THE ESSENTIAL BRAIN INJURY GUIDE

Neuroanatomy & Neuroplasticity
Section 2

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This training is being offered as part of the Brain Injury Alliance of Connecticut's ongoing commitment to provide education and outreach about brain injury in an effort to improve services and supports for those affected by brain injury.

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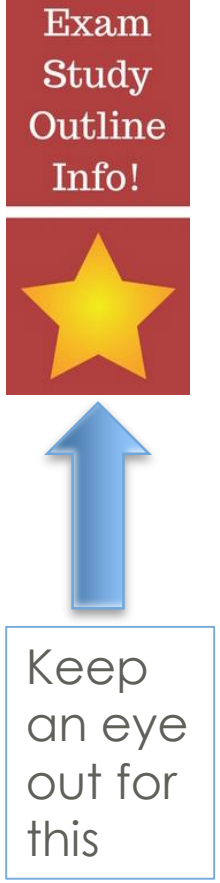
BRAIN INJURY ASSOCIATION OF AMERICA

Founded in 1996

ACADEMY OF CERTIFIED BRAIN INJURY SPECIALISTS

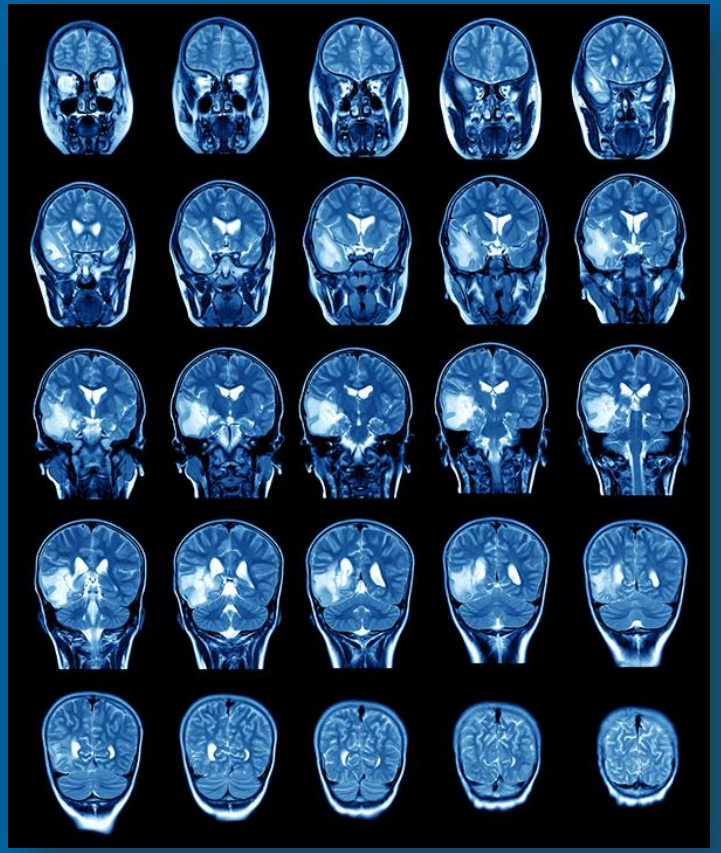
ACBIS Exam Study Outline

- Anatomy of the brain and spinal cord
- Characteristics of and relationships between neurons and synapses
- Importance of reticular activating system
- Types of imaging
- Blood-brain barrier
- Effects of neuroplasticity
- Principles of neuroprotection
- Experience-dependent learning

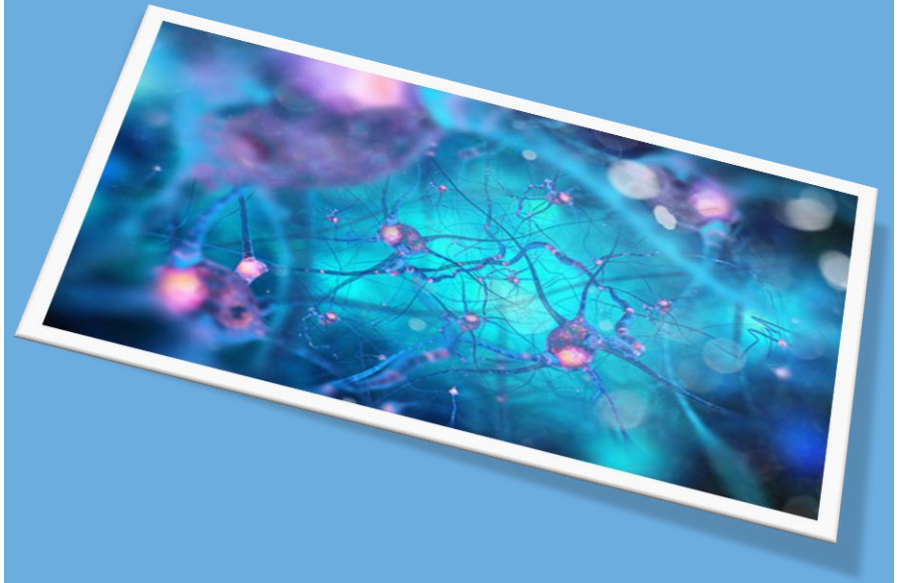


Neuroanatomy and Neuroimaging

Chapter 2



Learning Objectives



Understand the anatomy of the brain, spine, and spinal cord

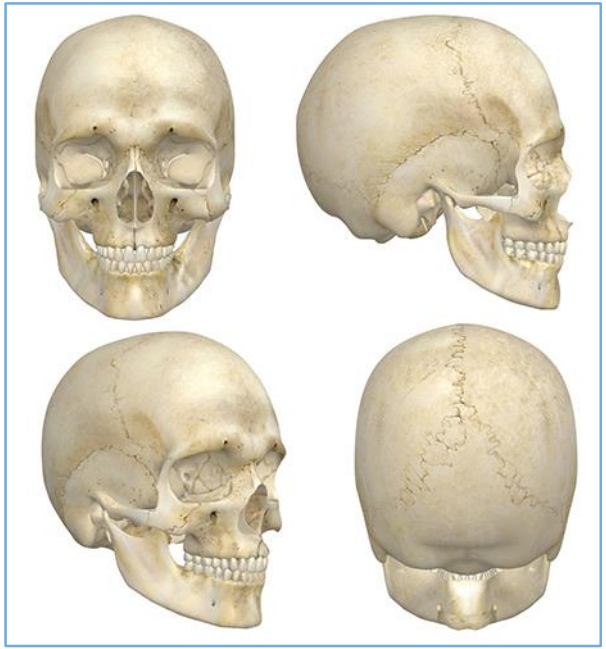
Distinguish between symptom patterns due to brain injury and syndromes in spinal cord injury

Articulate the methods of neuroimaging which support diagnostic and treatment decisions when a patient has sustained either a brain injury or spinal cord injury.

NEUROANATOMY

Skull Anatomy

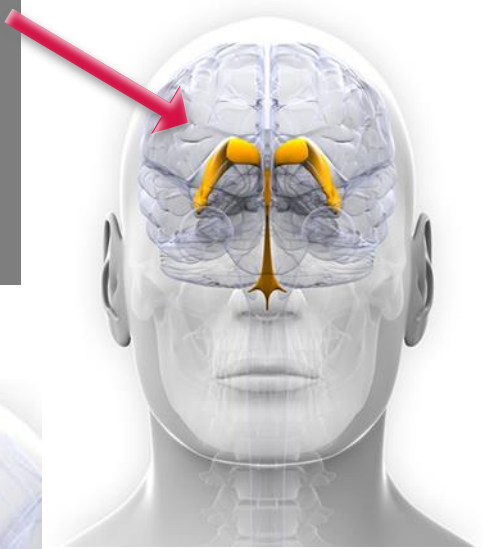
- The skull is a rounded layer of bone designed to protect the brain from penetrating injuries
- The inside of the skull is rough with many bony protuberances
- These ridges can result in injury to the brain during rapid acceleration/deceleration



Cerebrospinal Fluid

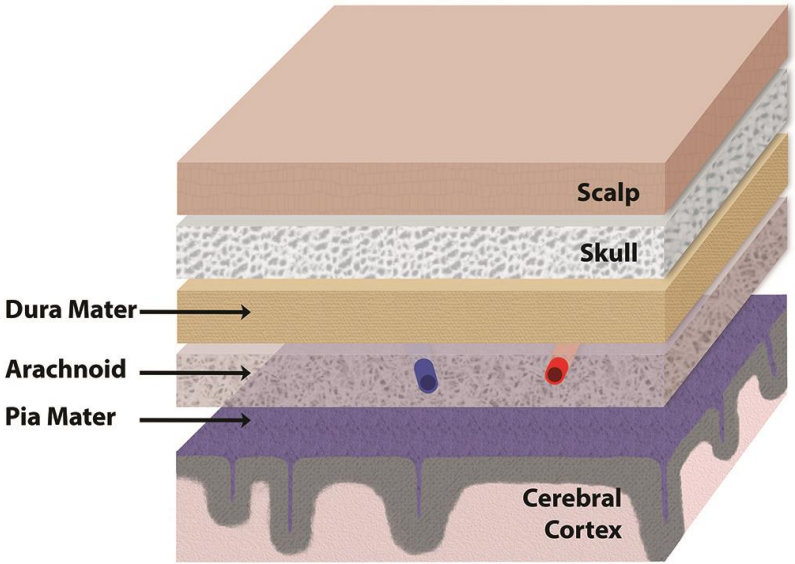
- Cerebrospinal fluid (CSF) is a clear liquid in the brain and spine
- It is produced within the ventricles of the brain and circulates throughout the brain and spine
- CSF fills the ventricles and meninges, supporting the brain inside the skull
- The ventricles are a series of reservoirs in the center of the brain
- The ventricles produce, store and circulate CSF

Lateral Ventricles



3rd & 4th Ventricles

The Meninges



- The meninges are layers of tissue that separate the skull and the brain
- There are 3 layers
  - Pia Mater
  - Arachnoid
  - Dura Mater

Exam Study Outline Info!

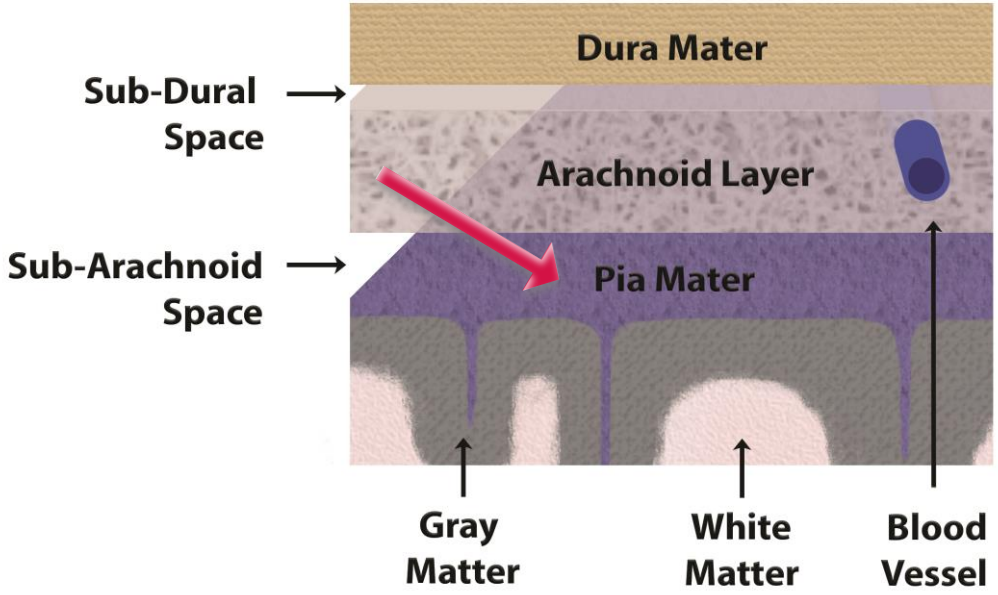
Essential TIP!

The Meninges P-A-D the Brain

Pia Mater Arachnoid Dura Mater

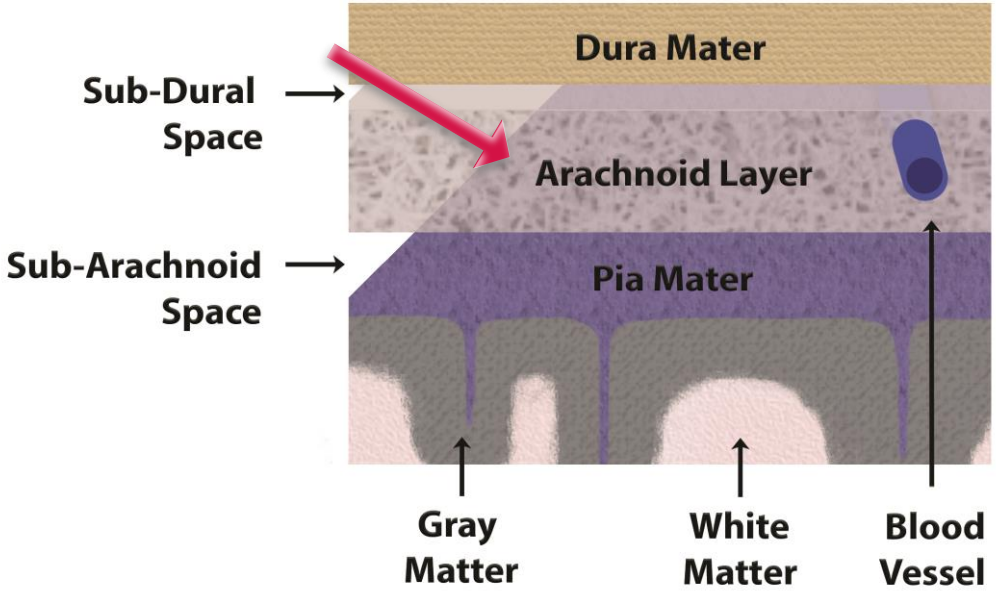
Pia Mater

- Third layer of meninges
- Latin for 'tender matter'
- Molds around the sulci and gyri of the brain



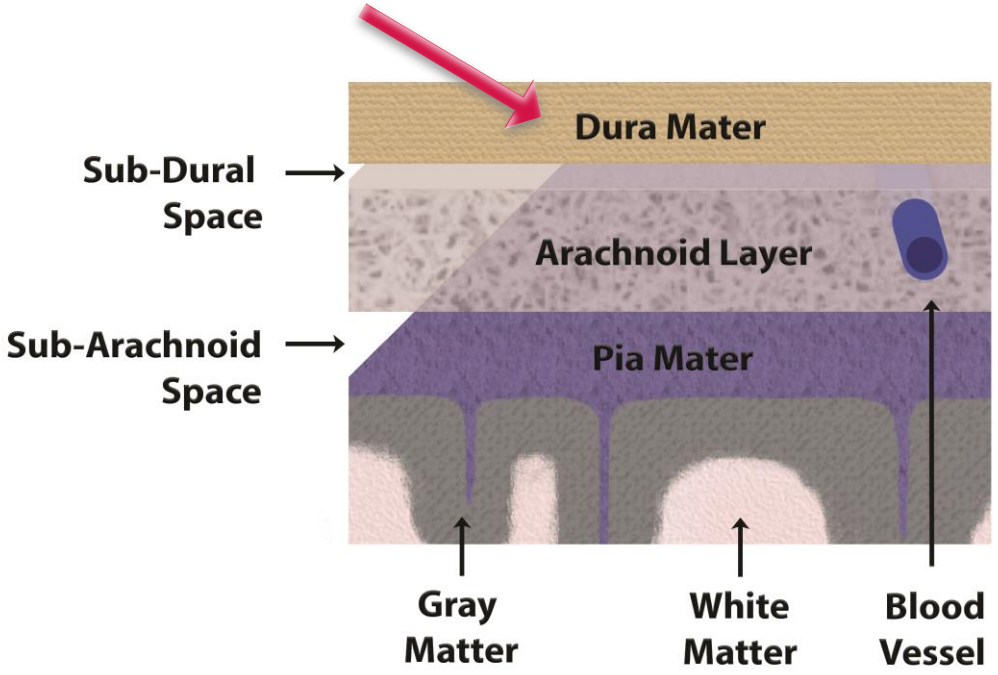
Arachnoid Layer

- Second layer of meninges
- Consistency similar to a spider web
- Below the Arachnoid layer is the subarachnoid space
  - When there is a bleed in this space it is called a subarachnoid hematoma

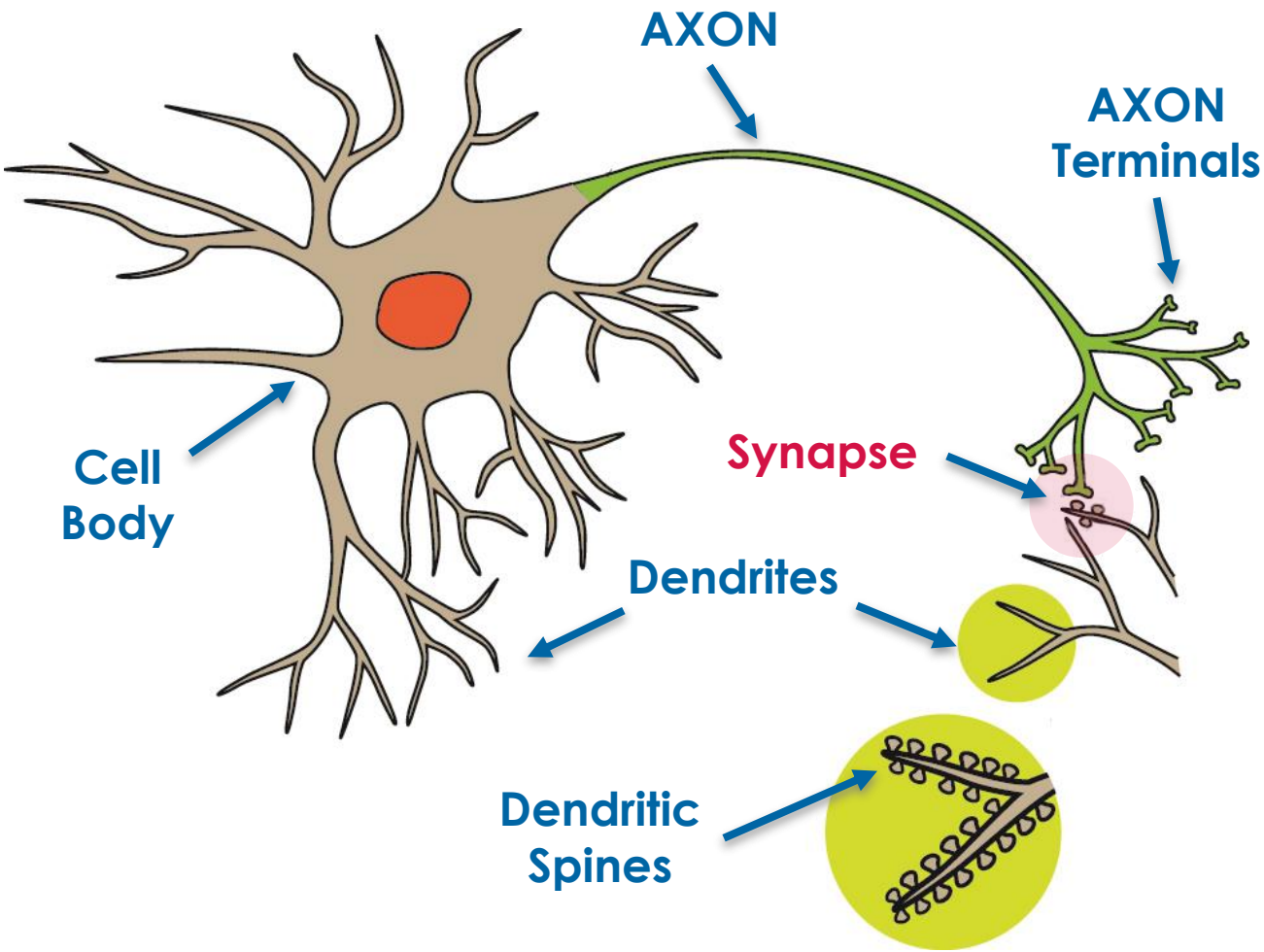


Dura Mater

- Outer layer of the meninges
- Latin for "tough mother"
- A heavy cabbage-like covering
- Below the Dura Mater is the subdural space
  - When there is a bleed in this space it is called a subdural hematoma



The Brain is Composed of Discrete Cells: Neurons and Glia

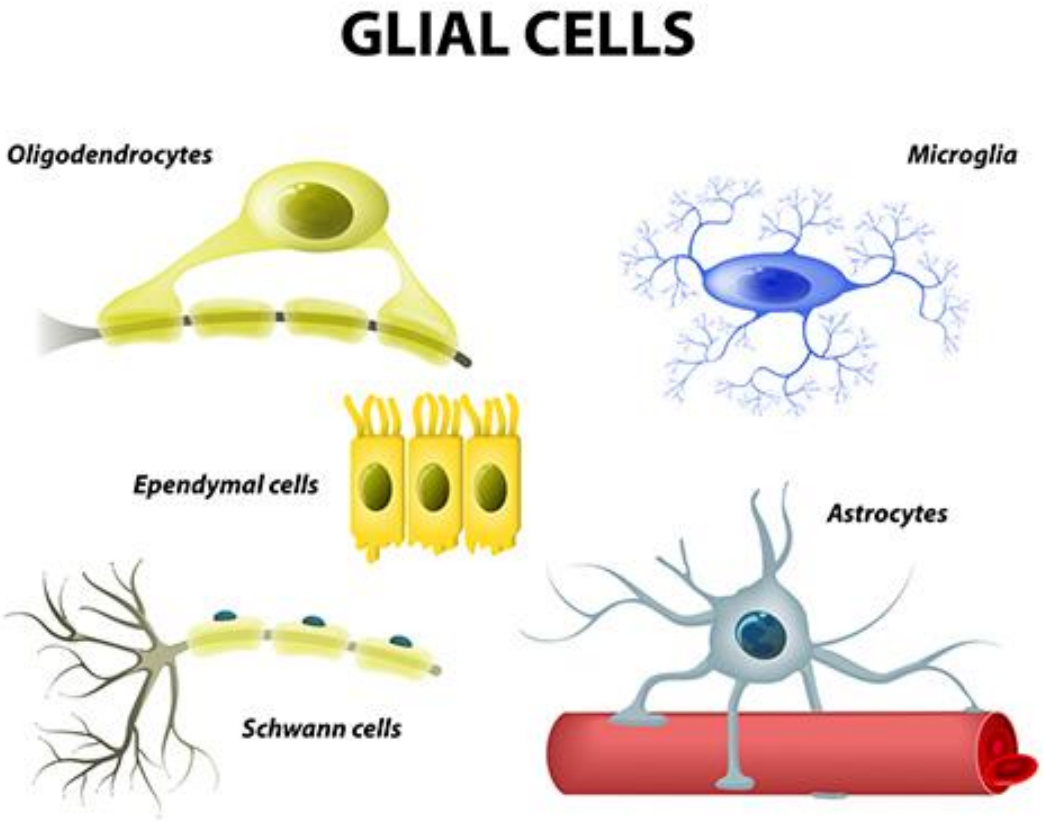


Neurons are communicating cells

Glial cells are non-communicating cells supporting and nourishing neurons

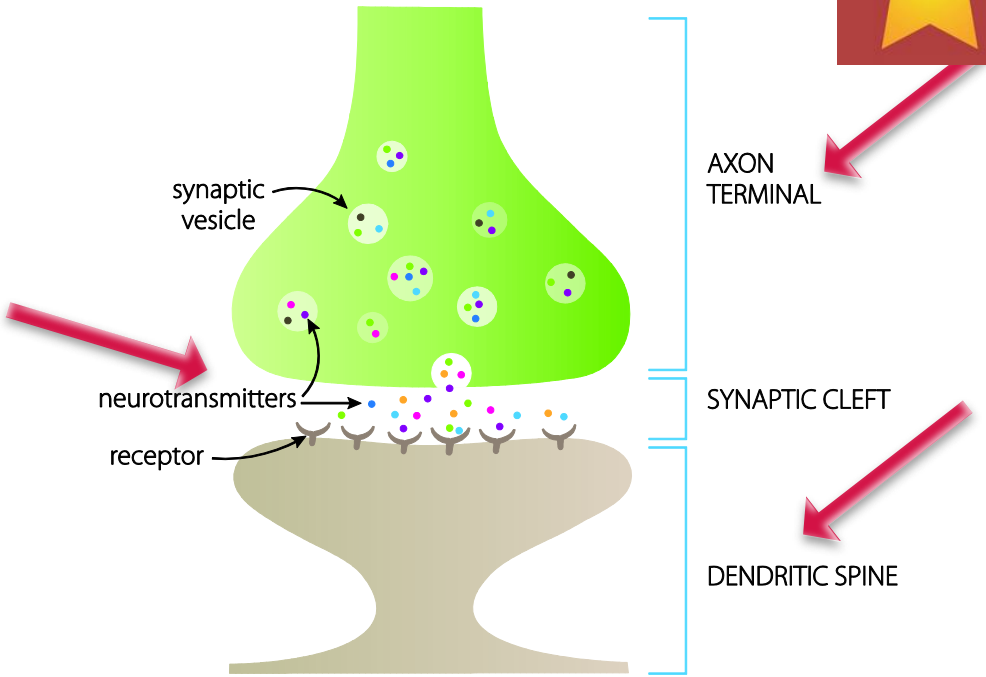
Glia

Glial cells support and maintain neurons



Neurons Communicate with Each Other Via Synapses

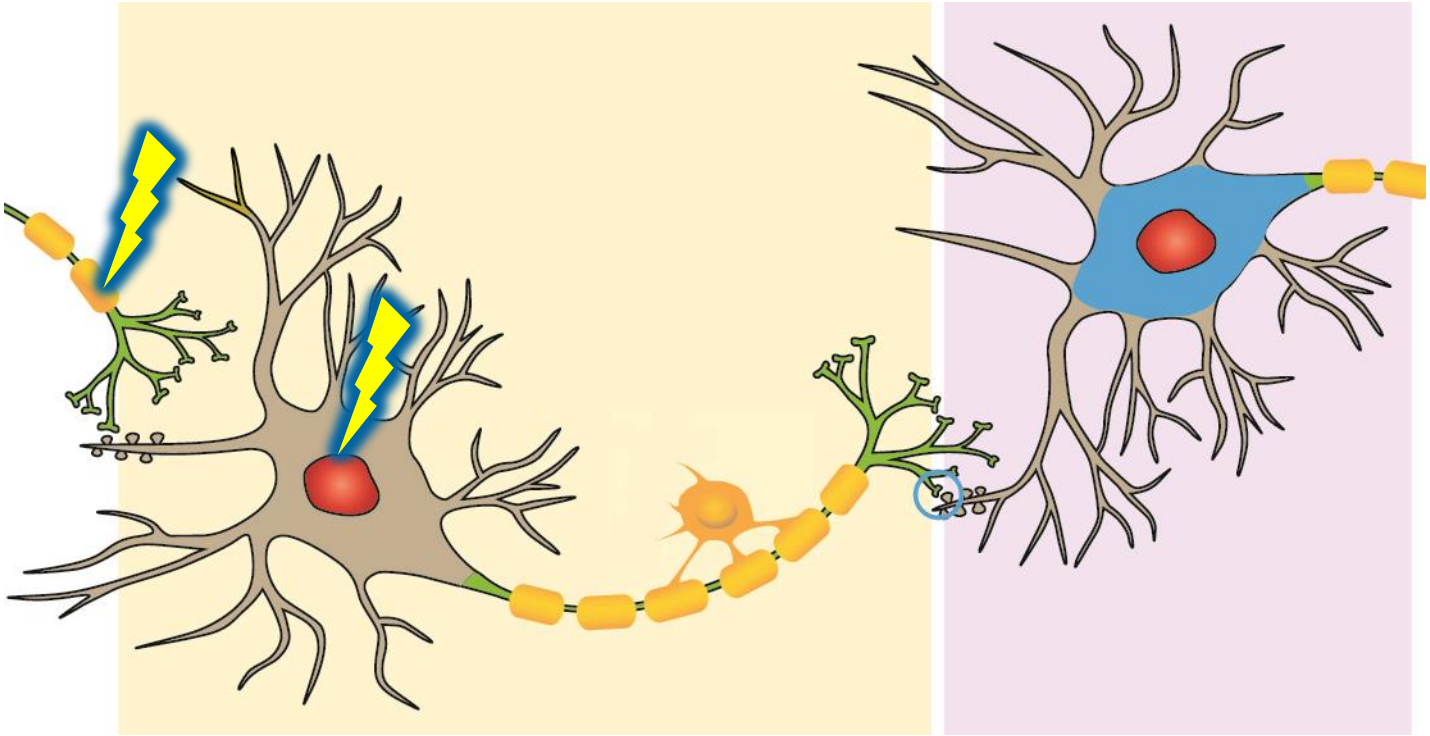
- Neurons have processes that support electrochemical transmission
- This allows them to communicate via an electrochemical process
- Synapses are junctions between neurons where this electrochemical process takes place
- The gap between an axon of one neuron and the dendrite of another neuron is the synapse



Neuron A

Neuron B

Neuron C



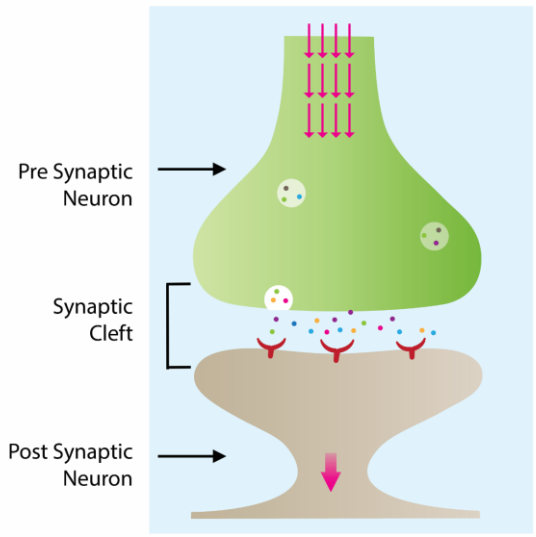
A signal from the axon of **Neuron A** travels to the dendrite of **Neuron B**

An action potential then generates from the cell body of **Neuron B**

This sends a signal down the axon and passes that signal to the dendrite of **Neuron C**

The process proceeds forward so long as an action potential continues to generate and the needed neurotransmitters and other chemicals such as calcium and potassium, etc., are present

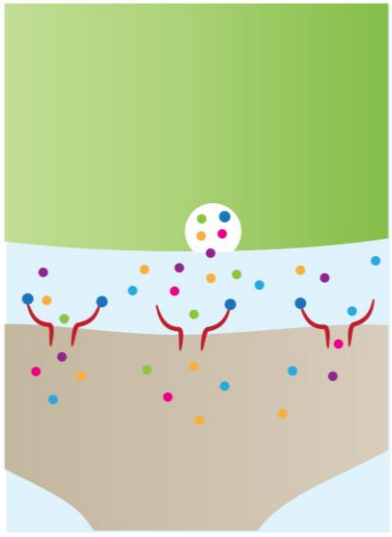
Step 1
Synaptic stimulation with release of glutamate.



A synapse is stimulated.

This results in the release of the neurotransmitter glutamate from the axon terminal into the synaptic cleft.

Step 2
Glutamate binds to AMPA and NMDA receptors.

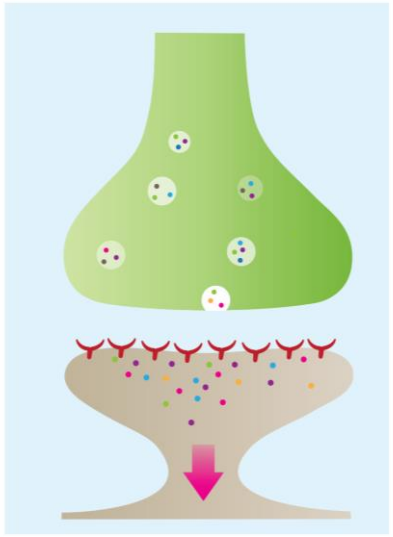


Glutamate binds to the AMPA and NMDA receptors.

With weak levels of stimulation AMPA receptors open, allowing Na^+ into the post-synaptic cell.

For NMDA receptors to allow Na^+ and Ca^{2+} into the post-synaptic cell there must be higher rates of stimulation.

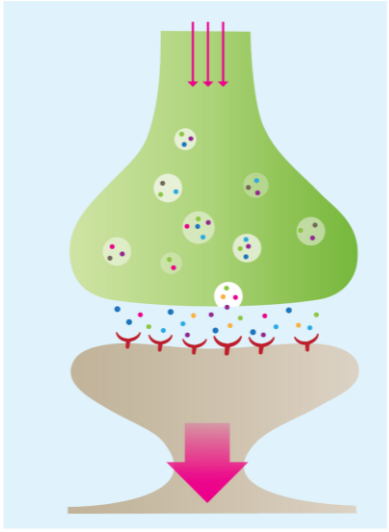
Step 3
Influx of Na^+ and Ca^{2+} into the post-synaptic neuron.



With higher rates of stimulation both AMPA and NMDA receptors allow Na^+ and Ca^{2+} into the post synaptic neuron.

The influx of Ca^{2+} begins a cascade of biological reactions.

End Result
Stronger link between the synapsed neurons.



Increased neurotransmitters.

Increased AMPA & NMDA receptors.

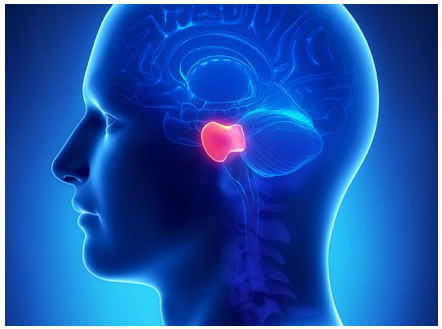
Increased response to a given stimulus.

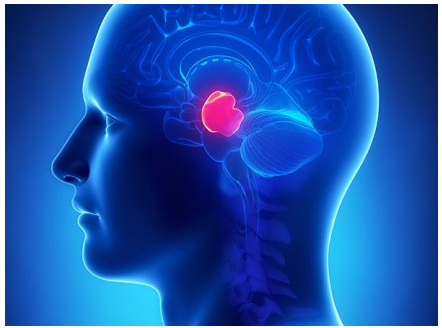
Brain Stem Components

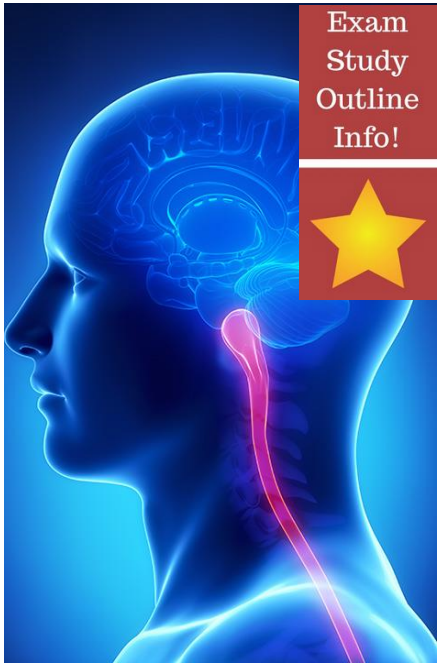
There are
3 components

1. Medulla
2. Pons
3. Midbrain

The brainstem is located at the top of the spinal column







It is the central point for all incoming and outgoing information and basic life functions

The Medulla

- The medulla merges with the spinal cord creating the base of the brain stem
- The medulla serves as a control center for involuntary reflexes such as breathing, heart rate, blood pressure, swallowing, vomiting and sneezing
- Involved in many basic living functions; injury to the medulla is life threatening

The Pons

Exam Study Outline Info!

- The pons is the rounded brainstem region between the midbrain and the medulla
- The pons connects the cerebellum and the cerebral cortex
- The pons is essential for facial movements, facial sensation, hearing, and coordinating eye movements

Midbrain

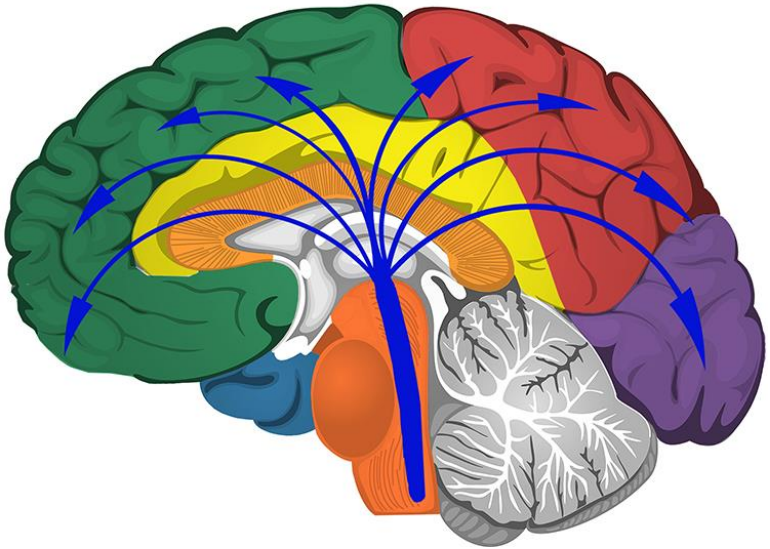
Exam Study Outline Info!

- The smallest part of the brain stem
- Involved in elementary forms of vision and hearing
- Plays a pivotal role in alertness and arousal

Reticular Activating System

Exam Study Outline Info!

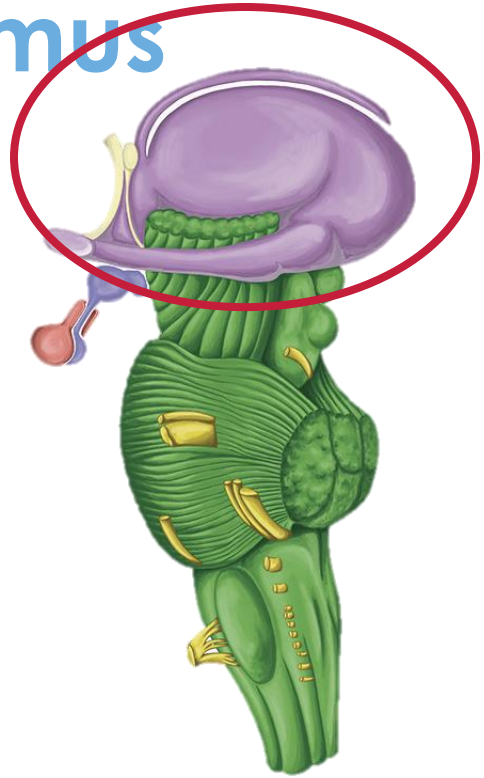
- A collection of nerve fibers and nuclei within the brainstem
- Modulates arousal, alertness, concentration and basic biological rhythms
- Acts to activate/inactivate the brain with numerous connections to the cerebral cortex



DIENCEPHALON

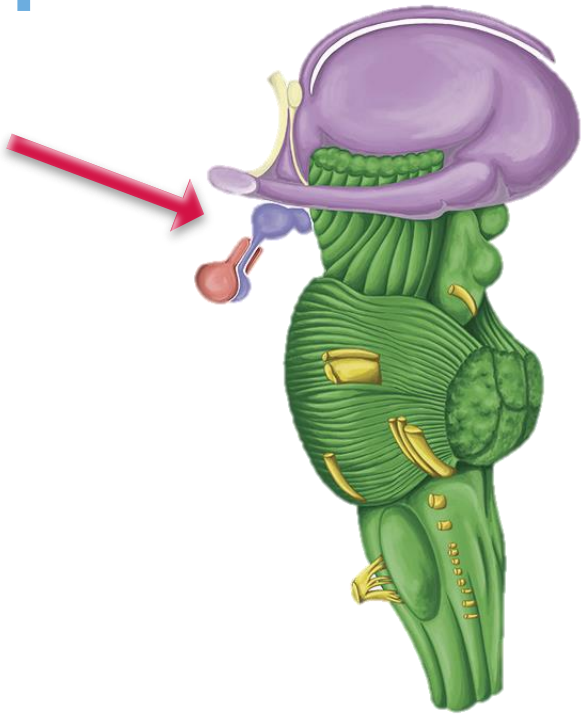
Diencephalon-Thalamus

- Sensory inputs pass through it to the higher levels of the brain
- Sits at the top of the brainstem, just below the cortex
- Many nuclei
- All senses, except smell, relay their impulse through the thalamus
- Injury causes a wide range of symptoms



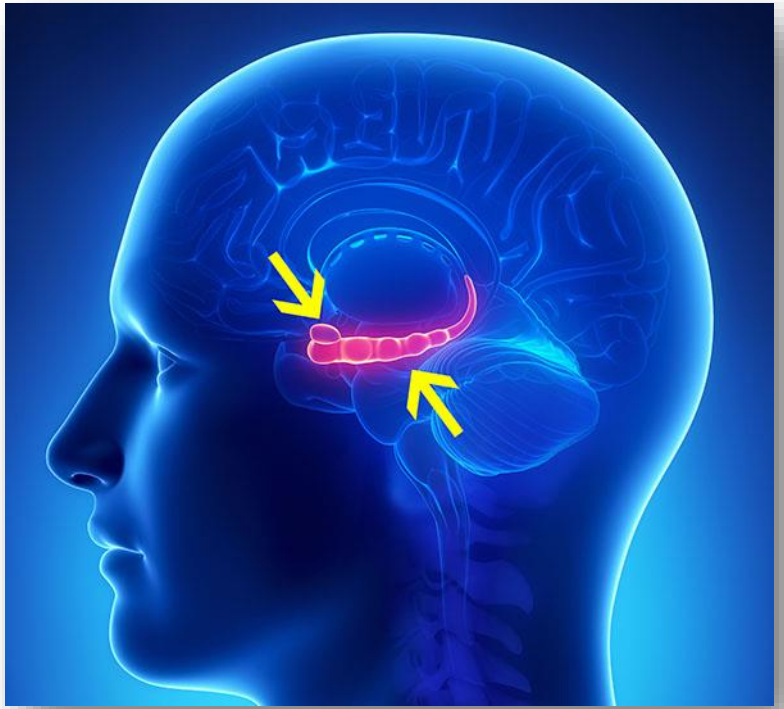
Diencephalon-Hypothalamus

- Controls the autonomic nervous system
- Regulates body temperature
- Regulates hunger and thirst
- Controls endocrine system
- Controls sleep wake cycle
- Controls emotional responses and behavior



Limbic System

- It is a deep brain structure which sits on top of the brain stem and is interconnected with the diencephalon
- It is highly connected with other areas of the brain
- Involved in control of all internal and external responses and actions

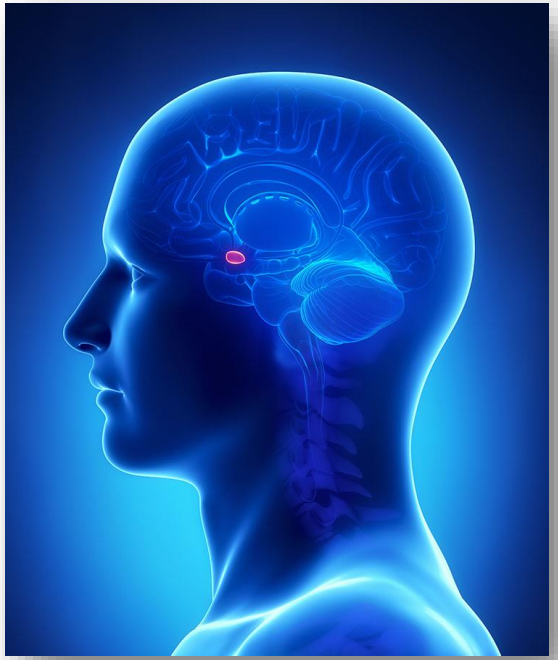


Limbic System - Hippocampus

Exam Study Outline Info!

- Sits within the temporal lobe, with a structure on each side of the brain
- It is very susceptible to anoxia/hypoxia
- Associated with memory functioning
- Injury causes impaired short-term memory, problems consolidating short-term memories into long term memory and difficulty organizing and retrieving stored memories

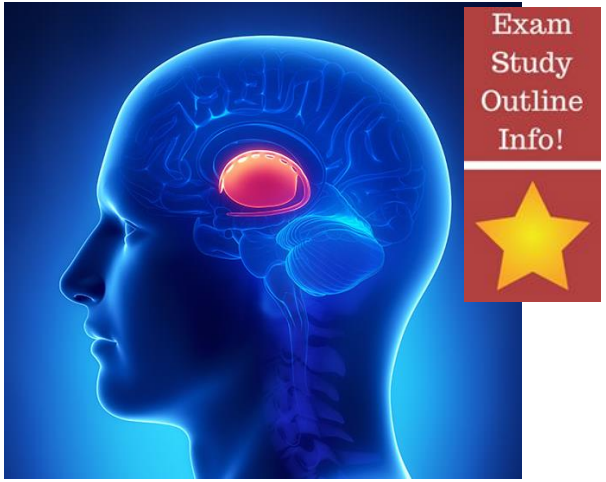
Limbic System - Amygdala



- Located near the hippocampus
- It is speculated that when a perception reaches the cerebral cortex it is transmitted to the amygdala and evaluated for emotional content
- It is tied to emotional memories and reactions, giving it the name the "fight or flight" structure

Basal Ganglia

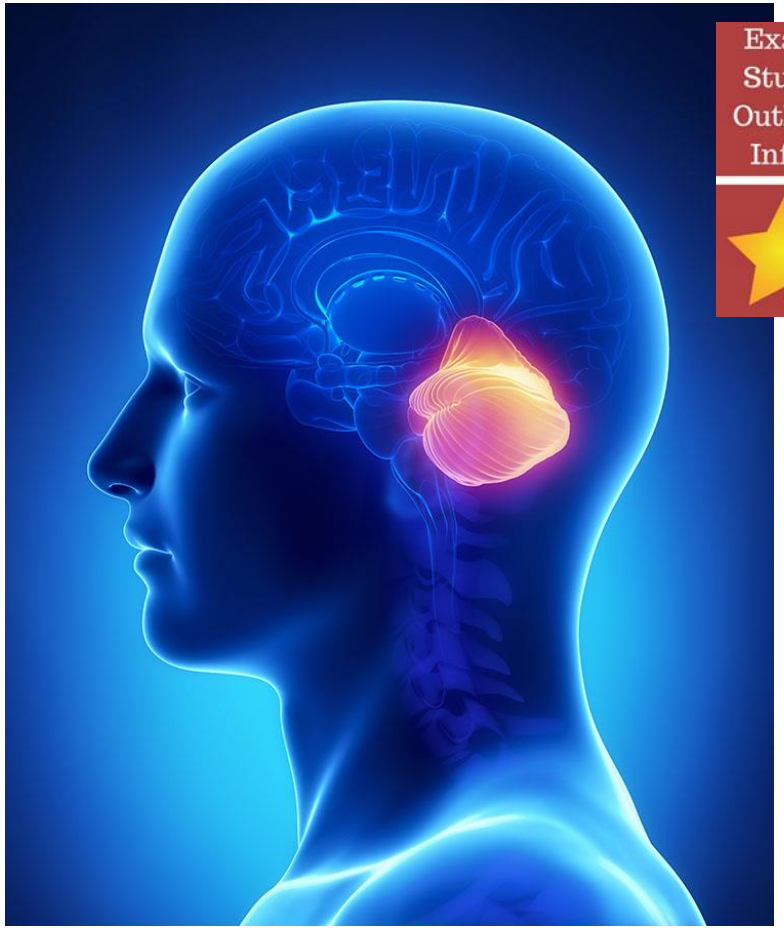
- Receives input from the cerebral cortex, processes the information, and sends it back to the cerebral cortex
- Keeps on the alert for when something is not working the way it should and determines what behaviors to execute
- It regulates activities of the motor and premotor areas
- Handles physical movements by relaying information from the cerebral cortex to the brain stem and cerebellum



- Injury affects voluntary motor nerves causing slowness and loss of movement, tremor, and muscular rigidity

Cerebellum

- Located in the lower back section of the brain
- Coordinates and modulates all body movement
- Controls the direction, rate, force, and steadiness of movements
- Injury causes problems with fine motor movement, trajectory of movement, balance and proprioception

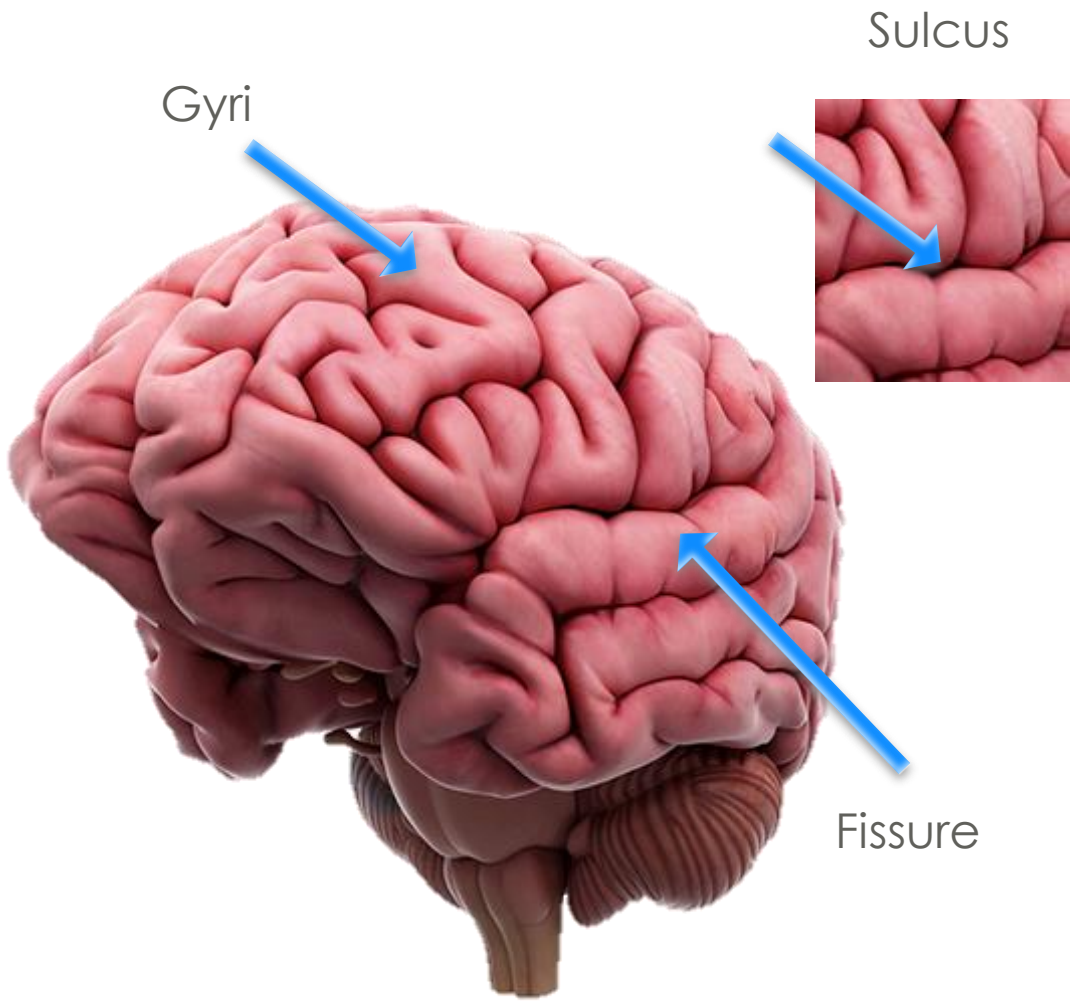


- Two Hemispheres
- Four Lobes
- Interconnected

THE CEREBRAL CORTEX

Cerebral Features

- Gyri- Elevated ridges that wind around the brain
- Sulci- Small grooves dividing the gyri
- Fissures- Deep grooves, usually dividing large regions/lobes of the brain



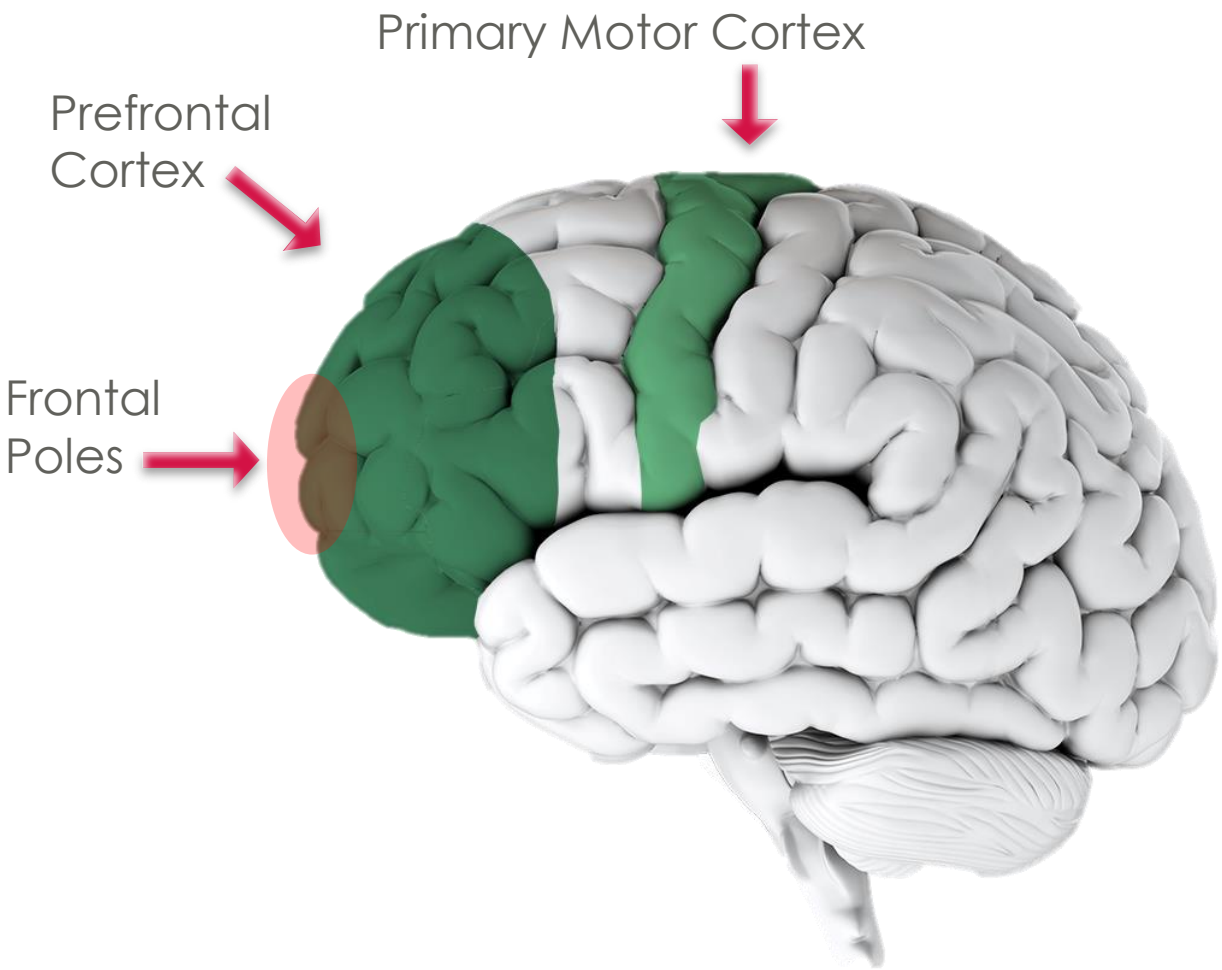
Information Processing

Right Hemisphere	Left hemisphere
▪ Holistic	▪ Linear
▪ Visual Spatial	▪ Verbal-analytic
▪ Intuitive	▪ Logical
▪ Controls left side of body	▪ Controls right side of body
▪ Music, art, shapes	▪ Speaking, reading, writing

Exam Study Outline Info!

LOBES OF THE CEREBRAL CORTEX

Frontal Lobe



Frontal Lobe Functions

Primary Motor Cortex

- Curves over the top part of the head
- Controls voluntary movement
- Injury causes weakness or paralysis on the opposite side of the body

Prefrontal Cortex

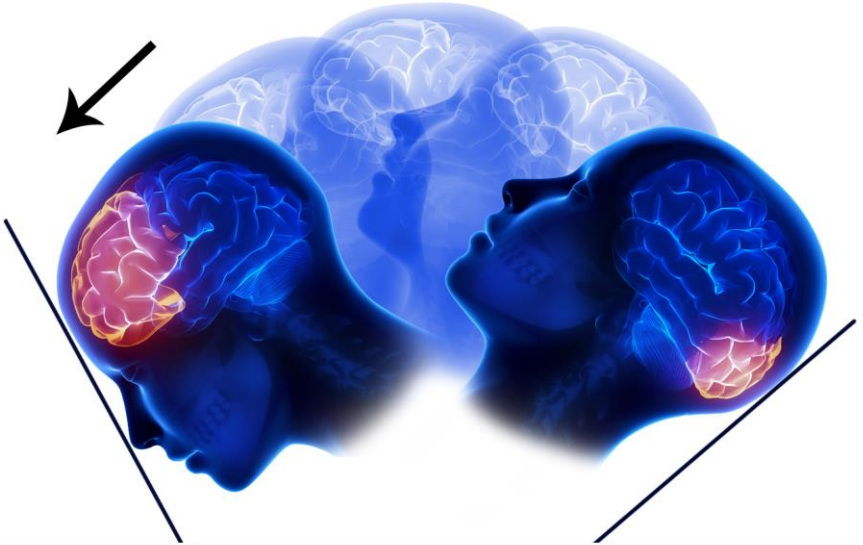
- Located at the front part of the frontal lobes
- Evaluates options, predicts outcomes and decides the best course of action
- Influences ability to learn from consequences
- Injury causes difficulty making decisions, organizing and prioritizing, initiating and inhibiting actions, controlling emotions and interacting socially

Frontal Lobe Functions

- Planning
- Organizing
- Problem Solving
- Judgment
- Impulse Control
- Decision Making
- Working Memory

Frontal Lobe Damage

- Changes in personality
- Poor self-awareness
- Reduced motivation/goal-directed behavior
- Impaired attention/short-term memory
- Poor judgement
- Inability to plan



Prefrontal Cortex Injuries in Children

- Brain is not fully developed
- Effects not immediately apparent
- May cause a wide range of poorly controlled behaviors

Temporal Lobe

Temporal Lobe

Functions	Impairments
▪ Memory ▪ Language ▪ Hearing	▪ Auditory Processing ▪ New learning ▪ Understanding, storing, and retrieving new information

Expressive Speech

Broca's Area

- Located in the left frontal-temporal lobe area
- Responsible for speech production
- When damaged:
  - Broca's Aphasia
    - Language expression is impaired
    - Speaks haltingly with few words

Receptive Speech

Wernicke's Area

- Located in the left temporal-parietal lobe
- Responsible for speech comprehension
- When damaged:
  - Wernicke's Aphasia
    - Language comprehension is impaired
    - Speaks fluently but does not make sense

Speech Production & Understanding

Broca's Area

- Left frontal-temporal lobe
- Speech Production
- Language expression is impaired
- Speaks haltingly with few words

Wernicke's Area

- Left temporal-parietal lobe
- Speech Comprehension
- Language comprehension is impaired
- Speaks fluently but does not make sense

Occipital Lobe

Primary Visual Cortex

Occipital Lobe

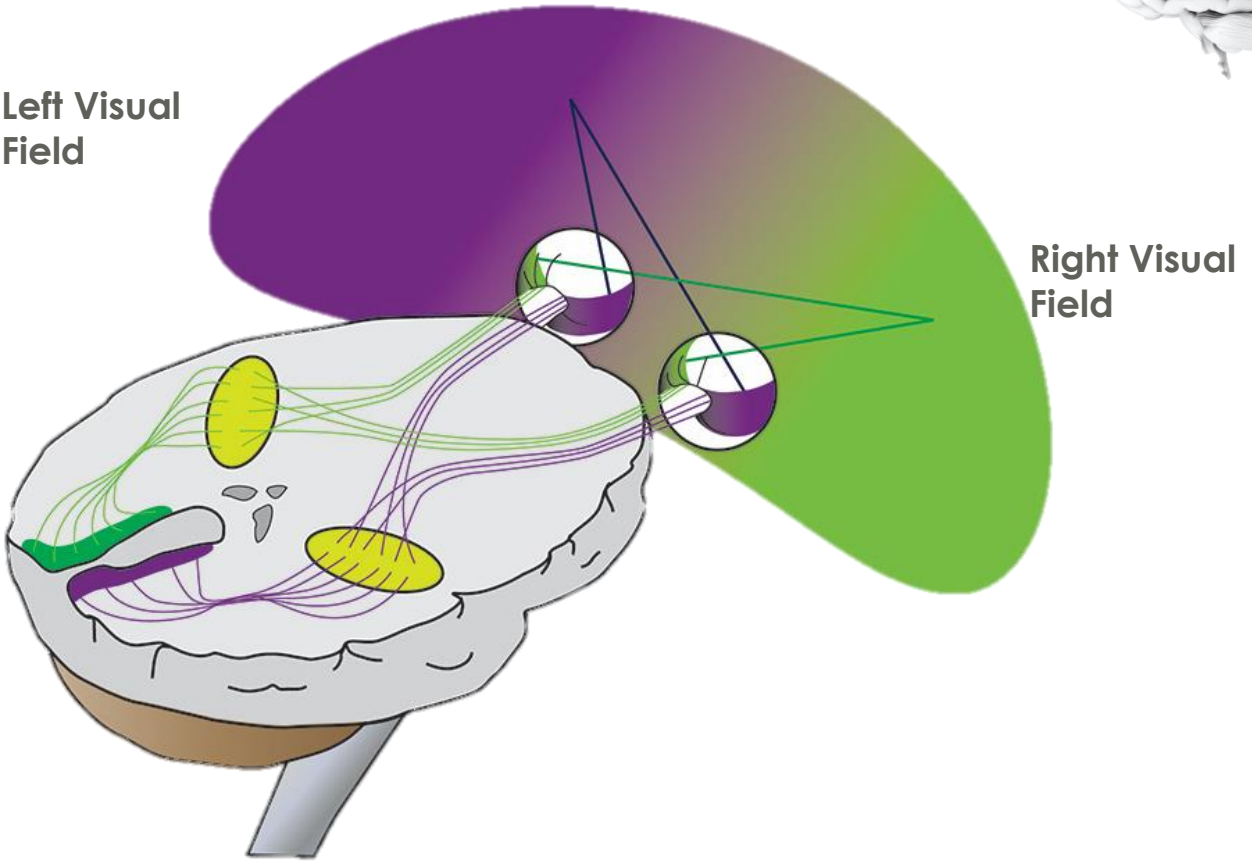
Functions

- Visual processing
- Interpret visual information
- Recognition of size, color, light, motion, dimensions, etc.

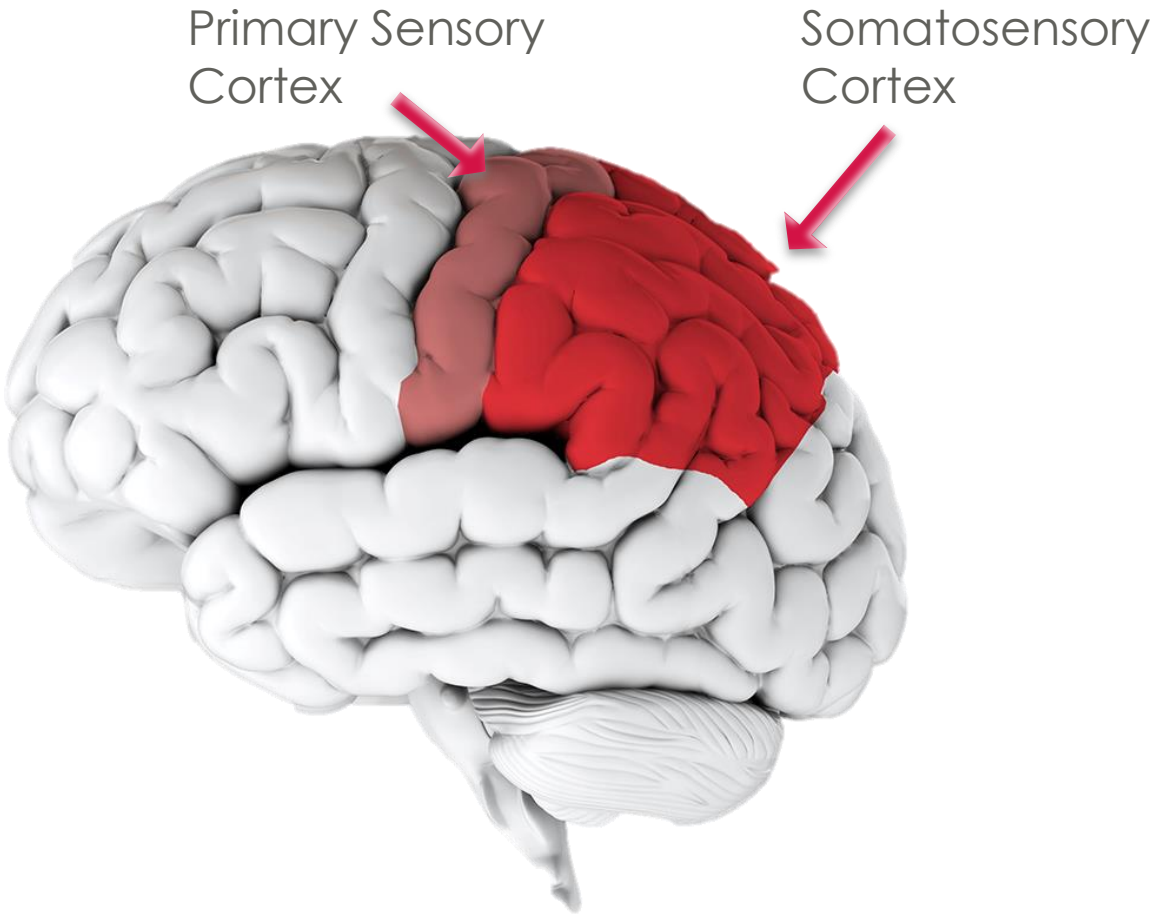
Impairments

- Cortical blindness
- Agraphia
- Field cuts
- Movement agnosia
- Visual Agnosia

Visual Pathway



Parietal Lobe



Parietal Lobe

Primary Sensory Cortex

Functions

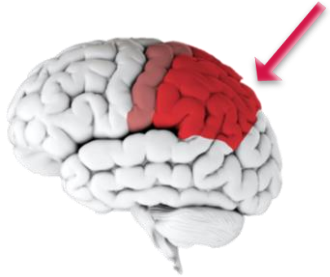
- Sensation and perception
  - Responds to touch, temperature and pain
  - Processes sensory information

Impairments

- Difficulty identifying sensation
  - Location
  - Type
    - Temperature
    - Pain
    - Movement

Parietal Lobe

Somatosensory Cortex



Functions

- Sensory Input Integration
- Spatial awareness and perception - awareness of body parts in space

Impairment

- Agraphia
- Acalculia
- Anosognosia
- Aphasia
- Impaired attention
- Neglect
- Left-right disorientation

Exam Study Outline Info!

SPINE AND SPINAL CORD

Spinal Column

Composition

- 33 Vertebrae (bones)
- Each joined together with discs (cartilage) and ligaments (fibrous tissue)
- Divided into 5 sections

Function

- Supports muscles and organs
- Protects the spinal cord

Spinal Column Divisions

Cervical Spine showing Lateral, Anterior, and Posterior view

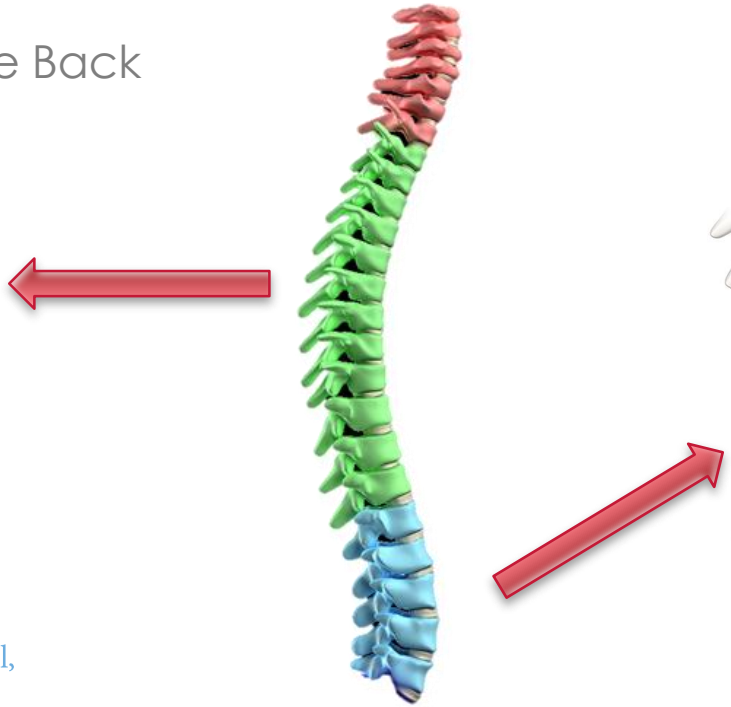
Cervical

- 7 topmost vertebrae
- Built for flexibility
- 1st vertebra is the **Atlas**
  - Supports the skull
  - Movement up & down
- 2nd vertebra is the **Axis**
  - Movement side to side

Spinal Column Divisions

- **Thoracic**
  - 12 vertebrae
  - Upper and Middle Back
  - Built for stability

Thoracic Vertebrae showing Lateral, Anterior, and Posterior views

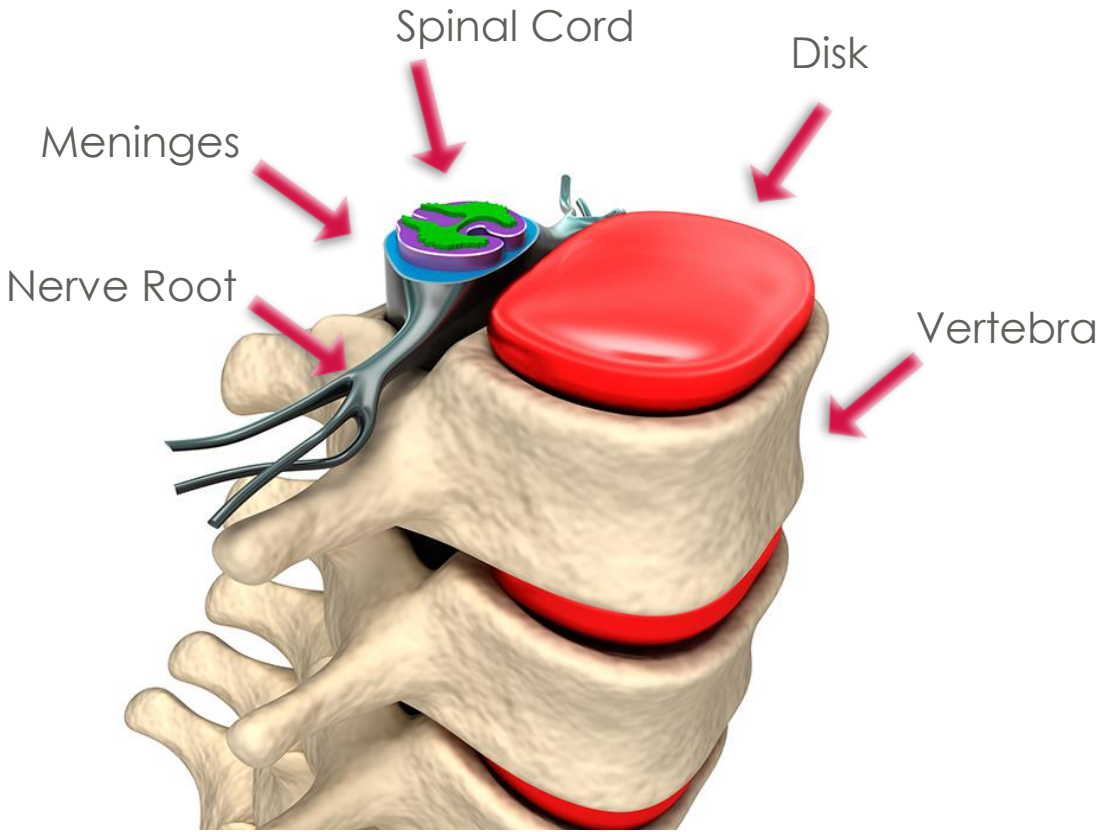


Lumbar

- Five vertebrae
- Lower back
- Built for weight bearing

Lumbar Vertebrae showing Lateral, Anterior, and Posterior views

Vertebral Bodies



Spinal Cord

Structure

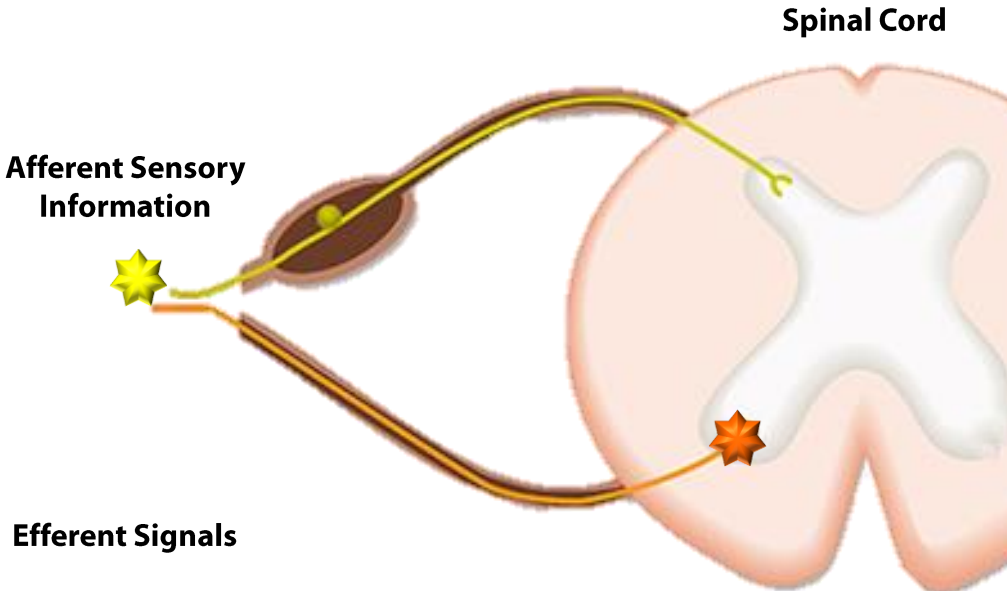
- Passes through the foramen magnum into the vertebral canal
- 31 pairs of spinal nerves branch off the spinal cord
- Made of a core of gray matter surrounded by white matter
- Has 3 levels of meninges

Essential TIP!

Afferent Nerves
Ascend upward

Function

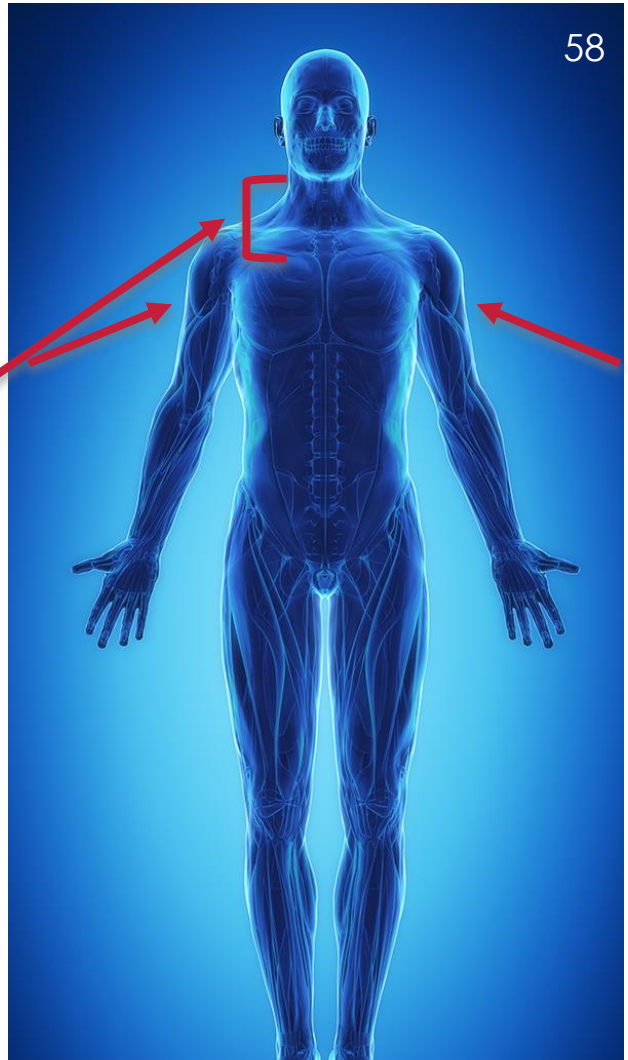
- It sends messages to the brain through afferent nerve tracts
- Receives message from the brain through efferent nerve tracts



Spinal Cord Syndromes

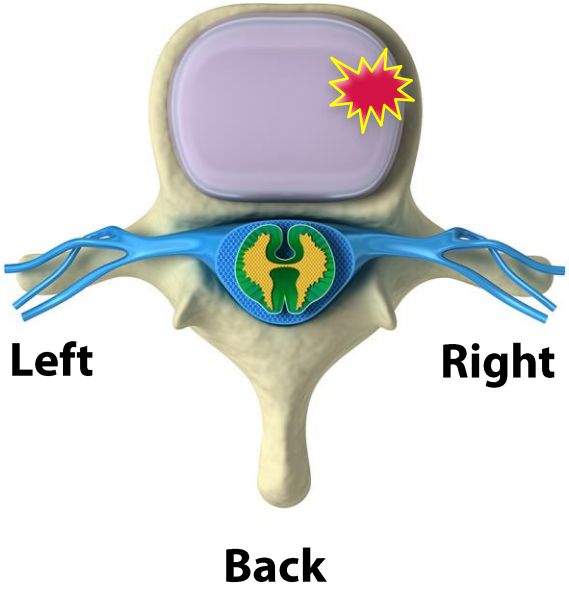
- **Central Cord Syndrome**
  - Cervical injury site; incomplete injury
  - Often the result of a fall in a person with neck arthritis or spondylosis
  - Presents as weakness and numbness in arms
  - Often accompanied by bowel/bladder incontinence

Left Right



Spinal Cord Syndromes

- **Brown-Sequard Syndrome**
  - Only one side of the spinal cord is injured



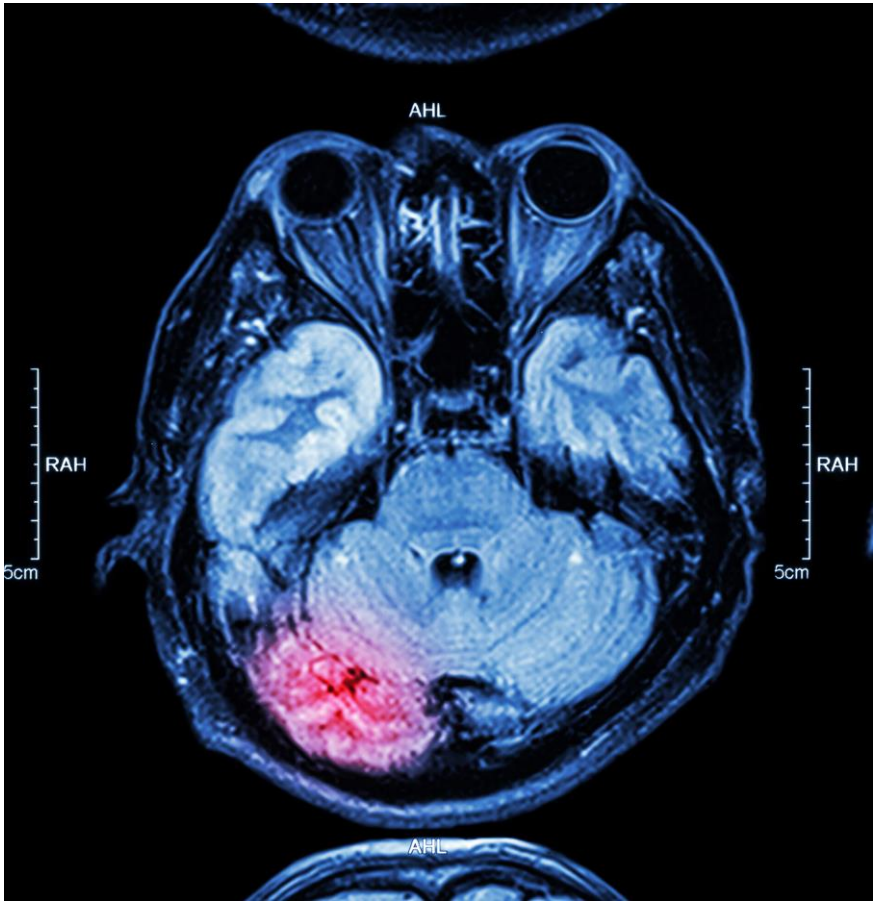
Paralysis and loss of touch sensation on the same side

Loss of pain and temperature sensation on the opposite side side

Spinal Cord Syndromes

- **Anterior Cord Syndrome**
  - Loss of muscle control, pain and temperature sensation below the level of the lesion
  - No loss of proprioception and touch sensation below the level of the lesion

- **Posterior Cord Syndrome**
  - Presents with strength but no sense of where limbs are in space below the level of damage

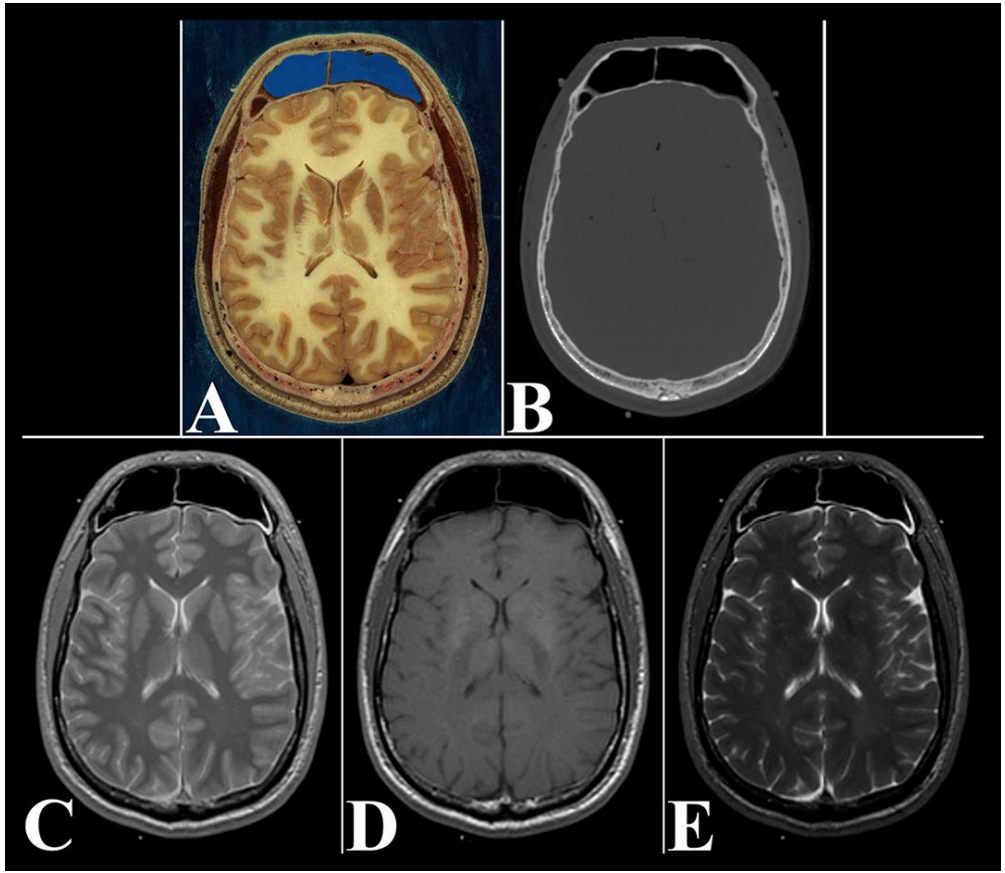


Exam Study Outline Info!

NEUROIMAGING

Computed Tomography (CT)

- An X-ray procedure that combines multiple x-ray images with the aid of a computer to produce cross sectional views and three dimensional images of the internal organs and structures of the body
- Useful for identifying gross anatomical changes
  - Skull fracture
  - Hemorrhage
  - Blood clot
  - Swelling
  - Penetrating object

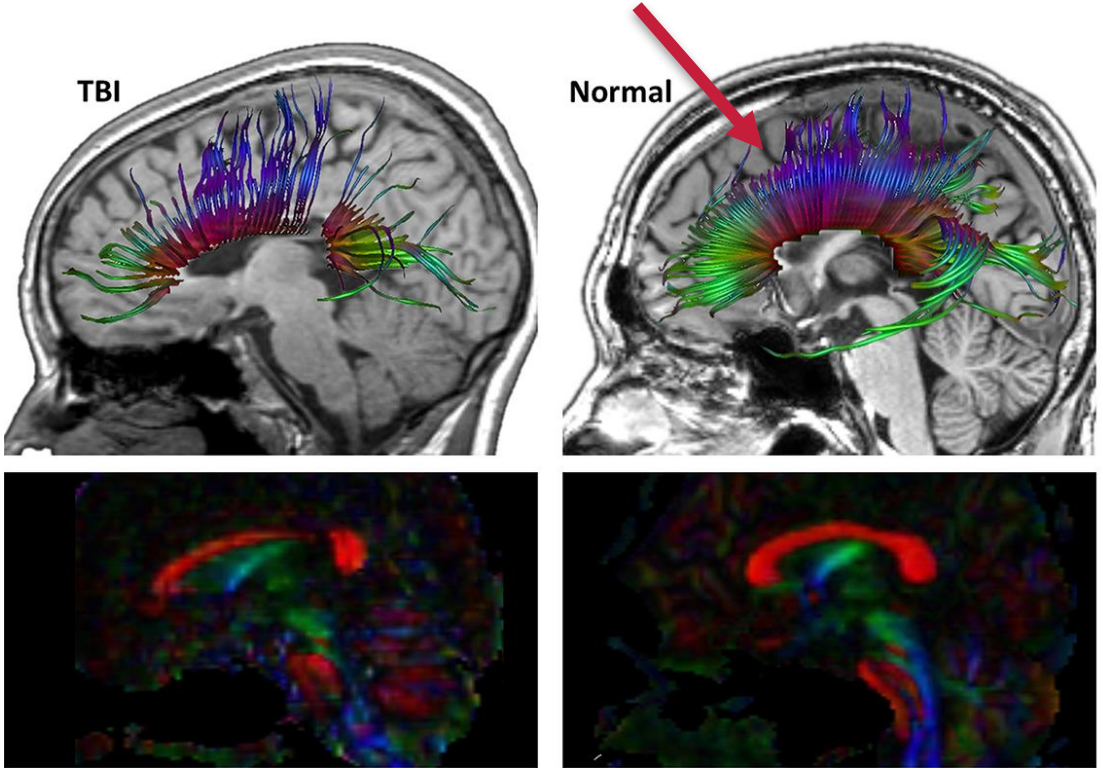


Magnetic Resonance Imaging

- Also known as MRI
- Uses a magnetic field, radio frequency pulses, and a computer to produce detailed pictures of organs, soft tissues, bone, and other internal body structures
- MRI provides better detail than CT
  - More sensitive to a variety of pathologies
- Computer algorithms are used to create different forms of MRI, including
  - Diffusion Tensor Imaging
  - fMRI
  - T2 Weighted

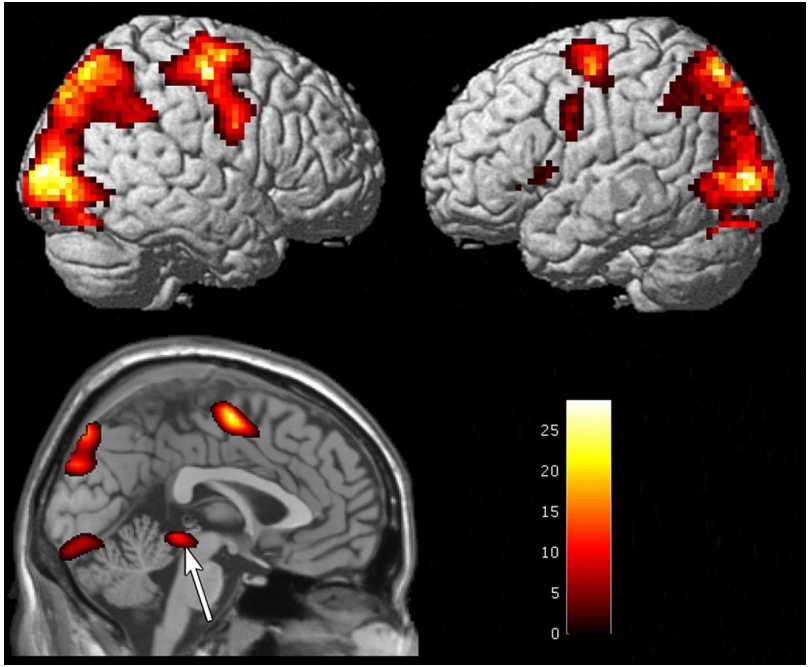
Diffusion Tensor Imaging

- A type of Magnetic Resonance Imaging which uses the rate at which water diffuses between cells to provide information about the internal structures of the body
- DTI provides information about the connectivity and continuity of neural pathways (i.e., white matter)



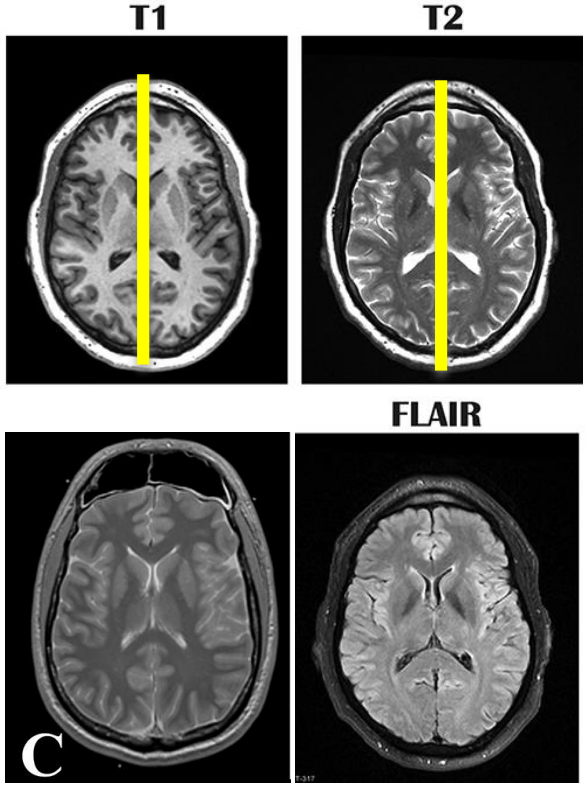
Functional MRI

- The individual performs a task while in the MRI scanner
- The scan measures and maps brain activity by detecting changes associated with blood flow
- Changes in blood flow follow changes in neural activity



Brain Symmetry & Imaging

- The brain in a normal state is symmetric
  - See T1 and T2
- Non-pathological brains and the structures that make up the brain should all appear similar to one another (i.e., from brain to brain)
  - See C and Flair

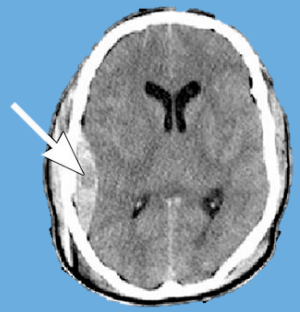


Mechanisms of Traumatic Injury

Categories of Brain Injury

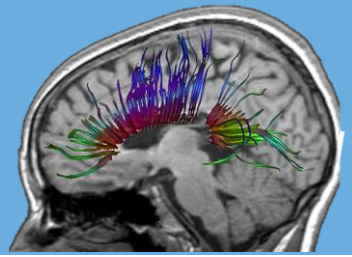
Focal

- Contusions
- Lesions
- Hematomas



Diffuse

- Diffuse Axonal Injury
- Hemorrhage



TRAUMATIC IMPACT Contact Injury Head struck by or against an object		TRAUMATIC INERTIAL Non-Contact Injury Brain moves within skull
CLOSED (Non-Penetrating)	**OPEN** (Penetrating) Skull Fracture Meninges Breach	**Rotational/Angular Forces** Non-Contact Injury Brain moves within skull
FOCAL - OR - DIFFUSE	PRIMARILY FOCAL	PRIMARILY DIFFUSE (MULTIFOCAL)
Brain Contusions Brain Lacerations Intracerebral Hemorrhage Diffuse Axonal Injury	Epidural Hematomas Subdural Hematomas Intracerebral Hemorrhage Infections	Diffuse Axonal Injury White Matter Lesion Hemorrhage

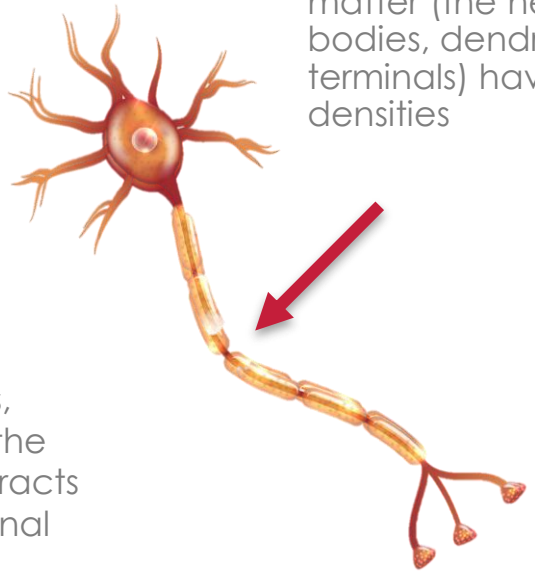
Mechanism of Injury

Acceleration-Deceleration (Traumatic Inertial)

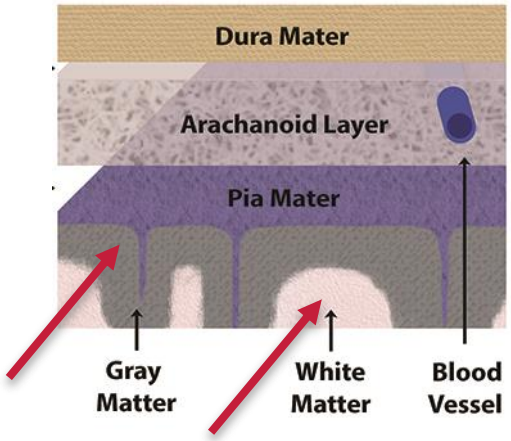
http://www.calshipleymd.com/medical-animation/neurology-library/diffuse-axonal-injury-dai/

1. Rapid acceleration of the brain followed by rapid deceleration

2. Results in the shearing of axons, and blood vessels throughout the brain, rendering white matter tracts (bundles of axons) non-functional
3. This is termed Diffuse Axonal Injury, or DAI



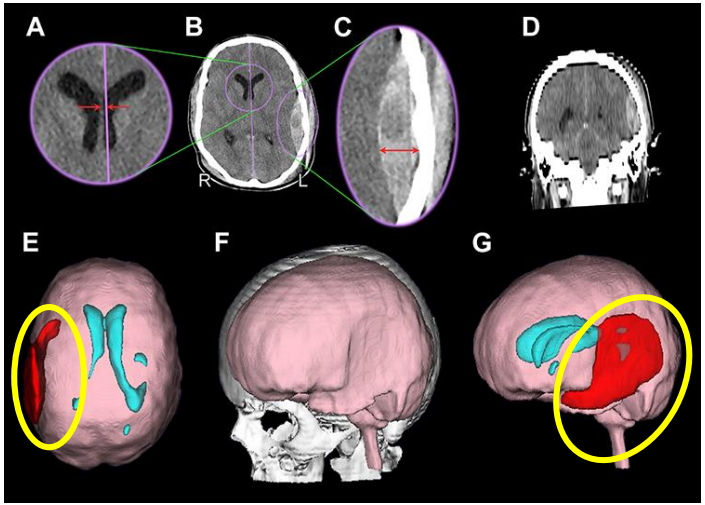
4. White matter (the neuron's myelinated axons) and gray matter (the neuron's cell bodies, dendrites and axon terminals) have different densities



5. The junction between gray and white matter is where DAI is more frequent
6. The Corpus Callosum often injured in this fashion

Mechanism of Injury

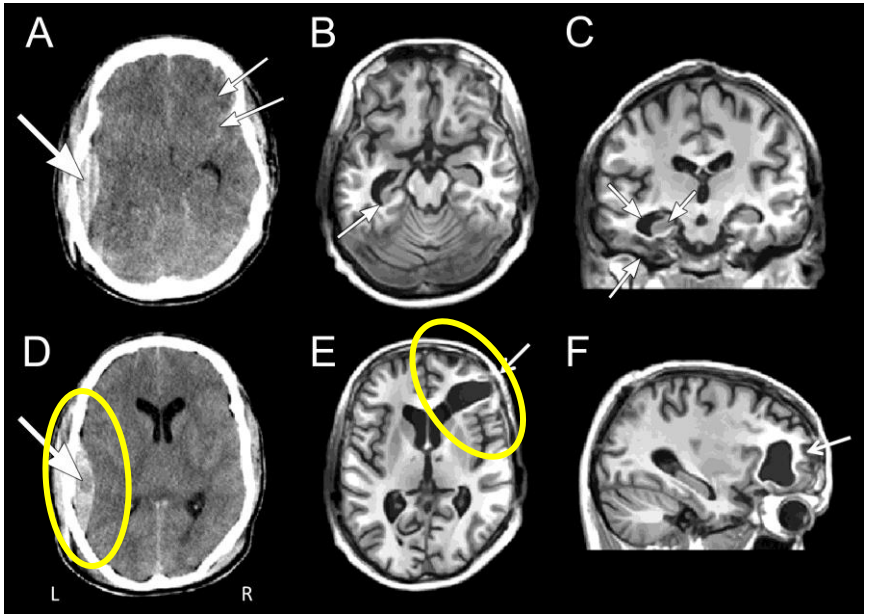
Coup Contrecoup



The initial site of injury (coup)

The contrecoup injury

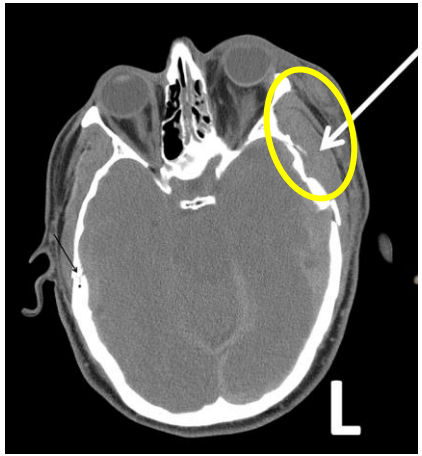
- The bouncing of the brain in the skull can result in injury in two sites



Mechanism of Injury:

Intracranial Pressure

- The brain can bleed and swell when injured
- This can lead to pressure on brain tissue and blood vessels, depriving the brain of oxygen, leading to additional injury



Mechanism of Injury

Hypoxia & Anoxia

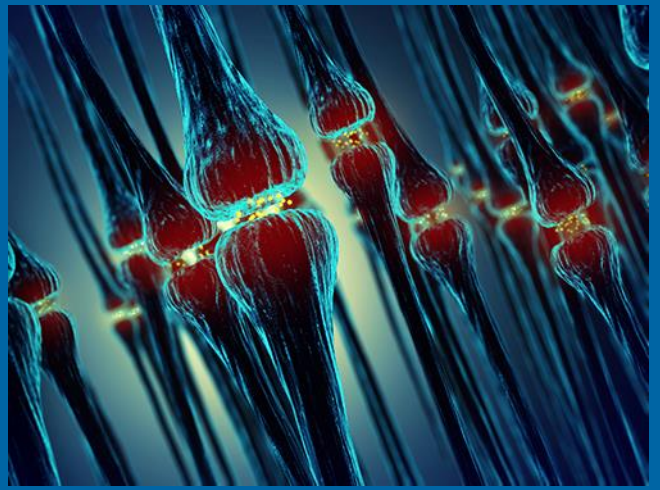
- Lack of oxygen causes brain cells to die
- When the cells die, they release chemicals that can cause further damage to the brain

Penetrating Injuries

- A penetrating injury results when an object penetrates the skull and enters the brain

Neuroprotection and Neuroplasticity

Chapter 3



Learning Objectives

Be able to explain factors leading to neurodegeneration following TBI

Be able to articulate the effects of brain injury and injury severity

Understand the conceptions of neuroprotection, neuroplasticity, and neurodegeneration

Be able to articulate the two main areas of the brain known to be sites of neurogenesis

Be able to distinguish between rehabilitative training models appropriate for TBI and those for stroke

NEUROPLASTICITY

Neuroplasticity

Exam Study Outline Info!

Neurons that Fire Together, Wire Together

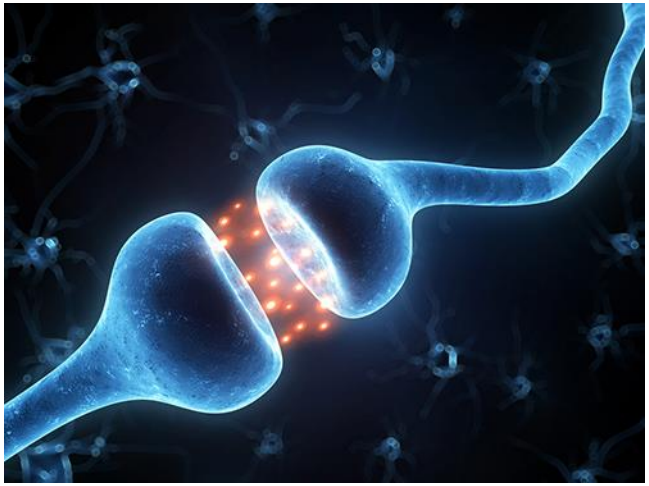
Definition

- The ability of the nervous system to change itself, form new connections, and create new neurons in order to compensate for injury or adapt to changes in the environment

Example

- The firing of Neuron A causes Neuron B to fire.
- The cycle repeats and chemical changes alter the connection and strengthen both neurons

Neuron B



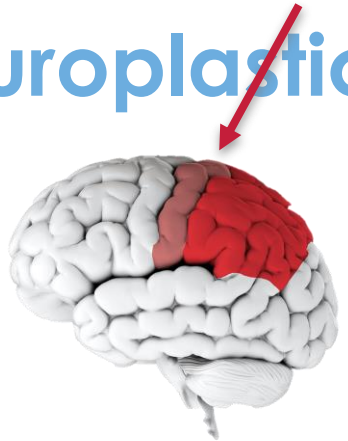
Neuron A

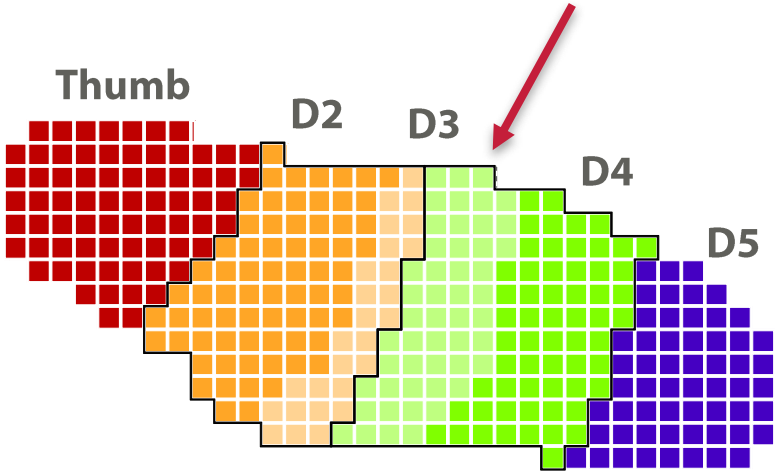
This is known as Hebbian Learning

Early Research on Neuroplasticity

Seminal work by Merzenich and colleagues

- They mapped the sensory cortex of monkeys to see which areas responded to cutaneous inputs from each digit
- The map on the right represents the sensory areas for each digit
- They then surgically removed digit 3
- This resulted in no inputs registering in the area where D3 inputs were prior to amputations
- As the monkeys used their hands post amputation, they remapped the sensory inputs at various points in time
- The vacated receptors where D3 registered previously were then taken over by inputs from the adjacent digits, namely D2 and D4





Experience Dependent Learning

- The previous slide showed that when inputs to the **sensory cortex** ceased in a particular area, adjacent inputs eventually took over those areas
- It highlights just how valuable cortical space is, and justifies the saying "**USE IT OR LOSE IT**" when it comes to our

Both of the these research examples show that **as our behavior or experience changes, there are resulting changes to our brain topography**

Merzenich and colleagues also researched this concept through mapping of the **motor cortex**

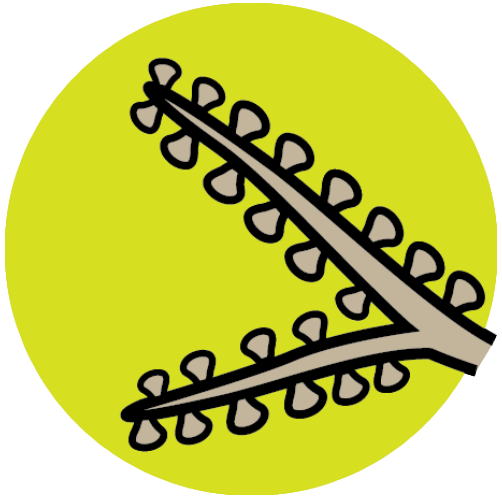
They trained monkeys on novel tasks that used only specific parts of their hands (digits, wrist, or forearm)

They found that as monkeys used only that specific area of their hand (e.g., digits), the size of the motor map increased for that area, and the size of the motor map for the other areas decreased (e.g. wrist and forearm)

Synaptogenesis

Definition: the formation of synapses between neurons

- The greater the numbers of synapses within a grouping of neurons, the greater the speed and efficiency with which those neurons communicate
- There are many factors that impact synaptogenesis but a key aspect of new synapse development is the dendrite
- The size and complexity of a dendrite arbor determine the volume of synapses
- There are hundreds to thousands of dendritic spines on each dendrite; these structures contain neurotransmitter receptors and receive synaptic transmissions



Dendritic spines have the ability to change in response to experience

Neuroplasticity Post-TBI

- Structural changes in the brain can occur in the area of the injury and remote areas connected to that area
- Neuroplasticity may be modulated by experience

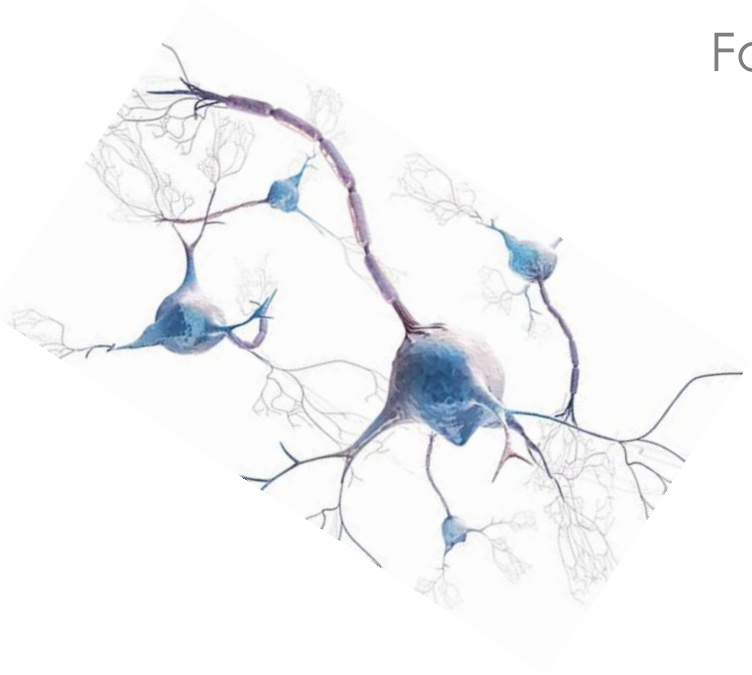
- Plasticity: the ability of the nervous system to change, grow or compensate for injury

Neuroplasticity Post-TBI:

Cortical Reorganization

- The brain's cortical map can change following injury
- The brain's cortical map can change through rehabilitation
  - ✓ Directed Exercise
  - ✓ Constraint Induced Movement Therapy

Neuroplasticity: TBI Research



Following traumatic injury

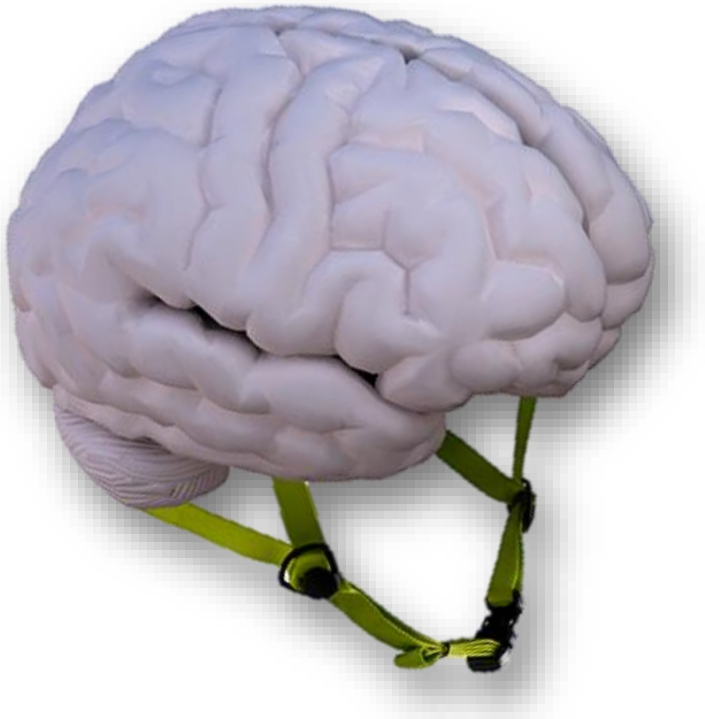
- The brain increases its own production of growth factors
- There is a decrease in the amount of structural materials found in the brain

Neurogenesis

- **Theory:** the brain does not produce new neurons after development
- **Research:** Neurogenesis occurs in the developed brain
  - ✓ Specific areas in the hippocampus
    - Subventricular zone
    - Dentate gyrus
  - ✓ Increase with exercise, decrease with stress
  - ✓ Cells may migrate to areas affected by the injury

Implications for Rehabilitation

- Spontaneous neuroplasticity in TBI does not appear to occur as it does in stroke
- Appears that TBI requires a more intense combination of rehabilitation therapies to improve function
- Further research is needed



NEUROPROTECTION

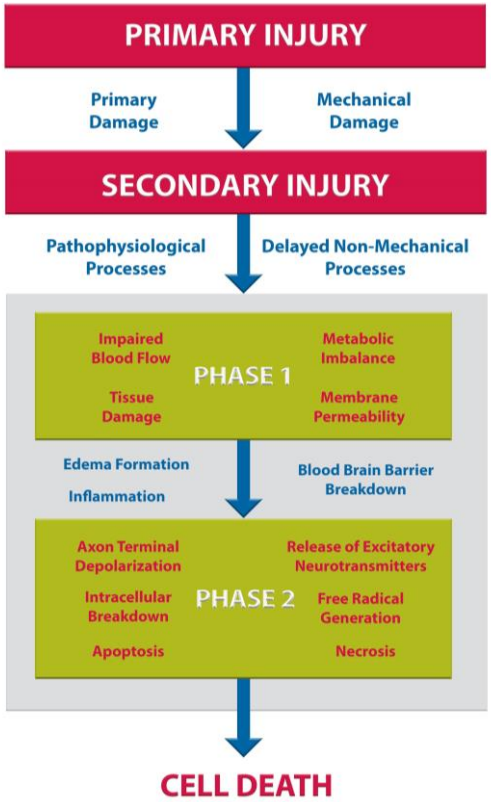
Neuroprotection

Exam Study Outline Info!

Definition: Preservation of neuronal functioning and structure; reducing the rate of neuronal loss over time; refers to the ability of a drug or biological agent to prevent brain cells from dying.

- Reducing cell loss following injury leads to better function
- As a result, research has focused on ways to reduce cell loss including:
  - Using substances to prevent secondary injury cascade
  - How the brain reorganizes and adapts to injury
  - Rehabilitation
- Research focused primarily on stroke
  - Tissue plasminogen activator (tPA)

Biological Cascade Following TBI



- Primary Injury- direct damage to the brain
- Secondary Injury- causes additional damage
  - Excitotoxicity
  - Edema
  - Apoptosis

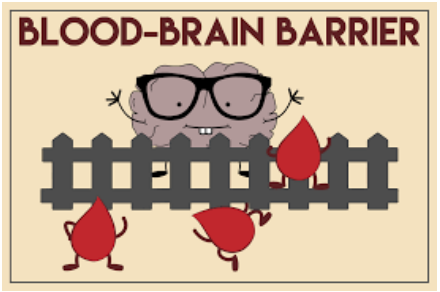
Exam Study Outline Info!

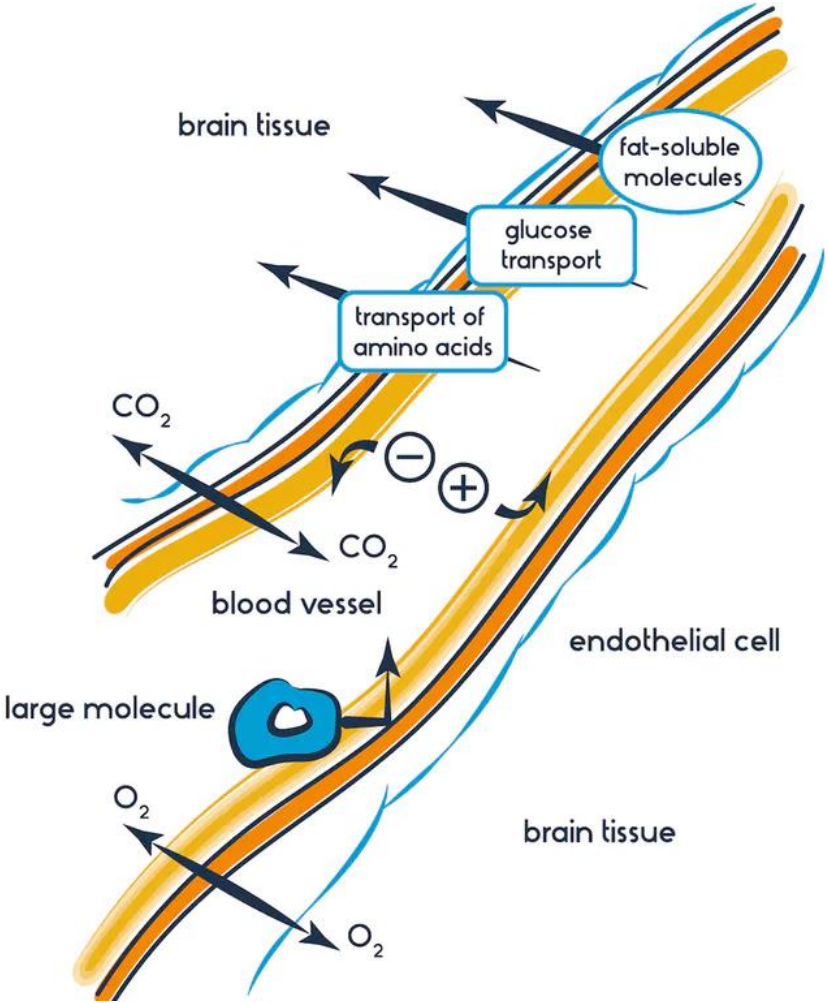
Blood-Brain Barrier

Definition: Protective system ensuring that, at the vascular level, harmful substances cannot pass through the membrane to harm the brain.

The purpose of the blood–brain barrier is to protect against circulating toxins or pathogens that could cause brain infections, while at the same time allowing vital nutrients to reach the brain.

Its other function is to help maintain relatively constant levels of hormones, nutrients and water in the brain – fluctuations in which could disrupt the finely tuned environment.





When functioning properly, the blood-brain barrier lets good things in, and keeps bad things out.

Secondary Injury

Excitotoxicity

- Failure of neurons to maintain resting state
- Sodium-potassium pump failure
- Excitotoxic accumulation of sodium and calcium

Edema

- Swelling in cells
- Increased Intracranial Pressure
- Contributes to apoptosis

Apoptosis

- Cells surrounding the primary injury die as a result
- This expands the size of the injury

Potential Neuroprotective Agents for TBI

- Neuroprotective agents limit neuronal death following injury and/or enhance recovery

Neuroprotective Agent	Intervention Target	Animal Models Showing Efficacy (Stroke)	Human Studies Showing Efficacy (TBI)
Magnesium	Increase Mg2 (decreased Mg2 results in excessive production of free radical and mild inflammation)	✓	Failed ☒
Progesterone	Decrease cerebral edema	✓	Initial Efficacy, Follow Up Trial ☒
Nicotinimide	Reduce injury volume; decrease glial activation; reduce BBB breaches; reduce edema	✓	Unknown ?

Q & A

Thank You!

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THE END