



Traumatic Brain Injury Basics: Causes, Mechanisms, and Consequences

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Overview

- Traumatic Brain Injury
 - Epidemiology of TBI
 - Mechanisms of injury
 - Classification of TBI's
 - Consequences



What is a Traumatic Brain Injury?

- CDC definition -

A traumatic brain injury (TBI) is caused by a bump, blow, or jolt to the head or penetrating head injury that disrupts the normal function of the brain.

- American Congress of Rehabilitation Medicine definition (2010)-

TBI is defined:

1) as an alteration in brain function, or other evidence of brain pathology, caused by an external force, manifested by 1 of the following clinical signs:

- Loss of consciousness (LOC)
- Alteration of consciousness (AOC) – dazed, disoriented, confused
- Posttraumatic amnesia (PTA)
- Focal neurologic deficit – may or may not be transient

2) or other evidence of brain pathology – e.g., on brain imaging



Is it that Clear???

What is a Traumatic Brain Injury

- Subconcussion?
 - Visible signs of brain injury not present
 - Gysland et 2012 (Annals of Biomedical Engineering):
 - Used head impact telemetry system – embedded accelerometers
 - Findings – ~1000 “subconcussive” impacts to head in a single season
 - No neurologic/cognitive impairment found
 - Cumulative effect over the course of a sports career?
 - See: Bailes et al. (2013) Role of subconcussion in repetitive mild traumatic brain injury. J. of Neurosurgery Nov, 119, 1235-45.





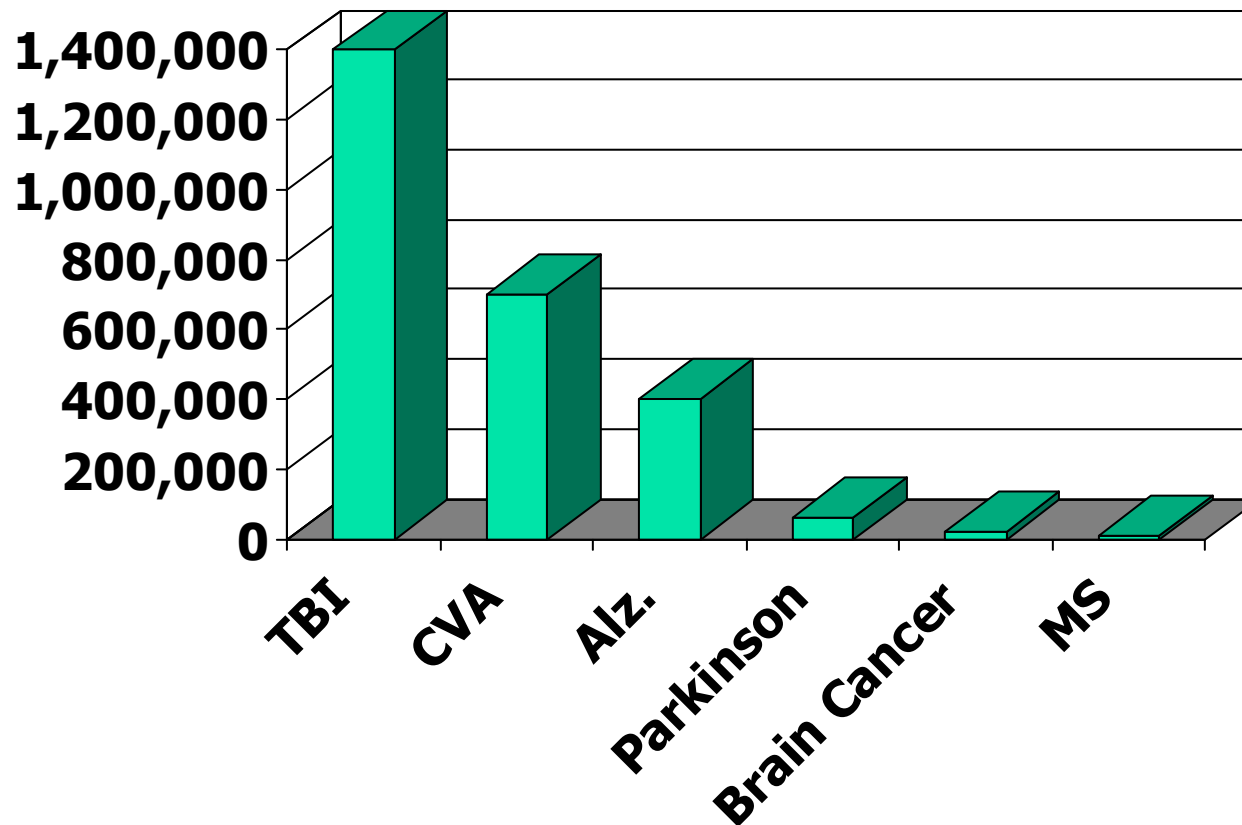
Epidemiology of Traumatic Brain Injury



Epidemiology of TBI in the USA

- Yearly incidence: At least 1.4 million persons sustain a traumatic brain injury annually
- Comparison to other acquired brain disorders →

Yearly Incidence of Brain Disorders in the USA*



*Incidence estimates based on data from various sources (e.g., CDC, society web pages)

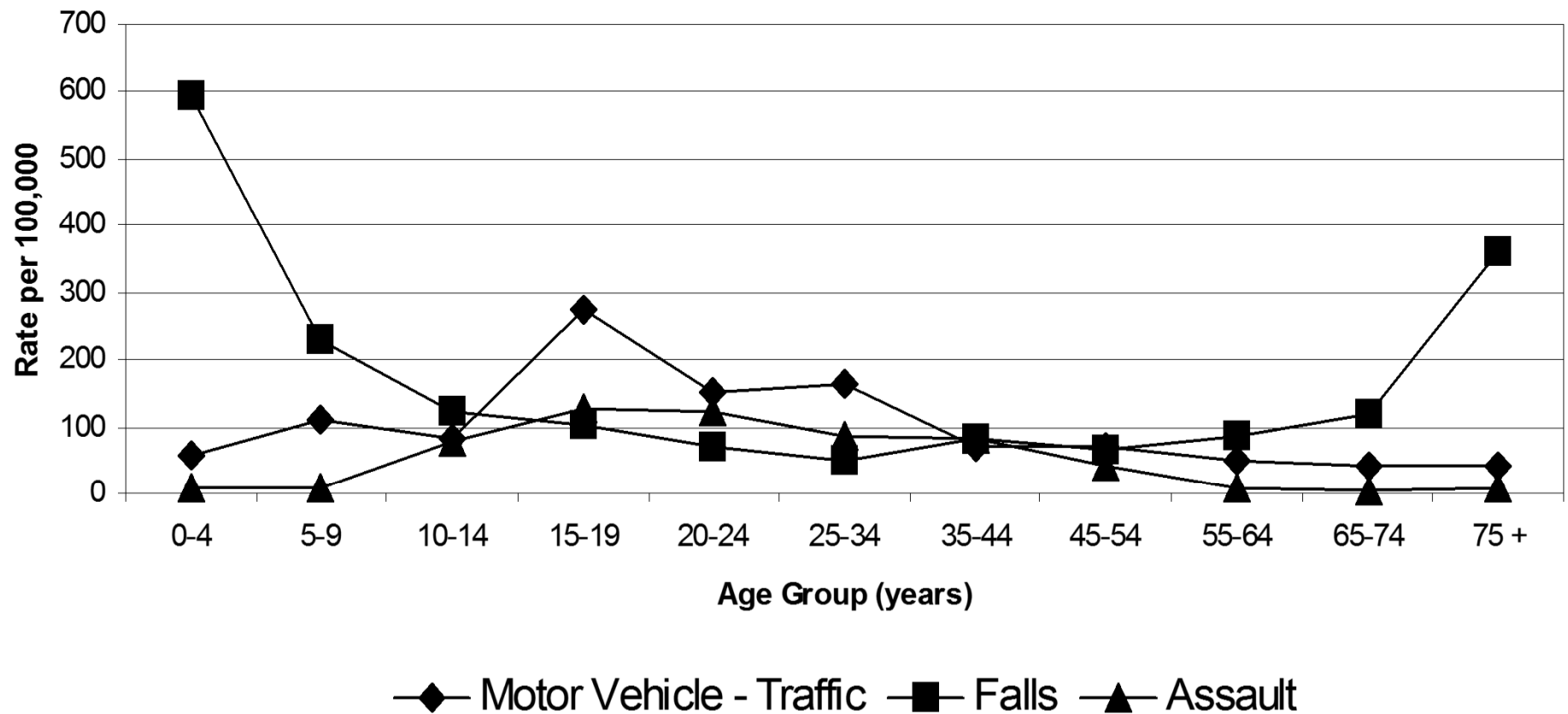


Risk Factors for TBI

- Age: 1-5 years, 15-24 years, elderly

TBI in the United States

TBIs by Cause*



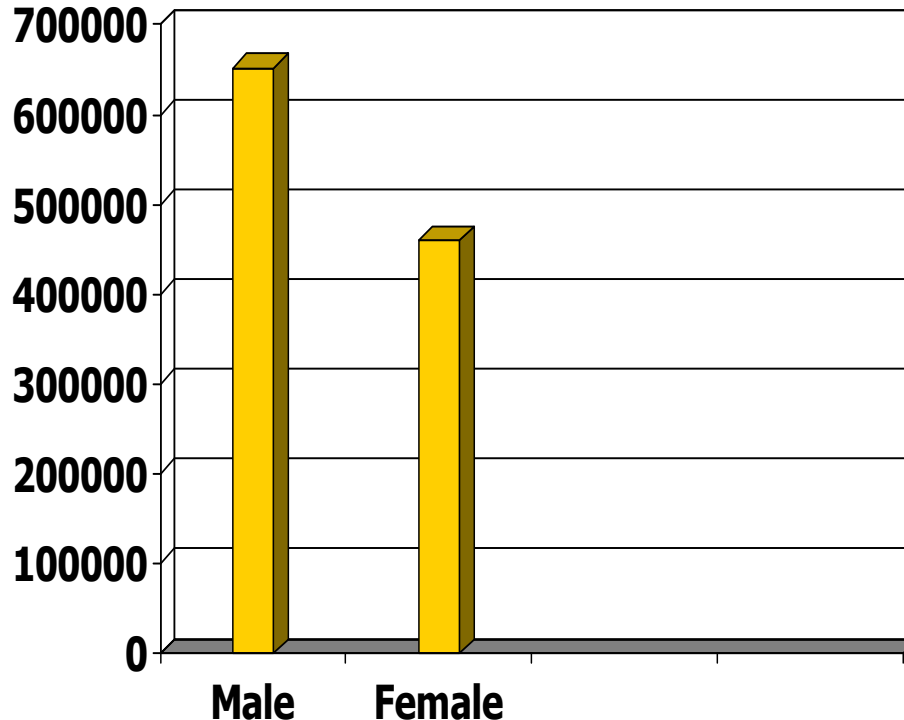
Source: CDC – Traumatic Brain Injury in the United States; 2006 – based on ER visits, Hospitalizations, Deaths



Risk Factors for TBI

- Age: 1-5 years, 15-24 years, elderly
- Male

Average Annual Incidence of TBI by Gender: 1995 – 2001



- Overall, approximately, 1.5 times as many TBI's occur among males as among females per year
- $M > F$ trend occurs in most age groupings
 - Except older adults (> 55): fairly even rates

Source: CDC – Traumatic Brain Injury in the United States; 2006 – based on ER visits, Hospitalizations, Deaths



Risk Factors for TBI

- Age: 1-5 years, 15-24 years, elderly
- Male
- Lower socioeconomic status / lower education / unemployment
- Prior head injury
- Alcohol / Recreational Drugs



Alcohol / Recreational Drug Use as a Risk Factor in TBI

- Corrigan et al (1995): persons hospitalized with TBI
 - One *third to one half* were intoxicated at time of injury
 - 50% to 60% had a history of alcohol or other drug abuse
- Bombardier et al (2002): persons admitted to inpatient rehab center
 - Alcohol
 - 42% had a positive BAL at time of injury
 - 65% with lifetime history of at-risk drinking
 - Recreational drugs
 - 38% had a positive toxicology screen for marijuana, cocaine, or amphetamines
 - 31% had used one or more recreational drugs at least 3 months prior to injury (primarily marijuana, cocaine, amphetamines)
- Alcohol effect on long-term outcome: Intoxication at time of injury *versus* alcohol history?
 - Findings are mixed – but most studies show an effect for one or both of the factors
 - Study by Wilde, Bigler et al (2004, *Journal of Neurotrauma*)
 - Both time of injury and chronic alcohol use were related to **increased brain atrophy** and **mildly decreased memory performance at 3 to 4 years postinjury**

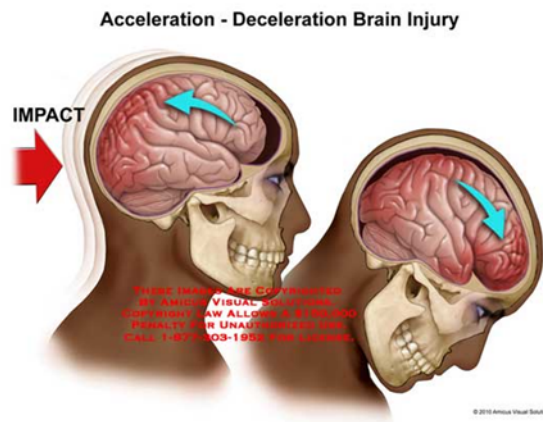


Mechanisms of Traumatic Brain Injury

Mechanisms of Traumatic Brain Injury

- Closed Head Injuries:

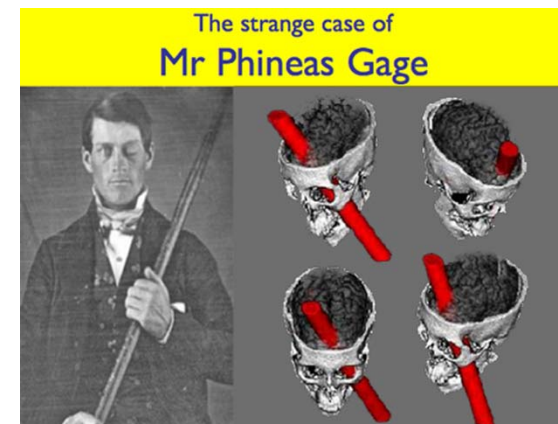
- Acceleration / Deceleration Injuries
- Blast Injuries



- Penetrating Wound Injuries

- Examples:

- Gunshot wound
- Skull fracture fragment enters the brain – may represent a combination of closed and penetration injury



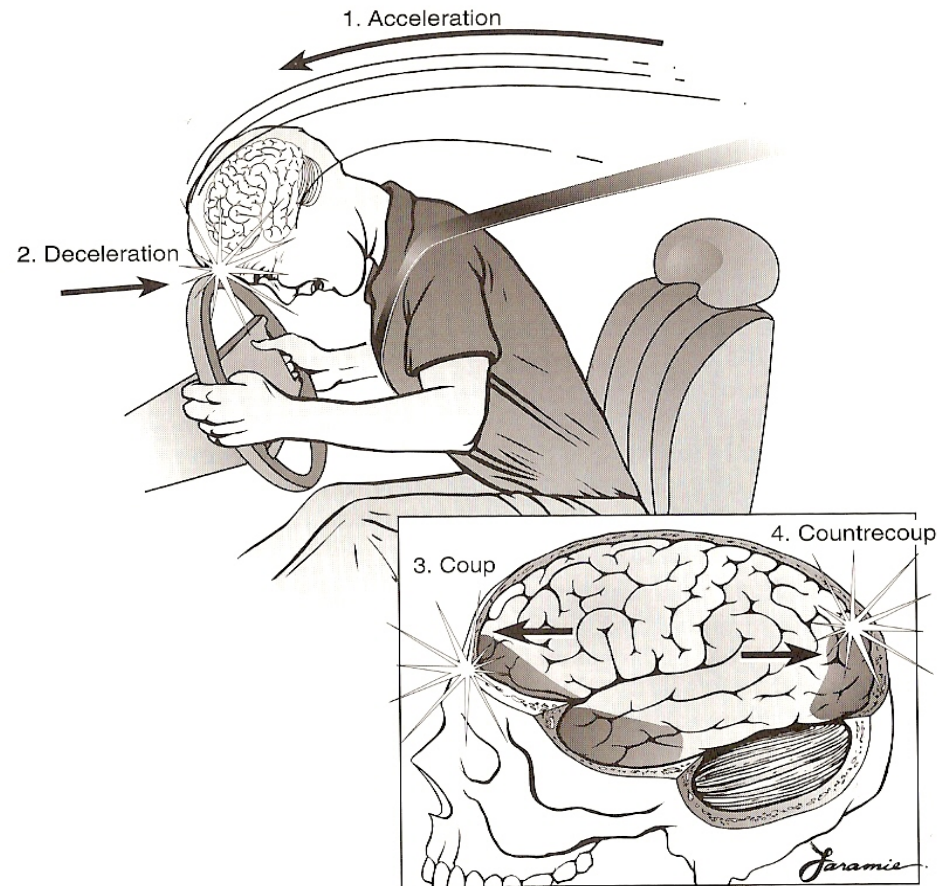


Closed Head Injury: Mechanisms of Injury

- Primary injuries – damage occurred at the time of impact
 - Hemorrhage / Hematomas
 - Contusions of the brain
 - Diffuse Axonal Injury
- Secondary or later effects of injuries

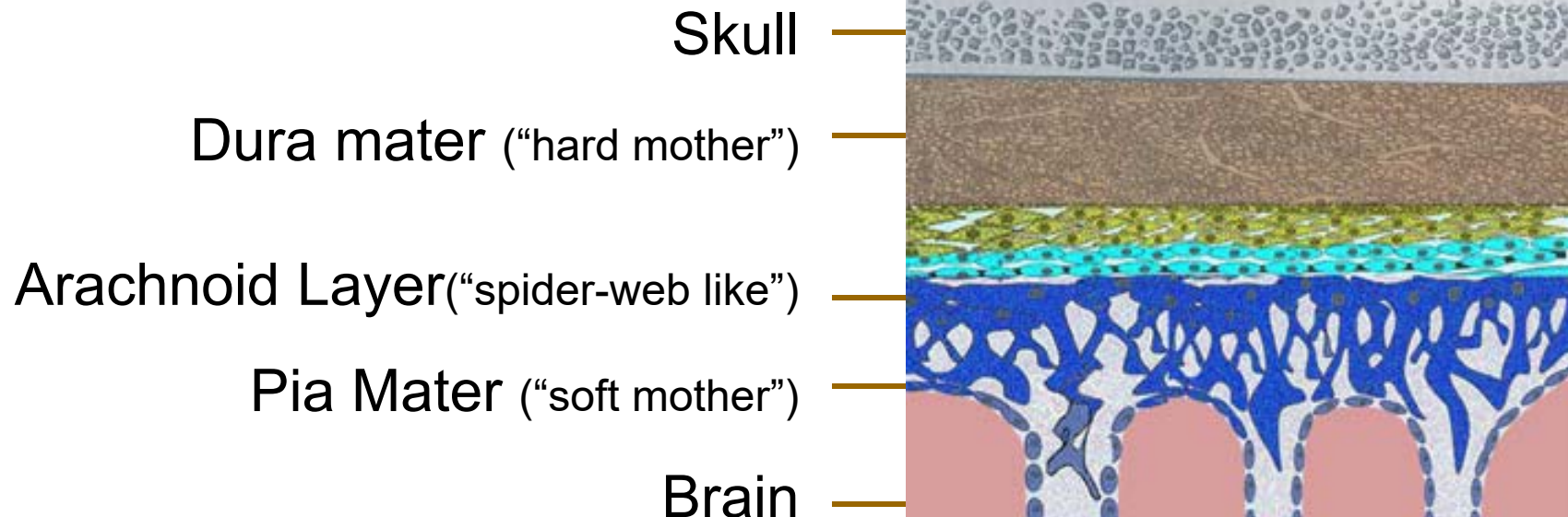
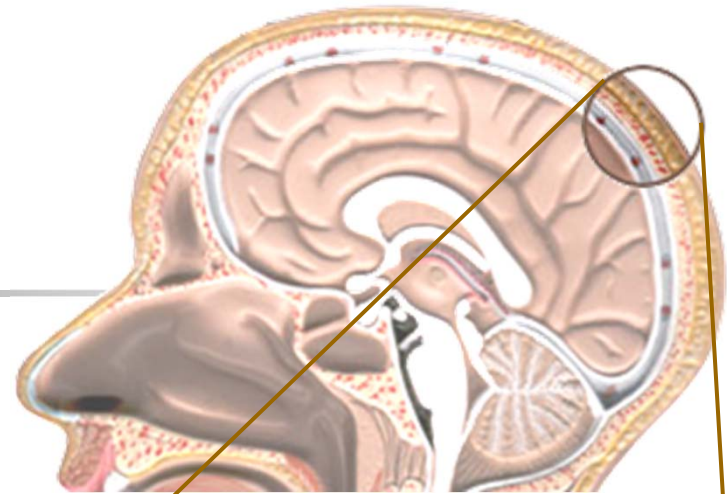
Acceleration-Deceleration Injury: Hematomas - Contusions

- Damage at the site of impact – coup injury
- Damage at opposite site of impact – countrecoup injury



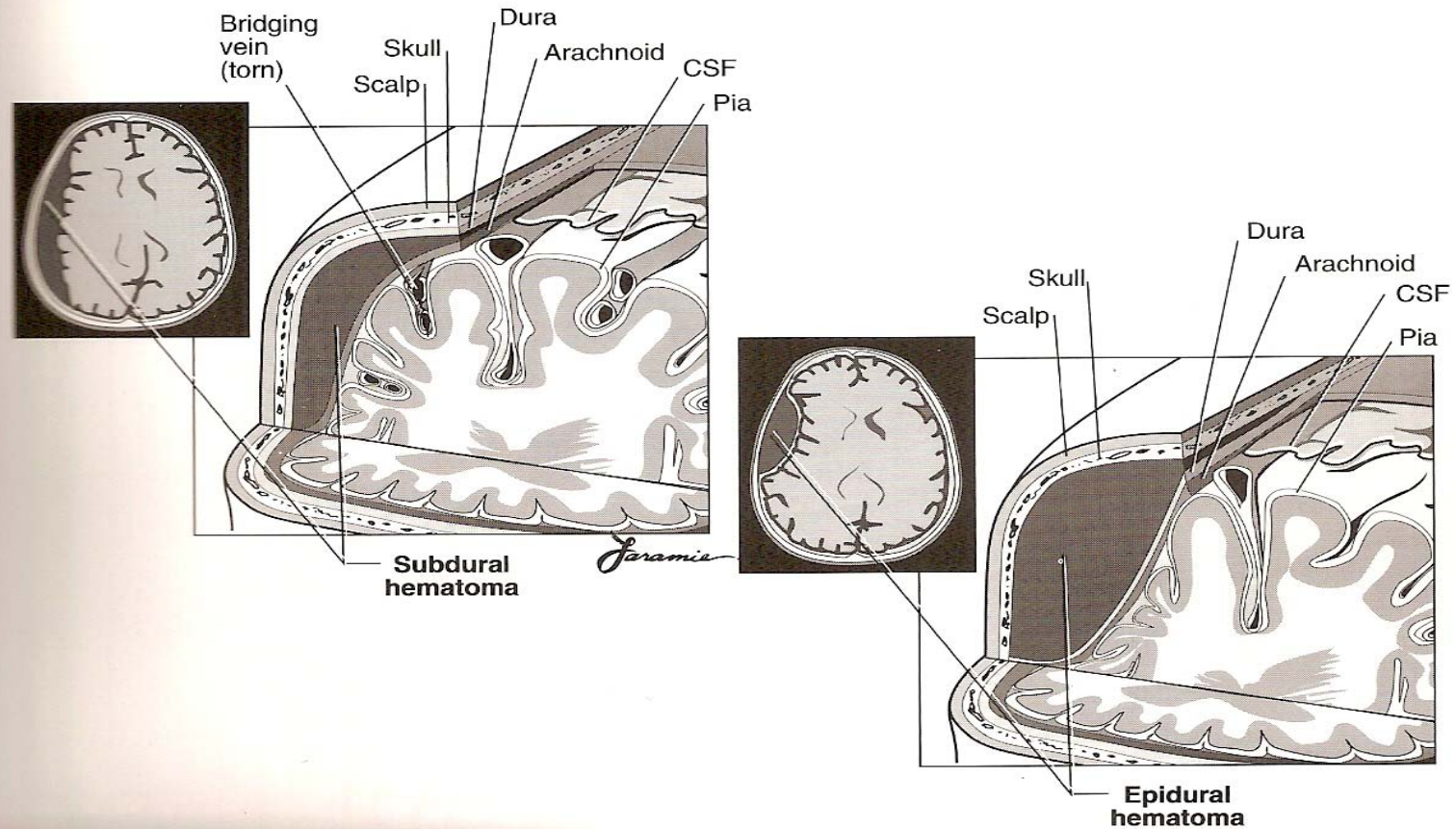
The Meninges

The meninges are layers of tissue that separate the skull and the brain.

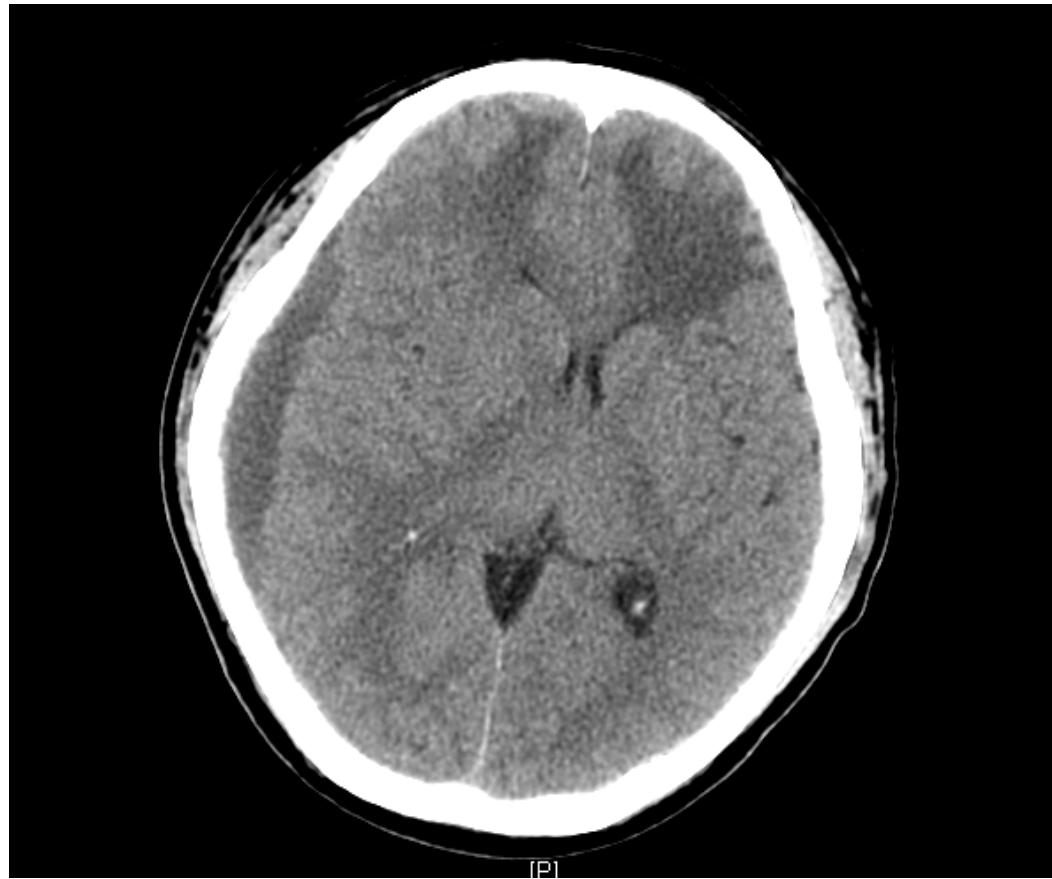


Hemorrhage / Hematoma

Figure 2.3
Intracranial Hemorrhages



Subdural Hematoma with Mass Effect

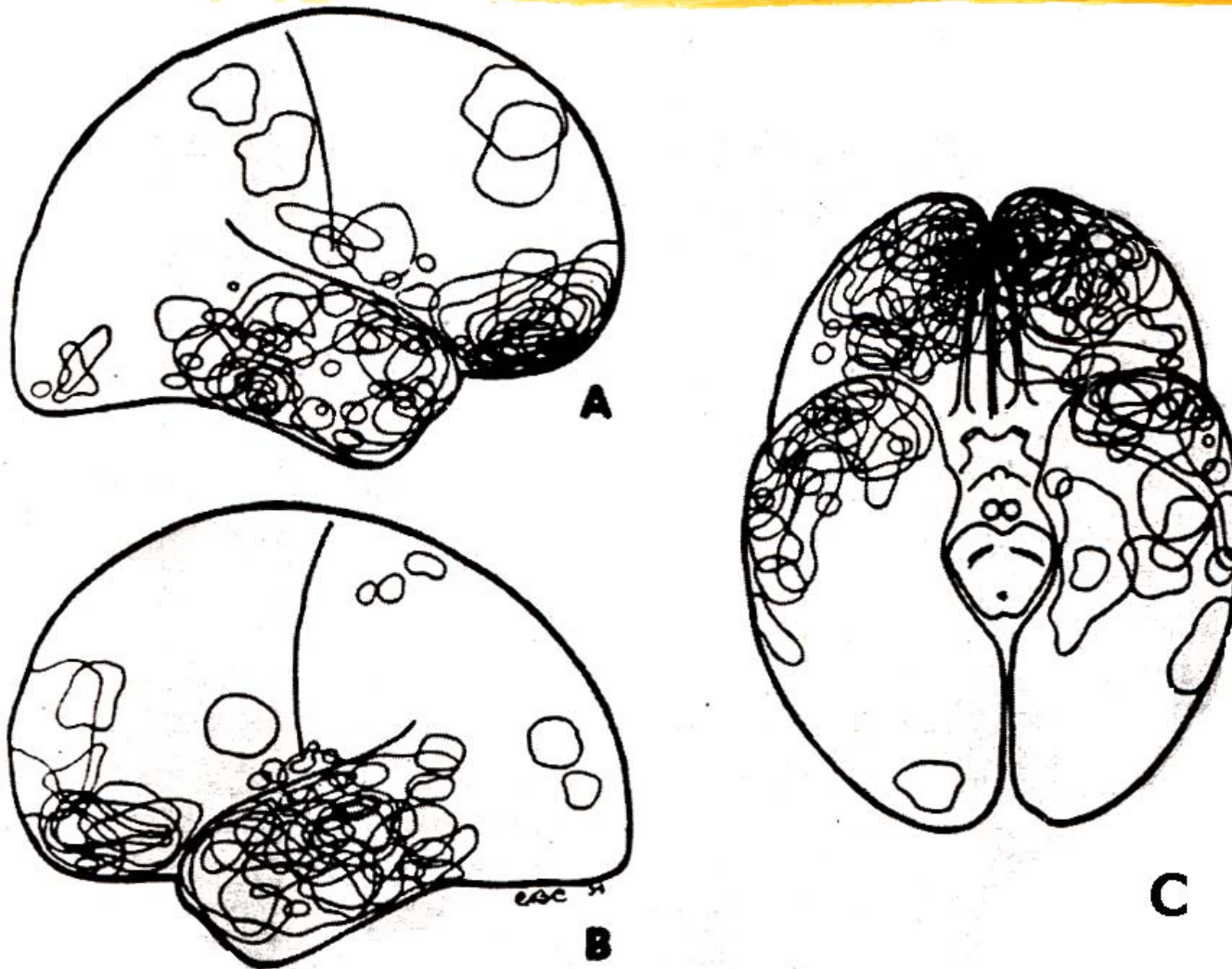


TBI-Related Contusions

- Bruising of the brain
- Most frequently in the cortex – gray matter
- Frontal-temporal regions most vulnerable



Figure 2-7. Composite views demonstrating contusional localization.

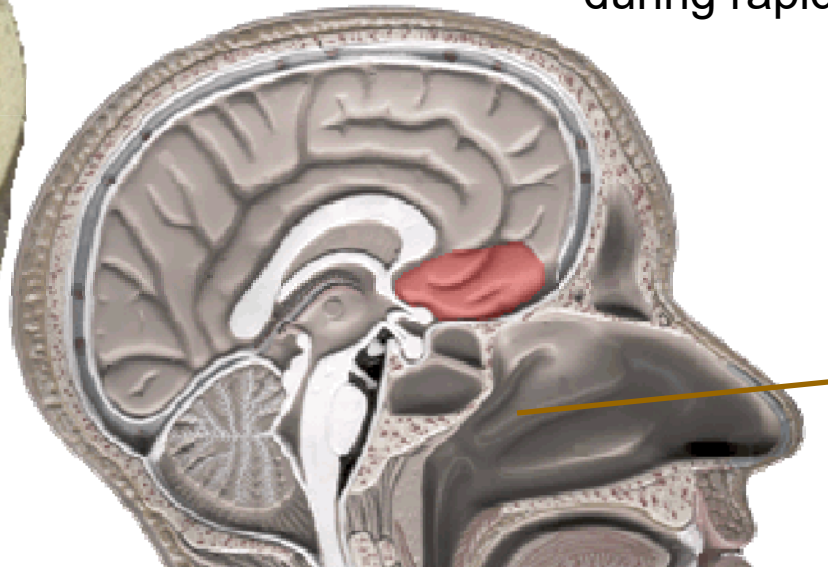
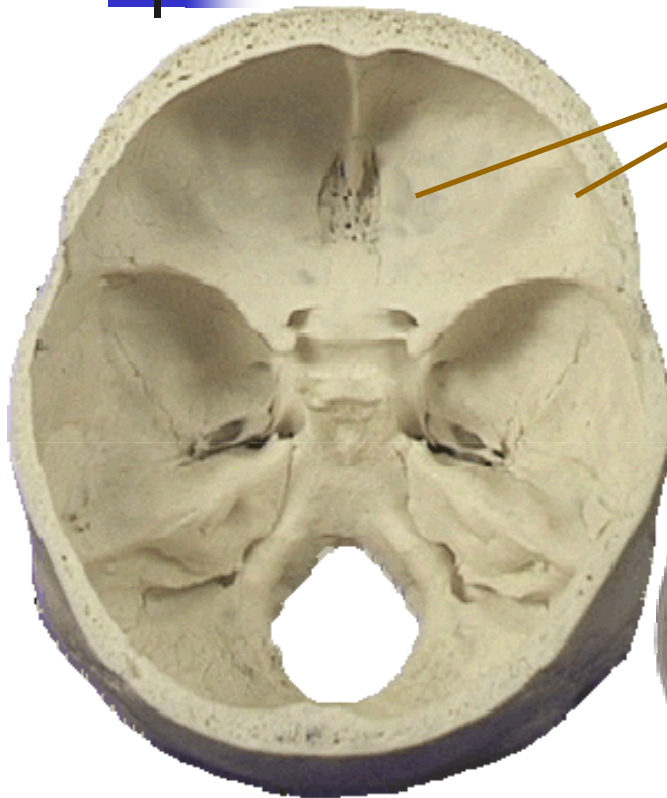


Interior Skull Surface

Bony ridges

The base of the skull is rough, with many bony protuberances.

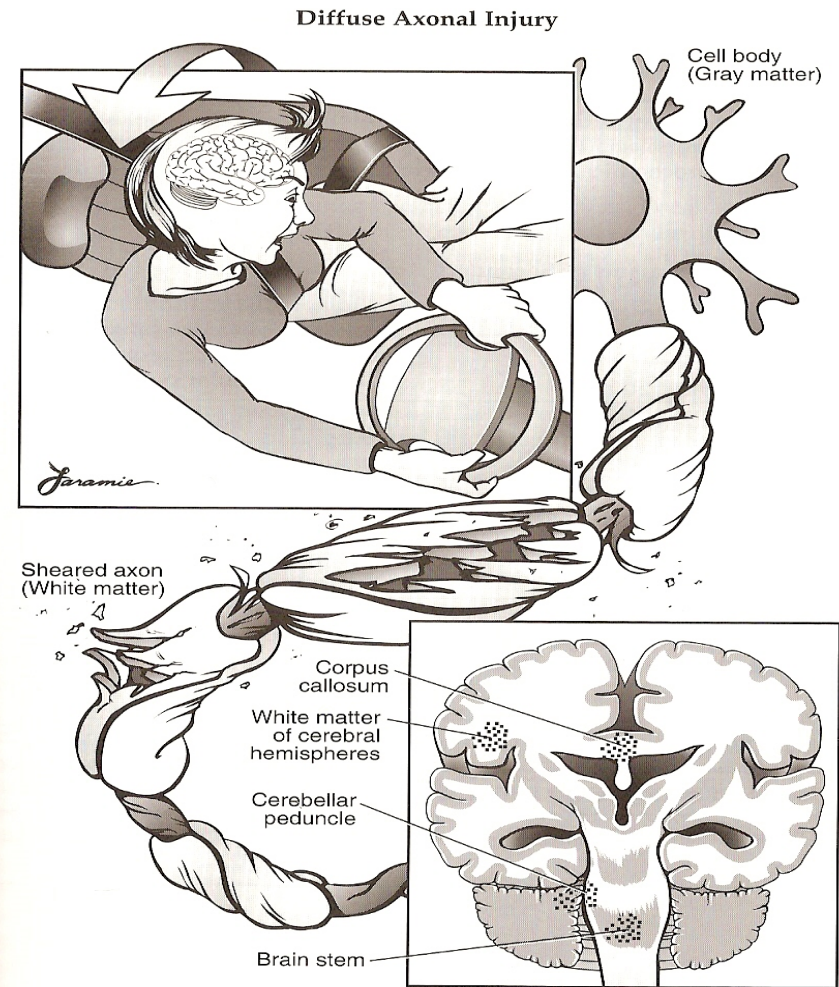
These ridges can result in injury to frontal and temporal lobes during rapid acceleration.



Injury from contact with skull

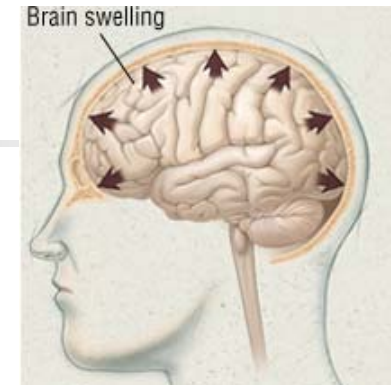
Diffuse Axonal Injury

- Rotation or rapid acceleration/ deceleration
>> shearing, stretching of axons
- Occurs in the white matter of brain: e.g.,
 - Corpus callosum
 - Gray-white matter junction
 - Brainstem

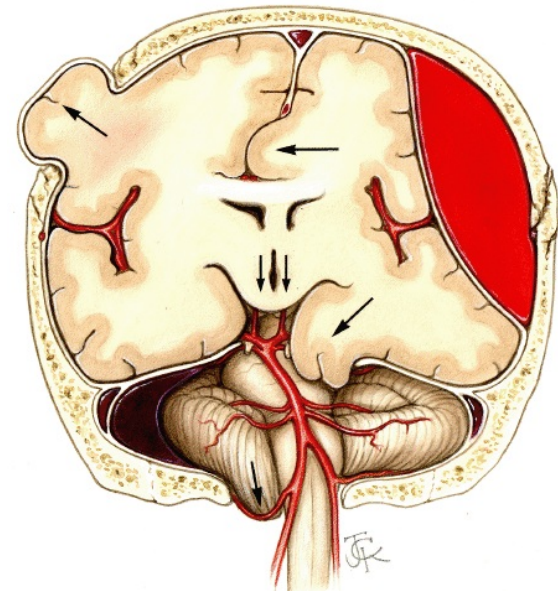


Secondary Effects of Closed Head Injury

- Increased intracranial pressure
 - Edema - swelling
 - Inflammatory response to injury
 - CSF response – poor reuptake
 - Subdural / epidural / subarachnoid hematomas
 - Brain contusions
 - **Risk for herniation – neuron death**
- Ischemia – loss of normal blood flow
 - Hypoxia (insufficient oxygen to brain)

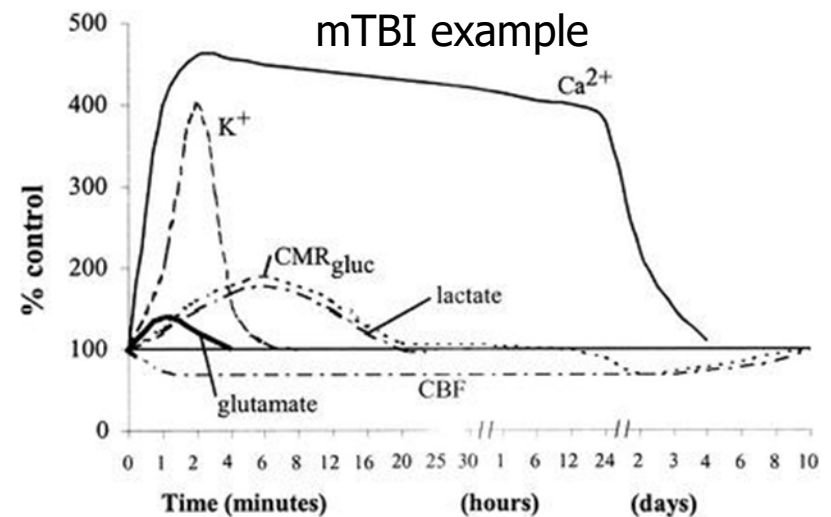


BRAIN HERNIATION



Secondary Effects of TBI

- Neurometabolic Cascade - changes in neuronal processes
 - Stress to neurons
 - Neuronal depolarization, release of excitatory neurotransmitters
 - Increased energy needs
 - Altered (decreased) blood flow
 - Increased energy needs of neurons not matched by blood flow supply
 - Affects conduction of neurons
 - Can be affected for hours, days, weeks or months
- Seizure
 - 17-20% of persons with moderate-to-severe TBI have seizures during the 1st 2 years
 - ~50% of seizures occur within the 1st 24 hours





Basic Acute Management Considerations in Moderate-to- Severe TBI

- Monitor mental status
- Brain imaging needs
- Monitor intracranial pressure
 - Medications to reduce swelling
 - Hypothermia
 - Surgical decompression if necessary
- Seizure prophylaxis
- Adequate nutrition
- Correction of electrolyte abnormalities



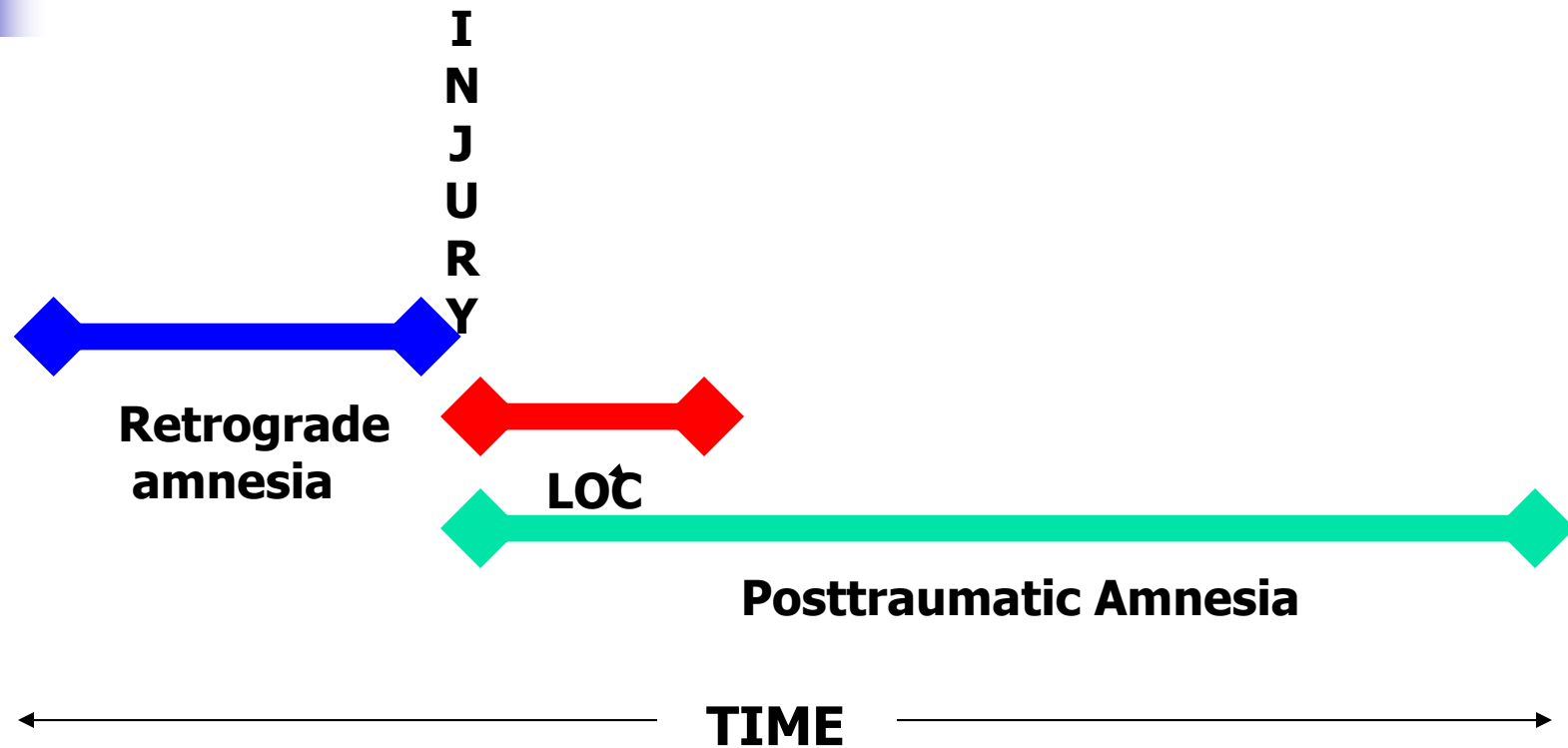
Classifying Severity of TBI



Traumatic Brain Injury Severity: Measurement

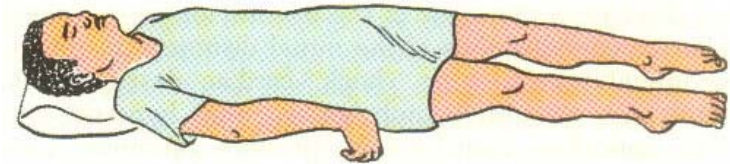
- Mild, Moderate, Severe
- Biomarker? → Brain Imaging Findings
- Clinical Measures
 - Length of coma (LOC)
 - Glasgow Coma Scale
 - Level responsiveness / depth of coma
 - Retrograde Amnesia
 - Absence of recall of events immediately prior to trauma
 - Posttraumatic amnesia
 - Absence of recall immediately following trauma

TBI Clinical Severity Parameters

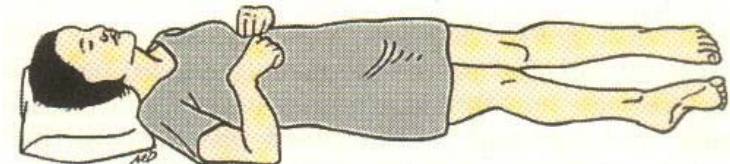


Glasgow Coma Scale

- Measures “depth” of coma (loss of consciousness), i.e., level of responsiveness
- Score range: 3 to 15
- 3 Responses
 - Best verbal response
 - 1 = none; 5 = fully oriented
 - No response, sounds, inappropriate words, confused, fully oriented
 - Eye opening
 - 1 = none; 4 = spontaneously
 - No opening, opens -- in response to pain (e.g., on fingernail), to speech, spontaneously
 - Best motor response
 - (1 = none; obeys = 6)
 - None, in response to pain: decerebrate (extension), decorticate (flexion), flexion/withdrawal to pain, localizes to pain, obeys commands



A. Extension posturing (decerebrate rigidity)



B. Abnormal flexion (decorticate rigidity)

<http://www.youtube.com/watch?v=FihnmEx6Rqk>



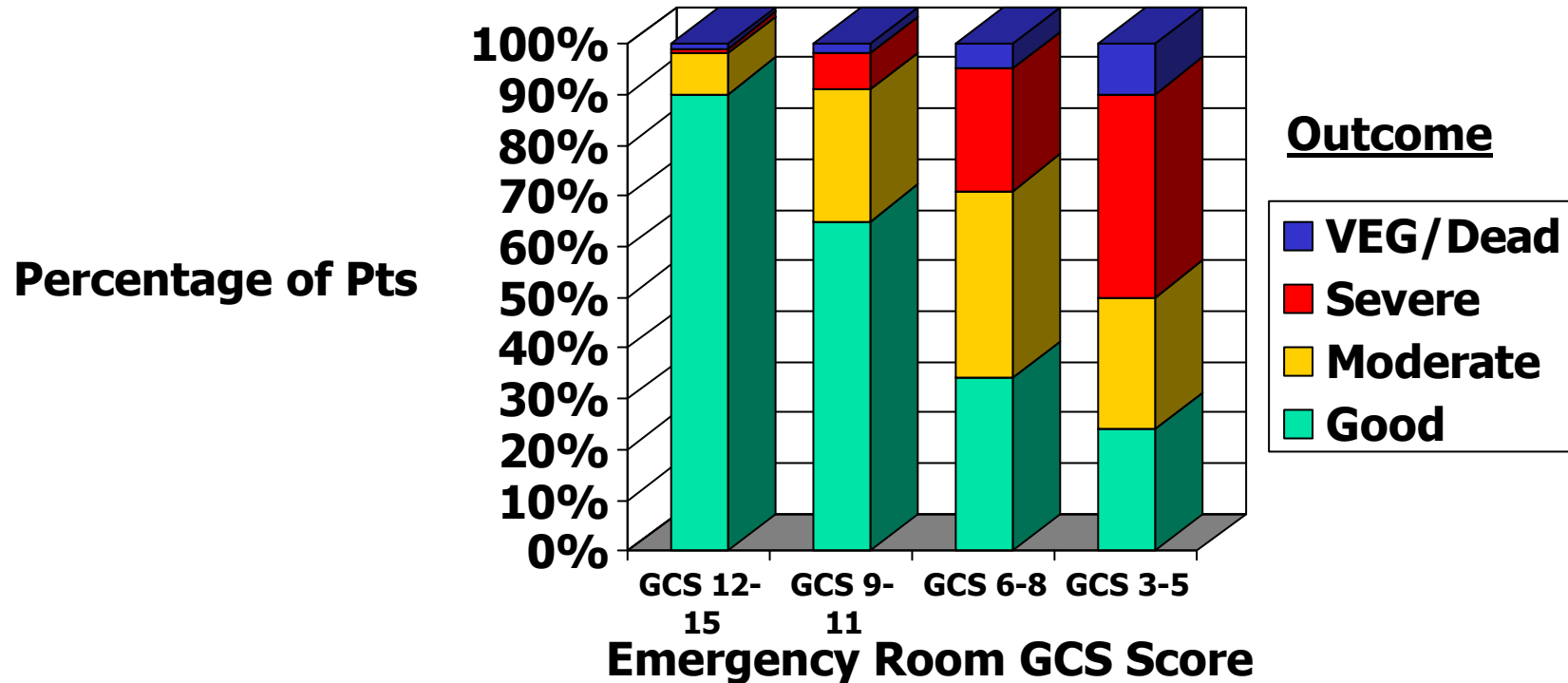
Clinical Indicators of Traumatic Brain Injury Severity*

<u>Indicator</u>	<u>Mild</u>	<u>Moderate</u>	<u>Severe</u>
GCS (best in 1st 24 hrs)	13-15	9-12	3-8
Length of Coma	≤ 30 min	30 min to 24 hours	> 24 hours
PTA	< 1 day	>1 day <7 days	> 7 days
RTA	None to a few min.	1 hour to 24 hours	> 24 hours
Structural Imaging	Normal	Normal or Abnormal	Normal or Abnormal

*Department of Defense 2008

TBI: 1-Year Overall Functioning Outcome by Injury Severity

Outcome Measure: Glasgow Outcome Scale



(Dikmen et al)



Incidence / Prevalence of TBI by Severity

- ~ 80% are mild injuries
- ~ 10 to 30% are moderate injuries
- ~ 5 to 25% are severe injuries

- Across study variation in severity definitions
 - Mild versus complicated mild
 - Goes back to definition of TBI
- Mild traumatic brain injury = concussion?



The Brain Imaging Issue and mTBI

- Standard structural head CT and brain MRI – used to test for acute post head injury changes – not diagnostic of mTBI
 - By definition – negative findings
 - Do not add much to the diagnosis of mTBI – but used to rule out moderate-severe TBI
 - If positive imaging finding → **complicated mTBI**
 - **Is the lack of findings an indication of lack of structural brain injury?**
- The quest for a “biomarker” of mTBI

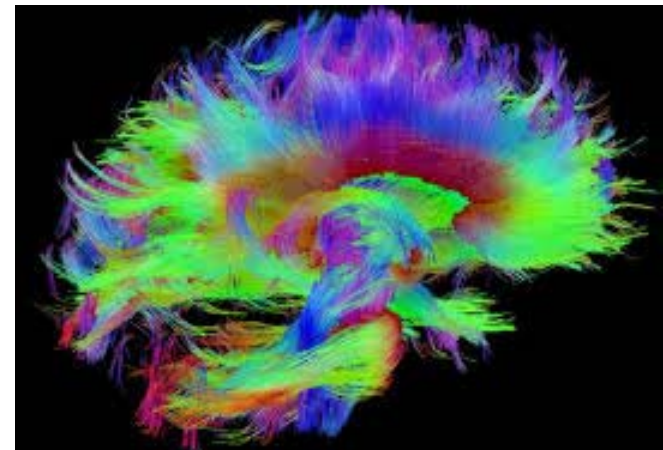
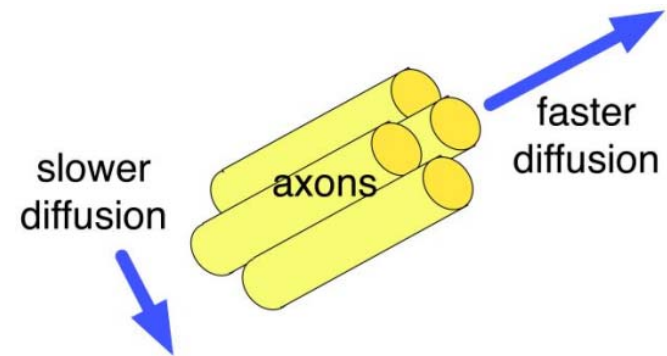


The Holy Grail – mTBI biomarkers

- Erin Bigler – Neuroimaging biomarkers in mTBI - Neuropsychol Rev (2013) 23:169–209
 - Delicate nature of neurons – especially axons
 - Closed head injuries stretch, twist, and/or shear axons
 - Result in diffuse or traumatic axonal injuries
 - Brain imaging advances have improved sensitivity
 - Argues – now at the “sensitivity” point that MRI techniques can provide a biomarker of mTBI
- Enter → *Diffuse Tensor Imaging* (and other newer imaging strategies – e.g., Magnetic Resonance Spectroscopy (MRS))

DTI Magnetic Resonance Imaging – A Primer

- Variant of conventional MRI
- DTI - sensitive at the **microscopic** level
 - Images white matter and sensitive to subtle changes in white matter fibers/tracts
 - Areas of suspected damage in mTBI
- Based on measuring the amount of water movement or diffusion
- DTI changes in white matter have been found in acute and late postinjury times
 - But not all studies and not all patients
- ***Does this change our impression of mTBI effects on the brain: are they as benign as we once thought?***





Consequences of Traumatic Brain Injury

"Of all the injuries, traumatic brain injury most frequently affects every domain of a person's health."

McCarthy et., *Archives of Physical Medicine and Rehabilitation*, July 2006



Consequences of Traumatic Brain Injury

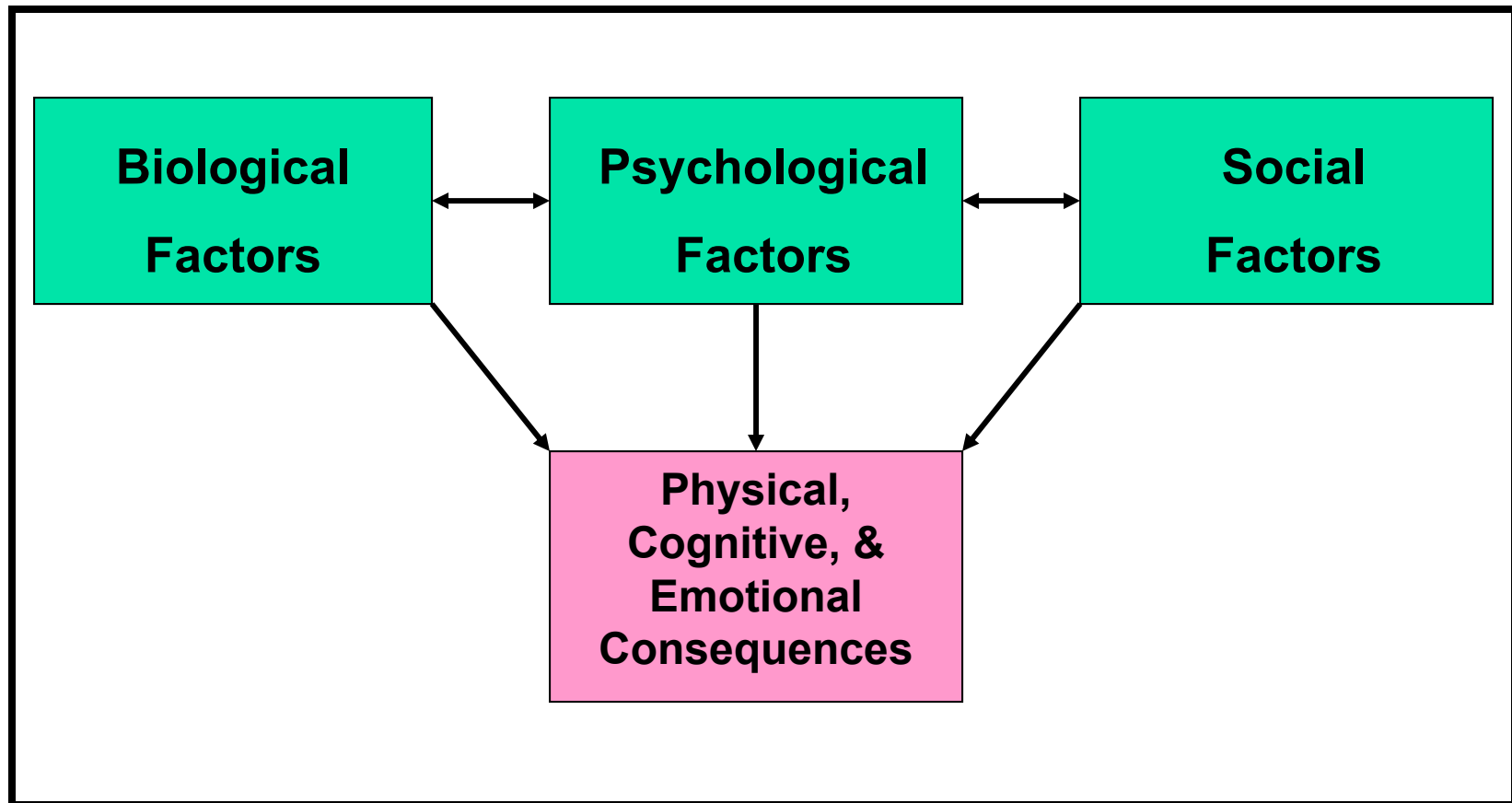
- Physical
- Cognitive / Language
- Emotional / Behavioral

Caveats in Predicting and Understanding TBI effects

- Nature of the brain injury
 - Where is the damage in the brain and what is the severity?
- Whose brain is it that was hurt?
 - Unique nature of each person's preinjury:
 - Physical capabilities
 - Cognitive abilities
 - Personality/emotional strengths and vulnerabilities
- What are the environmental demands on the person?
 - E.g., employment / family role

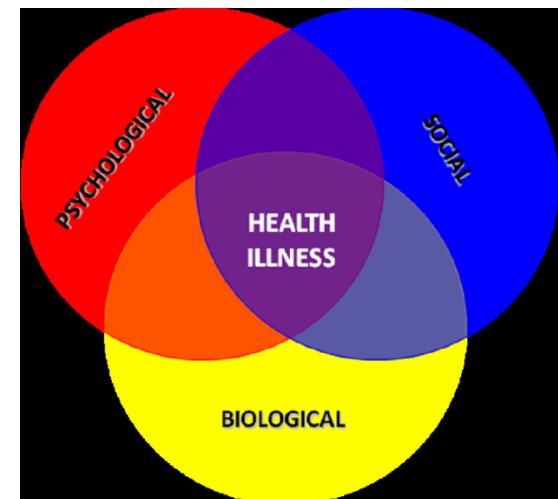


The Biopsychosocial Model



Factors Affecting Occurrence / Severity / Course of TBI Consequences – Biopsychosocial Analysis

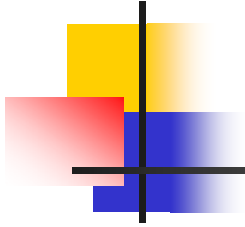
- Biological Factors
 - Severity of brain injury (primary / secondary effects)
 - Location of brain injury
 - Concomitant physical injuries
 - Preinjury medical history -- preinjury physical status
 - Age
 - Prior TBI ? – cumulative effect ?
 - Genetics
 - Medication
 - Pre / post injury alcohol / drug Use
- Psychological Factors
 - Preinjury cognitive capacity
 - Pre/post injury emotional/behavioral status
 - Values
 - Stress management ability
- Social Factors
 - Social support
 - Culture
 - Socioeconomic status
 - Treatment / counseling availability
 - Insurance
 - Living location (distance from care/support resources)





Physical Consequences of TBI

- Was there polytrauma?
- Motor Functioning – strength, spasticity, dysarthria, finger dexterity
- Sensory Functioning – vision, hearing, smell, taste, tinnitus, tactile
- Sensory-Motor Integration: Balance, coordination, motor control
- Pain
 - e.g., Natural history study: headache in 1st postinjury year (Hoffman et al 2012)
 - 40% with moderate to severe TBI
 - 60% with mild TBI
 - General population under 10%
- Sleep Disturbance
 - Subjective complaints – 30%-70%
- Fatigue – physical / mental
 - As many as 70% of persons with TBI report excessive daytime fatigue
 - Mental – extra effort to do even common tasks (e.g., sustain focus while reading)



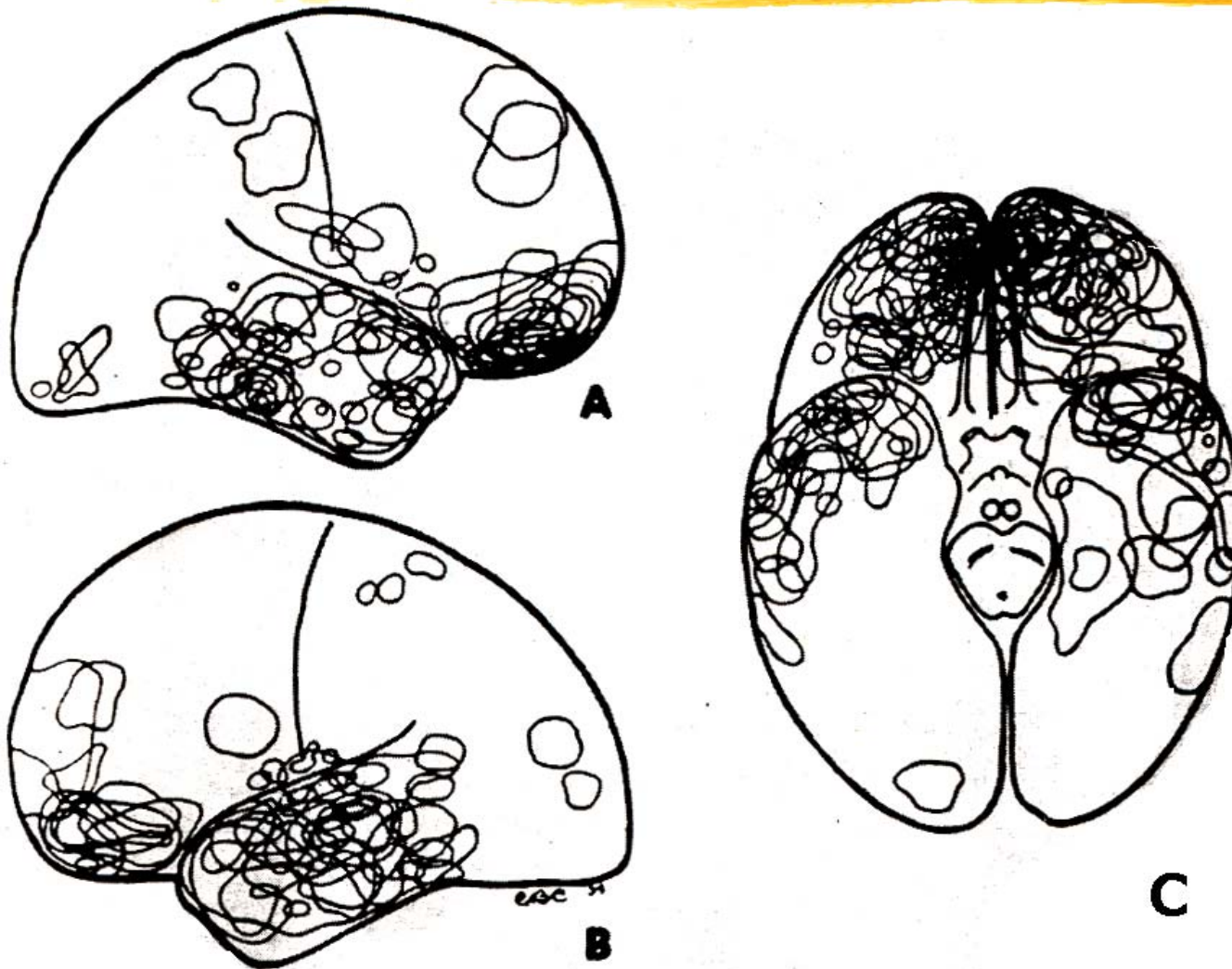
Cognitive Consequences



Predictable Patterns of Neuropsychological Deficits in TBI

- Certain brain structures are most vulnerable to TBI effects
 - Frontal and temporal lobes contusions
 - Axonal shearing at grey/white junction – diffuse axonal injury
- Added specific damage, e.g., contre-coup effects, parietal subdural

Figure 2-7. Composite views demonstrating contusional localization.

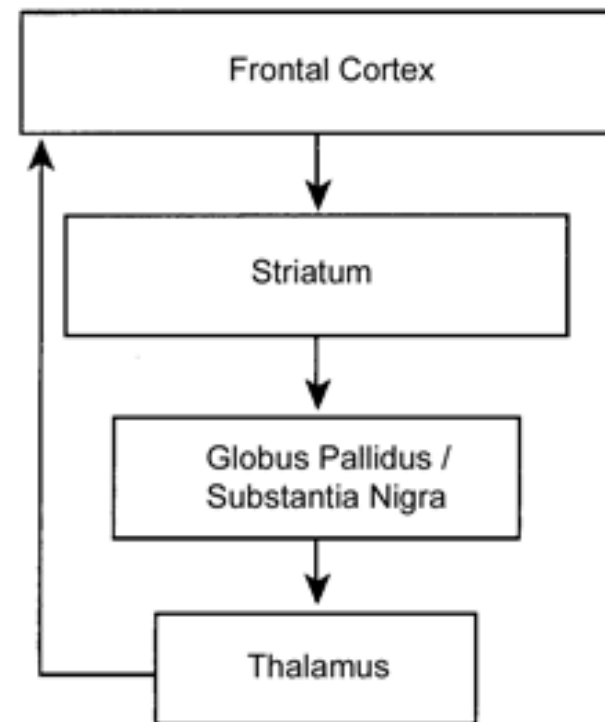
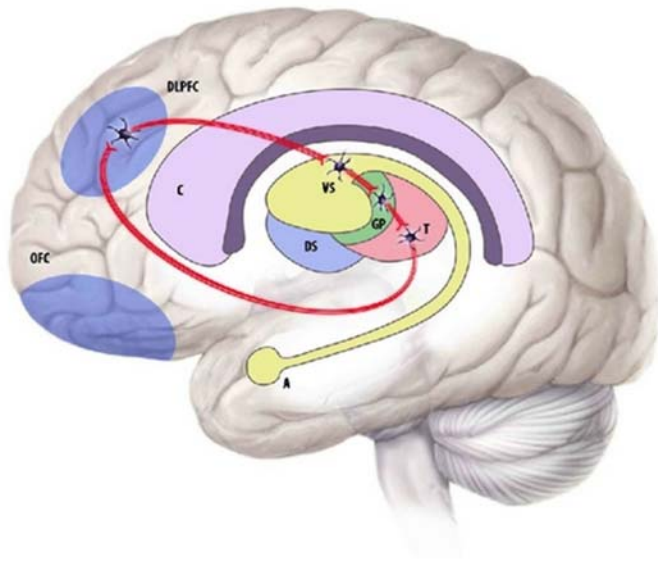




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Frontal-Subcortical Circuitry Vulnerability in TBI



General organization of frontal-subcortical circuits.



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Cognitive/Language Functioning after TBI

- Diffuse in nature
- Major cognitive domains affected:
 - Attention Skills / Speed of Mental Processing
 - Memory Functioning
 - Executive Functioning
- Other domains
 - Language Functioning
 - Visuospatial Processing



Attention Skills / Speed of Mental Problems after TBI

- Decreased span of attention and mental control - ability to process and manipulate of information in working memory
- Poor sustained attention/poor task persistence
- Diminished complex attention skills
 - Selective attention: easily distracted
 - Divided & alternating attention: limited ability to multitask
- Diminished speed of processing



Attention Skills / Speed of Mental Processing Problems after TBI

- Ubiquitous consequences → affect the quality and consistency of other cognitive abilities
- More mental effort to do the same tasks as they did before
- Leads to overstimulation → withdrawal of attentional focus
- Mental fatigue / anxiety / headache → further cognitive inefficiency



Memory Problems after TBI

- Recently acquired information / new learning mostly affected
 - Limited learning capacity – even with repetition
 - Poor ability to recall newly learned material over time
- Reasons for the problems secondary to disturbance in the memory processes of:
 - Encoding (e.g., Attention/working memory; complexity of info – organization)
 - Storage Decay
 - Retrieval (Info is stored but hard to retrieve)
 - *Interaction of temporal and frontal lobes*

Executive Functioning

- Capacities that enable a person to engage successfully in independent, purposive, self-serving behavior (Lesak, 2004)
- Involves an accurate awareness of self and ones capacity to carry out goal directed ability





Executive Functions

Cognitive Difficulty

- Decreased sustained attention
- Loss of divergent thought
- Decreased cognitive flexibility
- Diminished ability to:
 - Analyze and synthesize ideas
 - Plan / Organize
 - Problem-solve
- Anticipate consequences of behavior
- Self-monitor and correct behavior

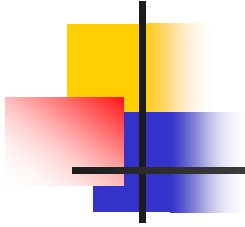
Functional Outcome

- Highly distractible
- Decreased behavioral initiation – apathy
- Poor judgment
- Poor impulse control
- Problems with socially appropriate responses
- Decrease awareness of impact on others
- Diminished ability to cope with stress / regulate affect
- Capacity for empathy
- Decreased ability to set and follow-through on short and long-term plans



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"Emotional and behavioral problems are the most difficult for (care providers) to understand, predict, and treat of all the residual effects of brain injury"

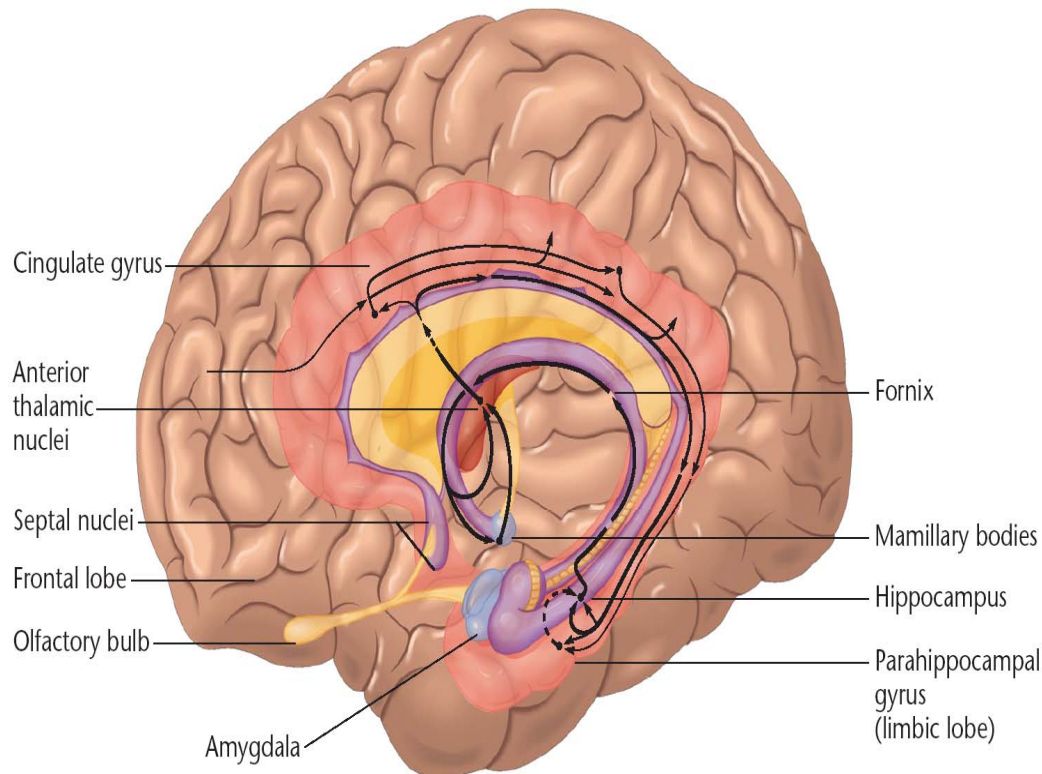
Burke, W. H. & Lewis, F.D. *Int. J. Rehab Research*, 1986, 9 (4), 335-342.



Emotional / Behavioral Consequences

- Mood and Anxiety Disorders
 - E.g., depression – 42% to 52% within the first year
- Adjustment Disorders / Issues
- Psychotic Disorders
- Personality Changes
 - Sense of self
 - Interpersonal style
- Behavioral Problems

Regions of Brain Associated with Postinjury Behavioral Problems



■ Limbic System

- Amygdala, Hippocampus Formation, Septum

■ Frontal Lobe



Common Behavioral Problems Following TBI

- Behavioral Deficits (Negative, Passive)
- Behavioral Excesses (Positive, Active)



Behavioral Deficits Following TBI

- Decreased arousal
- Decreased initiation
 - Diminished communication or activity level
- Apathy -- loss of emotional drive
- Blunted affect



Behavioral Excesses Following TBI

- Restlessness – Irritability - Agitation
- Social Skills Deficits
 - Anger Dyscontrol / Aggression
 - Impulsiveness – inappropriate behavior - disinhibition (performing a behavior without regard to consequences)
 - Loss of social tact, empathy

Reported Frequency of Problems Following Moderate to Severe TBI

McKinalay et al		Van Zomeren et al		Kersel et al		
TBI Dur: 12 mos. Relative report N = 55		TBI Dur: 24 mos. Patient Report N = 57		TBI Dur: 6 & 12 mos. Patient Report N = 59		
Problem	%	Problem	%	Problem	%	6 mth / 12 mth
Irritability	71	Forgetful	54	Impatience	51	/ 64
Impatience	71	Irritability	39	Irritable	49	/ 44
Tiredness	69	Slowness	33	Argumentative	44	/ 36
Memory	69	Attention	33	Anger	42	/ 44
Slowness	67	Fatigue	30	Lack of interest	41	/ 32
Bad Temper	67	Dizziness	26	Loss of motivation	36	/ 27
				Impulsive	29	/ 39



Course of Cognitive / Behavioral Sequelae

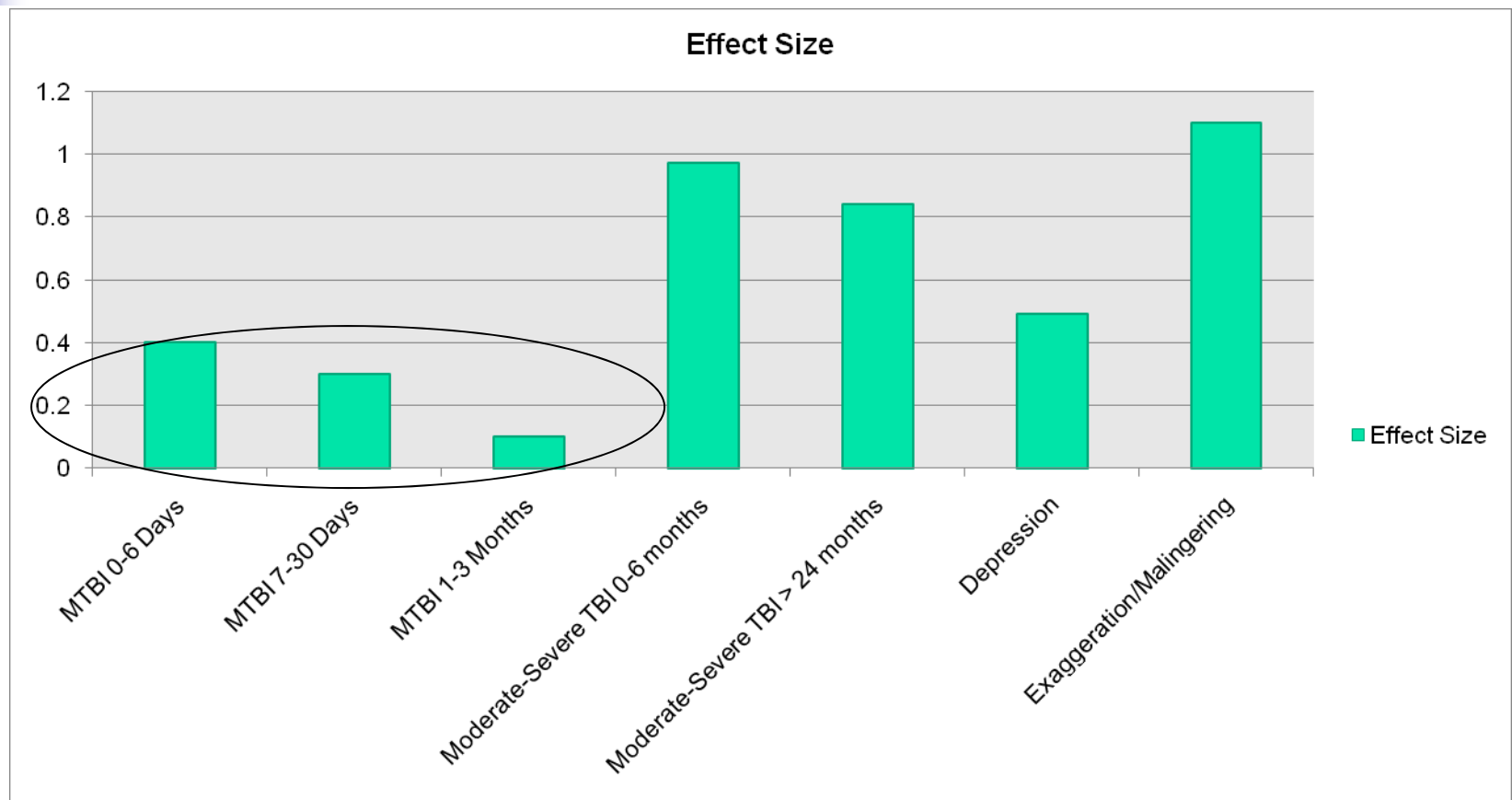
- Mild Brain Injury
- Moderate to Severe Brain Injury



Effects of TBI on Cognitive Functioning Over Time

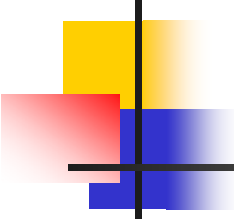
- Schretlen & Shapiro (2003): meta-analysis
 - 39 studies conducted between 1984 and 2003
 - MTBI and Moderate-Severe TBI's
 - MTBI defined as:
 - 1) alteration or loss of consciousness ≤ 30 min
 - 2) PTA ≤ 24 hrs
 - GCS 13-15
 - No + brain imaging or focal neurological signs (uncomplicated MTBI)
 - Studies compared TBI patient and control groups at various follow-up intervals (controls: medical or noninjured groups)
- Iverson (2005) - compared meta-analyses of other conditions (e.g., depression) or patient characteristics (e.g., evidence on poor effort) on cognitive functioning to Schretlen & Shapiro TBI findings

Effect Sizes on Overall Neuropsychological Functioning



Effect size: 0.2 – small; 0.5 – medium; 0.8 - large

****Iverson, G, (2005) Outcome from mild TBI, *Current Opinion in Psychiatry*, 18, 301-317**



Course of Cognitive / Behavioral Sequelae in Mild Traumatic Brain Injury

- Symptoms and/or effects on functional status resolve for the good majority of individuals within 3 to 6 months
- About 10-15% of patients with mTBI will report of cognitive / physical / emotional symptoms at 1-year post injury – *Postconcussion syndrome (PS)*
- PS – symptoms lasting at least 3 months postinjury
 - Cognitive – attention, memory
 - Somatic – headache, fatigue, insomnia, dizziness, tinnitus
 - Affective – Irritability, depression, anxiety, apathy, changes in personality



Identified Potential Factors Associated with Persistence of Postconcussive Symptoms

- Organic brain changes from injury?
- Comorbid / Preexisting Medical Conditions
 - Pain
- Prior brain injury (multiple concussions)
- Age
- *Psychological Factors (Adjustment disorders, depression, anxiety)*

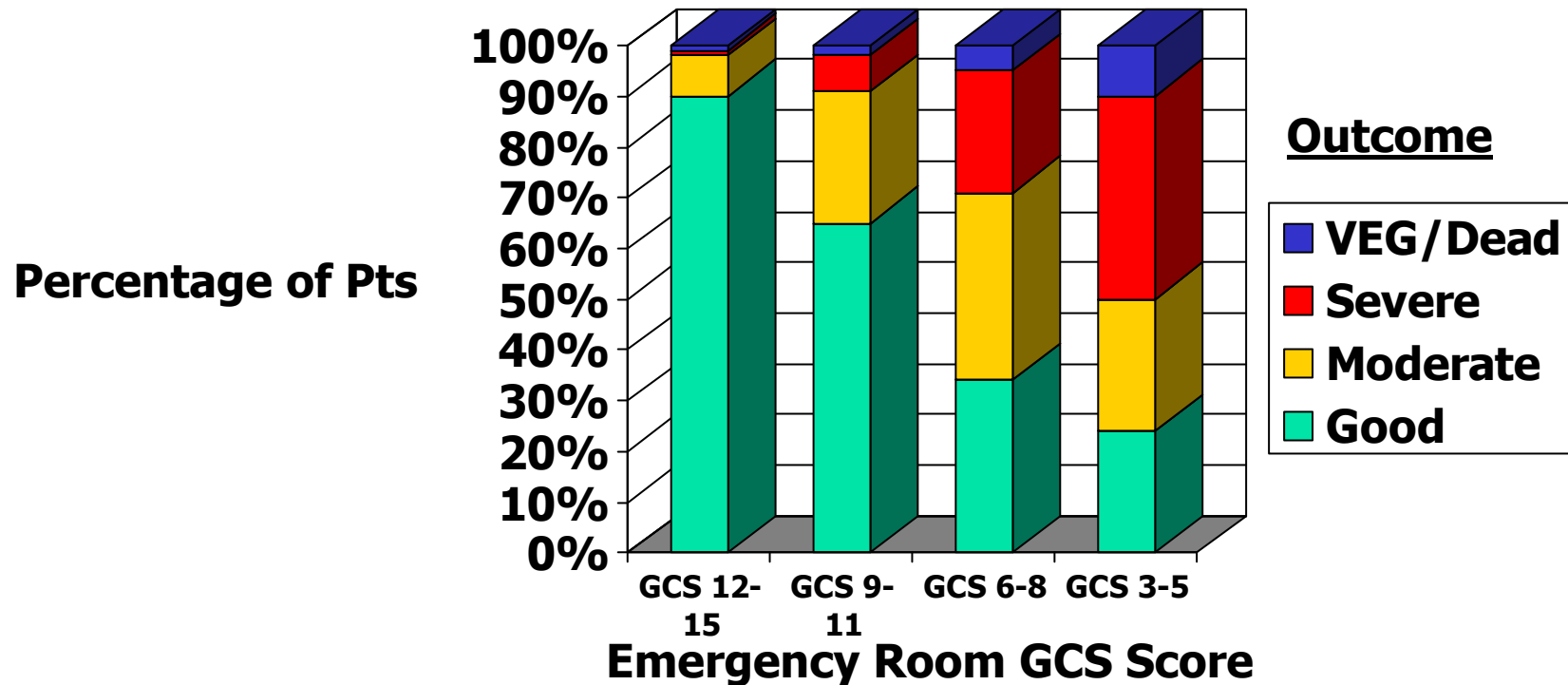
- Genetic Factors (e.g., apolipoprotein E 4 – ApoE 4)
- Preexisting cognitive / behavioral symptoms
- Substance abuse
- Medication effects
- Motivational Factors (Litigation, Disability)



Moderate-to-Severe TBI Outcome

TBI: 1-Year Overall Functioning Outcome by Injury Severity

Outcome Measure: Glasgow Outcome Scale



(Dikmen et al)

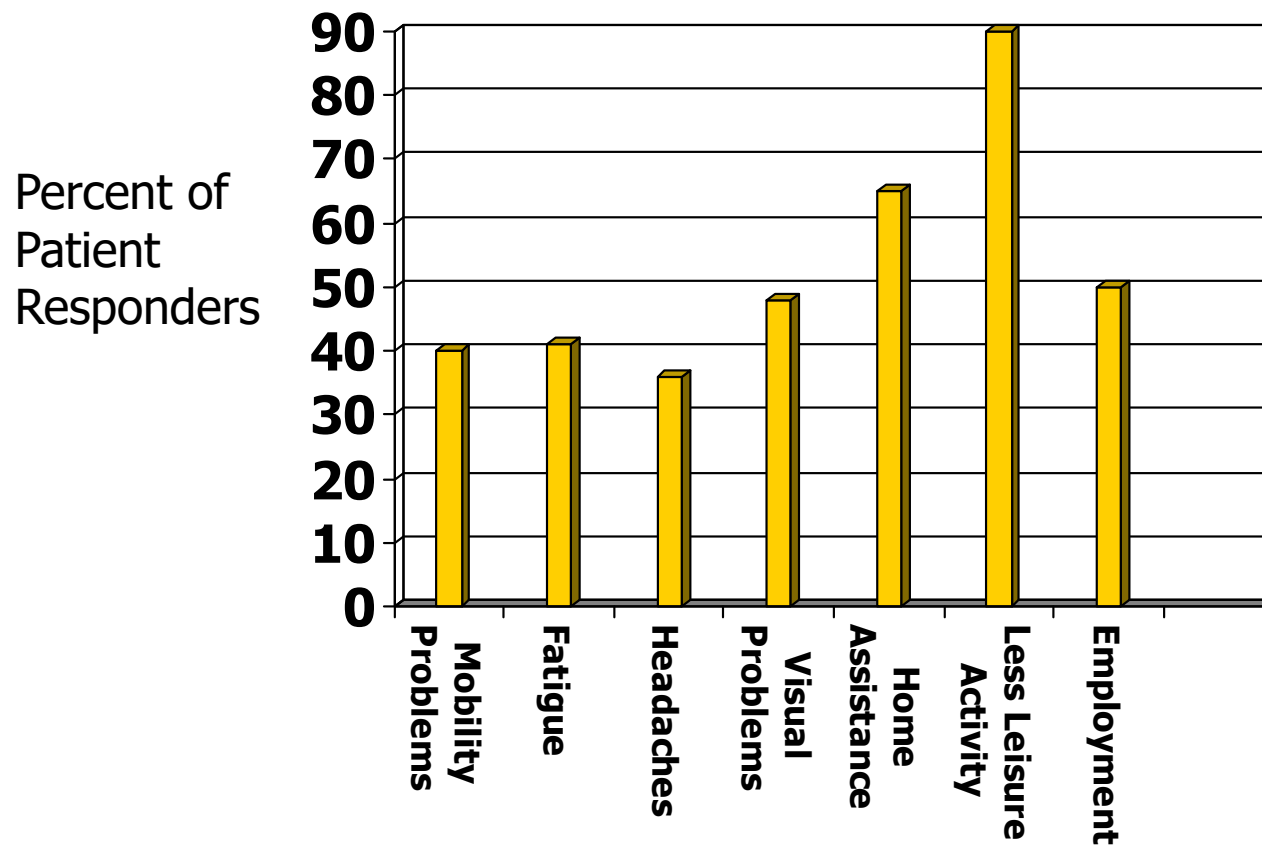


Outcome in Moderate-to-Severe Traumatic Brain Injury

- Survivors – typically show improvements in cognitive, behavioral, and physical symptoms over the first 6 to 12 months
- However, there is a wide range of variability, making it difficult to predict outcome for a single individual
- Millis et al.: Long-term outcome after TBI (*J Head Trauma*, 2001):
 - Compared 1 to 5 years postinjury cognitive functioning recovery in adults
 - Most likely persistent deficits were in attention, memory, and processing speed
 - As a group, gains evidenced from 1 to 5 years were significant but small.
 - However, most individuals did not show improvement
 - 22% showed significant improvement
 - 63% no significant change
 - 15% decline
 - Age was found to be a significant factor in change
 - *For each ten year increase in age: the risk for later decline increased 5 times*

Functional Outcome in Moderate-to-Severe Traumatic Brain Injury

Ponsford et al, 1995: *Outcome at 2 years postinjury*





Functional Outcome in Moderate-to-Severe Traumatic Brain Injury

- Dikmen et al (2003): Outcome 3 to 5 years after moderate to severe TBI (n = 210)
- Functional Status Examination (FSE) findings - Highlights:
 - Personal care: 70% same as before injury
 - Standard of living: 65% same as before
 - Cognitive Competency: 45% same as before
 - Social Integration: 53% same as before
 - Leisure activity: 40% same as before
- Quality of life: 0 – 100 scale (100 = perfect)
 - *Median rating = 81.7*

