HUMAN REPRODUCTIVE & NEUROENDOCRINE FUNCTIONS

BIOL 459

DR. MRS. DORCAS O. OWUSU

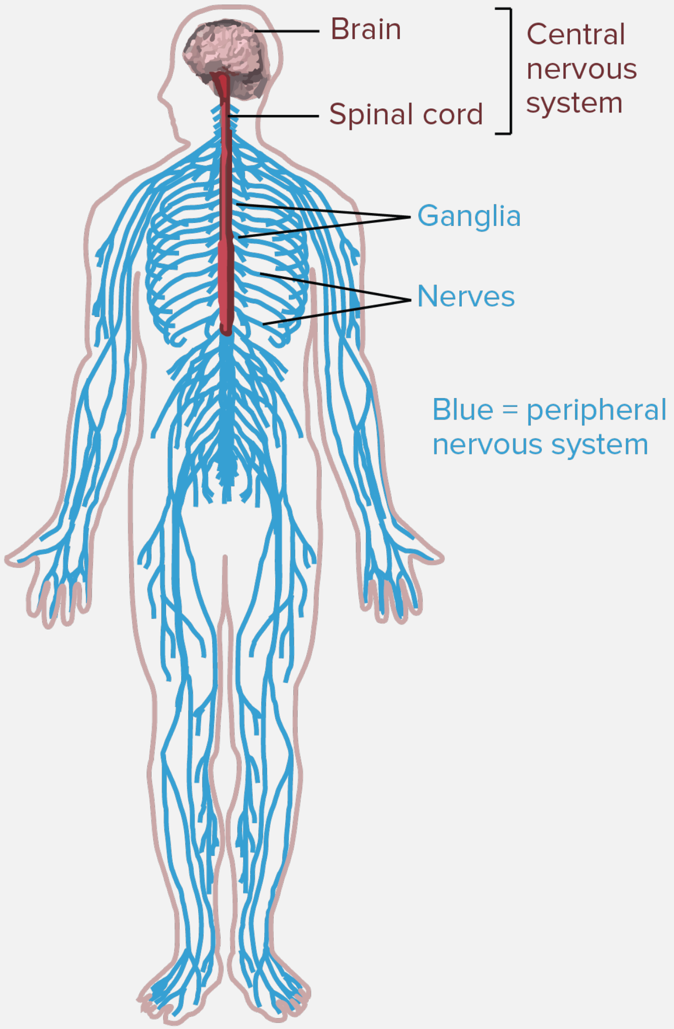
INTRODUCTION

BACKGROUND

- BIOL 254 Human Anatomy & Physiology II

INTRODUCTION

Organisation of the nervous system



COURSE OUTLINE

CNS

The brain

- Parts of the brain and their functions
- Blood-brain barrier.
- Cerebral circulation

The Spinal chord

- Spinal chord structure and characteristics
- Cerebrospinal fluid

COURSE OUTLINE

- Nerve tissue

PNS

Afferent,
- Efferent: Somatic, Autonomic (sympathetic & parasympathetic
- Cell types,
- neuronal processes,
- cell-cell communication (membrane potential, graded potential and action potential), neurotransmitters, synapse

- neuronal processes,
- cell-cell communication (membrane potential, graded potential and action potential), - neurotransmitters, synapse

Sensory Receptors
- Functional organization of Neurons

COURSE OUTLINE

PNS

- Afferent division (sensory)
- Efferent division (motor)
  - Somatic nervous system (SNS)
  - Autonomic nervous system (ANS)
    - ✓ Sympathetic
    - ✓ Parasympathetic

COURSE OUTLINE

Nerve tissue

- Cell types and structure
- cell-cell communication (membrane potential, graded potential and action potential) neurotransmitters, synapse.

Sensory Receptors

- Functional organization of Neurons
- Reflexes: monosynaptic, polysynaptic

COURSE OUTLINE

Male reproductive system

- Spermatogenesis,
- Sperm maturation, storage and capacitation
- Endocrine function of testis
- Abnormalities of testicular function.

COURSE OUTLINE

Female reproductive system

- Oogenesis,
- Menstrual cycle,
- Ovarian and uterine cycles,
- Control of menstrual cycle,
- Disorders of menstrual cycle,
- Ovarian hormones, puberty, menopause

INTRODUCTION

- 14 WEEKS
  - 2 PUBLIC HOLIDAYS (Mondays)
  - 1 MIDSEM WEEK
  - 1 REVISION WEEK
  - 3 WK EXAMS

✓ WEEKS ?????? (ACTUALS)

COURSE OUTLINE

Reproductive Biology

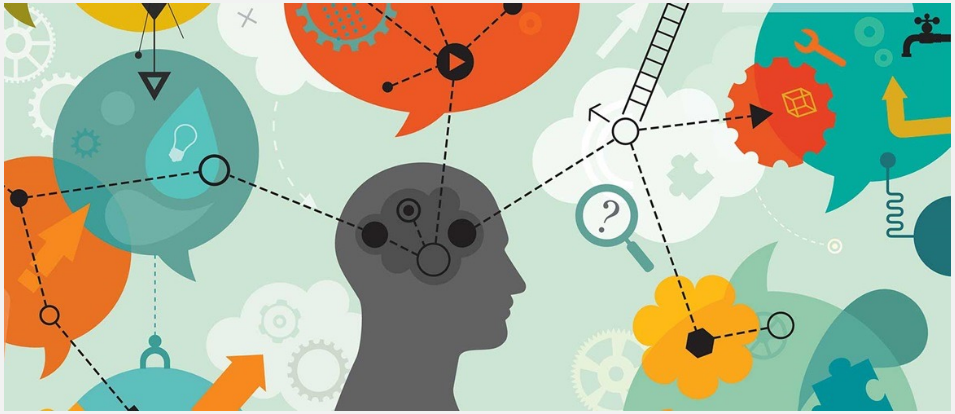
- Human sexual response
- Pregnancy
  - Fertilisation
  - Implantation
  - Placental functions
- Hormonal changes during pregnancy and parturition.
- Disorders in fertility.

ORGANISATION OF THE NERVOUS SYSTEM

ORGANISATION OF THE NERVOUS SYSTEM

- The nervous system is the major controlling, regulatory, and communicating system in the body.
- It is the centre of all mental activity including **thought**, **learning**, and **memory**.

- Work with the endocrine system in regulating and maintaining homeostasis



ORGANISATION OF THE NERVOUS SYSTEM

- Through its receptors, the nervous system keeps us in touch with our environment, both external and internal
- Like other systems in the body, the nervous system is composed of organs, principally:
  - The **brain**, **Spinal cord** and **Nerves**, and **ganglia**.

ORGANISATION OF THE NERVOUS SYSTEM

- Functions:
  - Sensory
  - Integrative
  - Motor

ORGANISATION OF THE NERVOUS SYSTEM

Sensory receptors

- Detect changes(stimuli) which occur inside and outside the body.
- They monitor such things as temperature, light, and sound from the **external environment**.
- Inside the body, the **internal environment** receptors detect variations in **pressure**, *pH*, ***carbon* dioxide** concentration, and the levels of various electrolytes.

ORGANISATION OF THE NERVOUS SYSTEM

Integration

- Sensory input is converted into electrical signals called **nerve impulses** that are transmitted to the brain.
- These signals are brought together to create **sensations**, to produce **thoughts**, or to add to **memory**

✓ ***Decisions are made each moment based on the sensory input.***

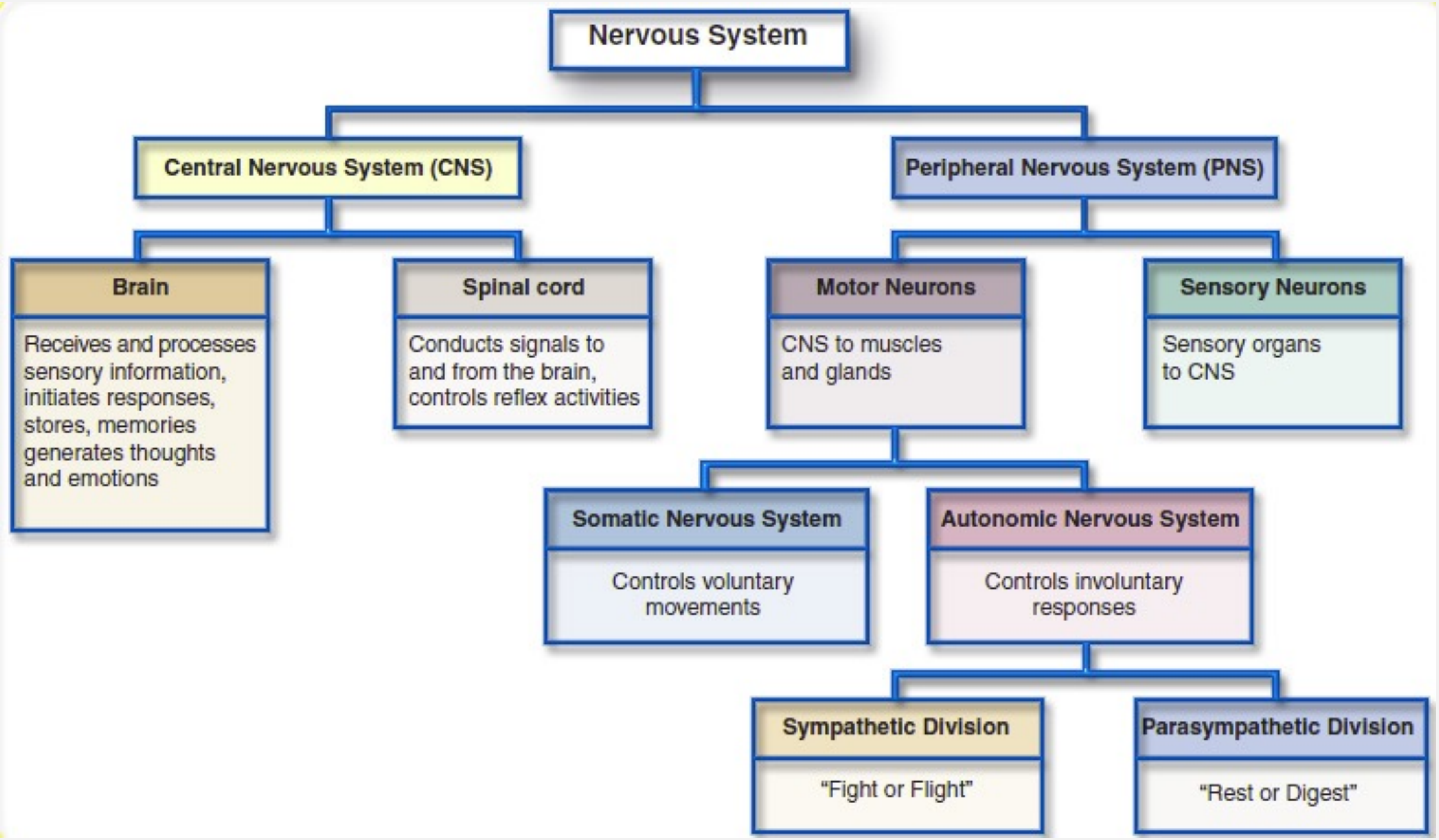
ORGANISATION OF THE NERVOUS SYSTEM

Motor output or **motor function**

- Based on the sensory input and integration, the nervous system responds by sending signals:
  - to muscles, causing them to contract, or
  - to glands, causing them to produce secretions

- ***Muscles*** *and* ***glands*** are called **effectors** because they cause an effect in response to directions from the nervous system.

ORGANISATION OF THE NERVOUS SYSTEM



CENTRAL NERVOUS SYST. (CNS)

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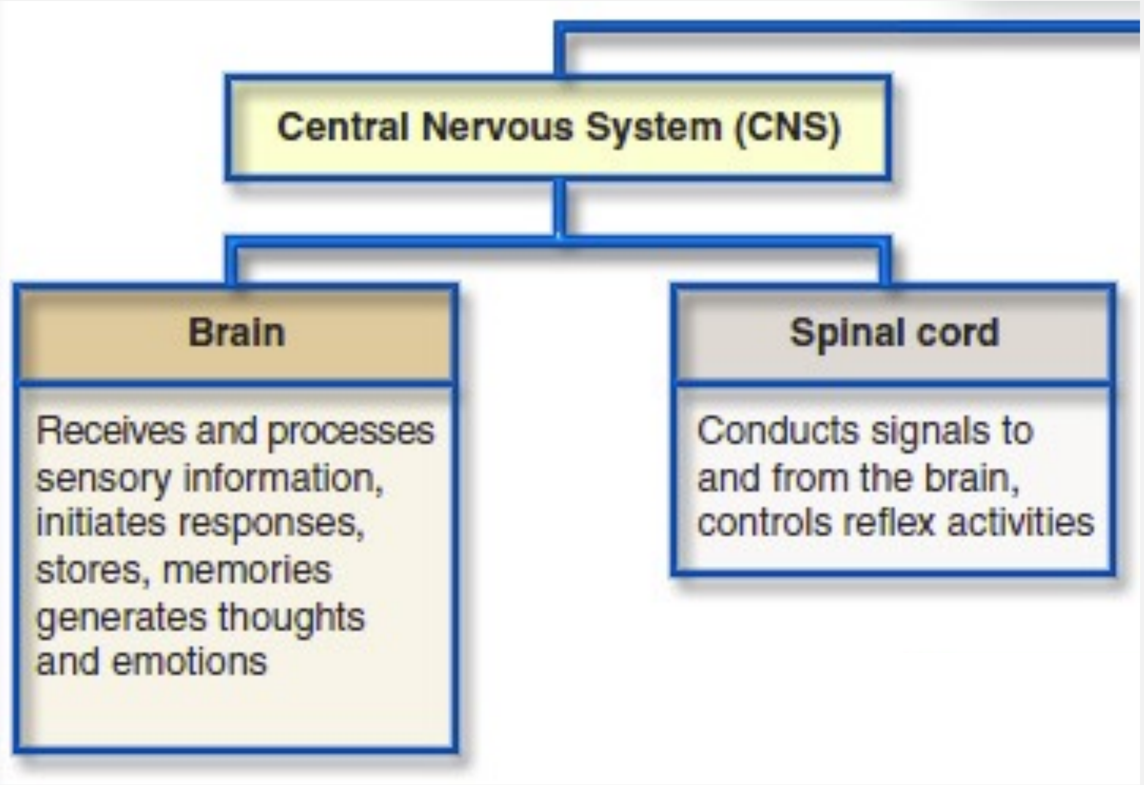
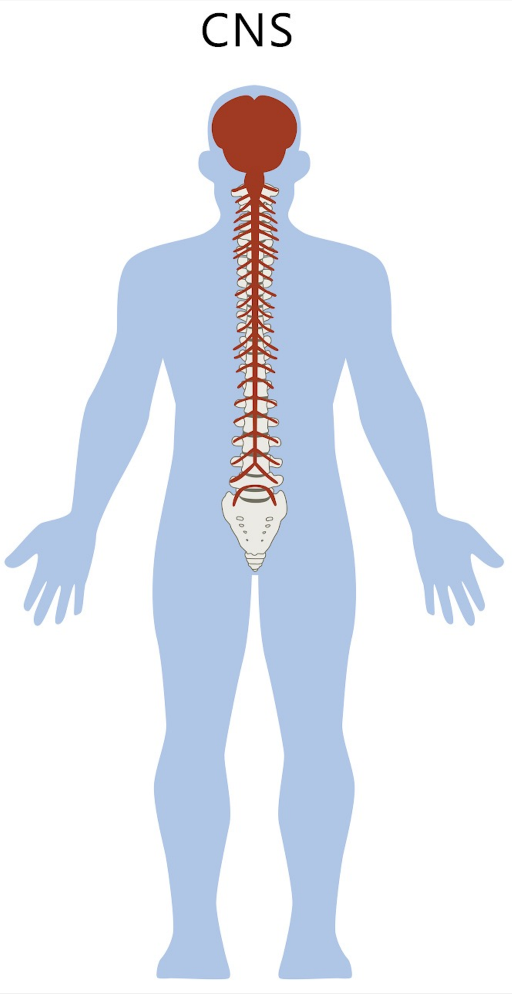
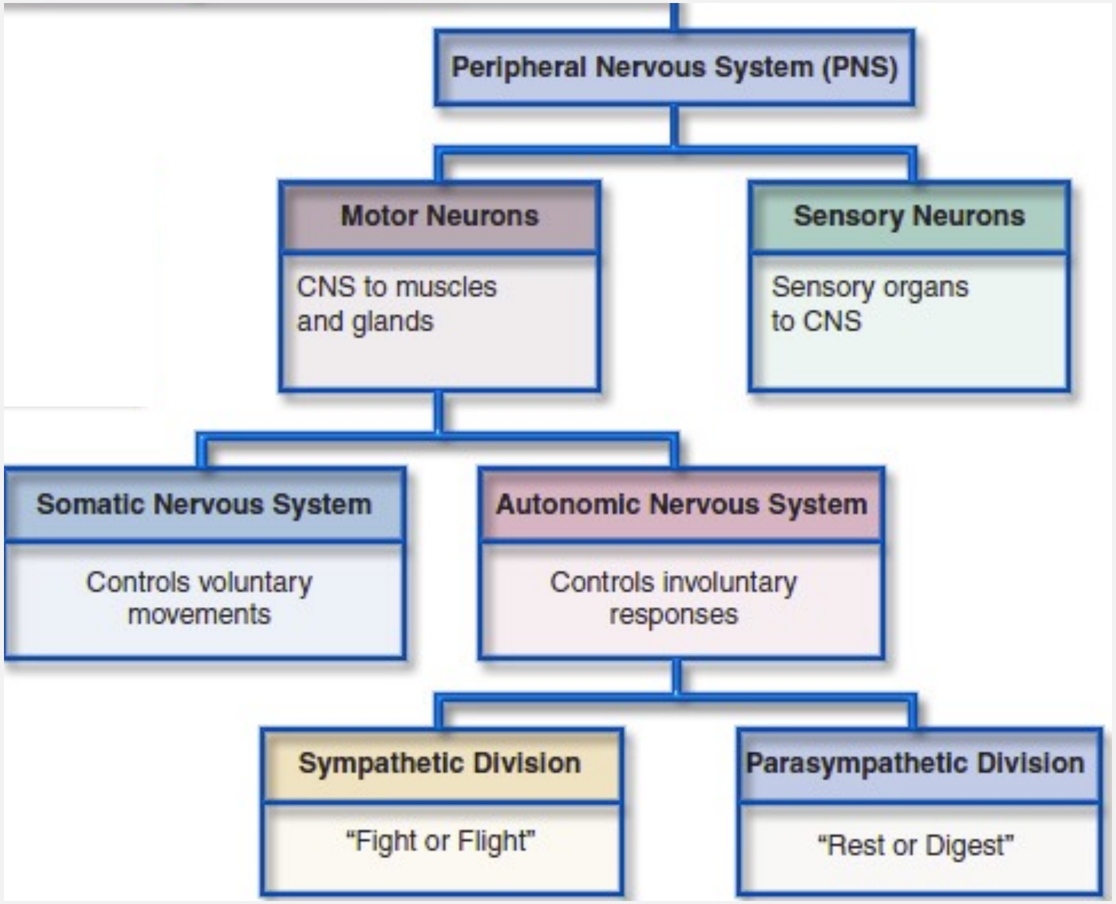


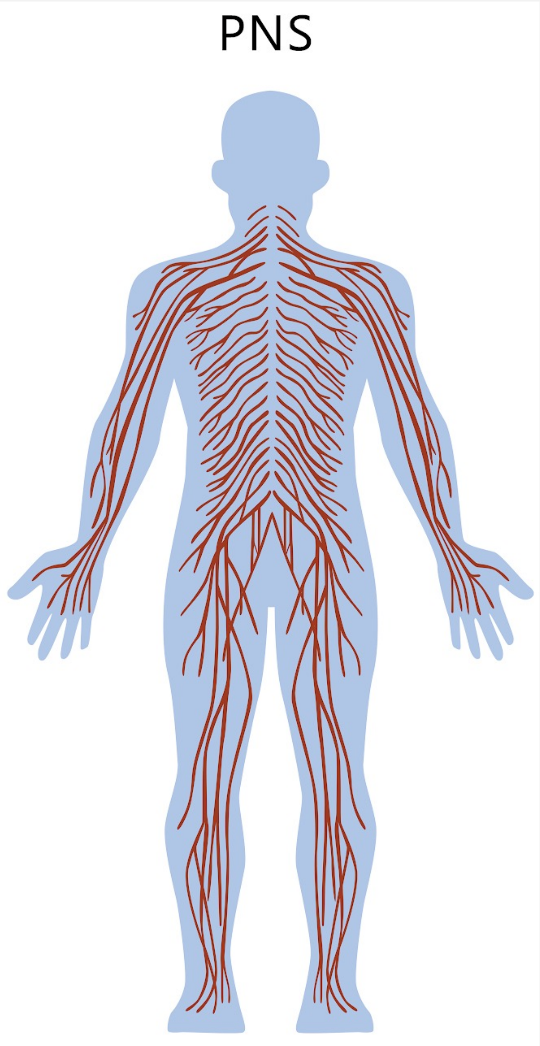


CENTRAL NERVOUS SYST. (CNS)

- **The brain** and **spinal cord** are the organs of the **central nervous system**.
- Located in the dorsal body cavity, are encased in bone for protection.
- The brain is in the **cranium**, and the spinal cord is in the **vertebral column**.
- The brain and spinal cord are continuous at the **foramen magnum.**
  - ➢ They are two separate organs

PERIPHERAL NERVOUS SYST. (PNS)





PERIPHERAL NERVOUS SYST. (PNS)

- The organs of the peripheral nervous system are the **nerves** and **ganglia**.
- Nerves: bundles of nerve fibres
- **Cranial nerves** and **spinal nerves** extend from the CNS to peripheral organs such as muscles and glands.
- The peripheral nervous system is further subdivided into:
  - *Afferent (sensory) division*
  - *Efferent (motor) division.*
- **The afferent or sensory division** transmits impulses from peripheral organs to the CNS.

PERIPHERAL NERVOUS SYST. (PNS)

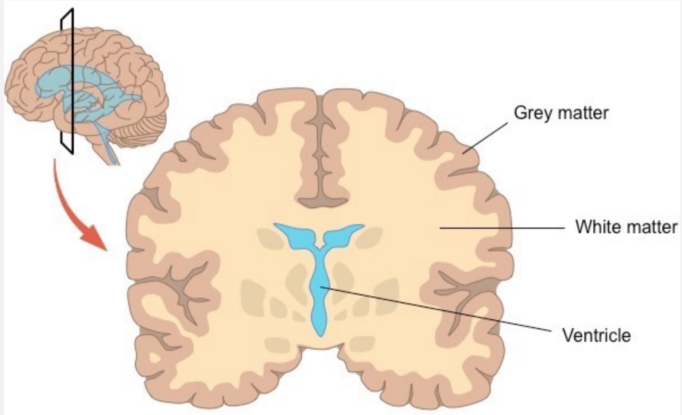
- The *efferent or motor division* transmits impulses from the CNS out to the peripheral organs to cause an effect or action.
- **Efferent or motor division:**
  - Somatic nervous system: supplies motor impulses to the skeletal muscles (voluntary nervous system)
  - Autonomic nervous system: supplies motor impulses to cardiac muscle, to smooth muscle, and to glandular epithelium.
    - It is further subdivided into **sympathetic** and **parasympathetic** divisions (involuntary nervous system)

THE BRAIN (CNS)

THE HUMAN BRAIN

Characteristics:

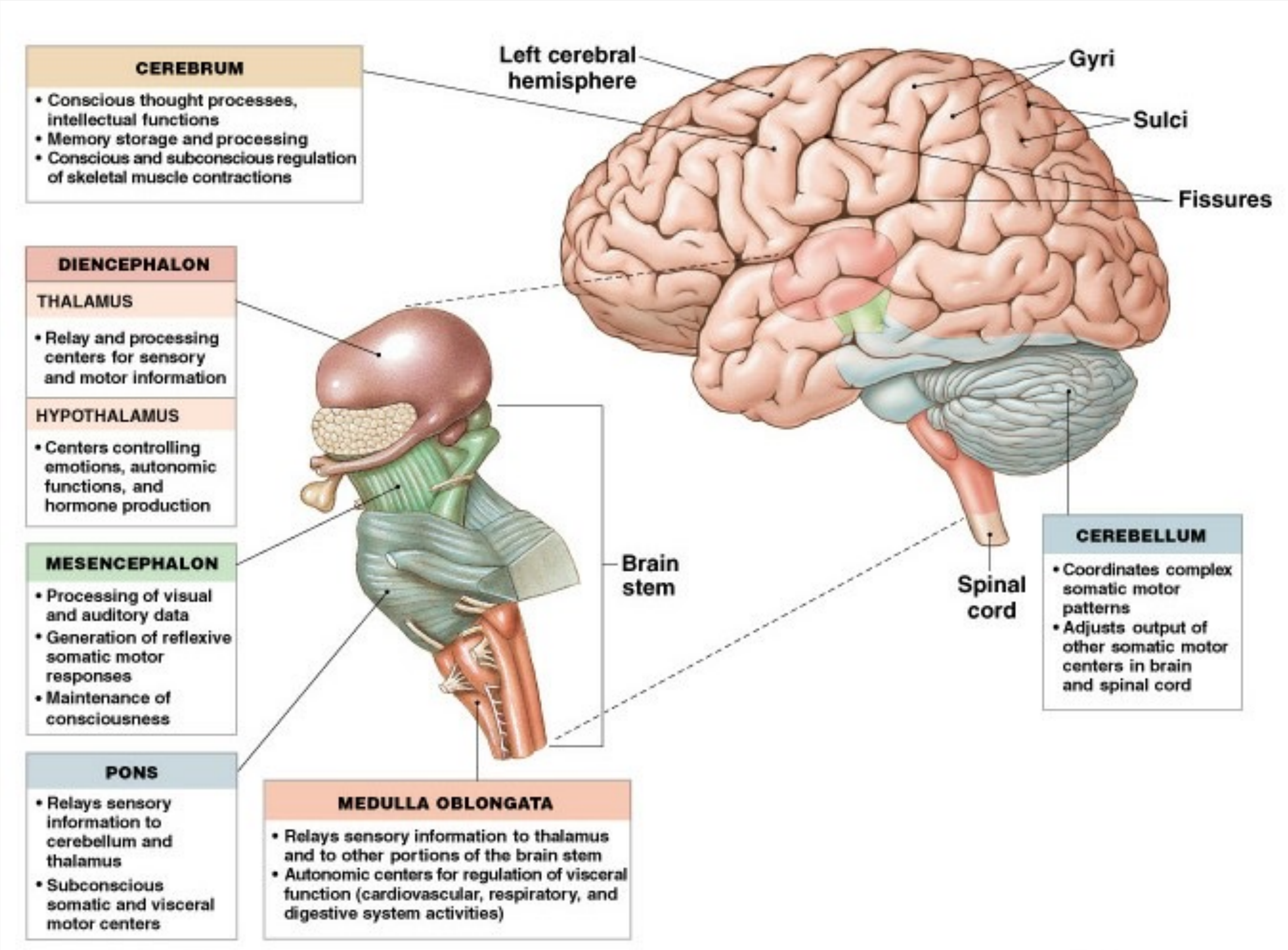
- It contains blood vessels and nerves, including neurons and glial cells.
- Contains almost 98% of the body's neural tissue
- Average weight about 1.4 kg



Divisions of the brain:

- Cerebrum (Telencephalon)
- Diencephalon (posterior) part of the forebrain
- Brain stem
- Cerebellum

MAJOR REGIONS OF THE BRAIN

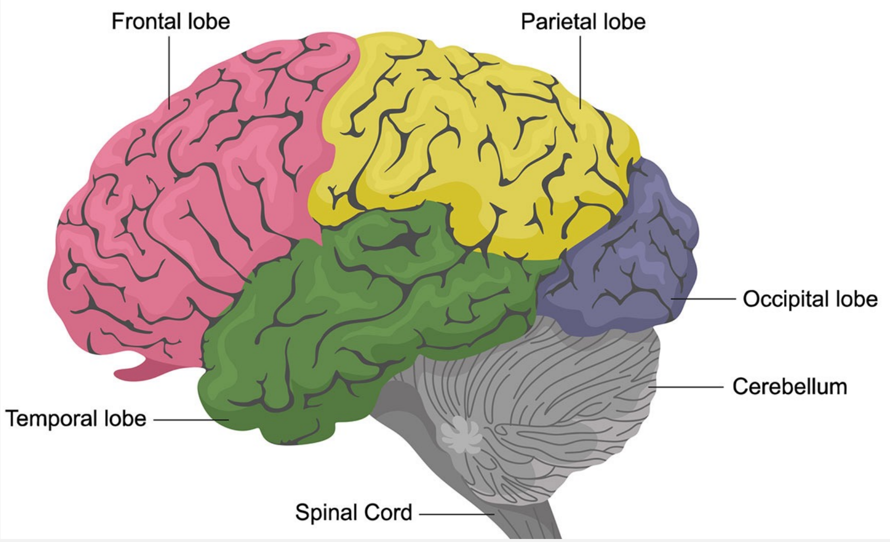


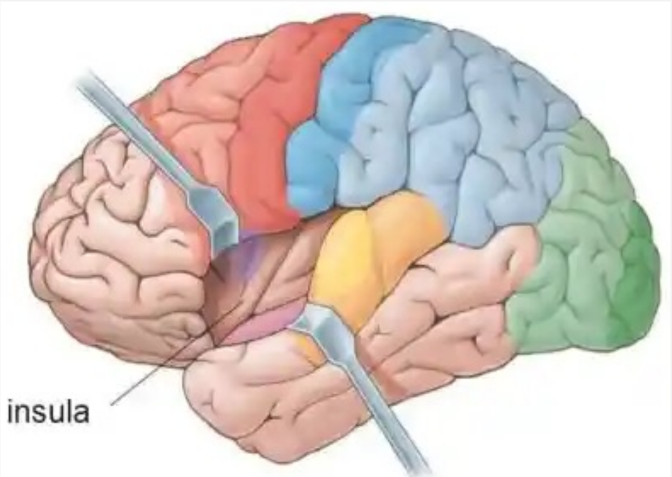
THE CEREBRUM

- The largest and most obvious portion of the brain is the cerebrum, which is divided by a deep longitudinal fissure into two **cerebral hemispheres**.
- The two hemispheres are two separate entities but are connected by an arching band of white fibres (mass of myelinated neuron processes), called the **corpus callosum** that provides a communication pathway between the two halves.
- Surface layer composed of **Gray matter** (neuron cell bodies and unmyelinated fibres) called cerebral/neural cortex.

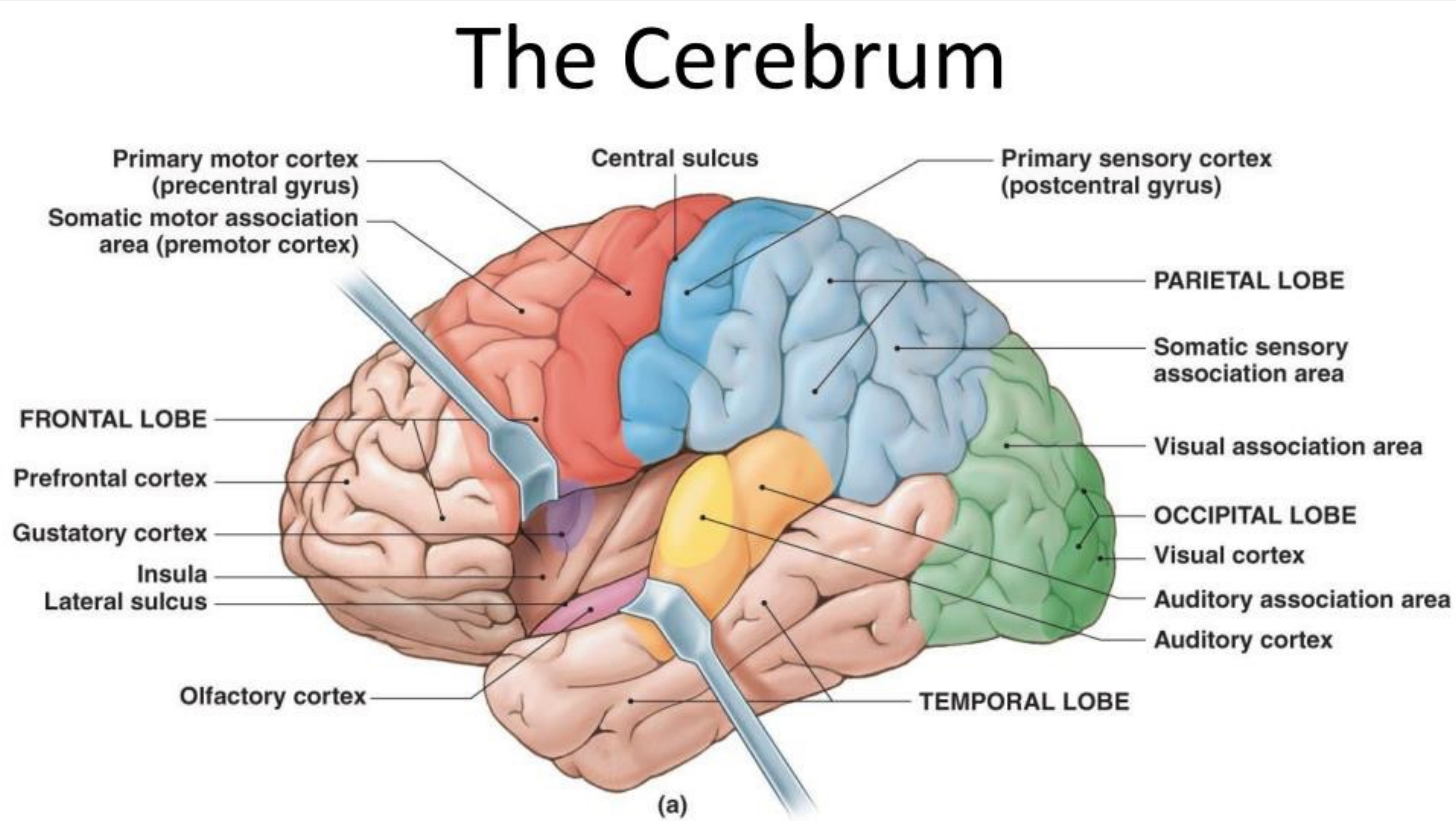
THE CEREBRUM

- Beneath the cerebral cortex is the **White matter.**
  - deep to basal cortex
  - around basal nuclei
- Each cerebral hemisphere is divided into five lobes:
- **Frontal lobe**, the **parietal lobe**, the **occipital lobe**, and the **temporal lobe**.
- A fifth lobe is the **insula**





MOTOR AND SENSORY AREAS OF THE COTRTEX



ASSOCIATION AREAS

- Occur in each cerebral cortex where they interrelate sensory inputs and motor outputs.
- **Sensory association areas:**
  - These areas analyse and interpret arriving information such as memory, reasoning, verbalizing, judgment and emotion
- **Somatic motor association area** (premotor cortex):
  - Coordinates motor responses (learned movements)
- The general interpretative area is involved with complex sensory experiences and thought processes.

SENSORY ASSOCIATION AREAS

- Somatic sensory association area:
  - interprets input to primary sensory cortex (e.g., recognizes and responds to touch)
- Visual association area:
  - interprets activity in visual cortex
- Auditory association area:
  - monitors auditory cortex

MOTOR AREAS

- Primary motor areas of cerebral cortex lies in the frontal lobes (along the post central gyri):

  - directs voluntary movements

- Pyramidal cells:
  - The Nervous tissues in this area contain large pyramidal cells (pyramid shaped).
  - Impulses from pyramidal cells travel through brain stem and spinal cord on corticospinal tracts
  - Axons in these areas cross over from one side of the brain to the other within the brain stem.

INTEGRATIVE CENTRES

- - Are located in lobes and cortical areas of both cerebral hemispheres

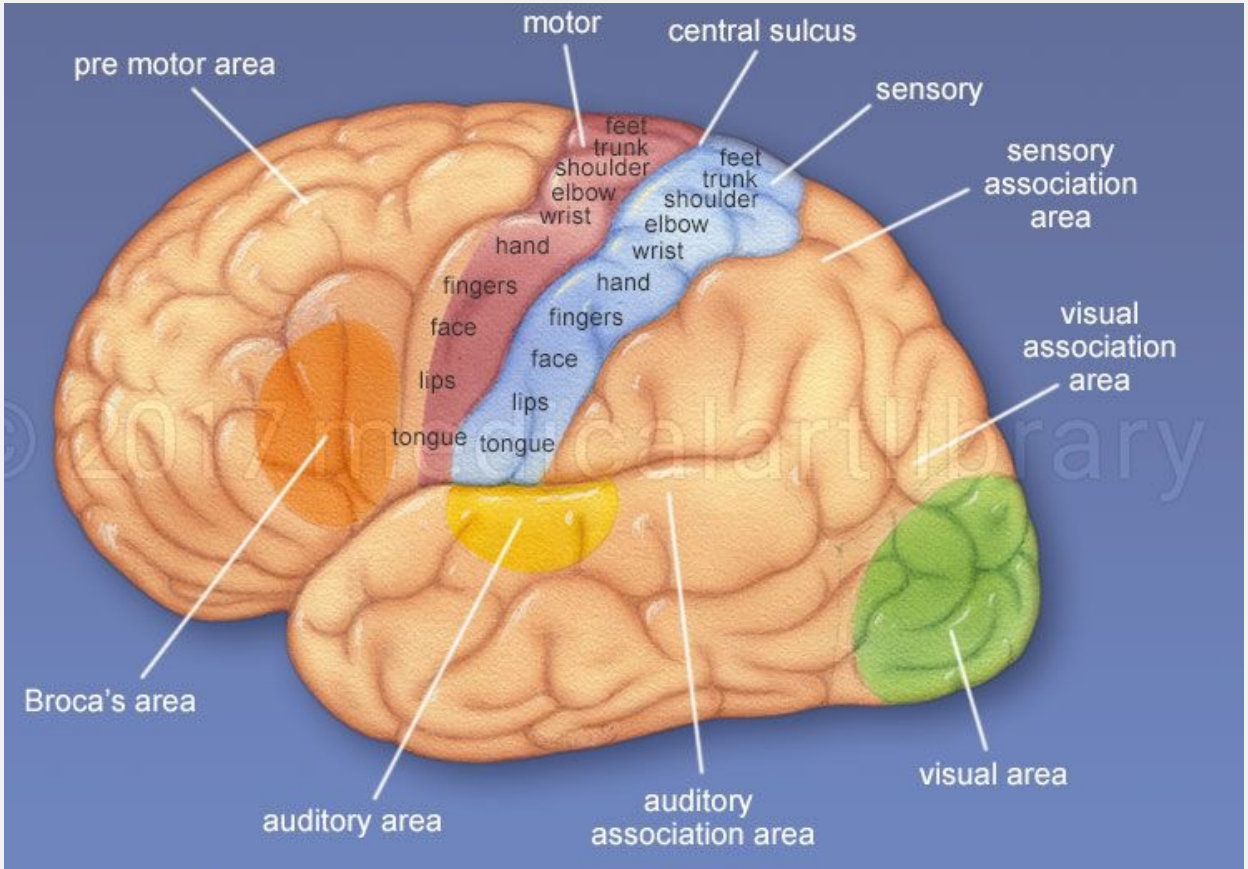
- - Receive information from association areas and direct complex motor or analytical activities

Divisions of the brain:

- Cerebrum
- Diencephalon
- Brain stem
- Cerebellum

THE CEREBRUM

Cerebral Cortex - Functional Areas



SPECIAL SENSORY AREAS

- Visual cortex:

  information from sight receptors

- Auditory cortex:

  information from sound receptors

- Olfactory cortex:

  information from odor receptors

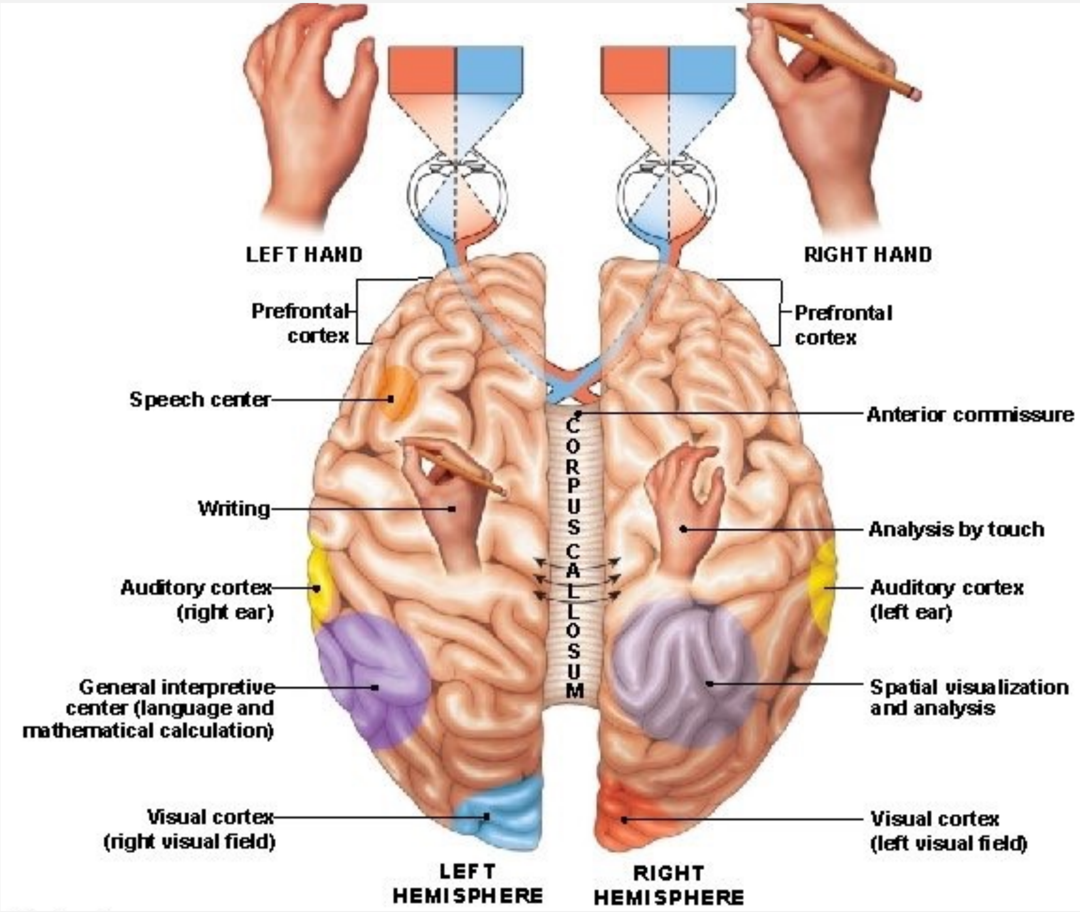
- Gustatory cortex:

  information from taste receptors

LATERALISATION OF THE HEMISPHERE

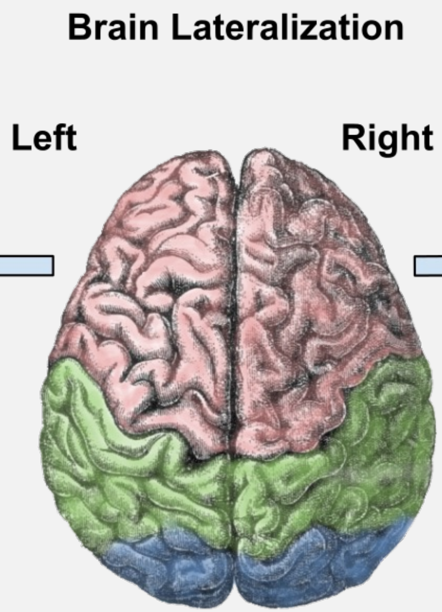
- Functional differences between left and right hemispheres

- Each cerebral hemisphere performs certain function not performed by the opposite hemisphere



LATERALISATION OF THE HEMISPHERE

- Analytical thought
- Detail Oriented Perception
- Ordered Sequencing
- Rational Thought
- Verbal
- Cautious
- Planning
- Math/Science
- Logic
- Right Field Vision
- Right Side Motor Skills



- Intuitive Thought,
- Holistic perception
- Random Sequencing
- Emotional Thought
- Non-verbal
- Adventurous
- Impulse
- Creative Writing/Art
- Imagination
- Left Field Vision
- Left Side Motor Skills

THE CEREBRUM

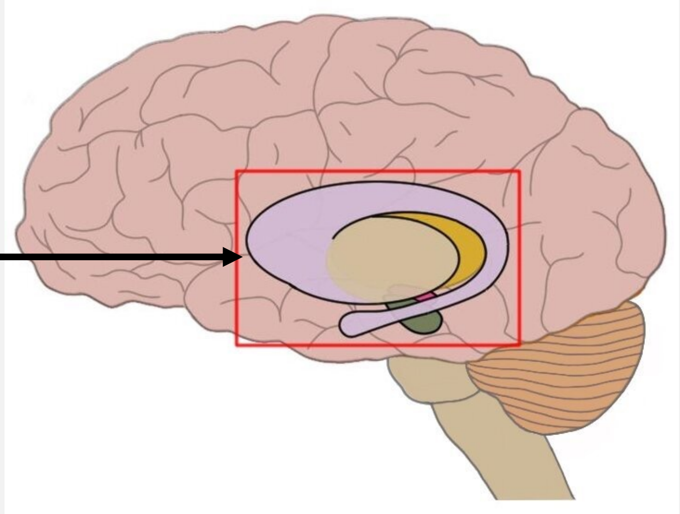
- Cerebral lobes and their functions?

THE CEREBRUM

Basal ganglia or basal nuclei:

- subcortical structures found deep within the white matter of the brain
- Responsible primarily for motor control, as well as motor learning, executive functions and behaviours, and emotions

Basal ganglia or basal nuclei



Divisions of the brain:

- Cerebrum
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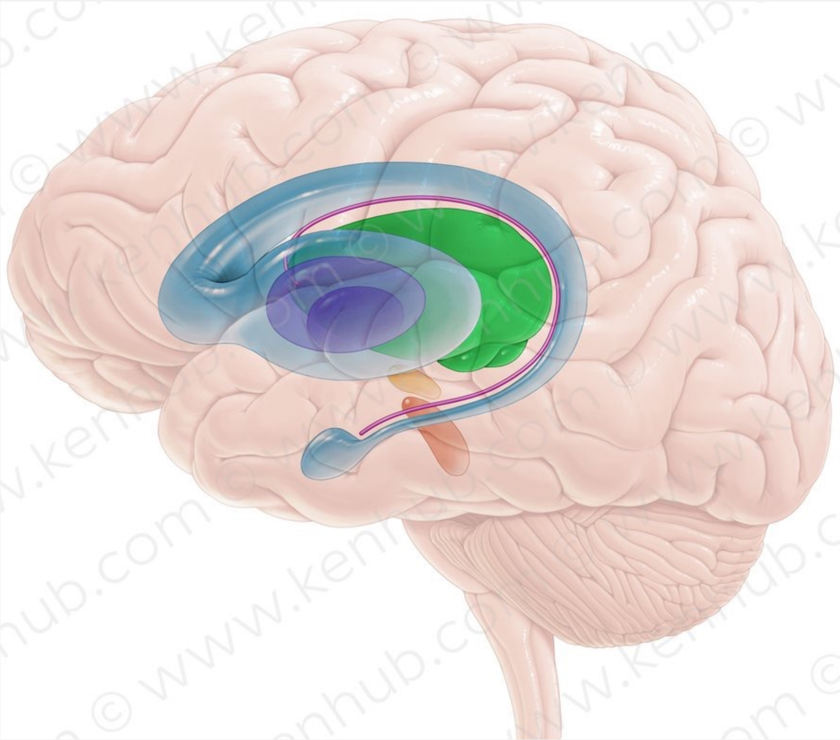
THE DIENCEPHALON

THE DIENCEPHALON

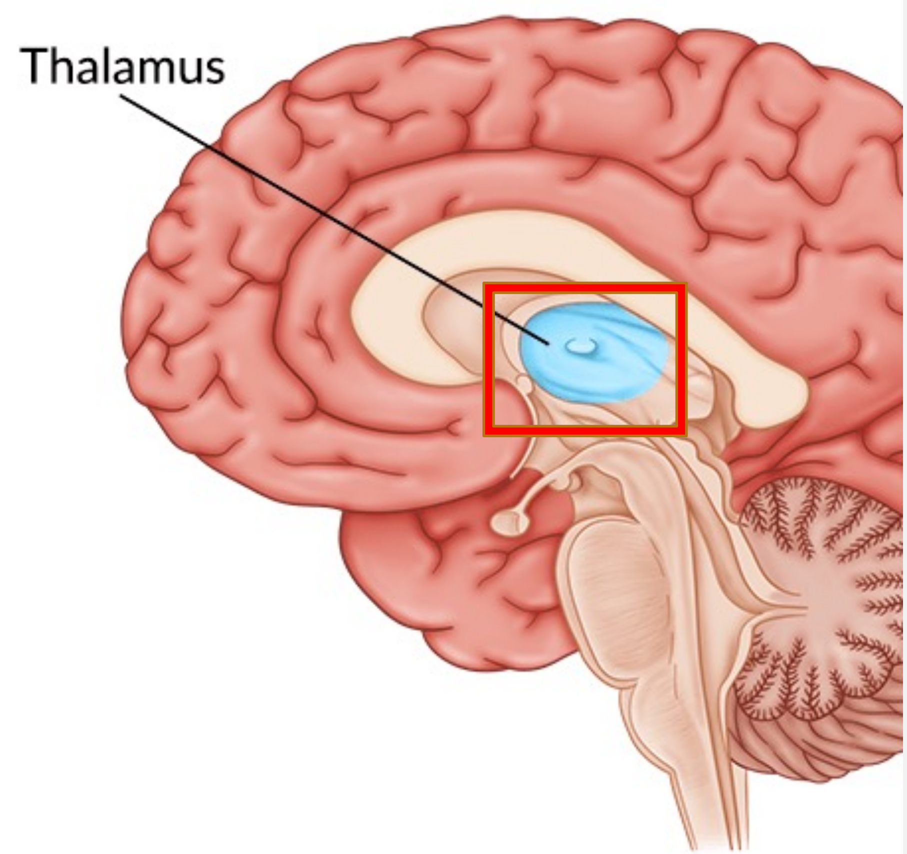
- The diencephalons is centrally located and is surrounded by the cerebral hemispheres.
- It includes the:
  - Thalamus
  - Hypothalamus
  - Epithalamus.



THE DIENCEPHALON

The Thalamus:

- 80 percent of the diencephalons
- consists of two oval masses of Gray matter that serve as **relay stations for sensory impulses** going to the cerebral cortex, except for the sense of smell.

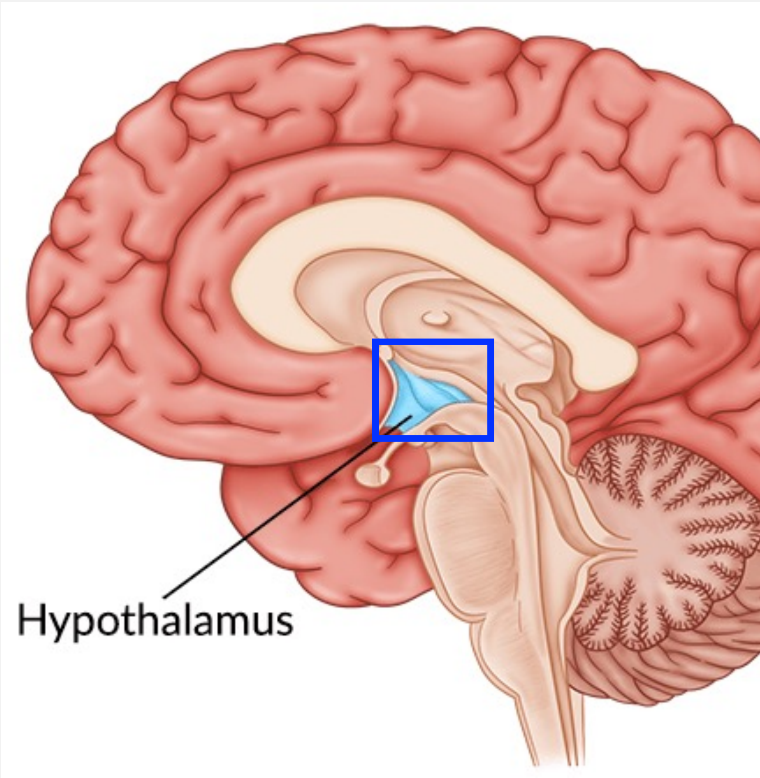


THE DIENCEPHALON

The Hypothalamus:

- Small region below the thalamus, which plays a key role in maintaining homeostasis because it is the link between the endocrine and nervous systems

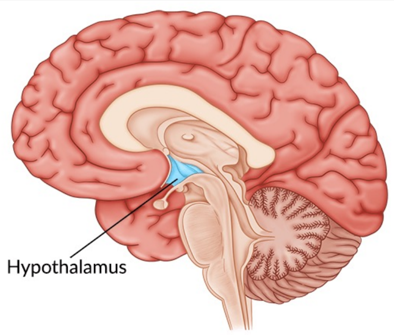
- The hypothalamus produces releasing and inhibiting hormones, which stop and start the production of other hormones in the body



THE DIENCEPHALON

The Hypothalamus:

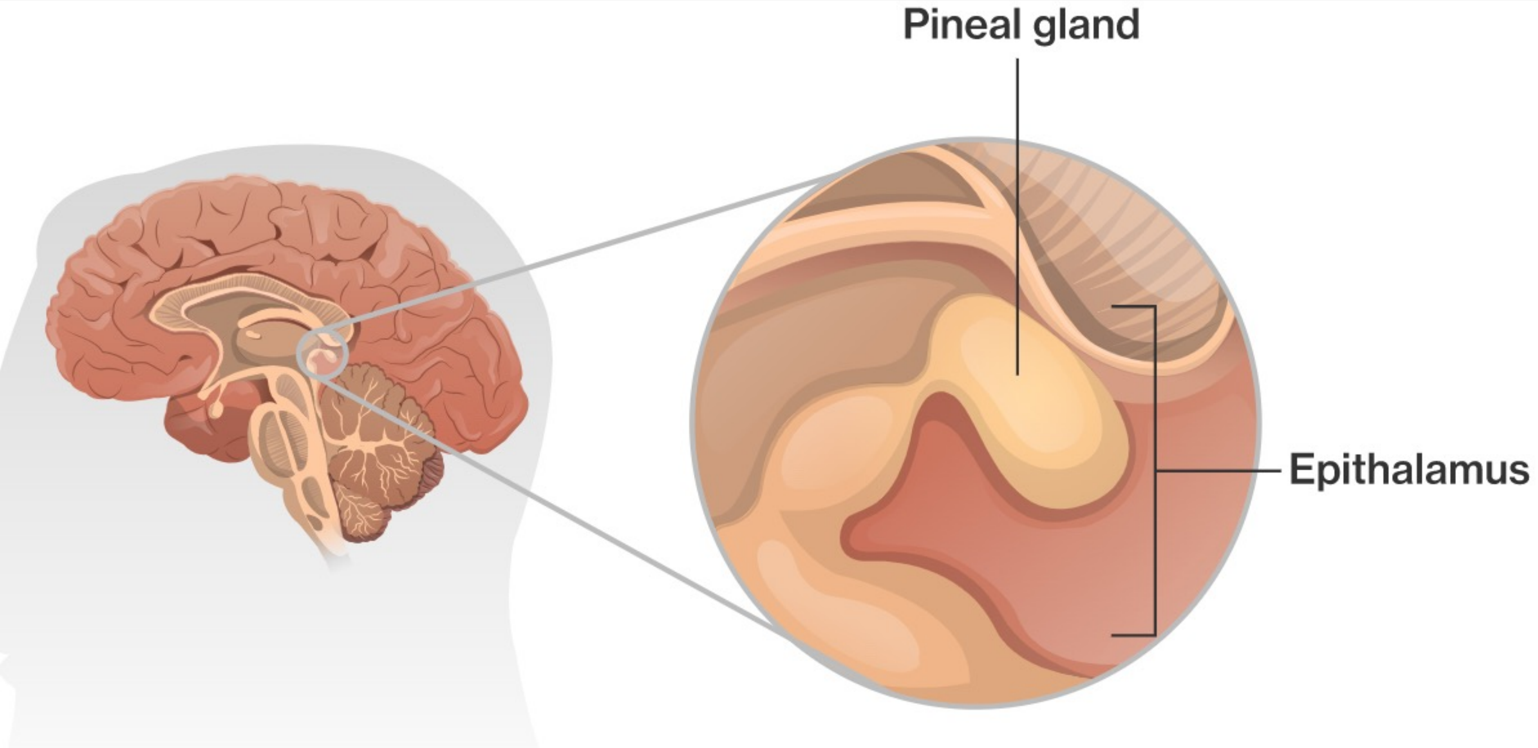
- Secretes hormones:
  - Antidiuretic hormone (ADH) by supraoptic nucleus
  - Oxytocin (OT) by paraventricular nucleus
- Produces emotions and behavioural drives:
  - the feeding centre (hunger) the thirst centre (thirst)



THE DIENCEPHALON

The Epithalamus

- The most dorsal portion of the diencephalons.



THE DIENCEPHALON

The Epithalamus

- This gland (pineal gland) is involved with the onset of puberty and rhythmic cycles in the body.
- also called conarium/epiphysis cerebri/pineal organ/ pineal body/ endocrine gland found in vertebrates that is the source of **melatonin,** a hormone derived from tryptophan that plays a central role in the **regulation of circadian rhythm** (the roughly 24-hour cycle of biological activities associated with natural periods of light and darkness).
- Responds to light and dark and secretes melatonin, which regulates circadian rhythms and the sleep-wake cycle
- Serves as a biological clock.

Divisions of the brain:

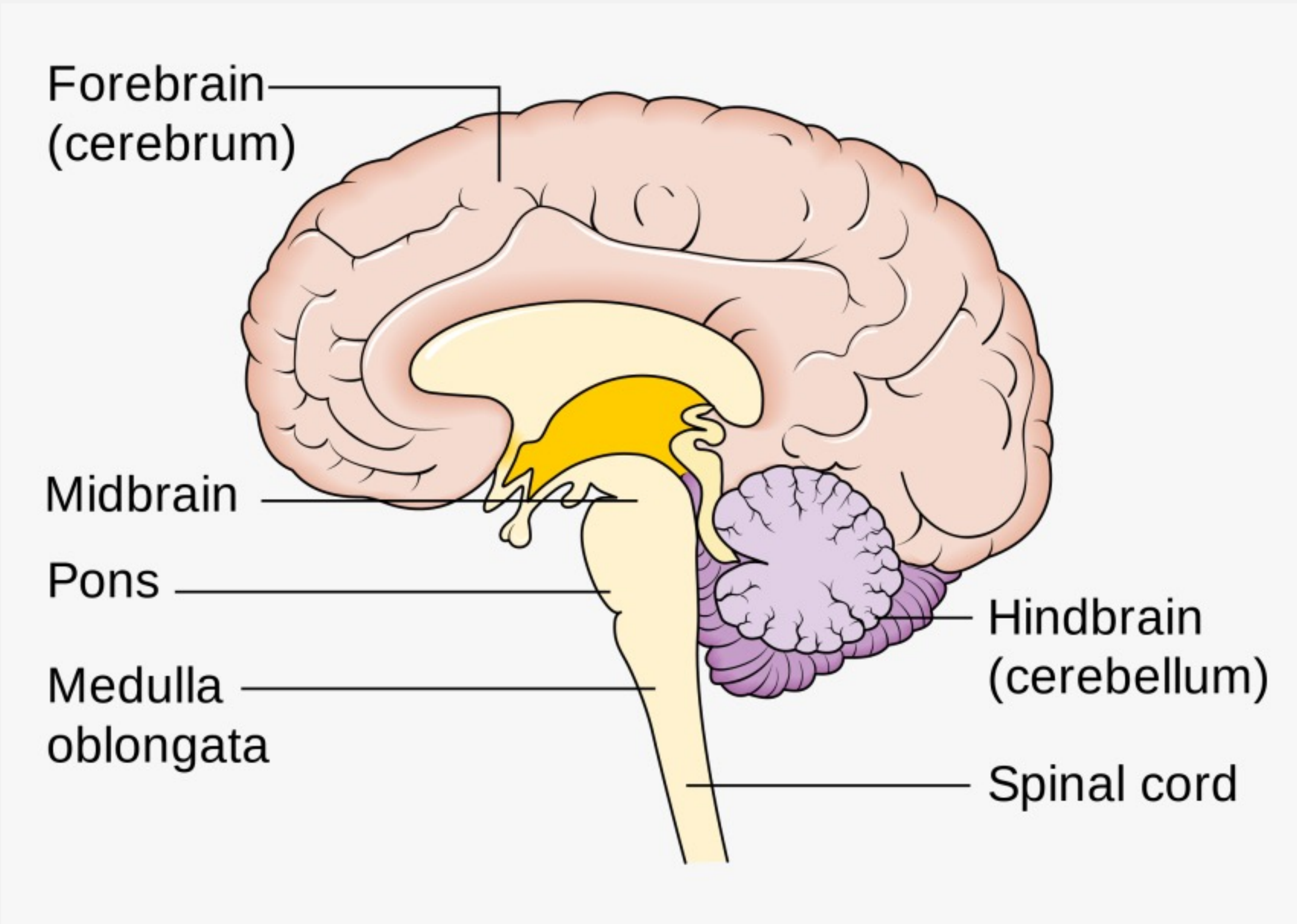
- Cerebrum
- Diencephalon
- Brain stem
- Cerebellum

BRAIN STEM

- The brain stem is the region between the diencephalons and the spinal cord.

- It consists of three parts:
  - Midbrain,
  - Pons
  - Medulla oblongata.

BRAIN STEM



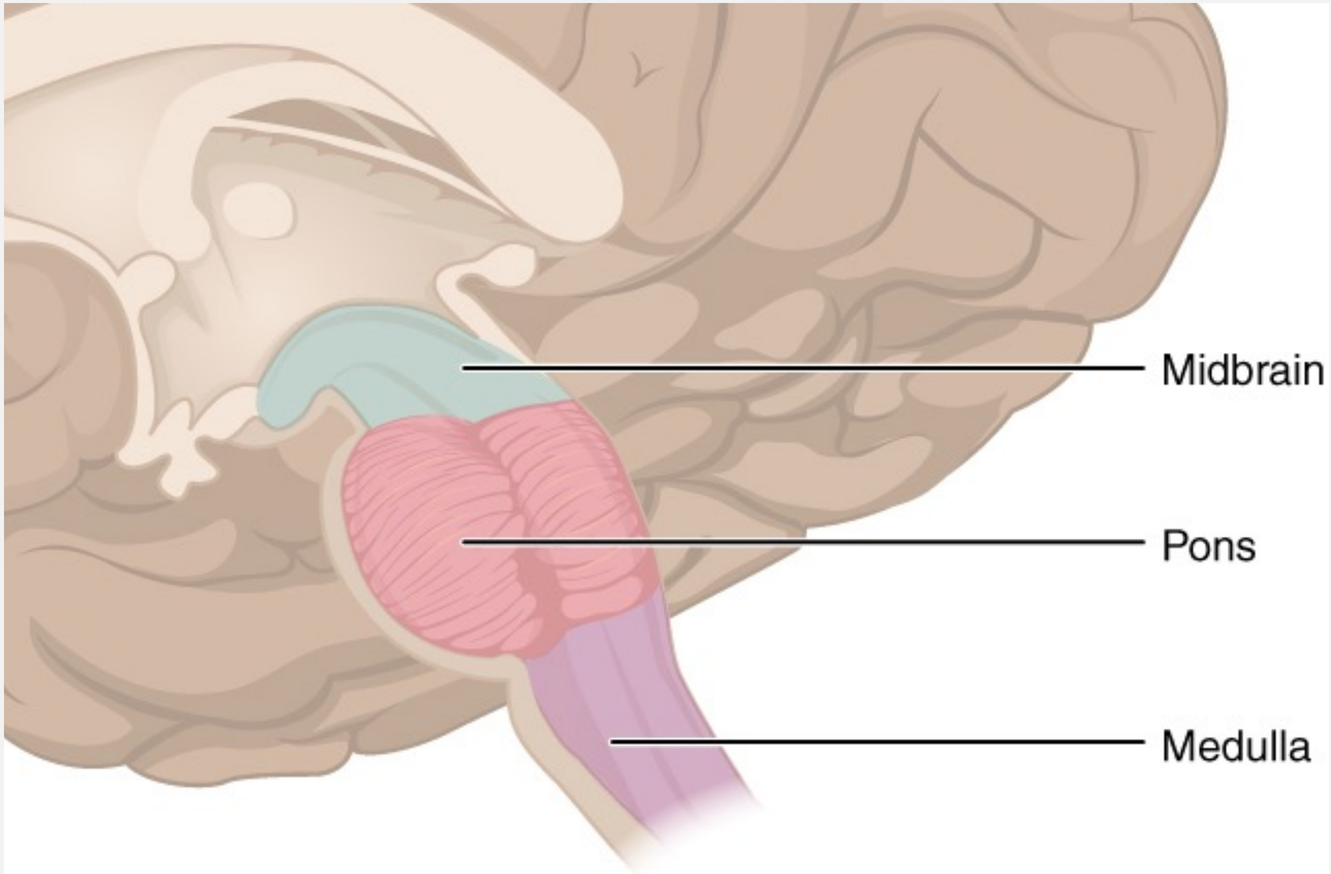
Forebrain
(cerebrum)
Midbrain
Pons
Medulla
oblongata
Hindbrain
(cerebellum)
Spinal cord

BRAIN STEM

The midbrain (mesencephalon)

- Most superior portion of the brain stem.
- Functions in processing information related to auditory and visual processing:
  - controlling the pupil and most eye movements,
  - movement, pain and temperature sensation, sleep and arousal, autonomic function
  - behavioural responses to fear and anxiety,
  - consciousness, sleep-wake cycle and coordination of certain movements

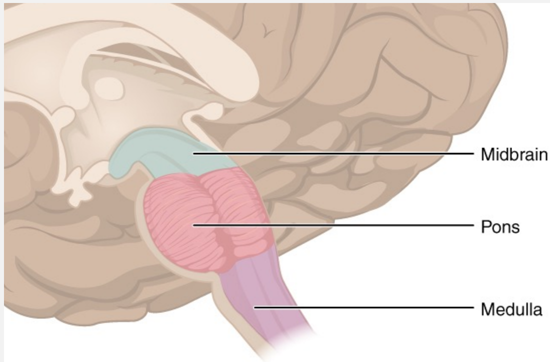
BRAIN STEM



BRAIN STEM

The pons

- The bulging middle portion of the brain stem.
- Region primarily consists of nerve fibres that form conduction tracts between the higher brain centres and spinal cord.
- Functions in generating **the respiratory rhythm of breathing** and fundamental to rapid eye movement (REM) sleep.



BRAIN STEM

The **Medulla oblongata**, or simply medulla,

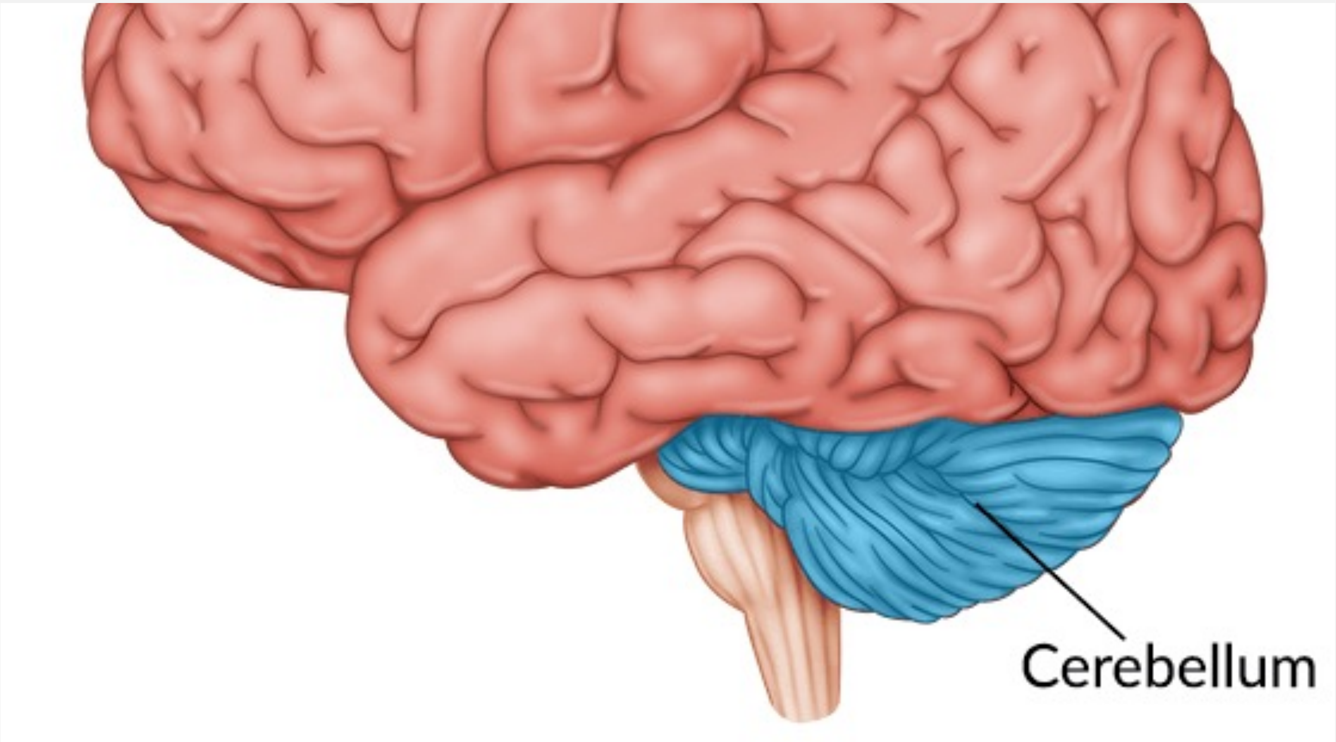
- Extends inferiorly from the pons.
- It is continuous with the spinal cord
- All the ascending (sensory) and descending (motor) nerve fibres connecting the brain and spinal cord pass through the medulla.
- Functions in autonomic nervous system, which allows for unconscious bodily **functions:** contains the cardiac, respiratory, digestion,
  - Reflexes: vomiting, sneezing, coughing and vasomotor centres,

Divisions of the brain:

- Cerebrum
- Diencephalon
- Brain stem
- Cerebellum

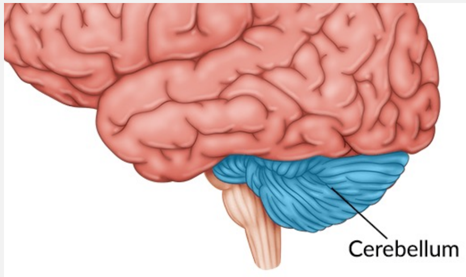
CEREBELLUM

- The cerebellum, the second largest portion of the brain, is located below the occipital lobes of the cerebrum.
-

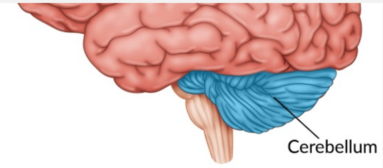


CEREBELLUM

- Three paired bundles of myelinated nerve fibres, called **cerebellar peduncles**, form communication pathways between the cerebellum and other parts of the central nervous system.
- Contains over 50% of the total number of neurons in the brain
  - Adjusts postural muscles
  - Fine-tunes conscious and subconscious movements

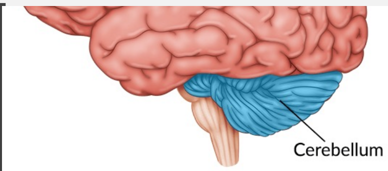


CEREBELLUM



- Functions for postural adjustments in order **to maintain balance**.
- Through its input from vestibular receptors and proprioceptors, it modulates commands to motor neurons to compensate for shifts in body position or changes in load upon muscles.

CEREBELLUM

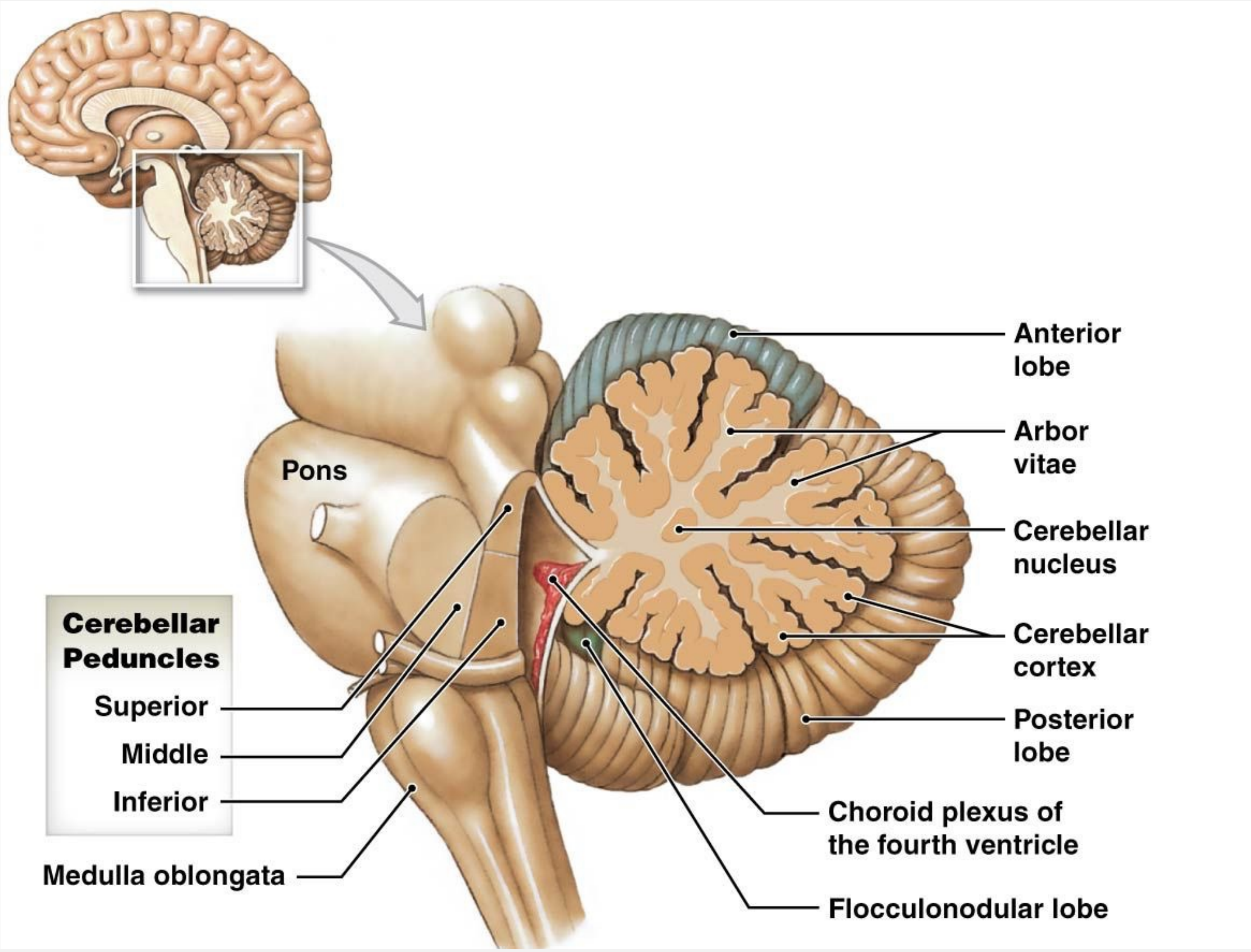


- **Balance and posture:** Your cerebellum works with sensory input from your eyes and ears to keep you upright and steady.
- **Motor learning:** This involves the learning and fine-tuning of various movements.
  - Example: specific, precise movements used for writing or for riding a bicycle.
- **Speech:** The cerebellum is also involved in the movements associated with speaking.

CEREBELLUM

- There are **two major components of the cerebellum**:
- **Cerebellar cortex:** This is a layer of thin, heavily folded tissue that contains most of the nerve cells in the cerebellum.
  - Contain Large, branched cells *(Purkinje Cells)*
- **Cerebellar nuclei:** Found deep within the cerebellum**,** the nerve cells of the cerebellar nuclei are primarily involved in sending information from the cerebellum
- **Cerebellar peduncles** connect the cerebellum to the brain stem

CEREBELLUM



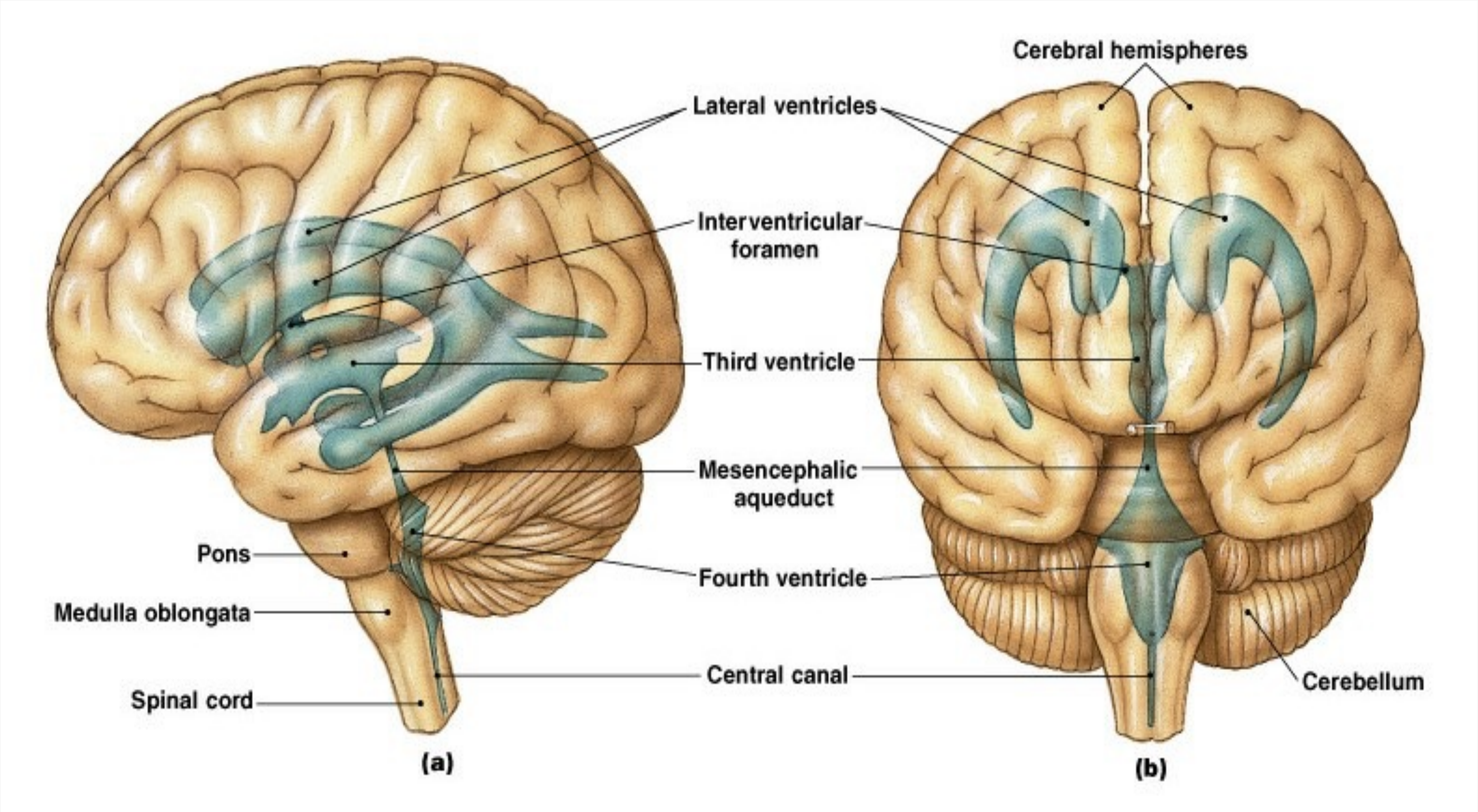
Anterior lobe
Arbor vitae
Pons
Cerebellar nucleus
Cerebellar Peduncles
Superior
Middle
Inferior
Cerebellar cortex
Posterior lobe
Choroid plexus of the fourth ventricle
Medulla oblongata
Flocculonodular lobe

BRAIN VENTRICLES

- Within the cerebrum and brain stem are interconnected cavities called **Ventricles** transport CSF around the cranial cavity

- ***Choroid plexuses*** located in the ventricles produce CSF, which fills the ventricles and subarachnoid space
  - ✓ cycle of constant production and reabsorption.
- There are four ventricles

BRAIN VENTRICLES



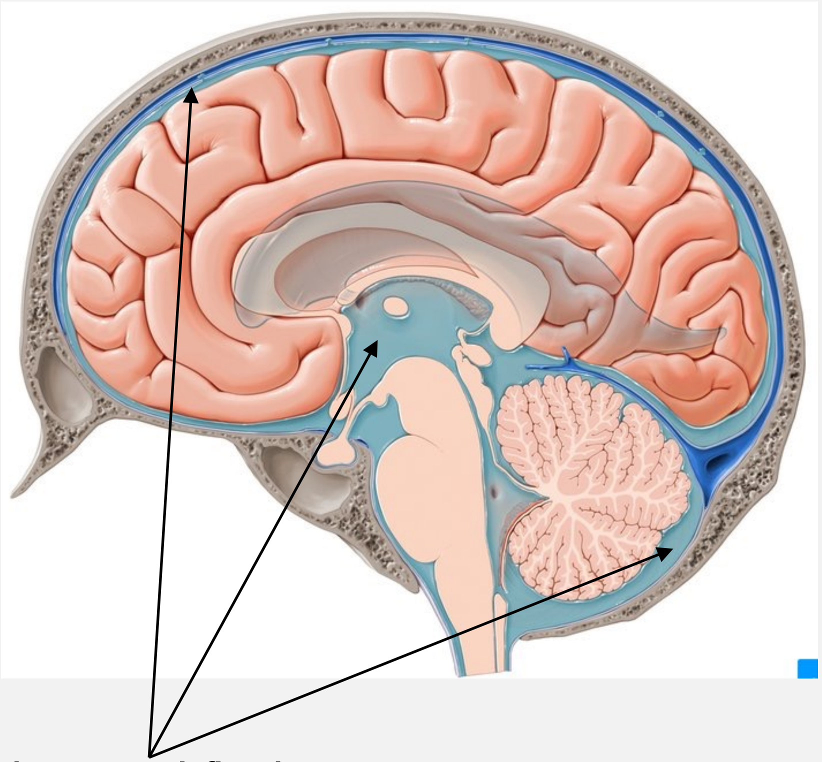
BRAIN PROTECTION AND SUPPORT

- Physical protection:
  - bones of the cranium
  - cranial meninges
  - cerebrospinal fluid

- Biochemical isolation:
  - blood–brain barrier

CEREBROSPINAL FLUID

- Cerebrospinal fluid (CSF), clear, colourless liquid (ultrafiltrate of plasma) that fills and surrounds the brain and the spinal cord and provides a mechanical barrier against shock



Cerebrospinal fluid

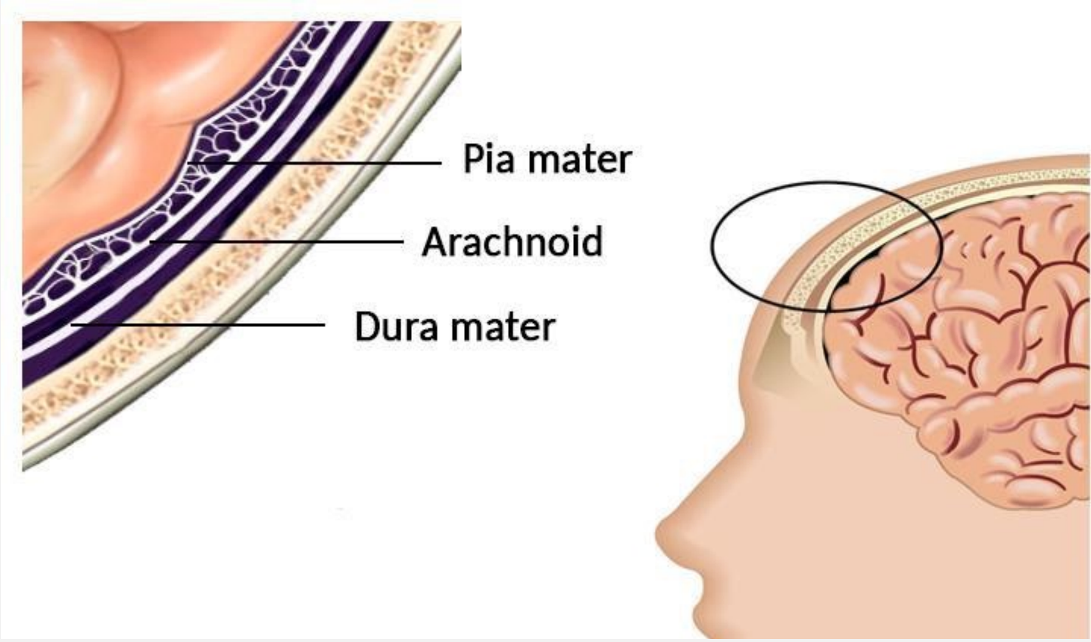
CEREBROSPINAL FLUID

- *Supports* the brain and provides *lubrication* between surrounding bones and the brain / spinal cord

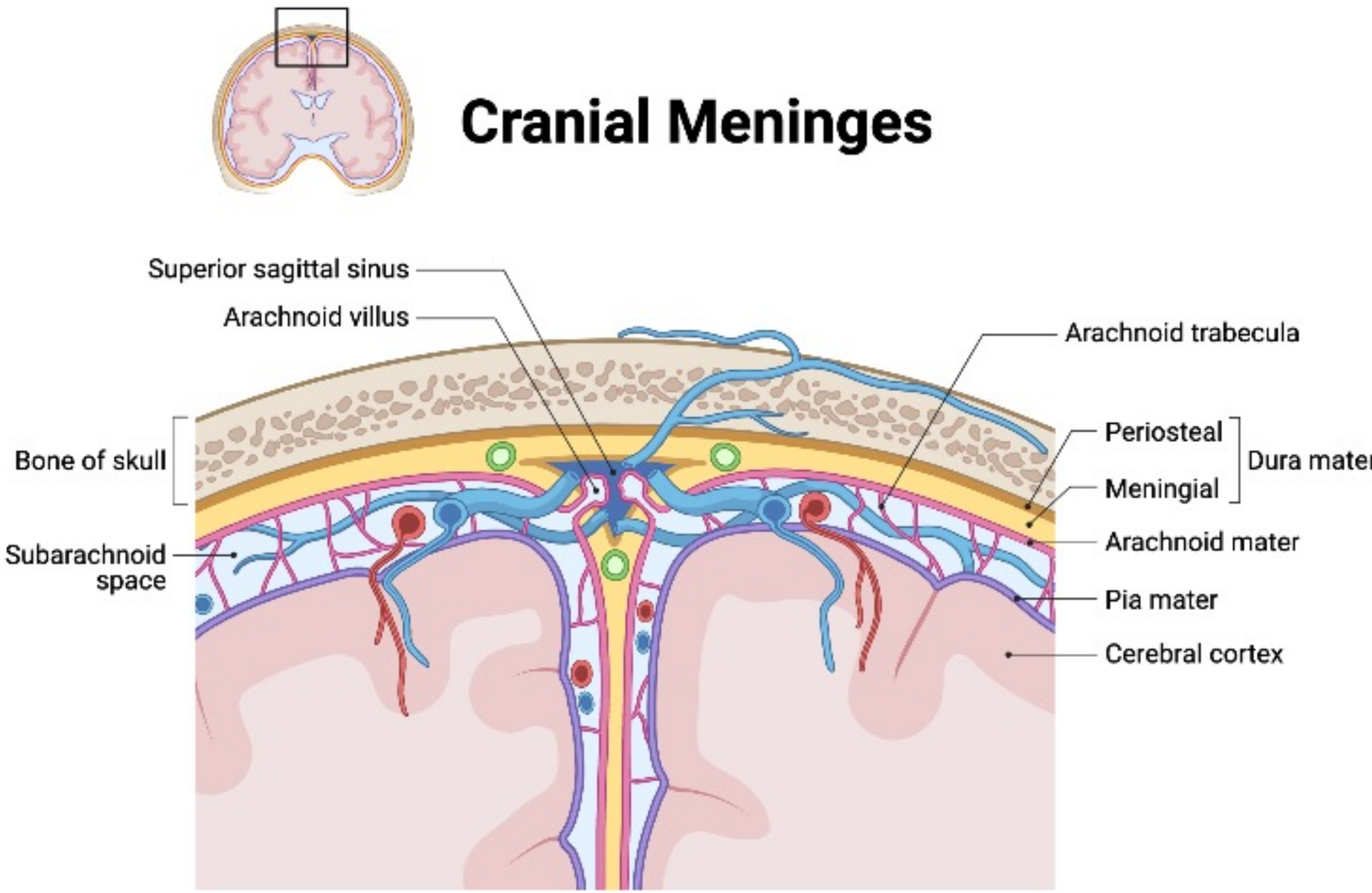
- *Transports* metabolic waste products, antibodies, chemicals, and pathological products of disease away from the brain and spinal-cord tissue into the bloodstream

CRANIAL MENINGES

- The brain and spinal cord are enclosed with the meninges which consist of three protective layers:
  - the dura mater
  - the arachnoid mater and
  - the pia mater



CRANIAL MENINGES



CRANIAL MENINGES

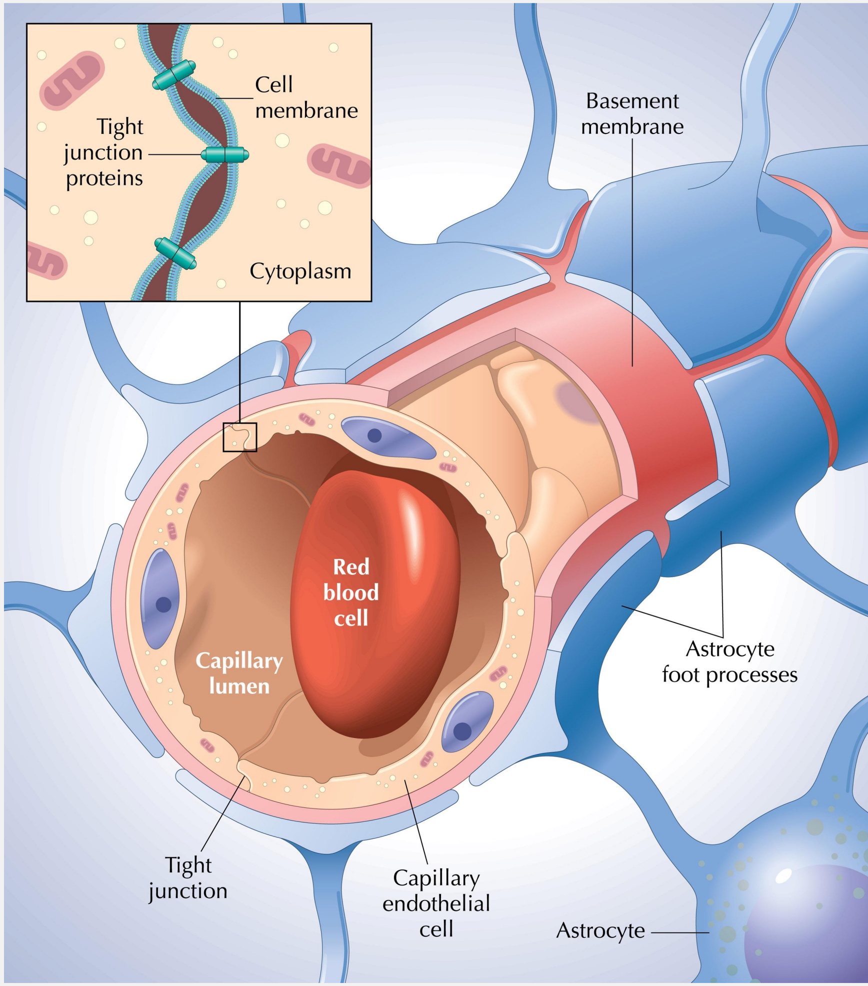
- They envelope the brain and spinal cord and separate them from the walls of their bony cases (skull and vertebral column)
- Function to protect the brain but also provide a framework for blood vessels, nerves, lymphatics and cerebrospinal fluid (CSF)

BLOOD–BRAIN BARRIER

- The brain has a large network of arterial and venous vessels taking blood to and from (respectively) brain tissue
- Formed by **network of tight junctions** between endothelial cells of CNS capillaries and the end feet processes of ***astrocytes***
- It is permeable to **glucose** and **fat soluble** drugs
- Lipid–soluble compounds (O_2, CO_2), steroids, and prostaglandins diffuse into interstitial fluid of brain and spinal cord

BLOOD–BRAIN BARRIER

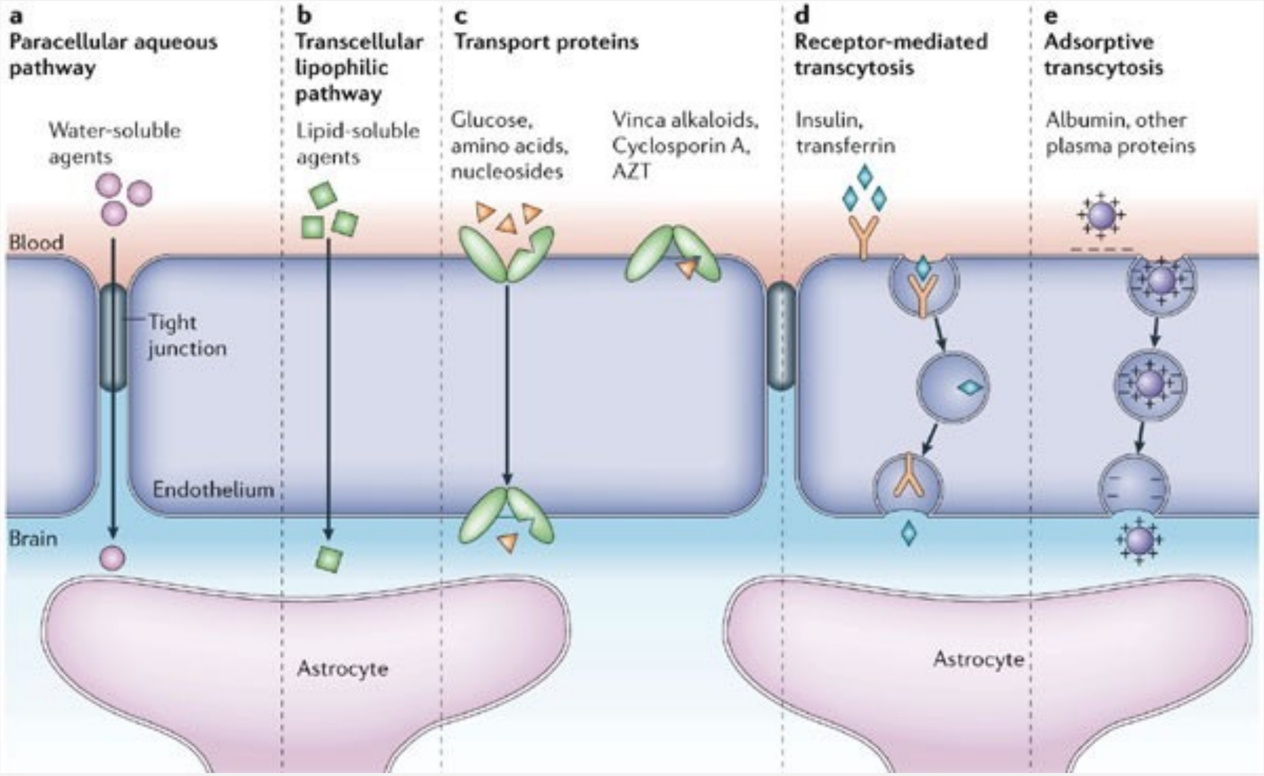
- ***Astrocytes:***
  - Astrocytes occupy a strategic position between capillaries and neurons.
  - They form perivascular endfeet at the BBB and regulate *ionic*, *amino acid*, *neurotransmitter* and water homeostasis of the brain.

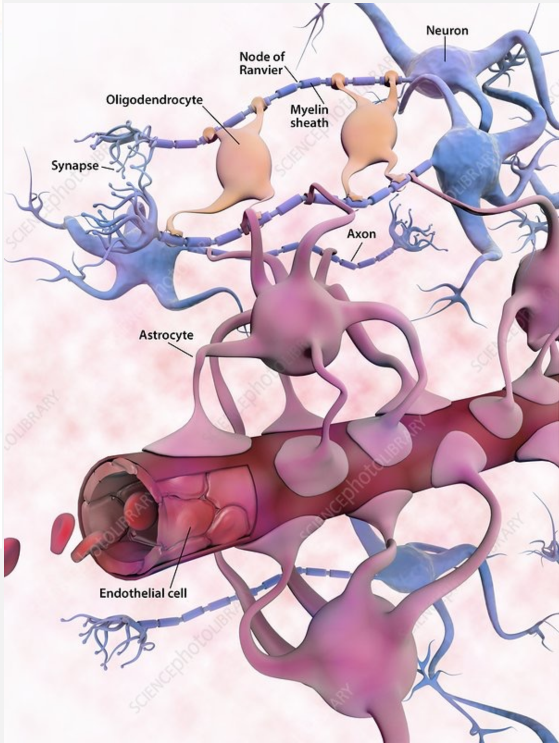


BLOOD–BRAIN BARRIER

- Control blood–brain barrier by releasing chemicals that control permeability of endothelium
- Eg. opening of the BBB's tight junctions under normal conditions allow the passage of growth factors and antibodies into the brain,
- ➢ inflammation can contribute to brain oedema

BLOOD–BRAIN BARRIER



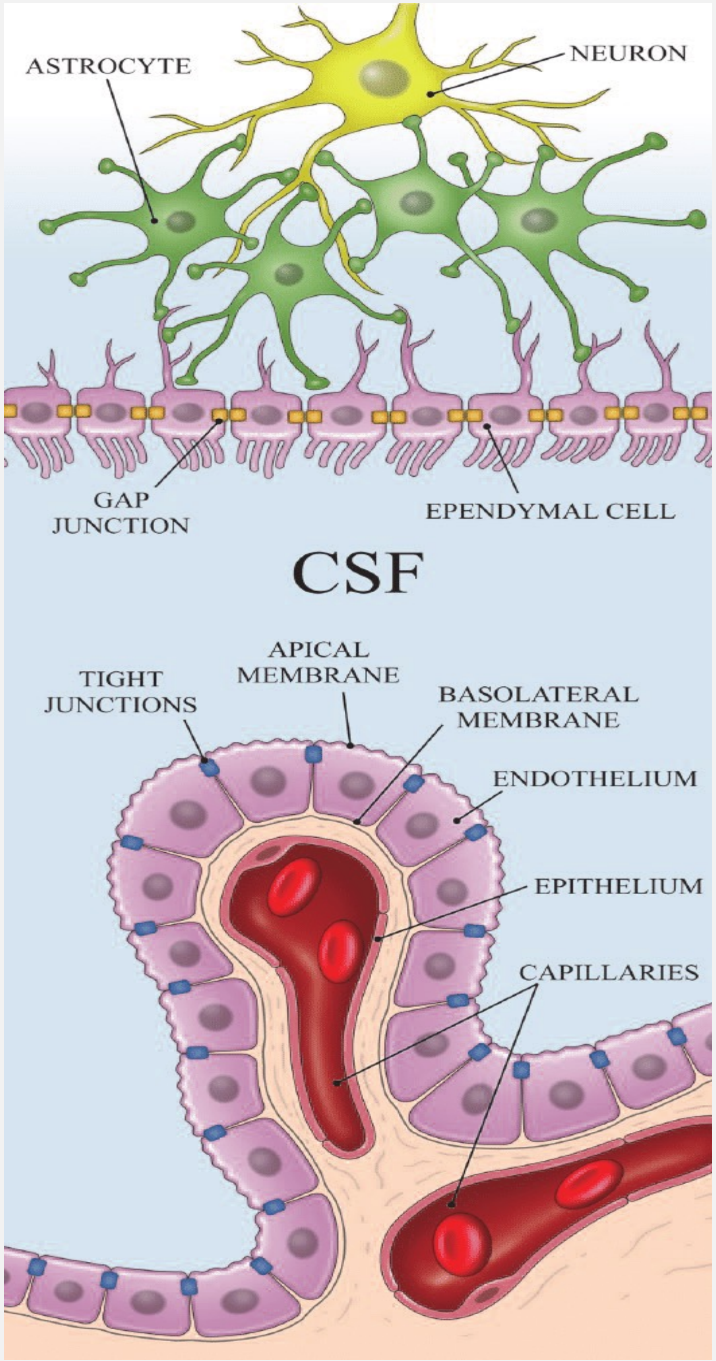


BLOOD–CSF BARRIER

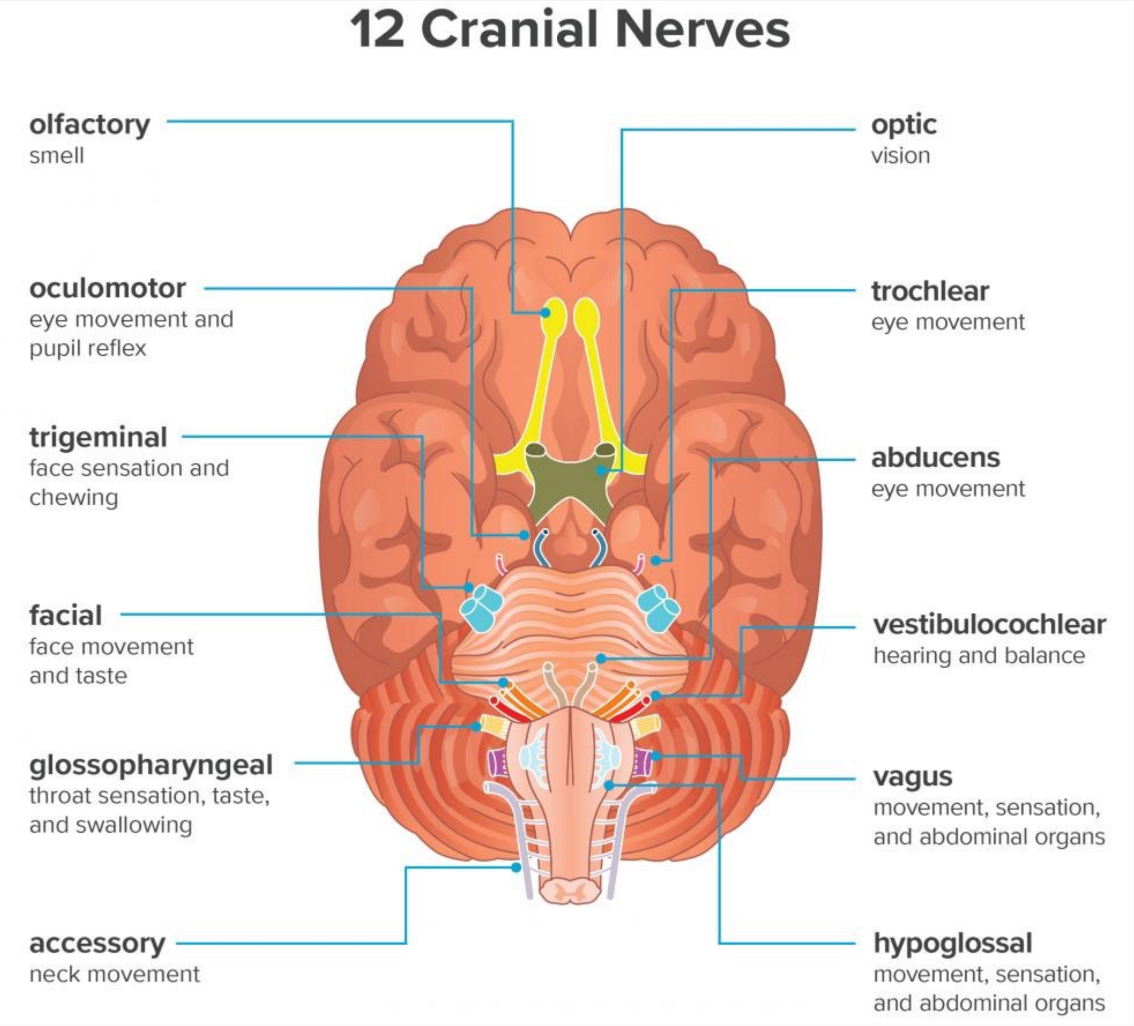
- The blood-cerebrospinal fluid barrier has fenestrated endothelial cells which allow easier passage of water, gases and lipophilic substances from the blood to the cerebrospinal fluid.
- There are choroidal epithelial cells that are integral to the production of cerebrospinal fluid.

BLOOD–CSF BARRIER

- Contains more tight junctions, act as an effective barrier between blood and cerebrospinal fluid.



CRANIAL NERVES

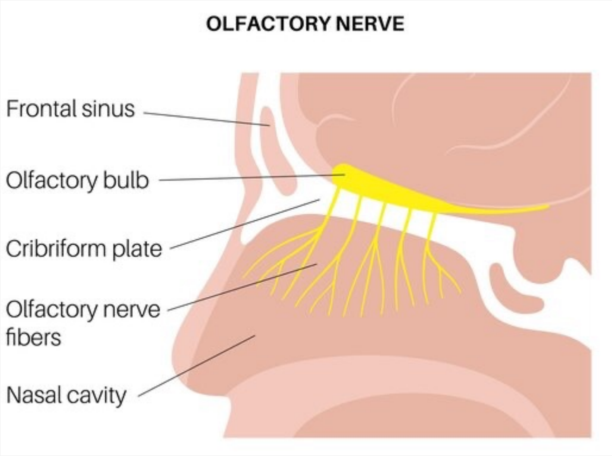


CRANIAL NERVES

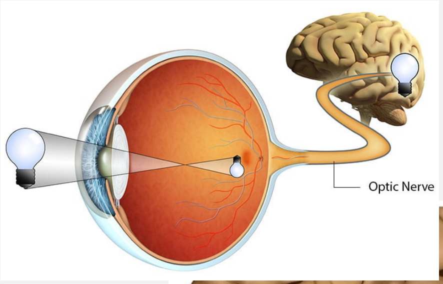
- Each of the 12 cranial nerve groups is identified by:
  - primary function
  - origin
  - pathway
  - destination

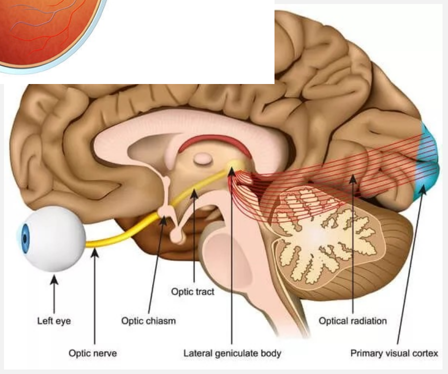
CRANIAL NERVES

- **I. Olfactory nerve:** contains sensory nerve fibres that transmits information to the brain relating to the *sense of smell*
- The olfactory tract travels to the **frontal lobe** and other areas of the brain that are involved with memory and identification of different smells



- **II. Optic nerve:** transmits information to the brain **(occipital lobe)** regarding a person's vision.
- Light to the eye hits the retina, which contains rods and cones. Photoreceptors send signals to brain o be integrated as *visual information*

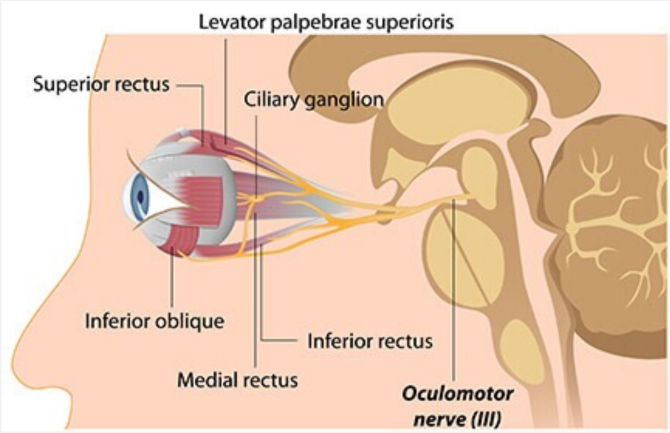




CRANIAL NERVES

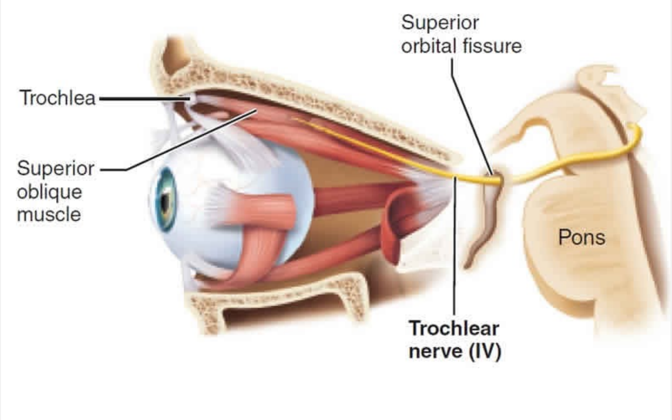
III. Oculomotor nerve: helps *control muscle* movements of the eyeball and upper eyelid, known as *extraocular muscles*.

- *involuntary functions* of the eye, adjust to short range and long range vision as well lighting



IV. Trochlear nerve: involved in eye movement.

- It powers the *contralateral superior oblique muscle* that allows the eye to point downward and inward.

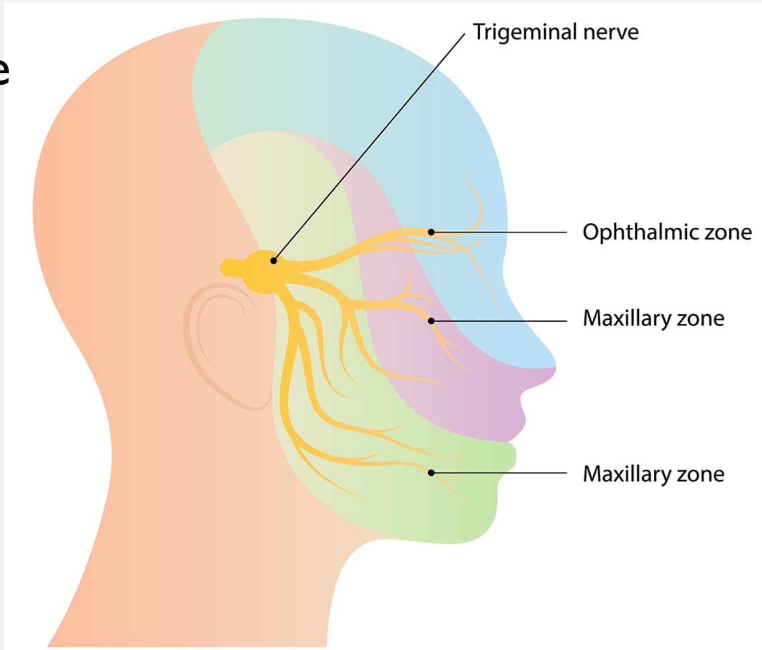


CRANIAL NERVES

V. Trigeminal nerve: the largest cranial nerve and has *both motor and sensory functions.*

- Motor functions help a person to *chew and clench the teeth* and gives sensation to muscles in the tympanic membrane of the ear

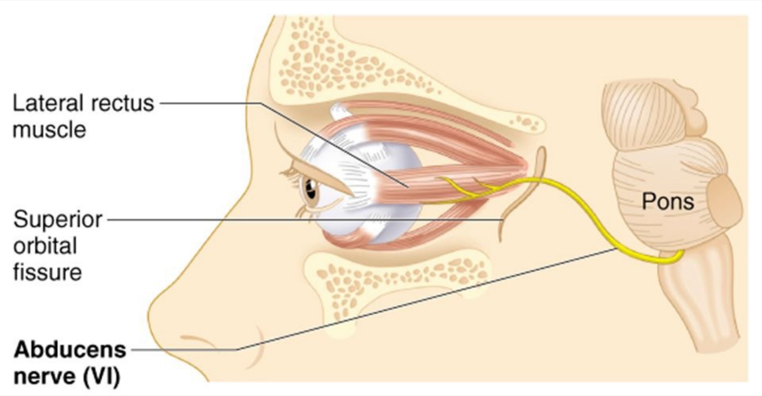
Sensory function:
Ophthalmic part gives sensation to parts of the *eyes; cornea, mucosa in the nose, and skin* on the nose, the eyelid, and the forehead.
Maxillary part gives sensation to the middle third of the face, *side of the nose, upper teeth, and lower eyelid.*
Mandibular part gives sensation to the lower third of the face, the *tongue, mucosa in the mouth, and lower teeth.*



CRANIAL NERVES

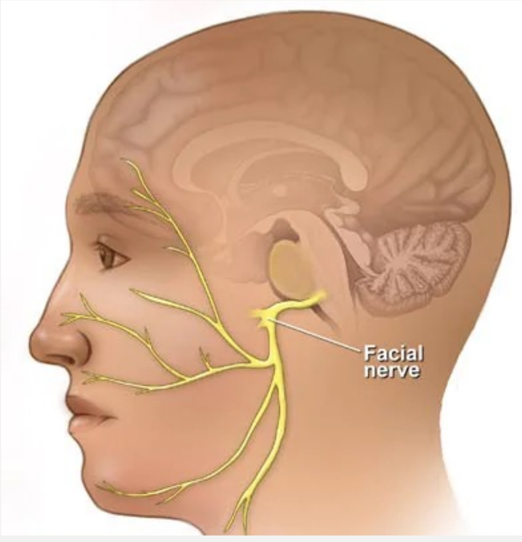
VI. Abducens nerve: helps *control eye movements*

- Helps the lateral rectus muscle, an extraocular muscles to turn the gaze outward.



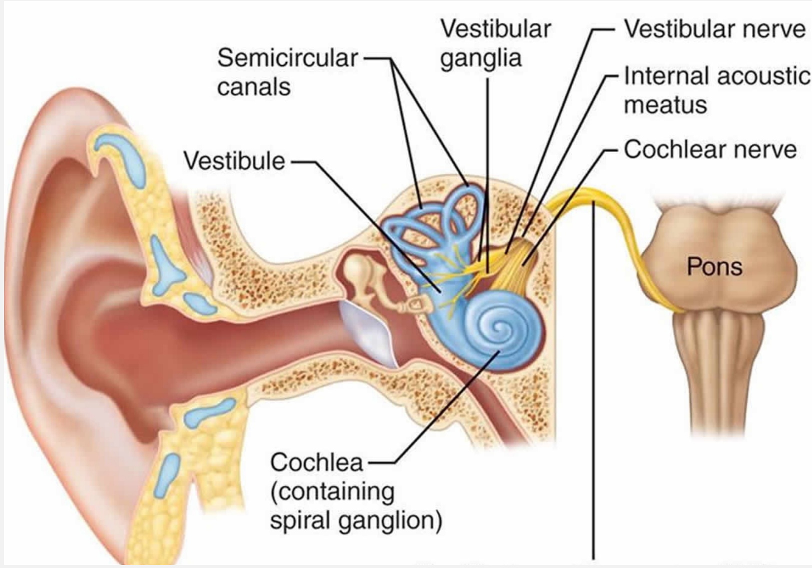
VII. Facial nerve; both motor and sensory functions

- movement of muscles that produce *facial expression*
- movement of the *lacrimal, submaxillary, and submandibular glands*
- the sensation of *taste and of external ear*



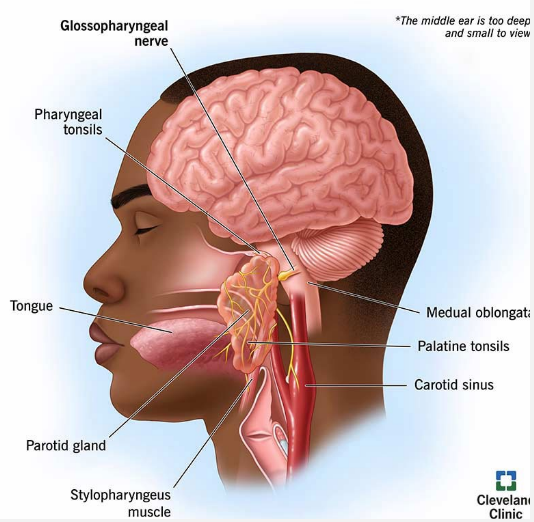
CRANIAL NERVES

- **VIII. Vestibulocochlear nerve:** vestibular nerve is for *maintaining body balance and eye movements*, while the cochlear nerve is for *hearing*
  - Determine the *frequency and magnitude of the sound*



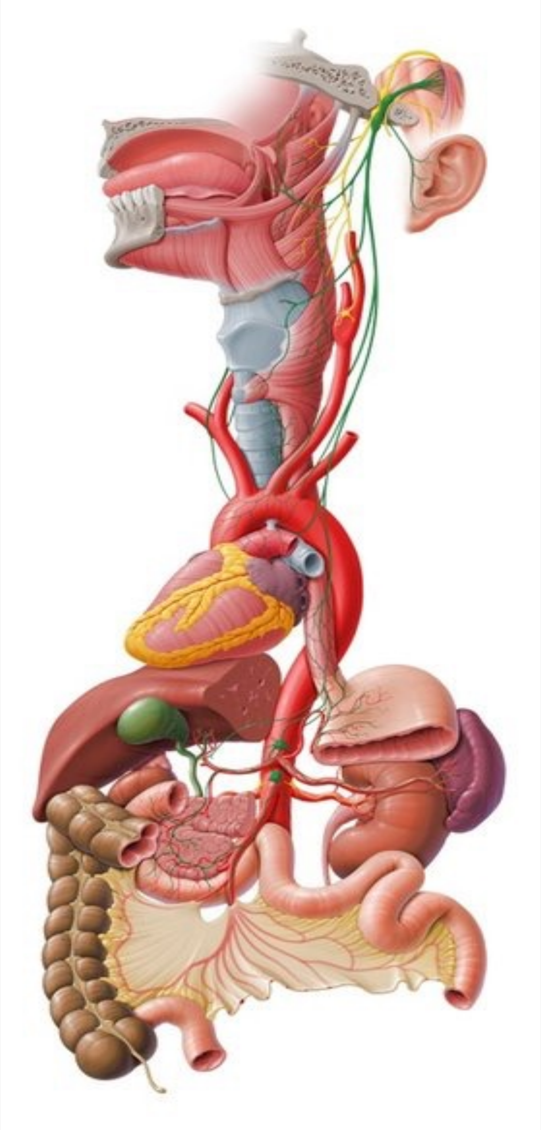
IX. Glossopharyngeal nerve

- provides motor, parasympathetic and sensory information
- receives information from the ***throat, tonsils, middle ear, and back of the tongue***
- provides movement to the ***stylopharyngeus***, *allows the throat to shorten and widen*



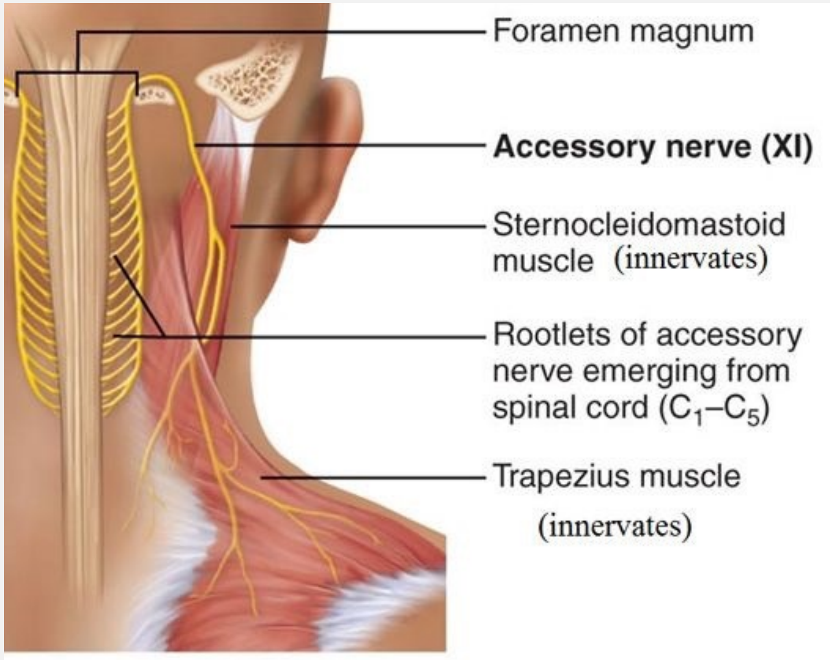
CRANIAL NERVES

- **X. Vagus nerve:** longest and most complex
- runs from the brain through the face and thorax to the abdomen
- provides movement to the throat and soft palate
- sensation to the outer part of the ear, the throat, the heart, abdominal organs
- regulates heart rhythm and innervates the smooth muscles in the airway, lungs, and gastrointestinal tract



CRANIAL NERVES

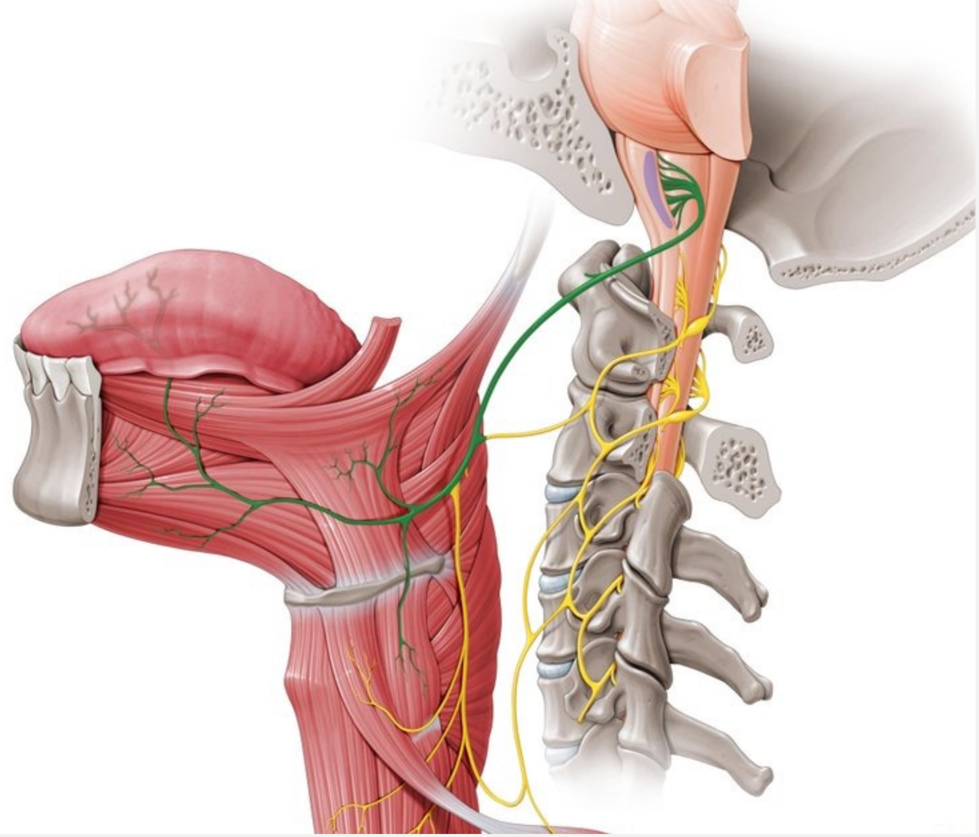
- **XI. Accessory nerve:** provides motor function to some muscles in the neck:
- It controls the ***sterno-cleido-mastoid*** and ***trapezius*** muscles that allow a person to *rotate, extend, and flex the neck and shoulders*



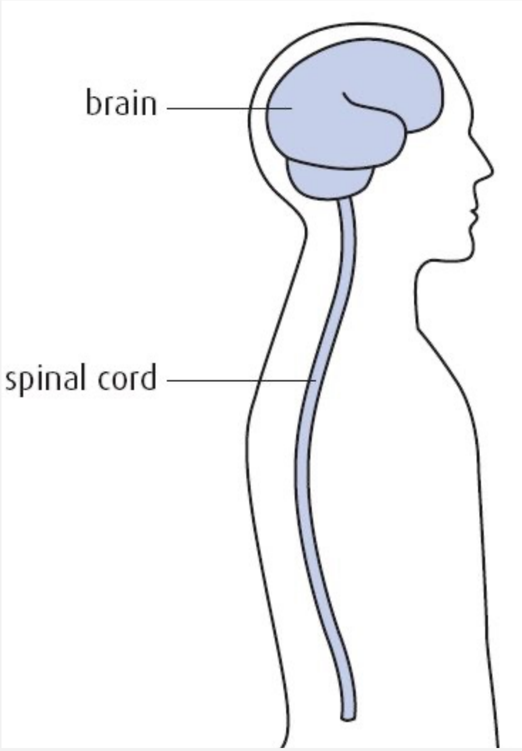
CRANIAL NERVES

XII. Hypoglossal nerve:
controls all tongue movements

- Originates from the medulla of the brain, through the neck, branches out, ending at the base and underside of the tongue

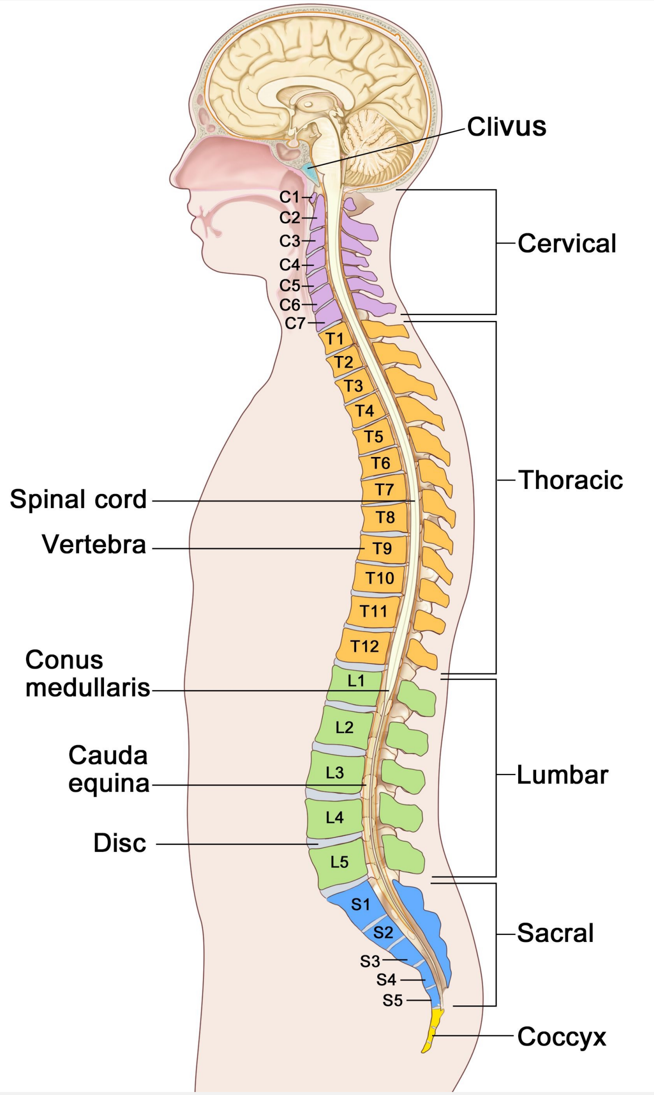


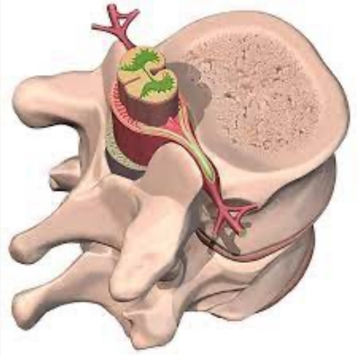
THE SPINAL CORD (CNS)



THE SPINAL CORD

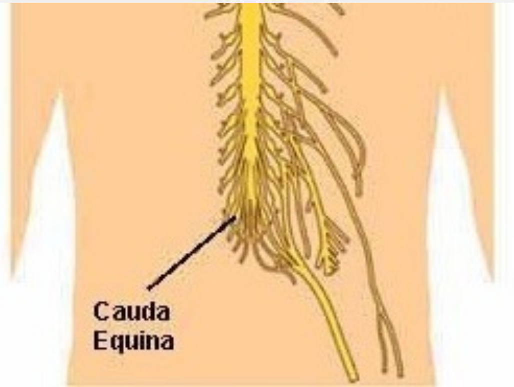
- The spinal cord is continuous with the medulla oblongata at the **foramen magnum.**
- The spinal cord is also surrounded by bone, meninges, and CSF.
- Cylindrical in shape and divided into 31 segments with each segment giving rise to a pair of spinal nerves.



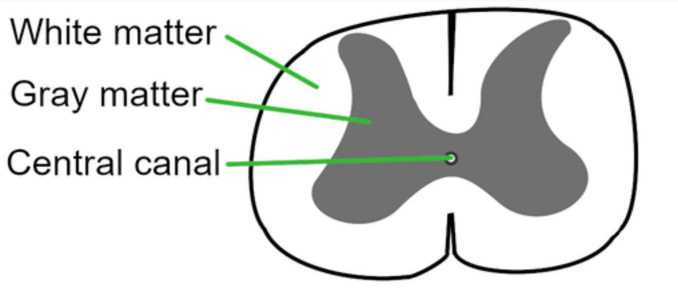


THE SPINAL CORD

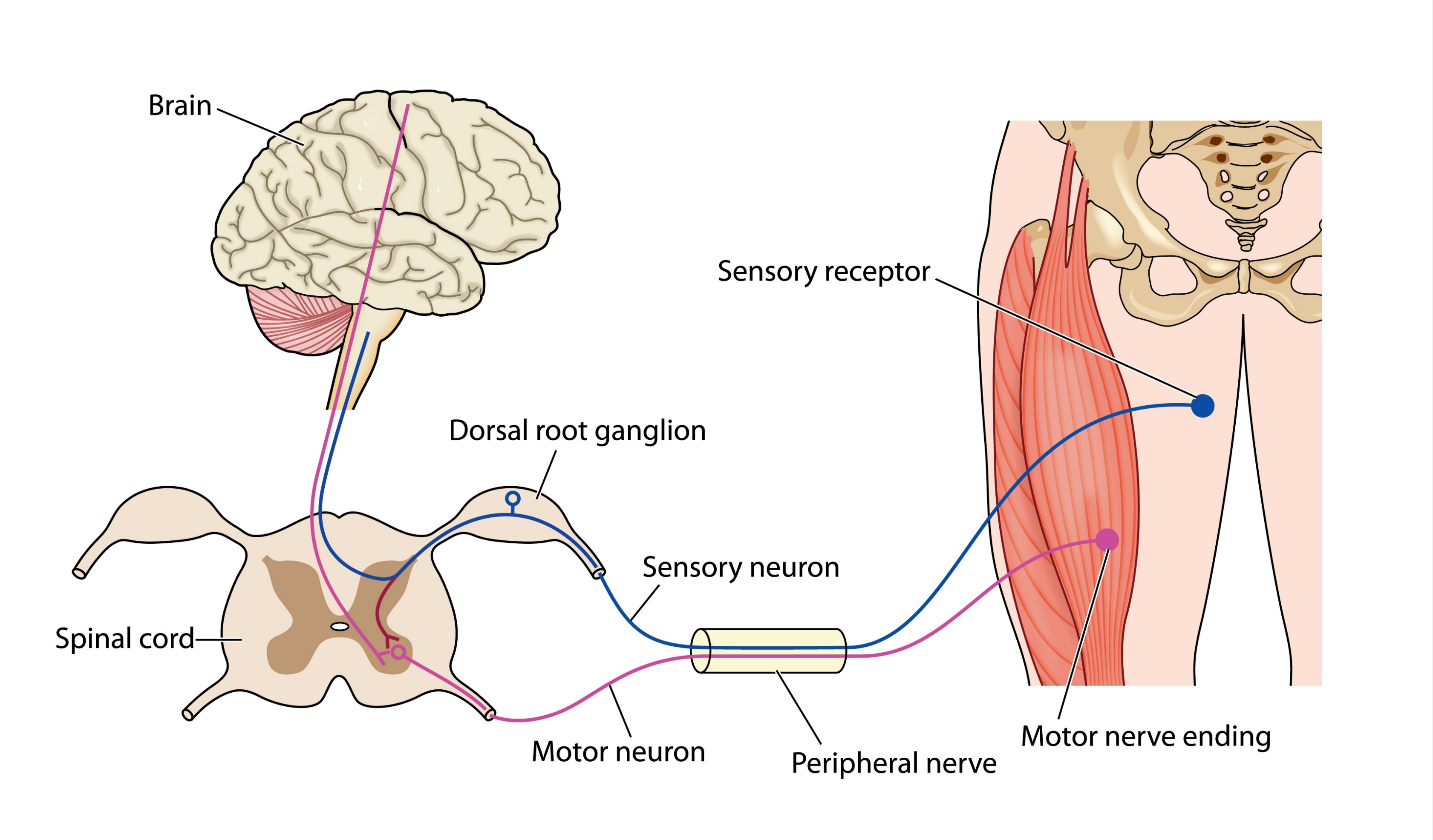
- At the distal end of the cord, many spinal nerves extend beyond the conus medullaris to form a collection(**cauda equina**).
- Transmit nerve signals from the motor cortex to the body, and from the afferent fibres of the sensory neurons to the sensory cortex.



- A cross section of the cord reveals that it consists of a core of grey matter within a white matter



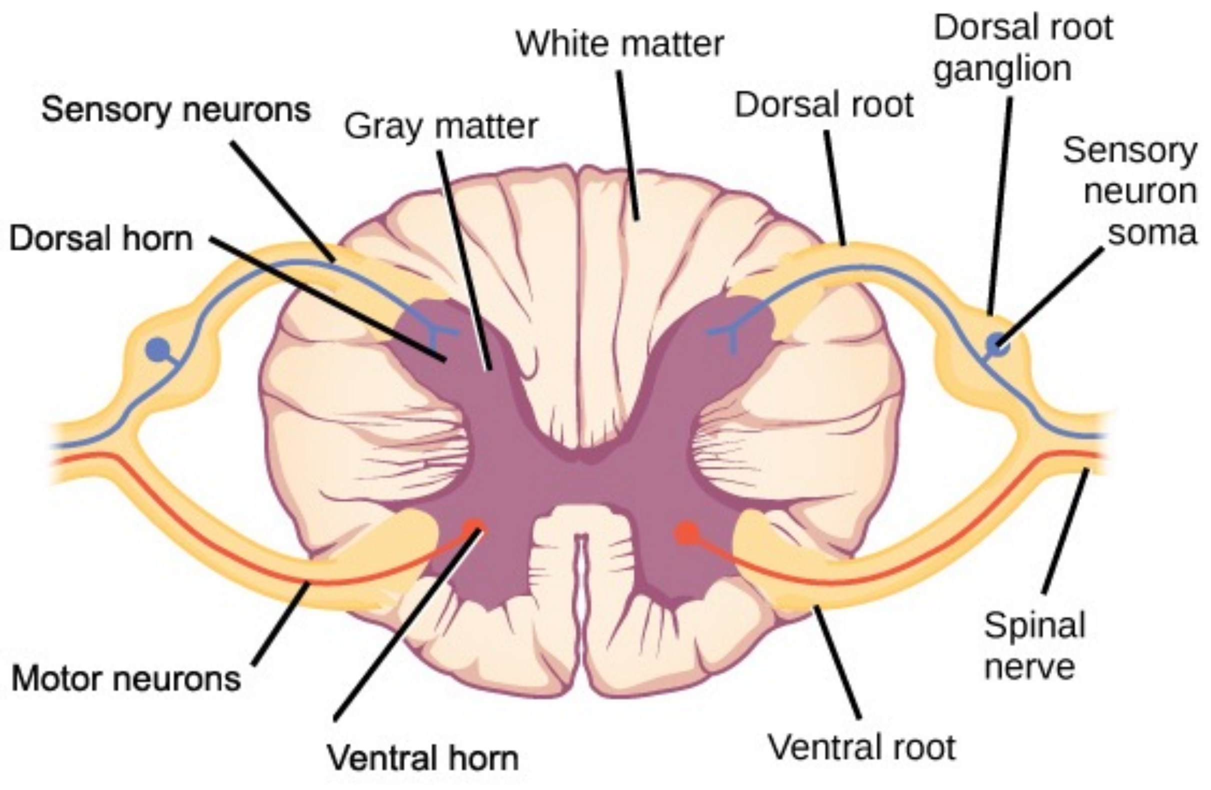
THE SPINAL CORD



THE SPINAL CORD

- Grey matter is shaped like the outstretched wings of a butterfly
- Upper and lower wings of grey matter are called the **posterior horns** and **anterior horns** respectively.
  - Anterior/ventral horns contain cell bodies of motor neurons.
  - Posterior/dorsal horns contain interneurons that receive impulses from sensory neurons.
- Majority of neurons in the grey matter of the spinal cord however are inter-neurons.

THE SPINAL CORD



Cross Section of Spinal Cord

THE SPINAL CORD

The spinal cord has two basic functions:

1. **It transmits impulses to and from the brain**
   - Serve as a conduction pathway
   - Sensory impulses travel to the brain on **ascending tracts** in the cord. Motor impulses travel on **descending tracts**.

THE SPINAL CORD

2. **It serves as a centre for spinal reflexes**

- Reflexes are responses to stimuli that do not require conscious thought and consequently, they occur more quickly than reactions that require thought processes.
- **The reflex arc** is the functional unit of the nervous system.
- Eg. *withdrawal reflex*; the reflex action withdraws the affected part before you are aware of the pain.
- Many reflexes are mediated in the spinal cord without going to the higher brain centres.

SPINAL CORD

The Meninges

- Specialized membranes isolate spinal cord from surroundings
- Functions:
  - protect spinal cord
  - carry blood supply
  - continuous with cranial meninges

SPINAL CORD

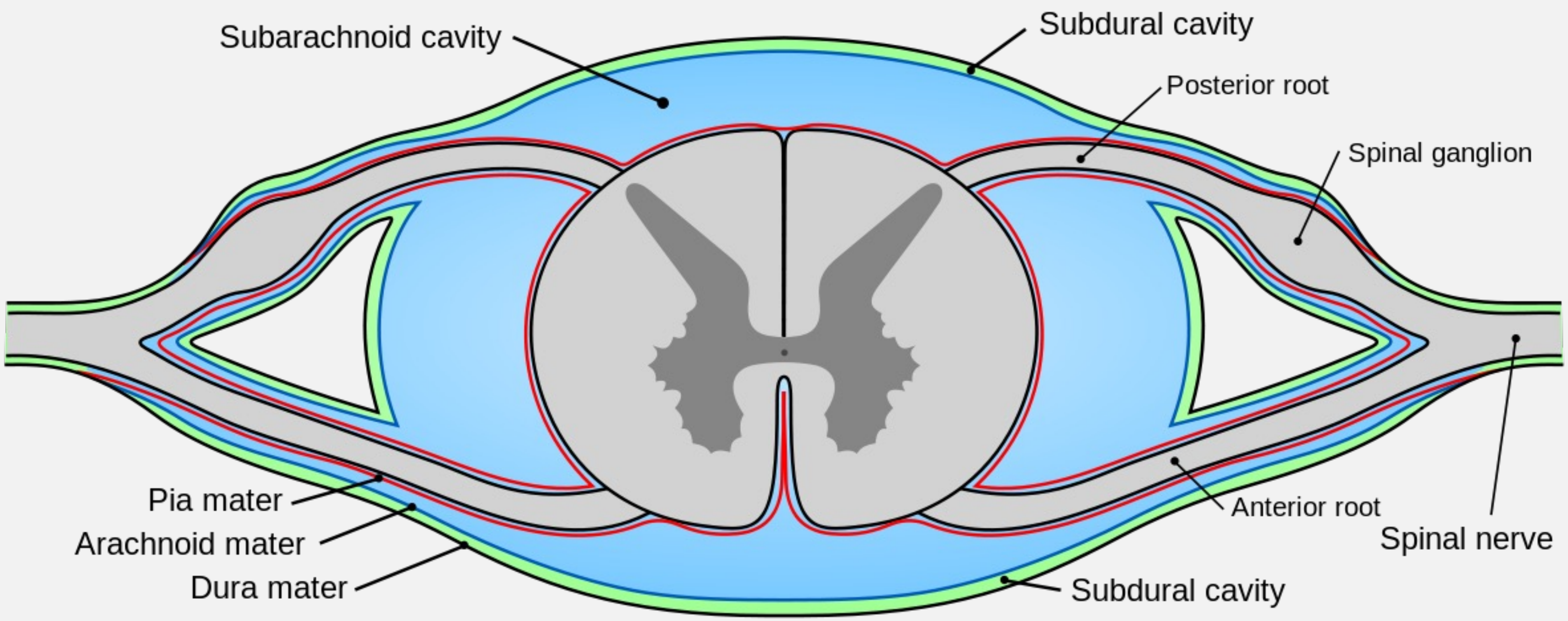
- Dura mater:

  outer layer of spinal cord
- Arachnoid mater:

  middle meningeal layer
- Pia mater:

  inner meningeal layer

SPINAL CORD



Subarachnoid cavity
Subdural cavity
Posterior root
Spinal ganglion
Pia mater
Arachnoid mater
Dura mater
Anterior root
Spinal nerve
Subdural cavity

SPINAL NERVES

SPINAL NERVES

- The spinal nerves emanate from the spinal cord as pairs of nerves composed of both sensory and motor fibres that function as the intermediary between the central nervous system (CNS) and the periphery

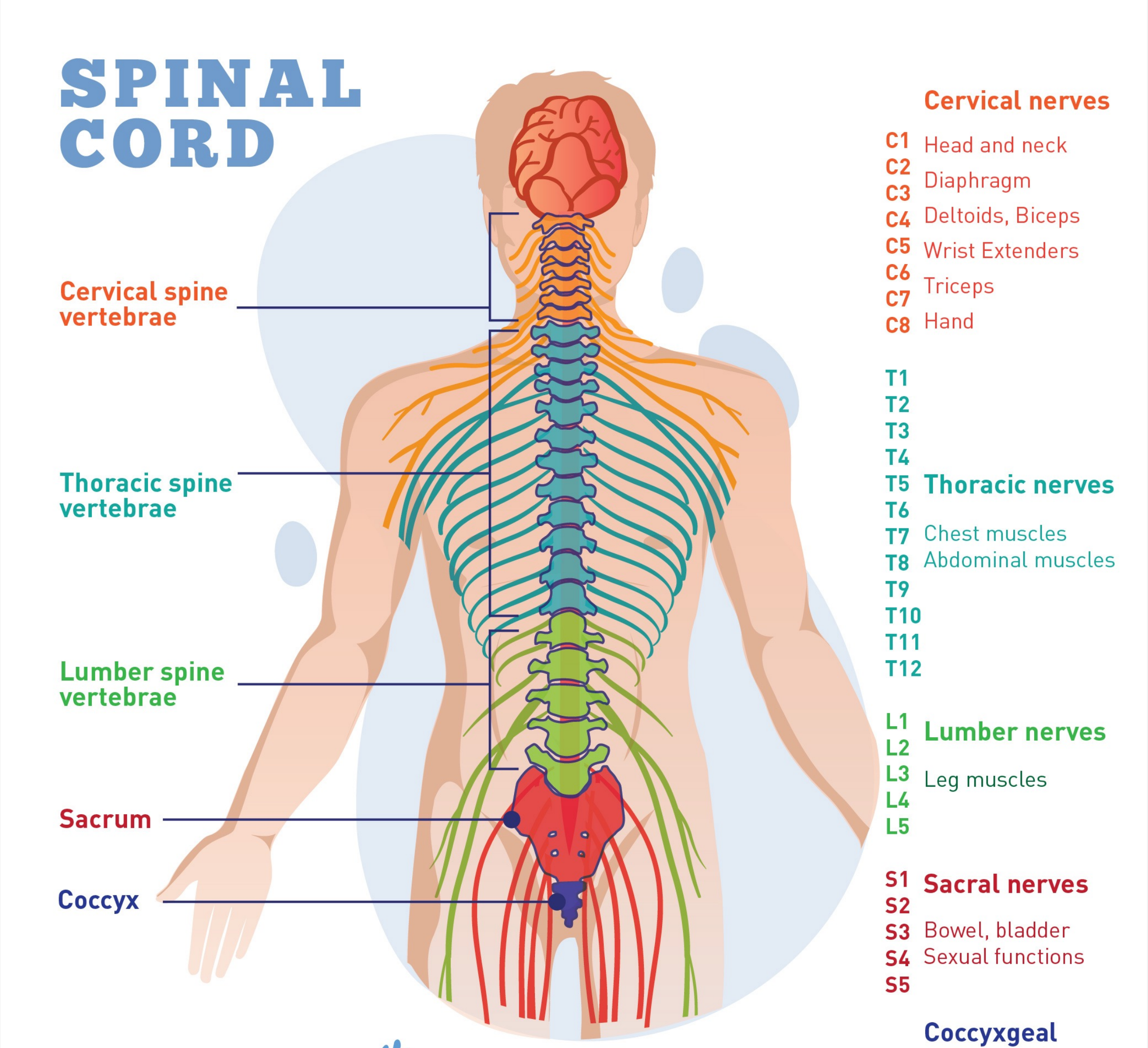
- These mixed nerves collectively transmit sensory, motor, and autonomic impulses between the spinal cord and the rest of the body

SPINAL NERVES

- 31 pairs of spinal nerves according to the vertebra column/level from which they arise
  - 8 cervical nerve pairs (C1-C8)
  - 12 thoracic nerve pairs (T1-T12),
  - 5 lumbar nerve pairs (L1-L5)
  - 5 pairs of Sacral nerves (numbered S1 to S5)
  - Single coccygeal nerve pair.

- Each nerve forms from nerve fibres extending from the posterior (dorsal) and anterior (ventral) roots of the spinal cord

SPINAL NERVES

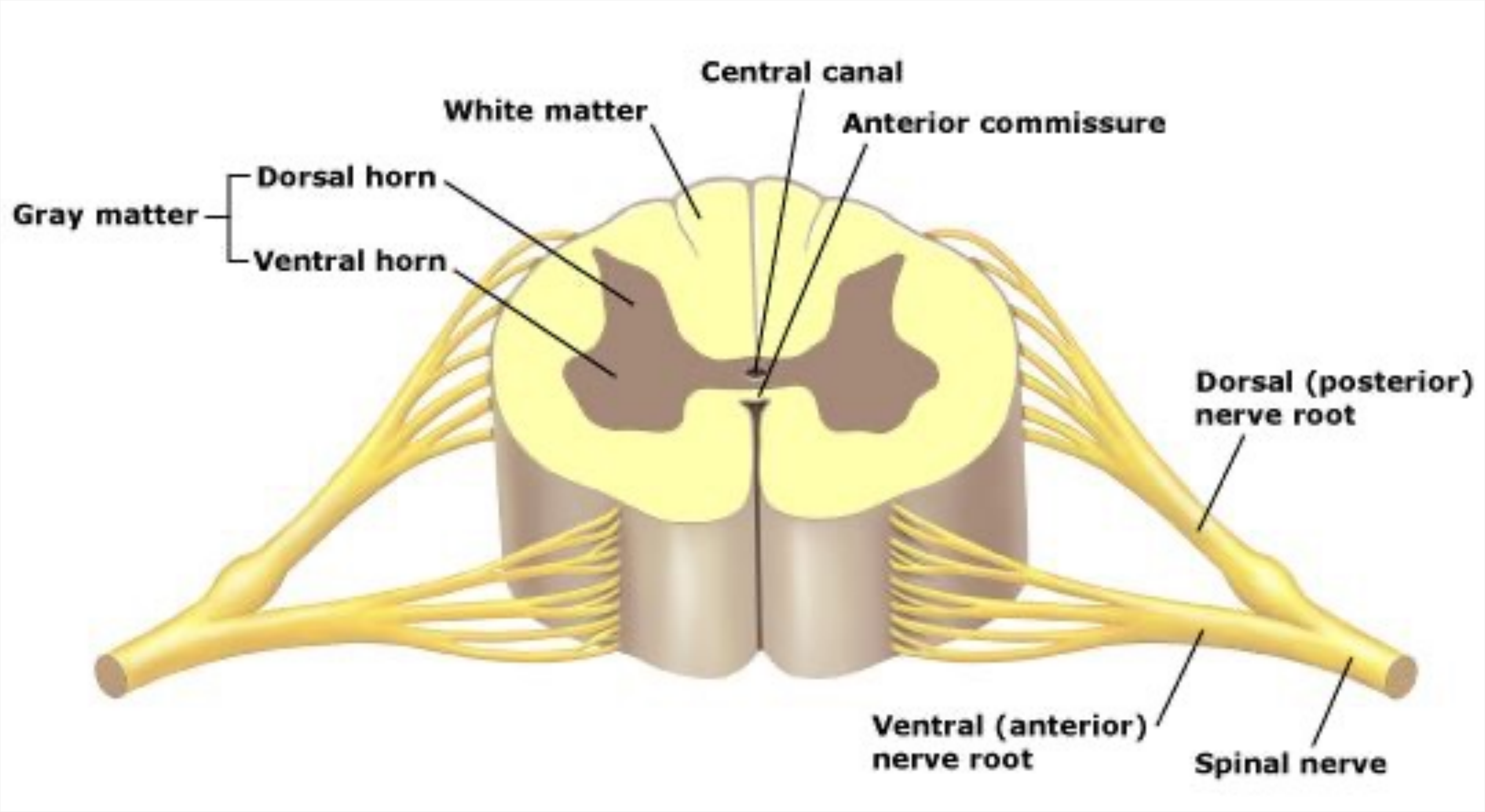


SPINAL NERVES

Roots

- Each spinal nerve emerges from the cord by 2 short branches or roots within the vertebral column
- **ventral root**:
  - contains axons of motor neurons
- **dorsal root:**
  - contains axons of sensory neurons

SPINAL NERVES



SPINAL NERVES

Dorsal Roots (posterior or **sensory root)**

- Can be identified by an enlargement called the **dorsal root ganglion**
  - This ganglion contains cell bodies of sensory neurons whose dendrites conduct impulses inward from the peripheral body parts
  - The axons of these neurons extend through the dorsal root and into the spinal cord

SPINAL NERVES

Dorsal Roots

- The dorsal root is composed of **afferent sensory axons** that transmit visceral and somatic sensory information from peripheral receptors back to the central nervous system.
- The dorsal **root is synapses** at the dorsal horn of the spinal cord:
  - in the dorsal root ganglion - for pseudounipolar neurons
  - an interneuron in the cord's gray matter as part of the motor reflex arc
- Fibres of the dorsal root may ascend through multiple pathways in the spinal cord to provide sensory information to the thalamus

SPINAL NERVES

Ventral root (anterior or motor root)

- Consists of axons from the motor neurons whose cell bodies are located within the gray matter of the cord
- The ventral (anterior) root bundle is responsible for transmitting somatic motor output from the brain and spinal cord to the body's skeletal muscles.

SPINAL NERVES

Ventral root (anterior or motor root)

- Cell bodies of the efferent motor fibres get housed in the anterior horn of the spinal cord
- All the muscles innervated by a particular spinal nerve as known as the **nerve's myotome.**
- The ventral root is composed of both alpha and gamma motor neuron axons, which supply striated muscle

SPINAL NERVES

- Spinal nerves emerge from the spinal column through an opening between adjacent vertebrae

  (known as **inter-vertebral foramen**).

- This is the case for all of the spinal nerves except the first pair, which emerge between the occipital bone and the uppermost vertebrae.

SPINAL NERVES

Spinal nerves contain both sensory and motor fibres

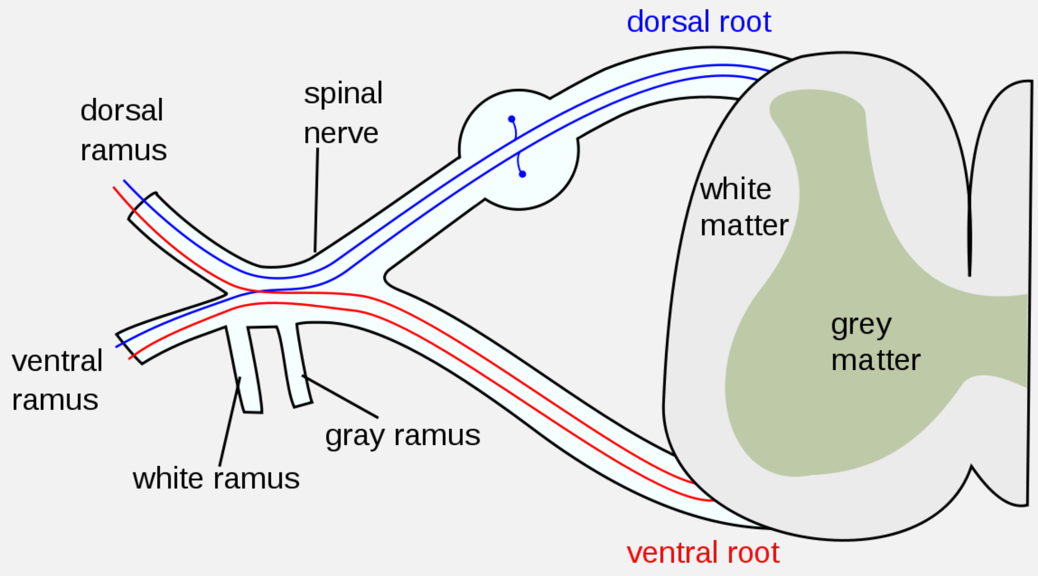
- **Sensory functions:**
  - The spinal nerves receive sensory messages from the skin, internal organs, and the bones.
  - These spinal nerves will then send this sensory information to the sensory roots before reaching the sensory fibres at the back of the spinal cord.

- **Motor functions:**
  - The motor roots receive nerve messages via the front of the spinal cord and then transmits these messages to the spinal nerves.
  - Eventually this information will be sent to small nerve branches which will activate the muscles of the limbs and other body parts.

SPINAL NERVES

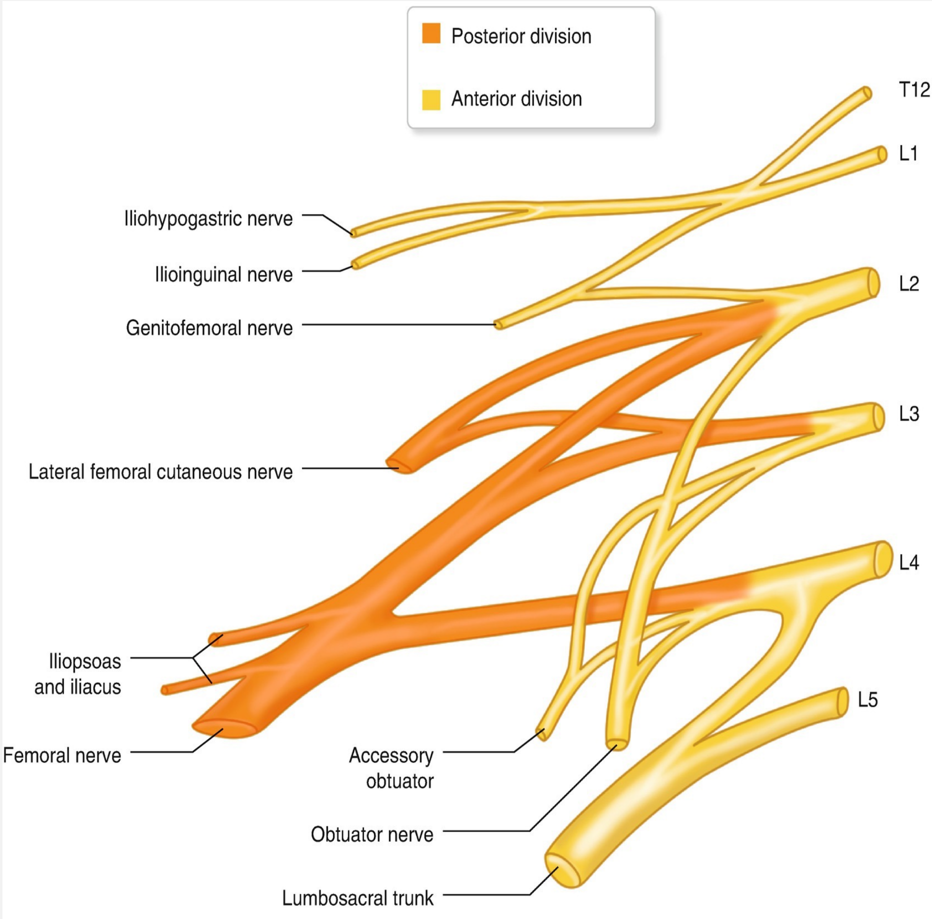
- After exiting the vertebral column, the bundled spinal nerve divides into **ventral and dorsal rami**

  - The ventral rami provide the spinal contributions to all major neural plexuses



SPINAL NERVES

- Some groups of spinal nerves merge with each other to form a large **plexus.** Some spinal nerves divide into smaller branches, without forming a plexus.
- **A plexus** is a group of nerves that combine with each other.
- There are five main plexi formed by the spinal nerves:



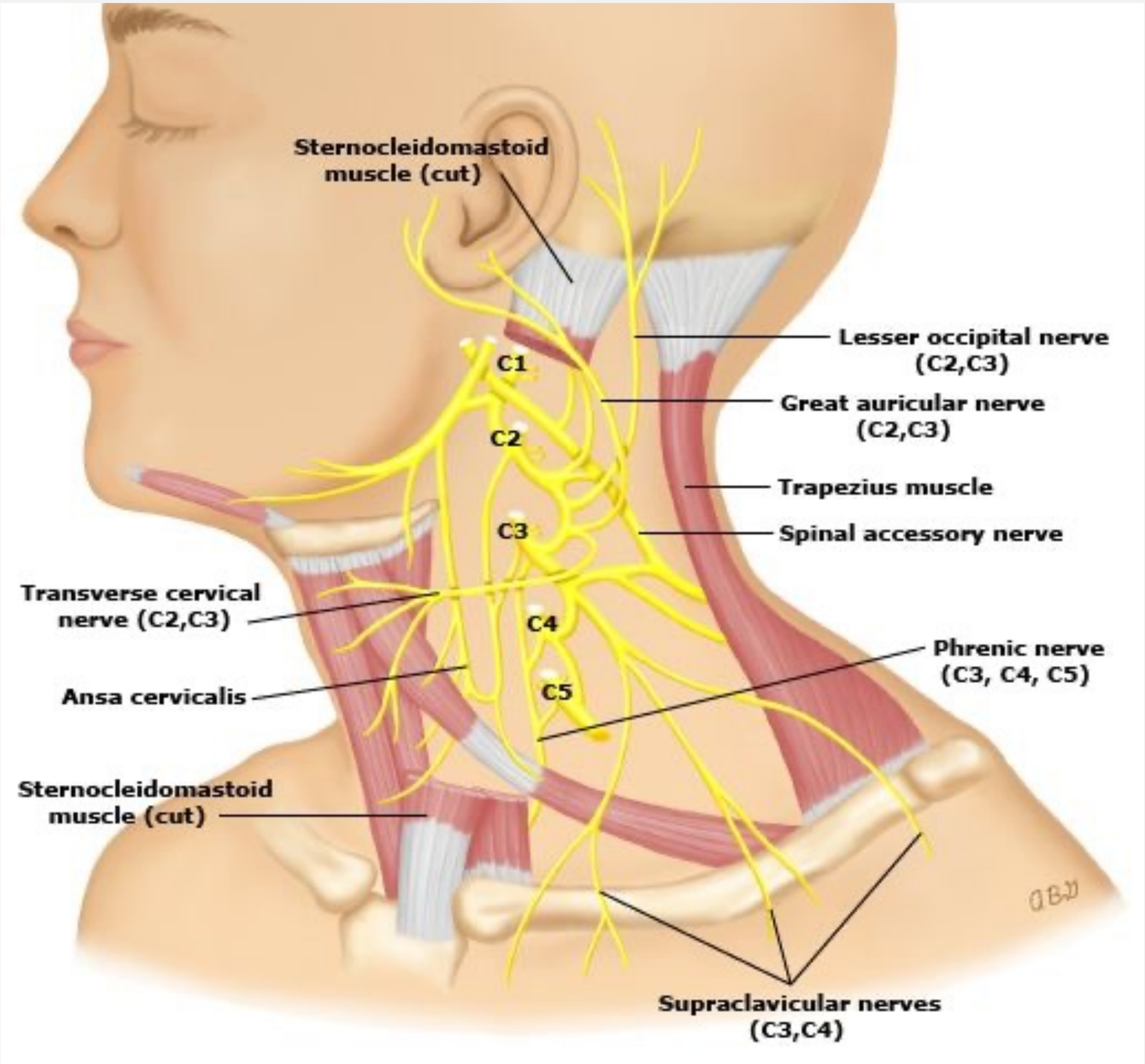
SPINAL NERVES

Cervical Plexus:

- The upper half of the cervical nerves comprise the cervical plexus; from the anterior rami of C1 to C5.
- Its sensory functions at the scalp, neck, chest, and axilla as well as proprioceptive innervation of the same area through:
  - occipital nerve (C2 to C3),
  - auricular nerve (C2, C3),
  - transverse cervical nerve (C2, C3)
  - supraclavicular nerve (C3, C4).
- The motor branches of the cervical plexus promote movement of the neck and innervation of the diaphragm.

SPINAL NERVES

Cervical Plexus:



SPINAL NERVES

Cervical Plexus (summary)

C1, C2, and C3 – these cervical spinal nerves help to control the head and neck, including forward, backward, and sideward movements.
C4 – these help to control the upper shoulder movements, as well as helping to power the diaphragm.

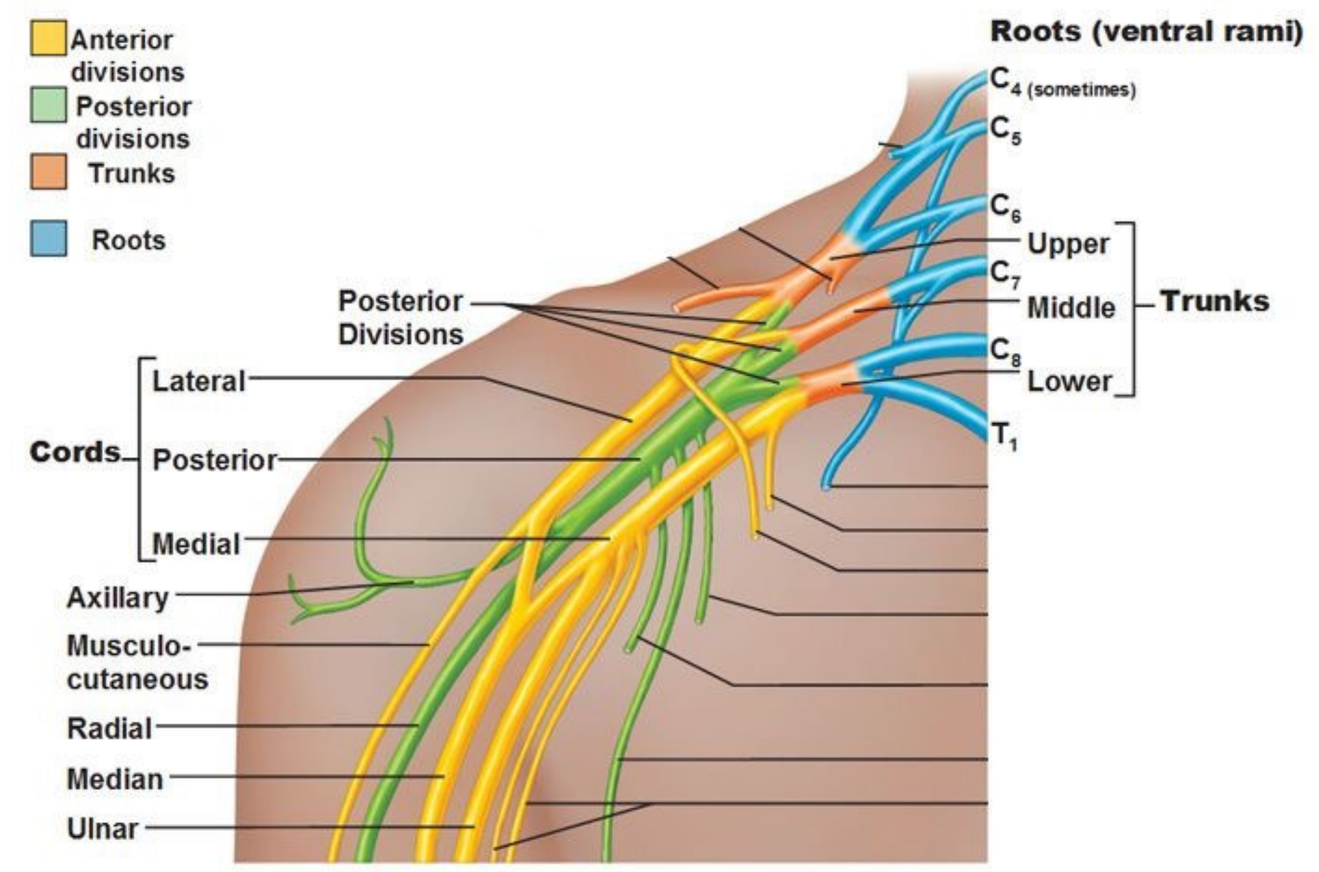
SPINAL NERVES

Brachial Plexus

- Formed from the ventral roots C5-C8, with additional contribution from T1.
- The five nerve roots coalesce into trunks, divisions, cords, and branches that innervate about 50 muscles and skin in the upper extremities and pectoral region
  - C5-C6 form the superior trunk,
  - C7 extends as the middle trunk
  - C8 and T1 join to create the inferior trunk.

SPINAL NERVES

Brachial Plexus



Roots (rami C_5–T_1), trunks, divisions, and cords

SPINAL NERVES

Brachial Plexus(summary)

C5 – these help to control the deltoids and biceps, the areas of the upper arm, down to the elbows.
C6 – these help to control the wrist extensions, with some supply given to the biceps.
C7 – these help to control the triceps as well as the wrist extensor muscles.
C8 – these help to control the hands, as well as finger flexion (hand grip).

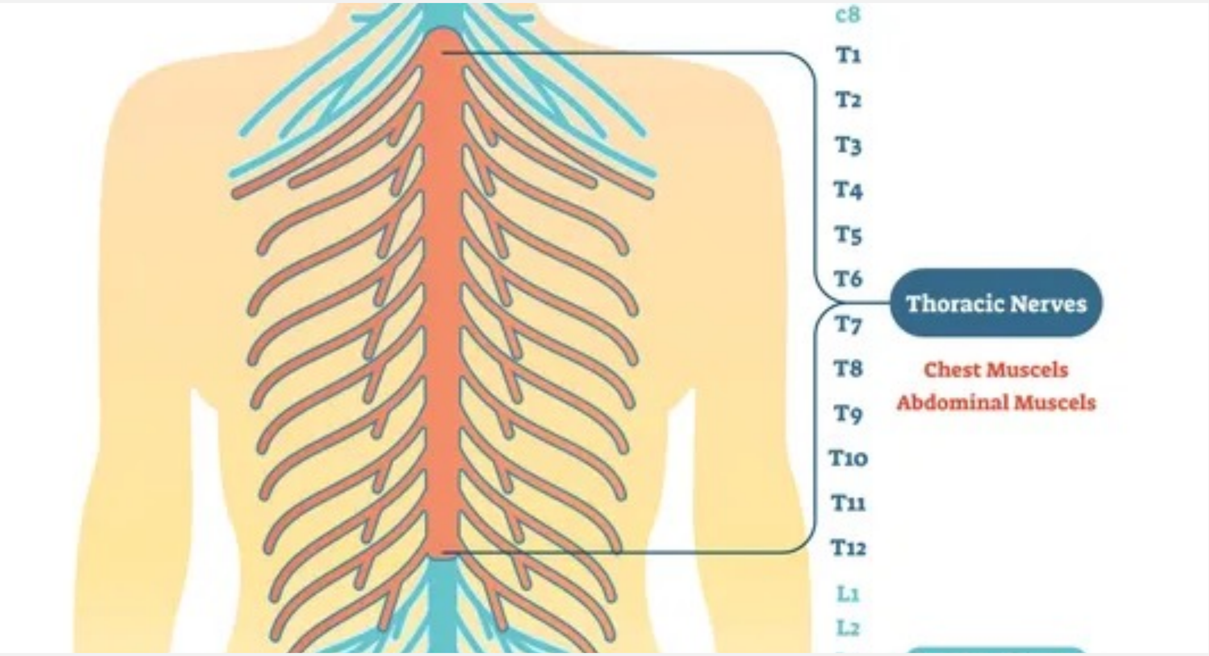
SPINAL NERVES

Thoracic Nerves

- There are 12 pairs of spinal nerves in the thoracic spine, one for each corresponding spinal segment.
- The thoracic nerves are responsible for cutaneous innervation of the skin, musculoskeletal system and viscera.
- Peripheral and visceral motor fibres also innervate the muscules of the thorax and deep back, abdominal wall, and gut.

SPINAL NERVES

Thoracic Nerves



SPINAL NERVES

Thoracic Nerves (summary)

T1 and T2 – these thoracic spinal nerves supply the top of the chest, arms, and hands.
T3, T4, T5 – these nerves supply into the chest wall as well as aid in breathing.
T6, T7, T8 – these nerves supply into the chest and down into the abdomen.
T9, T10, T11, T12 – these nerves supply into the abdomen and lower in the back.

SPINAL NERVES

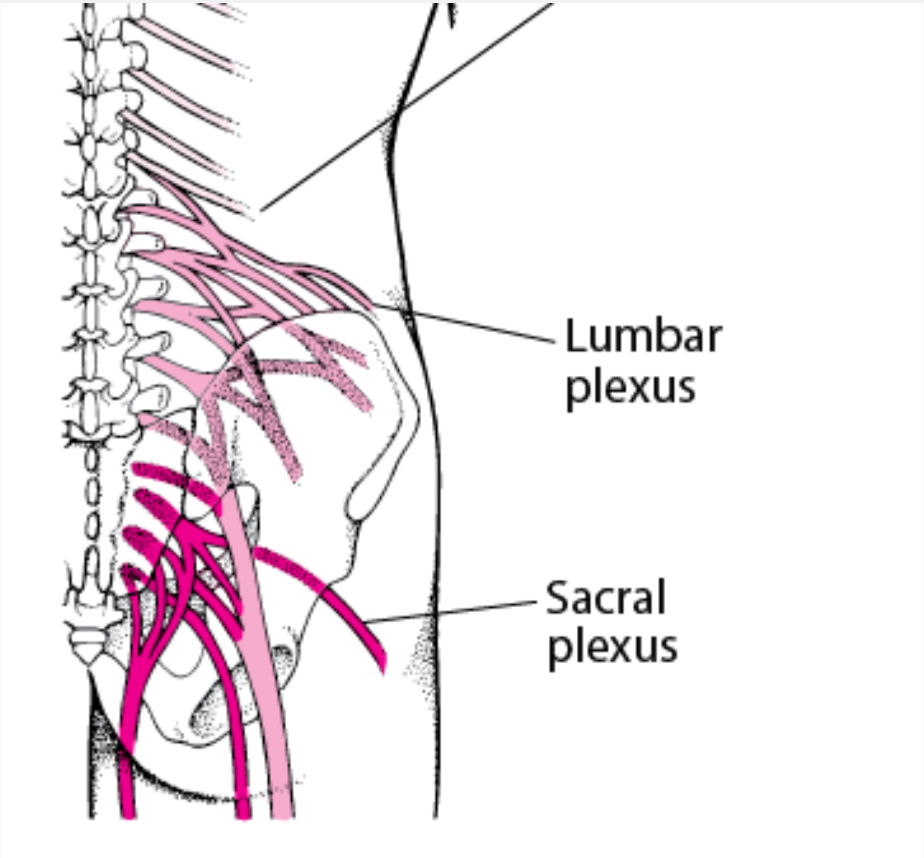
Lumbo-sacral Plexus

- The lumbar and sacral plexuses share nerve root overlap and are thus often referred to simply the lumbosacral plexus acral Plexus

- Provides all sensory and motor innervation to the lower extremity, with some additional innervation of the abdominal wall. The combined plexus gives rise to **six sensory nerves** and six more **sensorimotor branches**

SPINAL NERVES

Lumbo-sacral Plexus



SPINAL NERVES

Lumbo-sacral Plexus (summary)

L1 – these lumbar spinal nerves provide sensations to the groin as well as the genitals.
L2, L3 and L4 – these nerves provide sensations to the front of the thighs and the inner side of the lower legs. They also help to control movements of the hip and knee muscles.
L5 – these nerves provide sensations to the outer side of the lower legs and the upper foot. These also help to control the hips, knees, feet, and toe movements.

SPINAL NERVES

Lumbo-

sacral Plexus (summary)

S1 – these sacral spinal nerves affect the hips and the groin area.
S2 – these nerves affect the back of the thighs.
S3 – these nerves affect the medial buttock area.
S4 and S5 – these nerves affect the perineal area.

PERIPHERAL NERVOUS SYS.

THE NERVOUS SYSTEM

- A network of billions of nerve cells linked together in a highly organized fashion to form the rapid control center of the body.

Functions include:

1. Responds to the environment and regulates the body.
2. Integrating center for homeostasis, movement, and almost all other body functions.
3. The nervous system is much more rapid and targets cells more specifically.

THE NERVOUS SYSTEM

- It is able to integrate more types of information from the environment and to respond with a broader range of reactions
- A sizable portion of the nervous system is involved in **collecting information** about our environment.
- The information is integrated and interpreted by the central nervous system (brain, spinal cord) and used to cause a response often by stimulating muscles or glands.

BASIC FUNCTIONS OF THE NERVOUS SYSTEM

Sensation

- Monitors changes/events occurring in and outside the body. Such changes are known as **stimuli** and the cells that monitor them are **receptors.**

Integration

- The parallel processing and interpretation of sensory information to determine the appropriate response

Reaction: Motor output.

- The activation of muscles or glands (typically via the release of neurotransmitters (NTs))

ORGANIZATION OF THE NERVOUS SYSTEM

- The nervous system collects information from the environment, processes the information obtained, and then reacts in an appropriate manner.

- This is accomplished as a *concerted effort between both the central and peripheral nervous systems*.

ORGANIZATION OF THE NERVOUS SYSTEM

Central Nervous System: (The centre of integration and control)

- The brain
- The spinal cord

Peripheral Nervous System

- The nervous system outside of the brain and spinal cord consists of:
  - 31 Spinal nerves (carry info. to and from the spinal cord)
  - 12 Cranial nerves (carry info. to and from the brain)

PERIPHERAL NERVOUS SYSTEM

- Responsible for communication between the CNS and the rest of the body.
- Can be divided into:

1. **Sensory Division / Afferent division**
   - Afferent neurons lead from their sensory receptors in the periphery to the central nervous system which processes the information.
   - *Conducts impulses from receptors to the CNS*
     - *interior and exterior*
   - **Sensory nerve fibres** can be somatic (from skin, skeletal muscles or joints) or visceral (from organs within the ventral body cavity)

PERIPHERAL NERVOUS SYSTEM

1. **Motor Division: Efferent division**
   - Efferent neurons lead from the central nervous system back out to the periphery to cause the response to the stimulus.
   - *Conducts impulses from CNS to* ***effectors (muscles/glands)***

MOTOR / EFFERENT DIVISION

- There are two different classes of **efferent neurons** in the peripheral nervous system; *somatic motor* neurons and *autonomic neurons*
- **Somatic neurons:** VOLUNTARY
- Somatic nerve fibres conduct impulses from the CNS to skeletal muscles
  - Somatic motor neurons excite only skeletal muscle and are responsible for most of our voluntary movements

EFFERENT DIVISION

- **Autonomic neurons:** INVOLUNTARY
- Within the autonomic nervous system there are three divisions.

1. **The enteric** neurons connect to the wall of the intestinal tract and conducts impulses from the CNS
    - *smooth muscle*
    - *cardiac muscle, and*
    - *glands.*

AUTONOMIC NERVOUS SYSTEM

2. Sympathetic neurons

- *"Fight or Flight" : an automatic physiological reaction to an event that is perceived as stressful or frightening / danger in our environment*
- *react quickly to life-threatening situations / survival mechanism*
- Hypothalamus, command center through the autonomic nervous system to the adrenal glands.
- Controls such involuntary body functions as breathing, blood pressure, heartbeat, and the dilation or constriction of key blood vessels and small airways in the lungs called bronchioles.

AUTONOMIC NERVOUS SYSTEM

3. **Parasympathetic neurons**

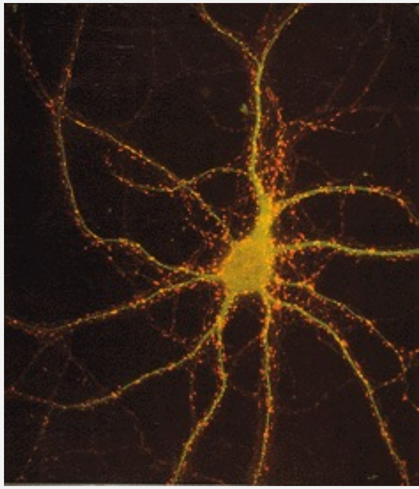
   - *“Rest and Digest”*
   - *include control of your heart rate, blood pressure, digestion, urination and sweating*
   - *constricts your pupils to limit how much light enters your eyes*
   - *glands in your mouth produce saliva*
   - *lowers your heart rate*
   - *increases your rate of digestion and diverts energy to help you digest food*

- The sympathetic and parasympathetic divisions are important in controlling many processes for body homeostasis

NERVOUS SYSTEM -CELL TYPES

NERVOUS TISSUE

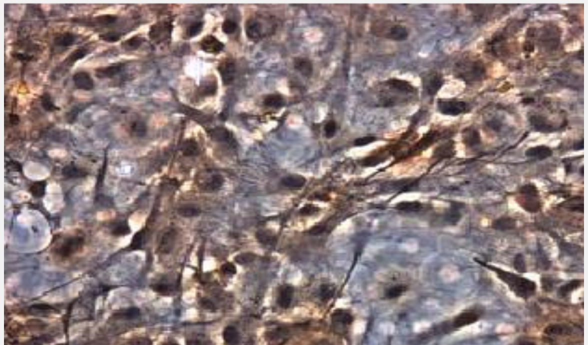
- Despite the fact that the nervous system is extremely complicated, there are relatively few cell types present.



2 cell types:

1. Neurons
   - Functional, signal conducting cells

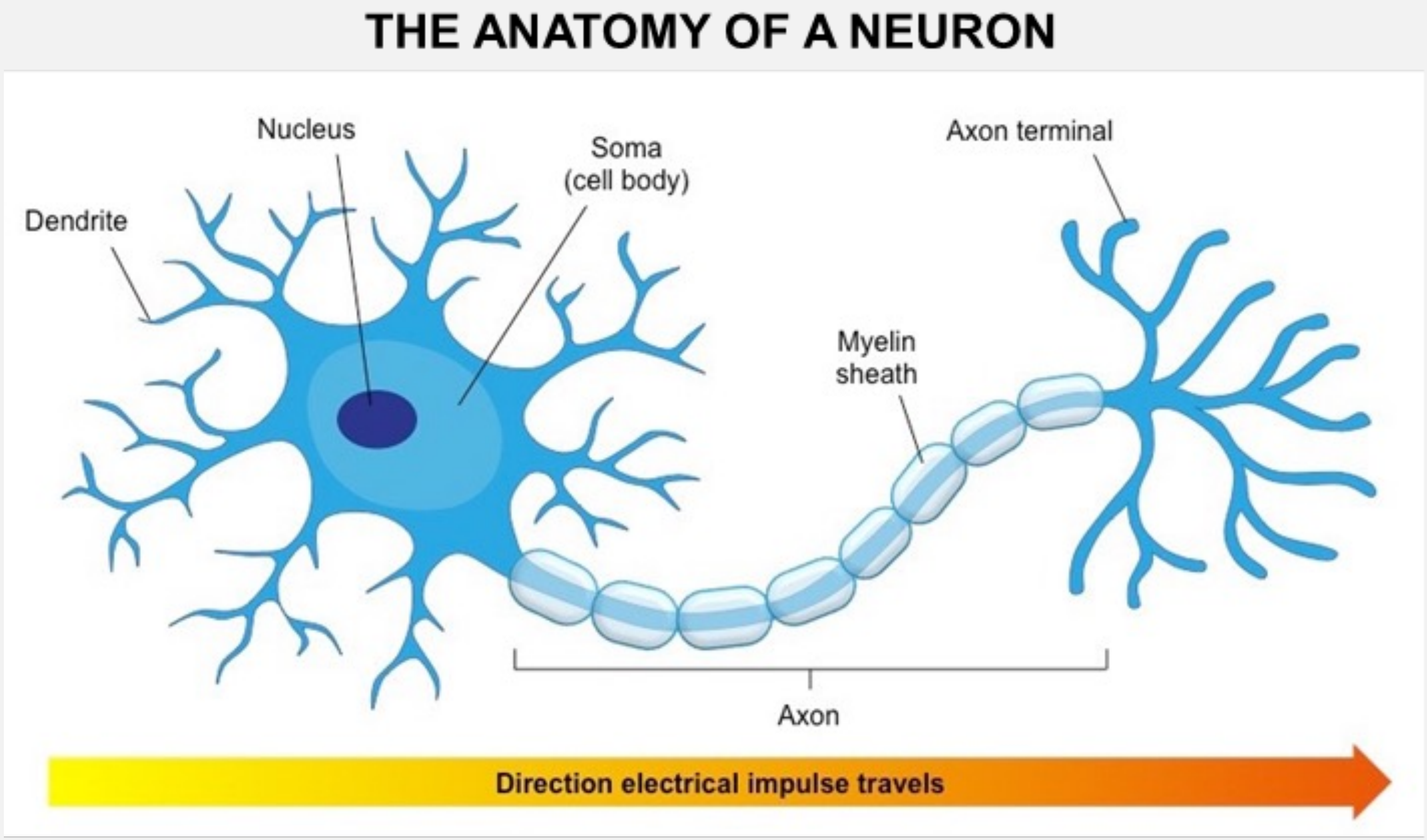
2. Glial Cells
   - Supporting cells



NEURONS

- The *functional and structural unit* of the nervous system.
- Neurons are the cells of the nervous system that **communicate and integrate information**
- They communicate with one another with their processes, or cell extensions, that emanate from the cell body
- Specialized to conduct information from one part of the body to another.

NEURONS


THE ANATOMY OF A NEURON
Nucleus
Soma
(cell body)
Axon terminal
Dendrite
Myelin
sheath
Axon
Direction electrical impulse travels

NEURONS

- **Dendrites** are processes which usually receive information from other neurons while axons are processes that usually pass information on to other neurons.

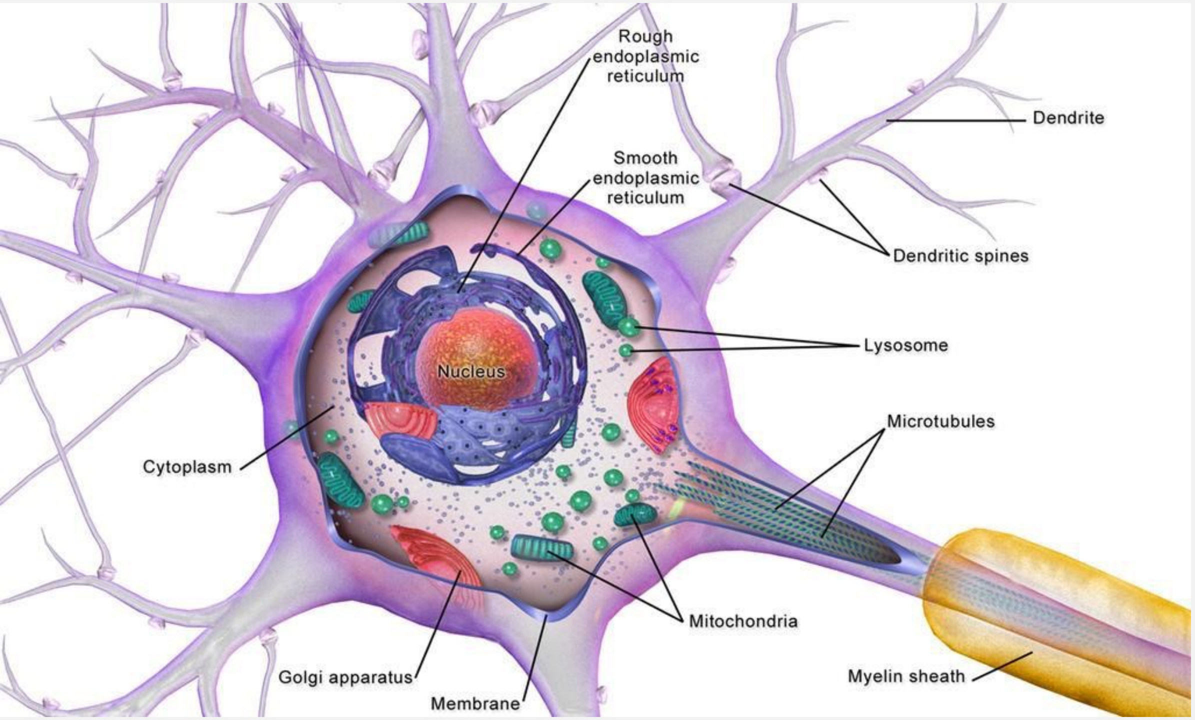
Neurons use:

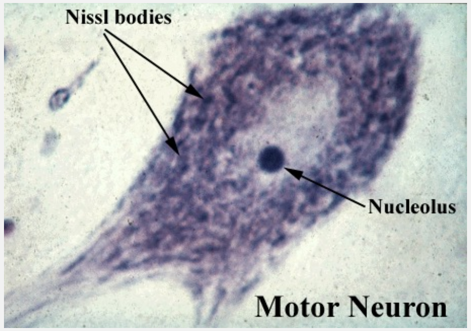
- ***electrical signals*** to communicate along their length and often use
- ***chemical signals*** to communicate with one another.
- The morphology of neurons can differ widely depending on their role in the nervous system.
- Some neurons that receive signals from many other neurons can have thousands of dendrites.

NEURONS

- However, most neurons have only a single axon.
- Axons can branch to form many ***axon terminals*** that can be used to communicate with many neurons downstream.
- There are many, many different types of neurons but most have certain structural and functional characteristics in common:
  - Cell body (soma)
  - One or more specialized, slender processes (axons/dendrites)
  - An input region (dendrites/soma)
  - A conducting component (axon)
  - A secretory (output) region (axon terminal)

NEURONS (SOMA)

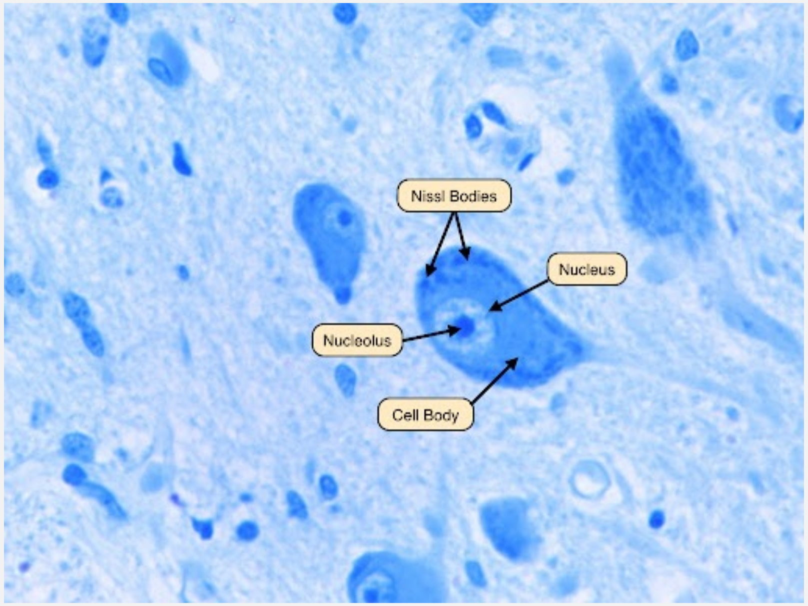




- Contains **nucleus** plus most normal **organelles**.
- ***Biosynthetic center*** of the neuron.
- Contains a *very active and developed rough endoplasmic reticulum* which is responsible for the synthesis of proteins.
  - The neuronal rough ER is referred to as the **Nissl body**.
- Contains many bundles of protein filaments (**neurofibrils**) which help maintain the shape, structure, and integrity of the cell.

NEURONS
(SOMA)

- Contain multiple mitochondria.
- Acts as a receptive service for interaction with other neurons.
- Most somata are found in the bony environs of the CNS. Clusters of somata in the CNS are known as **nuclei.**
- Clusters of somata in the PNS are known as **ganglia.**



GLIAL CELLS

- Several types of glial cells support neurons in the nervous system.
- Outnumber neurons by about **10 : 1**
- The axons of many neurons have a covering of specialized plasma membrane called **myelin** that makes the electrical signals that travel through axons *faster and more efficient.*

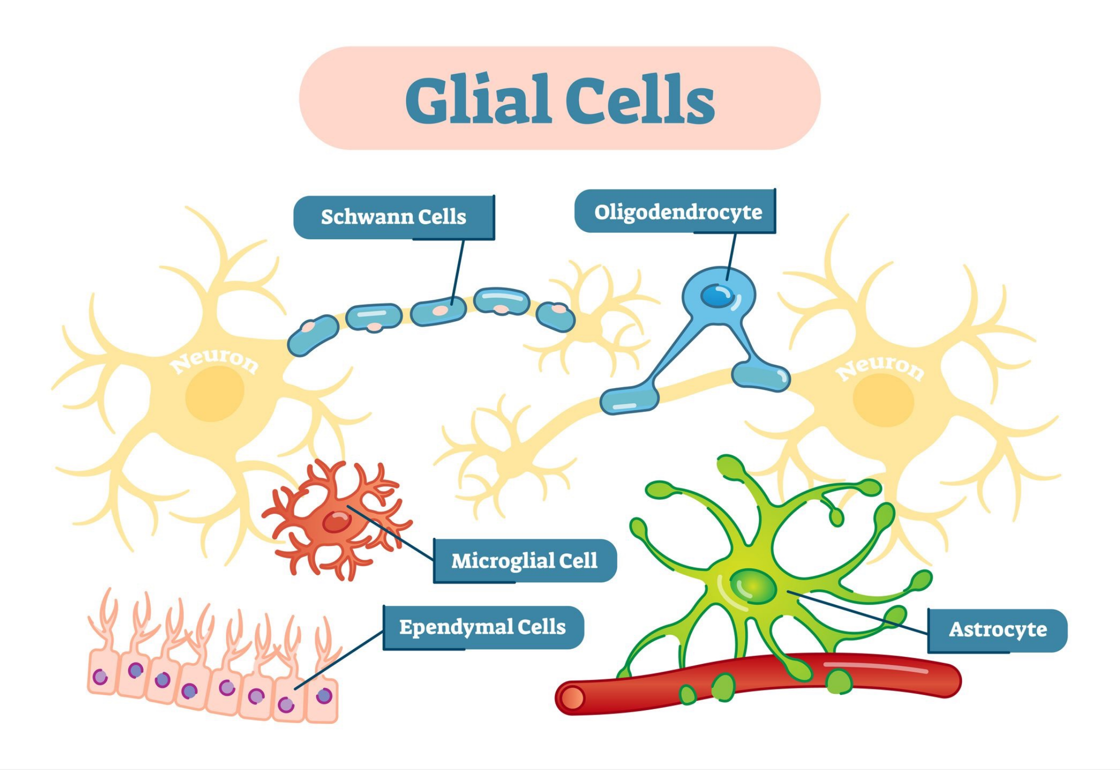
- In the central nervous system (the brain and spinal cord), **oligodendrocytes** use their processes to wrap many layers of myelin around each axon.
- Each oligodendrocyte insulates many axons.

GLIAL CELLS

- In the peripheral nervous system (outside of the brain and spinal cord), a single axon is coated by many **Schwann cells** that wrap themselves around a portion of a single axon to cover it with myelin.
- **Astrocytes** are another *type of glial cell* that function to support neurons in the central nervous system.
- provide metabolic support to neurons and maintain the extracellular environment so that neuronal signalling can occur.
- Some astrocytes have processes that coat the outside of blood vessels in the brain and help to form a tight blood-brain barrier that protects the brain from toxic substances in the blood.

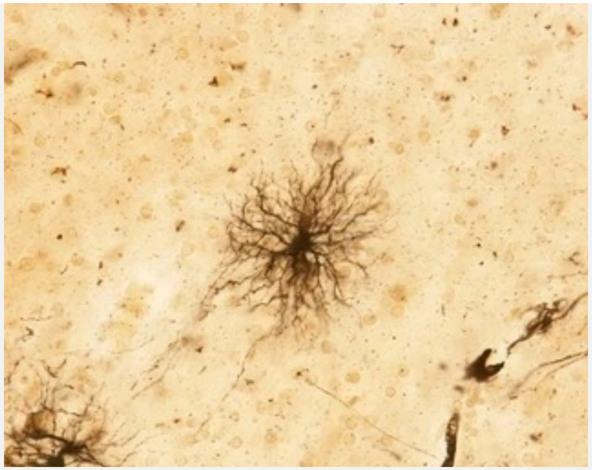
GLIAL CELLS

- ***Microglial*** cells are scavenger cells of the cells of the nervous system that can take up cellular debris as well as serve other immune functions for the brain.



GLIAL CELLS

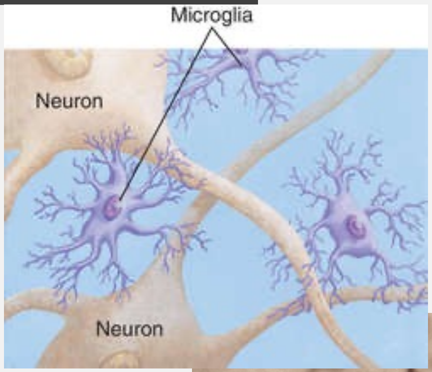
1. **Astrocytes**
   - Star-shaped, abundant, and versatile
   - Guide the migration of developing neurons
   - Act as K+ and NT buffers
   - Involved in the formation of the blood brain barrier
   - Function in nutrient transfer

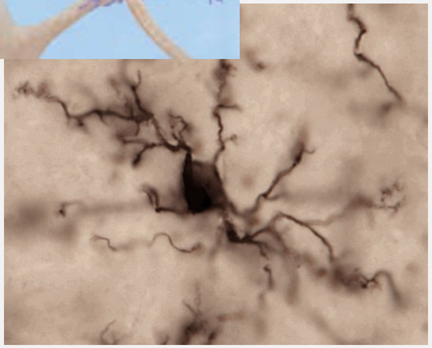


GLIAL CELLS

2. Microglia

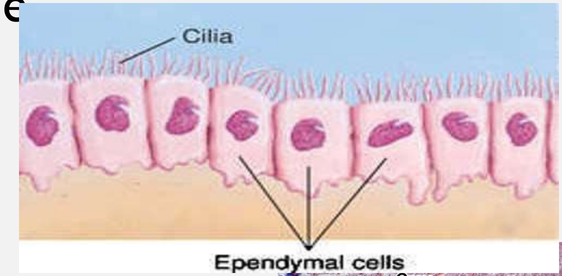
- Specialized immune cells that act as the macrophages of the CNS

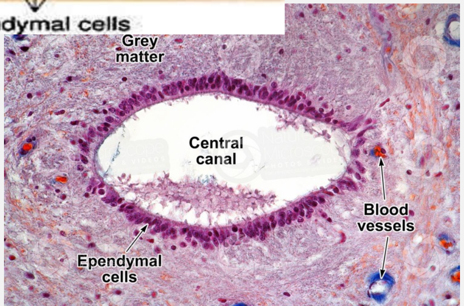




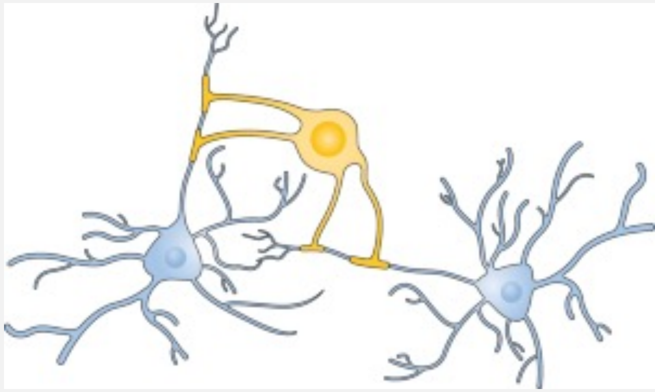
3. Ependymal Cells

- Low columnar epithelial cells that line the ventricles of the brain and the central canal of the spinal cord
- Some are ciliated which facilitates the movement of cerebrospinal fluid



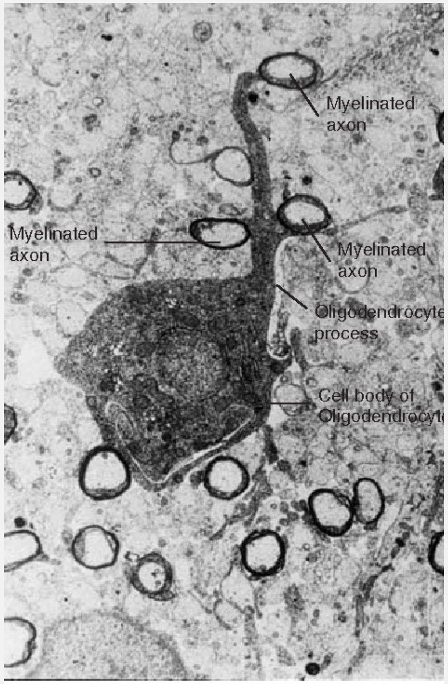


GLIAL CELLS



4. **Oligodendrocytes**

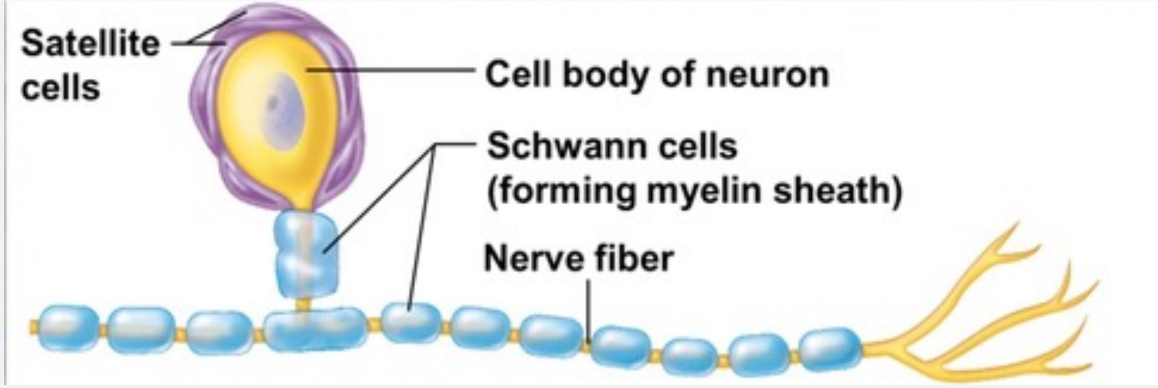
- Produce the **myelin sheath** which provides the electrical insulation for certain neurons in the CNS



GLIAL CELLS

- 2 types of glial cells (**satellite** and **Schwann cells**) surround neurons in the PNS

1. **Satellite cells**
   - Surround clusters of neuronal cell bodies in the PNS



2. **Schwann cells**
   - Form myelin sheaths around the larger nerve fibers in the PNS.
   - Vital to neuronal regeneration

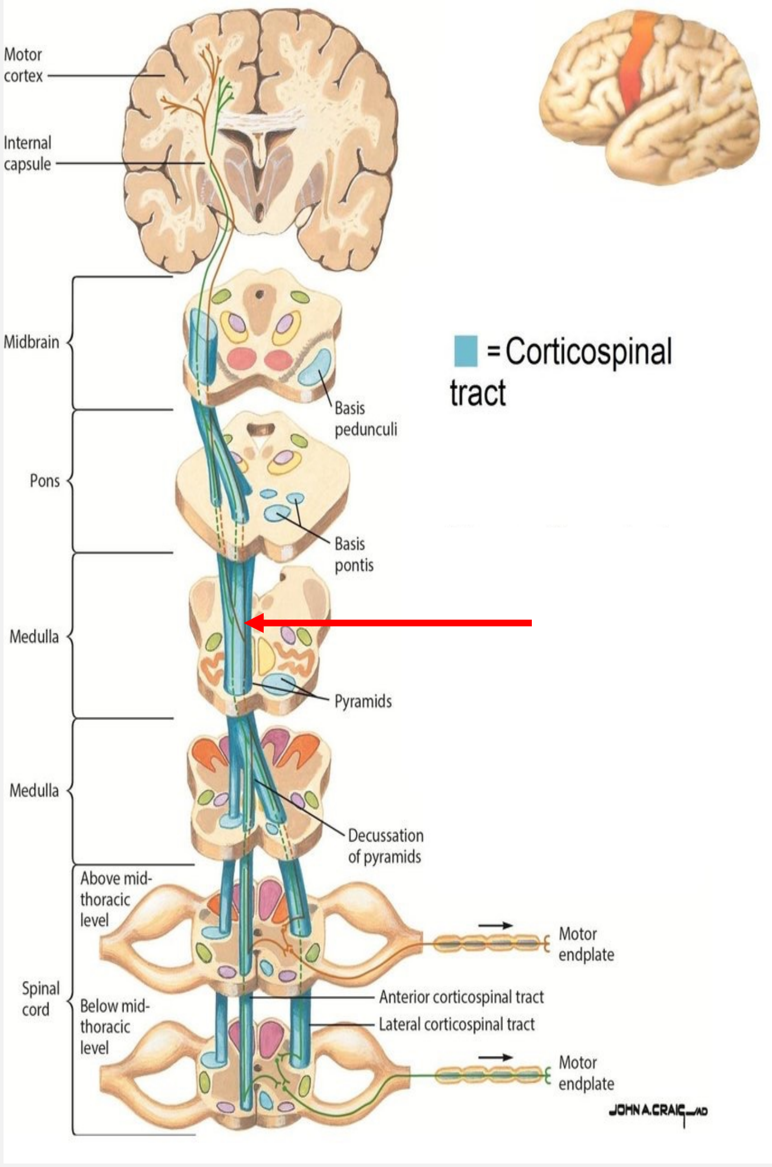
NEURONAL PROCESSES

> armlike extensions emanating from every neuron.

- 2 types: differ in structure and function:

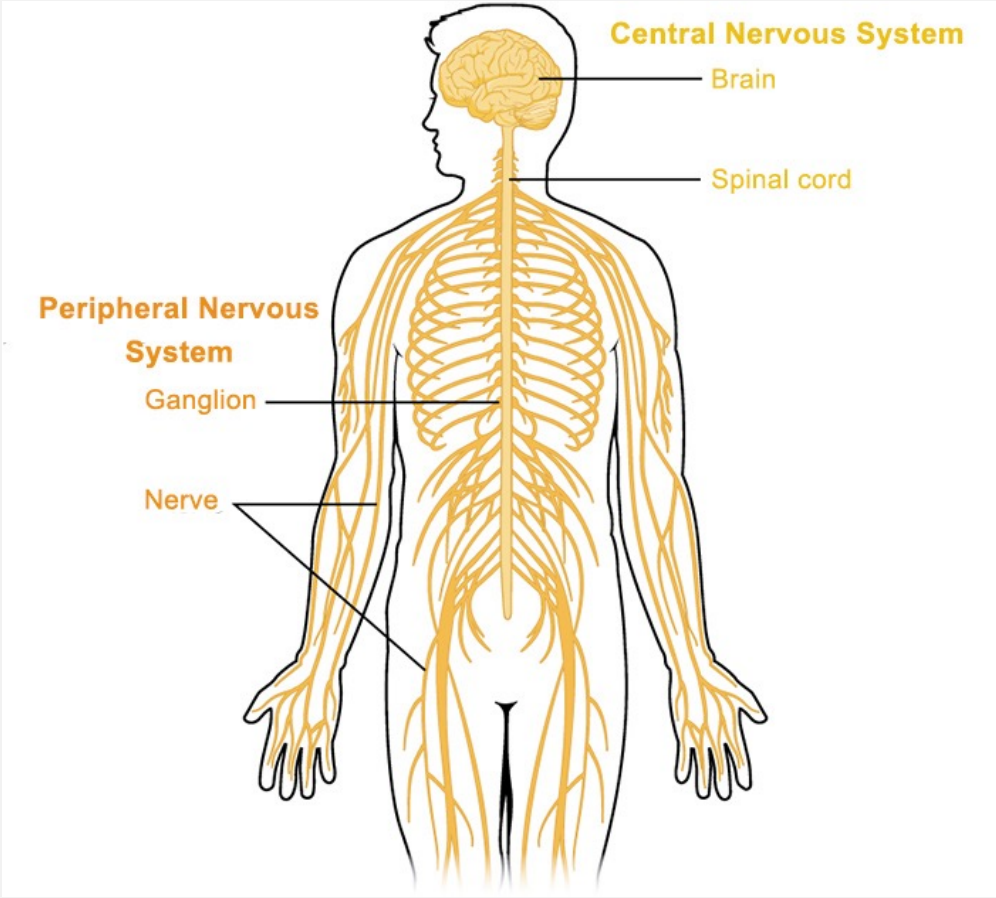
  Dendrites and **Axons**

- The CNS consists of both somata and processes whereas the bulk of the PNS consists of processes.
- Tracts = Bundles of processes in the CNS (red arrow)



NEURONAL PROCESSES

- Nerves = Bundles of processes in the PNS



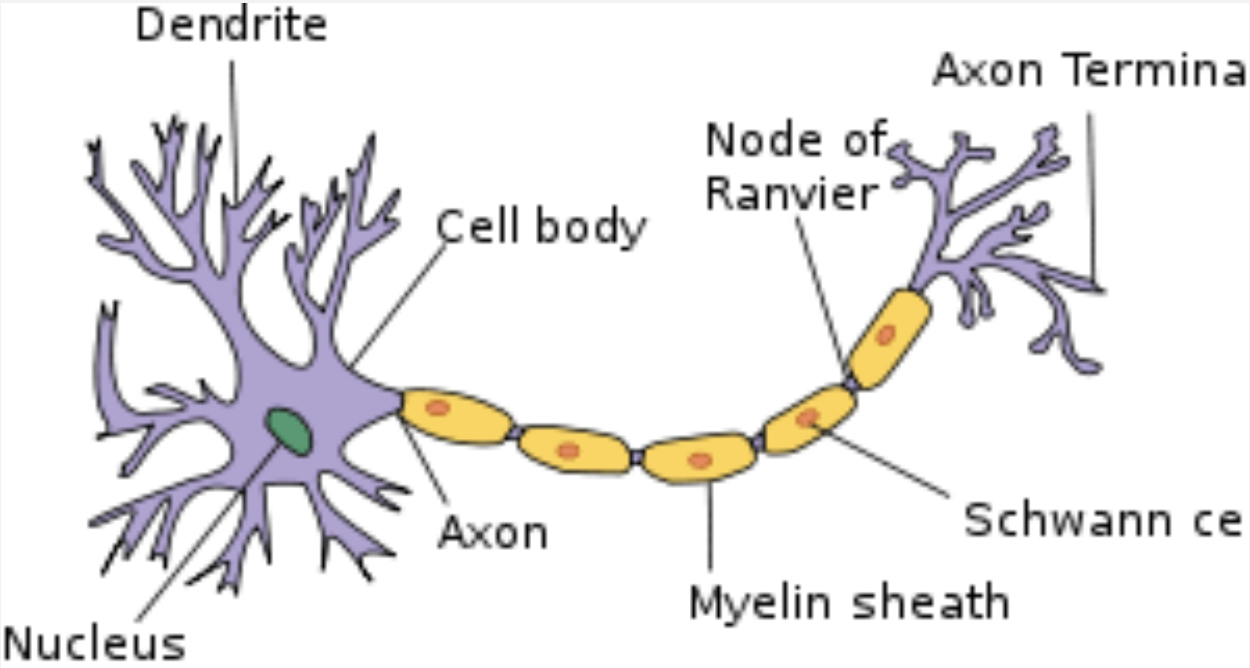
NEURONAL PROCESSES (DENDRITES)

- **Dendrites** are thin, branched processes whose main function is to receive incoming signals or become stimulated by other neurons and conduct the electrochemical charge to the cell body / soma

- They effectively increase the surface area of a neuron to increase its ability to communicate with other neurons.
  - Small, mushroom-shaped dendritic spines further increase the SA

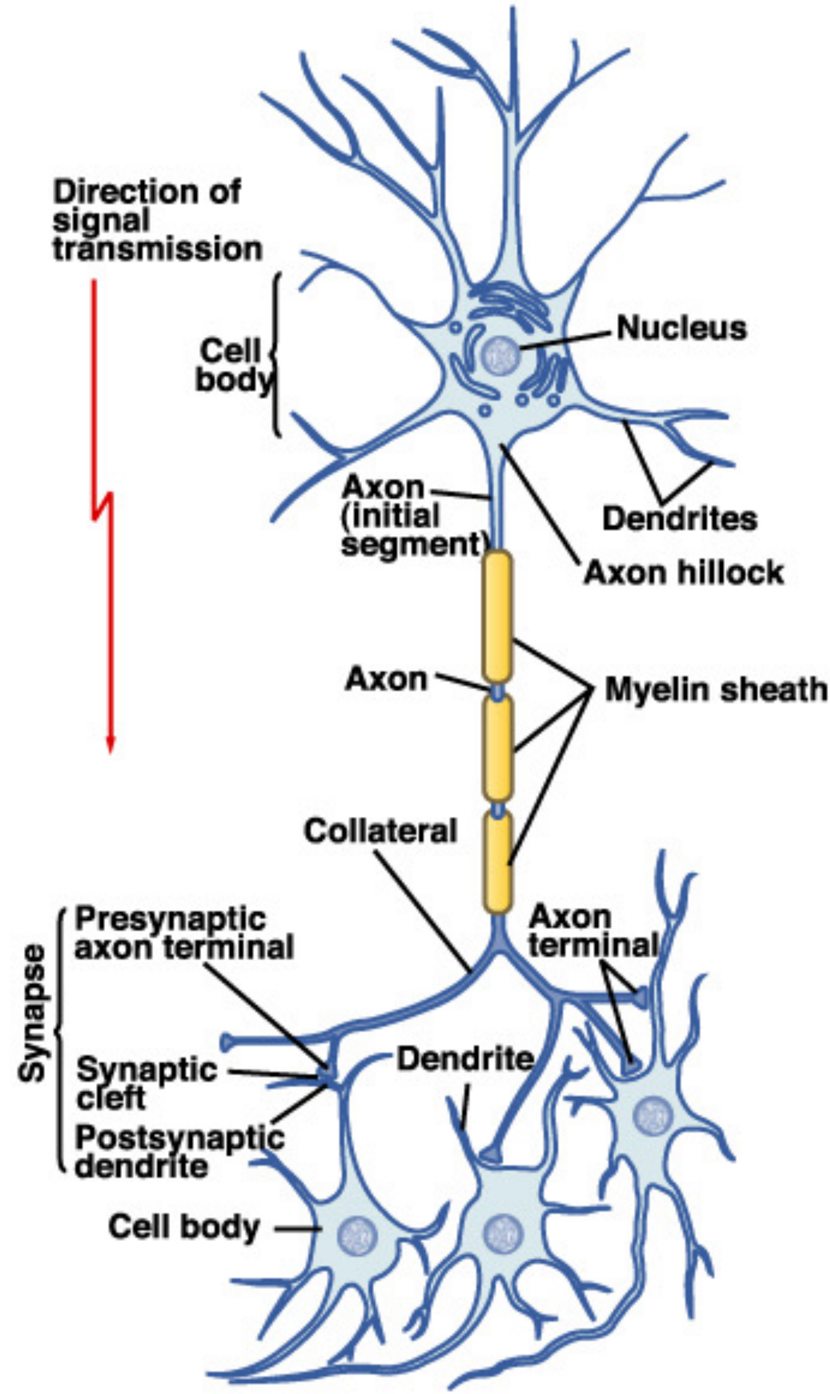
NEURONAL PROCESSES (DENDRITES)

- Convey info towards the soma thru the use of *graded potentials* – which are somewhat similar to *action potentials*.



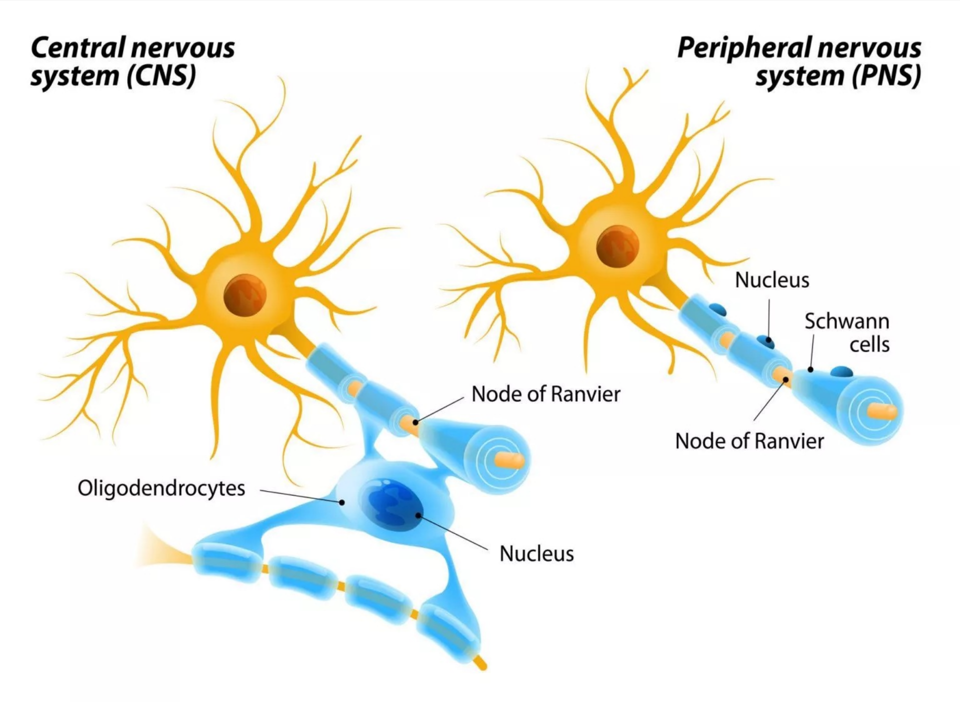
- Most neurons have a single **<u>axon</u>** – a long (up to 1m) process designed to convey info away from the cell body.

- Originates from a special region of the cell body called the **axon hillock**.
- Transmit action potential (AP)s from the soma toward the end of the axon where they cause **neurotransmitter (NT) release**.
- Often branch sparsely, forming collaterals.
- Each collateral may split into **telodendria** which end in a synaptic knob, which contains **synaptic vesicles** (membranous bags of NTs)



NEURONAL PROCESSES (AXONS)

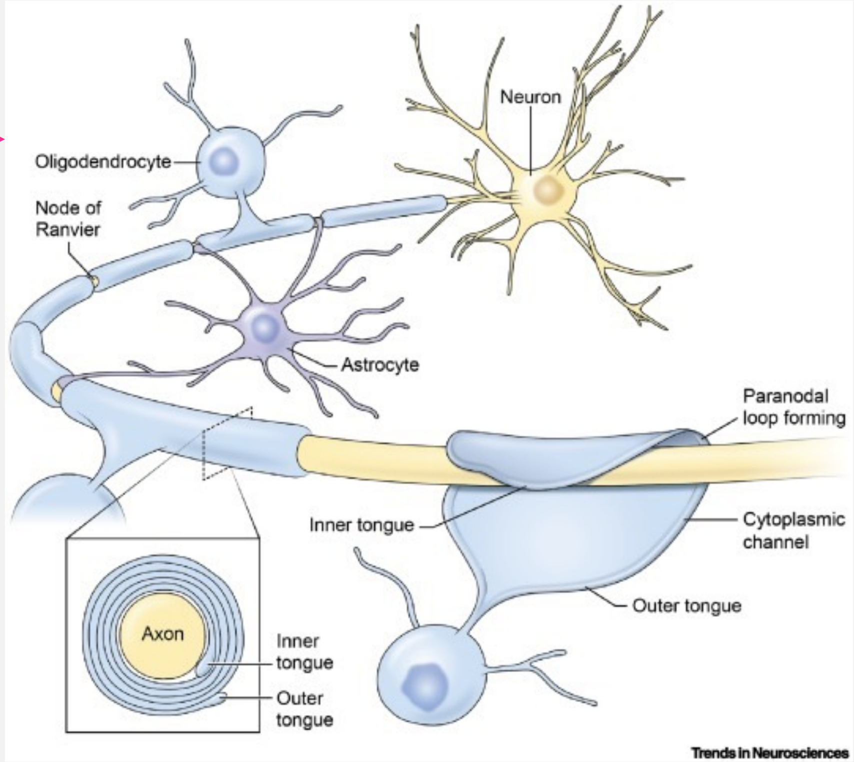
- **Axolemma** = axon plasma membrane.
- Surrounded by a myelin sheath, a wrapping of lipid which:
  - Protects the axon and electrically isolates it
  - Increases the rate of AP transmission



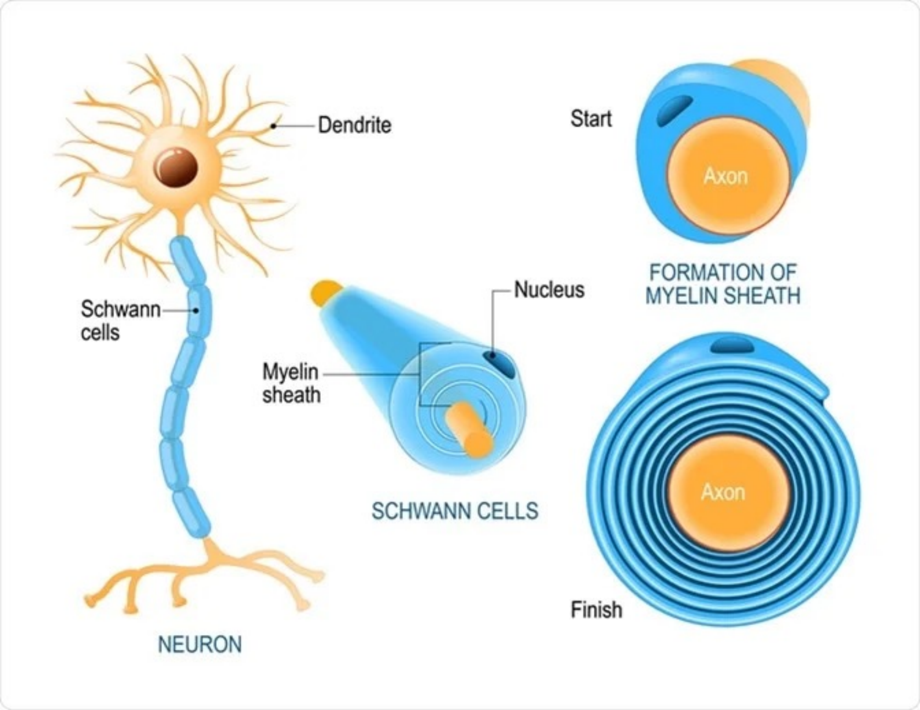
NEURONAL PROCESSES (AXONS)

- The myelin sheath is made by oligodendrocytes in the CNS and by Schwann cells in the PNS.
- This wrapping is never complete. Interspersed along the axon are gaps where there is no myelin – these are **nodes of Ranvier.**
- In the PNS, the exterior of the Schwann cell surrounding an axon is the **neurilemma**

Myelination in the CNS

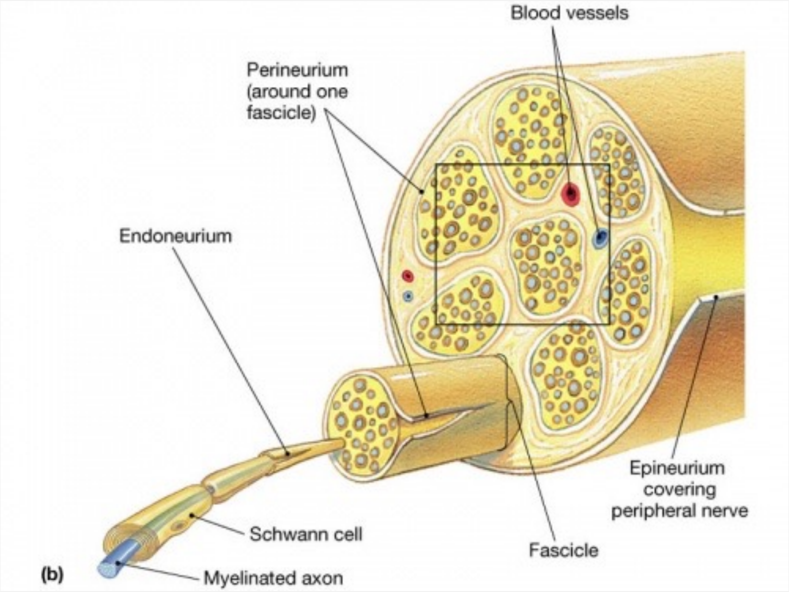


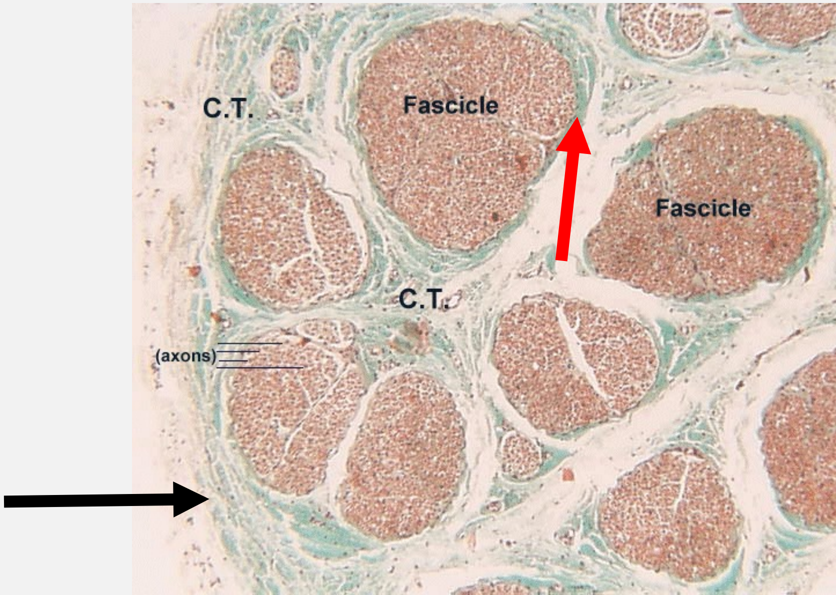
Myelination in the PNS



NEURONAL PROCESSES

- A bundle of processes in the PNS is ***a nerve***.
- Within a nerve, each axon is surrounded by an **endoneurium**
- Groups of fibers are bound together into bundles **(fascicles)** by a **perineurium** (red arrow).
- All the fascicles of a nerve are enclosed by a **epineurium** (black arrow).





NERVOUS SYSTEM - METHODS OF COMMUNICATION

COMMUNICATION

- Begins with the stimulation of a neuron.
  - One neuron may be stimulated **by another**, **by a *receptor*** cell
  - Once stimulated, a neuron will communicate information about the causative event.
- Such neurons are sensory neurons and they provide info about both the internal and external environments.
- Sensory neurons (afferent neurons) will **send info. to neurons in the brain and spinal cord.**

COMMUNICATION

- There, **association neurons *(interneurons)*** will integrate the information and then send commands to motor neurons (efferent neurons) which synapse with muscles or glands.
- Thus, neurons need to be able to conduct information in 2 ways:

1. From one end of a neuron to the other end.

   *This is accomplished electrically via **actions potentials (**APs).*

2. Across the minute space separating one neuron from another.

   *This is accomplished chemically via **neurotransmitters** (NTs)*

MEMBRANE POTENTIALS

Signalling Along Neurons

- The speed and efficiency of the nervous system is due to electrical and chemical signals that travel along and between neurons.

- Neurons use electric currents that can travel along their lengths in a very efficient manner.

- The current is generated by the *flow of ions across the plasma membrane* through ion channels.

MEMBRANE POTENTIALS

Electrochemical Gradient

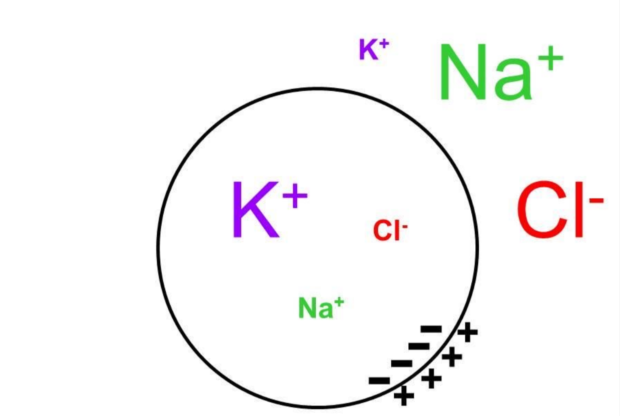
- For a neuron to generate a current, or **flow of electrical charge**, the cell spends energy to establish a *concentration and electrical gradient* of ions across the plasma membrane.

- The gradient is primarily established by affecting the concentration of three ions in the cell, Na+, Cl- and K+ (mM)

Ion	ECF / Plasma	ICF / Cytosol
Na^+	140.0	15.0
K^+	4.4	140.0
Cl-	105.0	7.0

MEMBRANE POTENTIALS

Equilibrium potentials



- Due to the concentration gradient of ions across the plasma membrane of cells, the intracellular fluid has a small **excess of negative charge compared to the extracellular fluid**.
- The separation of charge has the potential to do work. As a result, the magnitude of the charge difference between the inside and outside of the cell is referred to as the **membrane potential** and measured in **millivolts**.

MEMBRANE POTENTIALS

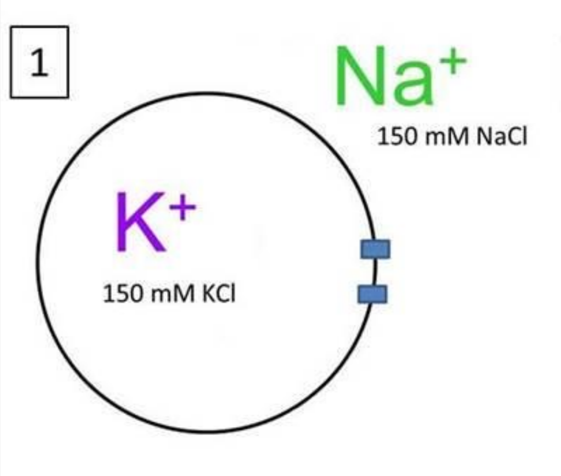
Equilibrium potentials

- If there is an excess of negative charges inside of the cell, the membrane potential is negative. If the excess charge on the inside of the cell is positive, the membrane potential is positive.

- The membrane potential of a cell under specific conditions is determined by the **concentration of ions** *inside* and *outside* of the cell and by the *permeability* of the membrane for those ions.

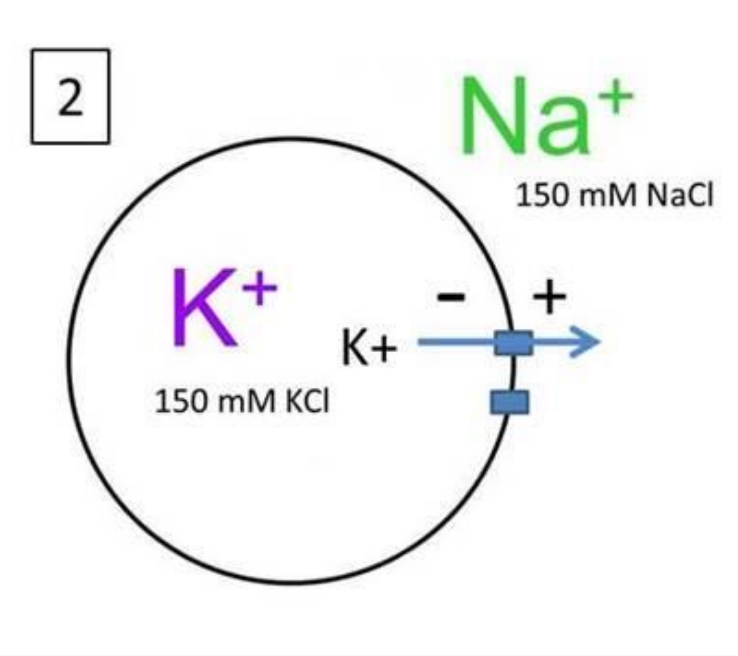
MEMBRANE POTENTIALS

- The simplest case is to consider a system that is permeable to only one ion. **In part 1,** there are two compartments separated by a membrane with two different solutions that differ in their Na+ and K+ concentrations.
- The ion channels in the membrane are not open.



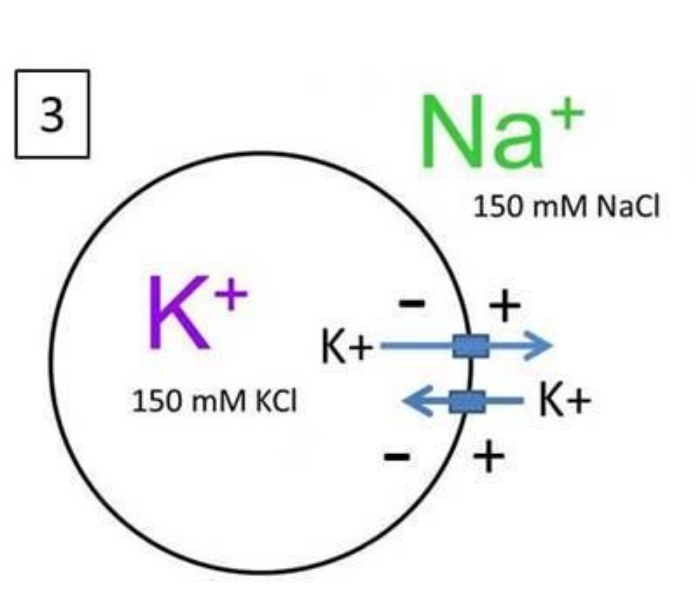
[1] Since the number of positive and negative charges is equal on both sides of the membrane, the membrane **potential is 0 mV.**

MEMBRANE POTENTIALS



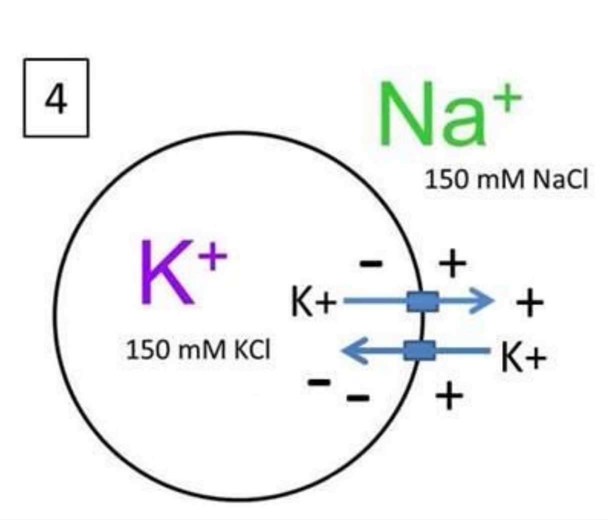
- **[2],**
- if K+ selective ion channels are opened, K+ will travel down its chemical concentration gradient out of the compartment which will cause an excess of positive charges outside the compartment and an excess of negative charges in the compartment.

MEMBRANE POTENTIALS



- **[3],**
- there is still a chemical concentration gradient for K+, but the increase in negative charges in the compartment is causing some K+ to be pulled back in.

MEMBRANE POTENTIALS



- **[4],**
- the number of K+ leaving the compartment because of the concentration gradient equals the number that are being pulled back into the compartment because of the excess of negative charge.
- The membrane potential of the compartment in here is the **equilibrium potential for K+** in this system.

MEMBRANE POTENTIALS

- In a cell, the equilibrium potential for **an ion** is determined by the concentration of the ion inside the cell versus the concentration outside the cell.
- The equilibrium potential for K^+ in a typical neuron is -90 mV (E_K) and for Na^+ is +60 mV (E_{Na}).
- The E_{Na} is positive while E_K is negative because Na^+ and K^+ accumulate on opposite sides of the plasma membrane.

Ion	ECF / Plasma	ICF / Cytosol
Na^+	140.0	15.0
K^+	4.4	140.0
Cl-	105.0	7.0

MEMBRANE POTENTIALS

- If a cell at a given time is permeable to only one ion, the membrane potential will become equal to the equilibrium potential for that ion.

- However, if ion channels open for more than one ion, then the membrane potential will be determined by the concentration of the ions inside and outside of the cell as well as the permeability of the cell to those ions.

MEMBRANE POTENTIALS

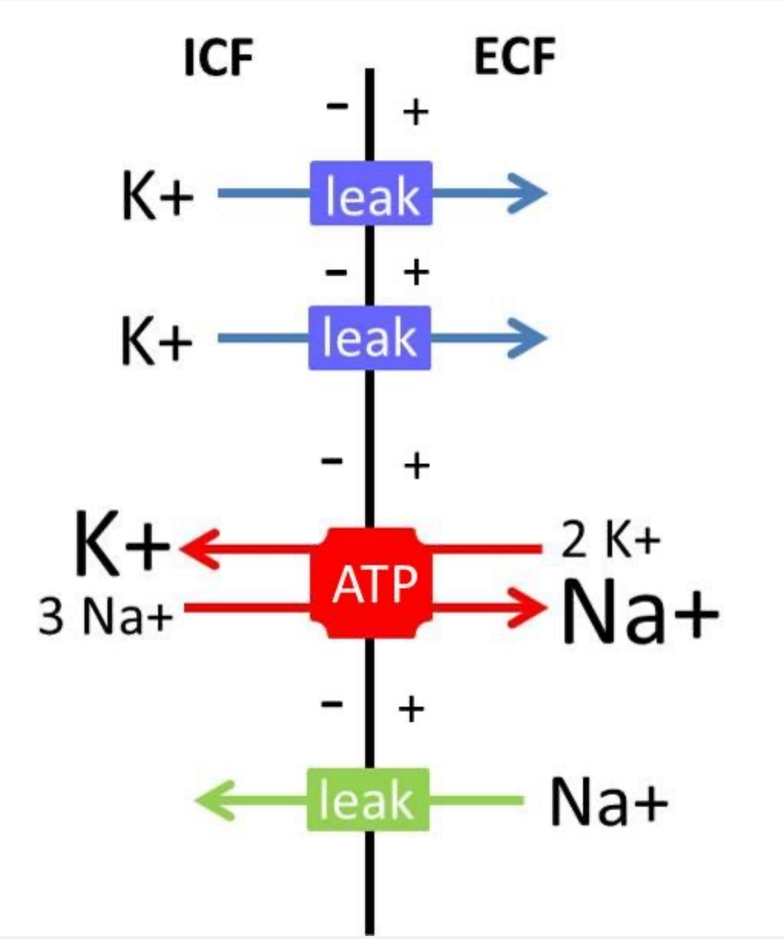
- Under resting conditions, there are **pumps** and **channels** that collectively contribute to the resting membrane potential.

- The **Na+/ K+-ATPase is a pump** that uses the energy from ATP to transport **Na+ out** of the cell and two **K+ into the cell**

MEMBRANE POTENTIALS

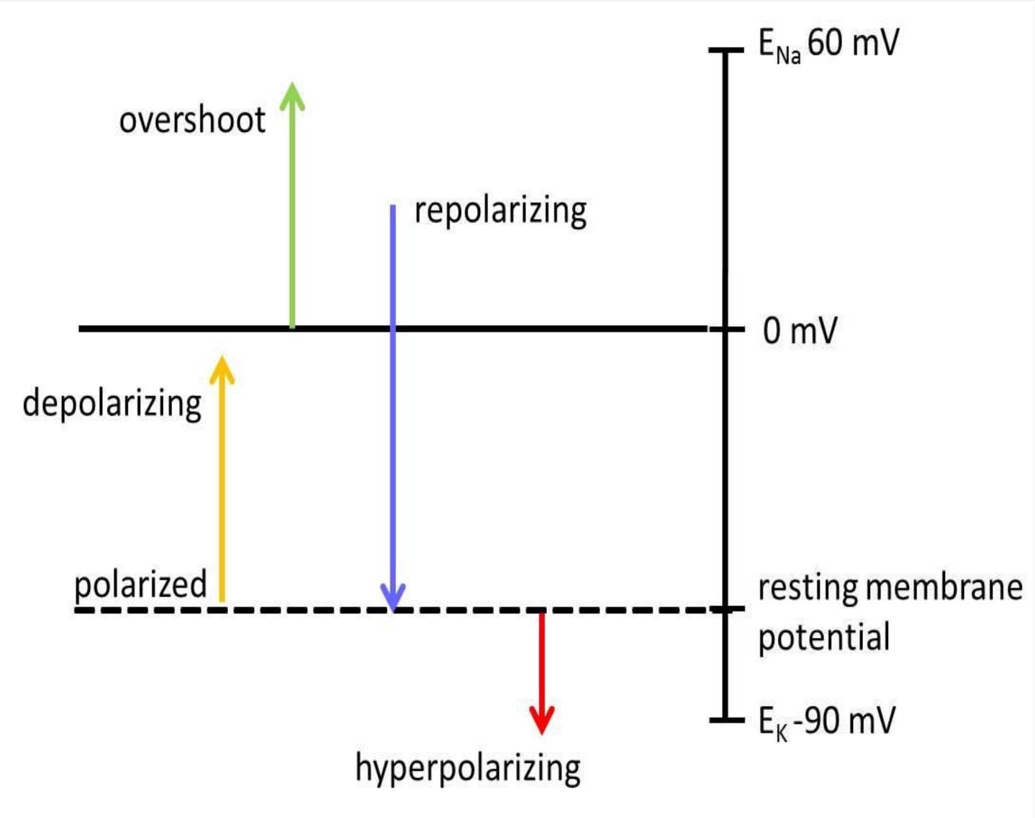
- This maintains the concentration gradients across the plasma membrane and causes the inside of the cell to have an excess of negative charges.
- In addition, there are some K+ channels that allow K+ to leave the cell which makes the inside of the cell even more negative.
- There are also some Na+ channels (fewer than the K+ channels) that let a little Na+ into the cell.
- Once the system reaches steady-state the Na+/ K+-ATPase is pumping the same number of Na+ and K+ and as the channels are letting through and they balance each other.

MEMBRANE POTENTIALS



- When taking into account the action of the Na^+/ K^+-ATPase and the K^+ and Na^+ channels, the resting membrane potential (-70 mV) is between the equilibrium potential for K^+ and Na^+ but closer to the equilibrium potential for K^+ because the membrane is more permeable to K^+.

MEMBRANE POTENTIALS



- **The membrane potential can change quickly and dramatically when the cell is excited.**
- When the membrane potential increases but still remains negative, the membrane is **depolarizing**.
- An **overshoot** is when the membrane potential becomes positive

MEMBRANE POTENTIALS

- When the membrane potential decreases towards the resting potential it is **repolarizing.**
- If the membrane potential goes below the resting potential then it is **hyperpolarized**

GRADED POTENTIALS

- ***Changes in membrane potential produce the electrical signals that neurons use to communicate.***
- A change in membrane potential at a location on the plasma membrane of a neuron results from opening of ion channels.
- The change in membrane potential can then travel along the length of the neuron due to neighbouring ion channels that are gated by electrical stimuli.

GRADED POTENTIALS

- **A graded potential is a transient change in the membrane potential that decreases in magnitude as it spreads out along the plasma membrane of the neuron and is proportional to the intensity of the stimulus.**

GRADED POTENTIALS

- If ion channels in a specific part of the membrane are activated and that portion of the membrane is depolarized, the positive charges that have entered the cell will diffuse along the inside of the membrane
- This area of depolarisation will continue to spread but will decrease in intensity over distance.
- If the stimulus is more intense, more ion channels will open and the change in potential will be greater.

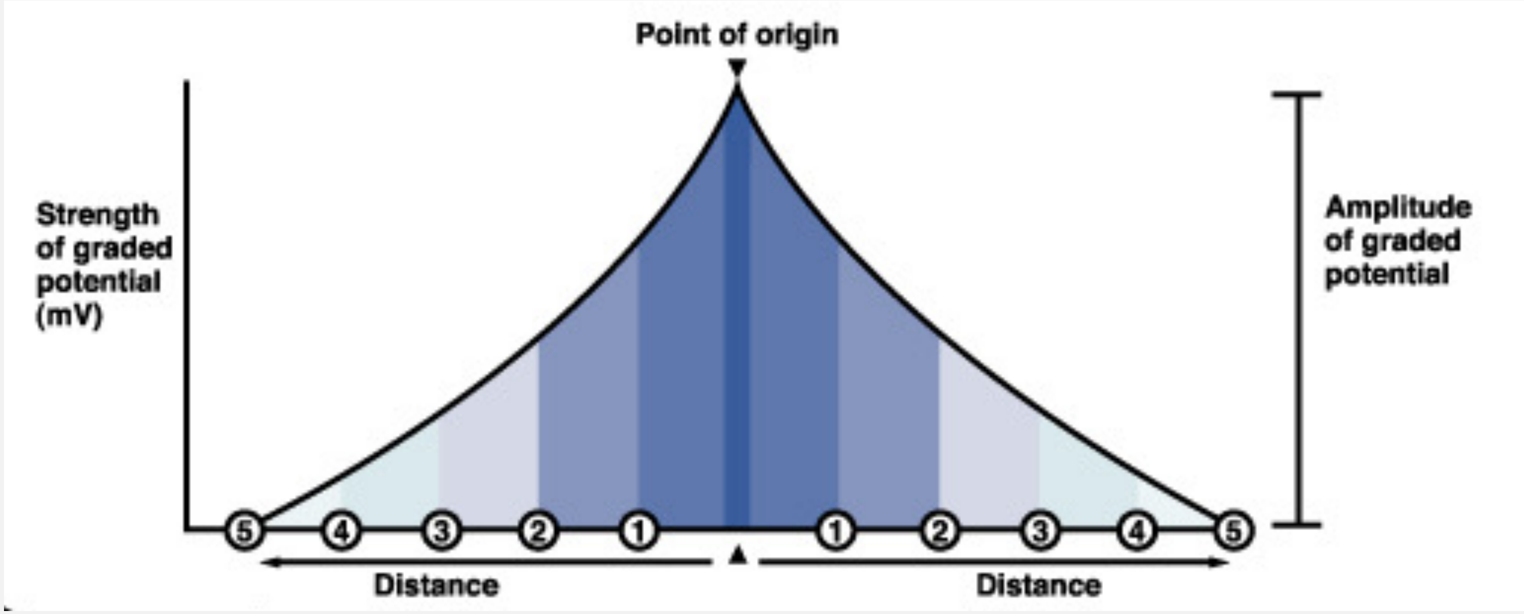
GRADED POTENTIALS

- This will result in the graded potential traveling a further distance
- Eg. the positive charge carried by the Na^+ spreads as a wave of depolarization through the cytoplasm

(much like the ripples created by a stone tossed into a pond).

GRADED POTENTIALS

- As the Na^+ drifts, some of it will leak back out of the membrane.
  - What this means is that the degree of depolarization caused by the graded potential decreases with distance from the origin.



GRADED POTENTIALS

- However, they can also be additive if they occur in rapid succession.
- Their initial amplitude may be of almost any size – it simply depends on how much Na+ originally entered the cell.
- If the initial amplitude of the GP is sufficient, it will spread all the way to the axon hillock where **V-gated channels** reside.
- If the arriving potential change is suprathreshold, an Action Potential (AP) will be initiated in the axon hillock and it will travel down the axon to the synaptic knob where it will cause (neurotransmitter) NT exocytosis.

GRADED POTENTIALS

- Graded potentials can **stimulate or inhibit** neurons and have no refractory(resting) period, or time period when the cell can not respond to a stimulus after the first change in potential.

- If the potential change is subthreshold, then no AP will ensue and nothing will happen.

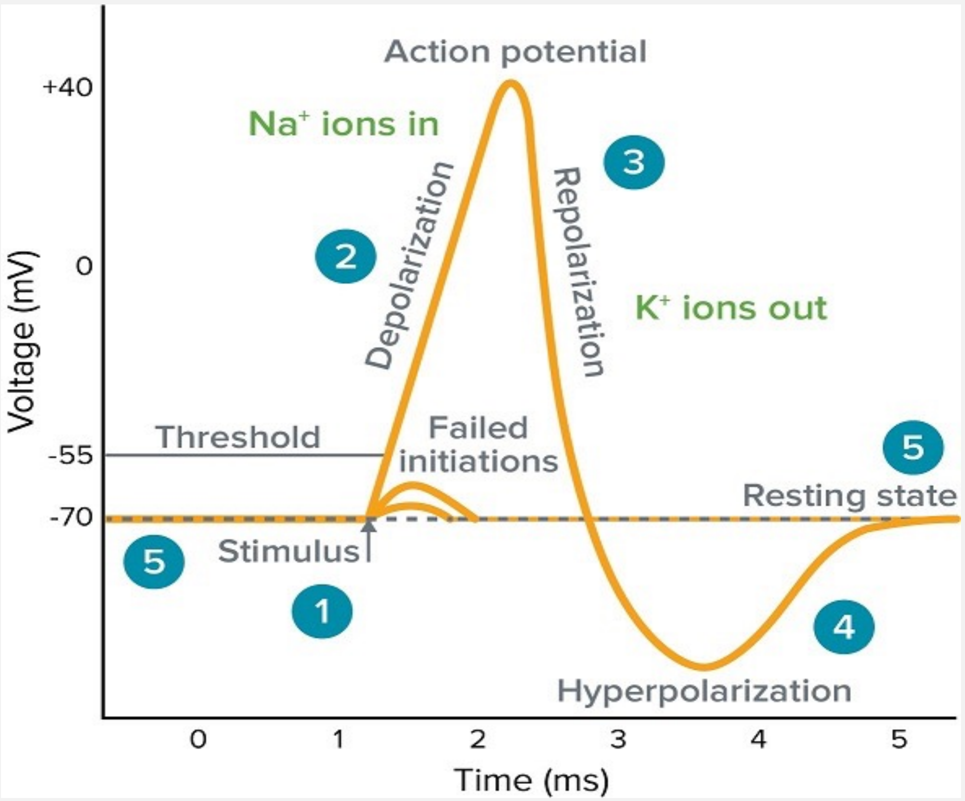
ACTION POTENTIALS

- Most neurons use action potentials as the most efficient and quickest way to convey electrical currents along the length of their axon.
- An action potential is an electrical signal like graded potentials but they differ in several ways.

ACTION POTENTIALS

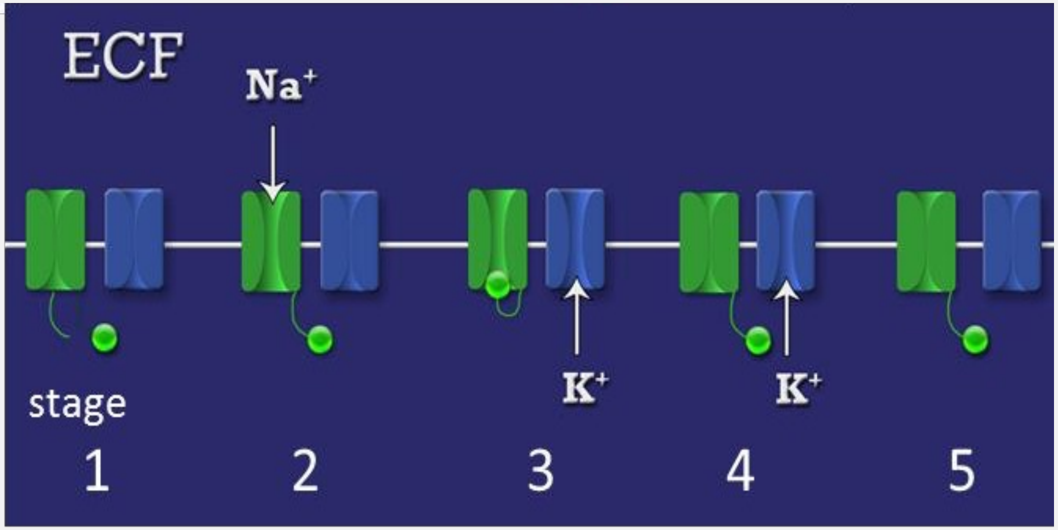
- **Action potentials are large changes in membrane potential** that have a similar pattern of membrane potential change.
- In this way, an action potential is an all-or-none phenomenon because either there is a large change in membrane potential if the stimulus was adequate or there is little change in membrane potential.
- Action potentials have the same intensity as they travel along a membrane – they do not diminish over distance.
- .

ACTION POTENTIALS



- At the beginning of an action potential the cell which was at resting membrane potential has a graded potential that causes the membrane to be depolarized.
- If the depolarization from the graded potential reaches a certain voltage, called **the threshold**, then enough voltage-gated Na+ channels will be opened to start an action potential (stage 2)

ACTION POTENTIALS



- Once enough Na^+ channels are open, Na^+ starts rushing into the cell due to the net negative charge inside the cell and the excess of Na^+ outside the cell.
- This causes the membrane potential to increase (stage 2) and surpass 0 mV due to the concentration gradient of Na^+

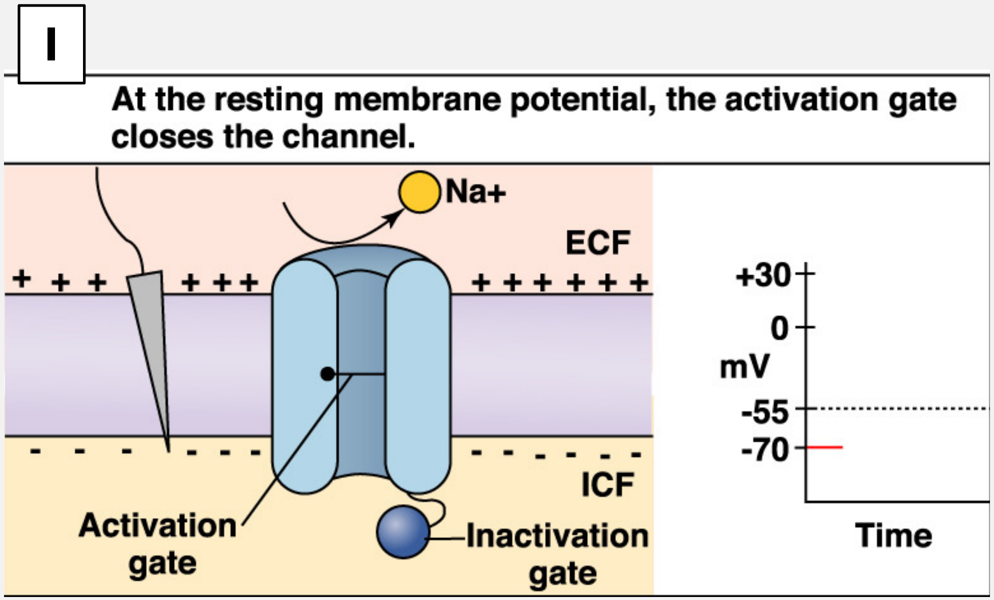
ACTION POTENTIALS

- The cell is so permeable to Na^+ that the membrane potential quickly comes close to the equilibrium potential for Na^+.
- Right before the membrane potential reaches the equilibrium potential for Na^+, the Na^+ channels inactivate and the slower opening voltage-gated K^+ channels open.
- When the K^+ channels open, there is an excess of positive charge and K^+ inside the cell (a positive membrane potential) so K^+ leaves the cell and travels down its concentration and electrical gradients.

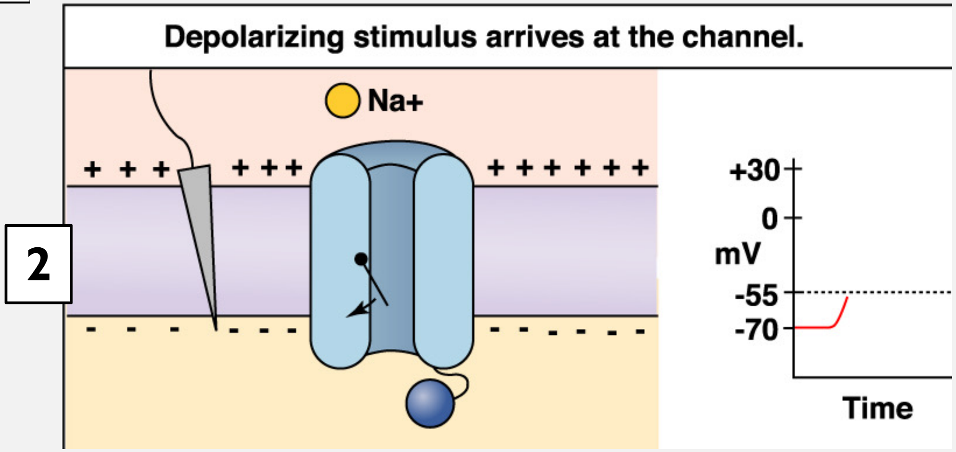
ACTION POTENTIALS

- This lowers the membrane potential (stage 3) and it approaches the equilibrium potential for K^+, which is below resting potential (stage 4). The K^+ channels start to close and the membrane returns to the resting potential (stage 5).

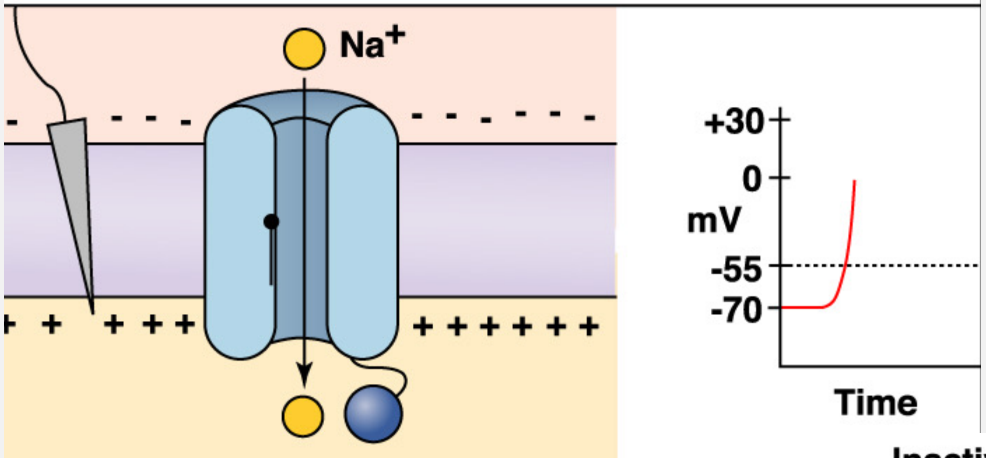
Eg: Na^+ CHANNELS



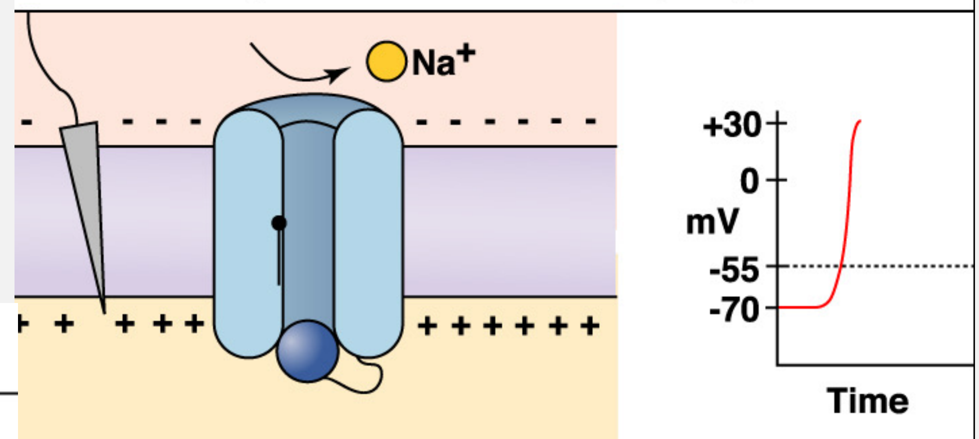
- They have 2 gates.
  - At rest, one is closed (the activation gate) and the other is open (the inactivation gate).
  - Suprathreshold depolarization affects both of them.



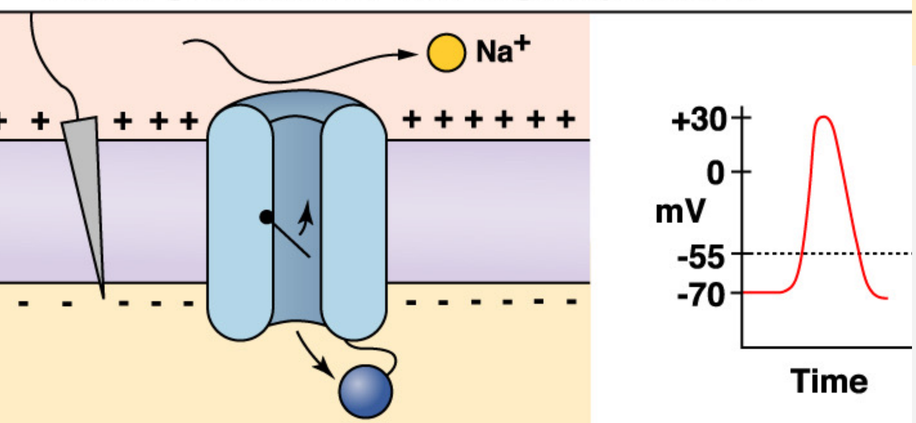
3 With activation gate open, Na^+ enters the cell.



4 Inactivation gate closes and Na^+ entry stops.



5 During repolarization caused by K^+ leaving the cell, the two gates reset to their original positions.



REFRACTORY PERIOD

- Once the Na+ channels have inactivated, the membrane must repolarize before the channel returns to the closed state and can be opened again.

- This means that there is a **refractory period** that prevents another action potential from occurring before the first one has ended.

REFRACTORY PERIOD

- Once an action potential occurs in one portion of the axon, the adjacent area will experience a depolarization from the spread of Na+ just like in a graded potential as long as the proper channels are expressed.

  - This will be above threshold and will cause an action potential in the adjacent area which allows the action potential to travel along the axon.

REFRACTORY PERIOD

- However, because of the refractory period, the action potential travels in one direction along the axon and not in two directions.
- In addition, each action potential that is produced down the axon will be identical and will not diminish over time or distance.

ABSOLUTE REFRACTORY PERIOD

- A Na^+ channel cannot be involved in another AP until the inactivation gate has been reset.

REFRACTORY PERIOD

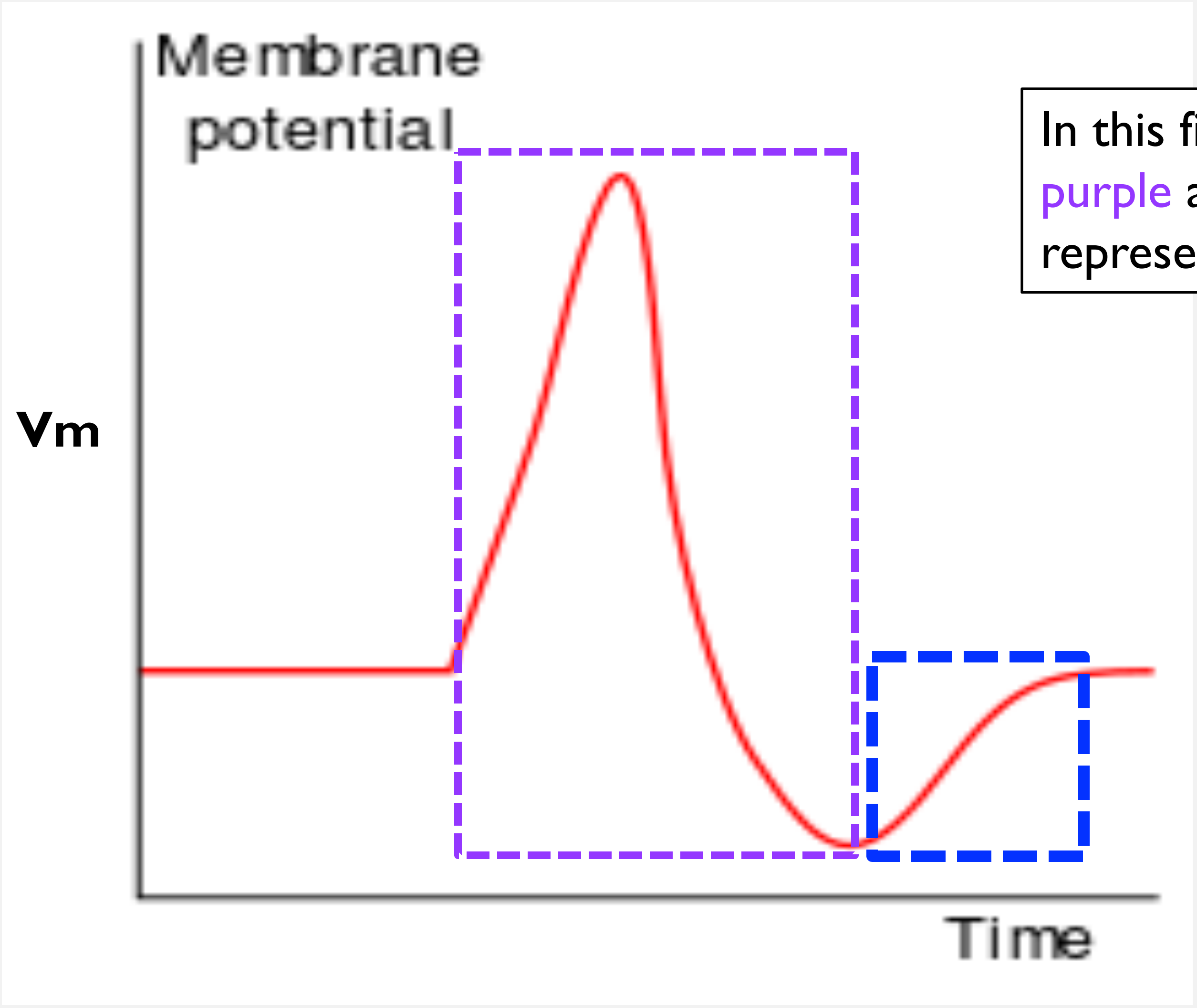
RELATIVE REFRACTORY PERIOD.

- Could an AP be generated during the undershoot?
  - Yes! But it would take an initial stimulus that is much, much stronger than usual.
  - This situation is known as the relative refractory period.

Imagine, if you will, a toilet.

When you pull the handle, water floods the bowl. This event takes a couple of seconds and you cannot stop it in the middle. Once the bowl empties, the flush is complete. Now the upper tank is empty. If you try pulling the handle at this point, nothing happens (*absolute refractory*). Wait for the upper tank to begin refilling. You can now flush again, but the intensity of the flushes increases as the upper tank refills *(relative refractory)*

ACTION POTENTIAL



In this figure, what do the purple and blue box represent?

ACTION POTENTIAL

- *What does it mean when we say an AP is "all or none?"*
  - *Can you ever have ½ an AP?*
- *How does the concept of threshold relate to the "all or none" notion?*
- *Will one AP ever be bigger than another?*
  - *Why or why not?*

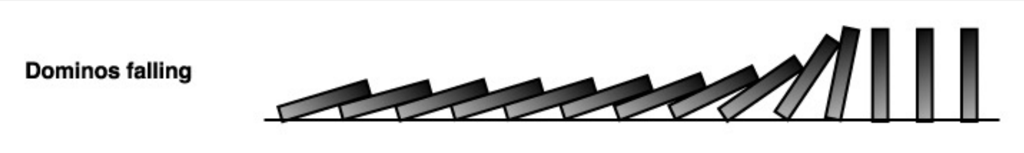
ACTION POTENTIAL CONDUCTION

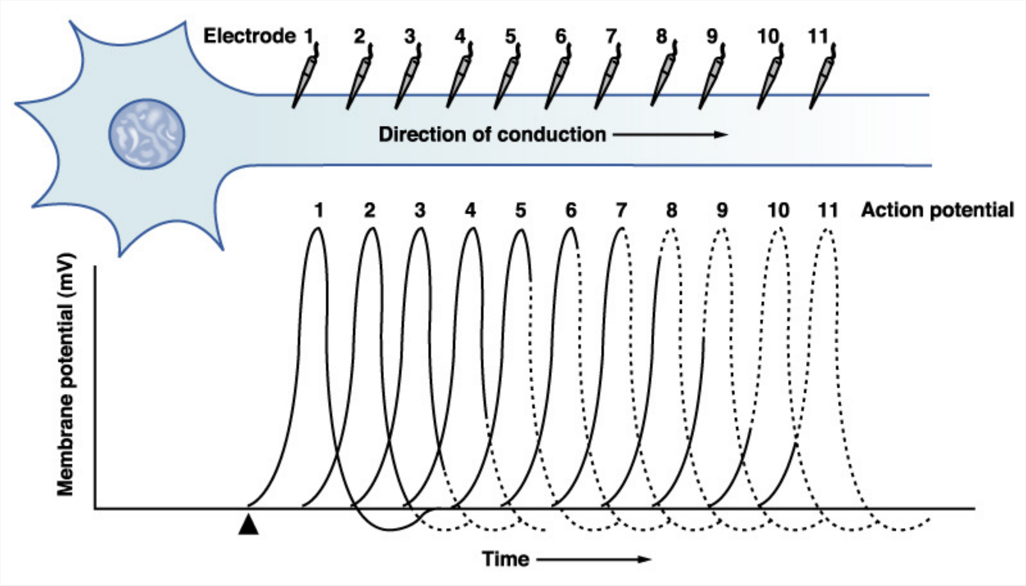
- If an AP is generated at the axon hillock, it will travel all the way down to the synaptic knob.
- The manner in which it travels depends on whether the neuron is myelinated or unmyelinated.

- **Unmyelinated neurons undergo the *continuous conduction* of an AP whereas myelinated neurons undergo *saltatory conduction* of an AP.**

ACTION POTENTIAL
- **CONTINUES** CONDUCTION

- Occurs in **unmyelinated** axons.
- In this situation, the wave of de- and repolarization simply travels from one patch of membrane to the next adjacent patch.
- APs moved in this fashion along the sarcolemma of a muscle fiber as well.
- Analogous to dominoes falling.

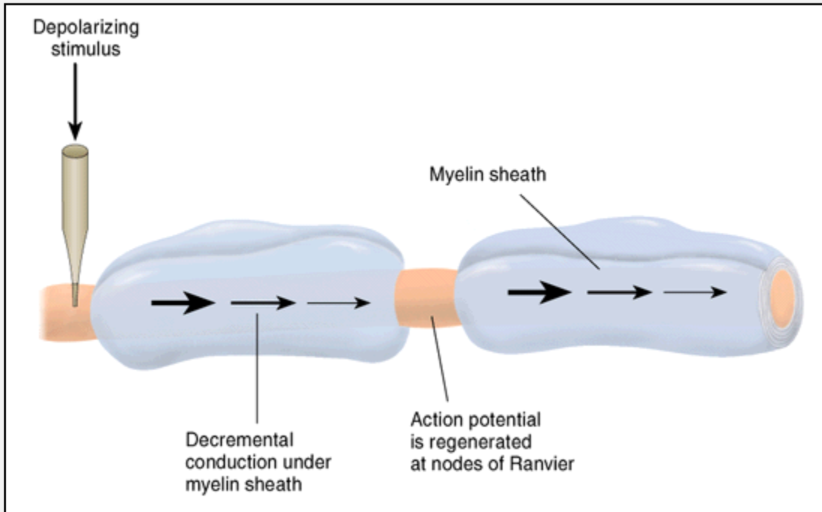




ACTION POTENTIAL

- **SALTATORY** CONDUCTION

- Occurs in **myelinated** axons.
- *Saltare* is a Latin word meaning "to leap."
- In the human body, axons are quite long (from the spinal cord to the tip of the toe). In order for an action potential to travel quickly along an axon that may be one meter long, some axons are myelinated.
  - There exist myelin free regions along the axon, **the nodes of Ranvier.**



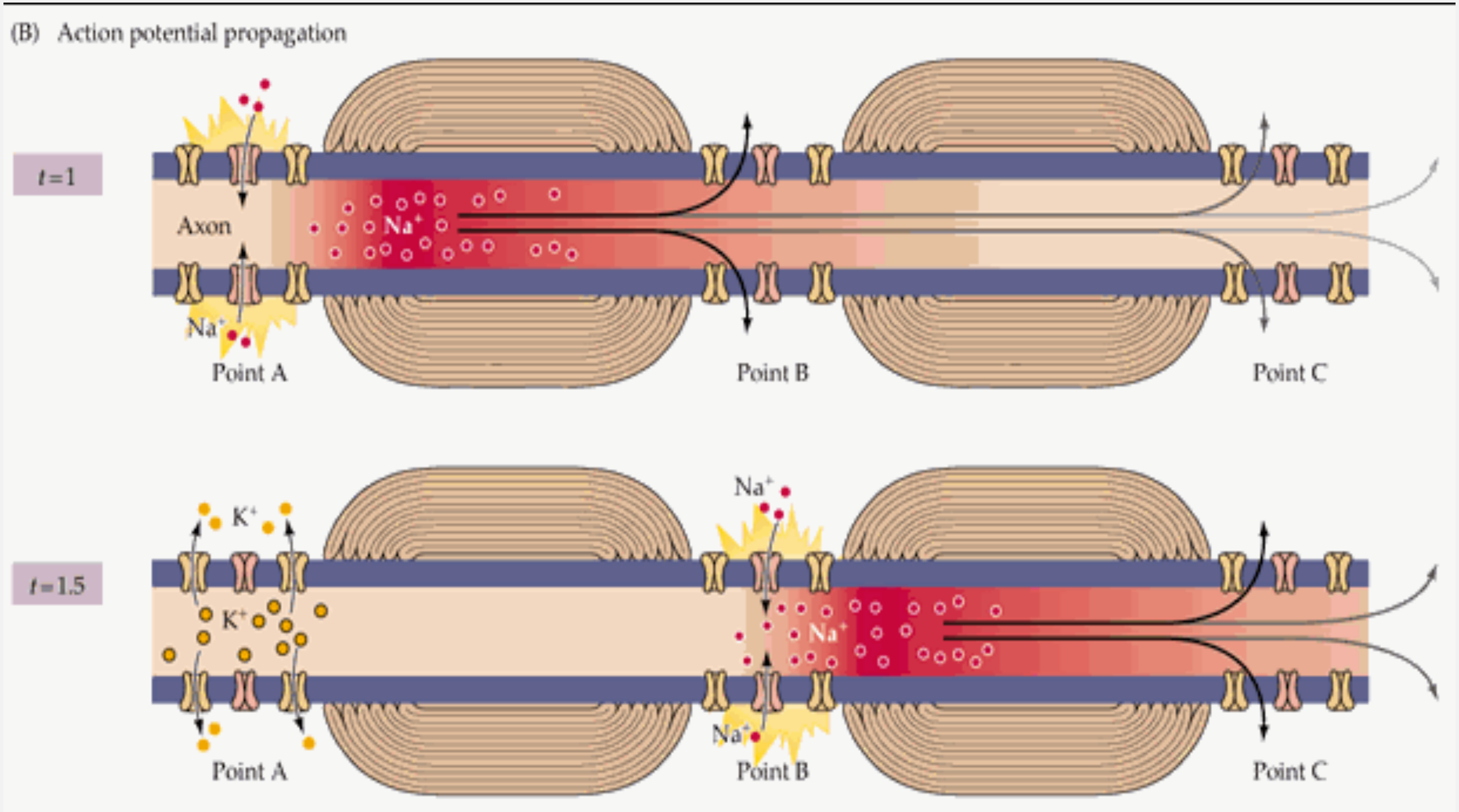
ACTION POTENTIAL

- SALTATORY Conduction

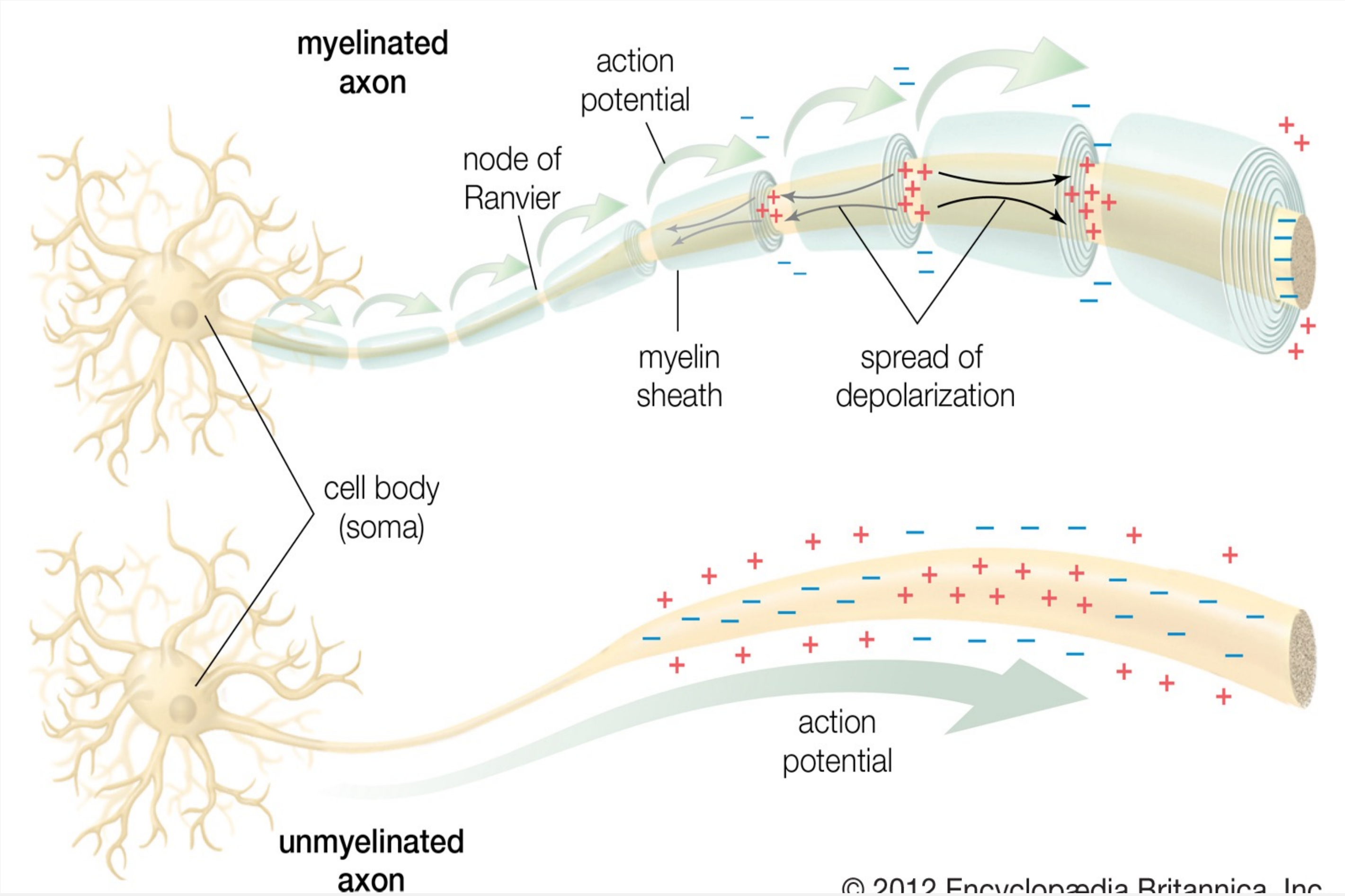
- The myelin speeds conduction along an axon by insulating it and preventing leaking of ions in the area around an action potential.
- This allows the change in membrane potential, to be detected further down the axon in the neighbouring node where there is a concentration of ion channels.
- In a myelinated axon, the action potential jumps from node to node allowing it to travel more quickly and more efficiently

ACTION POTENTIAL

- SALTATORY Conduction



RATES OF AP CONDUCTION



RATES OF AP CONDUCTION

- The diameter of an axon also determines how quickly action potentials travel down its length.
- Larger diameter axons have less resistance so action potentials travel more quickly along their length.
- This is exploited by the body. Neurons that sense touch have large diameter axons while pain and itch neurons have small diameter axons.

TYPES OF NERVE FIBERS

Group A

- Axons of the somatic sensory neurons and motor neurons serving the skin, skeletal muscles, and joints.
- Large diameters and thick myelin sheaths.

Group B

- Lightly myelinated and of intermediate diameter.

Group C

- Unmyelinated and have the smallest diameter.

Autonomic nervous system fibers serving the visceral organs, visceral sensory fibers, and small somatic sensory fibers are Type B and Type C fibers.

TYPES OF NERVE FIBERS

Autonomic nervous system fibers serving the visceral organs, visceral sensory fibers, and small somatic sensory fibers are Type B and Type C fibers.

CHEMICAL SIGNALS

- One neuron will transmit info to another neuron or to a muscle or gland cell by releasing chemicals called **neurotransmitters.**
- The site of this chemical interplay is known as the **synapse,** where the electrical signal from one neuron (***presynaptic neuron)*** is transmitted to another neuron (***postsynaptic neuron***).

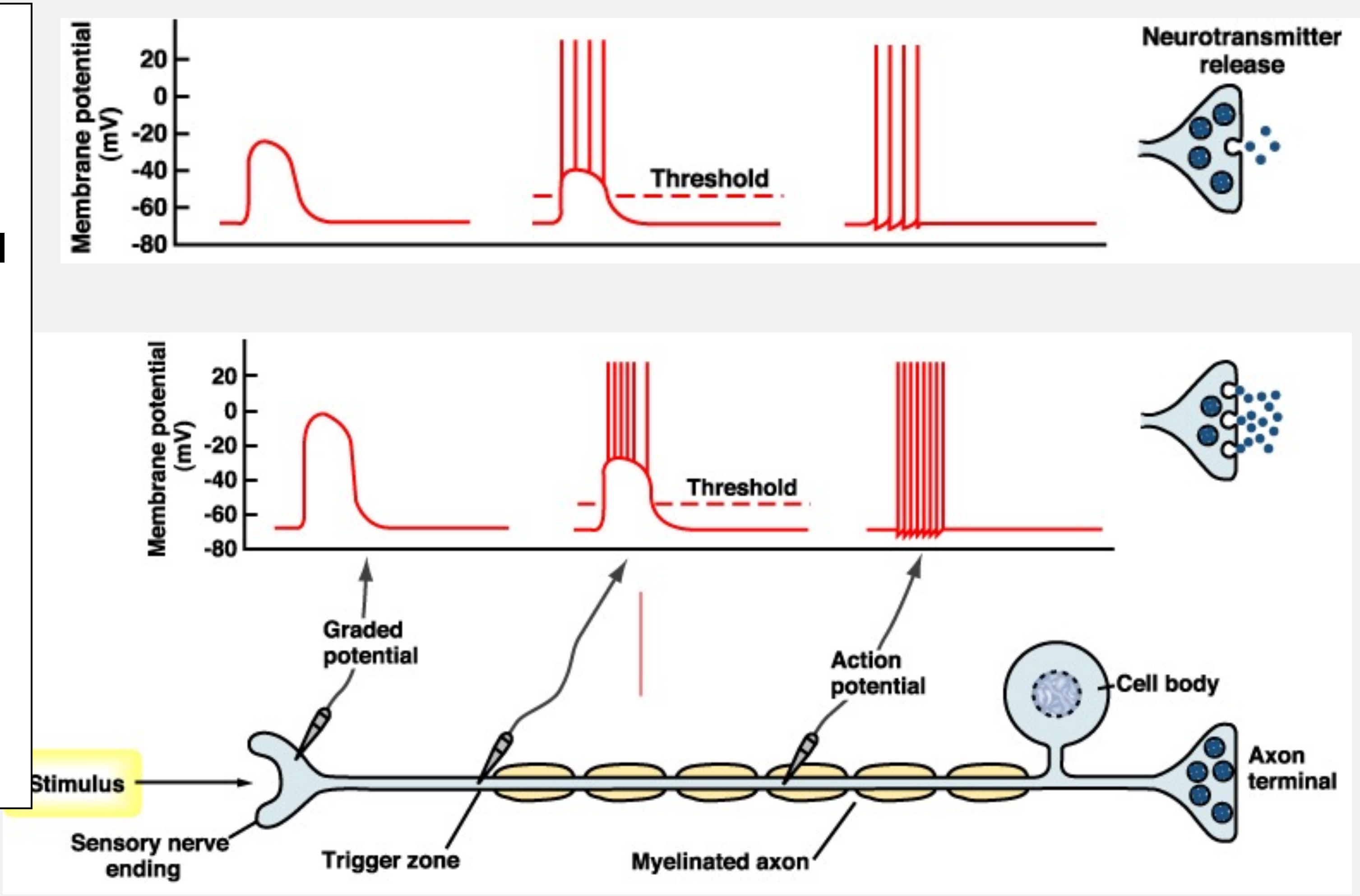
CHEMICAL SIGNALS

- An axon terminal (***synaptic knob***) will adjoin another cell, a *neuron*, *muscle fiber,* or *gland cell*

- This is the site of transduction – the conversion of an electrical signal into a chemical signal.
- The presynaptic neuron causes a graded potential to occur in the postsynaptic neuron.

CHEMICAL SIGNALS

In the diagram on the right, notice the effect that **the size of the graded potential has on the frequency of AP's and on the quantity of NT released.** The weak stimulus resulted in a small amt of NT release compared to the strong stimulus.



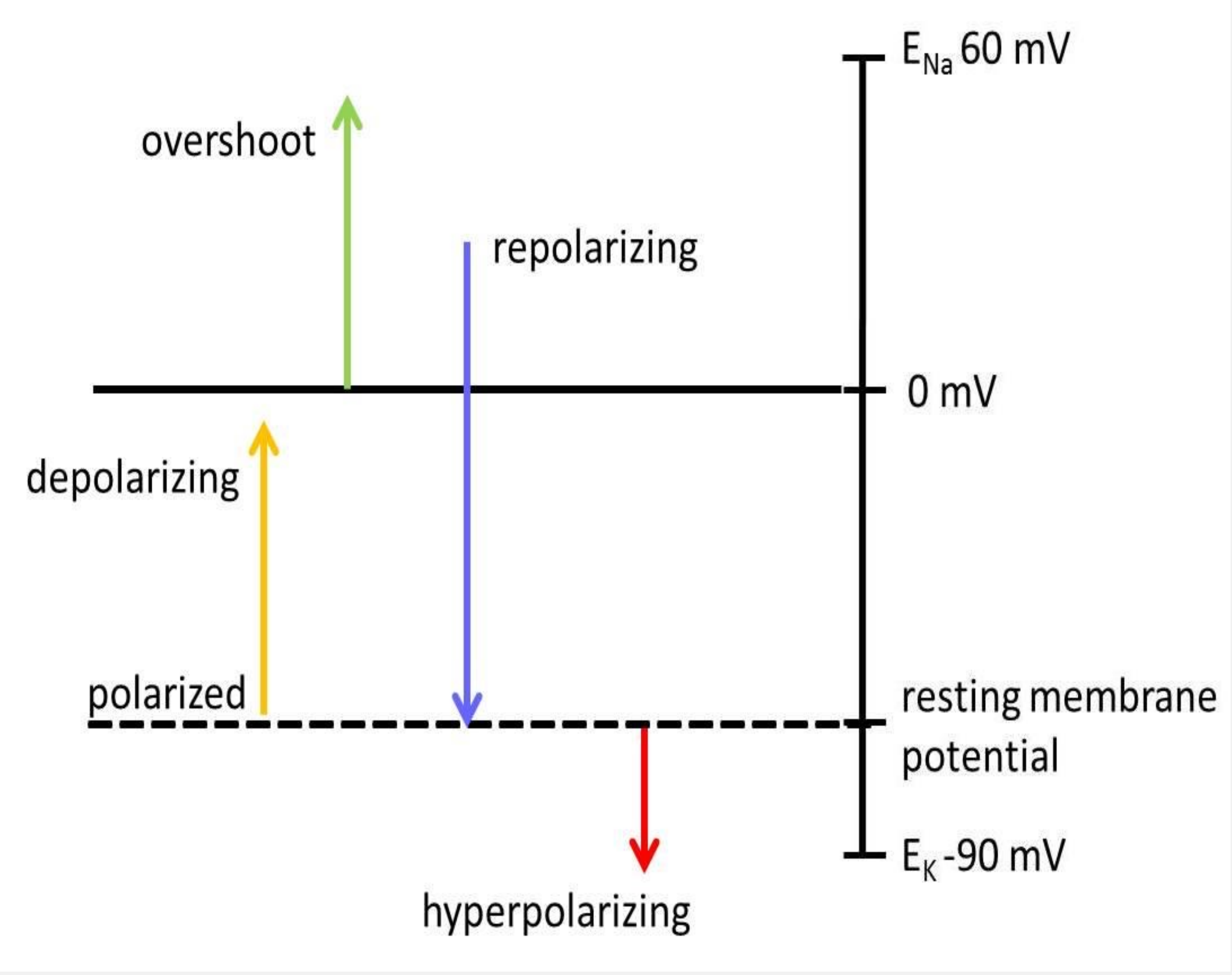
CHEMICAL SIGNALS

- The graded potential can ***depolarize the postsynaptic*** membrane, which makes the potential closer to threshold, and is called an **excitatory postsynaptic potential (EPSP)**
- Alternatively, the graded potential can hyperpolarize the postsynaptic membrane, which makes the membrane potential farther from threshold, and is called an **inhibitory postsynaptic potential (IPSP)**

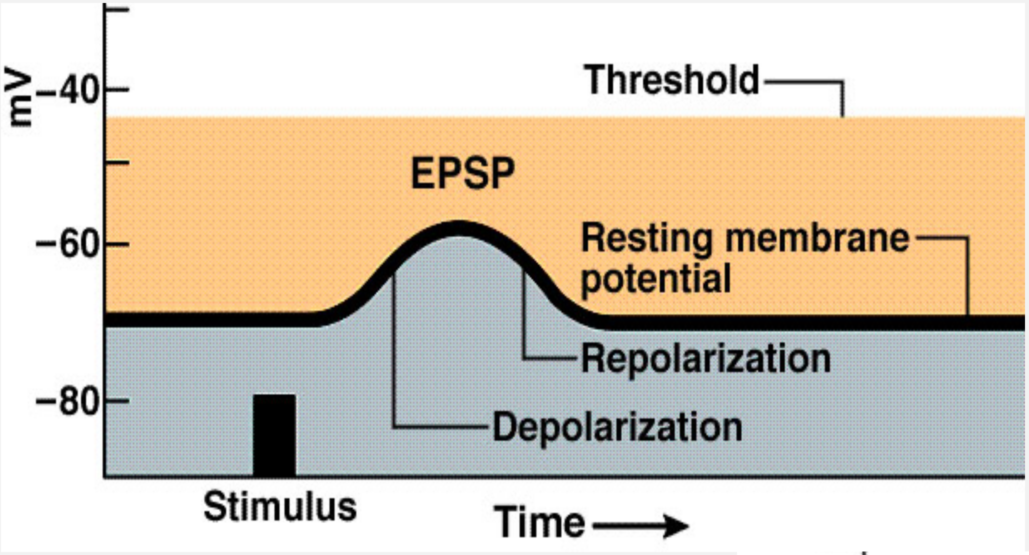
CHEMICAL SIGNALS

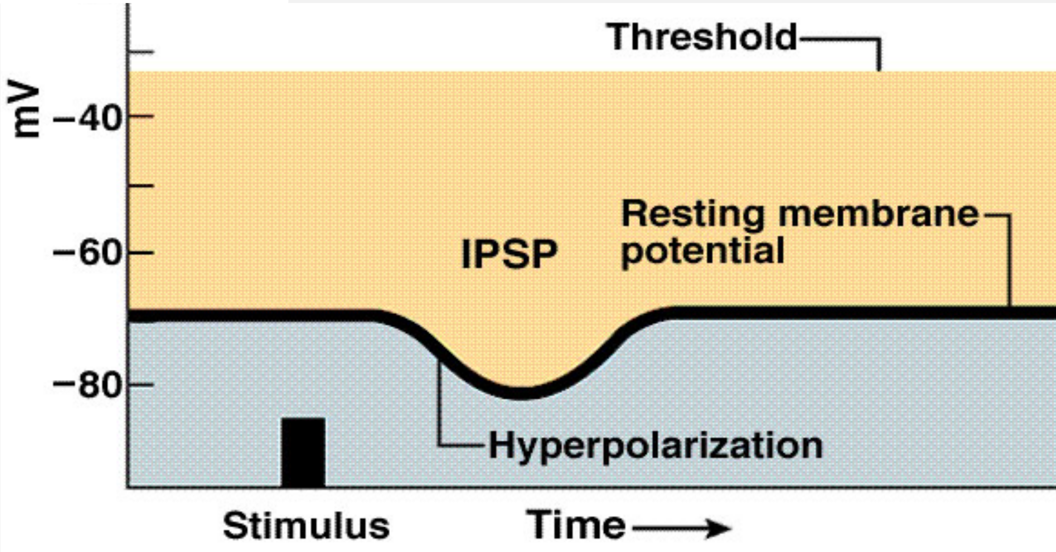
- Since presynaptic neurons cause graded potentials in postsynaptic neurons, **spatial and temporal summation of signals from multiple synapses can occur** so the postsynaptic neuron can integrate information.

CHEMICAL SIGNALS



CHEMICAL SIGNALS



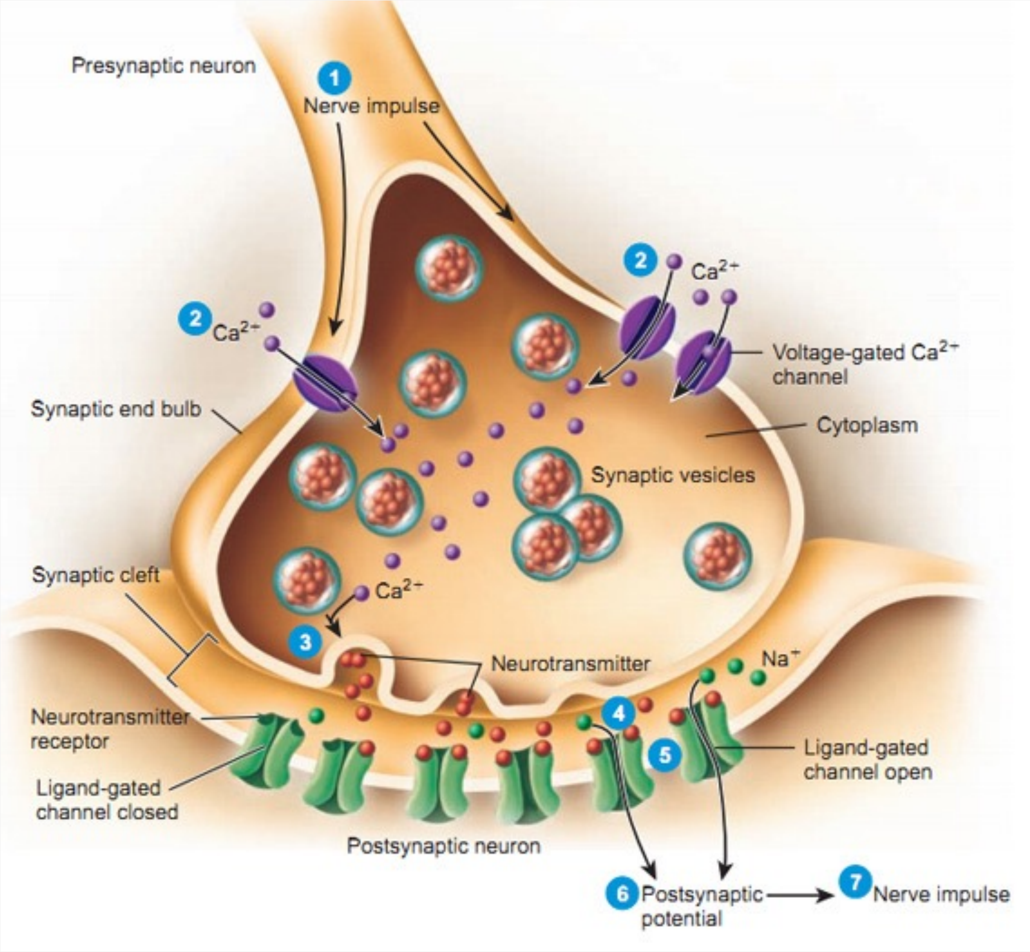


SYNAPTIC TRANSMISSION

[1] An AP reaches the axon terminal depolarizing the presynaptic membrane and causes v-gated Ca^{2+} channels to open.

[2] Ca^{2+} rushes in, binds to regulatory proteins & initiates exocytosis of NT
(e.g. *Acetylcholine molecules*)

[3] then fuse with the presynaptic membrane releasing NT molecules into the synaptic cleft

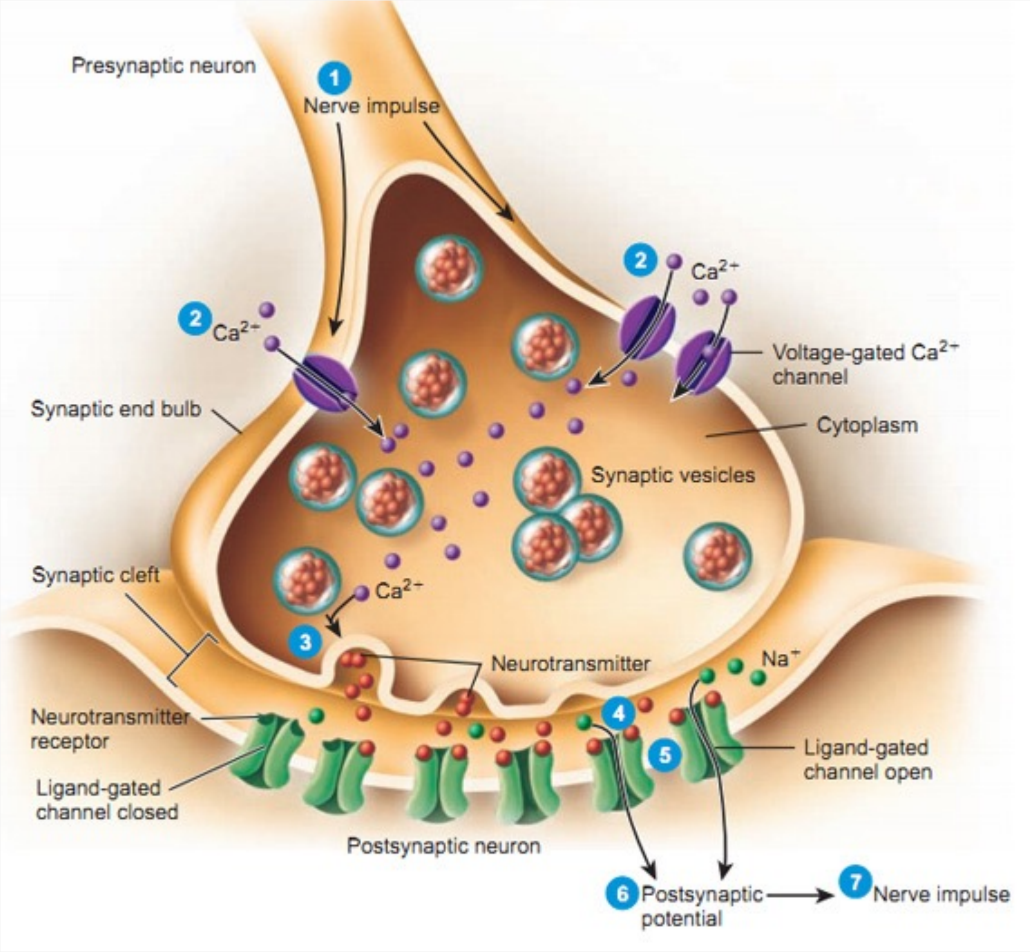


SYNAPTIC TRANSMISSION

[4] NTs diffuse across the synaptic cleft and then bind to receptors on the postsynaptic membrane

[5] ligand-gated Na+ channels in the postsynaptic membrane open.

Na+ ions subsequetly rush into the postsynaptic cell and initiate some sort of response on the postsynaptic cell.



EFFECTS OF THE NEUROTRANSMITTER

- Different neurons can contain different NTs.
- Different postsynaptic cells may contain different receptors.
  - Thus, the effects of an NT can vary.

- Some NTs cause ***cation channels*** to open, which results in a ***graded depolarization*.**

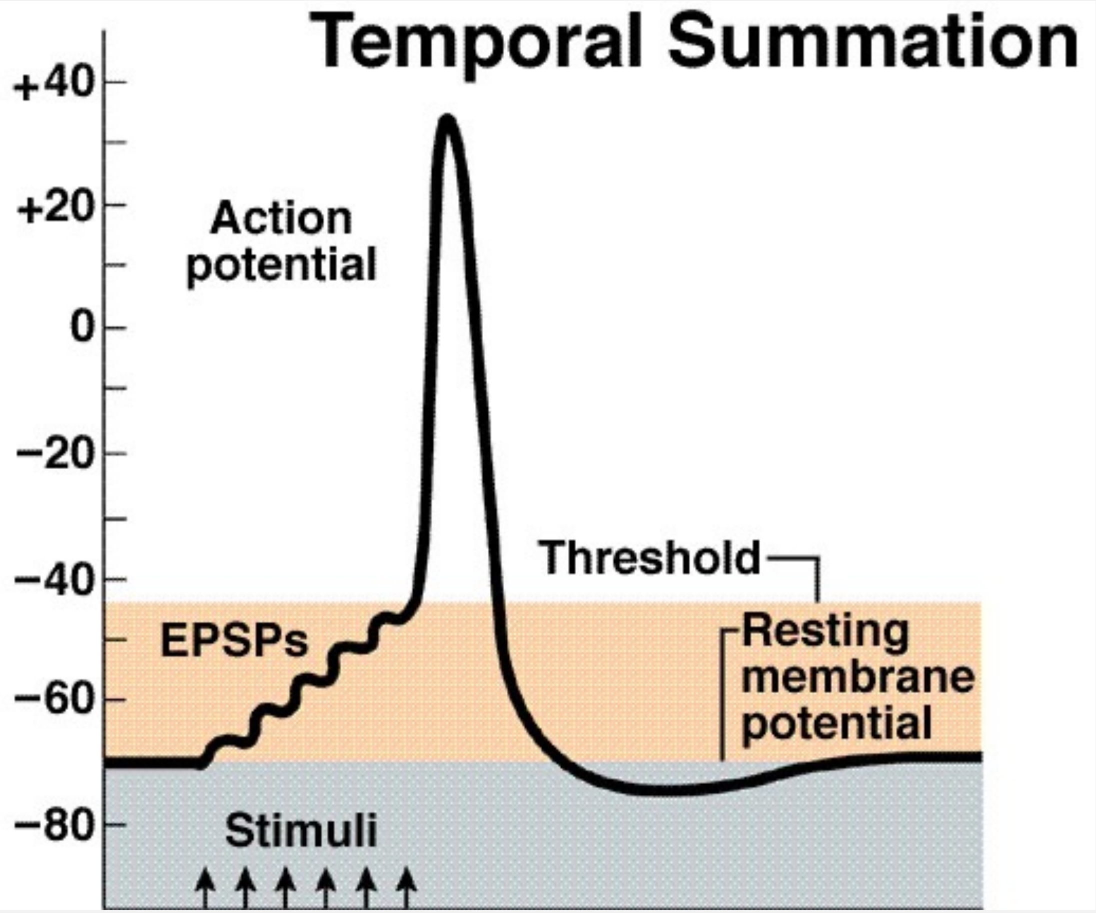
- Some NTs cause ***anion channels*** to open, which results in a ***graded hyperpolarization***.

SUMMATION

- One EPSP is usually not strong enough to cause an AP However, EPSPs may be summed ***"temporal summation"***
- The same presynaptic neuron stimulates the postsynaptic neuron multiple times in a brief period.
- The depolarization resulting from the **combination of all the EPSPs may be able to cause an AP.**

- ***Spatial summation***
  - Multiple neurons all stimulate a postsynaptic neuron resulting in a combination of EPSPs which may yield an AP

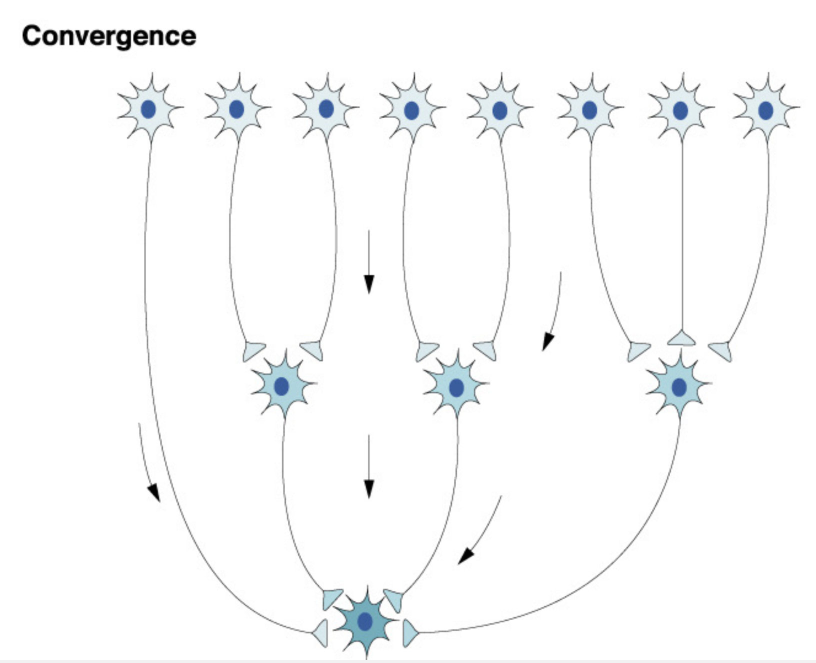
SUMMATION



Temporal Summation
+40
+20
0
−20
−40
−60
−80
Action potential
Threshold
EPSPs
Resting membrane potential
Stimuli

COMMUNICATION

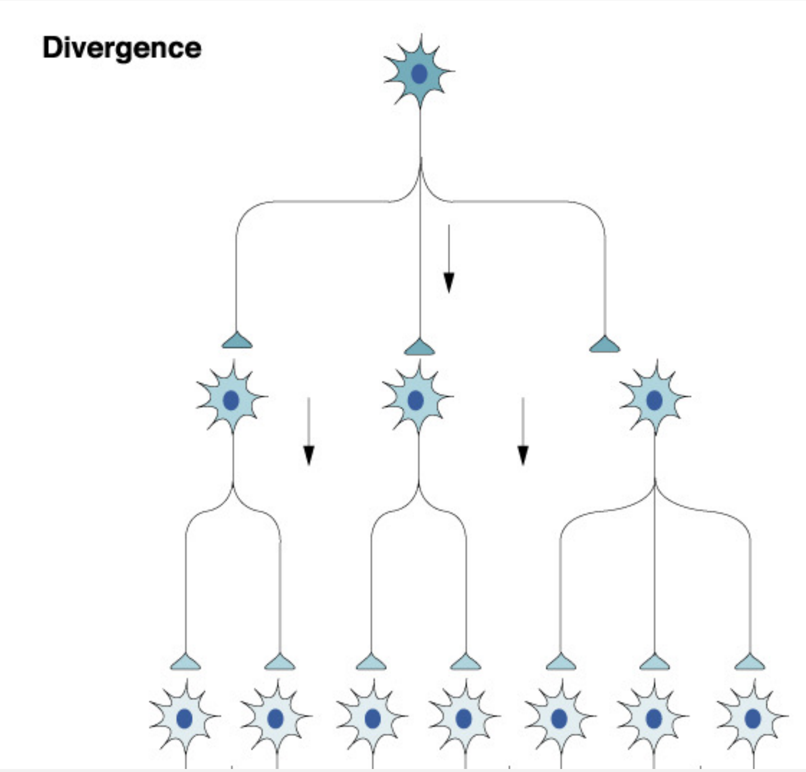
- Communication between neurons is not typically a one-to-one event.
  - Depending on the role of a particular neuron, it can receive signals from many presynaptic neurons (convergence)
  - A single postsynaptic neuron may have synapses with as many as 10,000 postsynaptic neurons.



COMMUNICATION

OR

- It can send signals to many postsynaptic neurons (divergence)
- A single neuron branches and its collaterals synapse on multiple target neurons.



EFFECTS OF THE NEUROTRANSMITTER

- Neurons may also form reverberating circuits.
  - A chain of neurons where many give off collaterals that go back and synapse on previous neurons.

SENSORY RECEPTORS

SENSORY RECEPTORS

- Sensory receptors help us learn about our environment, internal organs and processes (*interoceptors*) or outside (*exteroceptors*)

  - **Receptors are the *structures (or whole cells)* that detect sensations**.

- Sensory receptors ***occur in specialized organs*** such as the eyes, ears, nose, and mouth, as well as internal organs.
- Each receptor type conveys a distinct sensory modality for integration.

SENSORY RECEPTORS

- Stimuli from different sources are received and changed into the electrochemical signals
  - **what ultimately determines how we perceive the stimulus is *where the nerve fibre terminates* in the central nervous system.**
- When a receptor detects a stimulus, it generates a ***graded potential*** in a sensory neuron.
  - Graded potential above the threshold causes the sensory neuron to produce an ***action potential*** that is relayed into the central nervous system (CNS), where it is integrated with other sensory information

SENSORY RECEPTORS

- ***Transmembrane protein receptor*** in the cell membrane mediates a physiological change in a neuron.
  - through the opening of ion channels or changes in the cell signalling processes.
  - Some transmembrane receptors are activated by chemicals called ***ligands***.
    - Eg. a molecule in food can serve as a ligand for taste receptors.

SENSORY RECEPTORS

- Other **transmembrane proteins are sensitive to *mechanical*** or ***thermal* changes.**

- Physical changes in these proteins increase ion flow across the membrane, and can **generate a graded potential** in the sensory neurons.

SENSORY RECEPTORS

- Sensory receptors can be classified by the type of stimulus that generates a response in the receptor.
- **4 Broad receptors:**
    - Chemicals (chemoreceptors)
    - Temperature (thermoreceptors)
    - Pressure (mechanoreceptors)
    - Light (photoreceptors)

SENSORY RECEPTORS

Functions to:

- Give ***vision*** ***by rod and cone photoreceptors*** responding to light intensity and colour.
- Give ***hearing*** ***by mechanoreceptors*** in hair cells of the inner ear detecting vibrations conducted from the eardrum.
- Give **taste** by ***sensory neurons in our taste buds*** detecting chemical molecules in foods including sweetness, bitterness, sourness, saltiness
- Give **smell** by ***olfactory receptors*** recognizing molecular features of odours.
- Give ***touch, mechanoreceptors in the skin*** and other tissues respond to variations in pressure.

SENSORY RECEPTORS

Classification based on the type of stimulus

Chemical stimuli can be interpreted by

- ***chemoreceptors*** interprets chemical stimuli, such as an object's **taste or smell.**
- ***Osmoreceptors*** respond to solute **concentrations of body fluids.**
  - *pain is primarily a chemical sense* that interprets the presence of chemicals from tissue damage, or similar *intense stimuli, through a* ***nociceptor.***

SENSORY RECEPTORS

Classification based on the type of stimulus

- **Physical stimuli**, such as pressure and vibration, as well as the sensation of sound and body position (balance), are interpreted through a mechanoreceptor.
- Temperature, which is sensed through a thermoreceptor that is either sensitive to temperatures above (heat) or below (cold) normal body temperature.

SENSORY RECEPTORS

Classification by location:

- **Exteroceptor** is located near a stimulus in the external environment, such as the ***somatosensory receptors that are located in the skin***
  - sensory receptors are found in the dermis or epidermis.
- **Interoceptor** interprets stimuli from internal organs and tissues, such as the ***receptors that sense the increase in blood pressure in the aorta or carotid sinus***.

SENSORY RECEPTORS

Classification by location:

- **Proprioceptor** are located near a moving part of the body, such as a muscle, that interprets the positions of the tissues as they move.
  - Muscle spindles contain **mechanoreceptors that detect stretch in muscles.**

SENSORY RECEPTORS

Classification by Morphology or structure

- Somatic sensory receptors near the surface of the skin can usually be divided into two groups based on morphology:
- Free nerve endings characterize the nociceptors and thermoreceptors.(eg.muscle, joints, bone and viscera)
- Encapsulated receptors consist of the remaining types of cutaneous receptors. Have a special capsule which encloses a nerve ending.
    - Eg. Golgi tendon organs - tendon stretch, muscle contraction.

SENSORY RECEPTORS

Classification by Morphology or structure

- Sensory neurons can have either
  - (a) free nerve endings or
  - (b) encapsulated endings.
  - (c) specialized receptor cells,
    - Eg. Photoreceptors in the eyes, such as rod cells
    - These cells release neurotransmitters onto a bipolar cell, which then synapses with the optic nerve neurons.

Sensory receptors with corresponding stimuli to which they respond.

Receptor	Stimulus
Apmullae of Lorenzini (primarily function as electroreceptors)	Electric fields, salinity, and temperature
Baroreceptors	Pressure in blood vessels
Chemo receptors	Chemical stimuli
Electromagnetic radiation receptors	Electromagnetic radiation
Electroreceptors	Electrofields
Hydroreceptors	Humidity
Infrared receptors	Infrared radiation
Magnetoreceptors	Magnetic fields
Mechanoreceptors	Mechanical stress or strain
Nociceptors	Damage or threat of damage to body tissues (leads to pain perception)
Osmoreceptors	Osmolarity of fluids
Photoreceptors	Visible light
Proprioceptors	Sense of position
Thermoreceptors	Temperature
Ultraviolet receptors	Ultraviolet radiation

SENSORY RECEPTORS

Receptors of vision

- The **retina** absorb different frequencies of light. **Photosensitive transmembrane G-protein** that exists in rods and cones(cis-retinal and opsin).
  - Light is the stimulus and retinal is the receptor.
- The absorption of energy transforms transmembrane G-protein, **signalling the closure of Na^+ channels that are otherwise open when it is dark.**
- **Hyperpolarization occurs with light signalling.**

SENSORY RECEPTORS

Receptors of hearing

- The Inner hair cells transmit information to the **auditory nerve**, and outer cells mechanically amplify low-level sound entering the cochlea.
- Inner hair cells have an attachment with a tectorial membrane to which they bend against with movement of the cochlear duct membranes and fluids.
- When the stereocilia on the hair cells bend towards the longest cilia, **potassium and voltage-gated calcium channels open, and ion influx increases resulting in depolarization.**

SENSORY RECEPTORS

Receptors of hearing

- This depolarization allows for neurotransmitter release at the auditory nerve in the post synapse, **generating nerve impulses to be propagated from stereocilia of hair cells to the CNS**.

SENSORY RECEPTORS

Receptors of balance

- The inner ear senses balance.
- When in motion the endolymph vibrates and creates a stimulus for the utricle and saccule receptors of the vestibular system
    - saccule help sense vertical
    - utricle sense horizontal accelerations
    - semicircular ducts detect rotations
- Change in position, *shift these hair cells causes the opening of receptor channels leading to action potentials propagating from the hair cells to the auditory nerve.*

✓ The rate of fluid motion, plus the quality of the fluid, gives more information about the motion.

SENSORY RECEPTORS

Receptors of taste

- The different tastes: sweet, salty, bitter, umami, and sour.
- Taste buds are cells with pore for stimuli. there are nerve fibres that will transmit the chemical gustatory message from the receptor sells to the brain.
- *Stimuli binding to the receptor, G-protein coupled receptors (GPCRs), depolarizes the receptor and releases a neurotransmitter for a postsynaptic cell to uptake and transmit the message.*
- Higher concentrations create higher action potentials.

SENSORY RECEPTORS

Receptors of taste

- A receptor steadily acclimates with continual exposure to the stimulus.
- The terminal destination for these signals located is in the primary **gustatory cortex in the frontal and insular lobes**.

SENSORY RECEPTORS

Receptors of smell

- The smell occurs by binding of **odorant molecules** to *receptors on the membrane of the cilia, causing an action potential that sends this information to the brain.*
- These systems utilize G-protein receptors along with adenylate cyclase.
- When a substance is bound to its receptor, *the substrate allows ions to go down their gradient, and through their specific vibrational energies*, it causes a flow of chemical changes and subsequent signalling to the brain.

SOMATOSENSORY SYSTEM

- The **somatosensory** system is composed of neurons that make:
  - sensing touch,
  - temperature, and
  - position in space possible
- **It includes:**
  - ***sensory receptor neurons in the periphery*** (eg., skin, muscle, and organs)
  - ***neurons within the central nervous system***
- The sensory pathway consist of three neurons: Primary, secondary, and tertiary neurons

SOMATOSENSORY SYSTEM

Primary neuron:

- are sensory receptor that ***detects sensory stimuli*** like touch or temperature in the ***periphery***
- The cell body of the primary neuron is housed in the dorsal root ganglion of a spinal nerve

Secondary neuron:

- ***acts as a relay*** and is located in the *spinal cord* or the *brainstem.*
- The neuron's ascending axons travel up the spinal cord to the brain (thalamus or the cerebellum)

SOMATOSENSORY SYSTEM

Tertiary neurons:

- Cell bodies in the thalamus; project to the postcentral gyrus of the parietal lobe

- The somatosensory system functions:
  - ✓ Periphery: Sensory receptors (i.e., thermoreceptors, mechanoreceptors, etc.) detect the various stimuli.
  - ✓ Spinal cord: Afferent pathways in the spinal cord serve to pass information from the periphery and the rest of the body to the brain.
  - ✓ Brain: The postcentral gyrus contains Brodmann areas (BA) the somatosensory cortex.

SOMATOSENSORY SYSTEM

Tactile Sensation (Touch)

- Touch is sensed by mechanoreceptive neurons that respond to mechanical pressure or distortion in various ways.
- It is mediated by cutaneous mechanoreceptors located in our skin

  - They categorized by the type of sensation they perceive, and by the rate of adaptation.

SOMATOSENSORY SYSTEM

Each has a different receptive field:

- **Ruffini's endings** organs detect tension deep in the skin.
- **Meissner's corpuscles** detect changes in texture (vibrations around 50 Hz) and adapt rapidly.
- **Merkel's discs** detect sustained touch and pressure.
- **Hair follicle receptors** are located in hair follicles and sense the position changes of hair strands.
- **Mechano-receiving free nerve endings** detect touch, pressure, and stretching.
- **Pacinian corpuscles** detect rapid vibrations (about 200–300 Hz).

SOMATOSENSORY SYSTEM

- **Proprioceptive Sensations** (body's position in three-dimensional space)
  - Sense of the position of body parts and force being generated during movement
  - proprioception is activated by proprioreceptors in the periphery.
  - *Connected to sensory neurons located in the inner ear (motion and orientation)*
  - **Conscious proprioception** is communicated by the posterior (dorsal) *column–medial lemniscus pathway to the cerebrum.*
  - **Unconscious proprioception** is communicated primarily via the dorsal and ventral *spinocerebellar tracts to the cerebellum*.

SOMATOSENSORY SYSTEM

- Sensory receptors in the muscle; **muscle spindles** detect changes in the length of a muscle.
- Sensory neurons sends information on length to the CNS to be processed

SOMATOSENSORY SYSTEM

Somatic Sensory Pathways

- Composed of three neurons, with their cell bodies located in the ***dorsal root ganglion***, the ***spinal cord***, and the ***thalamus*** (primary, secondary, and tertiary)

- Somatosensory system detects various stimuli at the periphery (touch, pain, temperature, etc.,), it is then conveyed to the CNS by afferent neurons
- Type of sensory modality correlates the type of afferent neuron involved

SOMATOSENSORY SYSTEM

Ascending Pathways

- In the spinal cord, the somatosensory system includes ascending pathways from the body to the brain (the postcentral gyrus in the cerebral cortex)

SOMATOSENSORY SYSTEM

Cortical Homunculus

- Pictorial representation of the anatomical divisions of the primary motor cortex and the primary somatosensory cortex

SOMATOSENSORY SYSTEM

Somatic Sensory Pathways to the Cerebellum

- Proprioceptive information is conveyed through the ventral and dorsal spinocerebellar tracts; from the body to the cerebellum.
- The **ventral spinocerebellar tract** crosses to the opposite side of the body then cross again to end in the cerebellum (referred to as a double cross).
- The **dorsal spinocerebellar tract** (posterior spinocerebellar tract) conveys inconscient proprioceptive information from the body to the cerebellum.

REFLEXES

FUNCTIONAL ORGANIZATION OF NEURONS

- ≈ 10 million sensory neurons,
- ≈ 20 billion interneurons
- ≈ 1½ one-half million motor neurons.

- These neurons are arranged to form a neuronal pools, impulses generated:
  - **converge** on one neuron
  - **diverge** to many neurons
  - have a **feedback** on the neuron that originally generated the impulse.

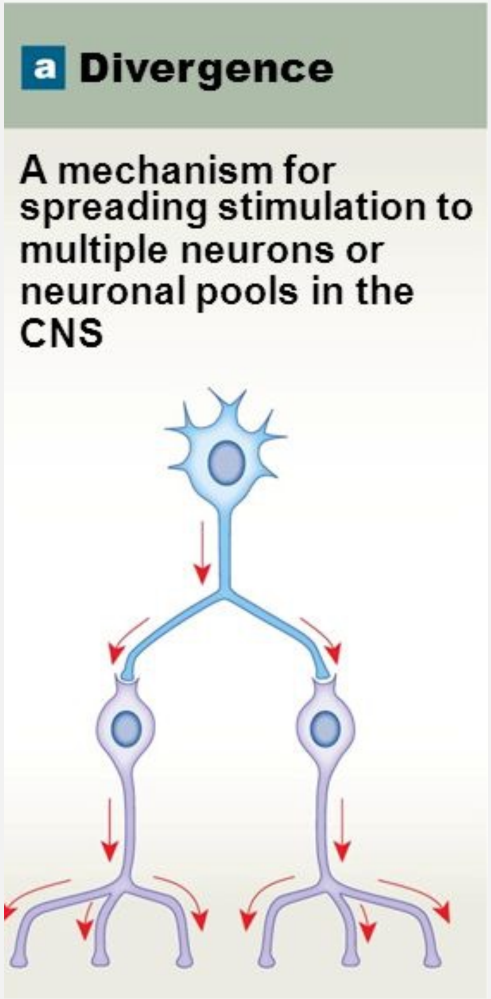
FUNCTIONAL ORGANIZATION OF NEURONS

Divergence:

- spreads stimulation to many neurons or neuronal pools in CNS
- wide distribution of a specific input; a signal is amplified with each transmission

✓ Single neuron could activate a large number of motor neurons

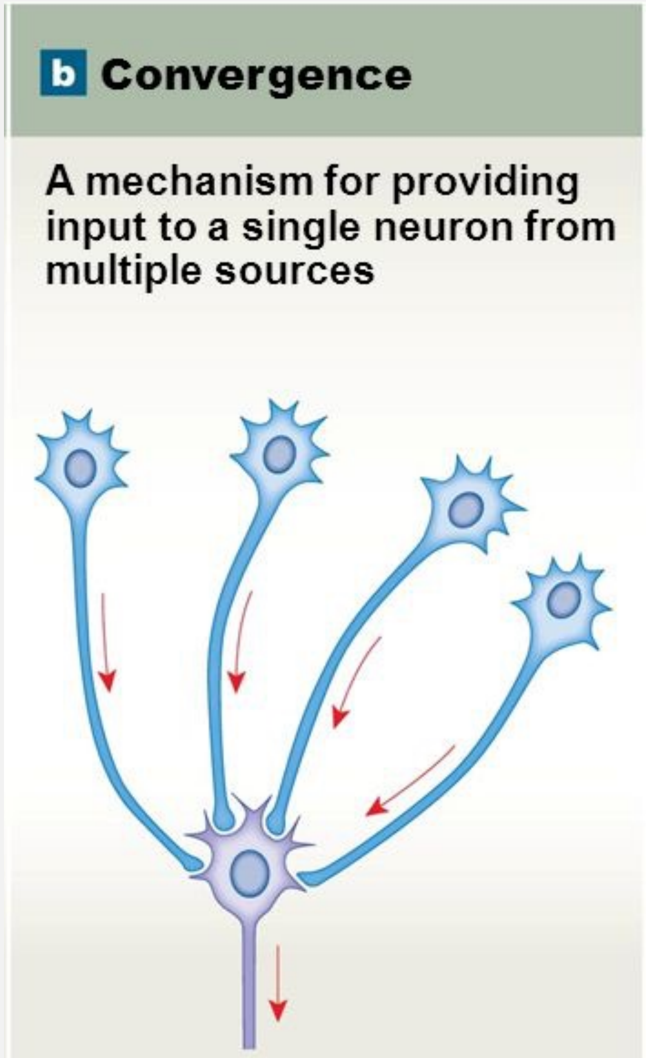
- *Eg. Running and screaming at the same time when in fright.*



FUNCTIONAL ORGANIZATION OF NEURONS

Convergence:

- brings input from many sources to single neuron; more input and a single output
- helps more than one neuron have a concentrated effect on a postsynaptic neuron
- Eg. Sensory information.
- *Eg. forcing yourself to carry a hot plate to the nearest table without it dropping*

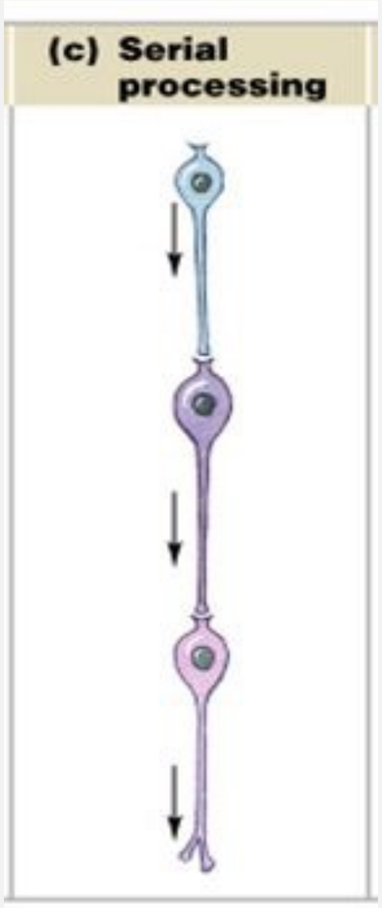


FUNCTIONAL ORGANIZATION OF NEURONS

NEURAL PROCESSING

Serial processing:

- moves information in single line
- affects only one neuron at a time
- This arrangement is seen in the way somatic sensations are conveyed to the brain (reflexes)
- This helps the brain discern the exact region from which the sensation originated.
- *Eg. sensations initiated in the left big toe reach the "toe area" in the brain on the right side*

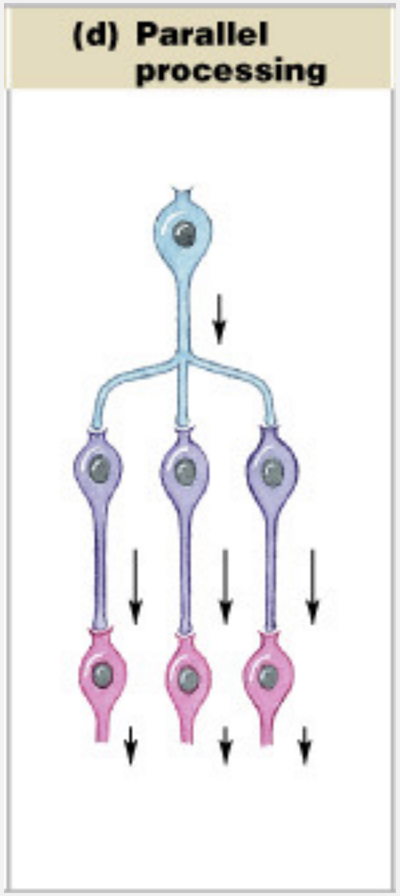


FUNCTIONAL ORGANIZATION OF NEURONS

NEURAL PROCESSING

Parallel processing:

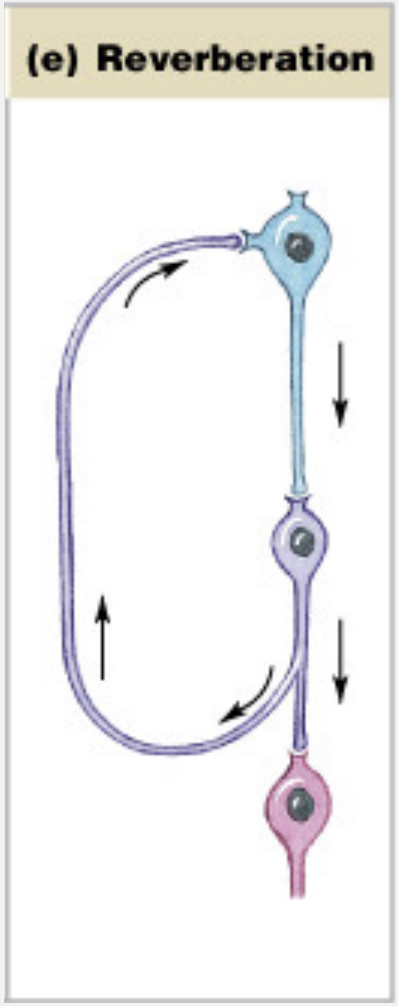
- moves same information along several paths simultaneously
- Allows the information to be processed by different neurons at the same time and produce a response in different regions of the body
  - ✓ ***Complex brain activity***
  - ✓ ***Think, plan, analyse, draw conclusions etc.***
- *Eg. Running and screaming at the same time when in fright (sympathetic nervous response).*
- *Eg. Hearing and smelling (thoughts, memories, emotions*



FUNCTIONAL ORGANIZATION OF NEURONS

Reverberation:

- positive feedback mechanism
- helps neurons down the circuit to initiate an impulse in the presynaptic neuron; neurons in a chain can feedback previous neuron - *oscillating circuit.*
- Involves more complicated circuits, with many neurons as seen in the CNS.
- These circuits continue on and on until the neurons are **inhibited or fatigued**
- *Eg. the respiratory centre, which helps with rhythmic activities such as breathing*
- *Eg. Walking, repetitive activity such as walking.*



SPINAL REFLEXES

SPINAL REFLEXES

Rapid, automatic nerve responses triggered by specific stimuli

- Controlled by spinal cord alone; not the brain
- Automatic responses coordinated within spinal cord
- Through interconnected sensory, motor, and interneurons

REFLEX

- A ***reflex arc*** defines the pathway by which a reflex travels from the ***stimulus*** to ***sensory neuron*** to interneuron to ***motor neuron*** *to an* ***effector / reflex muscle*** movement.

For:

✓ Quick response

✓ Safety mechanism

REFLEXES

Resulting motor response:

- **somatic reflexes**:
  - involuntary control of nervous system
    - superficial reflexes of skin, mucous membranes
    - stretch reflexes (deep tendon reflexes) e.g., patellar reflex
- **visceral reflexes**
  - control systems other than muscular system

REFLEXES

Complexity of neural circuit:

- **monosynaptic reflex:**
  - sensory neuron synapses directly onto motor neuron
- **polysynaptic reflex:**
  - at least 1 interneuron between sensory neuron and motor neuron

REFLEXES

Site of information processing:

- **spinal reflexes:**
  - occurs in spinal cord
- **cranial reflexes:**
  - occurs in brain

Range in increasing order of complexity:

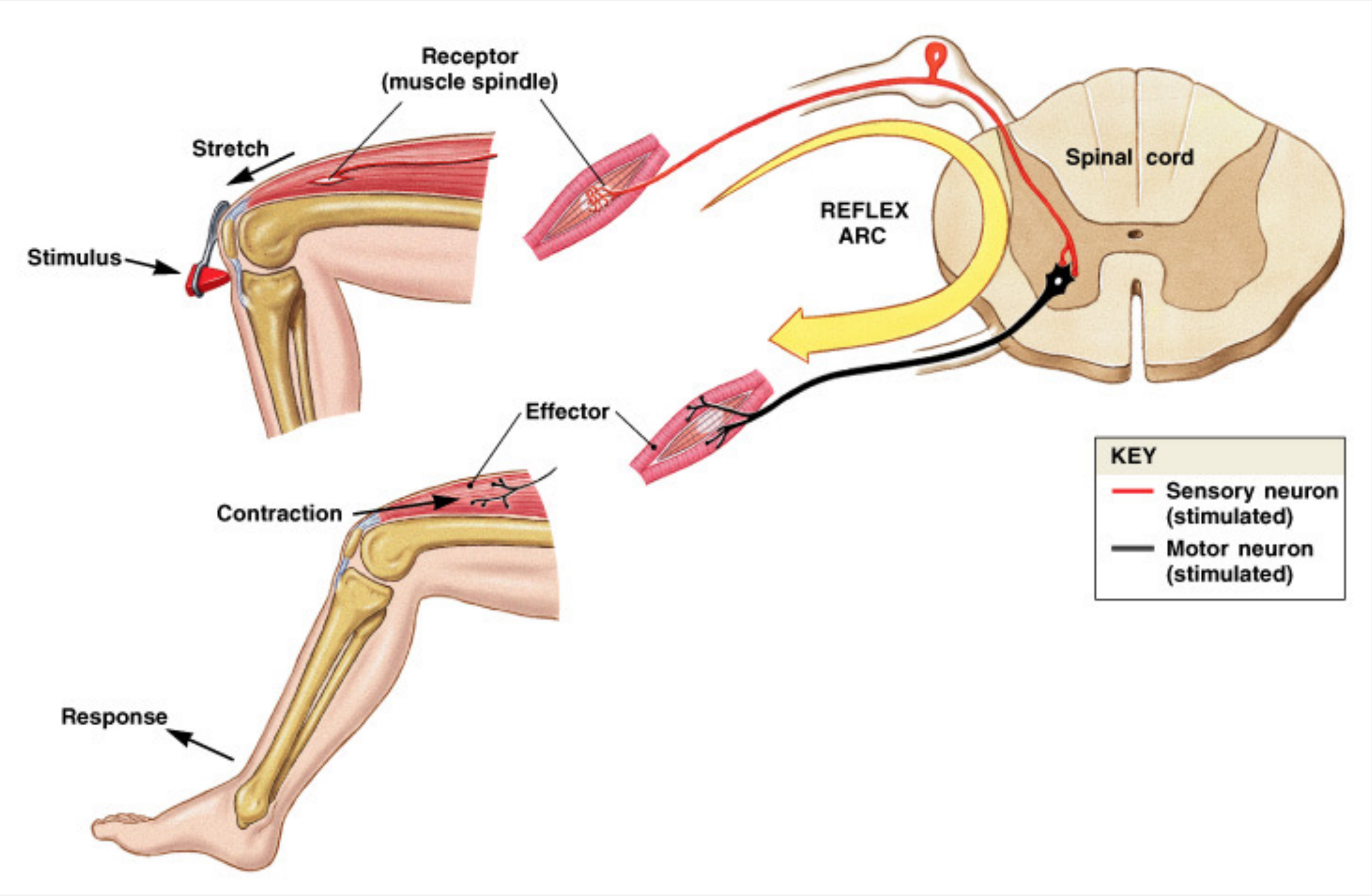
1. monosynaptic reflexes
2. polysynaptic reflexes

MONOSYNAPTIC REFLEX

- Consists of only one sensory neuron and one motor neuron, referring to the presence of a single chemical synapse.

- *In the case of peripheral muscle reflexes, brief stimulation to the muscle spindle results in contraction of the effector muscle.*
- Completed in *20–40msec*

MONOSYNAPTIC REFLEX



MONOSYNAPTIC REFLEX

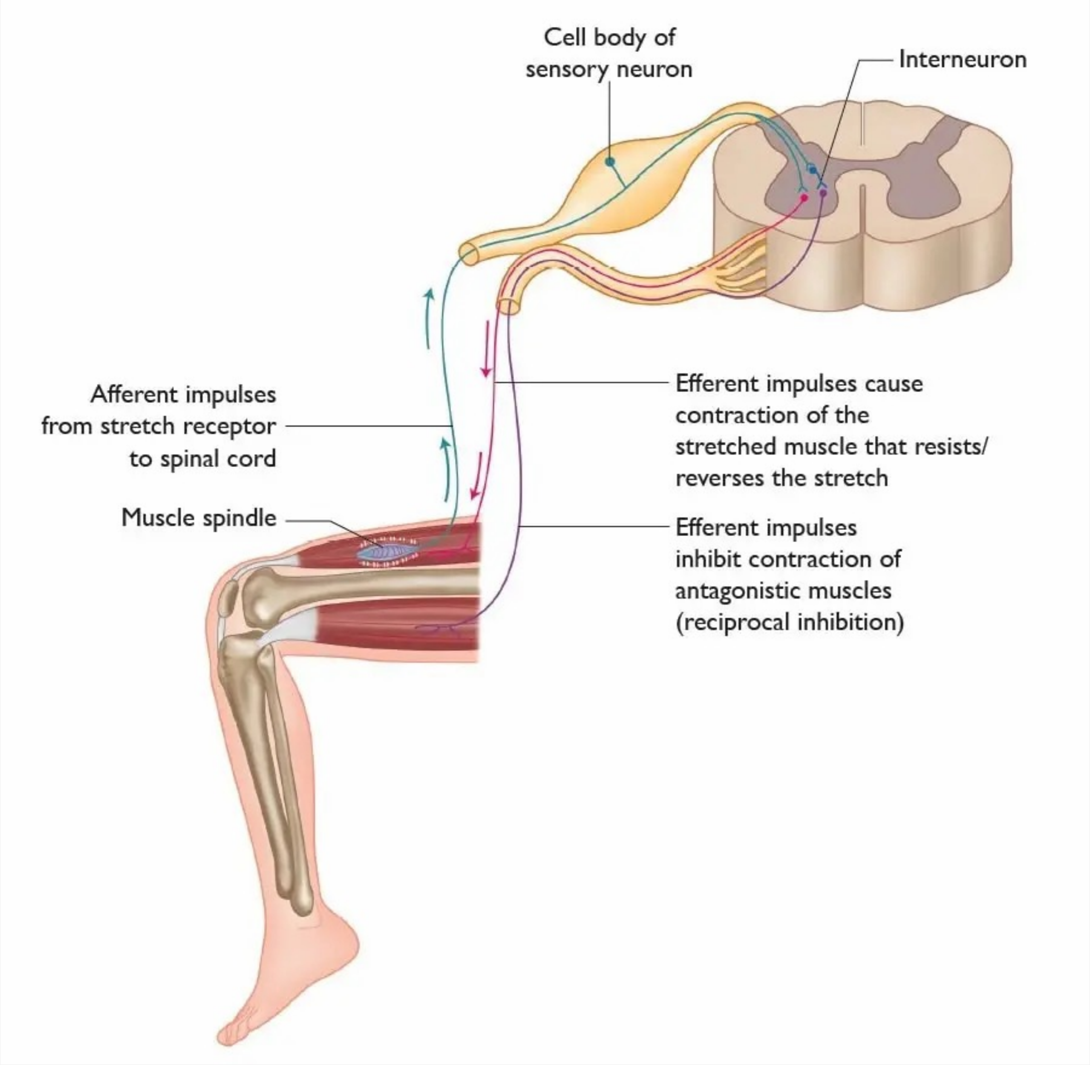
- This reflex begins inside the muscle spindle of the muscle.
- When the muscle experiences a stretch stimulus (mechanoreceptors), ***sensory impulses are transmitted from the muscle spindle via afferent fibres to the dorsal root of the spinal cord.***
- In the dorsal horn, of the grey matter of the spinal cord, ***the fibre synapses on the corresponding alpha motor neuron*** in the ventral horn of the spinal cord.

MONOSYNAPTIC REFLEX

- This alpha efferent fibre then exits through the ventral root, sending an action potential to the neuromuscular junction of the original muscle that initiated the reflex
  - to cause contraction.
  - to resist the force that initially caused the reflex.
- ***In contrast,*** the polysynaptic stretch reflex involves a single sensory stimulus that synapses on interneurons within the spinal cord gray matter, which allows communication to multiple muscles for contraction or inhibition.

MONOSYNAPTIC REFLEX

Stretch Reflex (myotatic reflex):



POLYSYNAPTIC REFLEX

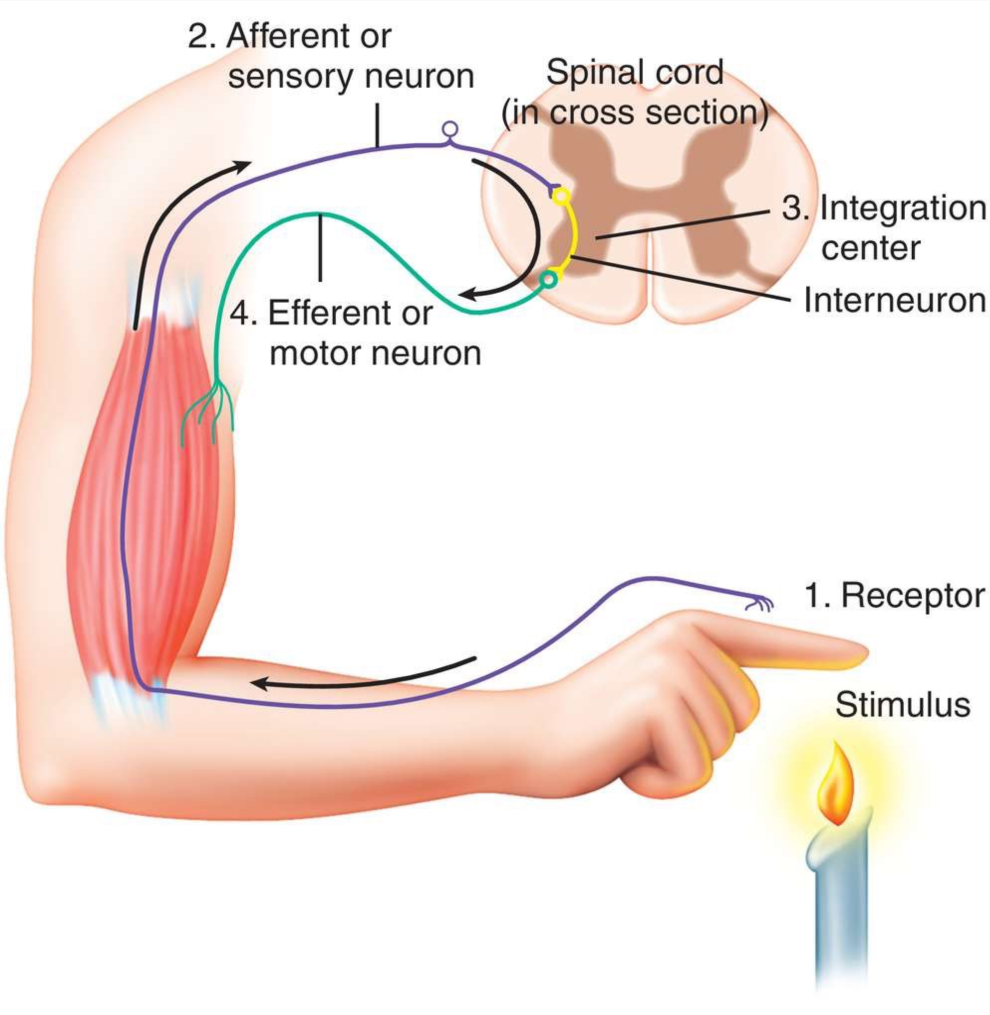
- The **polysynaptic stretch reflex** involves reflex pathways, *one or more interneurons connect afferent (sensory) and efferent (motor) signals within the spinal cord grey matter*
- allows communication to multiple muscles and processing for contraction or inhibition.

POLYSYNAPTIC REFLEX

Flexor/Withdrawal Reflex

- Contraction of limb flexor muscles that is evoked by a nociceptive stimulus and that withdraws the limb from the stimulus (pain – pressure, heat, chemical)
- protect the body from damaging stimuli
- Strength and extent of response:
  - depends on intensity and location of stimulus

POLYSYNAPTIC REFLEX



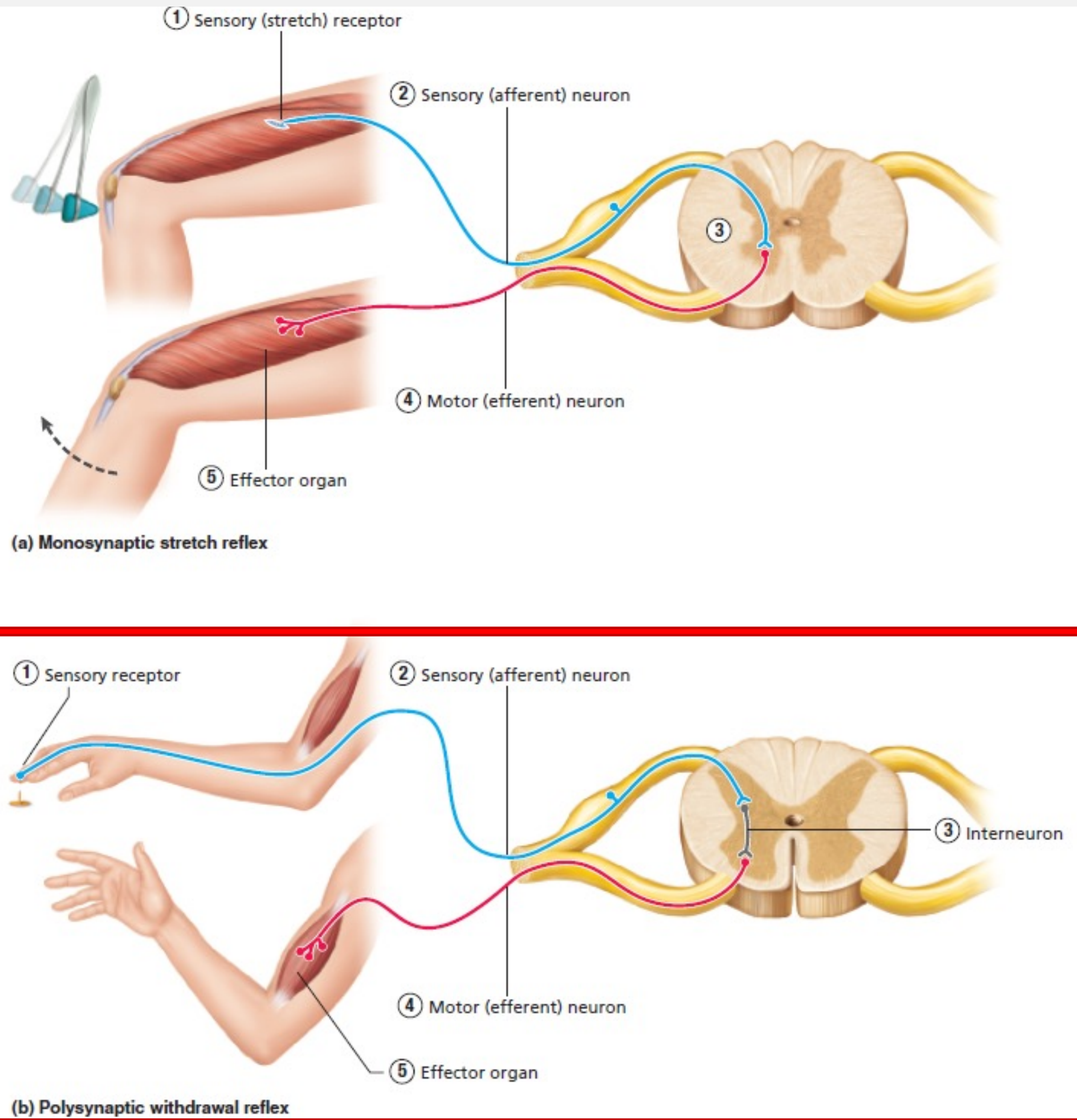


Figure 12.11 Types of reflex arcs. (**a**) A monosynaptic reflex arc has two neurons and a single synapse. (**b**) A polysynaptic reflex arc has more than two neurons (in this case, three) and therefore has at least two synapses. The five components of a reflex arc are indicated by number.

POLYSYNAPTIC REFLEX

Reciprocal Inhibition

- relaxation of muscles on one side of a joint to accommodate contraction on the other side

For flexor/withdrawal reflex to work:

- the stretch reflex of antagonistic (extensor) muscle must be inhibited (reciprocal inhibition) by interneurons in spinal cord

POLYSYNAPTIC REFLEX

Crossed Extensor Reflex:

- The crossed extensor reflex is a withdrawal reflex where the ***contralateral (opposite side) limb makes up for the loss of support created when the same side limb withdraws from a painful external stimulus.***

POLYSYNAPTIC REFLEX

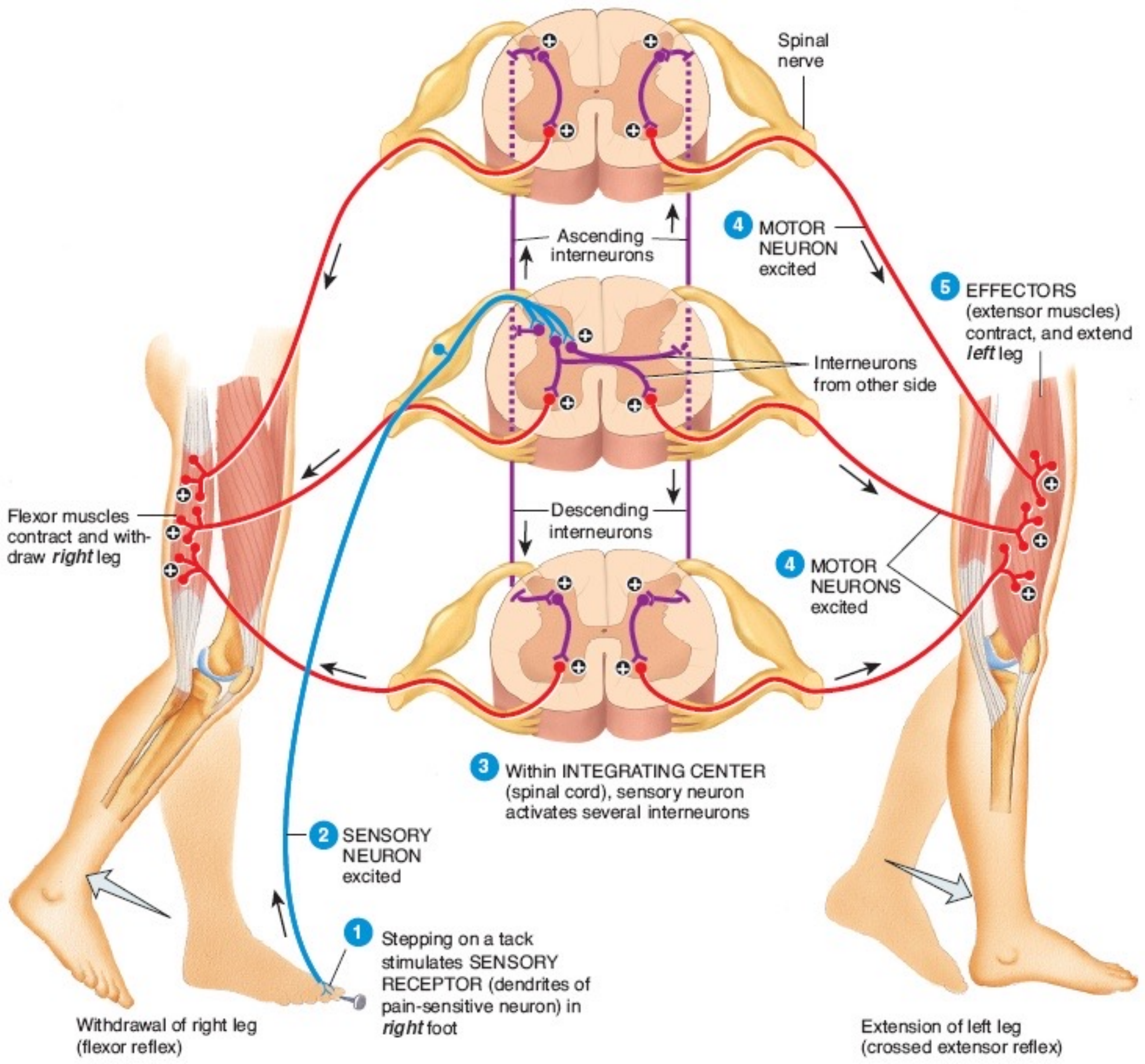
Crossed Extensor Reflex:

- When this reflex is occurring, ***flexors in the withdrawing limb would contract and extensors relax,*** while the opposite would occur in the contralateral limb

- Eg. when someone steps on a nail– the leg that stepped on the nail would withdraw, while the other leg supports the weight of the whole body.

POLYSYNAPTIC REFLEX

Crossed Extensor Reflex:



POLYSYNAPTIC REFLEX

Golgi Tendon Reflex:

- Or the **inverse stretch reflex** is a component of the reflex arc of the PNS.
- Functions as a ***negative feedback mechanism*** to control muscle tension by inducing muscle relaxation before the muscle forces become so extreme that tendons might tear.
- Although the golgi tendon reflex is much less sensitive than the stretch reflex, it can override the stretch reflex when tensions are extremely high.
- E.g. causing someone to drop a very heavy weight

INTEGRATION AND CONTROL OF SPINAL REFLEXES

- **Although reflex behaviors are automatic, processing centers in brain can facilitate or inhibit reflex motor patterns based in spinal cord**
- Automatic reflexes:
  - can be activated by brain as needed
  - use few nerve impulses to control complex motor functions
  - walking, running, jumping

REPRODUCTION

REPRODUCTION

Reproduction

- The male reproductive system,
  - Spermatogenesis,
  - Sperm maturation, storage and capacitation
  - Endocrine function of testis
  - Abnormalities of testicular function.

INTRODUCTION

The female reproductive system

- Oogenesis,
- Menstrual cycle,
- Ovarian and uterine cycles,
- Control of menstrual cycle,
- Disorders of menstrual cycle,
- Ovarian hormones, puberty, menopause,

INTRODUCTION

- Human sexual response
- Pregnancy
  - Fertilisation
  - Implantation
  - Placental functions
- Hormonal changes during pregnancy and parturition.
- Disorders in fertility.

REPRODUCTION

Sexual Reproduction

- Involves gamete (sperm and egg cell), each with a single set of chromosomes (**haploid**) combining to form a zygote that develops into an organism composed of cells with two sets of chromosomes (**diploid**).
- Two haploid gametes combine into one diploid cell known as a **zygote** in fertilisation.
- The zygote incorporates genetic material from both gametes.
- Multiple cell divisions, without change of the number of chromosomes, then form a multicellular diploid phase or generation.

REPRODUCTION

In human reproduction:

- Meiosis in the parents' gonads produces gametes that each contain only 23 chromosomes .
- Nuclei of the gametes come together to form a fertilized egg or zygote, the resulting child will have ***23 chromosomes from each parent, or 46 in total***.
- Any organism can only pass on 50% of its own genes to its offspring (impedes the accumulation of genetic mutations).
- ***Sexual selection (natural selection)*** allow some individuals out-reproduce others of a population because they are better at securing mates for sexual reproduction.

HUMAN REPRODUCTIVE SYSTEM

- **The human reproductive system** allows humans to reproduce and bear live offspring;
  - ✓ provided all organs are present, normally constructed, and functioning properly.
- **Features of human reproduction include:**
  - Liberation of an ovum, or egg, at a specific time in the reproductive cycle
  - Internal fertilization of the ovum by spermatozoa, or sperm cells
  - Transport of the fertilized ovum to the uterus, or womb

HUMAN REPRODUCTIVE SYSTEM

- Implantation of the blastocyst, the early embryo developed from the fertilized ovum, in the wall of the uterus
- Formation of a placenta and maintenance of the unborn child during the entire period of gestation
- Birth of the child and expulsion of the placenta
- Suckling and care of the child (natural)

HUMAN REPRODUCTIVE SYSTEM

- For this biological process to be carried out, certain organs and structures are required in both the male and the female.
- The primary reproductive organs, or **gonads** are the source of the ova / spermatozoa (germ cells).
  - female **ovary**; male **testis.**

HUMAN REPRODUCTIVE SYSTEM

Secondary reproductive organs:

- Does not produce gametes.
- **In male: -** a system of ducts, glands and penis
- **In female: -** uterine tubes, uterus and vagina

HUMAN REPRODUCTIVE SYSTEM

Secondary sex characteristics

- Specific characteristics or structures which help in distinguishing male and female sex.
- Play a role in mate attraction
- NO direct role in sexual reproduction.

HUMAN REPRODUCTIVE SYSTEM

- These characters or structures appear only on attaining puberty due to the production of sex hormones.

- **Male:** Growth of moustaches and beard, hair on chest and in the armpits, pubic hair, broad shoulders, deeper voice, increased aggressiveness

- **Female:** Growth of hair in armpits, pubic hair, soft skin, less hair on the body, shrill voice, onset of menstrual cycles, development of breasts, increase in size of vagina

MALE AND FEMALE REPRODUCTIVE SYSTEMS

- Are functionally different
- Female produces 1 gamete per month:
  - retains and nurtures zygote
- Male disseminates large quantities of gametes:
  - produces 500 million sperms per day

THE MALE REPRODUCTIVE SYSTEM

MALE REPRODUCTIVE SYSTEM

- The primary organ: **Testes or male gonads**
    - secrete male sex hormones (androgens)
    - produce male gametes (spermatozoa or sperm)
- **Emission:**
    - mature spermatozoa move along duct system
- **Semen:**
    - sperm mixed with accessory gland secretions
- **Ejaculation:**
    - semen expelled from body

MALE REPRODUCTIVE SYSTEM

Pathway of spermatozoa:

- Testis
- Epididymis
- Ductus deferens (vas deferens)
- Ejaculatory duct
- Urethra

MALE REPRODUCTIVE SYSTEM

Accessory organs:

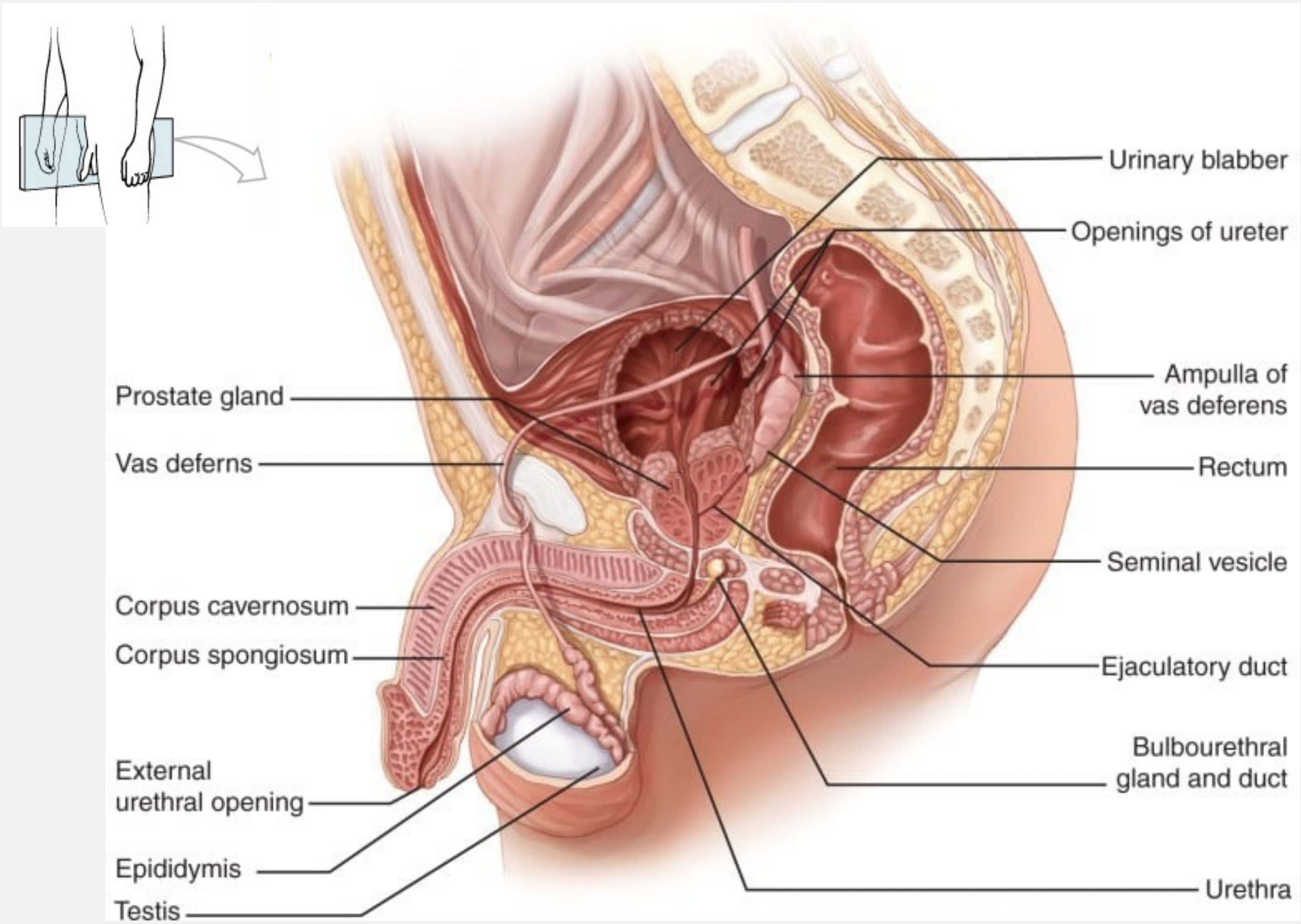
- Secrete fluids into ejaculatory ducts and urethra:
    - seminal vesicles
    - prostate gland
    - bulbourethral glands/Cowper's gland

MALE REPRODUCTIVE SYSTEM

External genitalia:

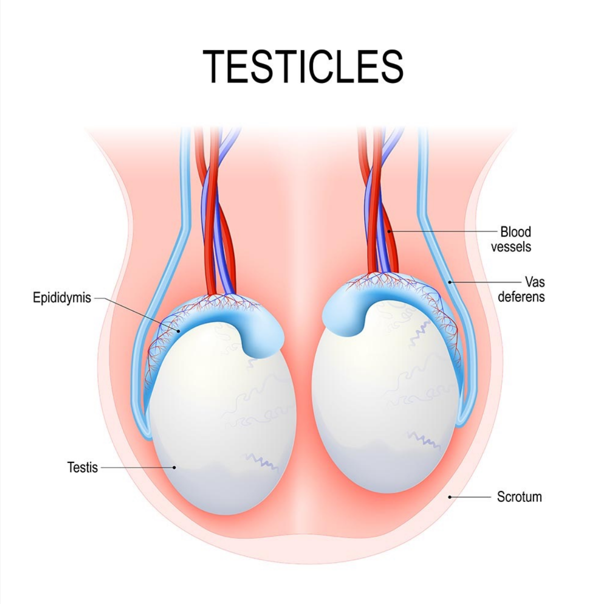
- Scrotum:
  - encloses testes
- Penis:
  - erectile organ
  - contains distal portion of urethra

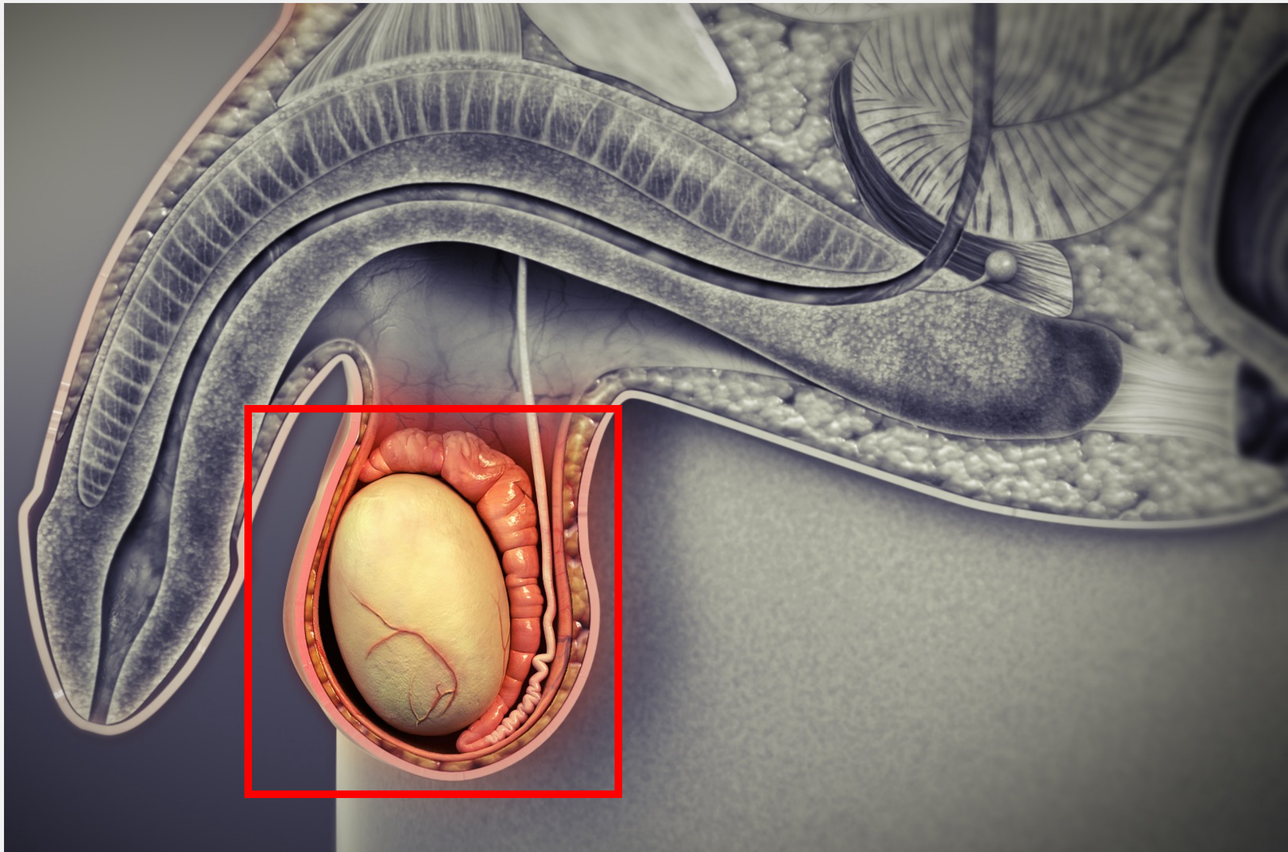
MALE REPRODUCTIVE SYSTEM



TESTIS

- **Testis**, plural **testes**





TESTIS

- A pair of oval-shaped organs.
- Weighs 10–20g
- 4-5cm long, 3cm wide
- Hangs in scrotum
- Contained within the scrotal sac

TESTIS

Formation:

- Testes is formed inside the body cavity:

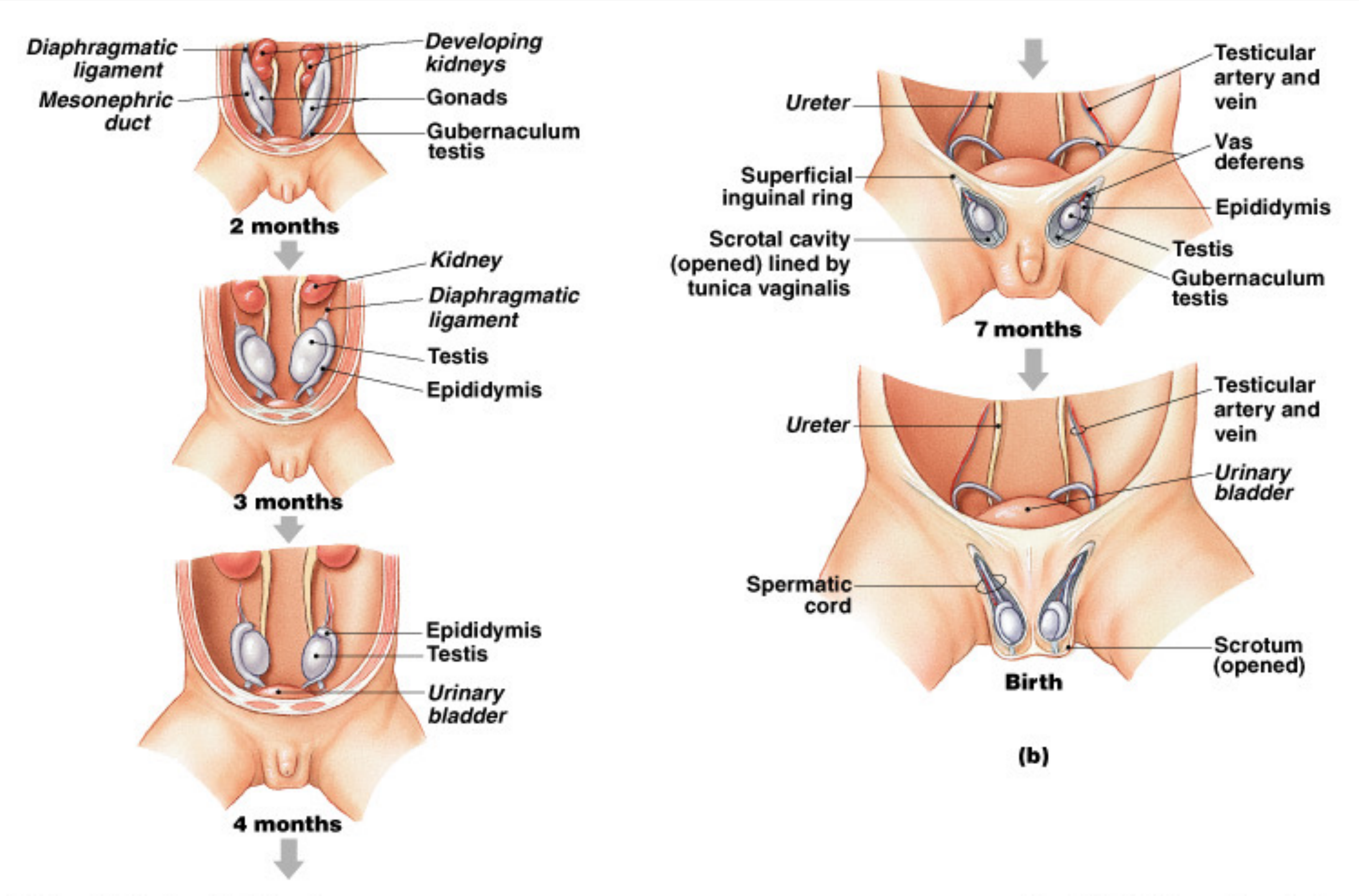
  - Adjacent to kidneys
  - Descent of the gonad to its adult position is by the guidance of the fibrous connective tissue called ***gubernaculum*.**
  - It extends from testis to pockets of the future peritoneum
  - Descends towards the ***labioscrotal swellings***

TESTIS

- ***The first phase of migration;*** the testes descend from their initial position *high posterior abdominal wall and remain in the lower portion* of the anterior abdominal wall until about **7 *months of the foetus.***

- ***The second phase of migration*** proceeds from then until about the ninth month, and is hormone-dependent, circulating hormones stimulate contraction of gubernaculum testis

TESTIS



Diaphragmatic ligament
Mesonephric duct
Developing kidneys
Gonads
Gubernaculum testis
2 months
Kidney
Diaphragmatic ligament
Testis
Epididymis
3 months
Epididymis
Testis
Urinary bladder
4 months
Ureter
Superficial inguinal ring
Scrotal cavity (opened) lined by tunica vaginalis
Testicular artery and vein
Vas deferens
Epididymis
Testis
Gubernaculum testis
7 months
Ureter
Spermatic cord
Testicular artery and vein
Urinary bladder
Scrotum (opened)
Birth
(b)

TESTIS

- Each testis moves through abdominal muscles and are accompanied by pockets of peritoneal cavity
- Accessory structures accompanying the testis during decent form the **spermatic cord**:
  - *ductus deferens*
  - *testicular blood vessels, nerves, and lymphatic vessels*

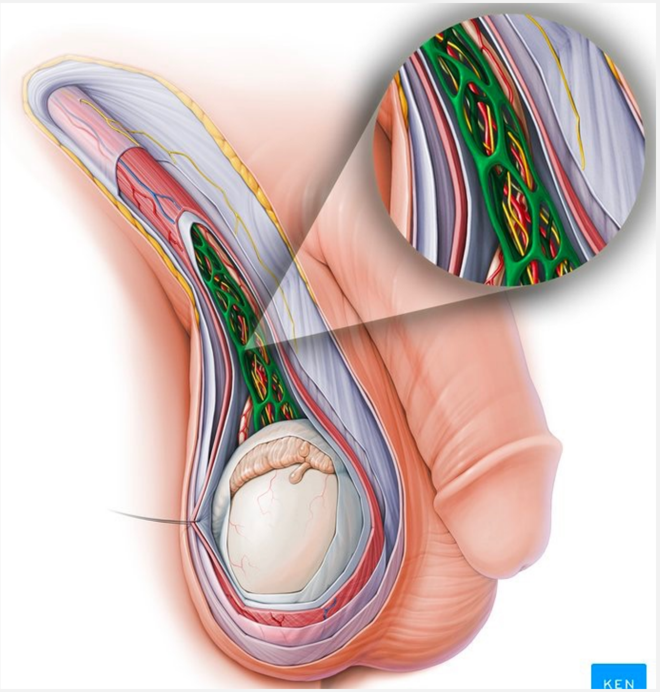
TESTIS

- The production of testosterone by the foetal testes is stimulated by, human ***chorionic gonadotropin*** a hormone secreted by the placenta.
- Within a few weeks following birth, testosterone secretion ceases, and the cells within the ***testes remain undeveloped through early childhood***
- During adolescence, *gonadotropic hormones from the **pituitary gland*** at the base of the brain stimulate the development of tissue, and the testes become capable of producing sperm and androgens

TESTIS

Spermatic cord

- Extend between abdominopelvic cavity and testes
- Consists of **layers of fascia** *(connective tissues)* **and muscle**



TESTIS

- In the testes, *blood vessels*, *nerve fibres*, *lymphatic vessels*, and the *ductus deferens* are enclosed by a connective the tissue sheath; **spermatic cord**
- Passes through inguinal canal
    - Passageways through abdominal musculature
    - Formed during development as testes descend into scrotum
- Descends into scrotum

TESTIS

Inguinal Hernias:

- The inguinal region is a weak place in the abdominal wall
- Can cause ***protrusions of visceral tissues into inguinal canal***
- Straining the abdominal muscles by lifting heavy objects can result in a tear of the inguinal tissue
- A loop of intestine then bulge into the scrotum through the tear

TESTIS

Blood vessels:

- The testes are supplied by long ***testicular arteries*** that branch from the *abdominal aorta*
- The testes are drained by the ***testicular veins***, which arise from a network known as the *pampiniform venous plexus.*
    - This network surrounds each testicular artery inside the scrotum, winding around it.

TESTIS

- In each pampiniform plexus, ***cooler venous blood absorbs heat from arterial blood***, this blood becomes cooler before entering the testes, which helps to keep the ***testes at cool, homeostatic temperature***.

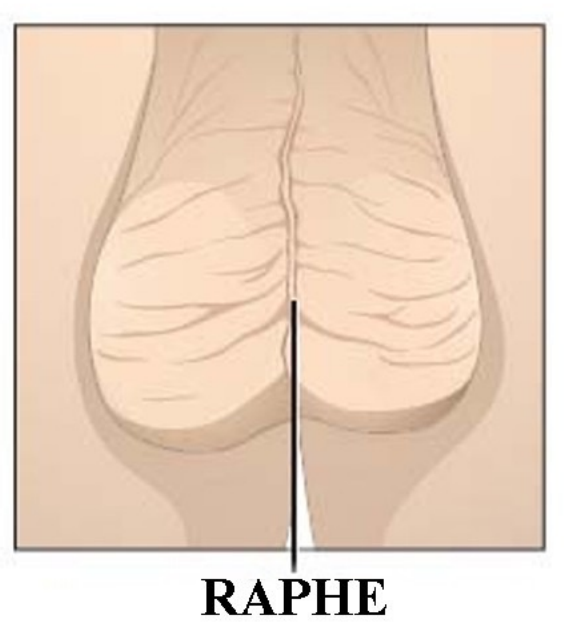
TESTIS

Nerves:

- The testes are served by the sympathetic and para-sympathetic divisions of the autonomic nervous system.
- Branches of ***genitofemoral nerve,*** ***from lumbar plexus***
- Forceful trauma to the testes transmits impulses, causing intense pain.

THE SCROTUM

- The scrotum consists of a flesh pouch of skin and subcutaneous tissue suspended below the perineum
- Encloses the testes.
  - External hairs
- Internally, the **medial septum** or ***raphe*** sub-divides it into two chambers, each enclosing a testis.
  - Is a raised thickening in scrotal surface



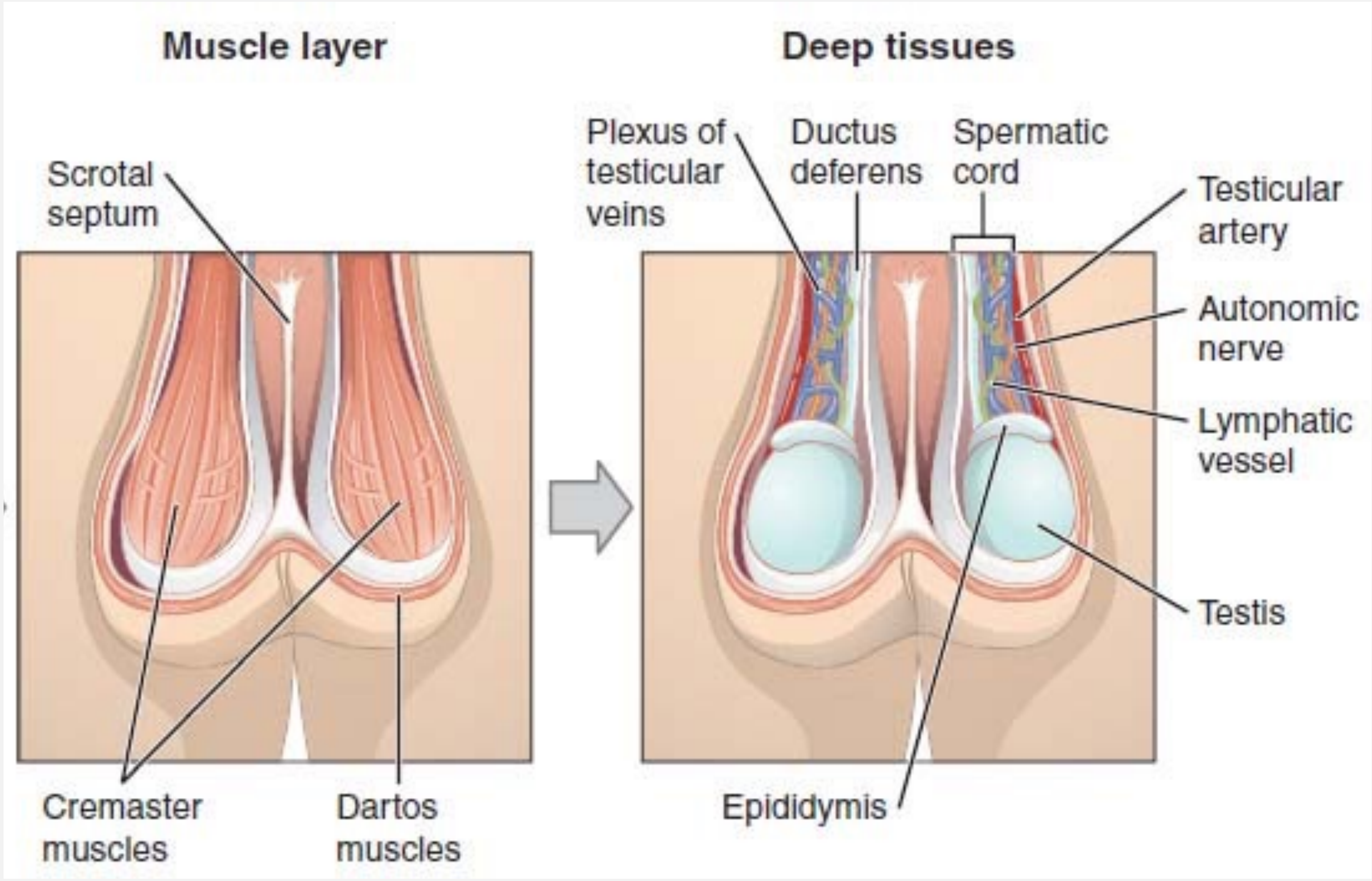
THE SCROTUM

- ***The scrotum protects and controls the temperature of the testes, which is important for sex cell production***.
- Normal sperm development and survival in the testes:
  - Sperm can not develop at the body temperature of 37°C
  - requires temperatures 2°C lower than body temperature
- When environmental temperatures are ***cold, the scrotum contracts and wrinkles***, ***moving the testes closer to the pelvic cavity to absorb heat***.

THE SCROTUM

- When it is ***warmer outside, the scrotum relaxes and hangs loosely*** to ensure the testes are about 2°C lower than body temperature.
- This is better for the sperm cells to be produced and to survive.

THE SCROTUM



Muscle layer
Scrotal septum
Cremaster muscles
Dartos muscles
Deep tissues
Plexus of testicular veins
Ductus deferens
Spermatic cord
Testicular artery
Autonomic nerve
Lymphatic vessel
Testis
Epididymis

THE SCROTUM

- The scrotum contains two sets of muscles (**dartos muscle** and **cremaster muscles**) that respond to temperature changes.

Dartos muscle

- Is a layer of smooth muscle in dermis of scrotum
- When cold, contracts making the scrotum taut and wrinkled
- This reduces the surface area of the scrotum, thus reducing heat loss

THE SCROTUM

Cremaster muscles

- Is a layer of skeletal muscle deep to dermis
- Tenses scrotum and pulls testes closer to body when it is cold
- When it is warm, the muscle relaxes and the testes are suspended farther from the body

THE SCROTUM

Regulating the temperature of the testes:

1. Position of the testes
2. Muscles relax or contract:
   - to move testes away or toward body
   - to maintain acceptable testicular temperatures
3. Pampiniform plexus
   - Acts as a counter current heat exchanger to cool the blood on its way to testis
   - The relatively cool blood (about 35 °C) ascending the plexus absorbs heat from the warmer blood descending through the testicular artery

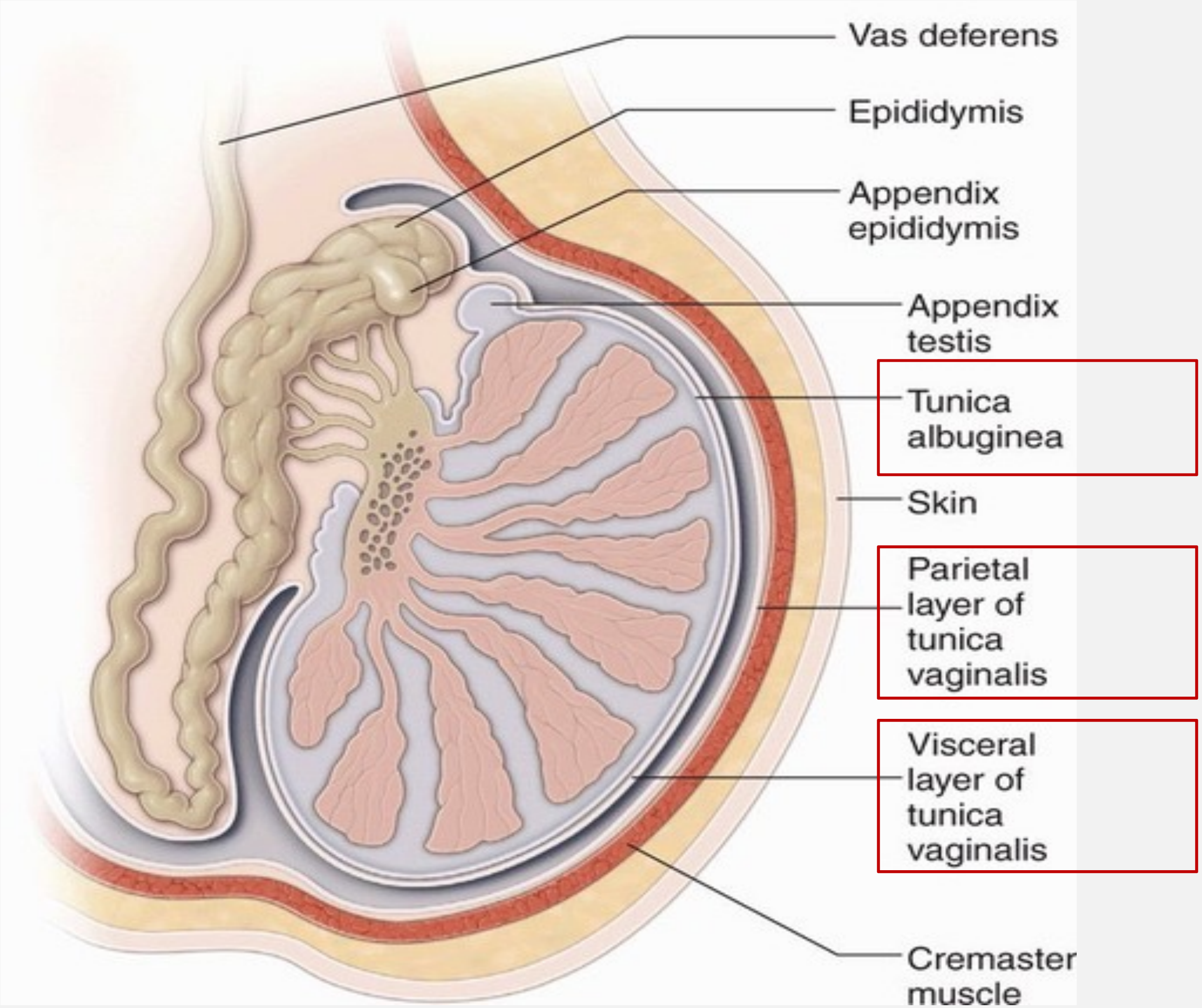
THE SCROTUM

- The testicle is covered by two tissue layers or tunica
  - The **tunica vaginalis**, beneath the tunica vaginalis is the capsule of the testis, termed the **tunica albuginea**

Tunica vaginalis

- Is a serous membrane that lines scrotal cavity
- Reduces friction between opposing surfaces:
  - **parietal** (scrotal)
  - **visceral** (testicular)

THE SCROTUM



Vas deferens
Epididymis
Appendix epididymis
Appendix testis
Tunica albuginea
Skin
Parietal layer of tunica vaginalis
Visceral layer of tunica vaginalis
Cremaster muscle

THE SCROTUM

Tunica albuginea

- This sac is lined internally by the tunica vasculosa, containing a ***network of blood vessels***
- Is a dense layer of white connective tissue, rich in ***collagen fibers***
- Continuous with fibers surrounding epididymis
- The tunica albuginea has extensions into each testis that act as partial partitions to divide the testis into approximately 250 compartments called ***lobules.***

THE SCROTUM

Tunica albuginea

- Each lobule contains one or more convoluted tubules, tightly-coiled (***seminiferous tubules***), where sperms are formed by a process called **spermatogenesis.**
- The tubules, extend about 80cm

THE TESTES

Seminiferous tubules

- Seminiferous tubules contain epithelium consisting of ***Sertoli cells*** that envelope and support ***germ cells*** undergoing progressive differentiation and development into mature **spermatozoa.**

- Made up of a *thickened stratified epithelium* that surrounds a central lumen filled with fluid.

THE TESTES

Seminiferous tubules

- Each seminiferous tubule of the adult testis has a central lumen, or cavity, which is connected to the **epididymis** and **spermatic duct (ductus deferens**).
- **Sperm cells originate as *spermatogonia* along the walls of the seminiferous tubules.**
- The spermatogonia mature into ***spermatocytes***, which mature into ***spermatids*** that mature into ***spermatozoa*** as they move into the central lumen of the seminiferous tubule.

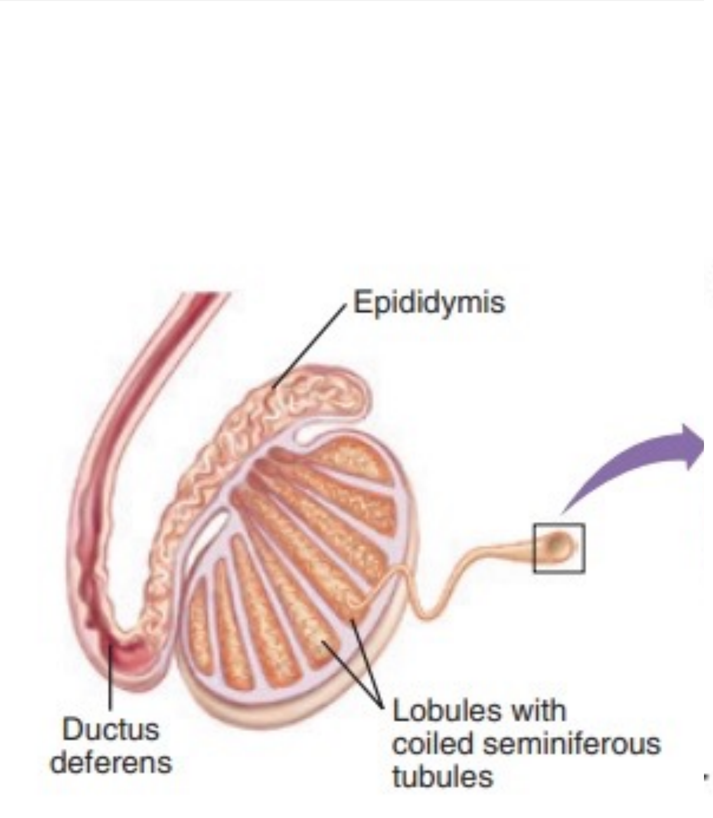
THE TESTES

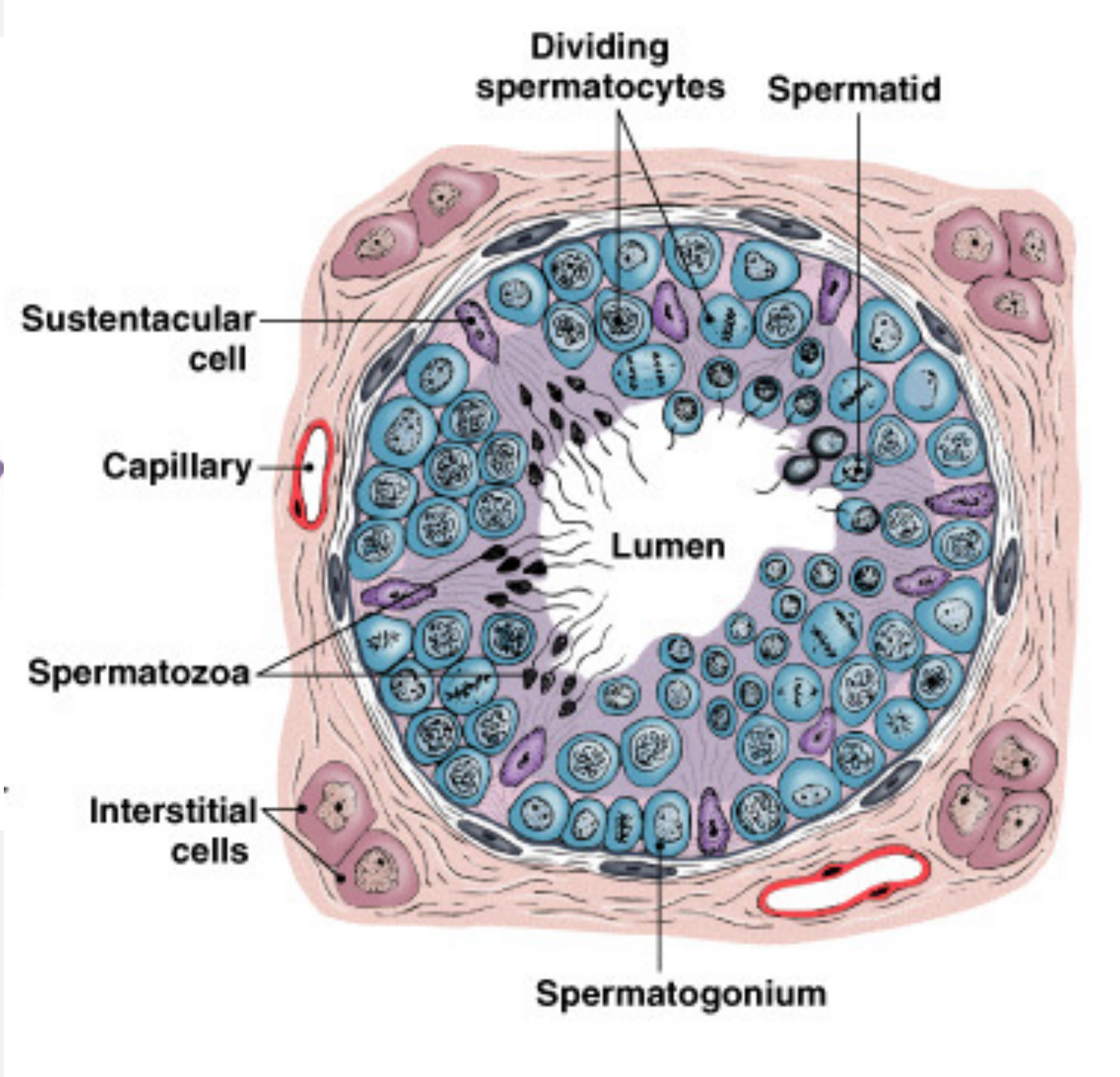
Seminiferous tubules

- The spermatozoa migrate, by short contractions of the tubule, to the **mediastinum testis**; they are then transported through a complex network of canals (**rete testis** and **efferent ductules**) to the epididymis for temporary storage.

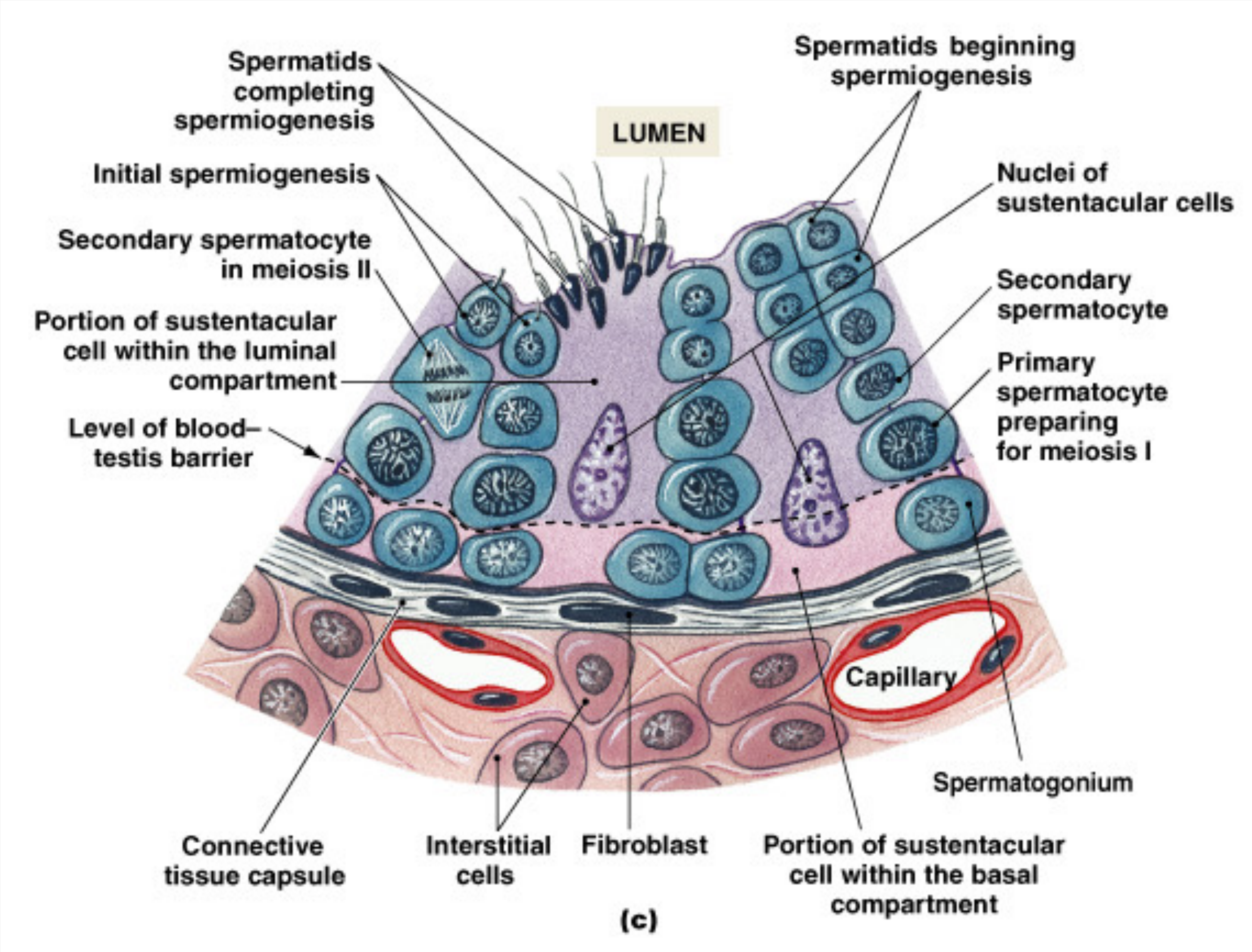
- The spermatozoa move through the epididymis and the spermatic duct to be stored in the **seminal vesicles** for eventual ejaculation with the seminal fluid.

THE TESTES


Epididymis
Ductus deferens
Lobules with coiled seminiferous tubules


Dividing spermatocytes
Spermatid
Sustentacular cell
Capillary
Lumen
Spermatozoa
Interstitial cells
Spermatogonium

THE TESTES

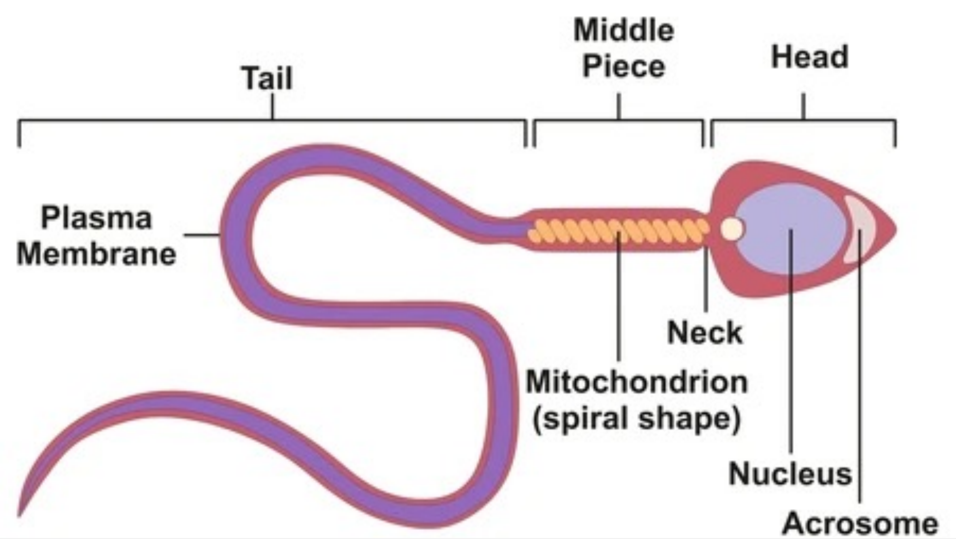

Spermatids completing spermiogenesis
Initial spermiogenesis
Secondary spermatocyte in meiosis II
Portion of sustentacular cell within the luminal compartment
Level of blood–testis barrier
LUMEN
Spermatids beginning spermiogenesis
Nuclei of sustentacular cells
Secondary spermatocyte
Primary spermatocyte preparing for meiosis I
Capillary
Spermatogonium
Connective tissue capsule
Interstitial cells
Fibroblast
Portion of sustentacular cell within the basal compartment
(c)

SPERMATOGENESIS

- Process by which sperm cells or **spermatozoa** are formed
- **Spermatogenic cells** form sperm cells
  - line the seminiferous tubules.
- ***Interstitial cells*** lie in spaces between the seminiferous tubules, produce and secrete male sex hormones
- ***Sertoli cells*** facilitate the progression of germ cells to spermatozoa via direct contact and by controlling the environment within the seminiferous tubules

SPERMATOGENESIS

- Sperm cells collect in the lumen of each tubule, pass to the epididymis, and then mature.
- Matured sperm cell - 0.06 mm *“tadpole shape”*.
- ~~~500 million sperm are produced daily by a healthy male.



SPERMATOGENESIS

- **Head:** nucleus; chromatin containing its 23 chromosomes.
- **Acrosome;** contains enzymes needed to penetrate an egg cell during fertilization.
- **Middle-piece** or body of the sperm cell has a filamentous core and spiralled mitochondria.
- **Tail** or flagellum consists of microtubules in an extension of the cell membrane.
  - The tail moves via ATP from the mitochondria, propelling the sperm cell through its containing fluid.

SPERMATOGENESIS

- Spermatozoan lacks an endoplasmic reticulum, golgi apparatus, lysosomes, peroxisomes, ribosomes ***(why?)***

In spermatogenesis:

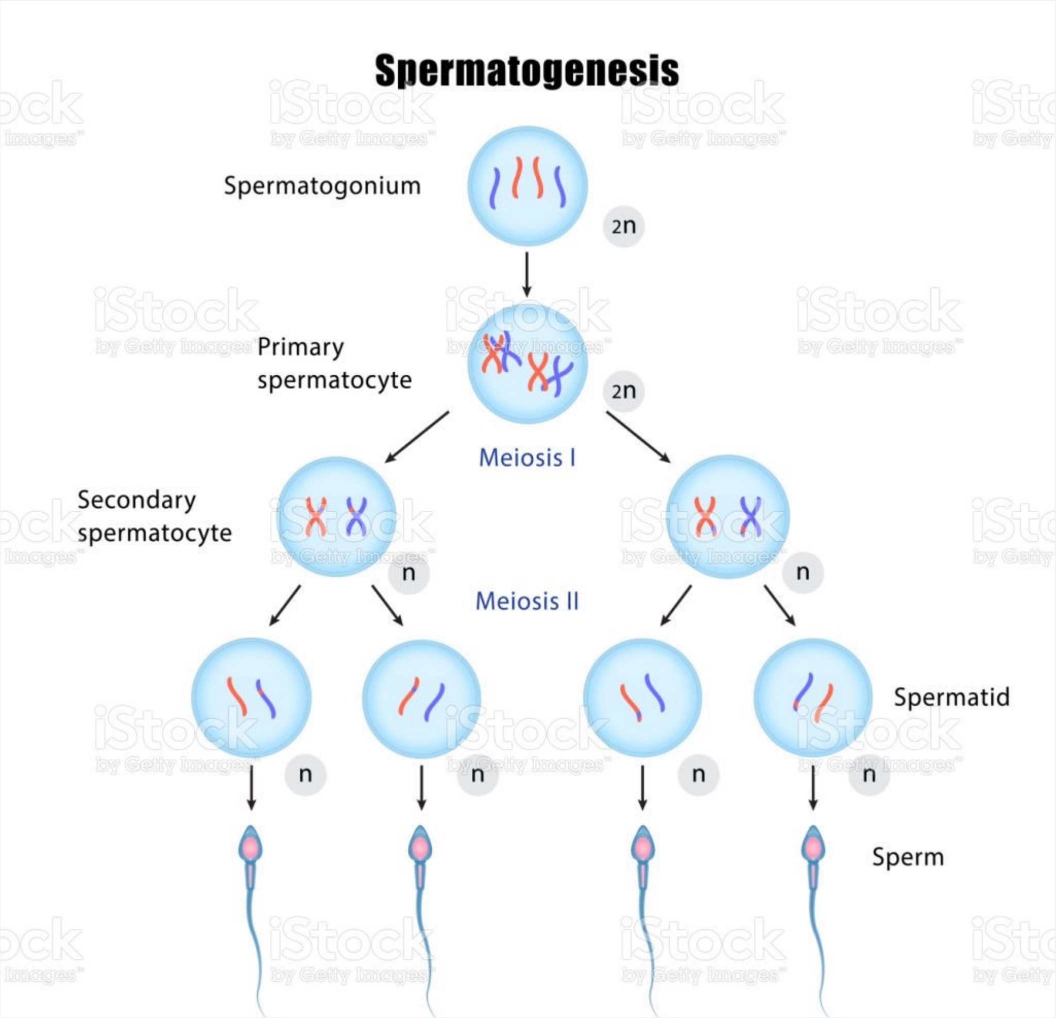
- **Mitosis:** diploid spermatogonium, divides mitotically, producing ***2 diploid*** daughter cells (primary spermatocytes)
- **Meiosis I:** 1° spermatocytes undergoes meiosis I, separates chromosome pairs that are homologous to ***produce 2 haploid*** secondary spermatocytes

SPERMATOGENESIS

- **Meiosis 2:** homologous pair separate its chromatids(spermatids)
- :- 1° spermatocyte that undergoes meiosis, four sperm cells with 23 chromosomes in each

Spermiogenesis: each spermatid matures into a single sperm or *spermatozoon*

SPERMATOGENESIS



SPERMATOGENESIS

Features:

- Mature spermatozoon lacks:
    - endoplasmic reticulum, Golgi apparatus, lysosomes, peroxisomes, ribosomes ***(why?)***
- Reduces sperm size and mass
- Sperm must absorb nutrients (fructose) from surrounding fluid

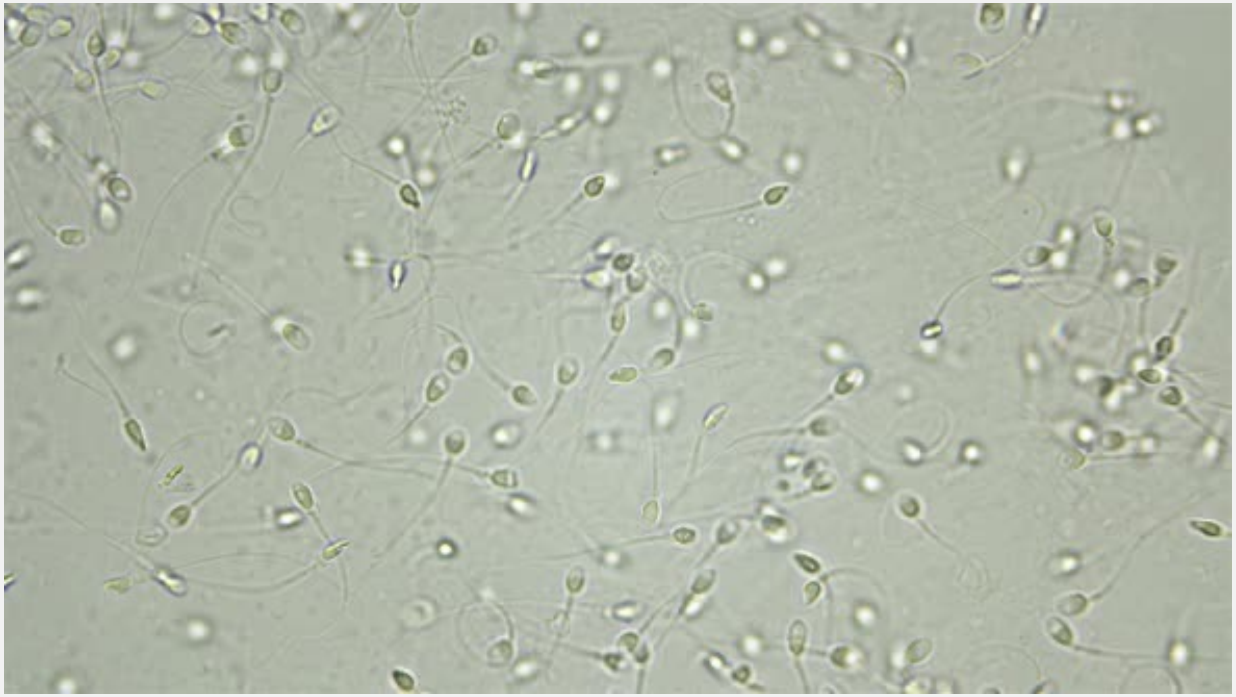
SPERMATOGENESIS

Capacitation

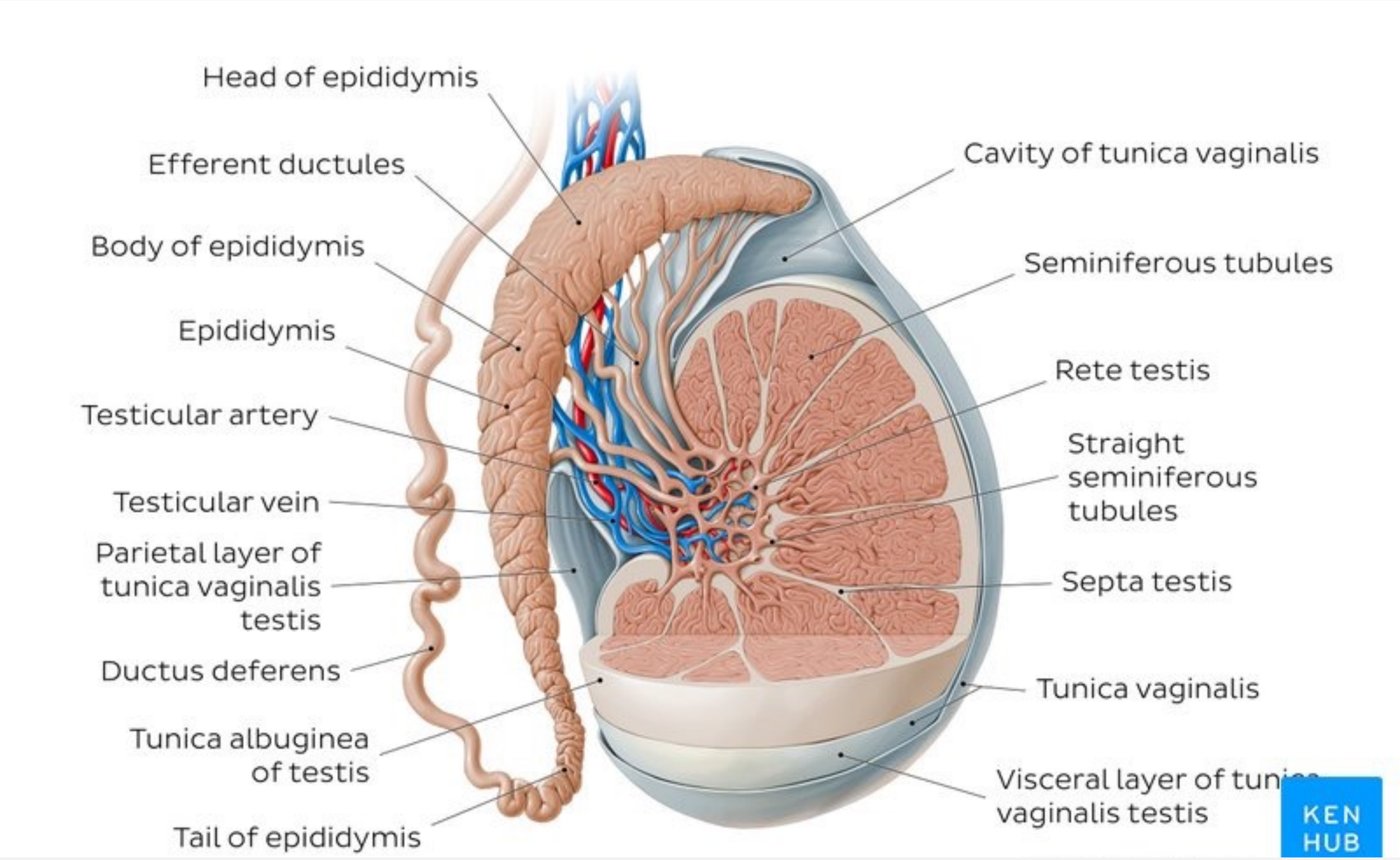
- *Spermatozoa become motile, when mixed with secretions of seminal vesicles*
- *Spermatozoa become capable of fertilization, when exposed to female reproductive tract*

SPERMATOGENESIS

Human spermatozoa under a microscope



THE TESTES


Head of epididymis
Efferent ductules
Body of epididymis
Epididymis
Testicular artery
Testicular vein
Parietal layer of tunica vaginalis testis
Ductus deferens
Tunica albuginea of testis
Tail of epididymis
Cavity of tunica vaginalis
Seminiferous tubules
Rete testis
Straight seminiferous tubules
Septa testis
Tunica vaginalis
Visceral layer of tun
vaginalis testis

THE TESTES

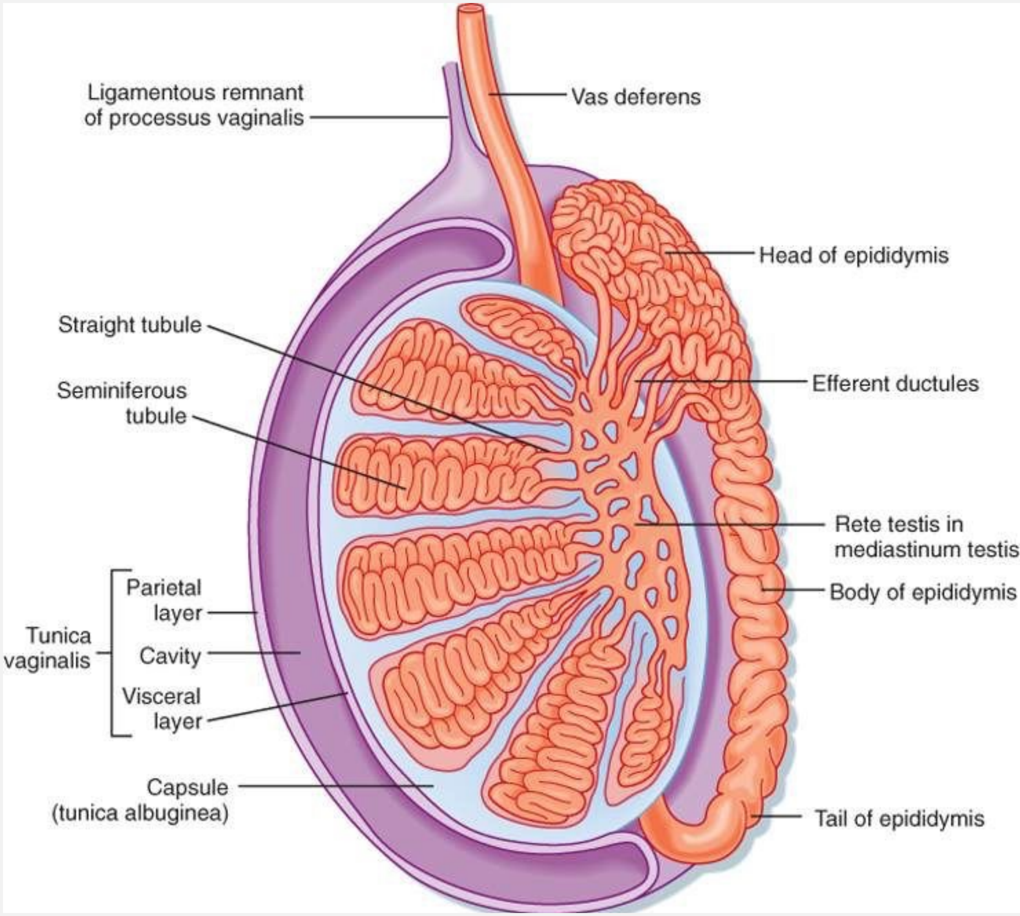
- In the spaces between adjacent seminiferous tubules are clusters of cells called ***interstitial cells*** or ***Leydig cells***
- Spaces also contain *blood vessels*

- **Interstitial cells / Leydig cells** *produce testosterone* in the testes under the control of pituitary luteinizing hormone (LH)

THE TESTES

- **The epididymis** is a long, coiled tube, about 7cm long that transports sperm ***from the testes to the vas deferens.***

- Consists of three parts: *head, a body, and a tail*

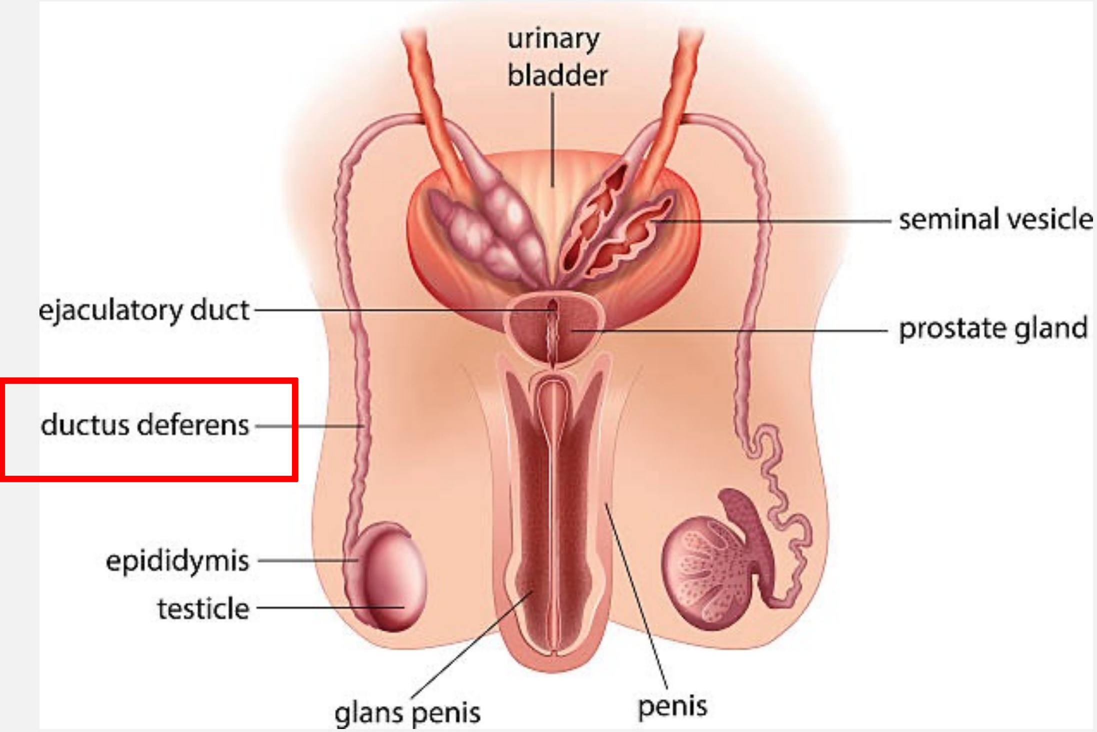


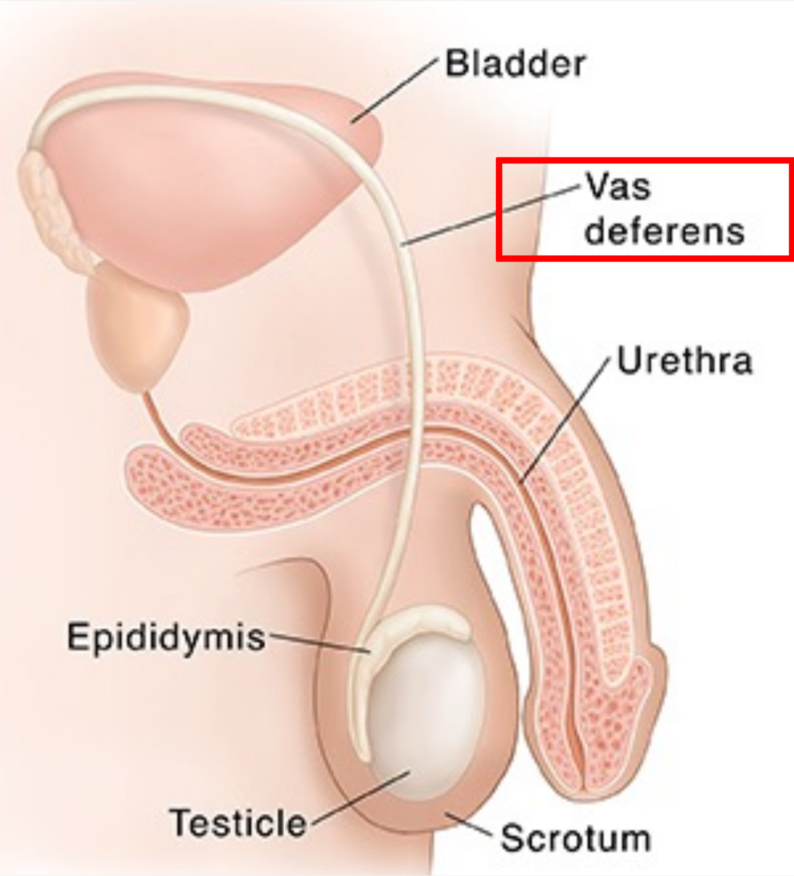
THE DUCTUS DEFERENS

- The **Ductus Deferens** also called **vas deferens** is about 40–45 cm long, ascends through inguinal canal as part of spermatic cord

- Can ***store spermatozoa for several weeks*** (approx. state of low metabolic rates)
- Is lined by ciliated epithelium and ***peristaltic contractions propel spermatozoa*** and fluid

THE DUCTUS DEFERENS

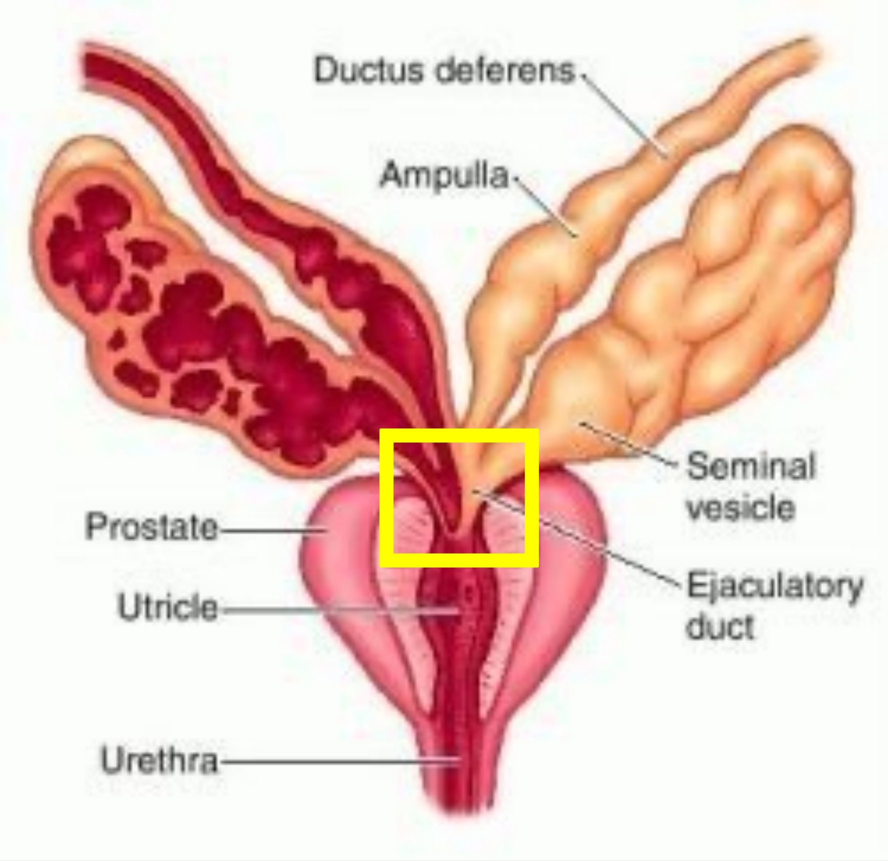




THE EJACULATORY DUCT

- Formed by the union of the ampula of the vas deferens with the duct of the seminal vesicle.

- They pass through the prostate, and open into the urethra



SEMINAL FLUID

- **Seminal fluid** is a mixture of *sperm and glandular secretions* (60% of semen volume)

- **Seminal vesicles:** secretions is slightly alkaline, to neutralize acids in prostate gland and vagina
  - *capacitation:* spermatozoa begin beating flagella, become highly motile

SEMINAL FLUID

Prostate gland secretes:

- **Spermine** which is a base that neutralizes vaginal acidity to protect the sperm, gives the semen a pH of 7.35 to 7.50
- **Clotting enzymes** that act on fibrinogen from seminal vesicles, causing newly ejaculated semen to temporarily coagulate and become sticky
- **Fibrinolysin** which liquefies the coagulated semen 15 to 30 mins after has had time to be taken into the uterus and liberates the sperm from the coagulate

SEMINAL FLUID

Bulbourethral glands: also called Cowper's Gland:

- Adds fluids to semen during the process of ejaculation, lubricate the spongy urethra for the passage of the ejaculate

Enzymes in the seminal fluid:

- Protease
- Seminalplasmin
- Prostatic enzyme
- Fibrinolysin

FUNCTIONS OF MALE GLANDS

1. Activating spermatozoa
2. Providing nutrients spermatozoa need for motility
3. Propelling spermatozoa and fluids along reproductive tract:
   - mainly by peristaltic contractions
4. Producing buffers:
   - to counteract acidity of urethral and vaginal environments

FUNCTIONS OF SUSTENTACULAR CELLS

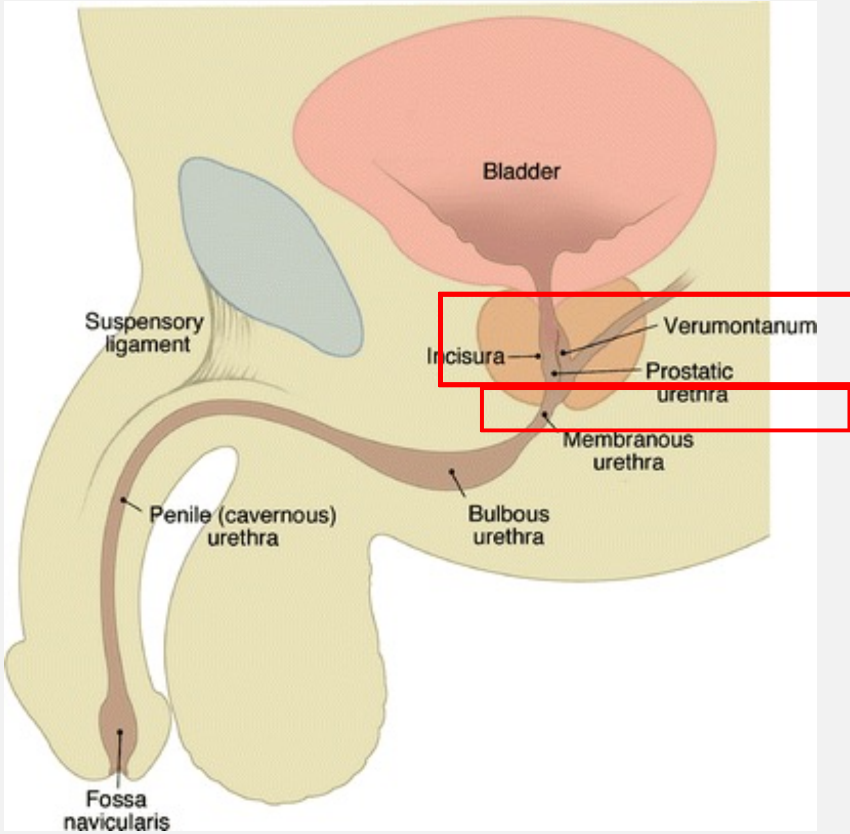
1. Maintain blood–testis barrier
2. Support mitosis and meiosis
3. Support spermiogenesis
4. Secrete inhibin
5. Secrete androgen–binding protein

FUNCTIONS OF SUSTENTACULAR CELLS

6. Maintains Blood–testis barrier:
   - isolates seminiferous tubules
   - Sustentacular cells are joined by tight junctions
   - divide seminiferous tubule into compartments

THE MALE URETHRA

- The male urethra is a ***narrow fibromuscular tube*** that conducts urine from the bladder or semen from the ejaculatory ducts to the exterior of the body



THE MALE URETHRA

- Extends 18–20 cm:

Is divided into 3 regions:

- **Prostatic** – is the proximal portion that passes through the prostate
- **Membranous** – a short (0.5cm) portion that passes through urogenital diaphragm
- **Spongy** – longest portion (15cm) extends from edge of urogenital diaphragm to the orifice on the glans of the penis

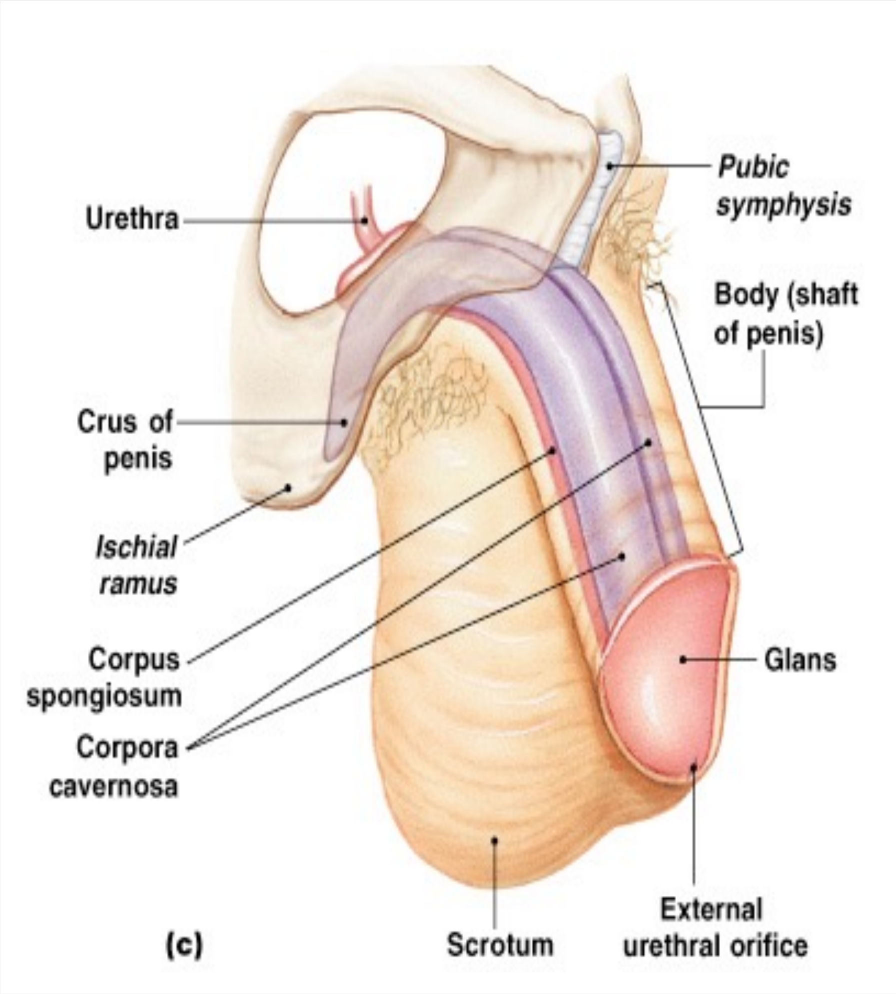
THE PENIS

An erectile copulatory organ that delivers sperm into female reproductive tract

- When erect, it ***stiffens*** and ***enlarges***, enabling insertion into the vagina during sexual intercourse
- It is made up of a ***spongy network*** of ***connective tissue*** and ***smooth muscle*** with vascular spaces that become filled with blood

THE PENIS

- Is divided into **3 regions:**
  - root
  - Body (shaft)
  - glans



THE PENIS

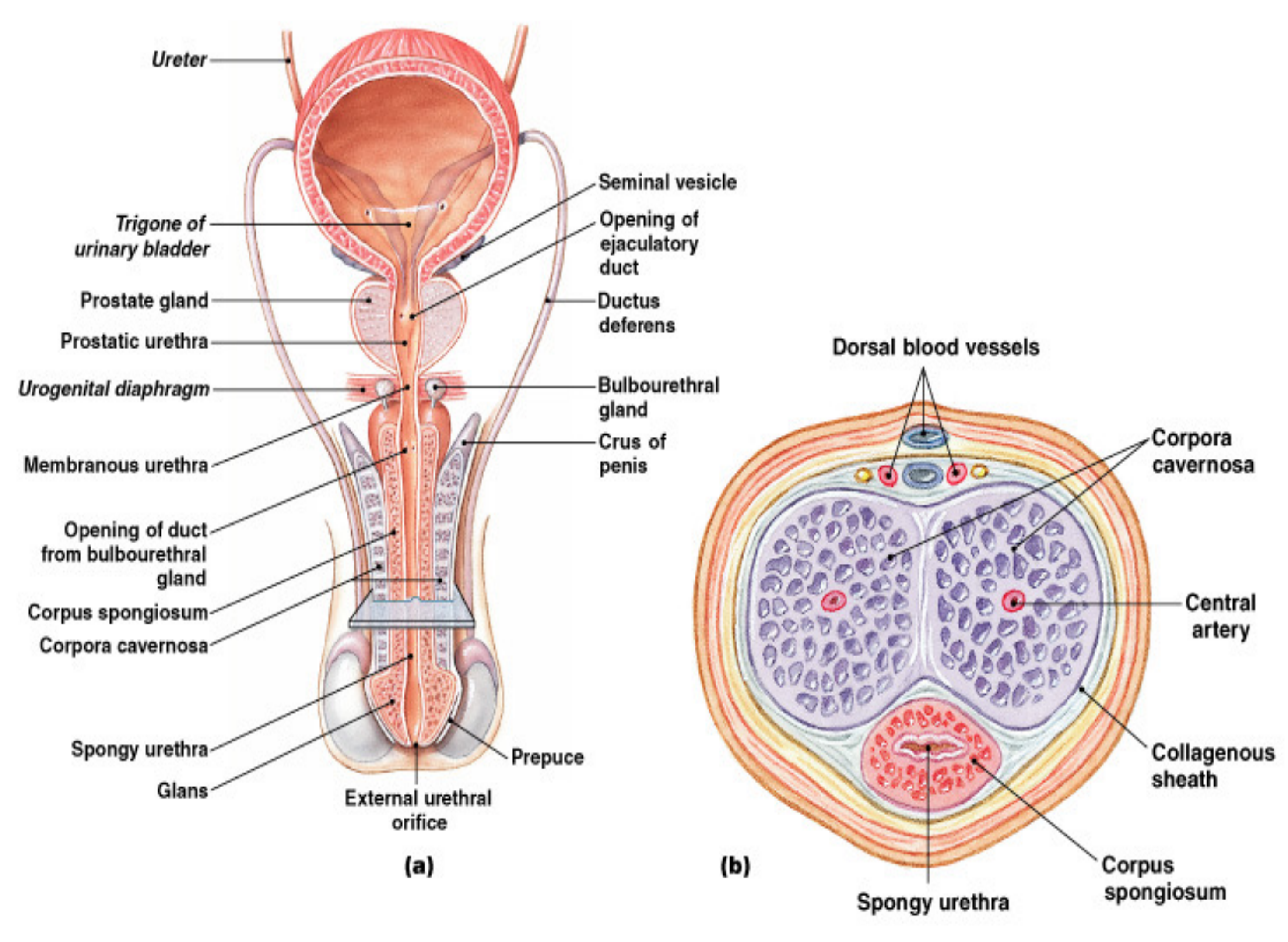
- **Body:** composed of three cylinders of **erectile tissue** – **two**-***corpora cavernosa***, and **one**-***corpus spongiosum***.

- **Glans** – made of corpus spongiosum.
  - the opening of the urethra, termed the external urethral orifice.
  - supplied with nerve endings and is *highly sensitive to stimulation*
- **Prepuce / foreskin** attaches to neck and continues over glans

DERMIS OF THE PENIS

- **Contains a layer of smooth muscle:**
  - continuation of dartos muscle
- **Underlying areolar tissue:**
  - allows skin to move freely
- **Subcutaneous layer:**
  - contains superficial *arteries*, *veins*, and *lymphatic vessels*

ERECTILE TISSUE



ERECTILE TISSUE

- The erectile tissue of the penis contains many **vascular spaces.**
- During sexual stimulation, these spaces fill with blood as the *arteries relax and allow more blood inflow; at the same time, the veins close up.*

Pressure traps within the corpora cavernosa makes the penis expand and holds the erection.

- When the inflow of blood stops and the veins open, the penis becomes soft.

EJACULATION

Propulsion of semen from the duct system

- ~300 million sperm per ejaculation *(healthy male)*

- ***Emission:*** movement of sperm cells from the vas deferens and secretions of the prostate gland and seminal vesicles into the urethra *(Semen)*
- At sufficient level of stimulation *orgasm and ejaculation begins under the control of the sympathetic nervous system* emission occurs

EJACULATION

Semen is ejected through the urethra with rhythmic peristaltic contractions in the testicular ducts, epididymis, ductus deferens**, and **ejaculatory ducts.

- Also rhythmic contractions of the ***seminal vesicles*** and ***prostate gland.***
- *Bladder sphincter muscle constricts* to prevent urine expulsion or semen reflux into the bladder
- *Somatic motor impulses to the erectile columns(muscles)* causes rhythmic contractions to force semen through the urethra to outside the body

EJACULATION

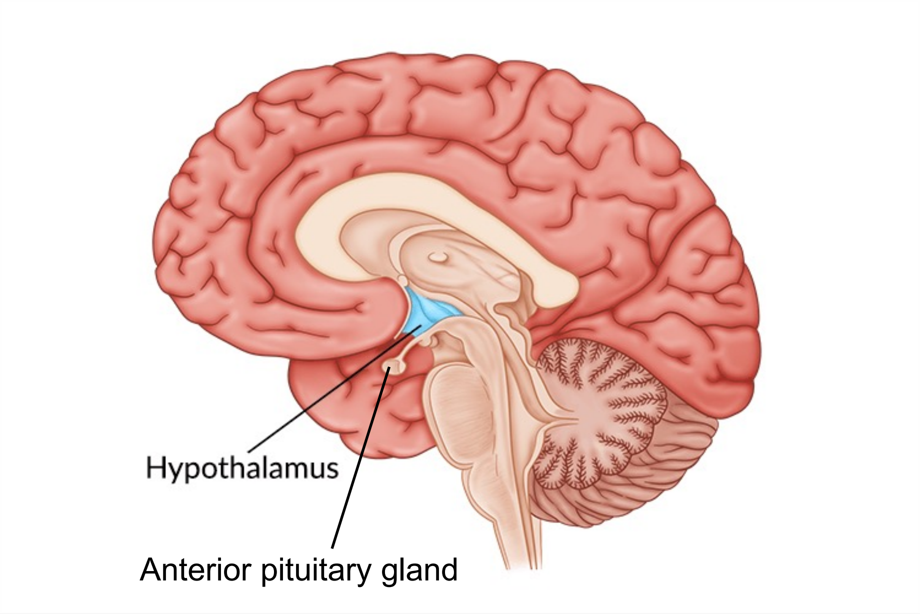
- Intense pleasure is experienced, and systemic changes include:
  - *elevated blood pressure*, *rapid heartbeat*, and *generalized muscle contraction*

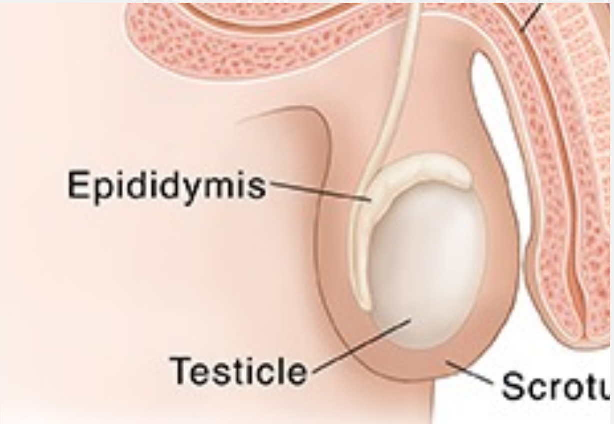
- After ejaculation, period of **resolution** occurs, in which the arteries of the erectile tissue immediately constrict.
- Smooth muscles in the vascular spaces contract partially, and veins of the penis carry away excess blood, gradually returning the penis to its flaccid state.

HORMONAL REGULATION

HORMONAL REGULATION

Male reproductive functions are controlled by **hormones** from the hypothalamus, anterior pituitary gland and testes





HORMONAL REGULATION

- The hormones begin and maintain sperm cell production
- Control development and maintenance of secondary sex characteristics.
  - ✓ Before puberty, spermatogenic cells are undifferentiated.

HORMONAL REGULATION

- The hypothalamus secretes ***gonadotropin-releasing hormone (GnRH)***
- Anterior lobe of **pituitary gland** in response, releases:
  - Gonadotropins also known as ***Luteinizing hormone (LH)***
  - ***Follicle–stimulating hormone (FSH)***

HORMONAL REGULATION

Follicle–stimulating hormone (FSH)

- FSH stimulates seminiferous tubule cells to respond to the male sex hormone testosterone.
- Target supporting cells (sustentacular cells) of seminiferous tubules
- Sustentacular cells:
  - ✓ promote spermatogenesis
  - ✓ secrete androgen-binding protein (ABP)

HORMONAL REGULATION

Luteinizing hormone (LH)

- Also known as ***interstitial cell-stimulating hormone***, LH promotes development of testicular interstitial cells of the testes
- Induces secretion of:
  - ✓testosterone
  - ✓other androgens (eg. androstenedione, dihydrotestosterone (DHT).

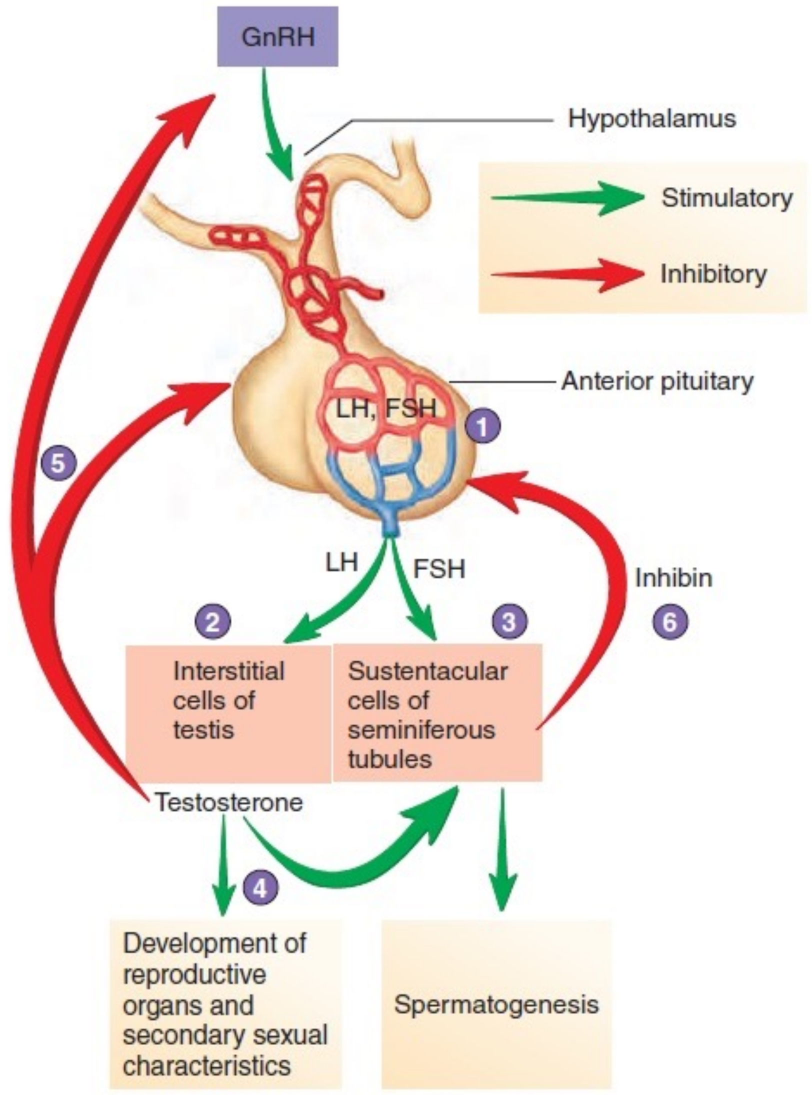
HORMONAL REGULATION

Inhibin

- Another hormone, is secreted with increasing levels of FSH and LH
- to keep the anterior pituitary gland from oversecreting FSH or LH for testosterone through a ***negative feedback.***

HORMONAL REGULATION

1. Gonadotropin-releasing hormone (GnRH) from the hypothalamus stimulates the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the anterior pituitary.
2. LH stimulates testosterone secretion from the interstitial cells.
3. FSH stimulates sustentacular cells of the seminiferous tubules to increase spermatogenesis and to secrete inhibin.
4. Testosterone has a stimulatory effect on the sustentacular cells of the seminiferous tubules, as well as on the development of reproductive organs and secondary sexual characteristics.
5. Testosterone has a negative-feedback effect on the hypothalamus and pituitary to reduce GnRH, LH, and FSH secretion.
6. Inhibin has a negative-feedback effect on the anterior pituitary to reduce FSH secretion.



HORMONAL REGULATION

Testosterone

- Is an important androgen
- Mostly ***produced by the testicular interstitial cells***
    - Small amounts from the adrenal cortex
- Testosterone rapidly produced for **puberty** and throughout the life of males (basically sperm quantity remain constant throughout life)
    - Synthesized from cholesterol (*like steroid hormones*)

HORMONAL REGULATION

Testosterone functions:

1. Stimulates spermatogenesis: promoting functional maturation of spermatozoa
2. Affects CNS (brain) function:
   - stimulating sexual activity.
   - libido (sexual drive) and related behaviors
3. Stimulates cellular metabolism: especially protein synthesis
   - Red blood cell production
   - Muscle growth

HORMONAL REGULATION

Testosterone functions:

4. Establishes ***male secondary sex characteristics***:
    - *Enlargement of the larynx and thickening of vocal folds, which lower the pitch of the voice*
    - *Increased body hair on the face, chest, armpits, and pubic area*
    - *Thickening of the skin*
    - *Decreased hair growth on the scalp*
    - *Increased muscular growth, broadening of shoulders, and narrowing of waist*
    - *Thickening and strengthening of the bones*

HORMONAL REGULATION

Testosterone functions:

5. ***Maintains accessory glands and organs*** of male reproductive tract
   - Without it, all accessory organs atrophy, erection and ejaculation are impaired

HORMONAL REGULATION

Testosterone functions:

- Functions like other steroid hormones in circulation
- ***Bound "transport proteins" to regulate their availability***; the protein bound and free states.
    - ✓ **Sex hormone-binding globulins** (SHBG) carries 2/3 of circulating testosterone
    - ✓ **Albumins:** binds to and transports hormones, including testosterone(1/3)

HORMONAL REGULATION

Testosterone functions:

- Diffuses across target cell membrane: Binds to intracellular receptor to form ***hormone–receptor complex***
  - binds to DNA in nucleus to activate certain genes, resulting in increased protein synthesis in target cells.
  - testosterone is transformed to steroid hormones
    - prostate, it is converted to ***dihydro-testosterone***
    - brain neurons to ***oestradiol*****.**

REPRODUCTION

THE FEMALE REPRODUCTIVE SYSTEM

INTRODUCTION

The female reproductive system

- Oogenesis,
- Menstrual cycle,
- Ovarian and uterine cycles,
- Control of menstrual cycle,
- Disorders of menstrual cycle,
- Ovarian hormones, puberty, menopause,

FEMALE REPRODUCTIVE SYSTEM

- The primary organ: female gonads
    - are the ovaries; *source of ova* (eggs)
    - *female sex hormones* oestrogens and progestogens

FEMALE REPRODUCTIVE SYSTEM

The accessory sex organs are:

- The internal and external reproductive organs

FEMALE REPRODUCTIVE SYSTEM

- The **fallopian** or ***uterine tubes*** conduct ova to the uterus

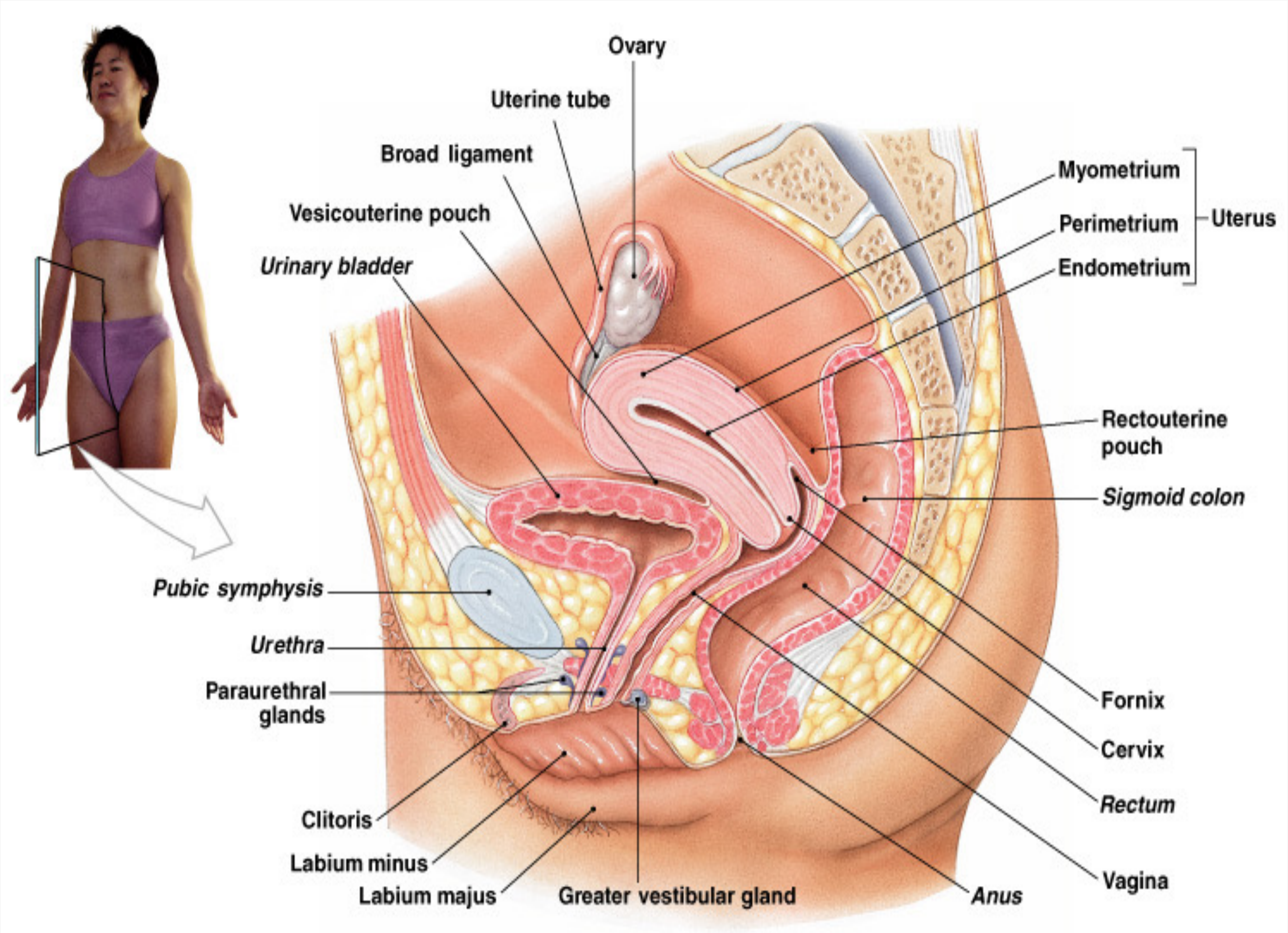
- The ***uterus*** connects through the cervical canal with the vagina.
- The vagina opens into the vestibule, which lie the external genitalia, collectively known as the ***vulva.***

FEMALE REPRODUCTIVE SYSTEM

Functions:

- Produces sex hormones and functional gametes
- Protects and supports developing embryo

FEMALE REPRODUCTIVE SYSTEM



FEMALE REPRODUCTIVE SYSTEM

Organs of the Female Reproductive System

- Ovaries
- Uterine tubes
- Uterus
- Vagina
- External genitalia

Accessory Glands:

- Release secretions into female reproductive tract

OVARIES

OVARIES

- The female gonads comparable to the to the testes in a male, are the ***two ovaries***
- Lies near lateral walls of pelvic cavity, on either side of the uterus
- Oval-shaped, solid structures about 3.5 – 5cm long, 2.5cm wide, and 1cm thick
- weigh 6–8 g

OVARIES

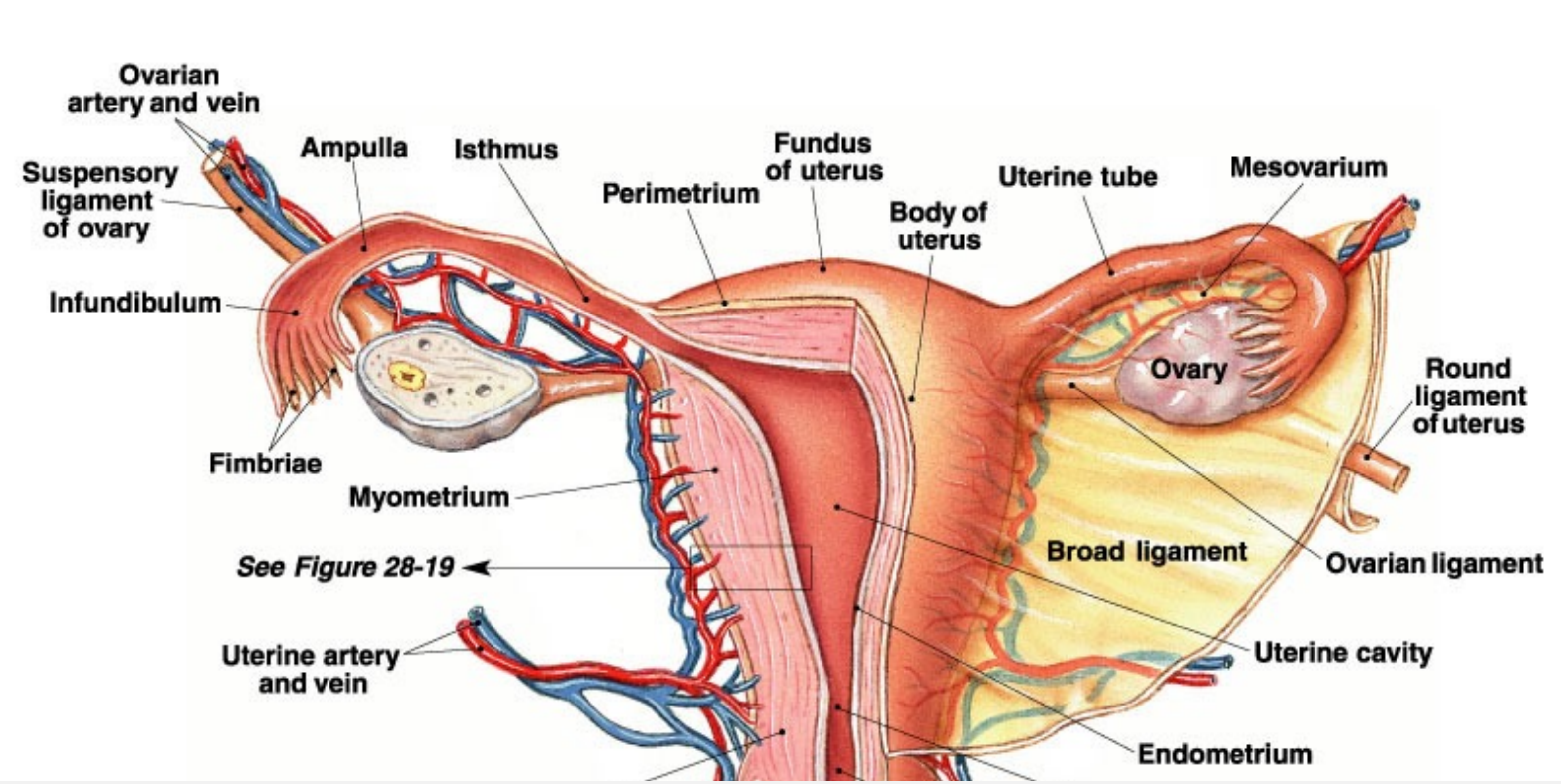
Functions:

- Production of immature *female gametes* (oocytes)
- Secretion of female *sex hormones* (oestrogens, progesterone)
- Secretion of *inhibin*: feedback control of pituitary FSH

OVARIES

- Each ovary is anchored:
  - To the uterus by an ***ovarian ligament*** and
  - Laterally to the pelvic wall by the ***suspensory ligament***.
  - ***Mesovarium*** suspends each ovary in between these points
  - **The broad ligament** *(include mesovarium and suspensory ligament)* support the ovarian ligaments, uterus, uterine tubes, and vagina.

OVARIES



Ovarian artery and vein
Ampulla
Isthmus
Suspensory ligament of ovary
Perimetrium
Fundus of uterus
Uterine tube
Mesovarium
Body of uterus
Infundibulum
Ovary
Round ligament of uterus
Fimbriae
Myometrium
See Figure 28-19
Broad ligament
Ovarian ligament
Uterine artery and vein
Uterine cavity
Endometrium

OVARIES

- ***ovarian arteries,*** uterine arteries and ovarian vein travel through the mesovaria and suspensory ligaments to serve the ovaries

- Vessels connect to ovary at ovarian hilum, where ovary attaches to mesovarium

OVARIES

Germinal epithelium

- Each ovary is externally covered by a fibrous ***tunica albuginea***.
- Surface is further covered by the ***germinal epithelium*** *(Visceral Peritoneum)*
- This epithelium is a continuation of the peritoneum.

OVARIES

Stroma

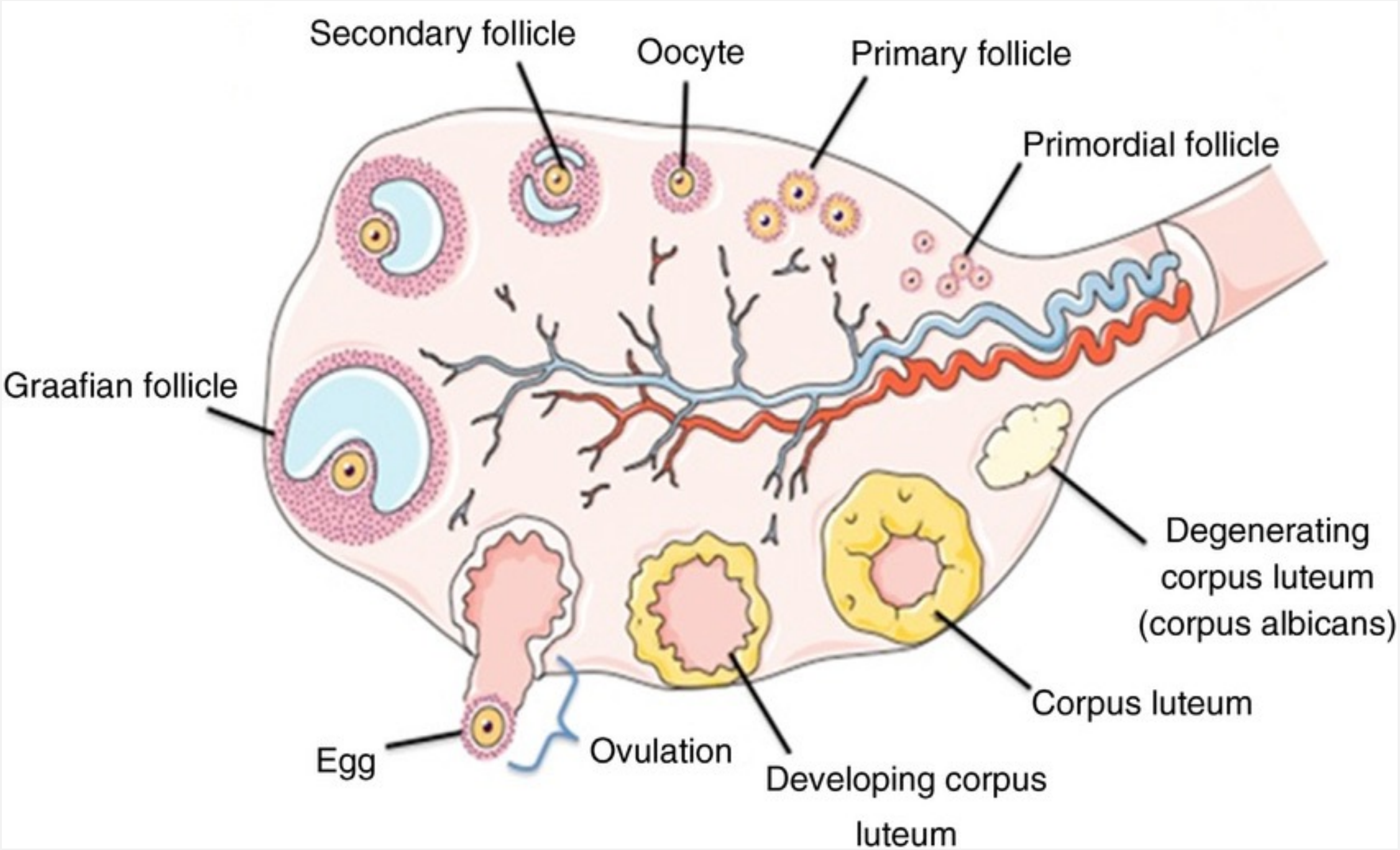
- Forms the interior tissues of ovary:
- Each ovary has an superficial/*outer* ***cortex*** *(fine network of fibres)* enclosing the developing gametes.
- An deeper/*inner* ***medulla*** contains the primary blood vessels and nerves.

OVARIES

Stroma

- ***Ovarian follicles*** (graafian follicles) resembling sacs and are embedded in the cortex of each ovary
- One **oocyte/germ cell** is found in each follicle, encased in a variety of cells.
- If only a single layer is present, these are called **follicle cells**, but if more than one layer is present, they are called ***granulosa cells***
- About *700,000 primary follicles* are contained in the two ovaries of a young female.
  - Most of these degenerate before or after puberty.

OVARIES



Secondary follicle
Oocyte
Primary follicle
Primordial follicle
Graafian follicle
Degenerating corpus luteum (corpus albicans)
Corpus luteum
Egg
Ovulation
Developing corpus luteum

OOGENESIS

Ovum production

- Begins before birth
- Accelerates at puberty
- Ends at **menopause**
- A female foetus develops several millions of primordial follicles in the outer ovarian cortex

OOGENESIS

- Each follicle consists of a primary oocyte surrounded by follicular cells.
- Most primordial follicles formed and oocytes degenerate by puberty, known as ***Atresia***
- only about <u>1 million remain at birth</u>, with only <u>400,000 left at puberty</u>.
- The ovary releases less than 500 oocytes during a female's reproductive life.

OOGENESIS

- In women of childbearing age, one ripening follicle ejects its oocyte from an ovary every month in a process called ***ovulation.***
- The ruptured follicle then changes its appearance, becoming a glandular structure, the ***corpus luteum*** (soon degenerates)

- *The surfaces of the ovaries show pits and scars in older women because they have released many oocytes over a lifetime.*

OOGENESIS

The Ovarian Cycle

- Includes monthly oogenesis between puberty and menopause
- At 8 to 20 weeks of a growing foetus, cells that are to become mature ova have been multiplying (mitosis)
- *At birth, all of the egg cells that the ovaries will release during the active reproductive years of the female are already present in the ovaries*
- Between third and seventh months: primary oocytes prepare for meiosis and stop at prophase of meiosis I

OOGENESIS

The Ovarian Cycle

- At puberty: rising FSH triggers start of ovarian cycle
- Some **primary oocytes are stimulated** to develop further month after month

Meiosis **(**half its chromosomes)

- The oocyte undergoes uneven cell division to produce 1 **ovum** (with original cytoplasm) known as the ***secondary ovum***
- the smaller cell is known as a *polar body*; 2 or 3 **polar bodies** (that disintegrate)

OOGENESIS

The Ovarian Cycle

- The secondary oocyte grows in the ovary until it *reaches maturation*
- Ovary releases secondary oocyte (relatively mature ovum) and is *carried into the fallopian tubes:*
  - suspended in metaphase of meiosis II
  - meiosis is completed upon fertilization

OOGENESIS

Terms:

- ***Ovarian Follicles*****:** Are specialized structures in cortex of ovaries where oocyte growth and meiosis I occur

- ***Primary Oocytes:*** located in outer part of ovarian cortex, near tunica albuginea, in clusters called **egg nests**

- ***Primordial Follicle*****:** Each primary oocyte in an egg nest, surrounded by follicle cells

OOGENESIS

Terms:

- ***Granulosa / Follicular cells:*** produce hormones(eg. oestrogen) and growth factors that interact with the oocyte during its development. They primarily express FSH receptors.
- ***Thecal Cells:*** Theca cells are a group of endocrine cells in the ovary made up of connective tissue surrounding the follicle. Theca cells are stimulated by LH to produce androstenedione from cholesterol.
  - ✓ Synthesize androgens; work with granulosa cells to produce oestrogens
- ***zona pellucida*** (ZP) is a complex microvilli and glycoprotein matrix surrounding the primary oocyte

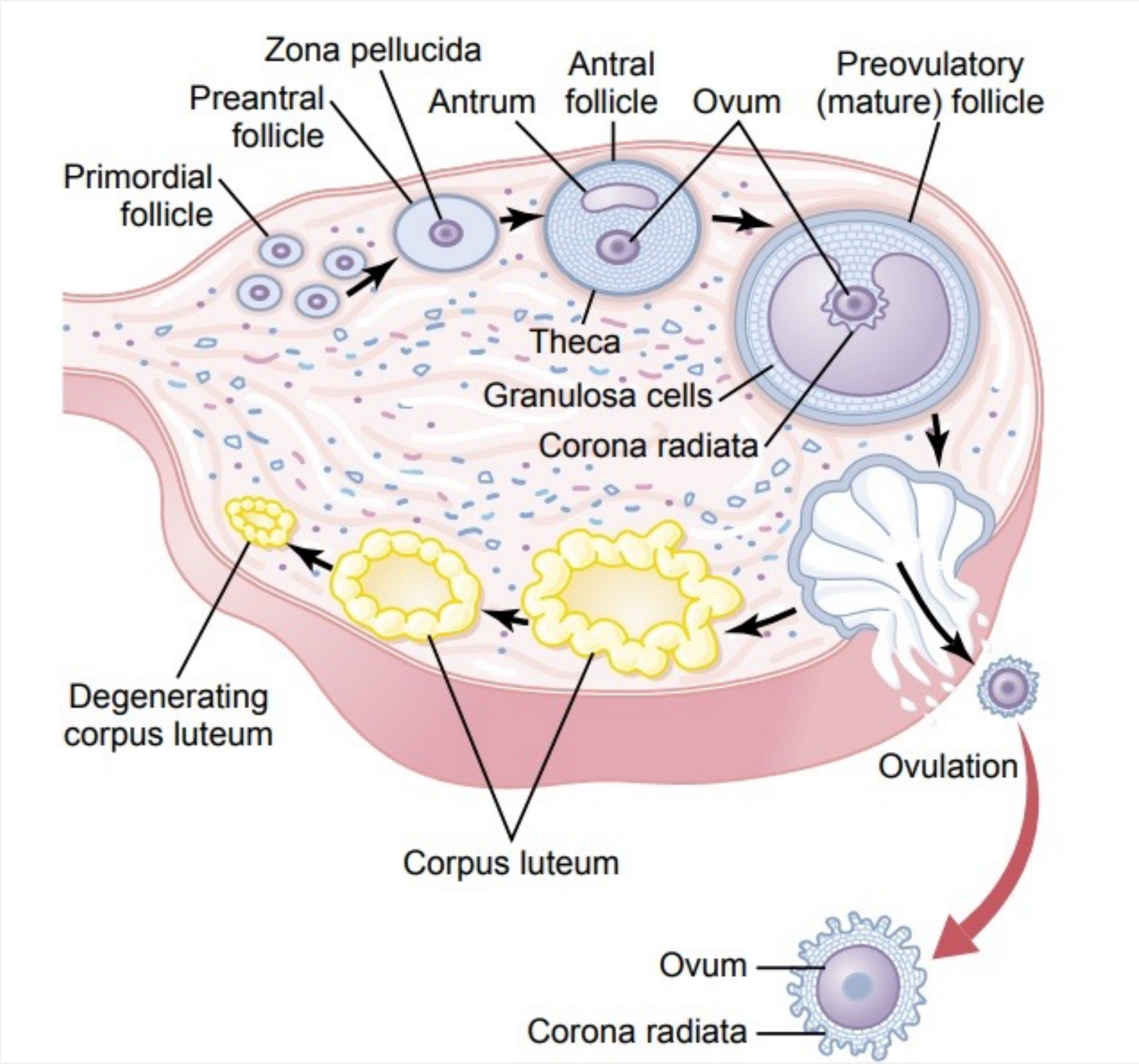
OOGENESIS

Terms:

- ***Antrum:*** Is the expanded central chamber of follicle, surrounded by granulosa cells

- ***Corona Radiata:*** Granulosa cells associated with secondary oocyte

OOGENESIS


Zona pellucida
Preantral follicle
Primordial follicle
Antrum
Antral follicle
Ovum
Preovulatory (mature) follicle
Theca
Granulosa cells
Corona radiata
Degenerating corpus luteum
Corpus luteum
Ovulation
Ovum
Corona radiata

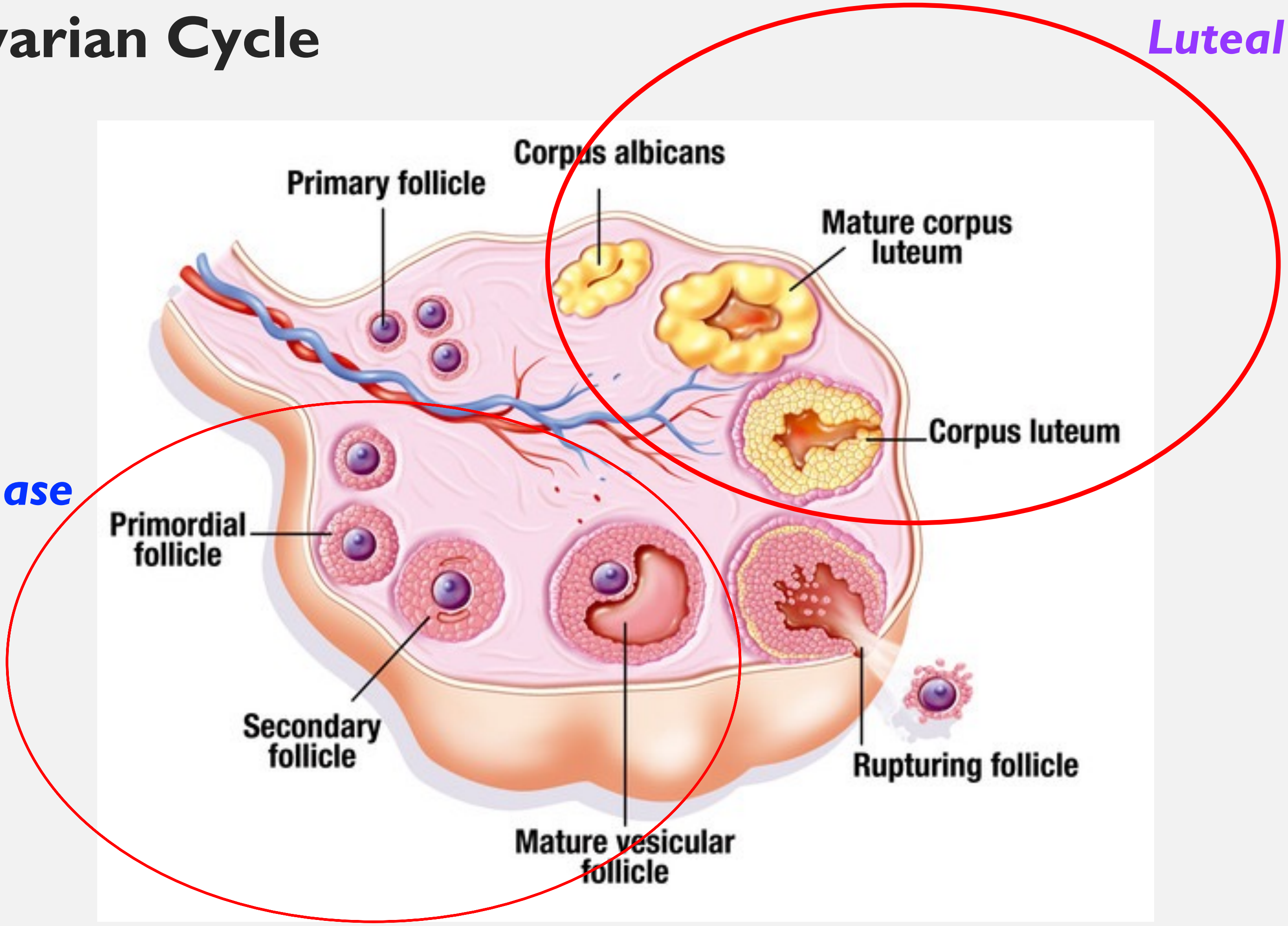
OVARIAN CYCLE

The ovarian cycle is divided into:

- ***Follicular phase*** (pre-ovulatory phase), the development of the follicle in response to follicle stimulation hormone (FSH).
- ***Luteal phase*** (post-ovulatory phase), the corpus luteum forms on the ovary and secretes many hormones, most significantly progesterone, which makes the endometrium of the uterus ready for implantation of an embryo.

OVARIAN CYCLE

The Ovarian Cycle



OVARIAN CYCLE

Follicular Phase:

- follicle-stimulating hormone (FSH) is secreted by the anterior pituitary gland, its levels rises and peak
- The rise in FSH levels recruits 5 – 7 tertiary-stage ovarian follicles (Graafian follicles) for entry into the cycle during the first week of the follicular phase.
- *FSH stimulates:*
  - *proliferation of granulosa* cells in the developing follicles
  - *expression of luteinizing hormone* (LH) receptors on these granulosa cells

OVARIAN CYCLE

Ovulation

- Ovulation is the phase in which a mature ovarian follicle *ruptures and discharges an ovum* (oocyte or egg).

- The time immediately surrounding ovulation is referred to as the ***ovulatory phase*** or the periovulatory period.

OVARIAN CYCLE

Ovulation features

- *High oestrogen levels initiate the formation of a new layer of endometrium in the uterus.*

- Crypts in the cervix are stimulated to produce *fertile cervical mucus* that reduces the acidity of the vagina, creating a more hospitable environment for sperm.

OVARIAN CYCLE

Ovulation features

- *Basal **body temperature may lower** slightly under the influence of high oestrogen levels (effect on central autonomic nuclei involved in control of peripheral blood flow)*

- Ovulation normally occurs 30 (± 2) hours after the beginning of the LH surge (detectable in urine).

OVARIAN CYCLE

Luteal Phase

- The luteal phase (or secretory phase) begins with the formation of the *corpus luteum* and ends in either ***pregnancy*** ***or*** ***luteolysis*****.**
- The main hormone associated with this stage is ***progesterone***
  - FSH and LH cause the remaining parts of the dominant follicle to transform into the corpus luteum.
- Corpus luteum grow after ovulation and produces significant amounts of progesterone (with less oestrogen)

OVARIAN CYCLE

Luteal Phase

- Hormones suppress production of the FSH and LH
- Corpus luteum atrophy *(falling levels of progesterone and oestrogen)*

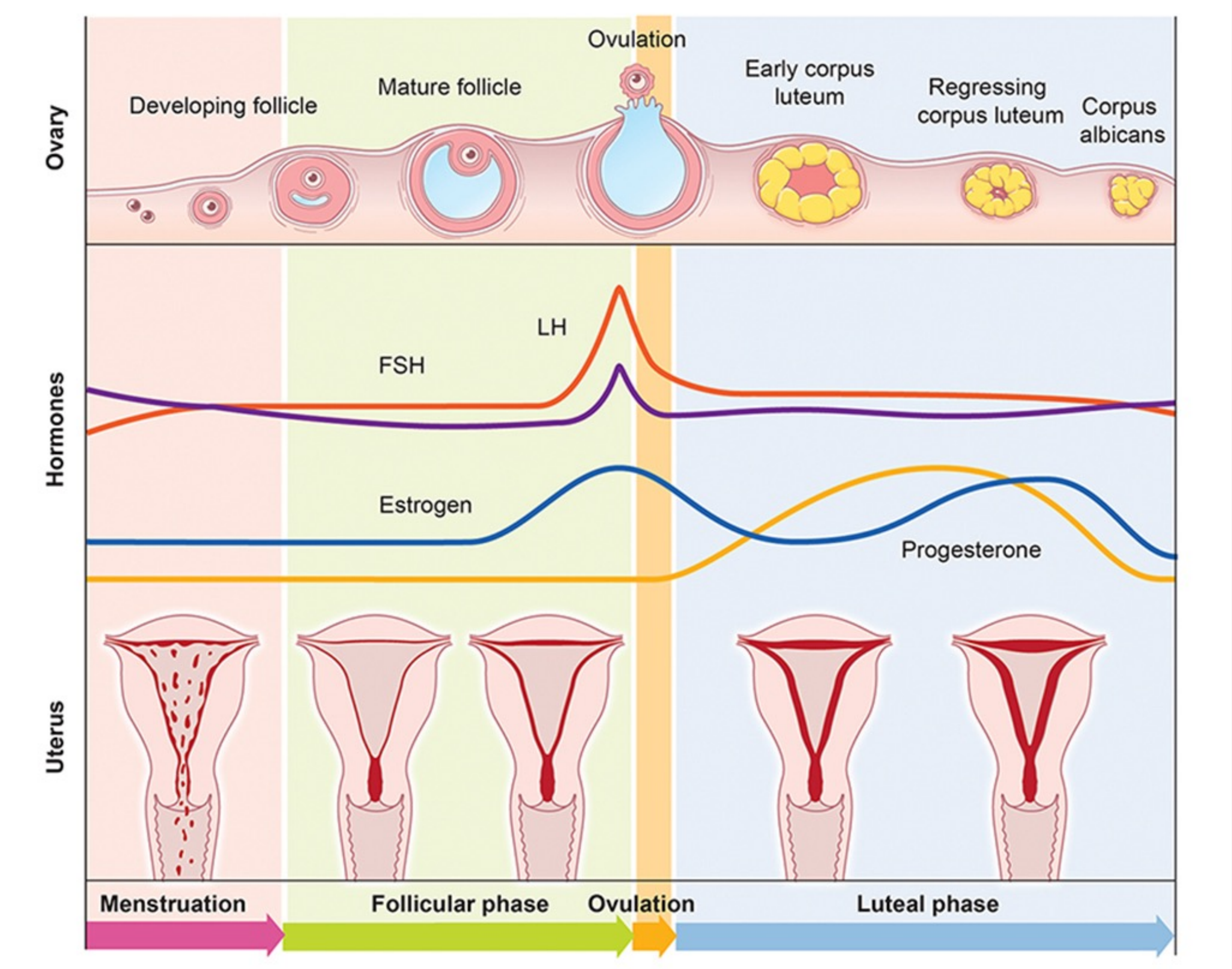
- ***Lower levels of oestrogen and progesterone allows increased levels of FSH, leading to recruitment of follicles for the next cycle***

OVARIAN CYCLE

Luteal Phase

- The loss of the corpus luteum can be prevented by implantation of an embryo.
- After implantation, *human embryos produce* ***human chorionic gonadotropin*** (hCG, *preg. test*), similar to LH and can preserve the corpus luteum.
- Corpus luteum will continue to produce progesterone (and maintain high basal body temperatures) for 8-12wks, after which the placenta takes over this function.

OVARIAN CYCLE



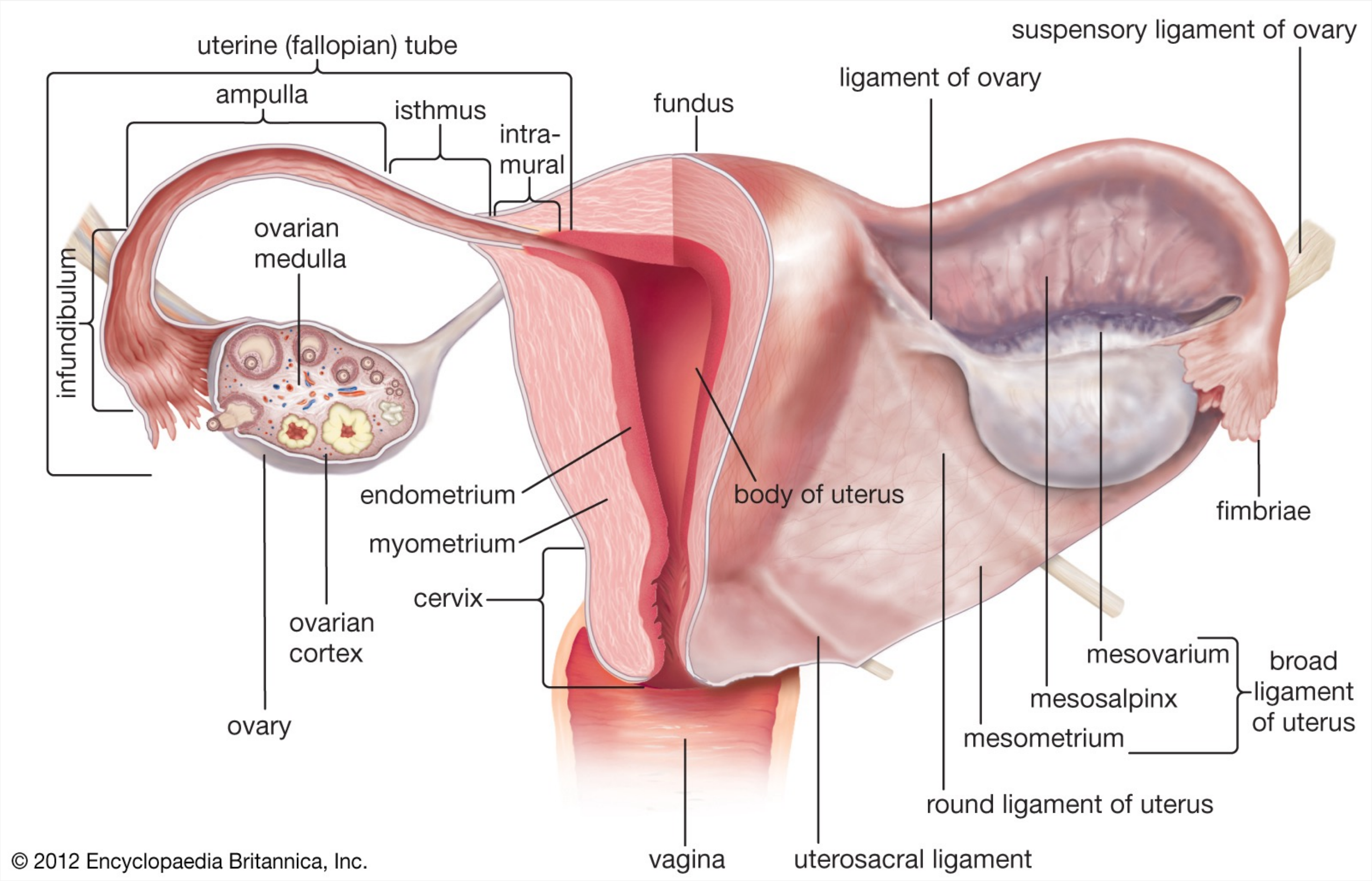
FEMALE REPRODUCTIVE SYSTEM

Female Duct System

- The female duct system has no or very little contact with the ovaries.
- The accessory structures:
  - two uterine tubes
  - uterus
  - vagina

UTERINE TUBES

UTERINE TUBES



UTERINE TUBES

- **The uterine tubes (fallopian tubes / *oviducts*) receive the ovulated oocytes from the ovaries and transport to uterus.**

- About10-13cm long.
- The uterine tubes are the sites *where fertilization usually occurs*.
- Each uterine tube empties into the upper area of the uterus through the ***isthmus***.
- curves around the ovary; at the distal ends to form an ***ampulla.***

UTERINE TUBES

- At the ovaries, each tube forms funnel-shaped ***infundibulum*** that partially encircles the ovary.
- *Finger-like* ***fimbriae*** surround its margin with some connecting with the ovary and also extending into pelvic cavity
- Epithelium lining is composed of *ciliated columnar epithelial cells,* cilia beat toward middle segment: contains scattered **mucin secreting cells**
- Mucosa is surrounded by concentric *layers of smooth muscle*
- The uterine tubes are *externally covered by peritoneum*

UTERINE TUBES

Oocyte transport

- Oocytes are *transported by ciliary movement* and *peristaltic contractions* in the uterine tube walls.
- Non-ciliated mucosal cells have *dense microvilli* and produce secretions that keep oocytes as well as any present *sperm nourished and moist*.
- A few hours before ovulation, *nerves from pelvic plexus initiate peristalsis* and "turn on" beating pattern

UTERINE TUBES

Oocyte transport

- From ***infundibulum to uterine cavity:*** normally takes 3–4 days
- For fertilization to occur: secondary oocyte must meet spermatozoa during first *12–24 hours*
- Fertilization typically occurs: near boundary between ampulla and isthmus

UTERINE TUBES

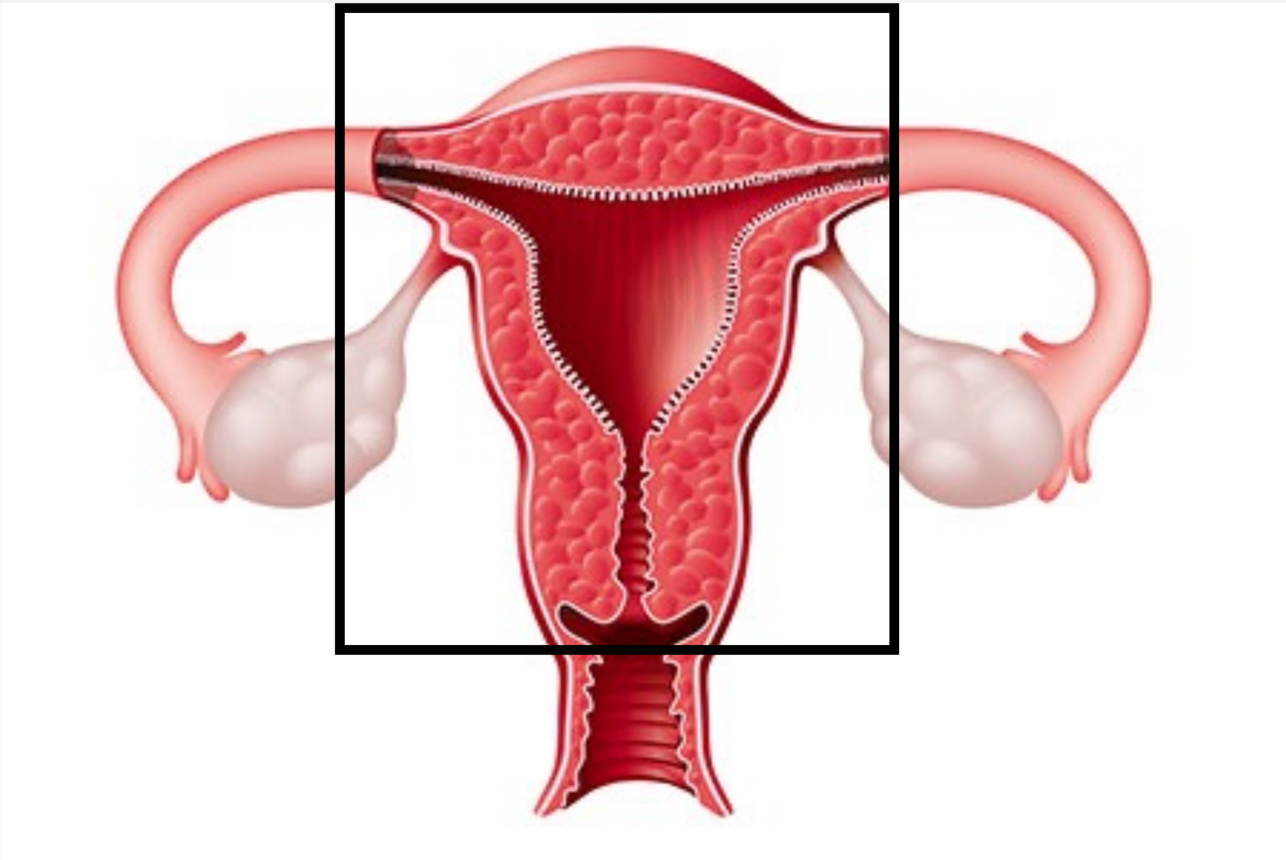
Oocyte transport

- Uterine tube is enriched with ***lipids and glycogen***: provides nutrient-rich environment for spermatozoa and developing pre-embryo

- ***Unfertilized Oocytes*** *degenerate* in terminal portions of uterine tubes or within uterus

THE UTERUS

THE UTERUS



THE UTERUS

Functions by providing for developing embryo (weeks 1–8) and fetus (week 9 through delivery):

1. mechanical protection
2. nutritional support
3. waste removal

THE UTERUS

- ***The uterus is hollow and muscular, shaped slightly like an inverted pear.***
- 7.5 cm long, 5 cm diameter; its size changes during pregnancy, able to hold the developing baby up until birth.
- Weighs 30–40 g
- Wall thickness is approximately 2 to 3 cm (0.8 to 1.2 inches).
- Normally bends anteriorly near base
  - in ***retroflexion***, uterus bends backward

THE UTERUS

Uterine Supporting Structures

- ligaments and the *mesometrium* supports of the uterus

- ***Round ligaments*** (Fibrous) bind the uterus to the anterior body wall.
- Extend through the inguinal canals, anchoring in the connective tissues of external genitalia.
  - restrict posterior movement

THE UTERUS

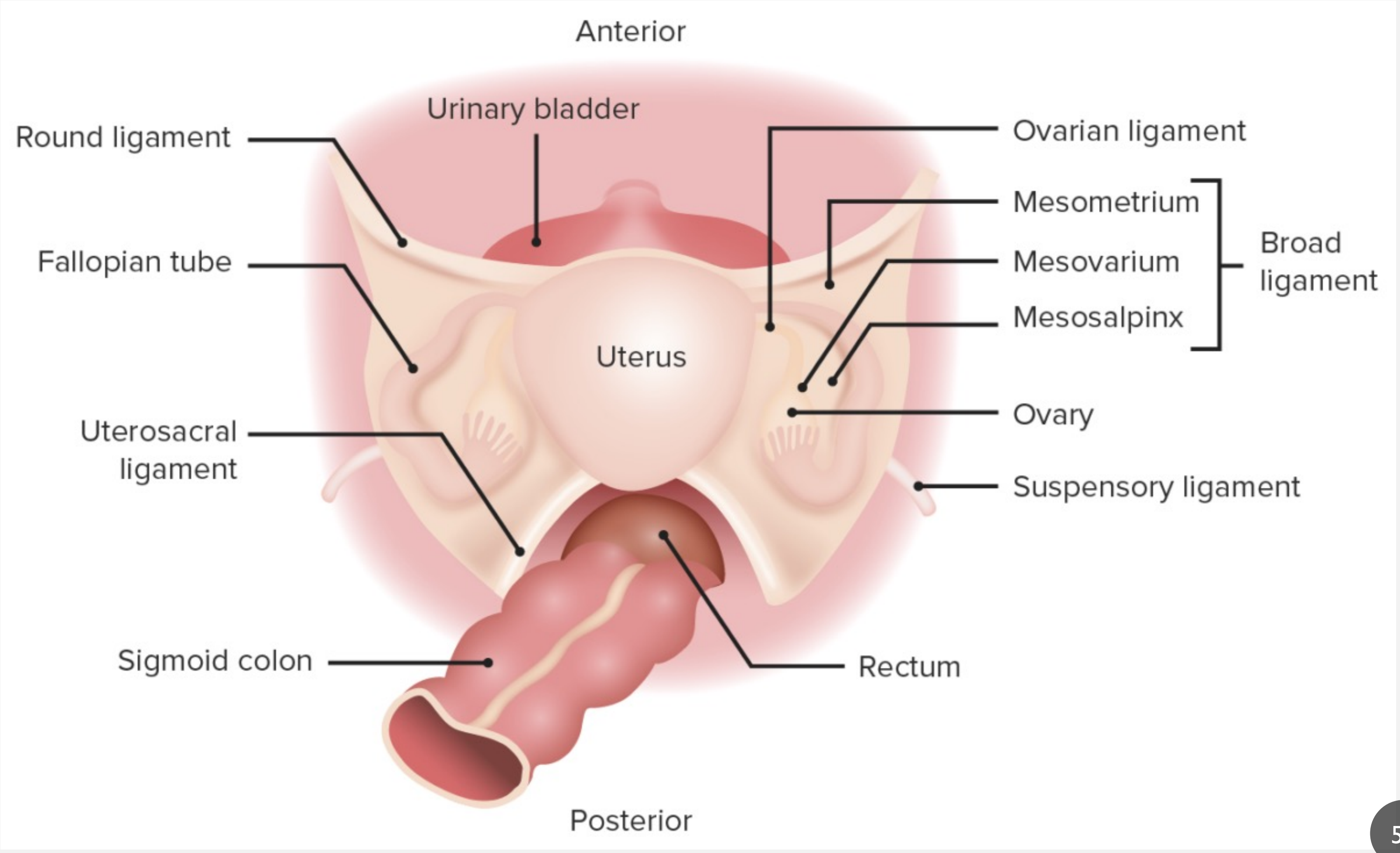
- ***Lateral (cardinal) ligaments:*** also called *lateral cervical ligaments*, extend from the cervix and superior vagina to the lateral walls of the pelvis.
  - prevent inferior movement

- Two ***uterosacral ligaments*** secure the uterus to the sacrum, posteriorly.
  - prevent inferior–anterior movement

THE UTERUS

- ***Ovarian Ligament:*** Joins the ovaries to the uterus
- ***Broad Ligament:*** This is a double layer of peritoneum attaching the sides of the uterus to the pelvis (mesenteric)
  - *These ligaments allow the uterus to be quite movable to accommodating filling and emptying of the bladder and rectum*

THE UTERUS



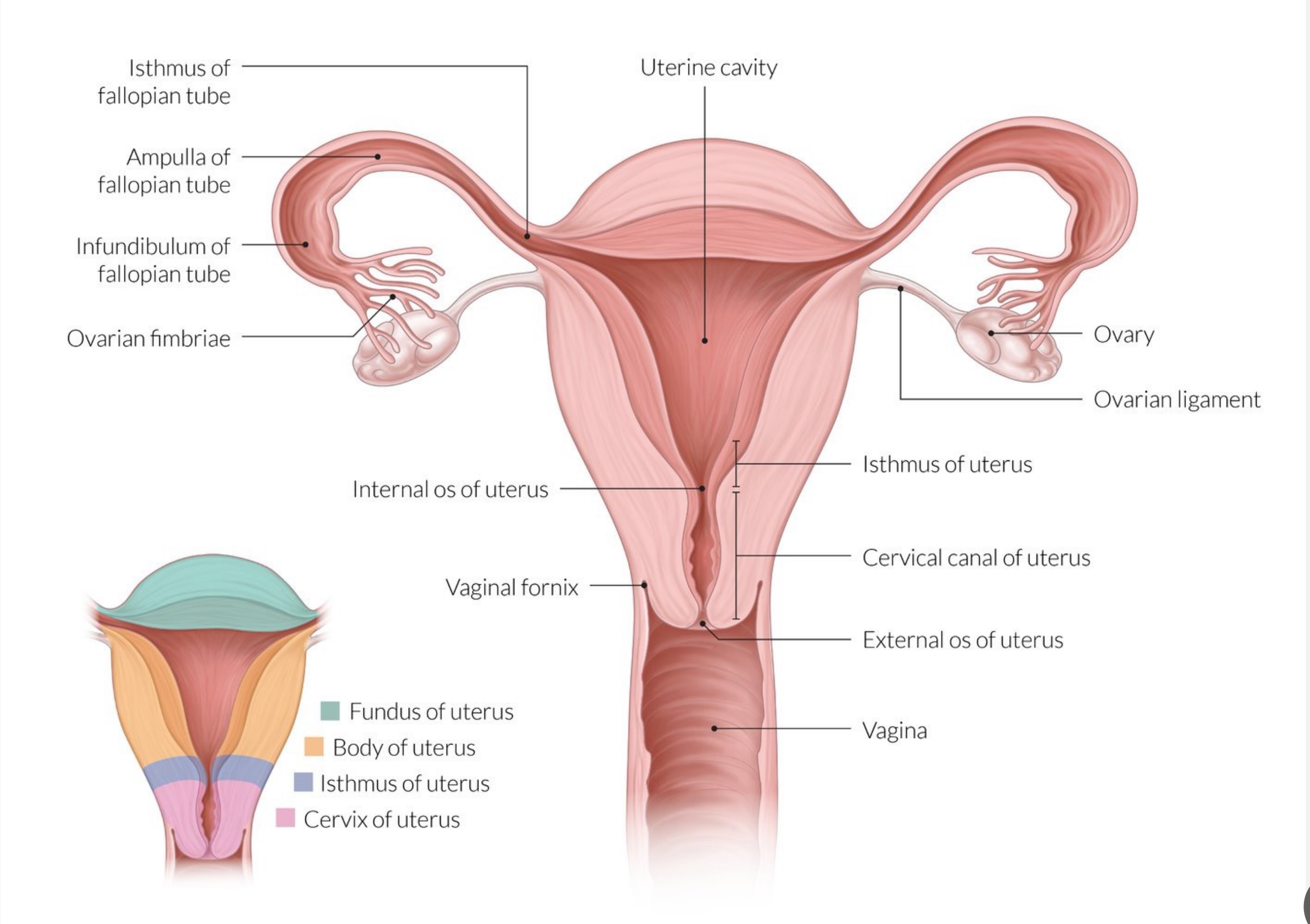
Anterior
Urinary bladder
Round ligament
Fallopian tube
Uterus
Uterosacral ligament
Sigmoid colon
Ovarian ligament
Mesometrium
Mesovarium
Mesosalpinx
Broad ligament
Ovary
Suspensory ligament
Rectum
Posterior

THE UTERUS

Has four major regions:

1. ***Fundus*** is the broad curved upper area in which the fallopian tubes connect to the uterus
2. ***Body/Corpus,*** the main part of the uterus, starts directly below the level of the fallopian tubes and continues downward until the uterine walls and cavity begin to narrow
3. ***Isthmus*** is the lower, narrow neck region; and the lowest section
4. ***Cervix;*** extends downward from the isthmus until it opens into the vagina, projects about 1.25 cm into vagina

THE UTERUS



Isthmus of fallopian tube
Ampulla of fallopian tube
Infundibulum of fallopian tube
Ovarian fimbriae
Uterine cavity
Ovary
Ovarian ligament
Isthmus of uterus
Internal os of uterus
Cervical canal of uterus
Vaginal fornix
External os of uterus
Vagina
Fundus of uterus
Body of uterus
Isthmus of uterus
Cervix of uterus

THE UTERUS

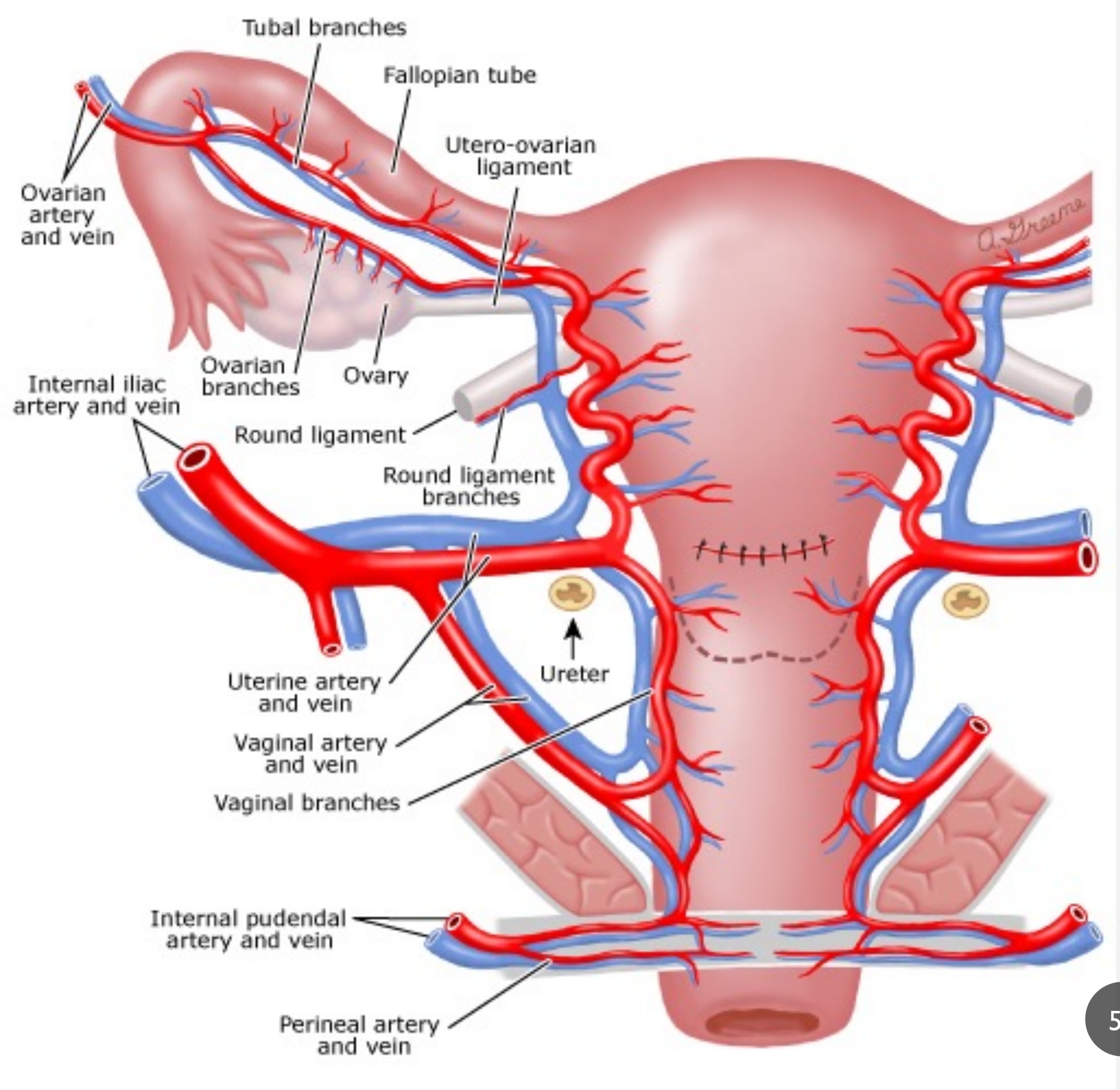
Vascular Supply

- ***uterine arteries*** *arise from the* internal **iliac arteries** of the pelvis

- Branches ascend along the sides of the uterus, splits into several ***arcuate arteries*** and further ***radial artery*** inside the myometrium.

THE UTERUS

Vascular Supply



THE UTERUS

Innervation

- *Sympathetic nerve arise* from *uterovaginal (hypogastric) plexus*
- ***Parasympathetic nerve fibres*** of the uterus are derived from the ***Sacral nerves (S2-S4).***

- The ***afferent fibres*** mostly ascend through the inferior hypogastric plexus to enter the spinal cord through ***T10-T12** and **L1** nerves*

THE UTERUS

Uterine Glands: Open onto endometrial surface and extends deep into lamina propria

Estrogen:

- causes uterine glands, blood vessels, and epithelium to change with phases of monthly uterine cycle

THE UTERUS

Uterine Wall

- Three layers of the wall of the uterus:
  - Thick, outer, muscular ***myometrium***
  - Thin, inner, glandular ***endometrium*** (mucosa)

    Glandular and vascular tissues support physiological demands of growing fetus
  - ***perimetrium***, incomplete serous membrane, continuous with peritoneal lining

THE UTERUS

Myometrium

- makes up most of the uterine volume and is the *muscular layer,* composed primarily of smooth muscle cells.
- arranged into longitudinal, circular, and oblique layers
- At delivery, provides *force to move fetus* out of uterus into vagina

THE UTERUS

Endometrium

- The endometrium is the inner epithelial layer, along with *its mucous membrane*, of the uterus. It has **basal and functional zones**

1. **Basal layer** (adjacent to myometrium) and a
   - attaches endometrium to myometrium
   - contains terminal branches of tubular endometrial glands
   - is not shed-off

THE UTERUS

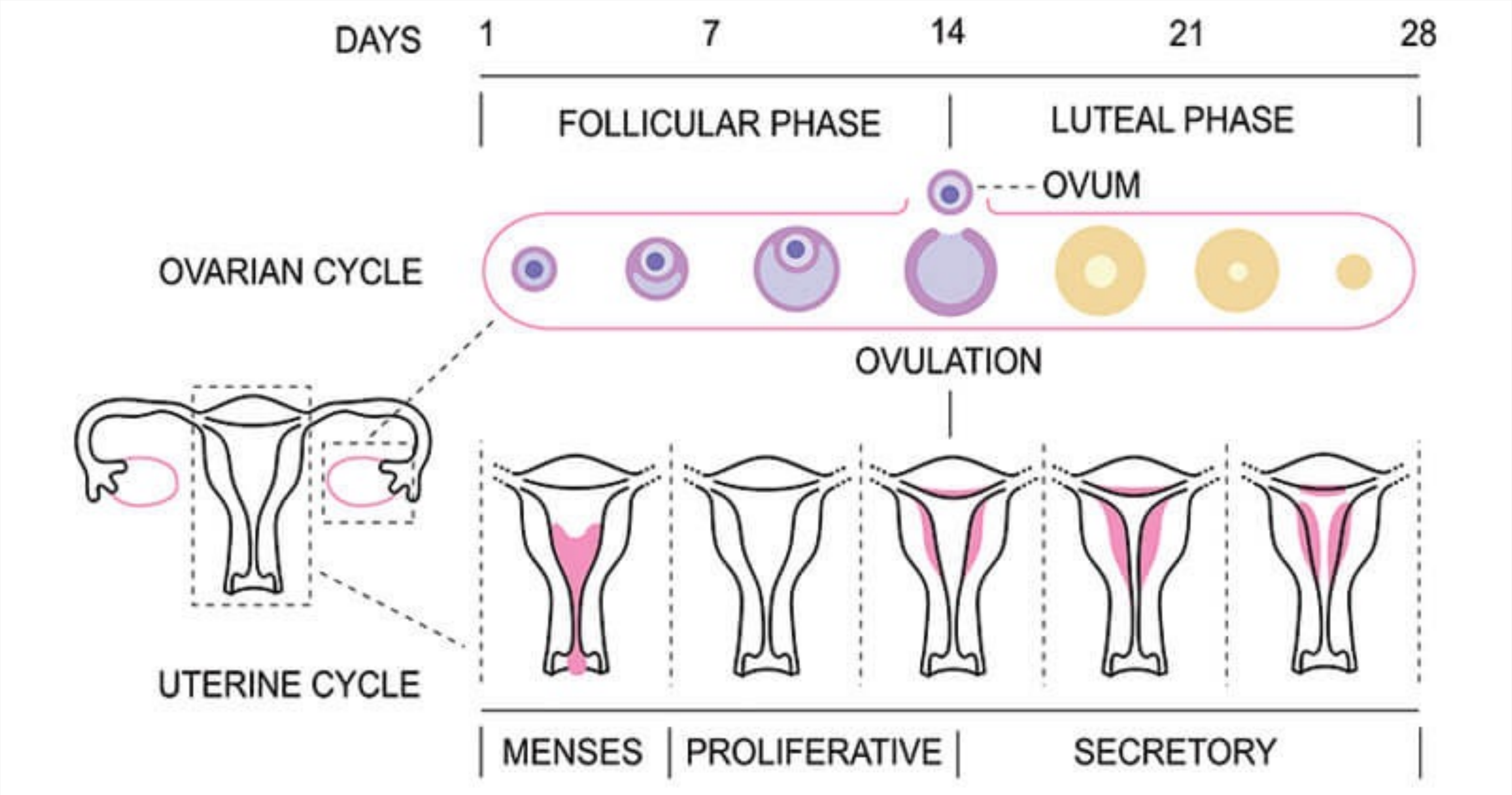
2. **Functional layer** (closest to uterine cavity),
   - Contains most of *uterine glands and blood vessels*
   - During pregnancy, further increase in size
   - Vascular spaces fuse and become interconnected, *forming the placenta*
   - Undergo proliferation induced by oestrogen (follicular phase), and later changes in this layer are engendered by progesterone from the corpus luteum (luteal phase).
   - the functional layer ***thickens and then is shed during menstruation***

THE UTERUS

Vascular supply to endometrium

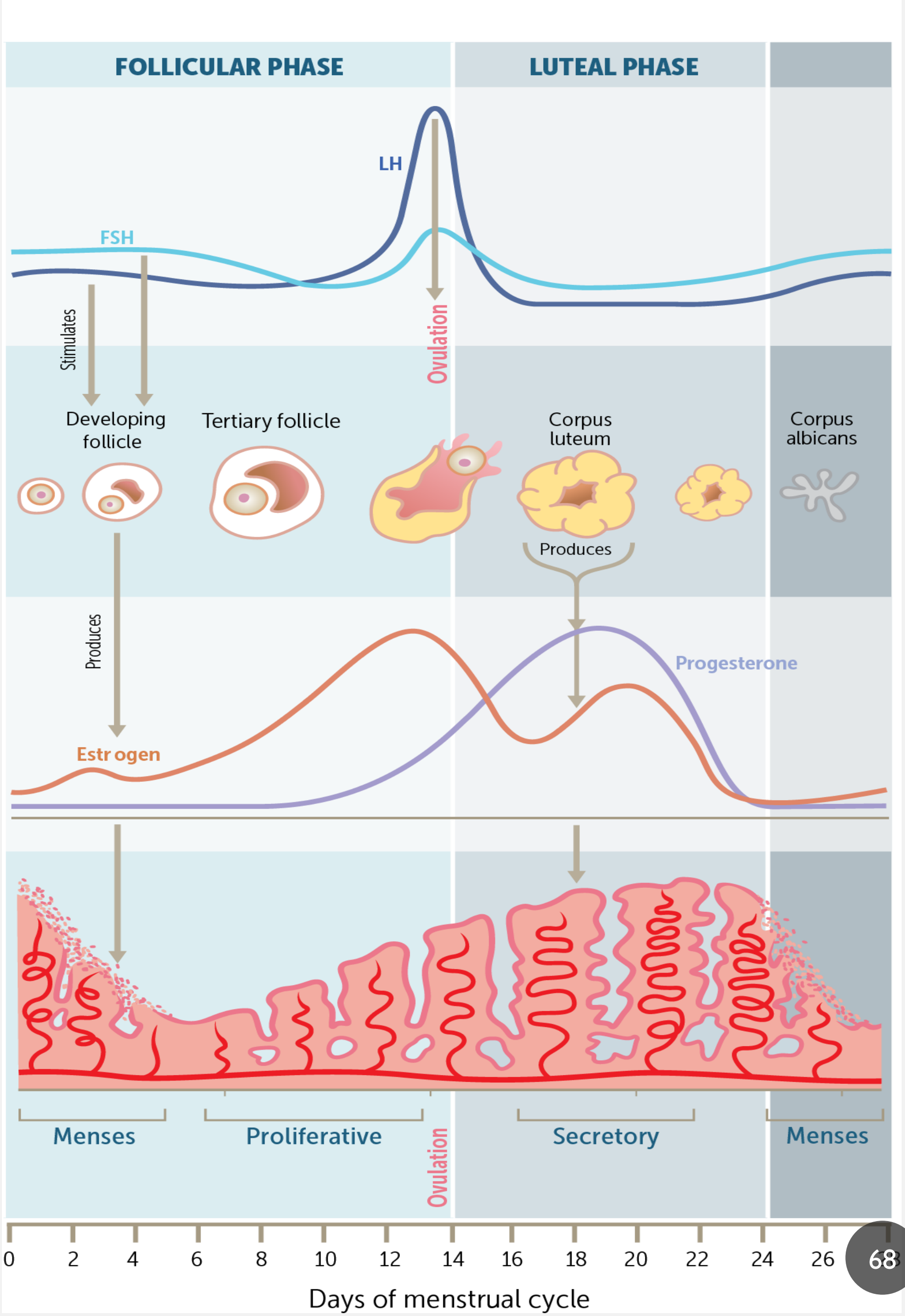
- **Arcuate arteries**: encircle endometrium
- **Radial arteries:** supply *straight arteries* to basilar zone and *spiral arteries* to functional zone

THE UTERUS



DAYS
1
7
14
21
28
FOLLICULAR PHASE
LUTEAL PHASE
OVUM
OVARIAN CYCLE
OVULATION
UTERINE CYCLE
MENSES
PROLIFERATIVE
SECRETORY

Menstrual cycle



THE UTERUS

Menstruation:

- Degeneration of the functional zone
- Is caused by constriction of ***spiral arteries***: to reducing blood flow, oxygen, and nutrients
- Weakened arterial walls rupture: releasing blood into connective tissues of functional zone
- Degenerating tissues break away, enter uterine lumen
- Entire functional zone is lost through cervix and vagina
- Deeper, basilar zone is supplied by straight arteries is not affected

THE UTERUS

Proliferative Phase:

- Occurs at same time as enlargement of primary and secondary follicles in ovary
- Is stimulated and sustained by estrogens secreted by developing ovarian follicles
- highly vascularized with Small spiral arteries formed from larger arteries in myometrium

THE UTERUS

The Secretory Phase:

- Begins at ovulation and persists as long as corpus luteum remains intact

- Endometrial Glands manufacture mucus rich in glycogen, essential for survival of fertilized egg
- increased secretion
- Generally lasts 14 days with decline in glandular activity

THE UTERUS

- The cycle ends as corpus luteum stops producing stimulatory hormones

Menarche

- The first uterine cycle (age 11–12)

Menopause

- termination of uterine cycles (age 45–55)

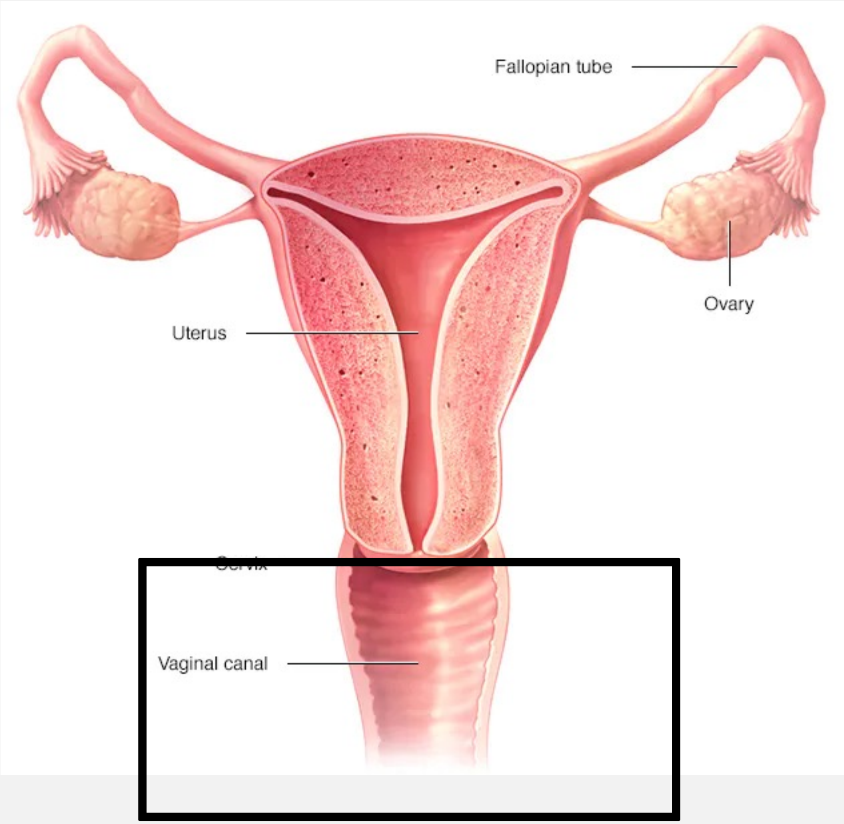
THE UTERUS

Amenorrhea

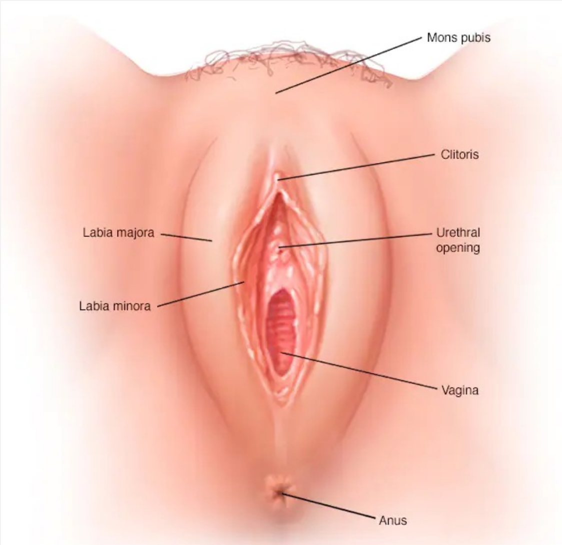
- *Primary amenorrhea:* failure to initiate menses
- *Secondary amenorrhea:* interruption of 6 months or more, caused by physical or emotional stresses

THE VAGINA

THE VAGINA



Fallopian tube
Ovary
Uterus
Cervix
Vaginal canal



Mons pubis
Clitoris
Labia majora
Urethral opening
Labia minora
Vagina
Anus

THE VAGINA

- The vagina is a fibromuscular canal that *connects the outer vulva to the cervix* of the uterus
- The opening of the vagina is in the middle of perineum, between the opening of the urethra and anus
- 7.5–9 cm long
- Highly distensible
- The cervix projects into vaginal canal

THE VAGINA

Functions:

- Provides a path for menstrual blood and tissue to leave the body
- Receives spermatozoa during sexual intercourse
- Forms inferior portion of birth canal

THE VAGINA

Vaginal wall consists of four layers:

1. Non-keratinized stratified ***squamous epithelium***
   - Changes with ovarian cycle
   - The mucosa of the epithelium forms folds called ***rugae*****,** which are more prominent in the outer of the vagina.
   - Rugae permit expansion of the vaginal cavity
2. ***Lamina propria*** of connective tissue, thick and elastic
3. ***Adventitia,*** that consists of blood vessels, lymphatic ducts, and nerves.

THE VAGINA

Vaginal Wall

4. smooth muscle with bundles of circular and longitudinal fibres
   - surrounded by ***elastic muscularis layer and 2 bulbospongiosus muscles*** along either side of vaginal entrance
   - cover ***vestibular bulbs :*** masses of erectile tissue: on either side of vaginal entrance. *(Have same embryological origins as corpus spongiosum of penis)*

THE VAGINA

- Vaginal secretions are primarily from the uterus, cervix, or from the Bartholin's glands in the labia.

THE VAGINA

External Genitalia

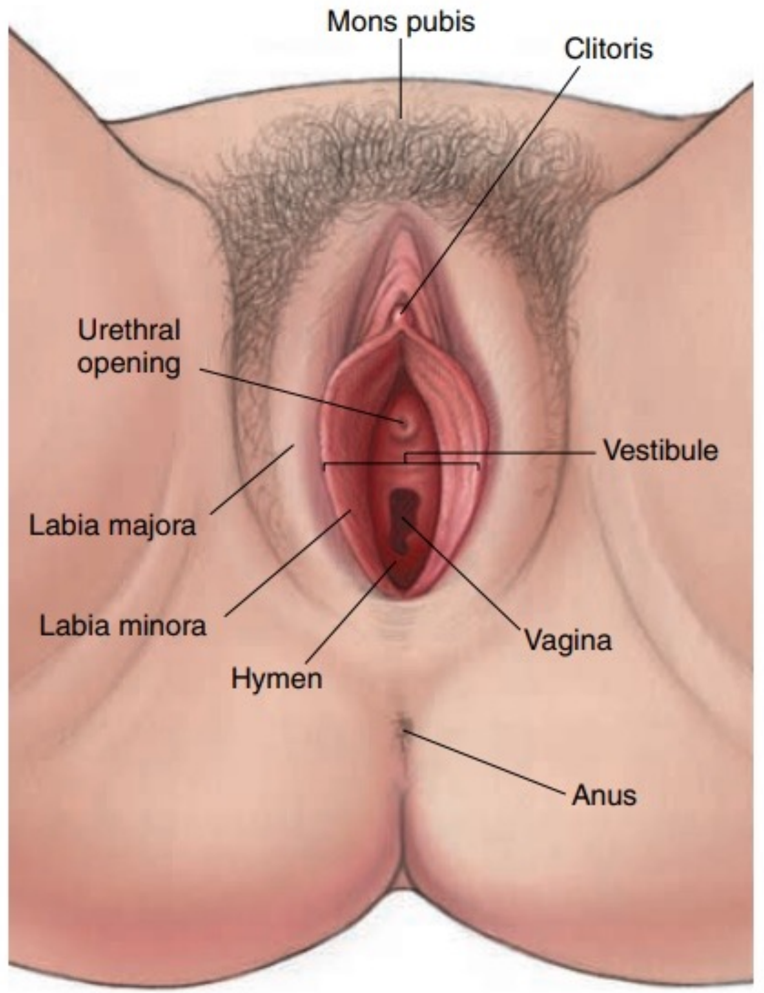


FIGURE 7.7. The Female External Genitalia—Inferior View

THE VAGINA

External Genitalia

- The ***mons pubis*** is a rounded area made of fatty tissue that overlies the pubic symphysis. This area becomes covered with pubic hair after puberty

Vulva: the outer part of the female genitalia

- It includes the *opening of the vagina* (vulva vestibule), the *labia majora* (outer lips), the *labia minora* (inner lips), *hymen*, *Bartholin's vestibular glands*, *Skene's vestibular glands* and the *clitoris*

THE VAGINA

External Genitalia

- ***Labia majora*** enclose and protect the other external reproductive organs.
    - They are made up of rounded folds of adipose tissue and thin smooth muscle covered by skin and hair.
    - They lie close together, *with a cleft that includes the urethral and vaginal openings* separating the labia longitudinally.
    - Sebaceous glands and apocrine sweat glands which secrete onto inner surface of labia majora

THE VAGINA

External Genitalia

- ***Labia minora*** are flattened, hairless longitudinal folds composed of connective tissue.
- They contain the *external openings of the urethra and vagina.*
- They merge posteriorly with the labia majora to form a ridge called the ***fourchette***.
- Anteriorly, they converge to form the *hood-like covering* of the clitoris.

THE VAGINA

External Genitalia

- ***Clitoris:*** projects from the anterior end of the vulva between the labia minora. 2 cm in length and 0.5 cm in diameter.
- It corresponds to the penis in males, forms a glans at its anterior end that has many sensory nerve fibres. Becomes erect during tactile stimulation and sexual arousal.
- The exposed portion is called the *glans of the clitoris* and the hooded fold is called the *prepuce of the clitoris*.

THE VAGINA

- **Hymen:** Is an elastic epithelial fold that partially blocks entrance to vagina
  - ruptured by sexual intercourse or tampon usage

THE VAGINA

Vulval vestibule

- Area between the labia minora where the vaginal opens and the urinary meatus
- about 2.5 cm posterior to the glans of the clitoris

Vestibular gland

- Lies on each side of the vaginal opening (***similar to the bulbourethral glands of males***)

THE VAGINA

- Release mucus into the vestibule, moistening and lubricating it for intercourse
- *(Bartholin's glands, Skene's/Paraurethral Glands glands)*

Vestibular bulb

- Mass of vascular erectile tissue
- *(similar to the single penile bulb and corpus spongiosum in males)*
- Engorge with blood during sexual stimulation, helping the vagina to grip the penis and causing the urethral orifice to shut.

THE VAGINA

Vascular* and *innervation

- Blood supply is provided by the three *pudendal arteries*.
- Venous return is via the external and internal *pudendal veins*
- vulva are drained by a chain of superficial inguinal lymph nodes
- *pudendal nerve* branches into perineal nerves of the labia and the dorsal nerve of clitoris
- clitoral glans is seen to be populated by a large number of small nerves

HORMONAL REGULATION

HORMONAL REGULATION

- Circulating Hormones Control female reproductive cycle
- Forms a complex pattern that *coordinates ovarian and uterine cycles*
    - ***uterine cycles;*** preparation and maintenance of the uterine lining
    - ***ovarian cycle;*** preparation of endocrine tissues and release of eggs
- Involves secretions of *pituitary gland* and *gonads*

HORMONAL REGULATION

The hypothalamus, anterior pituitary gland, and ovaries control:

- The maturation of female sex cells, development and maintenance of secondary sex characteristics, and changes during the monthly reproductive cycle
- At about 10 years, the hypothalamus begins to secrete more GnRH

HORMONAL REGULATION

- The anterior pituitary releases *FSH* and *LH,* controlling female sex cell maturation and producing female sex hormones
- *Oestrogens* and *progesterone* are released from the developing follicles
-

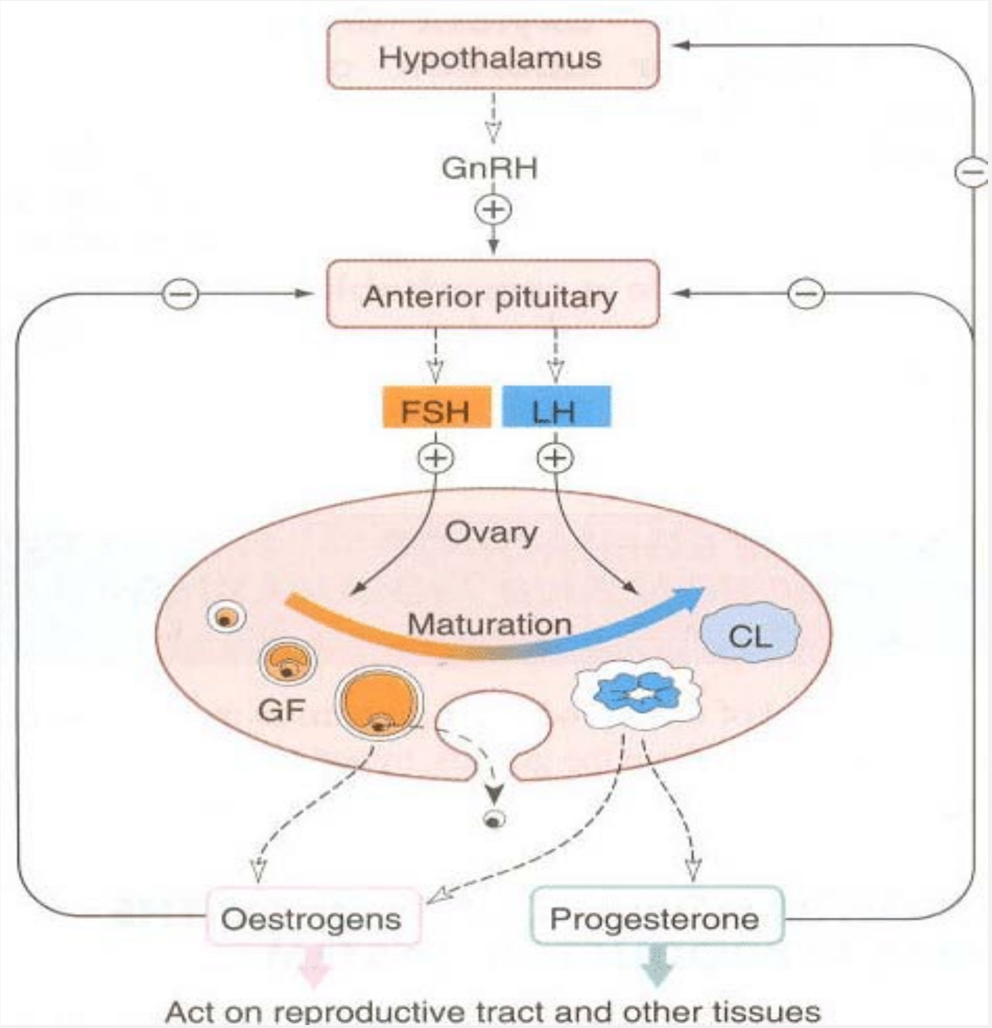
HORMONAL REGULATION

- Slowly rising levels of FSH and LH cause the growth of follicles on the surface of the ovary.
- As the follicles grow, they begin releasing oestrogens and a low level of progesterone.
- *Progesterone maintains the endometrium* to help ensure pregnancy

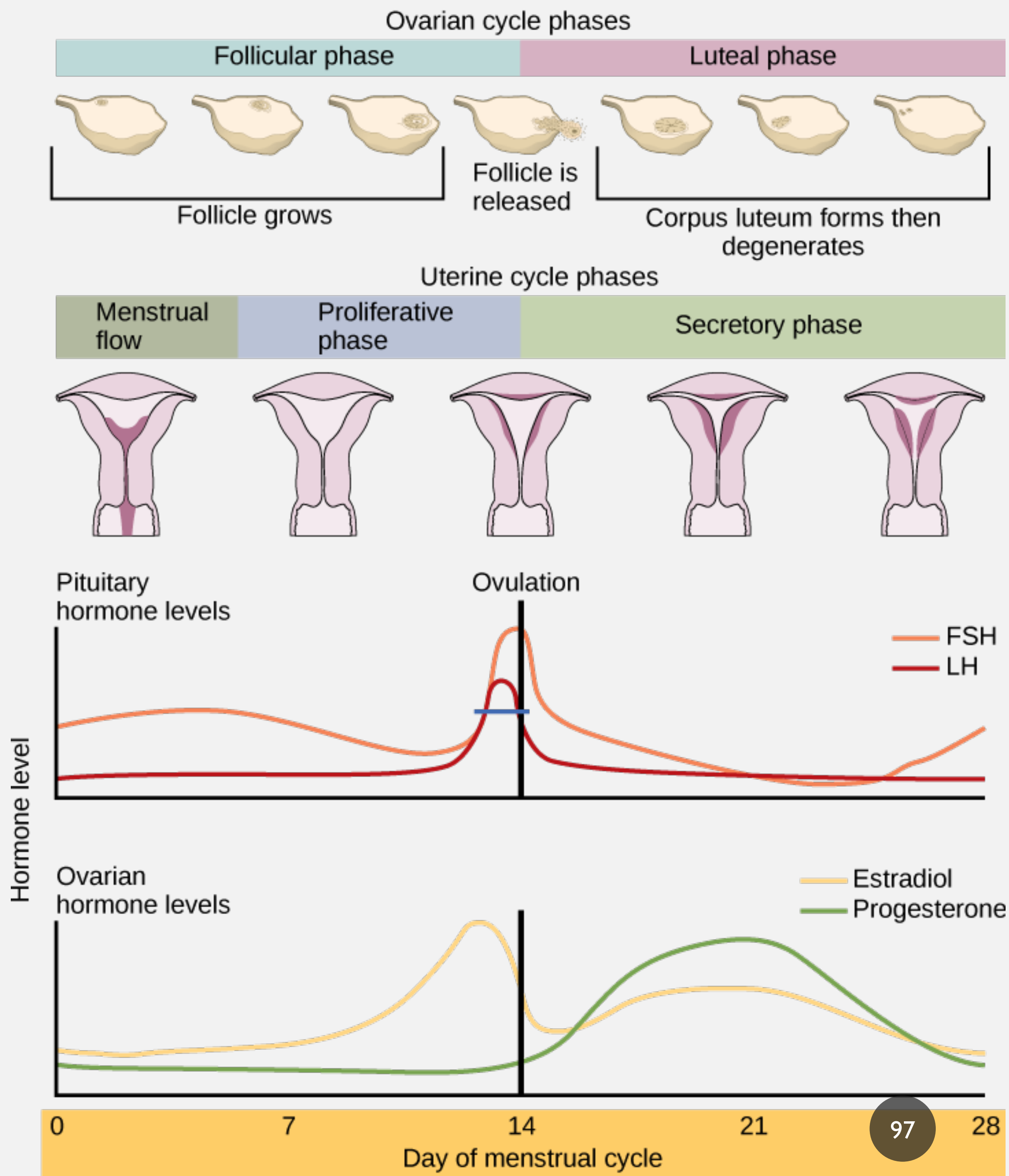
HORMONAL REGULATION

- If pregnancy implantation does not occur, the lining is sloughed off.
- After about five days, oestrogen levels rise and the menstrual cycle enters the proliferative phase.
- The endometrium begins to regrow, replacing the blood vessels and glands that deteriorated during the end of the last cycle

HORMONAL REGULATION

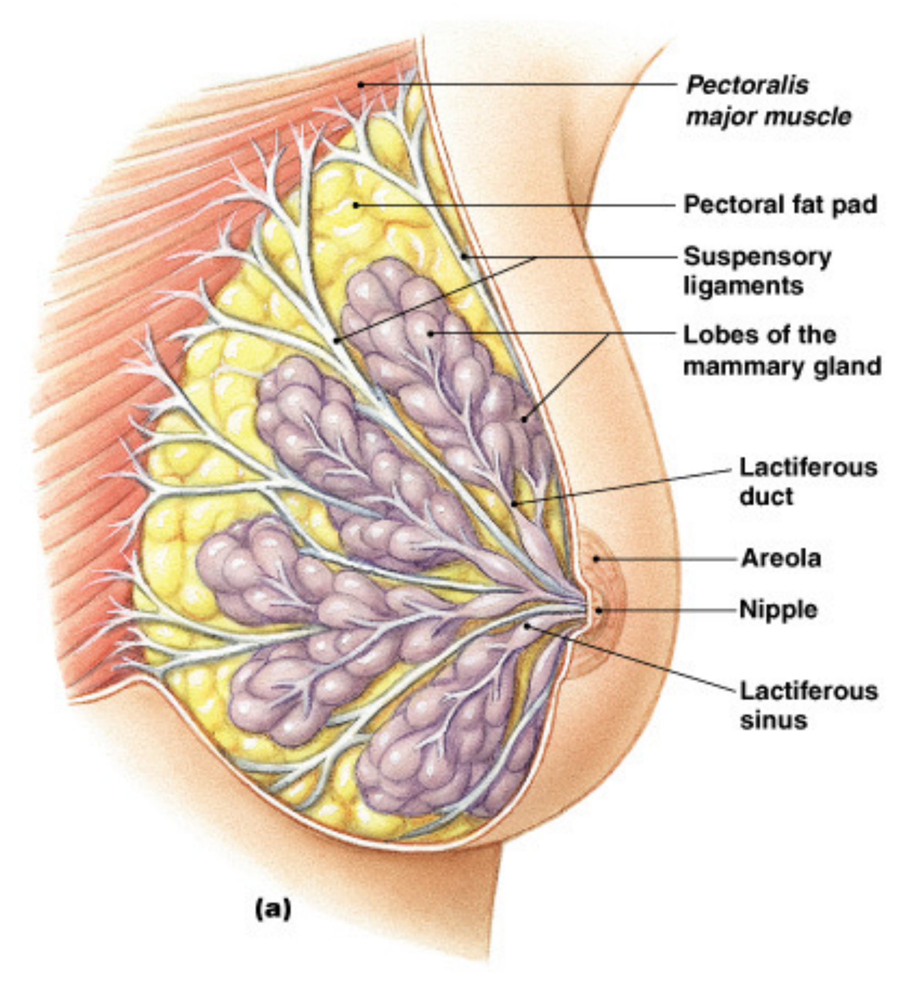


HORMONAL REGULATION



THE MAMMARY GLANDS

THE MAMMARY GLANDS



THE MAMMARY GLANDS

- Specialized to secrete milk after pregnancy
- They lie within the hypodermis; containing pectoral fat pads deep to skin of chest
- Nipple on each breast contains ducts from mammary glands to surface
- Areola: brown-darkbrown skin around each nipple
- *Smooth muscle fibres in the areola and nipple are controlled by the autonomic nervous system.*
  - This can cause the nipple to become erect when it is stimulated by touch or cold temperatures.

THE MAMMARY GLANDS

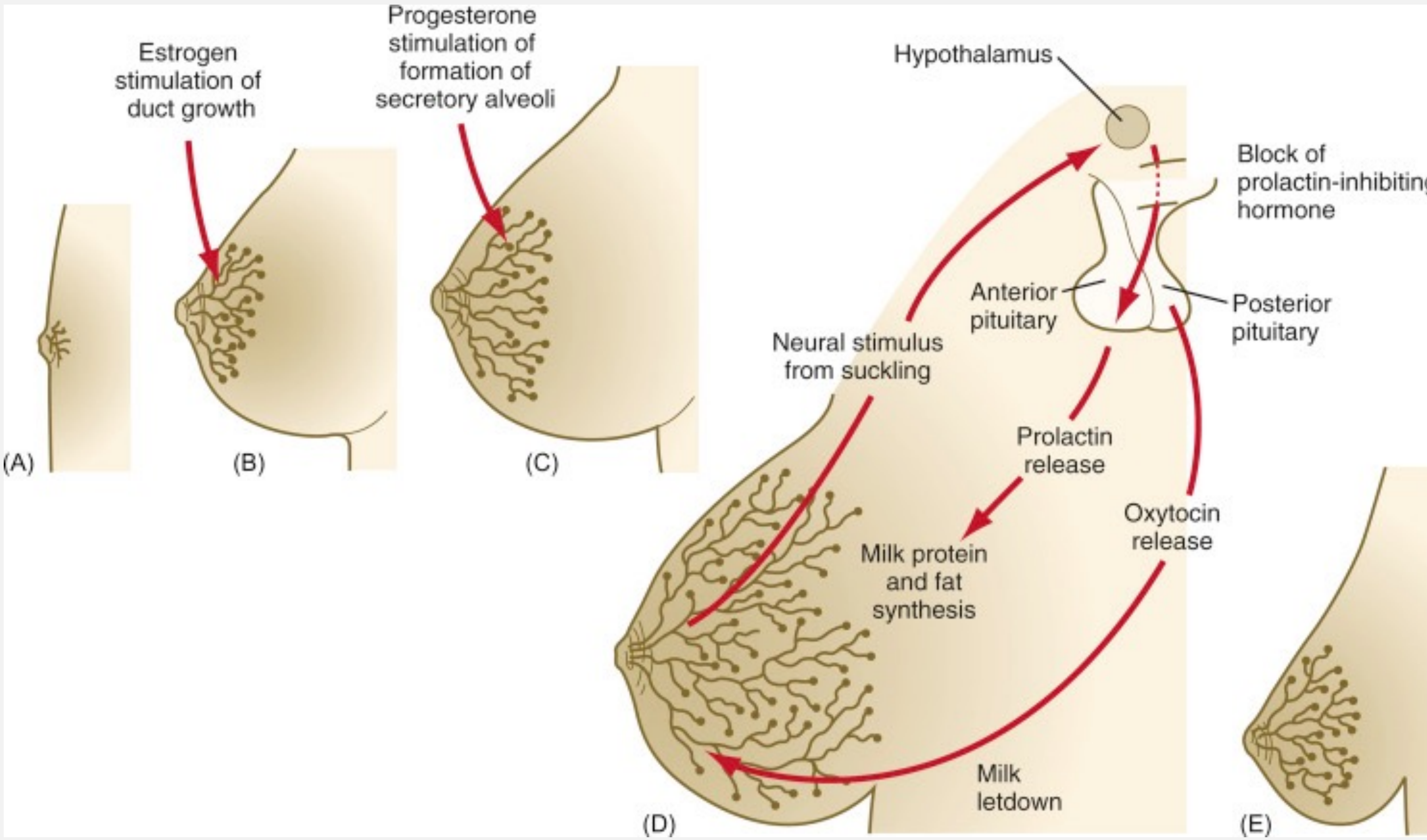
- ***Mammary gland is a modified sweat gland***

- 15–25 lobes (alveolar glands, ducts and lobules)
- ***Suspensory ligaments*** support the weight of the breast
- Milk is is secreted from glands into ***lactiferous ducts*** which open to the outside of the nipple
- Each duct, just below the areola, has a *dilated lactiferous sinus*, where milk accumulates during nursing

THE MAMMARY GLANDS

- Controlled by:
  - hormones of reproductive system
  - placenta
- At puberty:
  - The mammary glands develop because of ovarian - hormones.
  - The alveolar glands and ducts enlarge.
  - Fatty tissue deposits around and within the breasts.

THE MAMMARY GLANDS



SEXUAL RESPONSE

SEX

- Coitus / Copulation
- Sexual intercourse introduces semen into female reproductive tract

MALE SEXUAL RESPONSE

- Is coordinated by complex neural reflexes using ***sympathetic*** ***and parasympathetic*** divisions of ANS

- When sexual stimulation occurs, nerve impulses from the sacral area of the spinal cord release ***nitric oxide***, which *dilates the arteries* leading into the penis.
- Arterial pressure in the erectile tissue compresses the veins to *reduce blood flow away from the penis*.
- This leads to ***erection***

MALE SEXUAL RESPONSE

Erection

- The ***corpus spongiosum slightly expands*** and functions to keep the urethra open

- The penis is *prevented from excessive bending* by the ***collagen fibres surrounding the penis***.

MALE SEXUAL RESPONSE

Ejaculation

- Male orgasm is accompanied by propulsion of semen from the duct system; ***emission*** and ***ejaculation***,
- A typical ejaculation releases approximately 300 million sperm.
- Emission occurs as a result of spinal *sympathetic nerve impulses* that stimulate *peristaltic contractions in the ducts and glands*: *testicular ducts, epididymides, ductus deferentia, ejaculatory ducts, seminal vesicles and prostate gland*

MALE SEXUAL RESPONSE

- The ***bladder sphincter muscle constricts*** to prevent urine expulsion or semen reflux into the bladder.
- Contraction of the reproductive ducts and accessory glands fill the urethra with ***semen*****.**
- Pressure inside the erectile tissues, force semen through the urethra to outside the body, which is the process of ***ejaculation*****.**
- At the culmination of sexual stimulation, semen is propelled toward external urethral opening; ***orgasm***
- *Intense pleasure, systemic changes include elevated blood pressure, rapid heartbeat, and generalized muscle contraction.*

MALE SEXUAL RESPONSE

- After ejaculation, is the ***period of resolution***.
- The arteries of the erectile tissue constrict, gradually returning the penis to its flaccid state.

FEMALE SEXUAL RESPONSE

- The ***erectile tissues*** of the clitoris and vaginal entrance respond to sexual stimulation.
- ***Parasympathetic nerve*** impulses release **nitric oxide** to dilate the erectile tissues, increase blood inflow, and swell the tissues.
- The nipples become erect and the ***vagina expands and elongates***.
- The vestibular glands ***secrete mucus*** into the vestibule; for moistening and lubrication

FEMALE SEXUAL RESPONSE

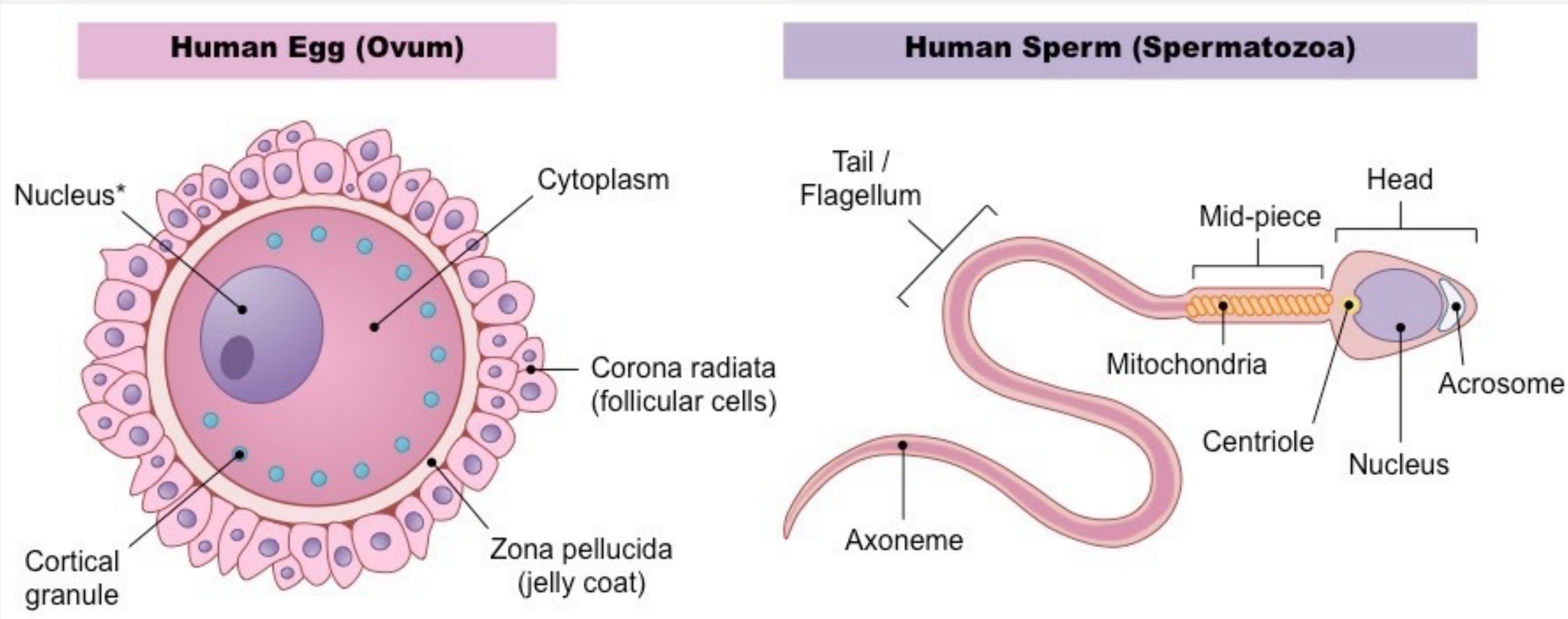
- The clitoris responds to local stimulation, culminating in an orgasm.
- Just before orgasm, the outer of the ***vagina is engorged with blood, increasing friction***.
- At ***orgasm***, muscles of the perineum and walls of both the uterus and uterine tubes ***contract rhythmically***.
- This ***helps transport sperm*** through the female reproductive tract toward the upper uterine tubes.

FEMALE SEXUAL RESPONSE

- Females libido is influenced by dehydro-epiandrosterone, produced by the adrenal cortex.

FERTILISATION

FERTILISATION



FERTILISATION

It involves:

- the *migration of spermatozoa* through the cumulus matrix,
- the *adhesion* and *penetration* of spermatozoa to the zona pellucida
- the fusion of the two plasma membranes
- oocyte activation and a fast block to polyspermy
- Sperm and egg pronuclei come together to form the nucleus of the zygote

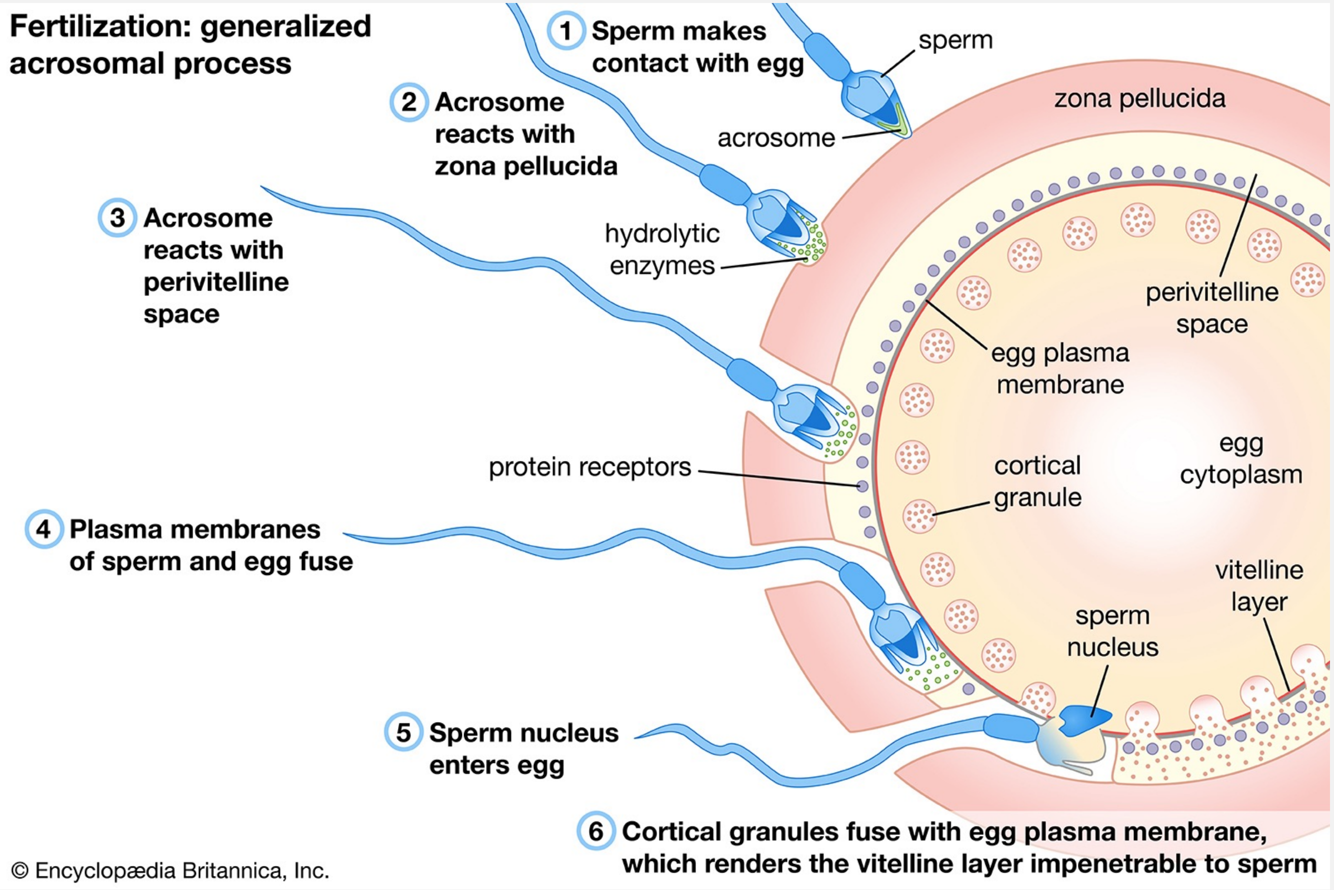
FERTILISATION

- Migration of the sperm to the location of the ovulated oocyte is by progesterone released by the *cumulus cells surrounding the oocyte*
- ***sperms that are not capable of fertilisation; characterized by slow linear motility patterns***
- In the fallopian tubes, ***alkaline pH*** gives sperm ***capacitation and hyperactivation***
- The capacitated spermatozoon and the oocyte ***meet in the ampulla of the fallopian tube***

FERTILISATION

- The sperm swim through the ***corona radiata***/ follicular cells until they reach the ***zona pellucida***
  - *the acrosome membrane-bound vesicle releases lysin breaks down the egg's membrane*
- The membranes fuse, the matrix hardens and becomes impermeable to sperms (polyspermy is prevented)
- The sperm's tail and mitochondria degenerate with the formation of the male pronucleus
  - ***The 23 chromosomes fuse to form the 2n nuclei of the zygote, followed by mitosis***

FERTILISATION

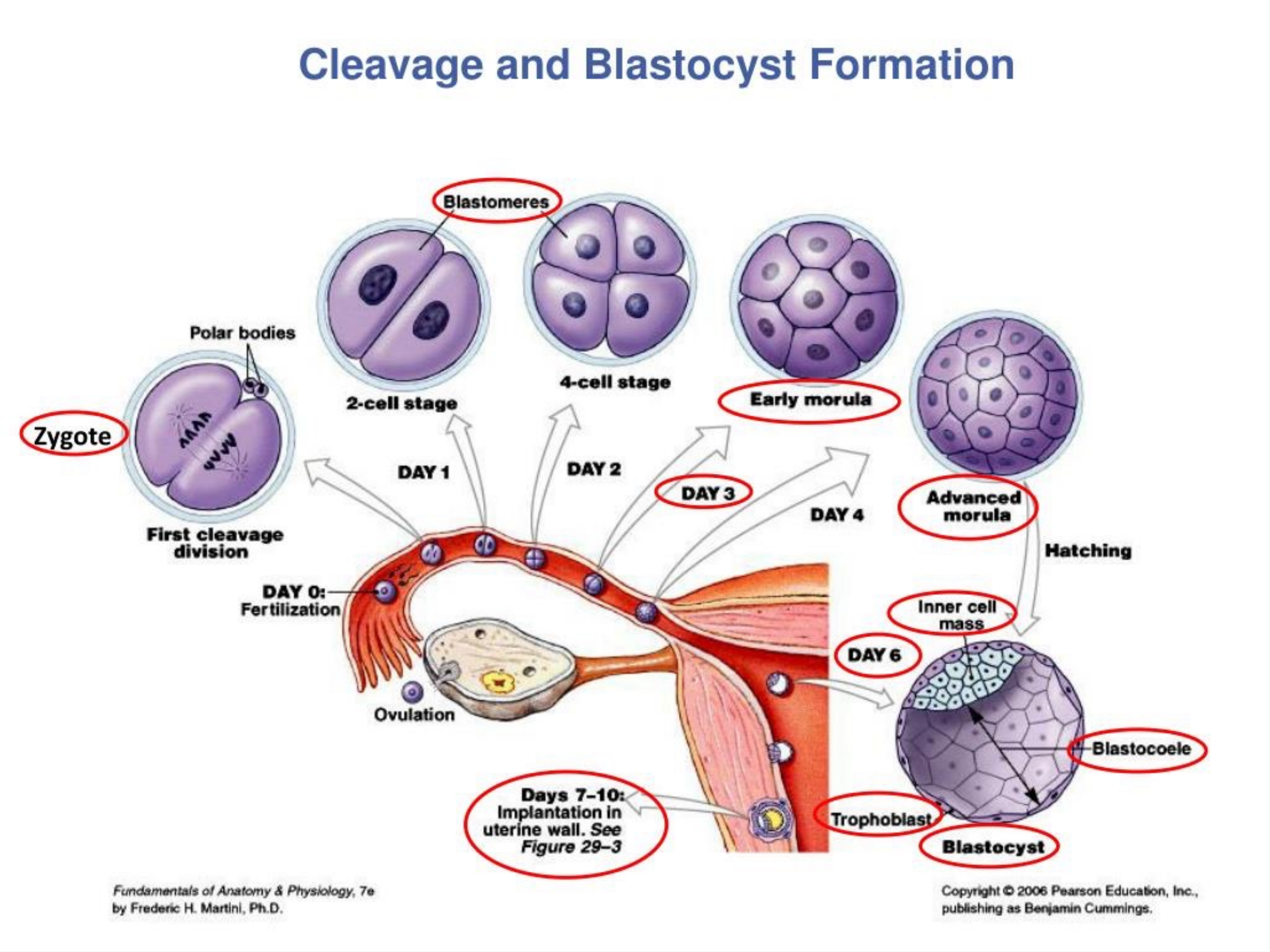


GESTATION

The zygote arrives at the uterus and attaches to the uterine wall, a process known as ***implantation***

Pregnancy begins when the blastocyst implants in the female's uterus and ends once the foetus leaves the uterus during labour or an abortion

GESTATION



Cleavage and Blastocyst Formation
Blastomeres
Polar bodies
2-cell stage
4-cell stage
Early morula
Zygote
DAY 1
DAY 2
DAY 3
DAY 4
Advanced morula
First cleavage division
Hatching
DAY 0: Fertilization
Inner cell mass
DAY 6
Ovulation
Blastocoele
Days 7–10: Implantation in uterine wall. See Figure 29–3
Trophoblast
Blastocyst
Fundamentals of Anatomy & Physiology, 7e by Frederic H. Martini, Ph.D.
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GESTATION

- ***Three trimesters, each approximately three months long:***
- the first, second, and third trimester.
- Birth normally occurs at a gestational age of ***about 40 weeks***, though it is common for births to occur from 37 to 42 weeks.
- Labour occurring prior to 37 weeks gestation is considered ***preterm labour.***

GESTATION

- The development of the mass of cells is called ***embryogenesis***
- *Cells differentiate into the various body organs*
- ***By the end of the embryonic stage***, there is development of placenta and umbilical cord, connects the developing embryo to the uterine wall to allow nutrient uptake, waste elimination, and gas exchange via the mother's blood supply.
- The beginnings of features such as fingers, eyes, mouth, and ears become visible.

GESTATION

1st trimester

- The spinal cord, brain, heart, and lungs grow and develop rapidly, the mouth, nose, eyes, ears, toes, and fingers begin to form
- Placenta (amniotic fluid) and Umbilical cord to nourish and dispose of wastes

GESTATION

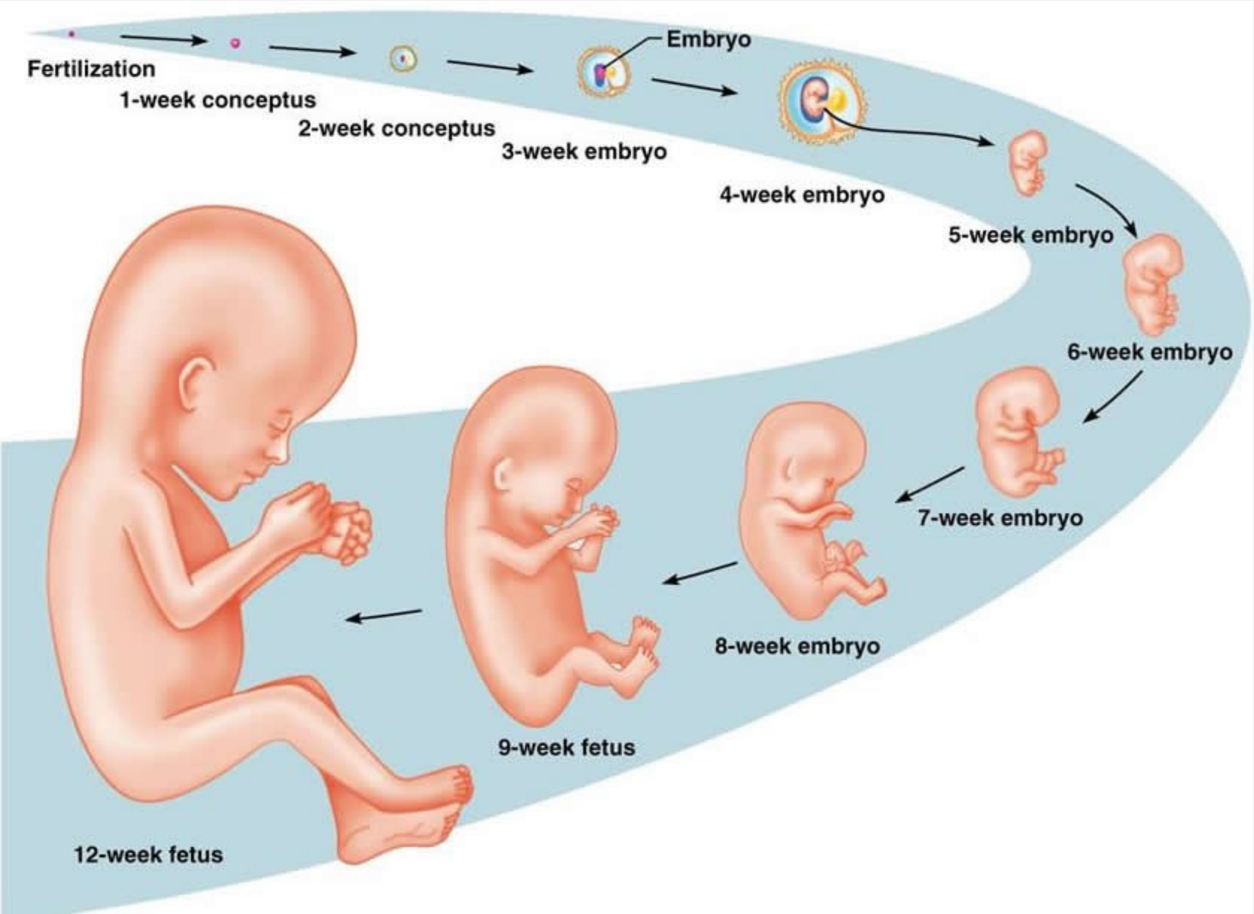
2nd trimester

- hair, including eyebrows and eyelashes, begins to grow, sensory neurons, muscles and bones

3rd trimester

- baby is in position for delivery, head resting on your cervix,
- “full-term” by week 37

GESTATION


Fertilization
Embryo
1-week conceptus
2-week conceptus
3-week embryo
4-week embryo
5-week embryo
6-week embryo
7-week embryo
8-week embryo
9-week fetus
12-week fetus

PARTURITION(BIRTH)

PATURITION

- Child birth:– ***biochemical substances produced by the foetus induce labour*** (oxytocin and placental inflammatory molecules, prostaglandins)

3 stages

1. Dilation: the onset of labour., until the cervix is fully dilated (0-10cm dilated, 13-14hrs / 8-9hrs)

- contractions facilitate dilatation or opening of the cervix

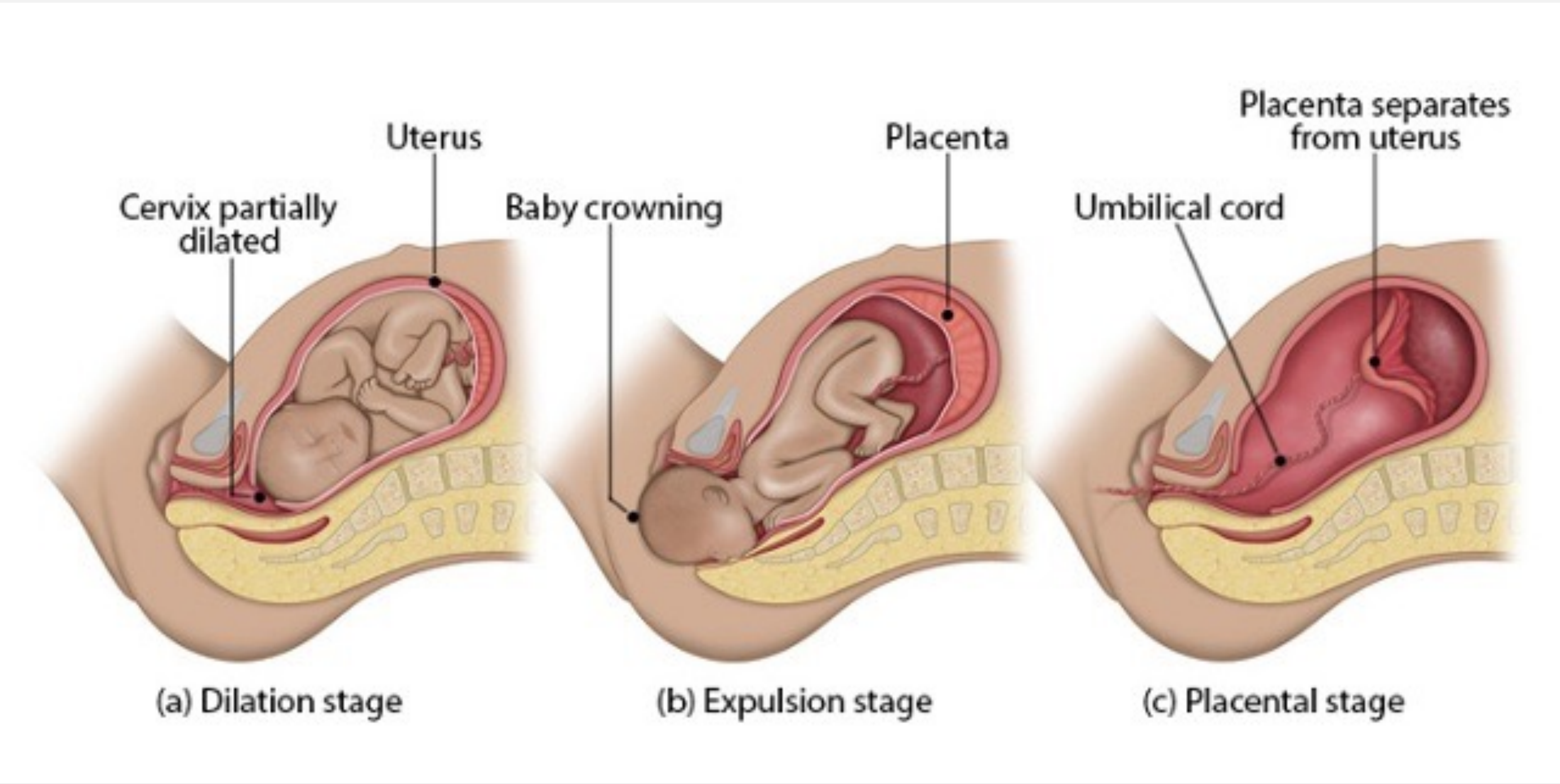
PATURITION

2. Expulsion: The baby's head moves down through the vagina

- Involuntary contraction of the abdominal muscles in time with uterine contractions
- Amnion breaks
- The child descends into and passes through the birth canal, with increased sensation of pain (L/S nerves)
- ***Presentation;*** normal, Posterior, Face, Breech, transverse

3. Delivery of placenta and membranes: placenta is separated from the membrane lining the uterus

PATURITION



Uterus
Cervix partially dilated
Baby crowning
Placenta
Placenta separates from uterus
Umbilical cord
(a) Dilation stage
(b) Expulsion stage
(c) Placental stage

SEXUALLY TRANSMITTED DISEASES

- **AIDS:** HIV
- **Chlamydia:** *Chlamydia trachomatis*
- **Gonorrhea:** *Neisseria gonorrhoeae*
- **Syphilis:** *Treponema pallidum*
- **Genital herpes:** *herpes simplex virus 2*
- **Genital warts:** *Herpes simplex virus*
- **Trichomoniasis:** *Trichomonas vaginalis*(parasite)

SEXUALLY TRANSMITTED DISEASES

Symptoms

- A burning sensation during urination
- Lower abdominal pain
- Fever
- Swollen neck glands
- Discharge from the vagina or penis
- Genital or anal pain, itching, or inflammation
- Pain during intercourse
- Oral or genital sores, blisters, bumps, or rash

INFERTILITY

INFERTILITY - MALES

- Having tried unsuccessfully to conceive for one year.

INFERTILITY - MALES

CAUSES:

1. Obstructions causing infertility in men

- *Blockages or absences of tubes* may be due to vasectomy or injury.
- *Sperm are made in the testicles, pass the epididymis where they mature and exit into the vas deferens.*
- *The vas deferens empties the sperm into the ejaculatory duct, where they are mixed with seminal fluid from the seminal vesicles and the prostate gland.*
- *During ejaculation, muscular contractions force the semen into the urethra and out of the penis.*

INFERTILITY - MALES

2. Sperm

- *sperm numbers or quality:* could be caused by genetic factors.

May lead to:

- **Absent sperm (azoospermia)** – the semen doesn’t contain any sperm.
- **Low sperm count (oligospermia)** – the ejaculate has insufficient sperm to bring about conception.

INFERTILITY - MALES

- **Abnormal shape –** a healthy sperm is shaped like a streamlined tadpole.

- **Poor motility** – a healthy sperm has a lashing tail which helps it to swim through the woman's reproductive system.

INFERTILITY - MALES

3. Functional Challenges:

- **Impotence** – *inability to get or maintain an erection* sufficient for sexual intercourse.
- **Ejaculation**– retrograde (when *semen enters the bladder instead* of emerging through the penis) and premature ejaculation.
- ***Testicles*** – *caused by injury, infection* or chemotherapy.

INFERTILITY - MALES

Functional Challenges:

- **Prostatectomy –** side effects of the surgical removal of the prostate gland, including infertility, impotence and incontinence.

Other Conditions– multiple sclerosis, diabetes and other disorders can cause erection and ejaculation difficulties.

Antibodies – immune system antibodies hinder the activity of sperm, by reducing the sperm's ability to attach onto the eggs membrane

INFERTILITY - MALES

Hormonal imbalance

- The pituitary gland in the brain influences hormone production in the testicles under the guidance of the hypothalamus.
- Failure to make enough of the hormone gonadotrophin.

INFERTILITY - MALES

Treatment

- surgery
- hormone therapy
- artificial insemination
- in-vitro fertilisation (IVF)
- intracytoplasmic sperm injection (ICSI)

INFERTILITY - FEMALES

1. **Ovulation**

- Hypothalamus and pituitary gland secrete hormones that controls maturation of eggs in the ovaries: Irregular hormones
- Age is a significant fertility factor.
  - The chance of pregnancy for a woman aged 40 years is only 5% per menstrual cycle.
- *A woman is born with her entire egg supply and, eggs become less viable with time: increased risk of miscarriage and genetic abnormalities*

INFERTILITY - FEMALES

Polycystic ovary syndrome

- Ovarian follicles fail to mature, instead form cysts at the periphery of the ovaries

Ovulation and proliferation of endometrium are irregular or don’t happen at all.

Fallopian tubes blocks

- Blocked or scarred fallopian tube may impede the egg’s progress, preventing it from meeting with sperm.

INFERTILITY - FEMALES

Uterus

- Fibroids – non-malignant tumours in uterus
- Polyps – overgrowths of the endometrium, which can be prompted by the presence of fibroids.

Cervix

- Cervical mucus at ovulation is too thin and watery to allow sperm swim through it.
  - some women the cervical mucus is too thick and this can hinder the sperm.

INFERTILITY - FEMALES

Endometriosis

- Develop tissue that looks and acts like endometrial tissue outside of the uterus.
- It can damage the fallopian tubes and the ovaries, and affect the movement of the egg and sperm.
- Can affect fertilisation, embryo growth and implantation.

INFERTILITY - FEMALES

Treatment

- Surgery
- Ovulation induction (using hormone treatment)
- Assisted reproductive technologies (ART) including in-vitro fertilisation (IVF).

AGEING AND REPRODUCTION

MENOPAUSE

- Occurs between 45 and 55 years of age, as a woman's oestrogen levels decline
- Premature menopause or premature ovarian insufficiency: before 40years

AGEING AND REPRODUCTION

MENOPAUSE - **Symptoms include:**

- hot flushes
- night sweats
- vaginal dryness and discomfort during sex
- difficulty sleeping
- low mood, anxiety, irritability and depression
- reduced sex drive (libido)
- problems with memory and concentration

AGEING AND REPRODUCTION

MALE MENOPAUSE “ANDROPAUSE”

- Physical and emotional symptoms when they reach their late 40s to early 50s

- **depression, loss of sex drive, erectile dysfunction**
- mood swings and irritability
- loss of muscle mass and reduced ability to exercise
- fat redistribution, eg. large belly
- lack of enthusiasm or energy
- difficulty sleeping (insomnia) or increased tiredness
- poor concentration and short-term memory

AGEING AND REPRODUCTION

MALE MENOPAUSE "ANDROPAUSE"

- Testosterone deficiency that develops later in life, also known as late-onset hypogonadism
- can sometimes be responsible above symptoms