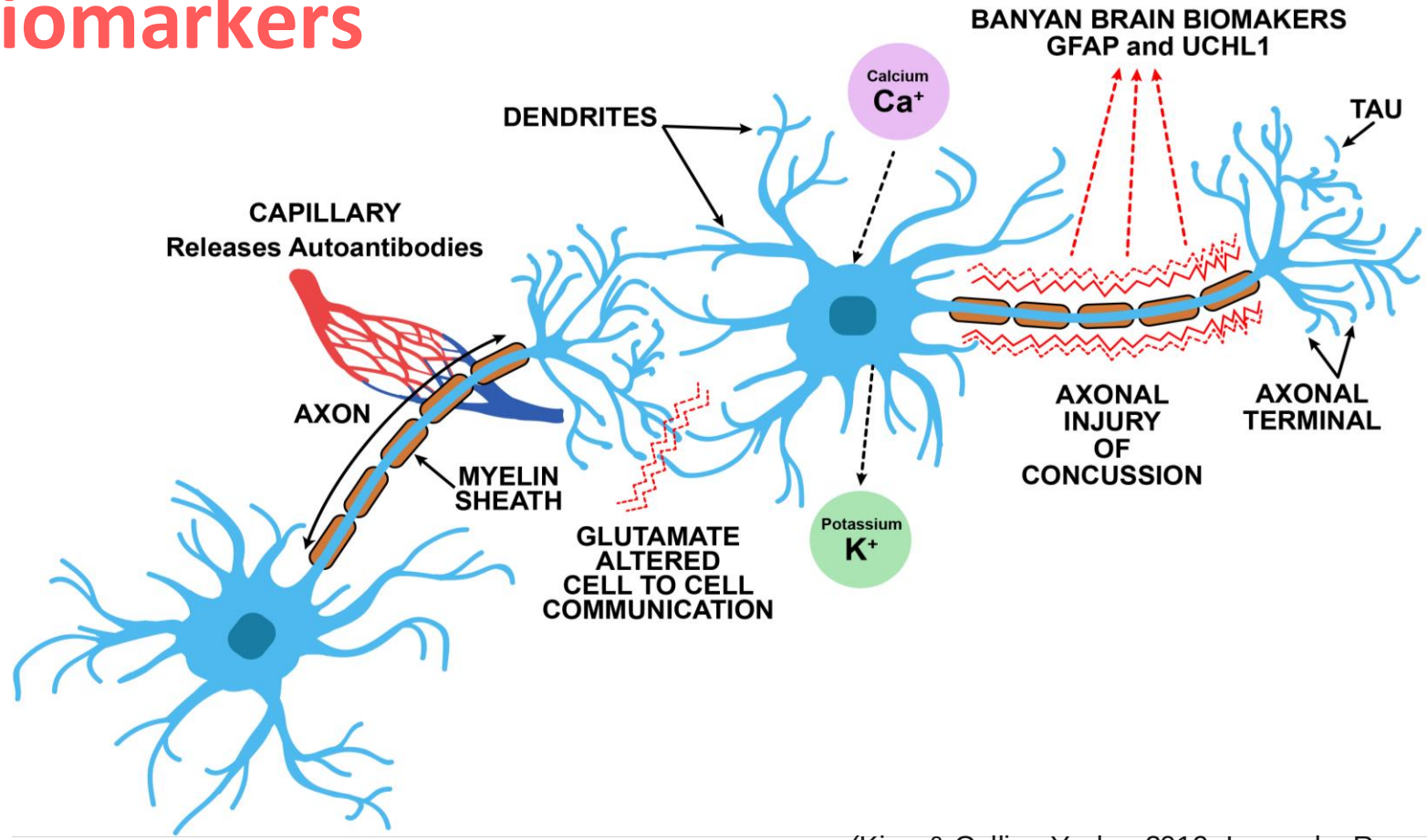
Tau

NFL-neurofilament light protein

UCH-L1- ubiquitin C-terminal hydrolase

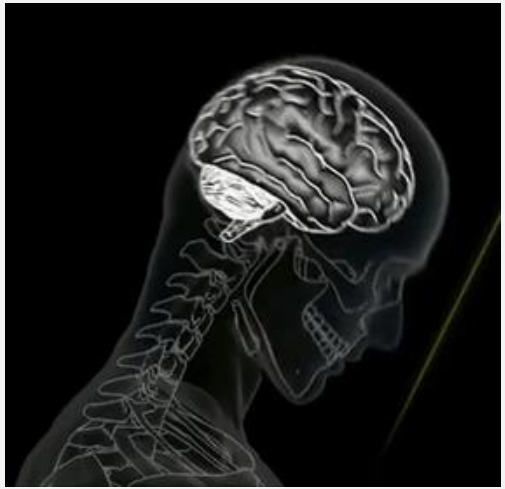
Amyloid

Biomarkers



(King & Collins-Yoder, 2019; Image by Roger Yoder)

The "Neurometabolic Cascade" – Giza & Hovda, 2001



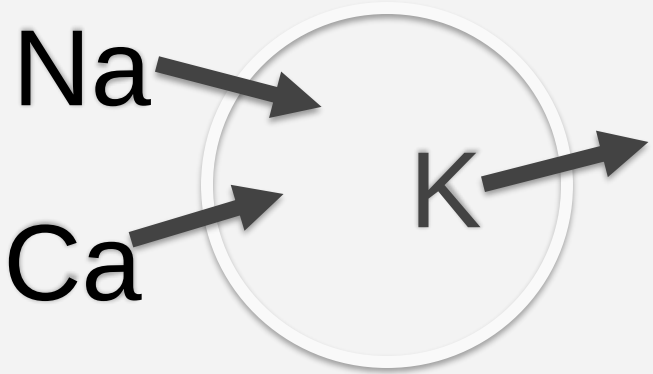
Abnormal Ionic Flux → Impaired Cellular Communication

Impaired Glucose Metabolism → Altered Energy Delivery

Abnormal Ionic Flux: Impaired Cellular Communication

- Channelopathies ensue
  - Damaged neuronal cell membranes allow passive diffusion of ions in **unconventional** directions: sodium influx, potassium efflux, calcium* influx
- Unusual triggering of voltage- or ligand-gated ion channels
- Hyperacute, indiscriminatory glutamate release

Symptom associated:
migraines



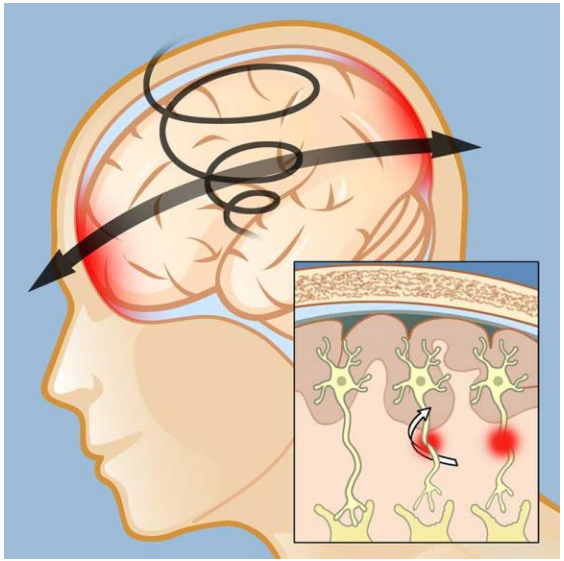
Impaired Glucose Metabolism: Energy Crisis

- Sky-high **increase** in cerebral metabolic rate (CMR)
- Initial hyperglycolysis + depleted energy reserves + impaired glucose metabolism (7-10 days) + increase in ADP
  - Supply ≠ Demand
- Glucose utilization in first 5 minutes of concussion is ↑**243%** (Yoshino)
- Ionic flux also further increases glucose utilization
- Mitochondrial are overloaded by Ca+ → dysfunction
- This process may be altered by gene expression

Symptom associated:
impaired memory

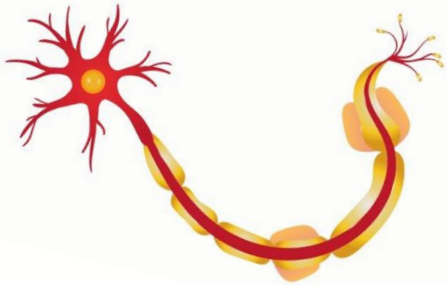
Axonal **Damage**

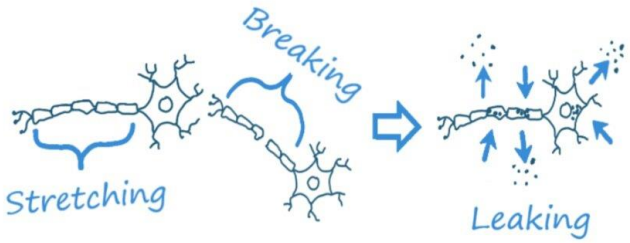
- Damage to critical axons includes *“mechanoporation, stretching and beading of individual axons, disruption of axonal transport and axonal blebbing, as well as disconnection”* -Giza & Hovda, 2014, p.6
- Potential axonal disconnection + atrophy
- White matter damage results in cognitive impairments



weillcornellbrainandspine.org/

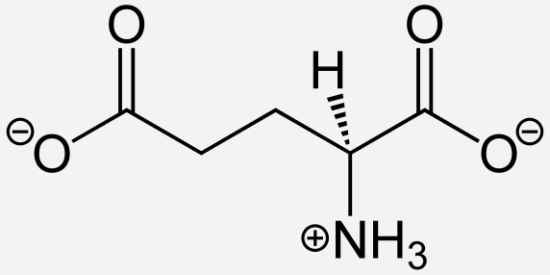
Symptom associated:
delayed cognition





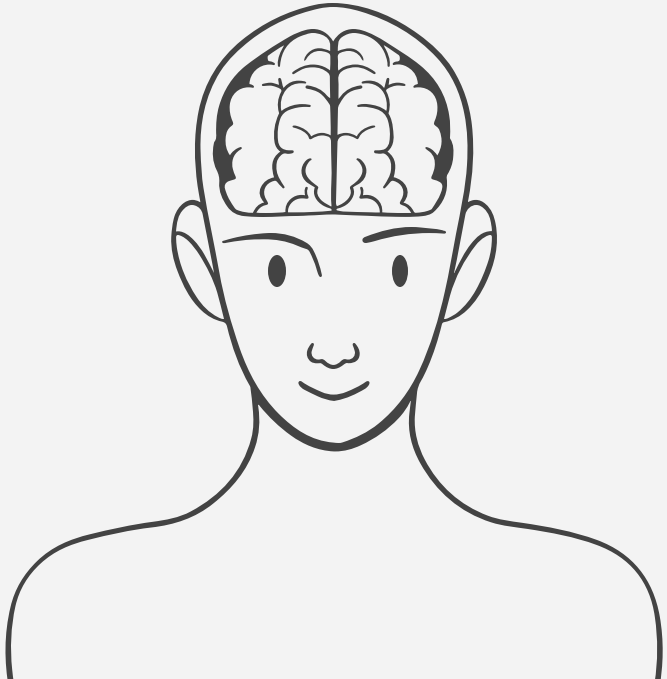
concussionalliance.org/

Altered Neurotransmission



Disruption in key receptors:

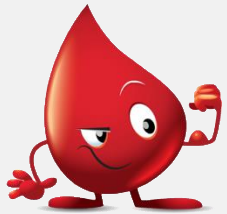
- **N-methyl-D-aspartate (NMDA)**
  - Memory, plasticity and brain development
- **Y-aminobutyric acid (GABA) receptors**
  - Fear-based learning, vulnerability to anxiety/PTSD
- **N-acetyl-L-aspartate subunits**
  - Role less known
  - Persists for 30-45 days

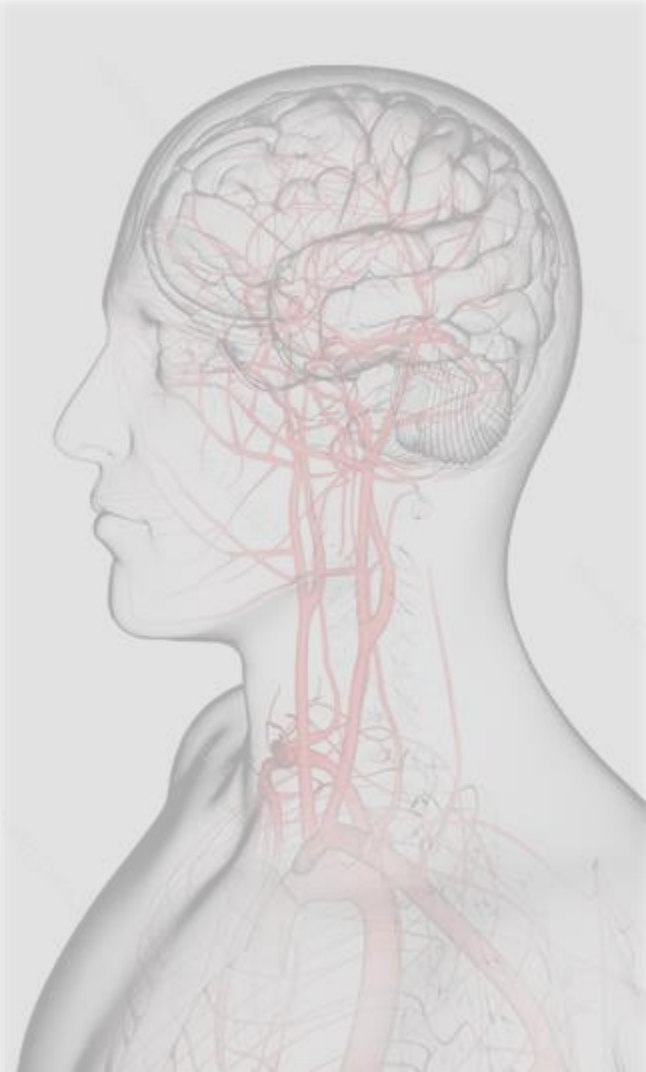


Altered Cerebral Blood Flow

- Likely *not* reaching ischemic levels but does impact energy delivery
- Reduction occurs in the setting of an increased cerebral metabolic rate (CMR)

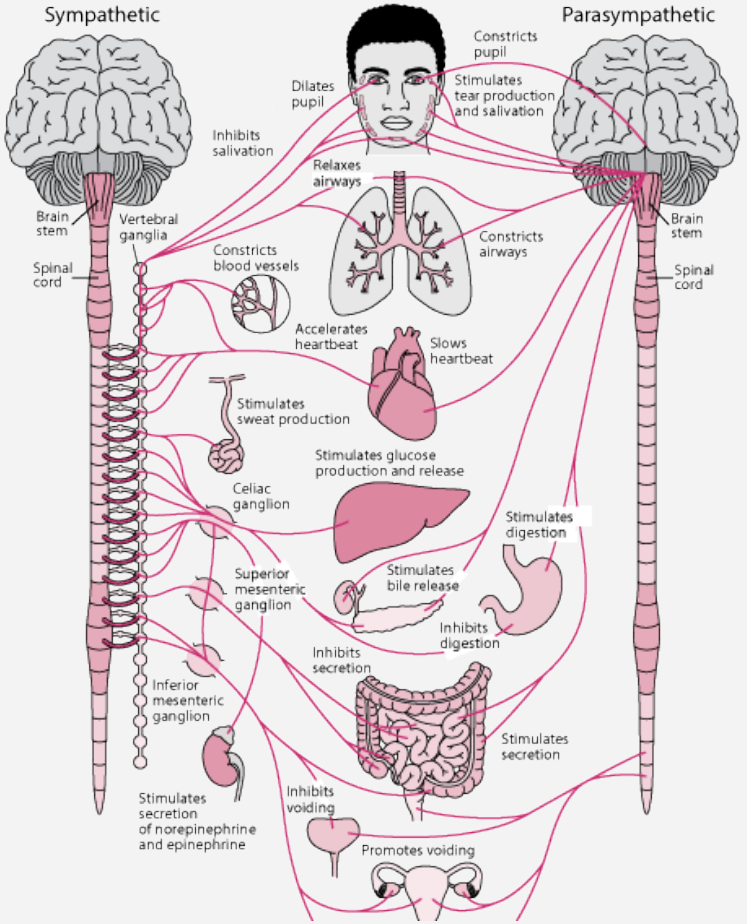
  Supply ≠ Demand
- Reduced CBF autoregulation
  - Decreased responsiveness to CO_2 levels
  - Altered responsiveness to systemic BP
- May last 2 weeks or longer





Autonomic **Dysfunction**

- Diminished heart rate variability (HRV)
  - Inability to respond to stress normally
  - Predictor for all-cause cardiac and/or arrhythmic mortality
- Alterations in peripheral vascular tone (stiff)
- Alterations in HR and SBP to parasympathetic stimuli
  - Independent from baroreceptor responses
- Slowed pupillary light reflex



Concussion Recovery

CLINICAL recovery is different from PHYSIOLOGICAL recovery!

CLINICAL RECOVERY = Absence of symptoms
Severity of initial symptoms correlates with duration of recovery

PHYSIOLOGICAL RECOVERY = Indeterminable time period (probably 30-45 days)
This is the most concerning period of vulnerability for the brain
CRNAs should be VERY concerned w/ persistent symptoms > 10-14 days (adults), > 4 weeks (pediatric)

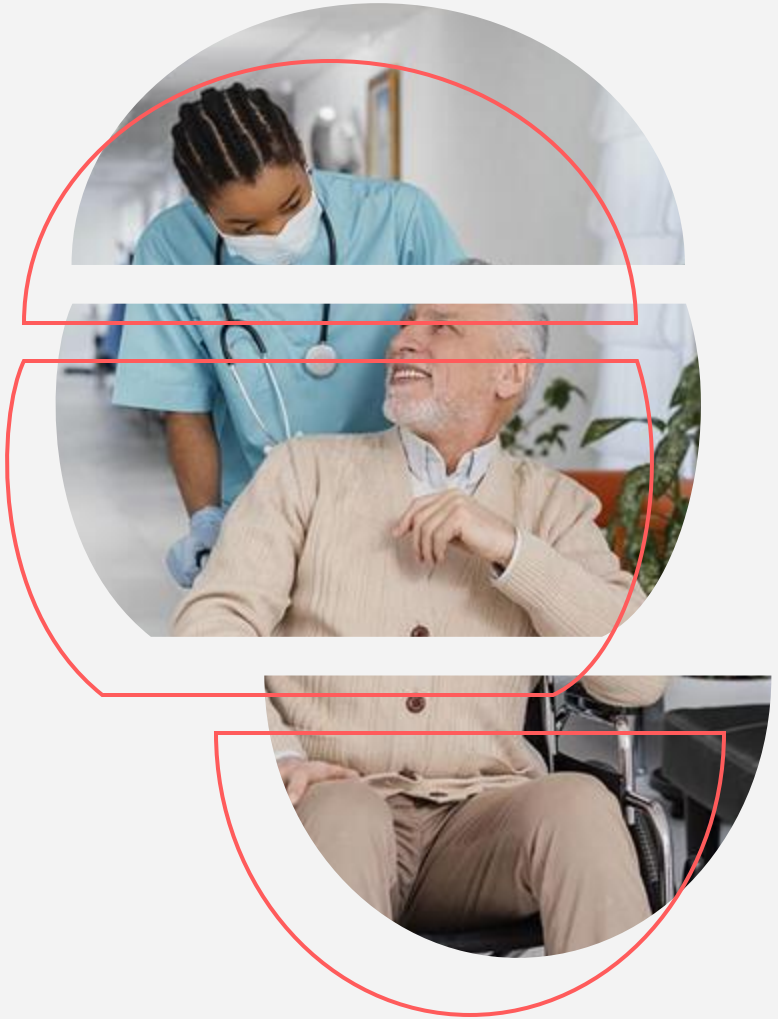
A definitive timeline for full recovery cannot be determined.

Clinical and Symptomatic **Recovery**

Balance and cognitive deficits are customary for 24-72 hours
Typically improve in the first 1-2 weeks

Most athletes return to the field of play within 10 days
This interval continues to lengthen

Preexisting conditions such as mental health problems or migraines are predictors of persistent concussion symptoms



Cellular/Physiological

Recovery

Cellular damage may persist long after physical symptoms resolve

Younger, myelinated cells tend to be more durable than more mature, unmyelinated cells

Accumulation of amyloid-beta peptide and tau protein; caspase activation in chronic mTBI or Chronic Traumatic Encephalopathy (CTE)

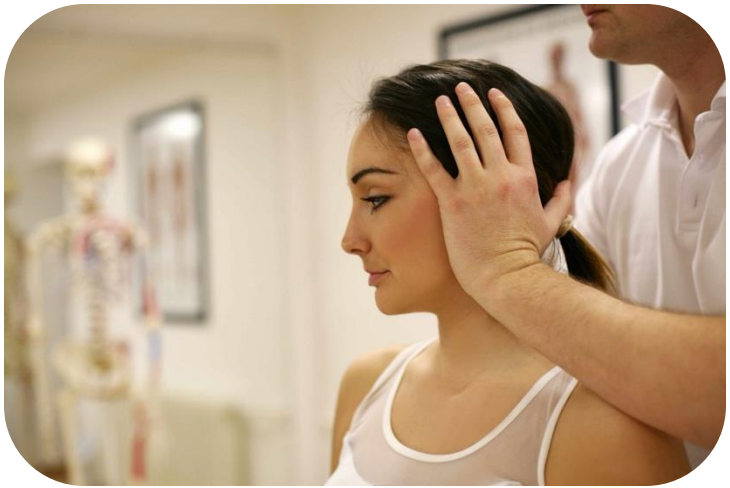
Inhalational agents may accelerate neurodegenerative changes

Concussion **Treatment**

- Medications are ineffective
- Rest vs. activity (physical and cognitive)

  The perioperative period is NOT a period of rest!

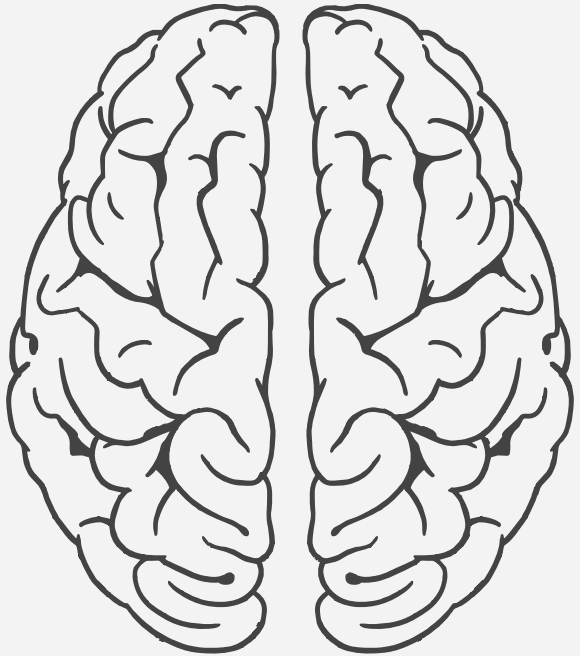
- Rehabilitation for persistent symptoms (> 10-14 days in adults, > 4 weeks in children)
- Requires a multidisciplinary approach



completeconcussions.com

Preoperative **Decision-Making**

DELAY or **PROCEED**?



It is reasonable to delay elective procedures until symptoms have resolved.

As in traumatic brain injury (TBI), the chief aim is to prevent ***secondary insults;*** ***MAXIMIZE*** cerebral oxygen delivery while ***minimizing*** metabolic demand

Intraoperative: **Anticipate Pathophysiologic Effects**

- Within **3 days** of concussion:
  - Physical, cognitive, emotional symptoms present
  - Impaired cognitive function and balance
  - Impairment of the vascular myogenic mechanism
  - Impairment of vagus nerve activity
- Within **7 days** of concussion:
  - Impairment of ANS activity
  - Inappropriate hemodynamic responses
  - Variable responses to CVR and CO2

Practice recommendations
Consider delay of elective surgery/procedures requiring anesthesia until concussive symptoms resolve. If surgery/procedures cannot be delayed due to emergent nature, the following goals should be considered: • Systolic blood pressure > 90 mm Hg • Intracranial pressure < 20 mm Hg • Cerebral perfusion pressure > 50 mm Hg • $Paco_2$ 30-40 mm Hg in absence of intracranial hypertension • Avoid hyperthermia (> 38°C) • Avoid hyperglycemia (> 200 mg/dL)

Table 3. Recommendations to Prevent Secondary Insults in Patients With Concussion

Numeric parameters adapted from Algarra et al.[11]

King D, Collins-Yoder A. Perioperative considerations in patients with concussion. *AANA Journal*. 2019;87(2):97-104.

Postoperative

(D'Souza et al, 2021)

- **Headaches more common within 90 days**
  16.7% v. 6.5%
- **Pain scores higher in PACU**
  28.3% v. 14.8% ≥ 7
- **RASS scores lower**
  −1.61 ± 1.2 v. −0.2 ± 0.4
- May be associated with long term changes such as neurocognitive dysfunction and CTE
  d/t hypotension, hypo/hypercarbia, hypoxia, hypo/hyperthermia, stress
- Much remains unknown (low power studies)

SUMMARY of Recommendations

- Providers must be aware of concussion prevalence, especially in the presence of traumatic injury
- Consider delay of elective and diagnostic procedures
- Anticipate pathophysiologic changes after concussion
- Optimize patient circumstances
- Support and pursue research endeavors

Recommendations
for future study

- Determine how long from time of concussion to anesthetic is safe
- Shift the clinical paradigm from subjectivity to objectivity
- Evidence-based guidelines
- Validation of neuroimaging technologies
- Alternatives to neuroimaging, such as serum biomarkers

THANKS!

DO YOU HAVE ANY QUESTIONS?

daniel.king@rosalindfranklin.edu

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