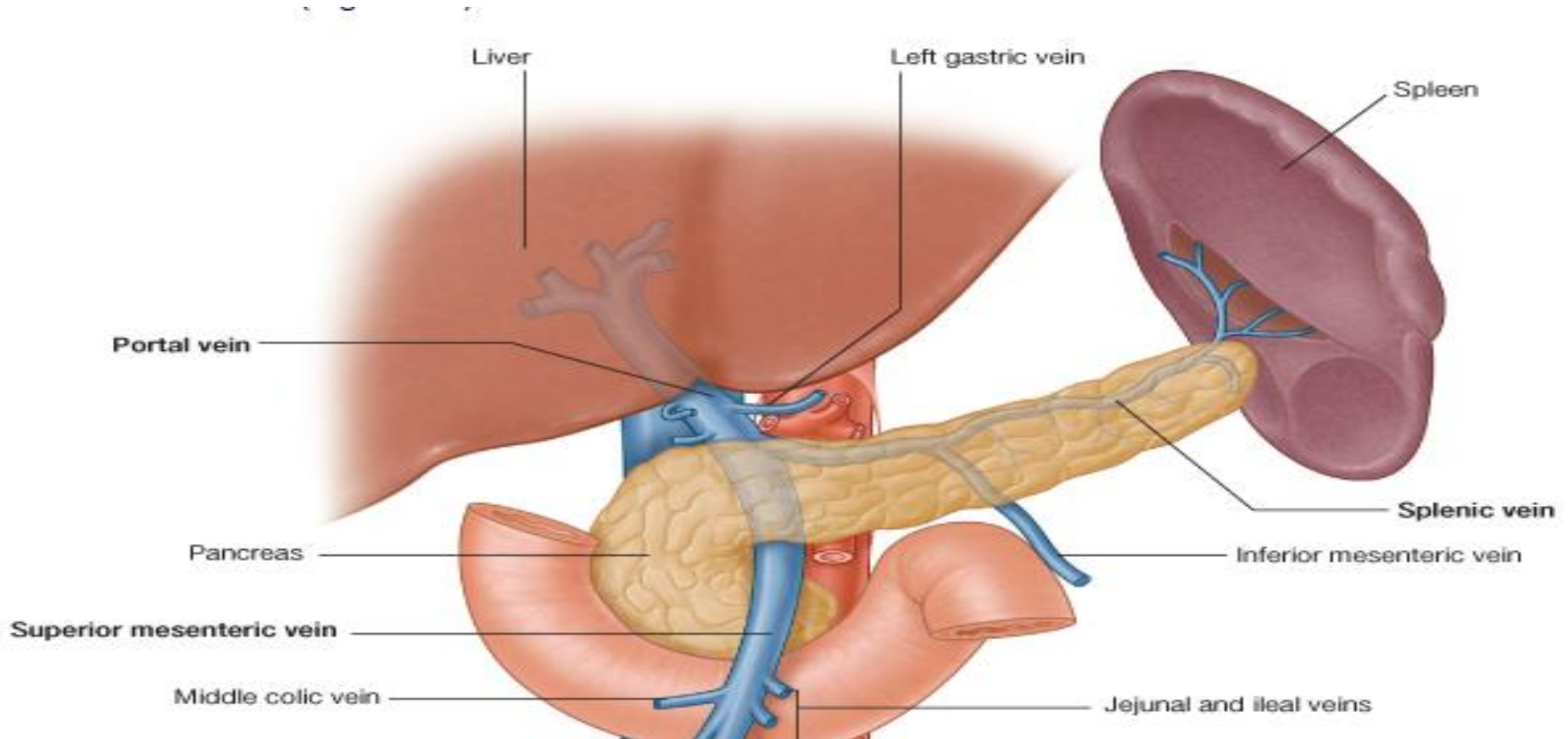


ANATOMY & PHYSIOLOGY

BY MR. LANGAT



**WELCOME TO THE
NURSING
WORLD**

AND TO C.C.N.,
MATHARI

OBJECTIVE

By the end of the course, the student will be able to describe the structure and functions of the body and its parts

Course outline

- See Ross and Wilson Anatomy and Physiology and Health and Illness, 11th Edition.

INTRODUCTION

- **Anatomy:** study of the structure of the body and the physical relationships involved between body parts.
- **Physiology:** study of how the parts of the body work, and the ways in which they cooperate together to maintain life and health of the individual.
- **Pathology:** study of abnormalities and how they affect body functions, often causing illness.
- **Pathophysiology:** is a convergence of pathology and physiology. It's a discipline which explains the physiological processes or mechanisms whereby disease(pathology) develops and progresses.
- NB: WE SHALL BE DISCUSSING ABOUT THE NORMAL ANATOMY AND PHYSIOLOGY

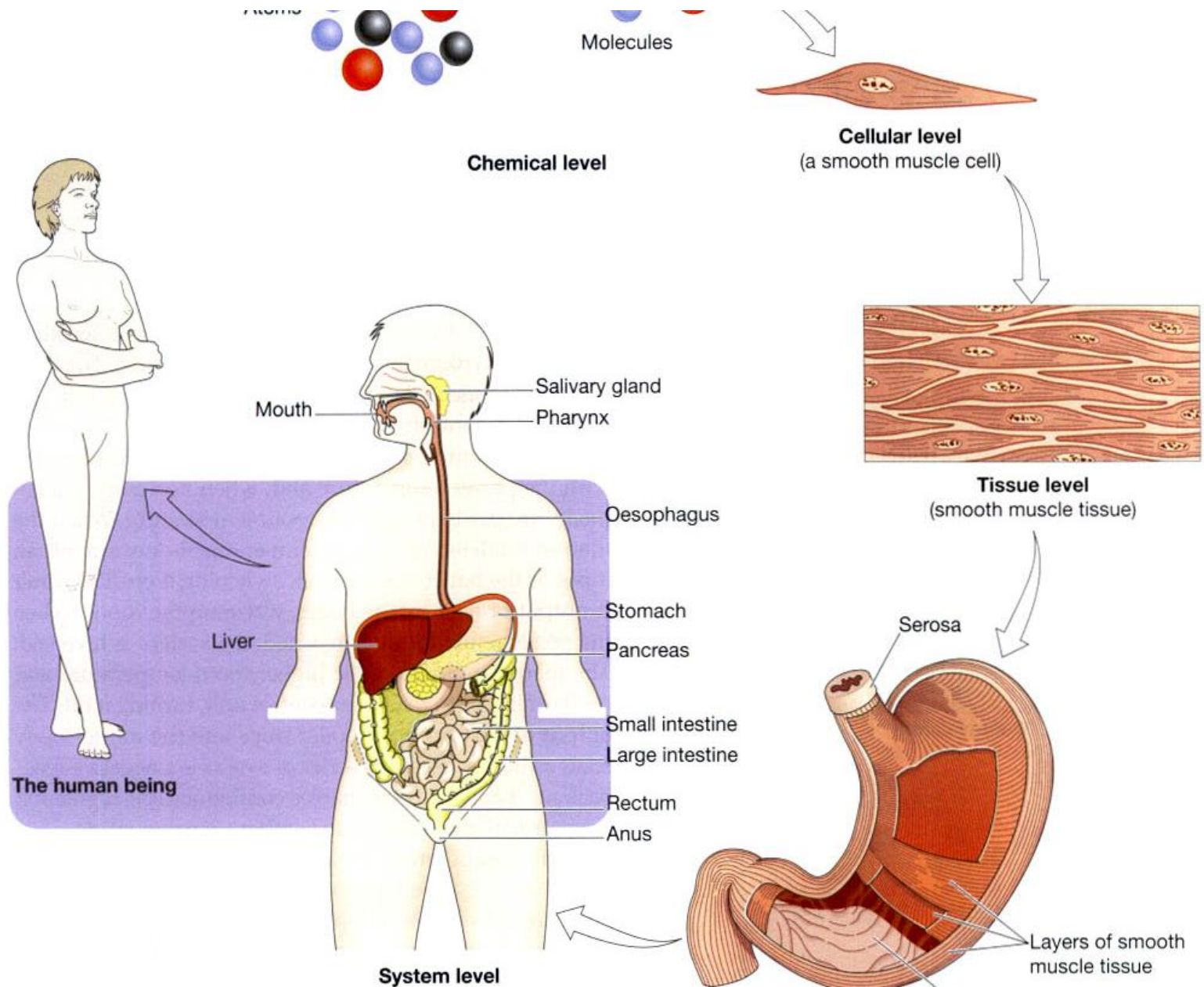
LEVELS OF STRUCTURAL COMPLEXITY

- **Cells:** smallest independent units of living matter
 - Can't be seen with the naked eye,
 - Can be microscopically distinguished by their size, shape and the dyes they absorb when stained in the laboratory.
- Each cell type
 - is specialised,
 - carries out a particular function that contributes to body needs.
- Cells with similar structures and functions form **tissues**.
- Different types of tissue form **organs** that carry out a specific function.
- **Systems** consist of a number of organs and tissues that together contribute to one or more survival needs of the body.

ORGANISATION OF THE HUMAN BODY

- **OBJECTIVES**

- By the end of this section you will be able to:
 - Describe the cell and its functions
 - Describe cell multiplication
 - Describe the transfer of substances across cell membranes
 - Describe tissues and their functions
 - Describe body fluids and electrolytes



Levels of structural complexity

Characteristics of Life

- **Movement** – change in position; motion
- **Responsiveness** – reaction to a change
- **Growth** – increase in body size; no change in shape
- **Reproduction** – production of new organisms and new cells
 - **Respiration** – obtaining oxygen; removing carbon dioxide; releasing energy from foods
 - **Differentiation** – unspecialized to specialized

Ct.....

- **Digestion** – breakdown of food substances into simpler forms
- **Absorption** – passage of substances through membranes and into body fluids
- **Circulation** – movement of substances in body fluids
 - **Assimilation** – changing of absorbed substances into chemically different forms
- **Excretion** – removal of wastes produced by metabolic reactions

Maintenance of Life

- Life depends on five (5) environmental factors:
 - Water
 - Food
 - Oxygen
 - Heat
 - Pressure

Requirements of Organisms

- **Water**
 - most abundant substance in body
 - required for metabolic processes
 - required for transport of substances
 - regulates body temperature
- **Food**
 - provides necessary nutrients
 - supplies energy
 - supplies raw materials

Requirements of Organisms

- **Oxygen (gas)**

- one-fifth of air
- used to release energy from nutrients

- **Heat**

- form of energy
- partly controls rate of metabolic reactions

- **Pressure**

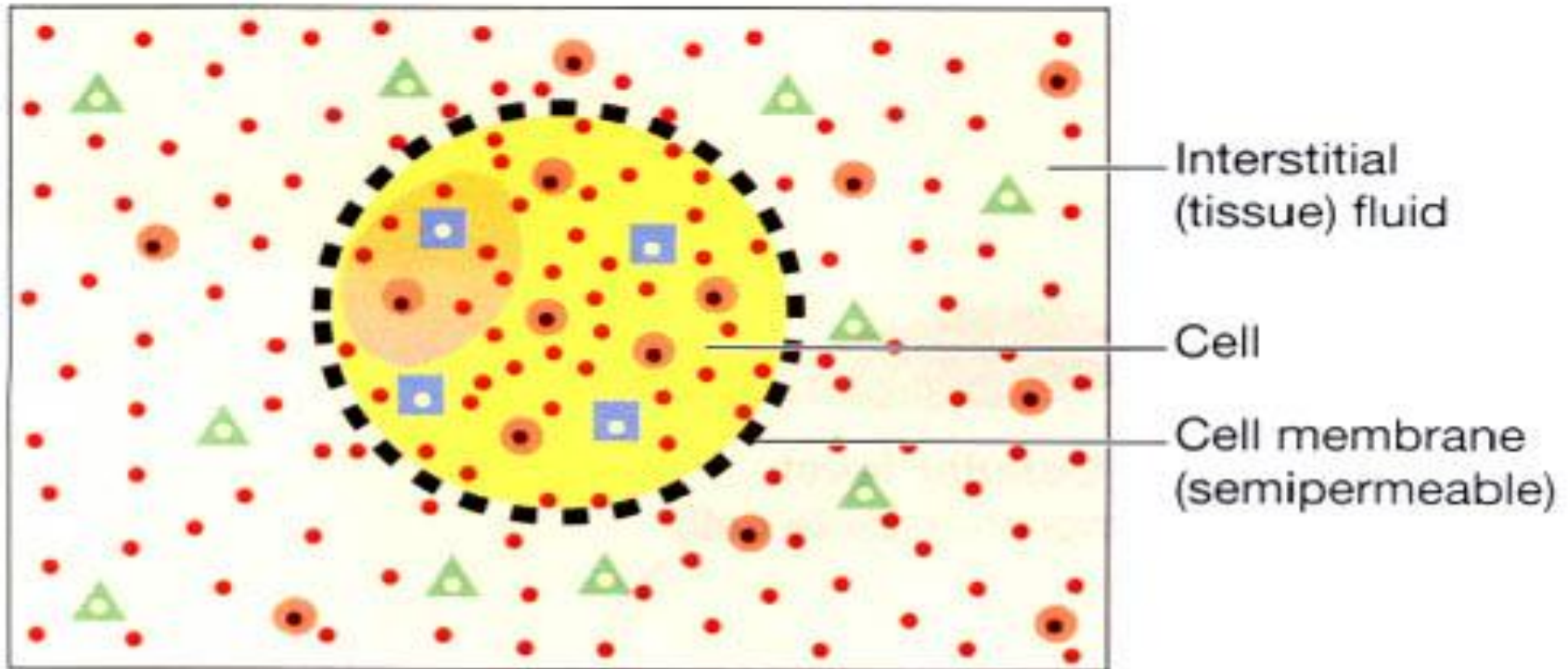
- application of force on an object
- atmospheric pressure – important for breathing
- hydrostatic pressure – keeps blood flowing





Internal environment and homeostasis

- External environment;
 - surrounds the body
 - provides the oxygen and nutrients required by all the cells of the body.
 - Its where waste products of cellular activity are excreted into
- **The skin** provides a barrier between the dry external environment and the watery environment of most body cells.
- **Internal environment:** water-based medium in which body cells exist.
- Cells are bathed in fluid called interstitial or tissue fluid. Oxygen and other substances they require must pass from the internal transport systems through the interstitial fluid to reach them.
- Similarly, cell waste products must move through the interstitial fluid to the transport systems to be excreted.

- A **Cell membrane** surrounds cells and provides a potential barrier to substances entering or leaving them.
 - It's semi-permeable/has selective permeability thus allowing the cell to regulate its internal composition.
- Smaller particles can usually pass through the membrane, some more readily than others, and therefore the chemical composition of the fluid inside is different from that outside the cell.

A cell with a semi-permeable membrane



-  Small particles able to pass through pores in the cell membrane
-  Large particles outside – cannot pass into the cell
-  Large particles inside – cannot pass out of the cell
-  Large particles inside and outside – cannot pass through cell membrane

HOMEOSTASIS

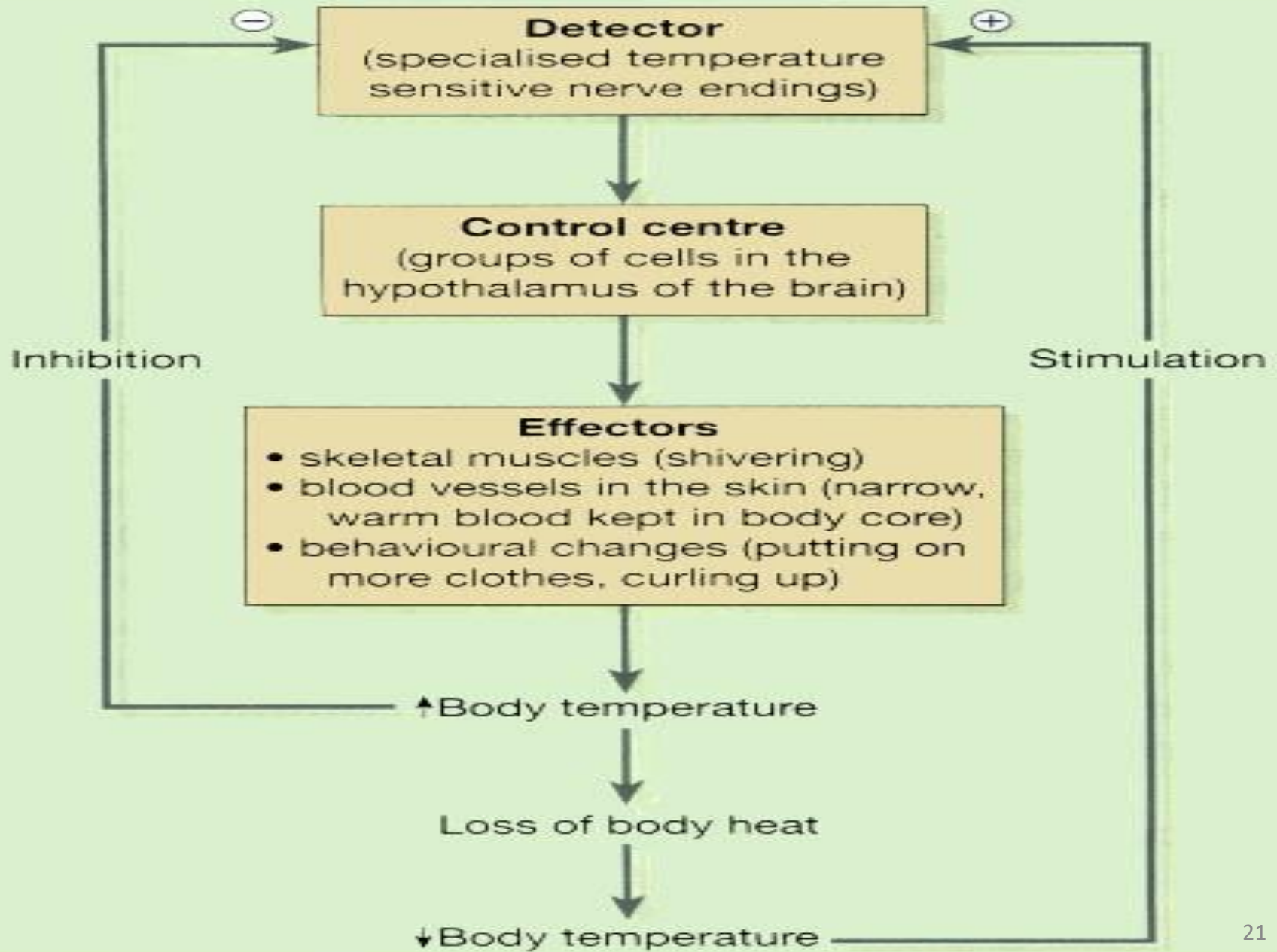
- **Def: the maintenance of the internal environment in a fairly constant state within narrow limits.**
- Maintained by control systems which detect and respond to changes in the internal environment.
- A control system has 3 basic components:
 - detector,
 - control centre
 - Effector(s)
- Control centre:
 - determines the limits within which the variable factor should be maintained.
 - receives an input from the detector or sensor,
 - integrates the incoming information.
- When the incoming signal indicates that an adjustment is needed the control centre responds and its output to the effector is changed. This is a dynamic process that maintains homeostasis.

- Examples of physiological variables
 - Temperature
 - Water and electrolyte concentrations
 - pH (acidity or alkalinity of body fluids)
 - Blood glucose levels
 - Blood and tissue oxygen and carbon dioxide levels
 - Blood pressure

Negative feedback mechanisms

- In systems controlled by negative feedback the effector response decreases or negates the effect of the original stimulus, restoring homeostasis.
- E.g; When body temperature falls below the preset level, this is detected by specialised temperature sensitive nerve endings. They transmit this information as an input to the hypothalamus of the brain which form the control centre.
- The output from the control centre activates mechanisms that raise body temperature (effectors).

- These include:
 - stimulation of skeletal muscles causing shivering
 - narrowing of the blood vessels in the skin reducing the blood flow to, and heat loss from, the peripheries
 - behavioural changes, e.g. we put on more clothes or curl up.
- When body temperature rises to within the normal range, the temperature sensitive nerve endings no longer stimulate the cells of the control centre and therefore the output of this centre to the effectors ceases.
- Most systems are controlled by negative feedback



Positive feedback mechanisms

- Are few
- The stimulus progressively increases the response, so that as long as the stimulus is continued the response is progressively being amplified (**amplifier or cascade systems**).
- E.g, blood clotting and uterine contractions during labour.
- During labour, contractions of the uterus are stimulated by the hormone oxytocin. These force the baby's head into the cervix of the uterus stimulating stretch receptors there. In response to this, more of the hormone oxytocin is released, further strengthening the contractions and maintaining labour.
- After the baby is born the stimulus (stretching of the cervix) is no longer present and the release of oxytocin stops

CHEMISTRY OF LIFE

ATOMS, MOLECULES AND COMPOUNDS

- **Atom:** the smallest particle of an element which can exist as a stable entity.
- **Element:** a chemical substance whose atoms are all of the same type; e.g. iron contains only iron atoms. There are 92 naturally occurring elements
- **Compounds:** contain more than one type of atom; e.g, water is a compound containing both hydrogen and oxygen atoms.
- Body structures are made up of combinations of four elements: **carbon, hydrogen, oxygen and nitrogen.**
- Small amounts of others are present, collectively described as **mineral salts**

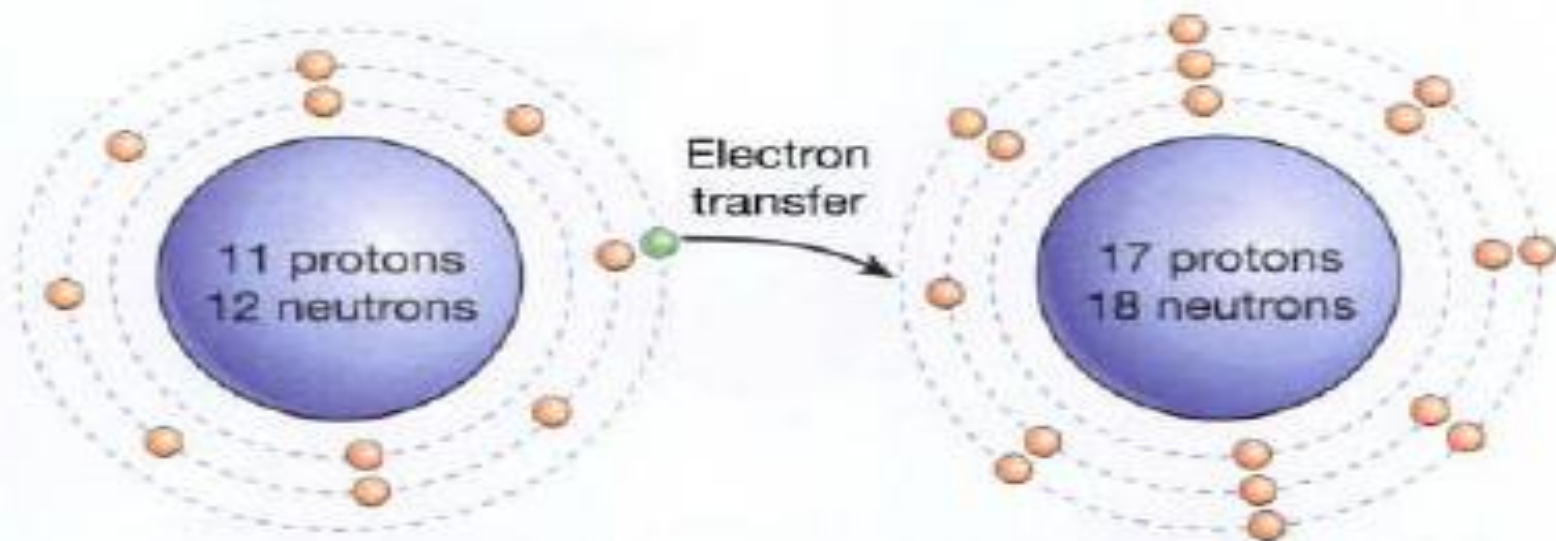
Atomic structure

- Atoms: made up of 3 main types of particles.
 - Protons: particles present in the nucleus or central part of the atom. Each proton has one unit of positive electrical charge and one atomic mass unit.
 - Neutrons: found in the nucleus of the atom. They have no electrical charge and one atomic mass unit.
 - Electrons: particles which revolve in orbit around the nucleus of the atom at a distance from it. Each electron carries one unit of negative electrical charge and its mass is so small that it can be disregarded when compared with the mass of the other particles.
- An atom is **electrically neutral**; the number of positively charged protons in the nucleus is equal to the number of negatively charged electrons in orbit around the nucleus.

- The chemistry of life depends upon the ability of the atoms to react and combine with one another to produce a wide range of molecules required for biological diversity.
- **How does this happen? When do atoms react?**
- **Isotopes:** are atoms of an element in which there is *a different number of neutrons in the nucleus*. This does not affect the electrical activity of these atoms because neutrons carry no electrical charge, but it does affect their atomic weight. **(How do u calculate the atomic weight of such atoms?)**

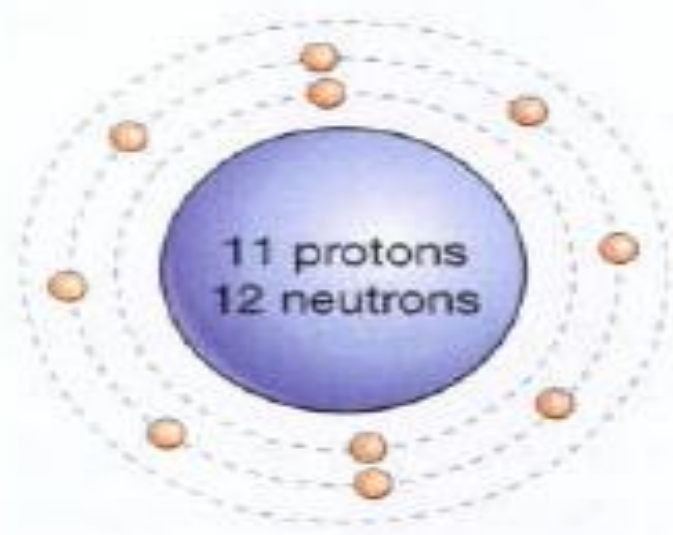
Bonds

- When atoms are joined together, they form a chemical bond. There are two types:- *Covalent and ionic*.
- *Covalent bonds* are formed when atoms share their electrons with each other. They are strong and stable.
- *Ionic bonds* are formed when electrons are transferred from one atom to another. They are usually weak. Eg. When sodium chloride is dissolved in water, the bonds breaks. Since the atoms are charged, they are no longer called atoms but *ions*.
- Positively charged ions are called *cations*
- Negatively charged ions are called *anions*

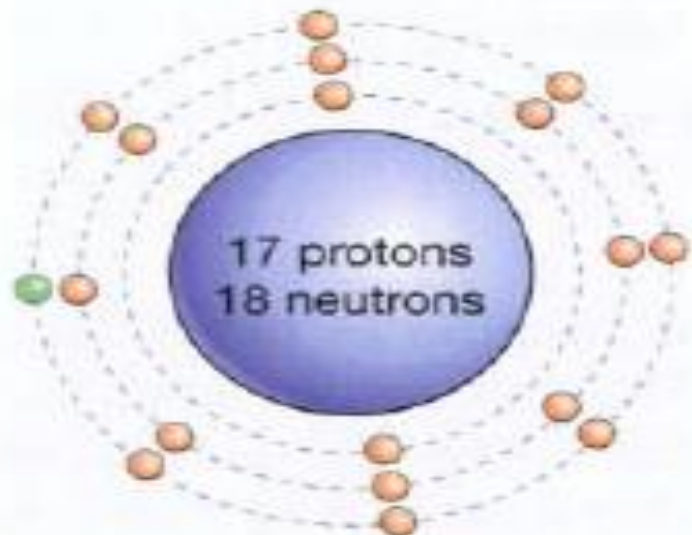


Sodium atom (Na)

Chlorine atom (Cl)



Sodium ion (Na⁺)



Chloride ion (Cl⁻)

MOLECULES AND COMPOUNDS

- **Molecules:** consist of two or more chemically combined atoms. The atoms may be of the same element, e.g. a molecule of atmospheric oxygen (O_2) consists of two oxygen atoms or contain two or more different elements; e.g. a water molecule (H_2O) contains two hydrogen atoms and an oxygen atom.
- When two or more elements combine, the resulting molecule can also be referred to as a **compound**.
- Compounds which contain the element **carbon** are classified as **organic**, and all others as inorganic. The body contains both.
- When the number of electrons in the outer shell of an element is the optimum number, the element is described as inert or chemically unreactive, i.e. it will not easily combine with other elements to form compounds.
- These elements are the inert or noble gases —**helium, neon, argon, krypton, xenon and radon**.

ELECTROLYTES

- Def: **An ionic compound that can conduct electricity**, e.g. sodium chloride solution
- Electrolytes are important body constituents because:
 - some conduct electricity, essential for muscle and nerve function
 - some exert osmotic pressure, keeping body fluids in their own compartments
 - some function in acid-base balance, as buffers to resist pH changes in body fluids.

Important electrolytes in the body

a) Sodium

- Most abundant ion in the extra-cellular compartment.
- **Functions.** Involved in the
 - Conduction of nerves
 - Contraction of muscles.
 - Regulation of acid and base balance.
- Acid and base balance is maintained through the exchange of hydrogen (H^+) ions with sodium (Na^+) ions in the kidneys.
- Foods rich in sodium are processed foods, snacks, smoked foods and table salt.

b) Potassium

- Most abundant ion in the intracellular compartment.
- Affects nerve conduction and muscle strength.
- Foods rich in potassium are unripe bananas, avocados, oranges, potatoes and dates.

c) Calcium

- Makes compounds with other elements.
- Important constituent of bones
- Involved in proper nerve and muscle functioning.
- Acts as a co-factor in the blood clotting mechanism.
- Foods that are rich in calcium are grains, legumes, and leafy vegetables.

d) Magnesium

- Normal constituent of bones.
- Involved in energy metabolism.
- Found in cocoa, seafood, dried beans and peas

ACIDS, ALKALIS AND pH

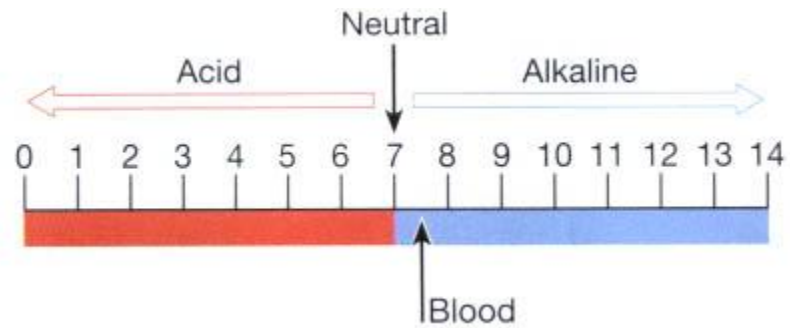
- **An acid:** a substance that produces hydrogen ions when dissolved.
- Acids act as electrolytes in water. They neutralise bases to produce salt and water.
- Common acids are hydrochloric acid and carbonic acid.
- **A base:** a substance that reacts with acid to form salt and water by accepting hydrogen ions and often releasing hydroxyl (OH^-) ions.
- Common bases are magnesium hydroxide and aluminium hydroxide.
- The balance between acids and bases must be maintained for the various processes in the body to take place optimally.

ACIDS, ALKALIS AND PH

- Number of H^+ present in a solution is a measure of the acidity of the solution.
- Maintenance of the normal H^+ concentration within the body is an important factor in maintaining homeostasis.
- **The pH scale**
- **Def:** A standard scale for the measurement of the hydrogen ion concentration in solution.
- Not all acids ionise completely when dissolved in water. The **hydrogen ion concentration** is a measure, therefore, of the **amount of dissociated acid (ionised acid) rather than of the total amount of acid present**. Strong acids dissociate more freely than weak acids, e.g. hydrochloric acid dissociates freely into H^+ and Cl^- , while carbonic acid dissociates much less freely into H^+ and HCO_3^- .

- Alkalinity of a solution depends on the number of hydroxyl ions (OH^-). Water is a neutral solution because every molecule contains one hydrogen ion and one hydroxyl radical. For every molecule of water (H.OH) which dissociates, one hydrogen ion (H^+) and one hydroxyl ion (OH^-) are formed, neutralizing each other.
- pH scale was developed taking water as the standard.
- In a neutral solution such as water, where the number of hydrogen ions is balanced by the same number of hydroxyl ions, the $\text{pH} = 7$.
- A pH reading below 7 indicates an acid solution, while readings above 7 indicate alkalinity.
- A change of one whole number on the pH scale indicates a tenfold change in $[\text{H}^+]$. Therefore, a solution of pH 5 contains ten times as many hydrogen ions as a solution of pH 6.
- Ordinary litmus paper colours blue for alkalinity and red for acidity.

The pH scale



PH VALUES OF BODY FLUIDS

- Vary.
- pH value in an organ is produced by its secretion of acids or alkalis which establishes the optimum level.

Body fluid	pH
Blood	7.35 to 7.45
Saliva	5.4 to 7.5
Gastric juice	1.5 to 3.5
Bile	6 to 8.5
Urine	4.5 to 8.0

Buffers

- Buffering mechanisms temporarily neutralize fluctuations in pH thus keeping it stable within its normal limits.
- The lungs and the kidney are the most active organs in buffering. Lungs regulate CO₂ levels in the body by either ↑ or ↓ breathing. Kidneys regulate pH by either ↑ or ↓ excretion of hydrogen and bicarbonate ions as required.
- Other buffer systems include body proteins and phosphate.
- Buffer substances/systems help maintain the Acid-Base balance so that the pH remains within normal, but narrow, limits

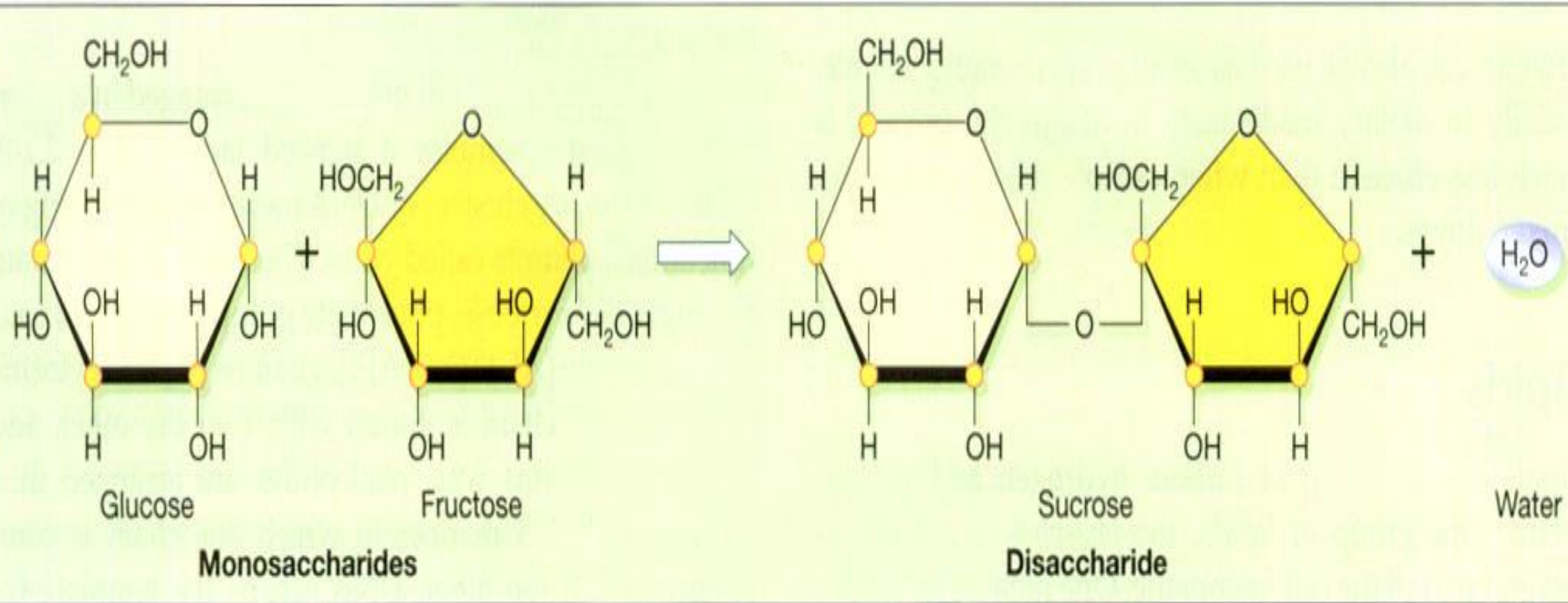
ACIDOSIS AND ALKALOSIS

- When the pH is below 7.35, and all the reserves of alkaline buffer are used up, the condition of **acidosis exists (Acidosis is an increased acidity in the blood and other body tissue).**
- When the reverse situation persists and the pH is above 7.45, and the increased alkali uses up all the acid reserve, the state of **alkalosis exists (Alkalosis refers to a condition reducing hydrogen ion concentration of arterial blood plasma)**

IMPORTANT BIOLOGICAL MOLECULES

1. CARBOHYDRATES

- Are the sugars.
- Composed of carbon, oxygen and hydrogen. Carbon atoms are normally arranged in a ring, with the oxygen and hydrogen atoms linked to them.
- When 2 sugars link up, the reaction occurring expels a molecule of water and the resulting bond is called a **glycosidic linkage**.
- **Monosaccharides**: Simple sugars, that can exist as single units e.g glucose,
 - **Glucose**: main form in which sugar is used by cells, and blood levels are tightly controlled.
- **Disaccharides**: molecule formed when 2 monosaccharides are linked together e.g. sucrose
- **Polysaccharides**: molecule formed when more than 2 monosaccharides e.g. starch.



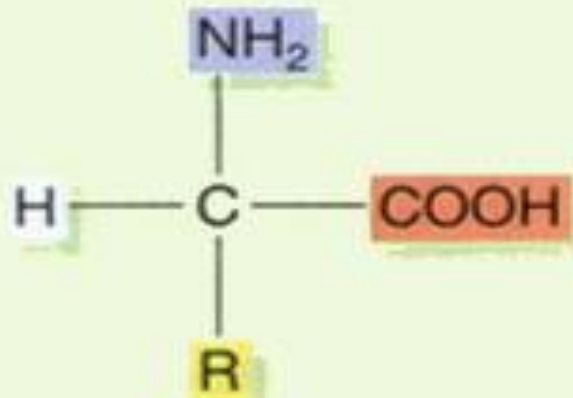
Glucose + fructose = sucrose

CARBOHYDRATES CT.

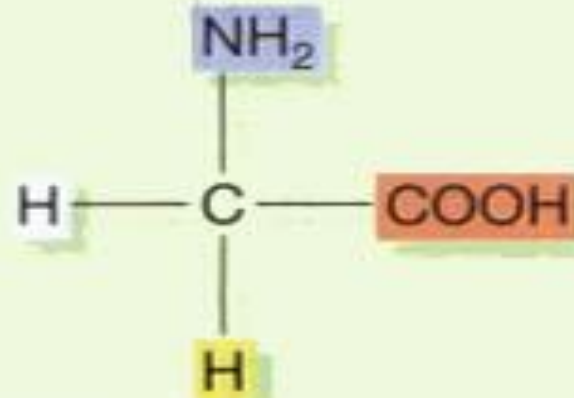
- Glucose can be broken down (metabolised) in either the **presence (aerobically) or the absence (anaerobically)** of oxygen, but the process is much more efficient when O₂ is used.
- During this process, energy, water and carbon dioxide are released. This family of molecules:
 - serves as a ready source of energy to fuel cellular activities
 - provides a form of energy storage, e.g. glycogen
 - forms an integral part of the structure of DNA and RNA
 - can act as receptors on the cell surface, allowing the cell to recognise other molecules and cells.

2. AMINO ACIDS AND PROTEINS

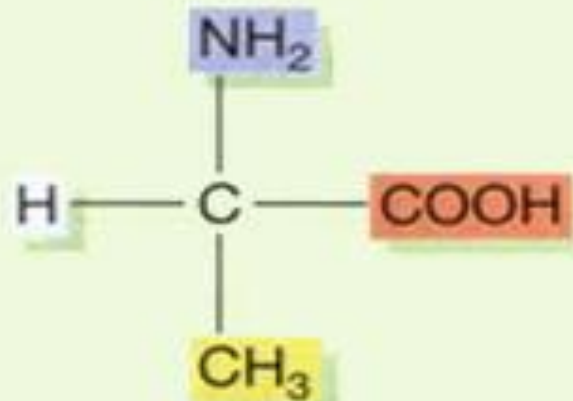
- Amino acids contain carbon, hydrogen, oxygen and nitrogen, and many in addition carry sulphur.
- 20 amino acids are known to be the principal building blocks of protein.
- Amino acids have a basic common structure, including an amino group (NH_2), a carboxyl group (COOH) and a hydrogen atom. **What makes one amino acid different from the next is a variable side chain (R).**
- When two amino acids join up the reaction expels a molecule of water and the resulting bond is called a **peptide bond**.



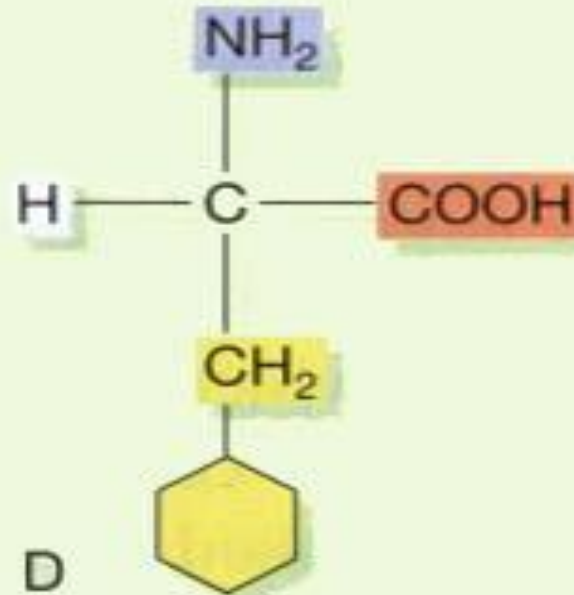
A



B



C



D

Amino acid structures: A. Common structure, R = variable side chain. B. Glycine, the simplest amino acid. C. Alanine. D. Phenylalanine.

- Amino acids are sub-divided into 2 categories,
 - essential amino acids
 - non-essential amino acids
- **Essential amino acids** cannot be synthesised in the body, therefore they must be included in the diet.
- **Non-essential amino acids** are those which can be synthesised in the body.
- Nutritional value of a protein depends on the amino acids of which it is composed.

Box 11.1 Essential and non-essential amino acids

Essential amino acids

Isoleucine

Leucine

Lysine

Methionine

Phenylalanine

Threonine

Tryptophan

Valine

Histidine

Non-essential amino acids

Alanine

Arginine

Asparagine

Aspartic acid

Cysteine

Cystine

Glutamic acid

Glutamine

Glycine

Hydroxyproline

Proline

Serine

Tyrosine

PROTEINS CT.

- Proteins:
 - made from amino acids joined together
 - are the main family of molecules from which the human body is built.
 - Protein molecules vary enormously in size, shape, chemical constituents and function.
 - can be used as an alternative energy source, usually in dietary inadequacy
- Many important groups of biologically active substances in the body are proteins, e.g.:
 - carrier molecules, e.g. haemoglobin
 - enzymes
 - many hormones, e.g. insulin
 - Antibodies

LIPIDS

- Made up of carbon, hydrogen and oxygen atoms.
- Strongly hydrophobic (water hating) thus they don't mix with water: an importance in their function in the cell membrane.
- **Groups**
 - **Phospholipids**, form an integral part of the cell membrane.
 - Fat soluble vitamins (A, D, E and K)
 - Fats (triglycerides)
 - Prostaglandins
 - cholesterol
- A molecule of fat consists of **several fatty acids, all linked to a molecule of glycerol.**

- Fats are
 - a source of energy,
 - provide a convenient form in which to store excess calorific intake.
- When fats are broken down, they release energy, but the process is less efficient than when carbohydrates are used, since it requires more energy for the breakdown reaction to take place.
- Used in the body for:
 - insulation
 - protection of body parts
 - energy storage.

Nucleic acids & NUCLEOTIDES

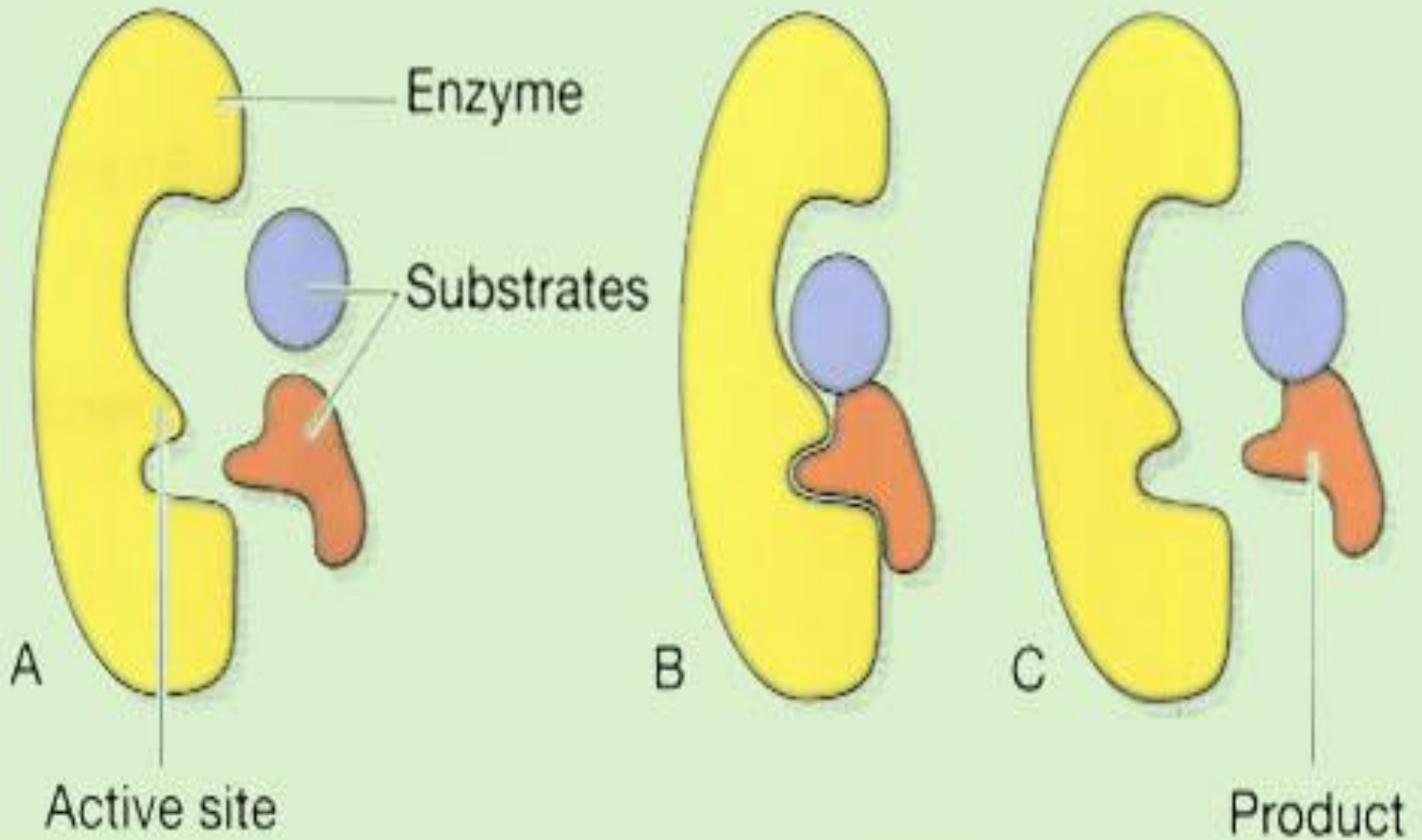
- **Nucleic acids:** large biological molecules essential for all known forms of life. They include DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).
- **Nucleotides:** biological molecules that form the building blocks of nucleic acids and
 - serve to carry packets of energy within the cell e.g., ATP (**Adenosine triphosphate (ATP)** is a [nucleotide](#), also called a nucleoside triphosphate, is a small molecule used in [cells](#) as a [coenzyme](#). It is often referred to as the "[molecular](#) unit of [currency](#)" of intracellular [energy transfer](#))
 - In the form of the nucleoside triphosphates (ATP), nucleotides play central roles in metabolism.
 - participate in cell signaling e.g., cAMP, (**Cyclic adenosine monophosphate**)
 - are incorporated into important cofactors of enzymatic reactions, e.g. coenzyme A.(involved in [synthesis](#) and [oxidation](#) of [fatty](#)

DEOXYRIBONUCLEIC ACID (DNA)

- A double strand of nucleotides arranged in a spiral (helix) which resembles a twisted ladder.
- **Chromosomes:** clusters of DNA molecules consisting of functional subunits called genes.
- The nucleotides contain the sugar deoxyribose, phosphate groups and one of 4 bases: **adenine [A], thymine [T], guanine [G] and cytosine [C]. A in one chain is paired with T in the other, and G with C.**
- Nucleotides are arranged in a precisely ordered manner in which one chain is complementary to the other.
- DNA acts as the template for protein synthesis and is stored safely in the nucleus.

ENZYMES

- **Enzymes:** proteins which act as catalysts for biochemical reactions. i.e, they speed the reaction up but are not themselves changed by it, and therefore can be used over and over again.
- Enzymes are **very selective** and usually **catalyse only one specific reaction**. The molecule(s) entering the reaction is called the **substrate** and it binds to a very specific site on the enzyme, called **the active site**.
- Whilst the substrate(s) is bound to the active site the reaction proceeds, and once it is complete the product(s) of the reaction breaks away from the enzyme and the active site is ready for use again
- Enzymes can catalyse both synthesis and breakdown reactions, and their names (almost always!) end in **~ase**.
- Enzyme action depends on: temperature, pH, cofactors etc.



Action of an enzyme: A. Enzyme and substrates. B. Enzyme-substrate complex. C. Enzyme and product.

MOVEMENT OF SUBSTANCES WITHIN THE BODY

INTRO

- Nutrients absorbed in the small intestine must move to various tissues, while waste substances must travel from the tissues to their exit points from the body.
- Communication molecules, such as hormones, have to travel from the site of production to their destination.
- Water itself, the principal constituent of the body, has to move in order to be able to be distributed throughout the body fluids and keep solutes at appropriate physiological concentrations, thus maintaining homeostasis.

- Substances will always travel from an area of high concentration to one of low concentration, assuming that there is no barrier in the way.
- Between two such areas, there exists a **concentration gradient** and movement of substances occurs down the concentration gradient, or downhill. No energy is required for such movement; this process is therefore described as **passive**.
- Where substances move uphill, i.e. against the concentration gradient; chemical energy is required, usually in the form of ATP. These processes are described as **active**.
- Passive movement of substances in the body proceeds usually in one of two main ways — **diffusion** or **osmosis**.

DIFFUSION

- **Def:** movement of a chemical substance from an area of high concentration to an area of low concentration.
 - occurs mainly in gases, liquids and solutions.
- Process of diffusion is speeded up if the temperature rises and/or the concentration of the diffusing substance is increased.
- Can also occur across a semi-permeable membrane, such as the plasma membrane; in this case, only those molecules able to cross the membrane can diffuse through. E.g., the capillary wall is effectively a semi-permeable membrane; whereas water can travel freely in either direction across it, large proteins in the plasma and red blood cells are too large to cross and therefore remain in the blood.



A Before diffusion

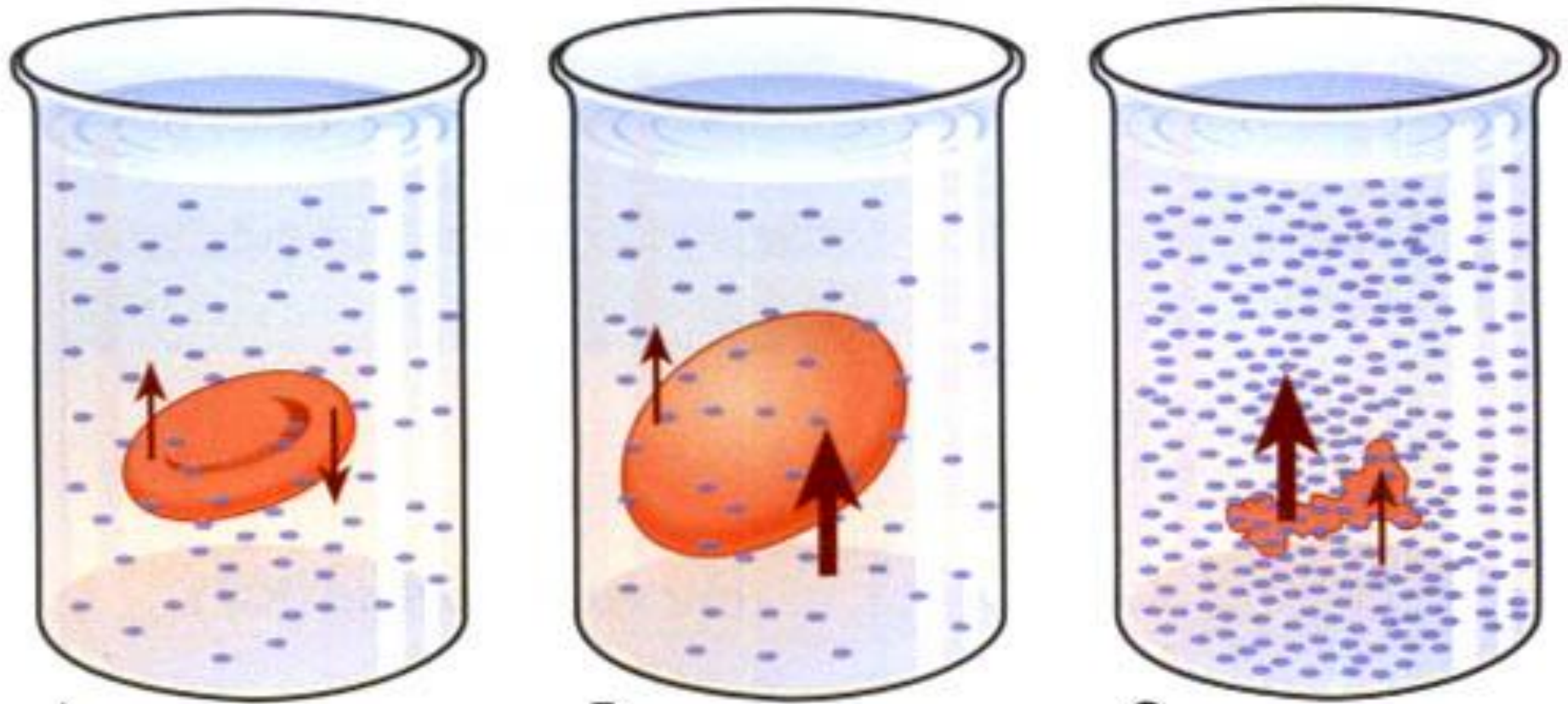


B After diffusion

OSMOSIS

- **Def:** the movement of water down its concentration gradient across a semi-permeable membrane.
- This is usually because the solute molecules are too large to pass through the pores in the membrane. The force with which this occurs is called the **osmotic pressure**.
- Water crosses the membrane down its concentration gradient from the side with the lower solute concentration the side with the greater solute concentration. This dilutes the more concentrated solution, and concentrates the more dilute solution.
- Osmosis proceeds until equilibrium is reached, at which point the solutions on each side of the membrane are of the same concentration and are said to be **isotonic**.

- The concentration of water and solutes in the plasma is maintained within a very narrow range because if the plasma water concentration rises, i.e. the plasma becomes more dilute than the intracellular fluid within the red blood cells, then water will move down its concentration gradient across the membranes and into the red blood cells.
- This may cause the red blood cells to swell and burst. In this situation, the plasma is said to be **hypotonic**.
- If the plasma water concentration falls so that the plasma becomes more concentrated than the intracellular fluid within the red blood cells (the plasma becomes **hypertonic**), water passively moves by osmosis from the blood cells into the plasma and shrinkage of the blood cells occurs.



A

B

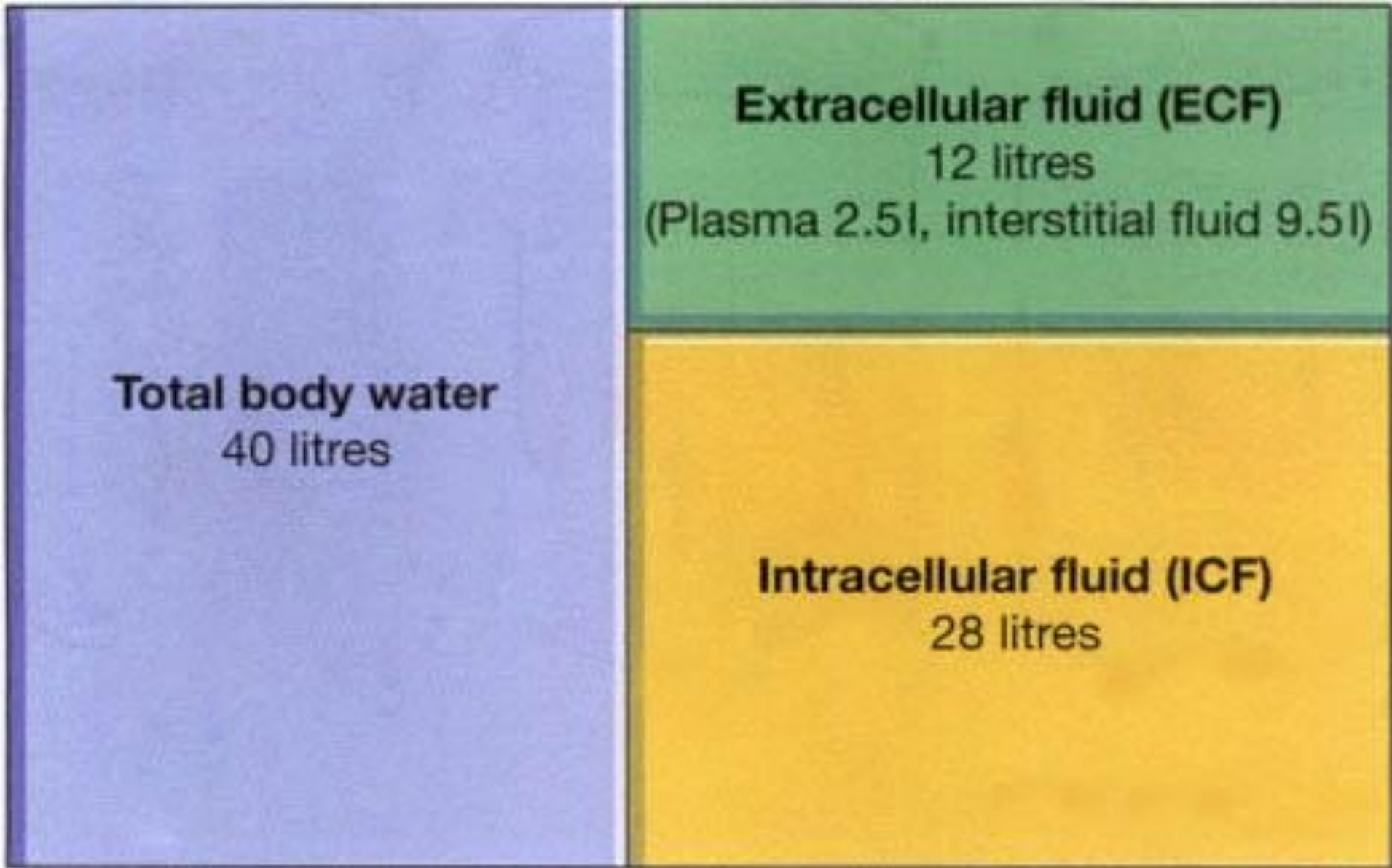
C

- = solute molecule

The process of osmosis. Net water movement when a red blood cell is suspended in solutions of varying concentrations (tonicity): A. Isotonic solution. B. Hypotonic solution. C. Hypertonic solution.

BODY FLUIDS

- Total body water in adults is about 60% of body weight.
 - Extracellular water.....about 22% of body weight
 - Intracellular water.....about 38% of body weight
- Proportion is higher in
 - young people and
 - adults below average weight.
- It is lower in
 - the elderly
 - Obesity



Distribution of body water in a 70 kg person.

Importance of water

1. It makes up part of all body fluids
2. It protects cells from outside pressure
3. It helps in the regulation of body temperature
4. It maintains intracellular pressure
5. It is involved in chemical reactions
6. It washes out wastes and is, therefore, a medium of excretion

Extracellular Fluid (ECF)

- Consists of
 - **blood,**
 - **plasma,**
 - **lymph,**
 - **cerebrospinal fluid**
 - **fluid in the interstitial spaces** of the body.
 - **Others** (synovial fluid, pericardial fluid, pleural fluid)
- Interstitial or **intercellular fluid (tissue fluid)** bathes all the cells of the body except the outer layers of skin.
- It is the medium through which substances pass from blood to the body cells, and from the cells to blood.

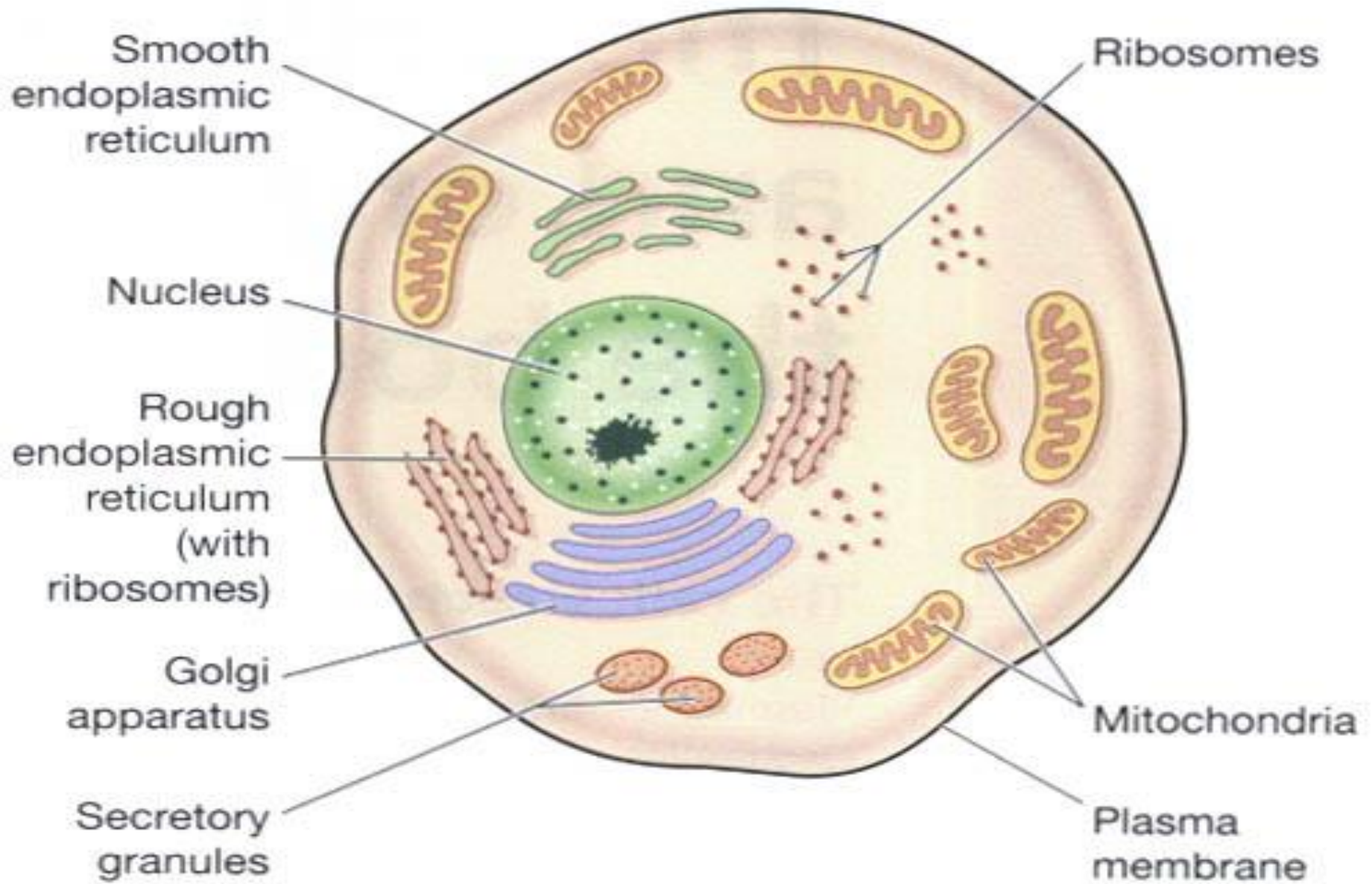
INTRACELLULAR FLUID (ICF)

- Its composition is largely controlled by the cell itself, because there are selective uptake and discharge mechanisms present in the cell membrane.
- Thus, sodium levels are nearly ten times higher in the ECF than in the ICF.
- This concentration difference occurs because although sodium diffuses into the cell down its concentration gradient there is a pump in the membrane which selectively pumps it back out again.

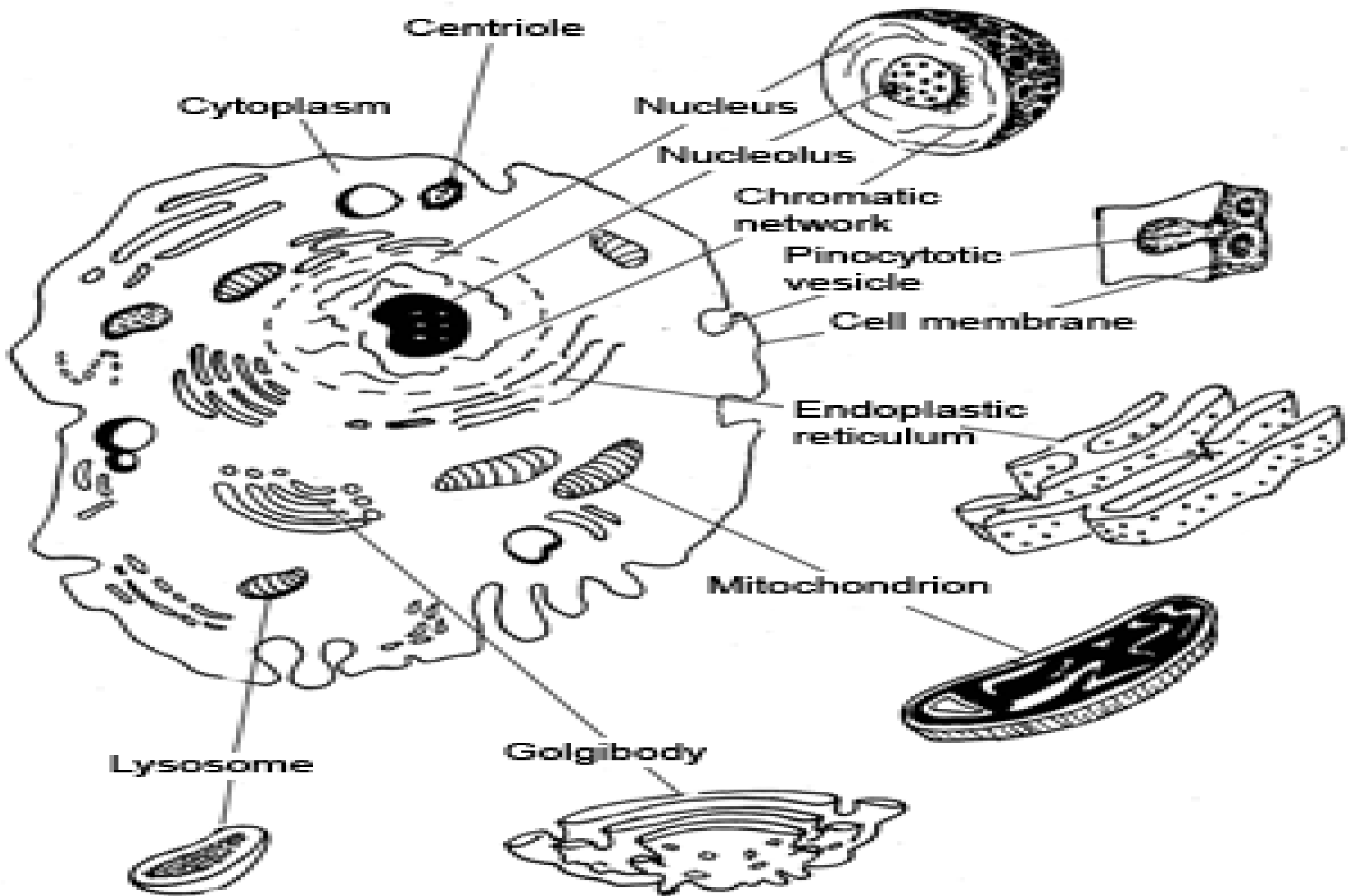
CELLS, TISSUES AND ORGANISATION OF THE BODY

THE CELL: STRUCTURE AND FUNCTIONS

- A cell consists of a
 - **plasma membrane**
 - **organelles** floating in a watery fluid called *cytoplasm*
- **Organelles**: small structures with highly specialised functions contained within a membrane.
- They include:
 - nucleus,
 - mitochondria,
 - ribosomes,
 - endoplasmic reticulum,
 - Golgi apparatus,
 - lysosomes,
 - microfilaments and microtubules.



SIMPLE CELL



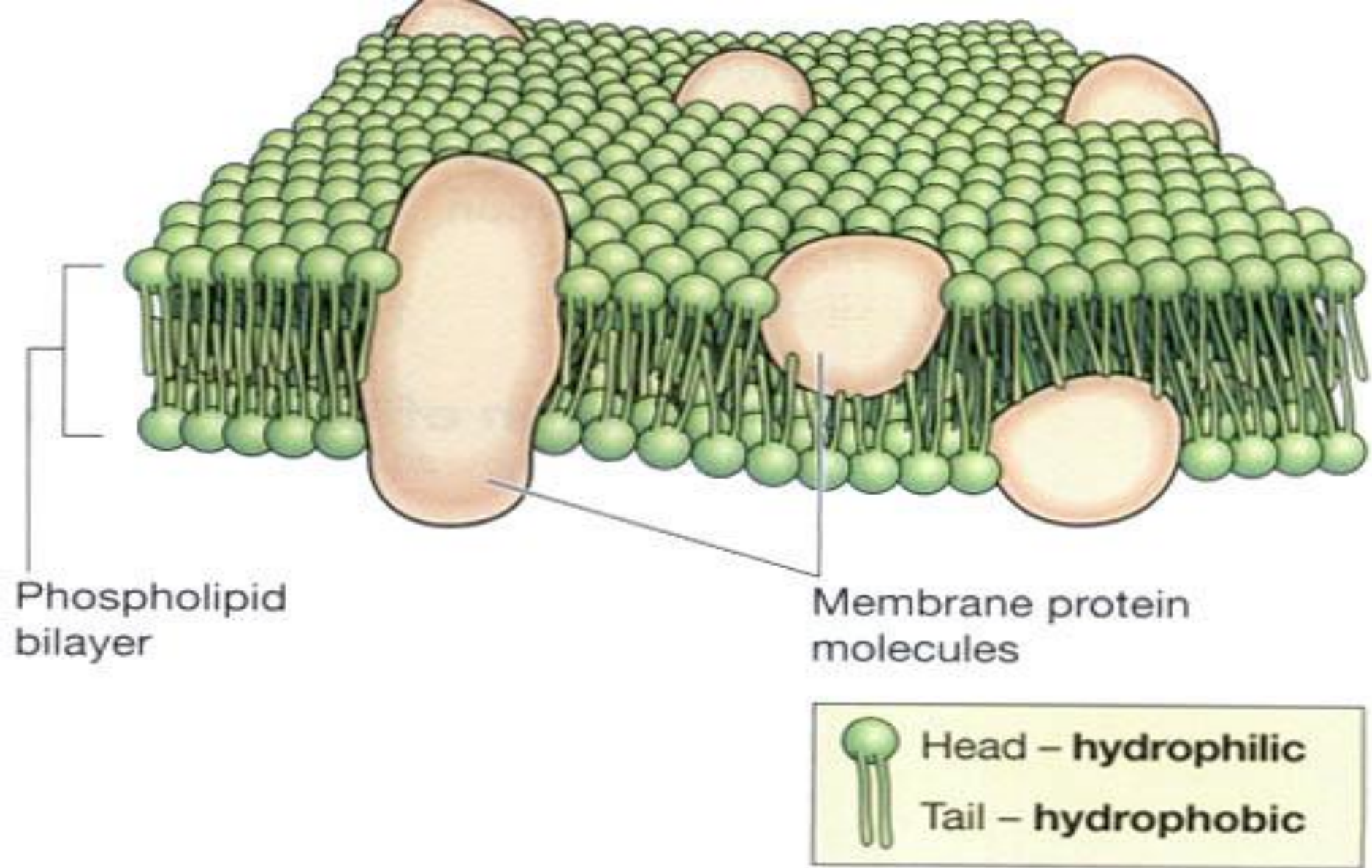
CELL STRUCTURE AND ITS FUNCTIONS

- All cells in the body have a cell membrane, which forms the boundary of the cell.
- The cell is made of **protoplasm**, divided into 2:
 - **Cytoplasm**: a gel-like substance in which many processes take place.
 - **Nucleus**: responsible for cell coordination and cell division. It is made up of protein granules, and is surrounded by a membrane, which separates it from the cytoplasm.
- The cell has two different nucleic acids:
 - The **ribonucleic acid (RNA)**; found in the nucleus & in the cytoplasm.
 - The **deoxyribonucleic acid (DNA)**; found exclusively in the chromosomes (in strands of chromatin) in the nucleus.
- **Chromosomes**: the units that are involved in the transfer of the genetic material during the process of reproduction

PLASMA MEMBRANE

- Has 2 layers of phospholipids with proteins and sugar molecules embedded in them.
- Some proteins extend all the way through the membrane providing channels that allow the passage of electrolytes and non-lipid-soluble substances.
- The phospholipid molecules have a
 - **Head:** is electrically charged and hydrophilic ('water loving')
 - **Tail:** has no charge and is hydrophobic ('water hating').
- The phospholipid bilayer is arranged like a sandwich with the hydrophilic heads aligned on the outer surfaces of the membrane and the hydrophobic tails forming a central water-repelling layer.
- These differences influence the transfer of substances across the membrane.

- The membrane proteins perform several functions:
 - Selective permeability and transport of solutes thru passive transport, active transport and group translocation
 - Electron transport and oxidative phosphorylation. It contains enzymes and other components of the respiratory chain
 - Excretion of hydrophilic exoenzymes and pathogenicity proteins
 - Biosynthetic functions – it bears enzymes and carrier molecules that function in biosynthesis of DNA, cell wall polymers and membrane lipids
 - Chemotactic systems – has receptors that attractants and repellants bind to.



PLASMA MEMBRANE

ORGANELLES

a) Nucleus

- All cells except mature erythrocytes have a nucleus.
- It is the largest organelle.
- Contained within a membrane similar to the plasma membrane but it has tiny pores through which some substances can pass between it and the **cytoplasm**.
- Contains the body's genetic material, which directs the activities of the cell. This is built from DNA and proteins called **histones** coiled together forming a fine network of threads called chromatin (resemble tiny strings of beads).
- The DNA makes up 46 chromosomes.
- Within the nucleus is the nucleolus which is involved in manufacture and assembly of ribosomes

b) Mitochondria

- Are membranous sausage-shaped structures in the cytoplasm.
- Factories for production of energy.
- They are involved in aerobic respiration, the processes by which chemical energy is made available in the cell.
- This is in the form of ATP, which releases energy when the cell breaks it down.
- Active cell types have largest number of mitochondria e.g. liver, muscle and spermatozoa

c) Ribosomes

- Tiny granules composed of RNA and protein. They synthesise proteins from amino acids, using RNA as the template.
- When present in free units or in small clusters in the cytoplasm, the ribosomes make proteins for use within the cell.
- Are also found on the outer surface of nuclear envelope and rough endoplasmic reticulum where they manufacture proteins to be used outside the cell.

Mitochondria Structural Features

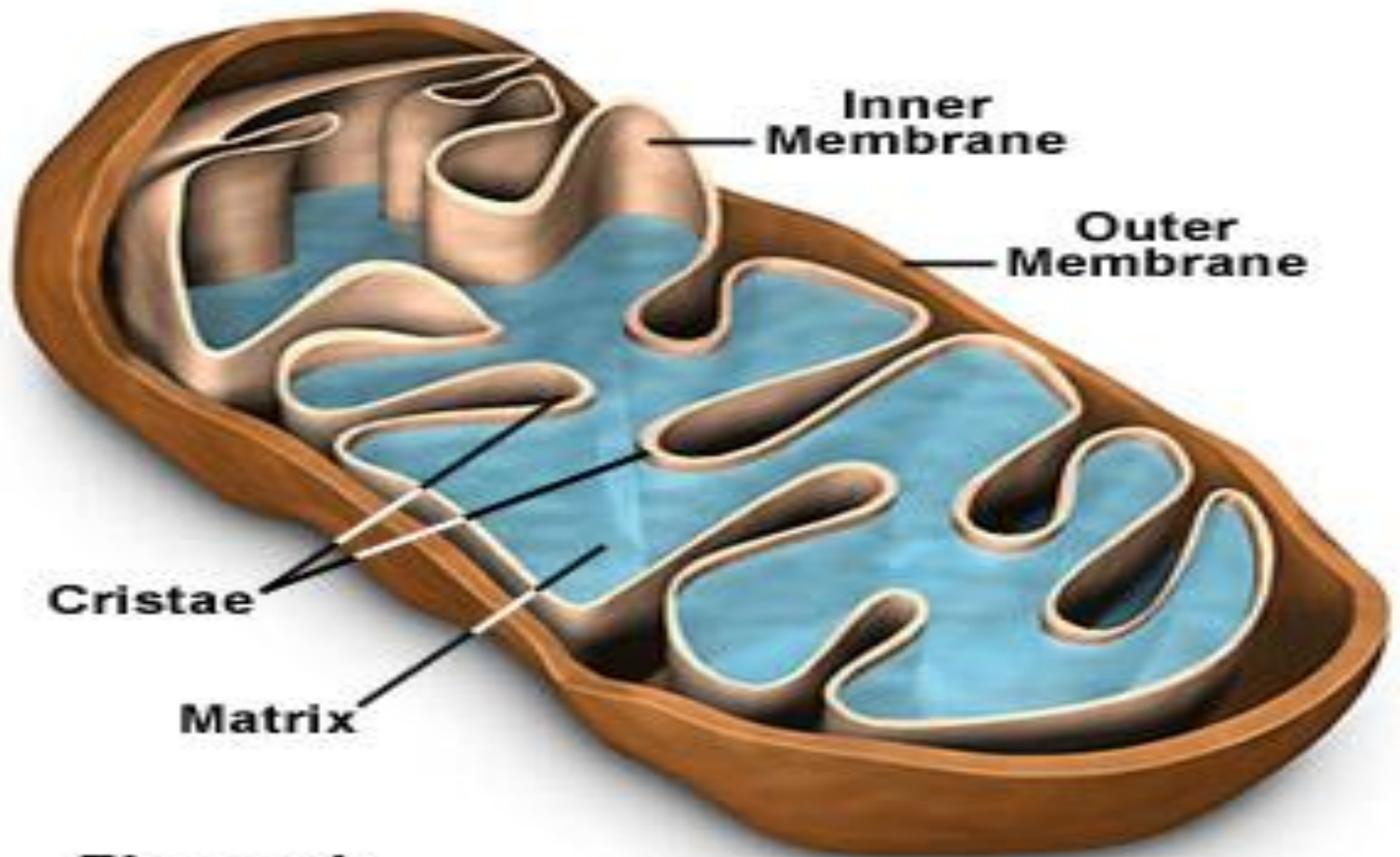


Figure 1

d) Endoplasmic reticulum (ER)

- A series of interconnecting membranous canals in the cytoplasm.
- 2 types: smooth and rough.
- Smooth ER
 - synthesises lipids and steroid hormones,
 - associated with the detoxification of some drugs.
- Rough ER is studded with ribosomes.
 - These are the site of synthesis of proteins that are 'exported' (extruded) from cells, i.e. enzymes and hormones that pass out of their parent cell to be used by other cells in the body.

e) Golgi apparatus

- Consists of stacks of closely folded flattened membranous sacs involved in protein and carbohydrate processing and transfer.
- Present in all cells but is larger in those that synthesise and export proteins. The proteins move from the endoplasmic reticulum to the Golgi apparatus where they are 'packaged' into membrane-bound vesicles called *secretory granules*. The *vesicles* are stored and, when needed, move to the plasma membrane, through which the proteins are exported out through exocytosis.

f) Lysosomes

- Secretory vesicle formed by the Golgi apparatus. They contain a variety of enzymes involved in breaking down fragments of organelles and large molecules (e.g. RNA, DNA, carbohydrates, proteins) inside the cell into smaller particles that are either recycled, or extruded from the cell as waste material.

- Lysosomes in WBCs contain enzymes that digest foreign material such as microbes.

g) Cytoskeleton

Microfilaments: Tiny strands of protein that provide structural support ,maintain the characteristic shape of the cell and permit cotraction.

Microtubules: Contractile protein structures in the cytoplasm involved in

- Movement of organelles within the cell
- the movement of chromosomes during cell division
- the movement of cell extensions

Centrosome: directs organization of microtubules.

Consists of centrioles and are involved in cell division

Cell extensions: microvilli, cilia and flagella. Have various functions.

CELL CYCLE

- Body cells get damaged, worn out and die and there4 needs to be replaced by growth and division of other similar cells.
- Two types of division; mitosis and meiosis
- **Mitosis:** a process that results in two new genetically identical daughter cells.
- **Meiosis:** a special division that occurs in the sex cells and results in formation of four daughter cells
- A typical cell cycle has two phases: Interphase and Mitosis
- INTERPHASE
- Has three phases, namely:
 - First gap phase (G_1) – cells grow in size and volume
 - S phase – there is synthesis of DNA(through replication)
 - Second gap phase (G_2) – further growth and preparation for cell division
 - NB:- Some cell enter a resting phase (G_0) instead of continuing in the cycle.

MITOSIS

- Has four distinct stages
 - Prophase: Replicated chromatin becomes tightly coiled. Chromatids become paired to form a chromosome unit (joined at the *centromere*). Mitotic apparatus (centrioles and mitotic spindle) appear and the centrioles move to either end of the cell and the nuclear envelope disappears.
 - Metaphase: chromatids align on the centre of the spindle attached by their centromeres
 - Anaphase: centromeres separate and each of the chromatids migrate to each end of the spindle
 - Telophase: the mitotic spindle disappears, the chromosomes uncoil and the nuclear envelope reforms.
- Cytokinesis then follows where all the other organelles, cytoplasm are added by the plasma membrane splitting to form two identical cells

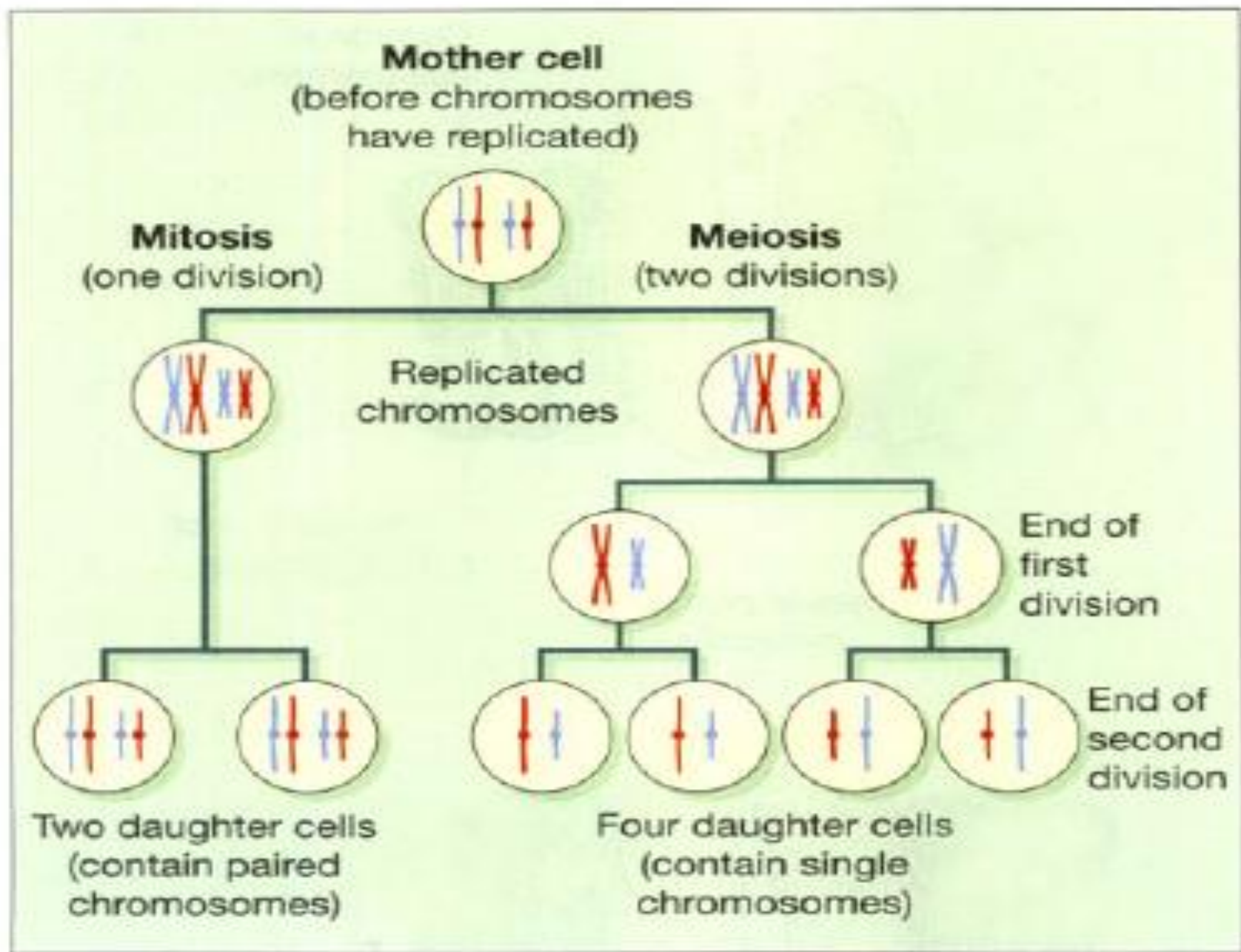
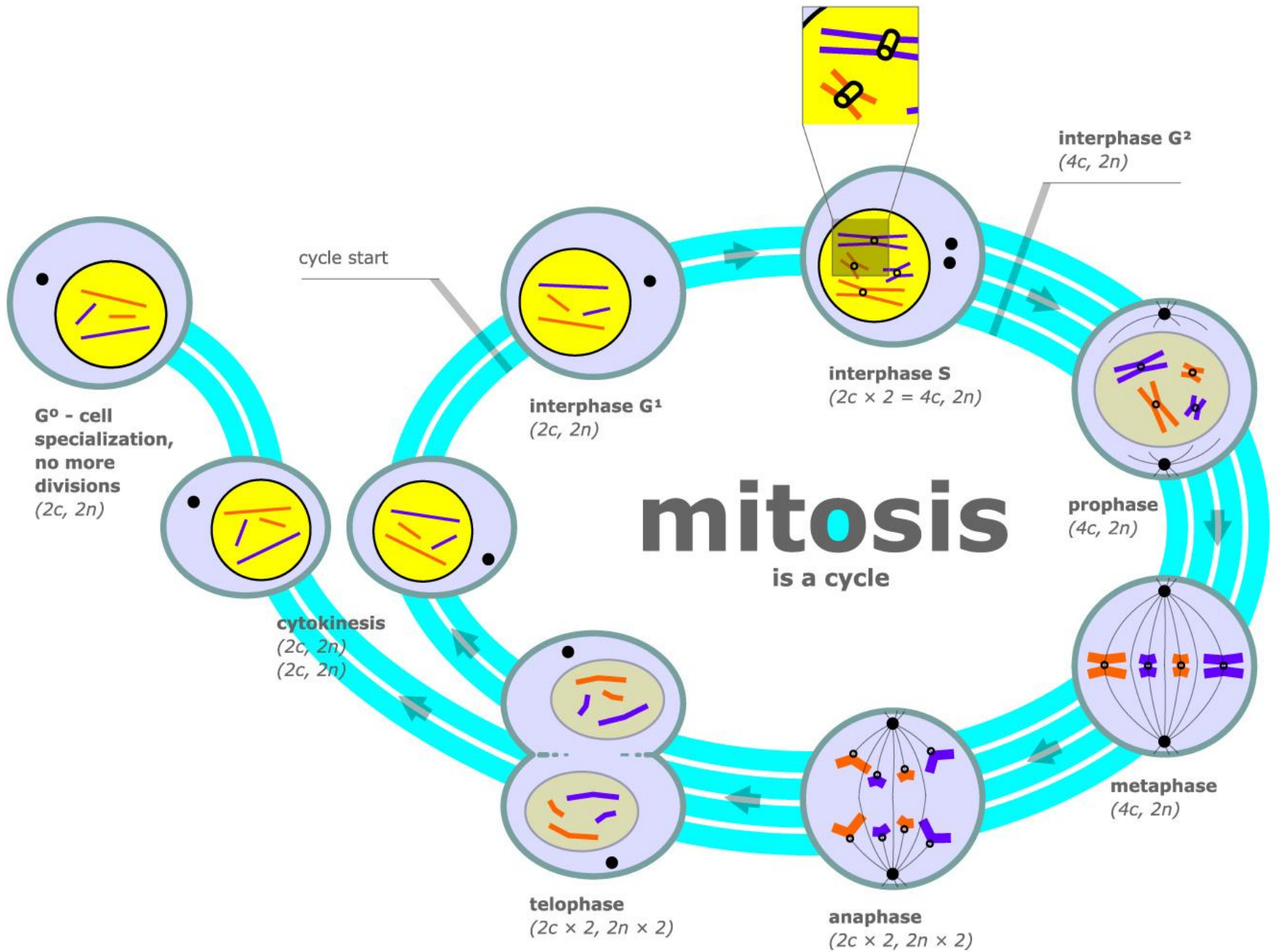


Figure 3.5 Cell division. Simplified diagram of mitosis and meiosis.



MEIOSIS

- Def: the process of cell division that occurs in the formation of reproductive cells (***gametes — the ova and spermatozoa***).
- The ova grow to maturity in the ovaries of the female and the spermatozoa in the testes of the male. In meiosis four daughter cells are formed after two divisions.
- During meiosis the pairs of chromosomes separate and one from each pair moves to opposite poles of the 'parent' cell. When it divides, each of the 'daughter' cells has only 23 chromosomes, called the ***haploid number***. This means that when the ovum is fertilised the resultant zygote has the full complement of 46 chromosomes (***the diploid number***), ***half from the father and half from the mother***.
- Thus the child has some characteristics inherited from the mother and some from the father.

- Determination of sex depends upon one particular pair of chromosomes: the ***sex chromosomes***.
- Females; have X chromosomes...are the same size and shape.
- Males; have one X chromosome and a slightly smaller Y chromosome.
- When the ovum is fertilised by an X-bearing spermatozoon the child is female and when it is fertilised by a Y-bearing spermatozoon the child is male.
- Sperm X + ovum X \rightarrow child XX = female
- Sperm Y + ovum X \rightarrow child XY = male

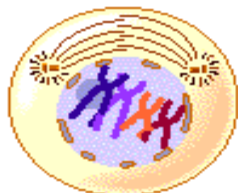
Interphase



MEIOSIS I

Prophase I

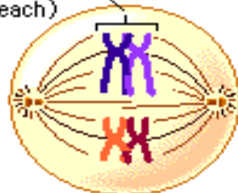
Synapsis and crossing over occur.



Tetrad (paired homologous chromosomes with two chromatids each)

Metaphase I

Tetrads line up on the metaphase plate.



Anaphase I

Homologous pairs separate.



Telophase I



Cytokinesis I



To Prophase II

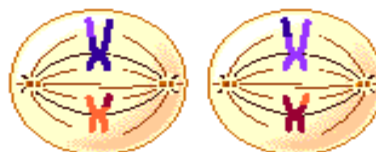
MEIOSIS II

Prophase II



Metaphase II

Chromosomes line up on the metaphase plate.



Anaphase II

Sister chromatids separate.



Telophase II



Cytokinesis II



4 haploid daughter cells are formed, each having only one chromosome of each homologous pair.

MUTATION

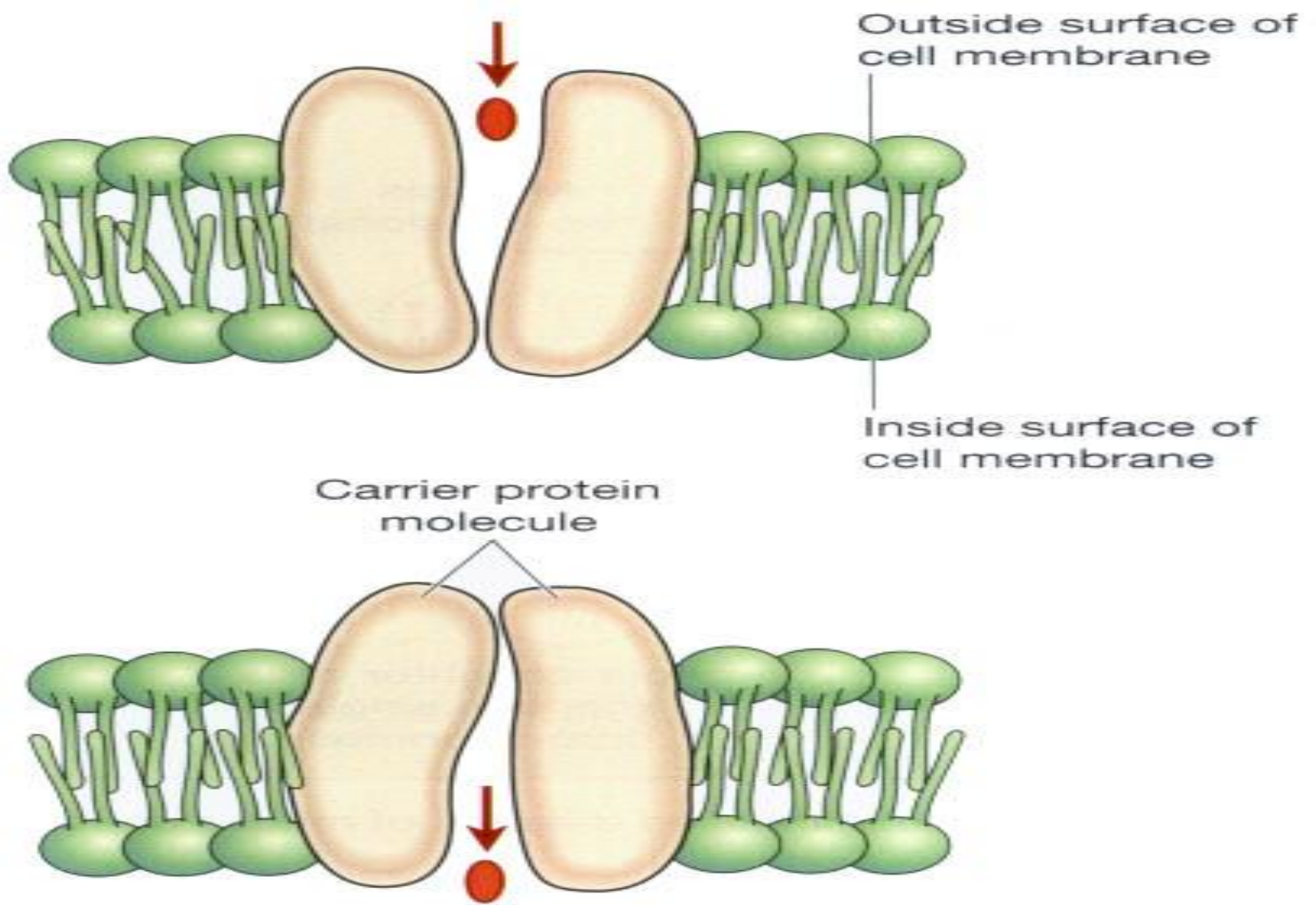
- Cells are said to mutate when their genetic make-up is altered in any way.
- Mutation may cause:
 - no significant change in cell function
 - modification of cell function that may cause physiological abnormality but does not prevent cell growth and multiplication, e.g. inborn errors of metabolism, defective blood clotting
 - the death of the cell.
- Some mutations occur by chance, others may be caused by extraneous factors, such as X-rays, ultraviolet rays or some chemicals.
- The most important mutations are those that occur in the ova and spermatozoa. Genetic changes in these cells are passed on to subsequent generations although they do not affect the parent.

TRANSPORT OF SUBSTANCES ACROSS CELL MEMBRANES

Passive transport: occurs when substances can cross plasma and organelle (semi-permeable) membranes and move down the concentration gradient (downhill) without using energy.

- a) Diffusion:** process in which dissolved substances move across cells following a concentration gradient so that they balance on both sides of that gradient
- Small substances diffuse down the concentration gradient crossing membranes by:
 - dissolving in the lipid part of the membrane, e.g. lipid-soluble substances: oxygen, carbon dioxide, fatty acids, steroids
 - passing through water-filled channels, or pores in the membrane, e.g. small water-soluble substances: sodium, potassium, calcium.

- b) Facilitated diffusion:** passive process utilized by substances that are unable to diffuse through the semi-permeable membrane unaided, e.g. glucose, amino acids.
- Specialized protein carrier molecules in the membrane have specific sites that attract and bind substances to be transferred. The carrier then changes its shape and deposits the substance on the other side of the membrane.
 - The carrier sites are specific and can be used by only one substance.
 - As there are a finite number of carriers, there is a limit to the amount of a substance which can be transported at any time. This is known as the ***transport maximum***.



Specialized protein carrier molecules involved in facilitated diffusion and active transport.

c) Osmosis: passive movement of solute materials/water from a region of higher concentration to that of lower concentration via a semi-permeable membrane.

Active transport: process where energy is utilized to transport substances up their concentration gradient (uphill).

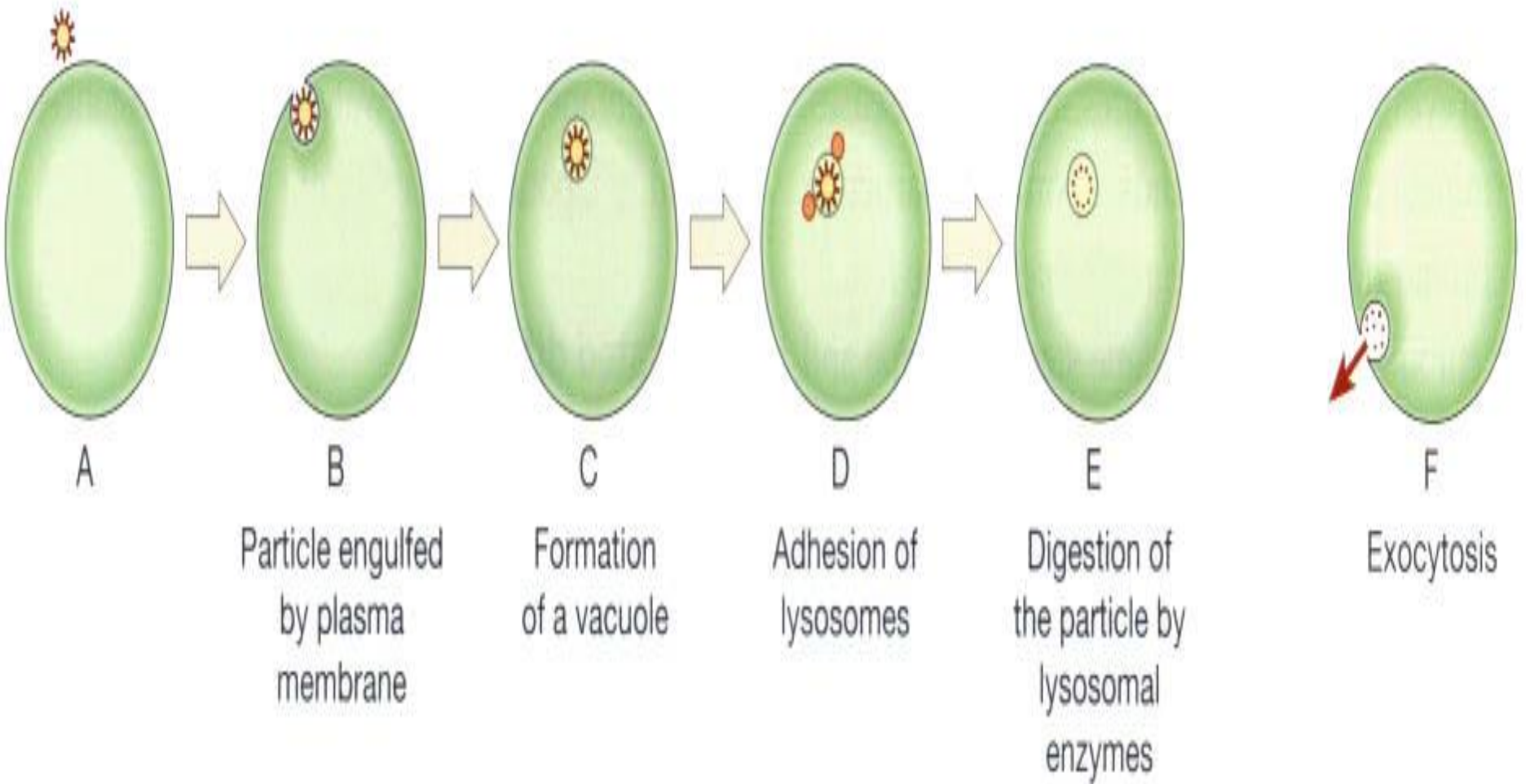
- Chemical energy in the form of ATP drives specialized protein carrier molecules that transport substances across the membrane in either direction.
- The carrier sites are specific and can be used by only one substance; thus transfer rate of substances depends on the number of sites available.

The sodium-potassium pump

- An active transport mechanism that maintains homeostasis of sodium (Na^+) & potassium (K^+) electrolytes.
- May utilize up to 30% of the ATP required for cellular metabolism.
- There is a tendency for these ions to diffuse down their concentration gradients, K^+ outwards and Na^+ into the cell.
- Homeostasis is maintained as excess Na^+ is pumped out across the cell membrane in exchange for K^+ .

Bulk transport

- Transfer of particles too large to cross cell membranes occurs by **pinocytosis or phagocytosis**. These particles are engulfed by extensions of the cytoplasm which enclose them, forming a membrane-bound vacuole.
- When the vacuole is small, **pinocytosis** occurs. In phagocytosis larger particles, e.g. cell fragments, foreign materials, microbes, are taken into the cell.
- Lysosomes then adhere to the vacuole membrane, releasing enzymes which digest the contents.
- Extrusion of waste material by the reverse process through the plasma membrane is called **exocytosis**.
- Secretory granules formed by the Golgi apparatus usually leave the cell in this way, as do any indigestible residues of phagocytosis.



Bulk transport across plasma membranes: A-E. Phagocytosis. F. Exocytosis.

TISSUES

- 4 main types, each of which has subdivisions.
- They are:
 - epithelial tissue or epithelium
 - connective tissue
 - muscle tissue
 - nervous tissue.

1. EPITHELIAL TISSUES

- Are found:
 - covering the body
 - lining cavities, hollow organs and tubes.
 - In glands.
- Functions:
 - protection of underlying structures from, for example, dehydration, chemical and mechanical damage
 - secretion
 - absorption.
- The cells are very closely packed and the intercellular substance,(the matrix) is minimal. The cells usually lie on a basement membrane, which is an inert connective tissue.
- Epithelial tissue may be:
 - *simple: a single layer of cells*
 - *stratified: several layers of cells*

A. Simple epithelium

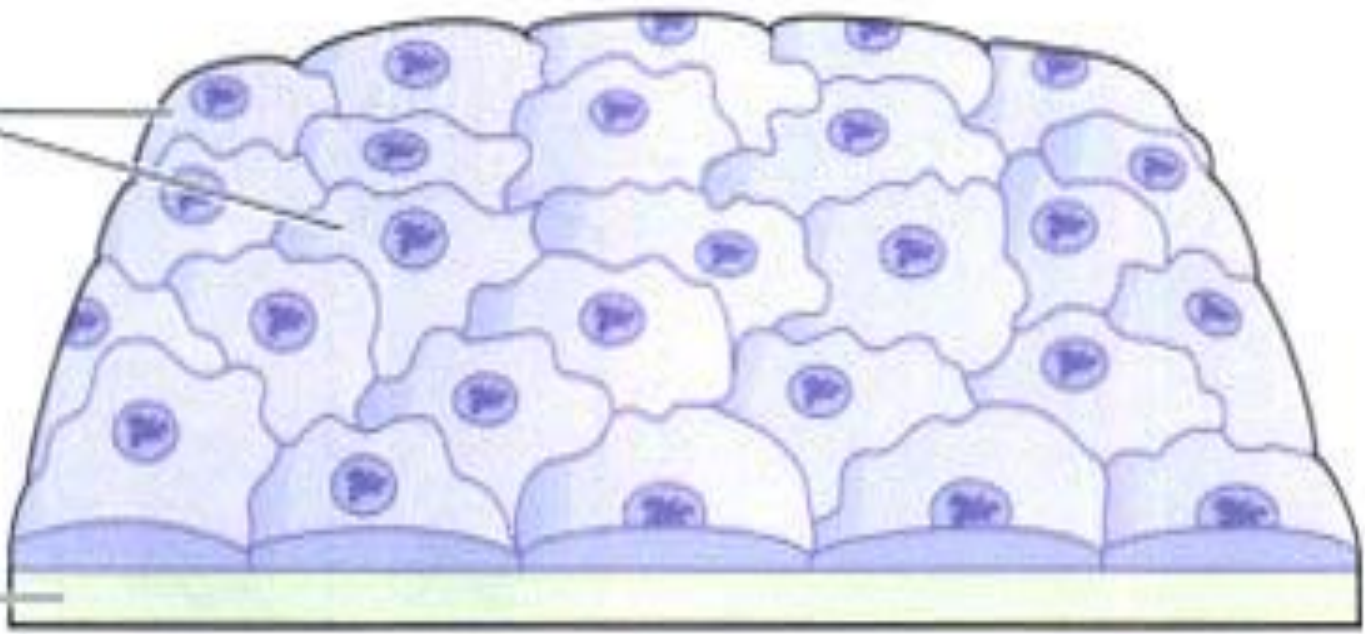
- Consists of a single layer of identical cells
- Usually found on absorptive or secretory surfaces, where the single layer enhances these processes, and not usually on surfaces subject to stress.
- Types:
 - Squamous epithelium
 - Cuboidal epithelium
 - Columnar epithelium
- The types are named according to the shape of the cells, which differs according to their functions. The more active the tissue, the taller are the cells.

a) Squamous (pavement) epithelium

- Composed of a single layer of flattened cells.
- The cells fit closely together like flat stones, forming a thin and very smooth membrane.
- Diffusion takes place freely through this thin, smooth, inactive lining of the following structures:
 - Heart (**endocardium**)
 - blood vessels **endothelium**
 - lymph vessels
 - alveoli of the lungs.
 - Lining of collecting ducts of nephrons

Squamous
epithelial cells

Basement
membrane



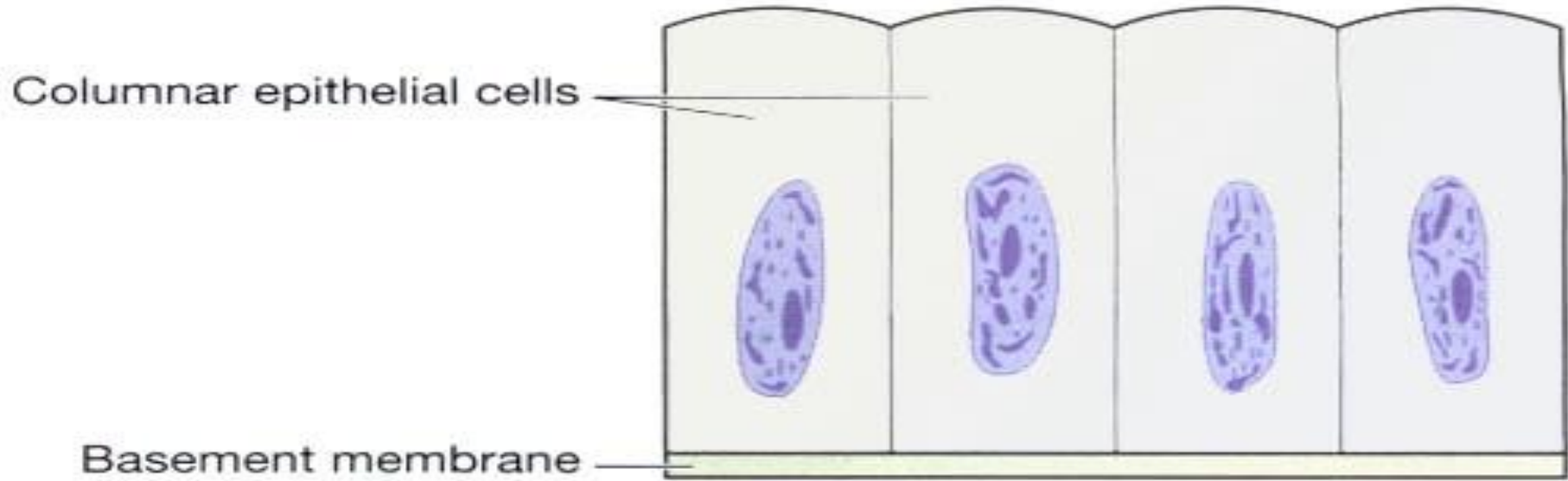
b) Cuboidal (cubical) epithelium

- Consists of cube-shaped cells fitting closely together lying on a basement membrane.
- Forms the **tubules of the kidneys** & found in some glands.
- Actively involved in secretion, absorption and excretion.

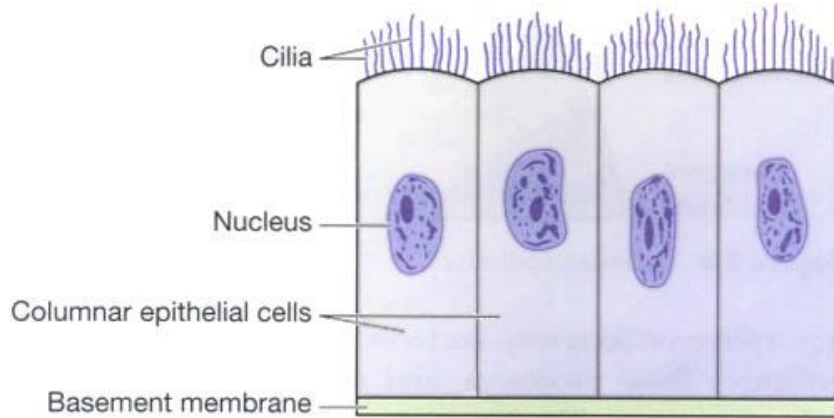
c) Columnar epithelium

- Formed by a single layer of cells, rectangular in shape, on a basement membrane.
- Found lining the many organs and often has adaptations suited to its functions e.g.:
 - **Stomach has simple columnar epithelium**
 - **Columnar epithelium in the small intestines are lined with microvillus which increases surface area for absorption.**
 - **Those in the trachea are ciliated and also have goblet cells. This produce mucus that traps dust and then the cilia removes it**

Columnar epithelium.



Ciliated columnar epithelium.



B. STRATIFIED EPITHELIA

- Consist of several layers of cells of various shapes. The superficial layers grow up from below.
- Basement membranes are usually absent.
- **Main function:** To protect underlying structures from mechanical wear and tear.
- 2 main types: **stratified squamous and transitional.**

a) Stratified squamous epithelium

- Composed of a no. of layers of cells of different shapes. In the deepest layers the cells are mainly columnar and, as they grow towards the surface, they become flattened and are then shed.

Keratinised stratified epithelium: Found on dry surfaces that are subjected to wear and tear, i.e. skin, hair and nails. Surface layer consists of dead epithelial cells to which the protein keratin has been added forming a tough, relatively waterproof protective layer that prevents drying of the underlying live cells.

Non-keratinised stratified epithelium: Found on moist surfaces that may be subjected to wear and tear but are protected from drying, e.g. the conjunctiva of the eyes, the lining of the mouth, the pharynx, the esophagus and the vagina.

b) Transitional epithelium: Composed of several layers of **pear-shaped cells** and is found lining the urinary bladder.

- Allows for stretching as the bladder fills.

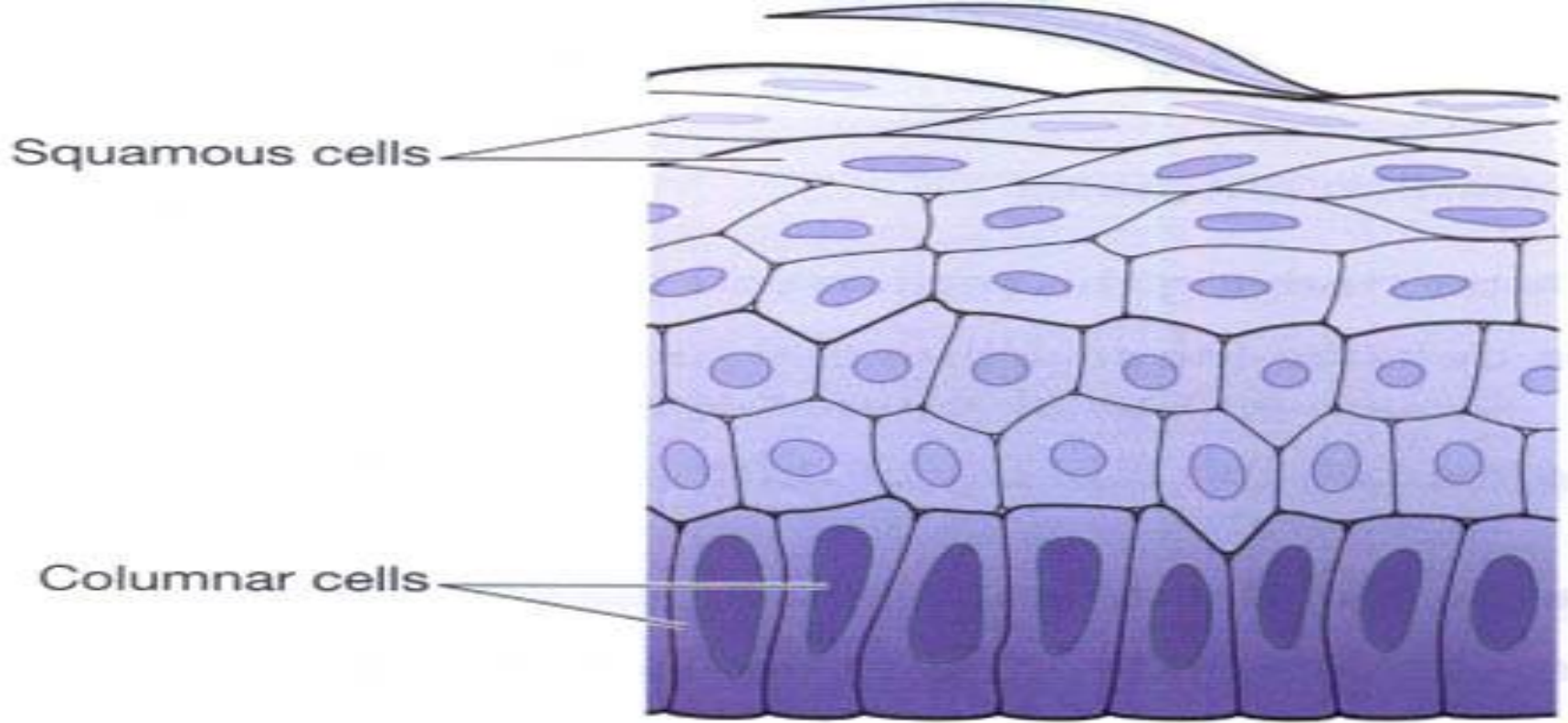
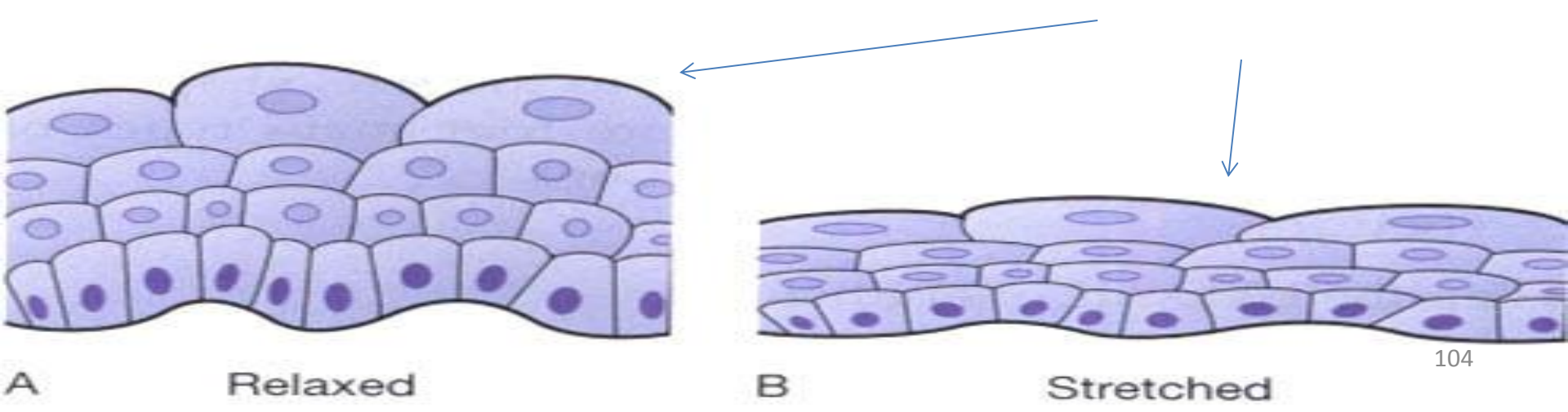


Figure 3.12 Stratified epithelium.



2. CONNECTIVE TISSUE

- Most abundant tissue in the body.
- The cells are **more widely separated** from each other than those forming the epithelium, and **intercellular substance (matrix) is present** in larger amounts.
- Fibers are usually present in the matrix, which may be of a semisolid jelly-like consistency or dense and rigid, depending upon the position and function of the tissue.
- Have a good blood supply.
- Major functions:
 - binding and structural support
 - protection
 - transport
 - insulation.

- It is the tissue that supports body structures
- It is found in every part of the body.
- It may be loosely structured, densely structured or fatty.
- The different cells that will make up this type of tissue include fibroblasts, macrophages, fat cells, leucocytes plasma cells and mast cells.
- The most densely structured connective tissue is bone and cartilage

CELLS OF CONNECTIVE TISSUE

- CT is found in all organs supporting the specialized tissue except blood.
- The different types of cell involved include:
 - Fibroblasts
 - Fat cells
 - Macrophages
 - Leukocytes
 - Plasma cells
 - Mast cells.

a) Fibroblasts.

- large flat cells with irregular processes.
- Produce collagen and elastic fibres and a matrix of extracellular material.
- Very fine collagen fibres, called **reticulin** fibres, are found in very active tissue, e.g., liver and lymphoid tissue.
- Particularly active in tissue repair (wound healing) where they may bind together the cut surfaces of wounds or form granulation tissue following tissue destruction.

b) Fat cells

- Also known as **adipocytes**
- Occur singly or in groups
- Abundant especially in adipose tissue.
- Vary in size and fat content

c) Macrophages

- Irregular-shaped cells with granules in the cytoplasm.
- Some are fixed, i.e. attached to connective tissue fibres, and others are motile.
- Important part of the body's defence mechanisms as they are actively phagocytic, engulfing and digesting cell debris, bacteria and other foreign bodies.
- Their activities are typical of those of the macrophage/monocyte defence system, e.g. **monocytes** in blood, **phagocytes** in the alveoli of the lungs, **Kupffer** cells in liver sinusoids, **fibroblasts** in lymph nodes and spleen and **microglia** cells in the brain.

d) Leukocytes

- Normally found in small numbers in healthy connective tissue but migrate in significant numbers during infection when they play an important part in tissue defence.
- Lymphocytes synthesize and secrete specific antibodies into the blood in the presence of foreign material, e.g microbes.

e) Mast cells.

- Similar to basophil leukocytes.
- Found in loose connective tissue and under the fibrous capsule of some organs, e.g. liver and spleen, and in round blood vessels.
- They produce granules containing **heparin, histamine** and other substances, which are released when the cells are damaged by disease or injury.
- Histamine
 - is involved in local and general inflammatory reactions,
 - stimulates the secretion of gastric juice
 - is associated with the development of allergies & hypersensitivity states.
- Heparin prevents coagulation of blood, which may aid the passage of protective substances from blood to affected tissues.

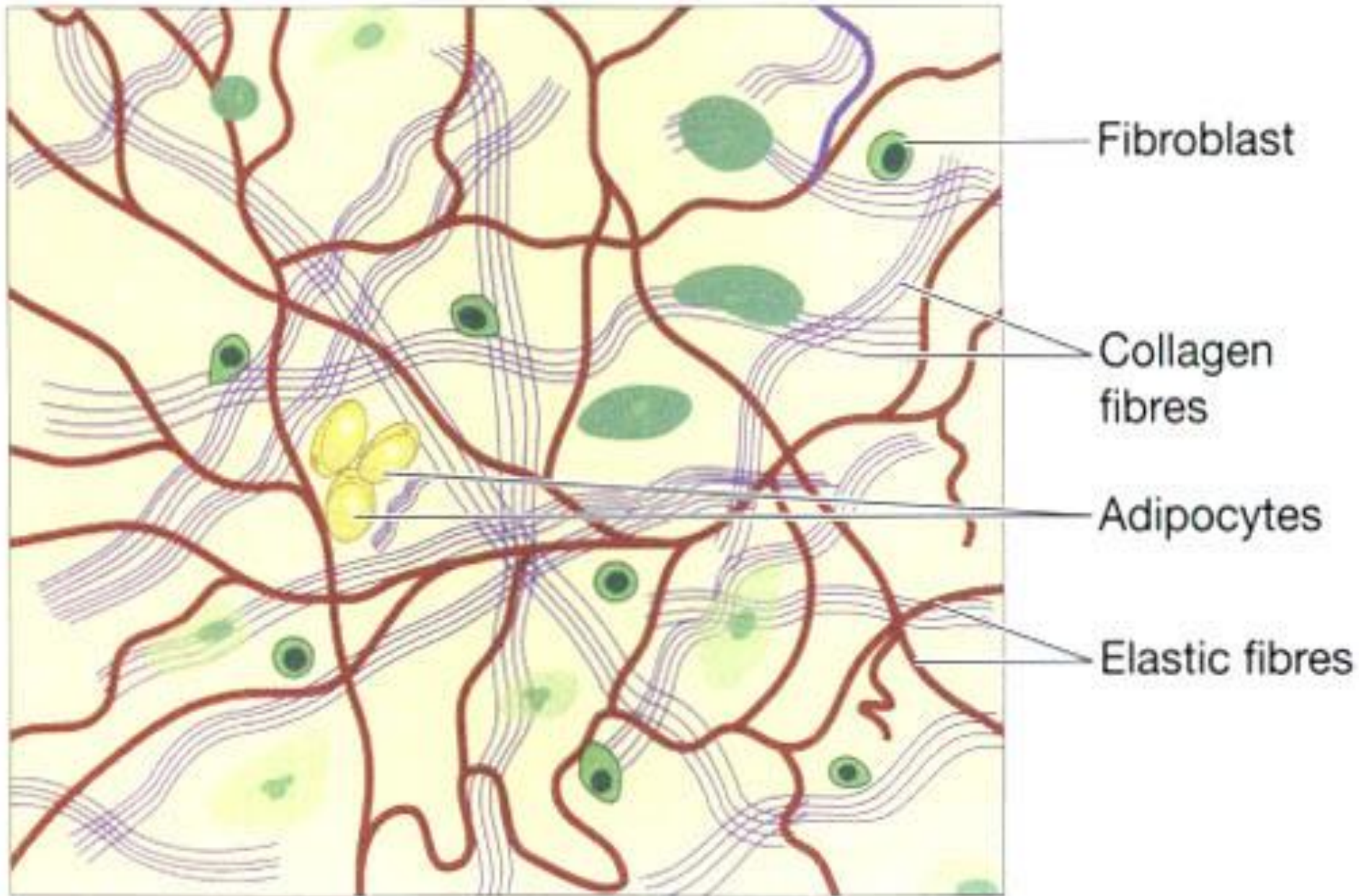
Ct....

F) Plasma cells

- Are type of w.b.c that synthesize and secrete specific defensive *antibodies*
- They develop from B-lymphocytes
- Types of Connective tissues
 - i. Loose connective tissue
 - ii. Dense connective tissue
 - iii. Adipose tissue
 - iv. Lymphoid tissue
 - v. Blood
 - vi. Cartilage
 - vii. Bone

LOOSE (AREOLAR) CONNECTIVE TISSUE

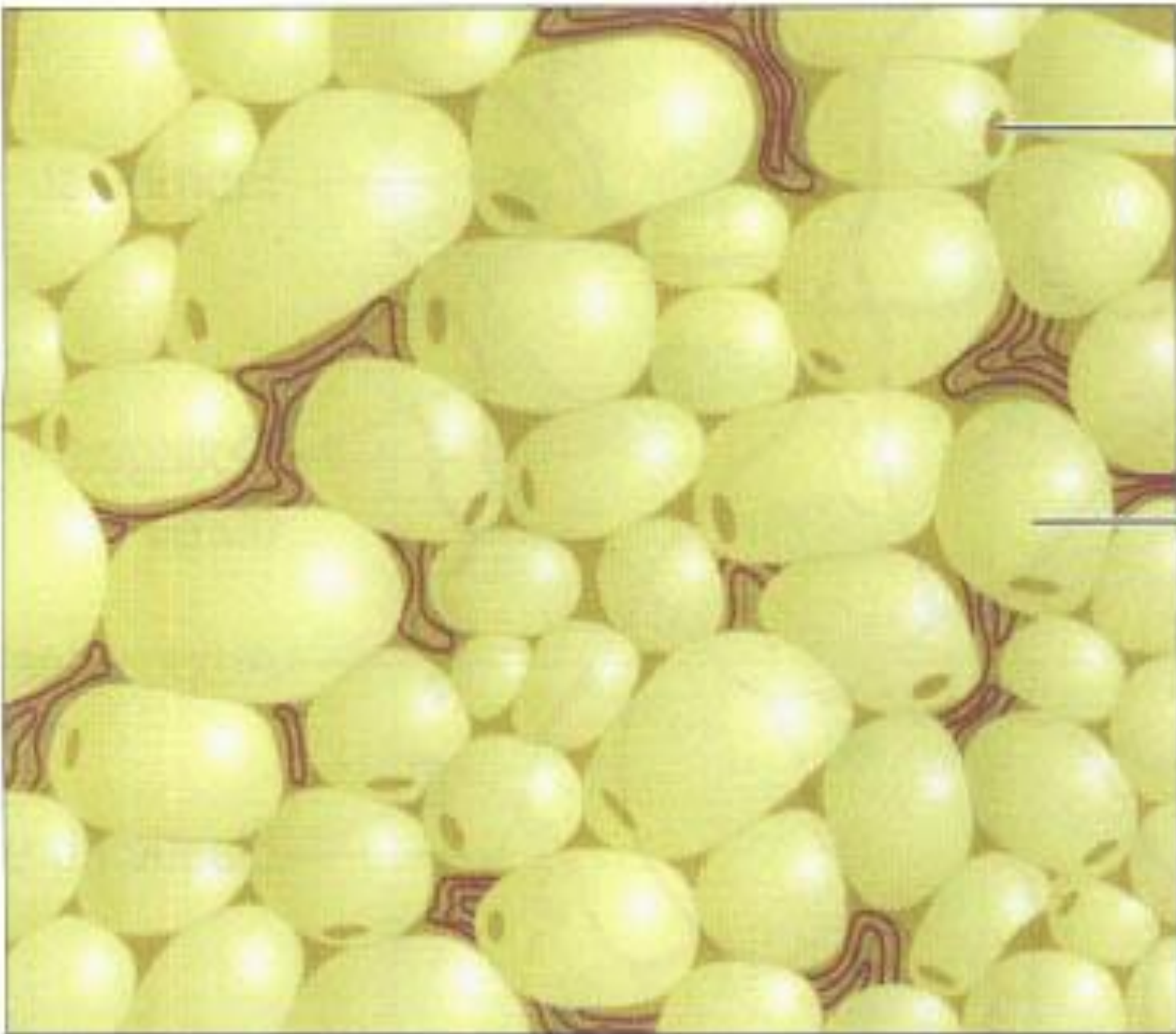
- Most generalized of all connective tissue.
- Matrix is semisolid with many **fibroblasts** and some **fat cells, mast cells** and **macrophages** widely separated by elastic and collagen fibres.
- Found in almost every part of the body providing elasticity and tensile strength.
- Connects and supports other tissues, e.g:
 - under the skin
 - between muscles
 - supporting blood vessels and nerves
 - in the alimentary canal
 - in glands supporting secretory cells.



Loose (areolar) connective tissue. ¹¹³

ADIPOSE TISSUE

- Consists of fat cells (adipocytes), containing large fat globules, in a matrix of areolar tissue.
- 2 types: **white and brown**.
- a) **White adipose tissue:** Makes up 20 to 25% of body weight in well-nourished adults.
 - Found supporting the **kidneys** and the **eyes**, between **muscle fibres** and under the **skin**, where it acts as a thermal insulator.
- b) **Brown adipose tissue:** Present in the newborn.
 - Has a more extensive capillary network than white adipose tissue.
 - When metabolised, it produces less energy and considerably more heat than other fat, contributing to the maintenance of body temperature.
 - Present in only small amounts in adults.



Nucleus

Adipocyte
(fat cell)

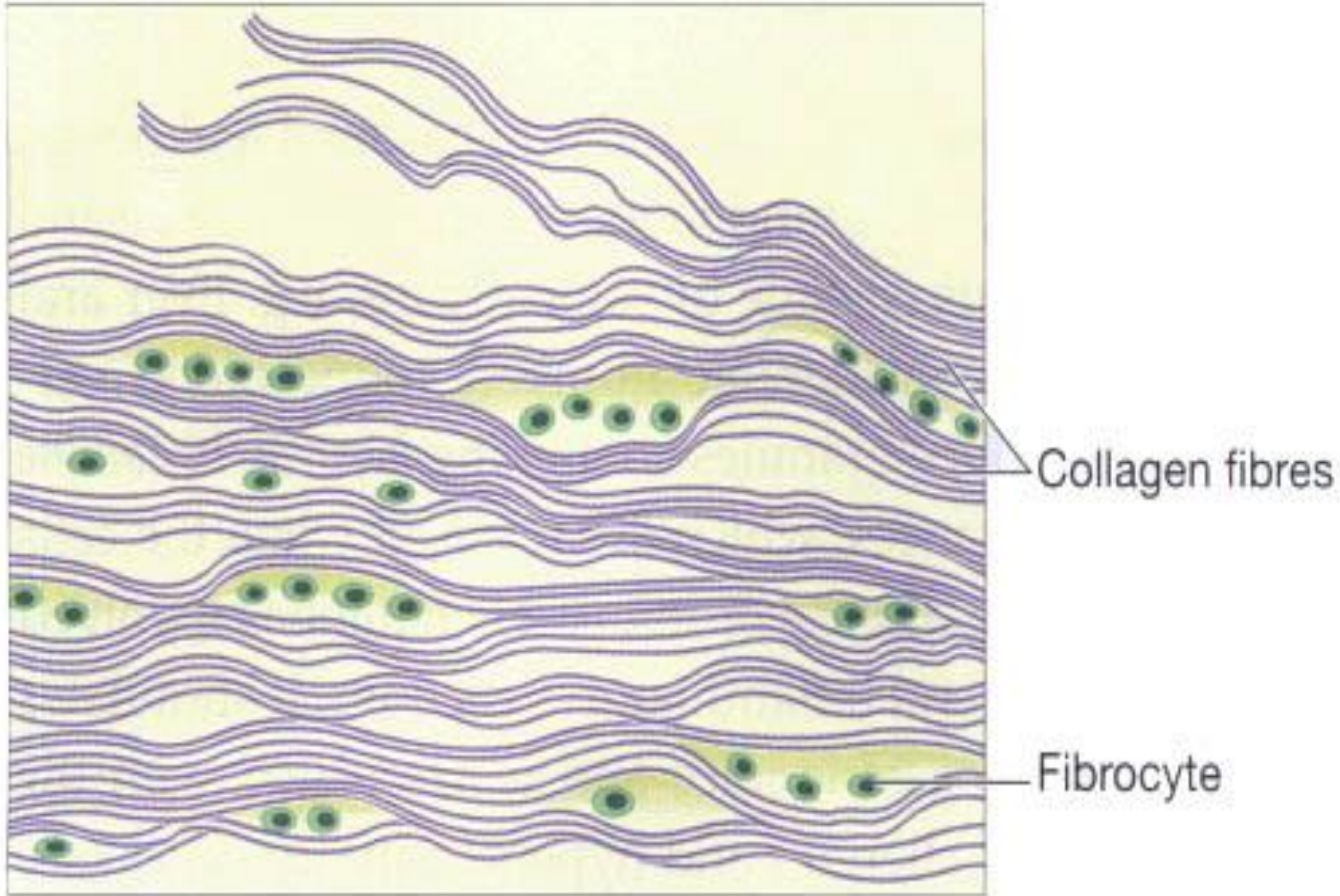
Adipose tissue

DENSE CONNECTIVE TISSUE

They contain more fibres and fewer cells than loose CT

a) Fibrous tissue

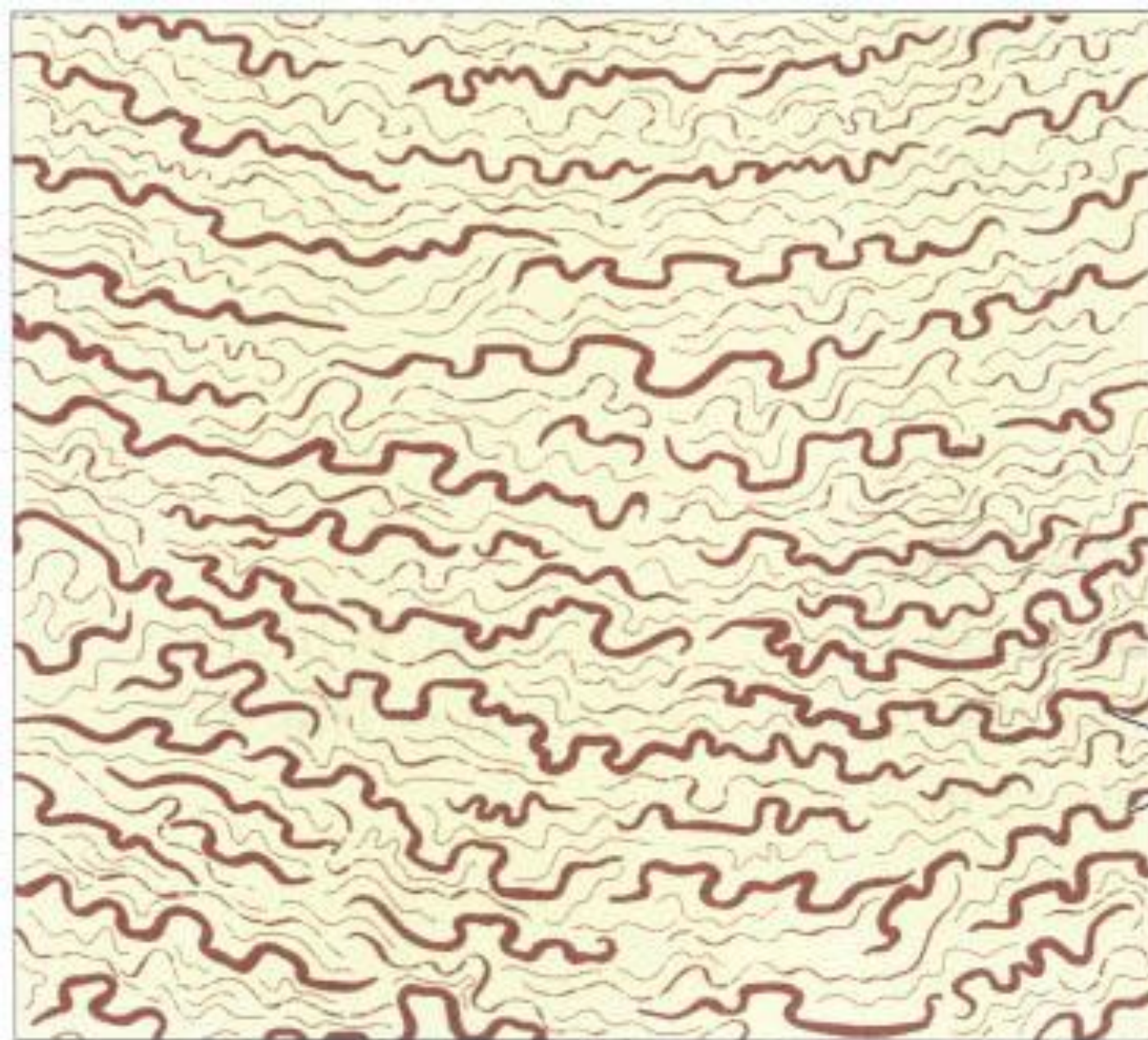
- Made up mainly of closely packed bundles of collagen fibres with very little matrix.
- Fibrocytes are few in number and are found lying in rows between the bundles of fibres.
- Found:
 - forming the ligaments, which bind bones together
 - as an outer protective covering for bone (**periosteum**)
 - As an outer protective covering of some organs, e.g. the kidneys, lymph nodes and the brain
 - forming muscle sheaths (**muscle fascia**) which extend beyond the muscle to become the tendon that attaches the muscle to bone.



Fibrous tissue

b) Elastic tissue

- Capable of considerable extension and recoil.
- Has few cells
- Matrix consists mainly of masses of elastic fibres secreted by fibroblasts.
- Found in organs where alteration of shape is required, e.g. in large blood vessel walls, the epiglottis, the trachea and bronchi and the lungs.

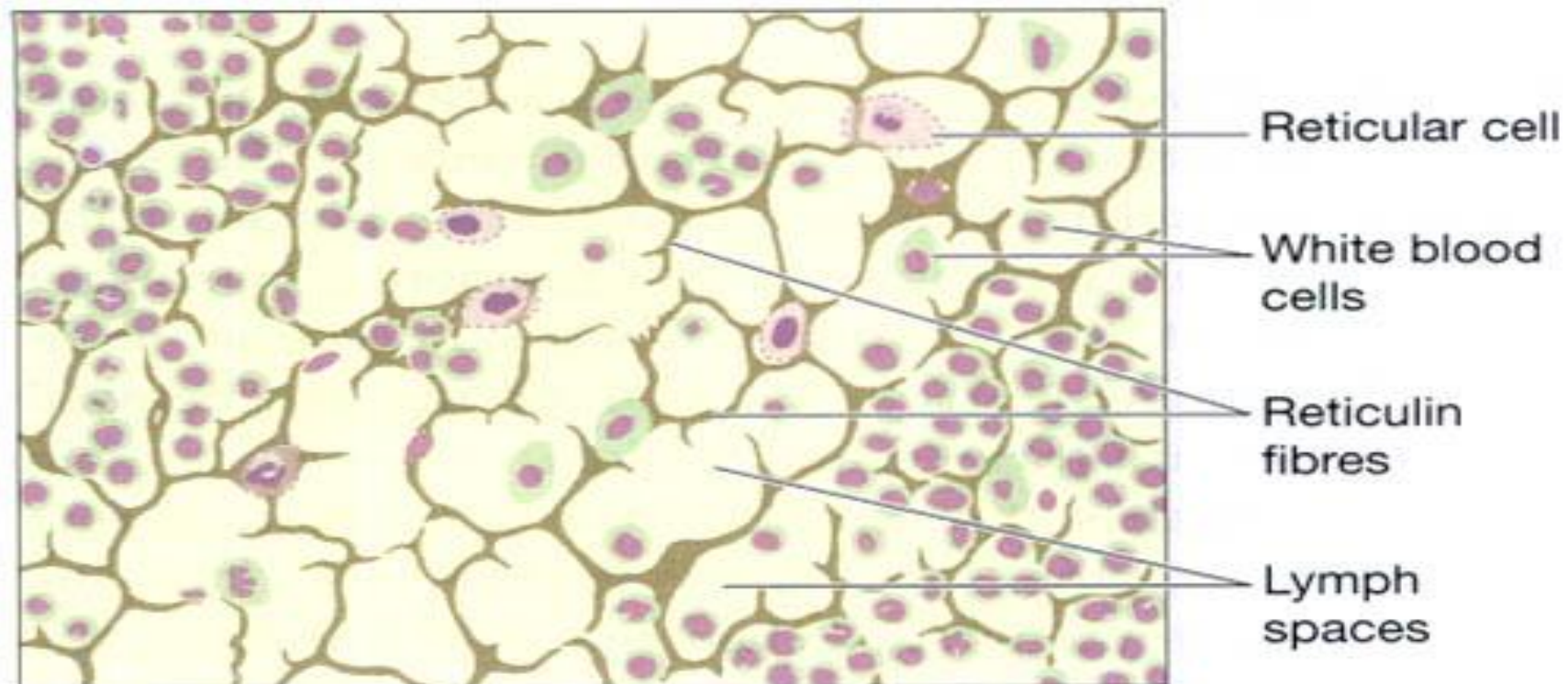


Elastic fibres

Elastic tissue

LYMPHOID TISSUE

- A.k.a reticular tissue
- Has a semisolid matrix with fine branching reticulin fibres.
- Contains reticular cells and WBCs (**monocytes and lymphocytes**)

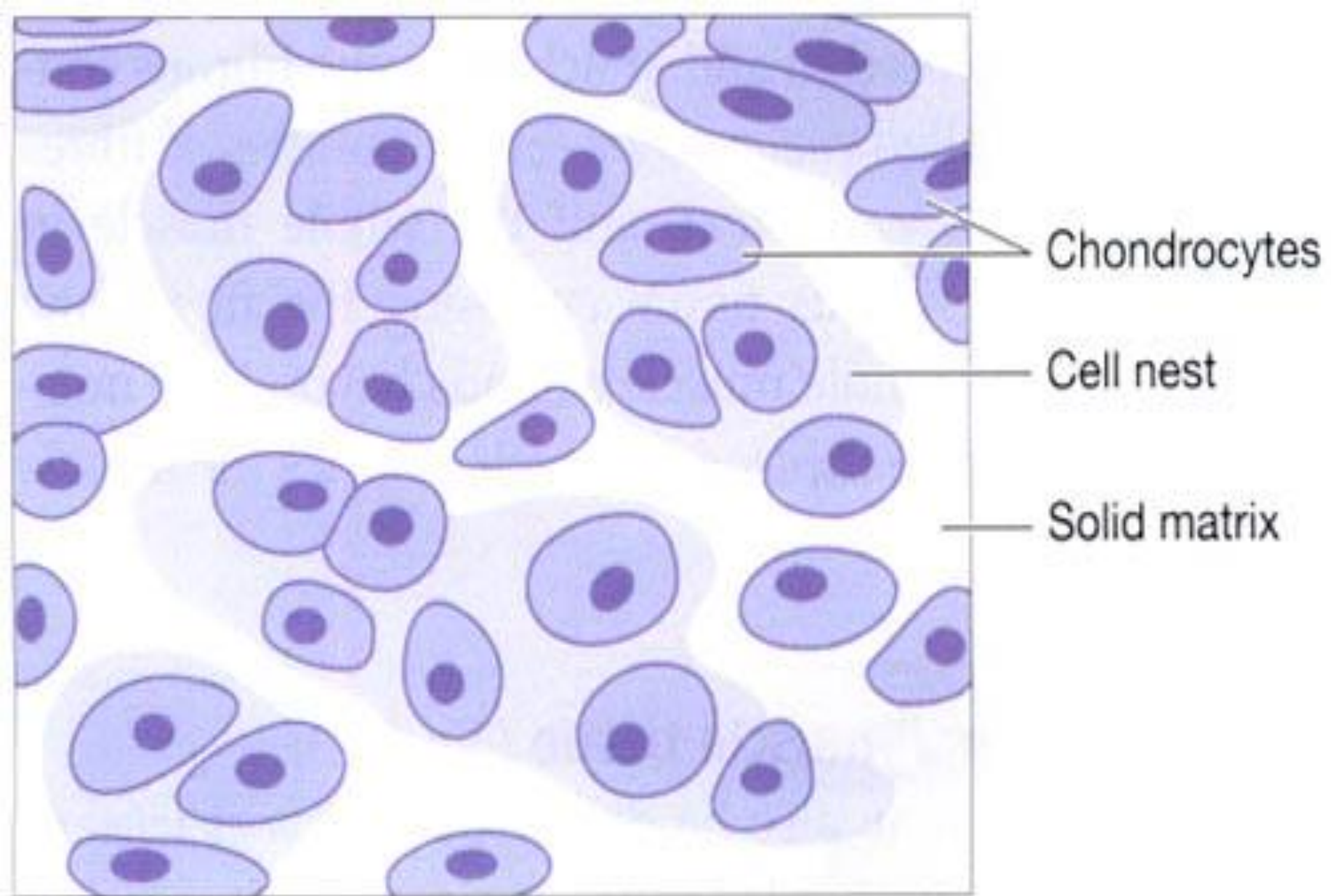


CARTILAGE

- Much firmer tissue than any of the other connective tissues; the cells are called **chondrocytes** and are less numerous. They are embedded in matrix reinforced by collagen and elastic fibres.
- 3 types:
 - hyaline cartilage
 - fibrocartilage
 - elastic fibrocartilage.

a) Hyaline cartilage

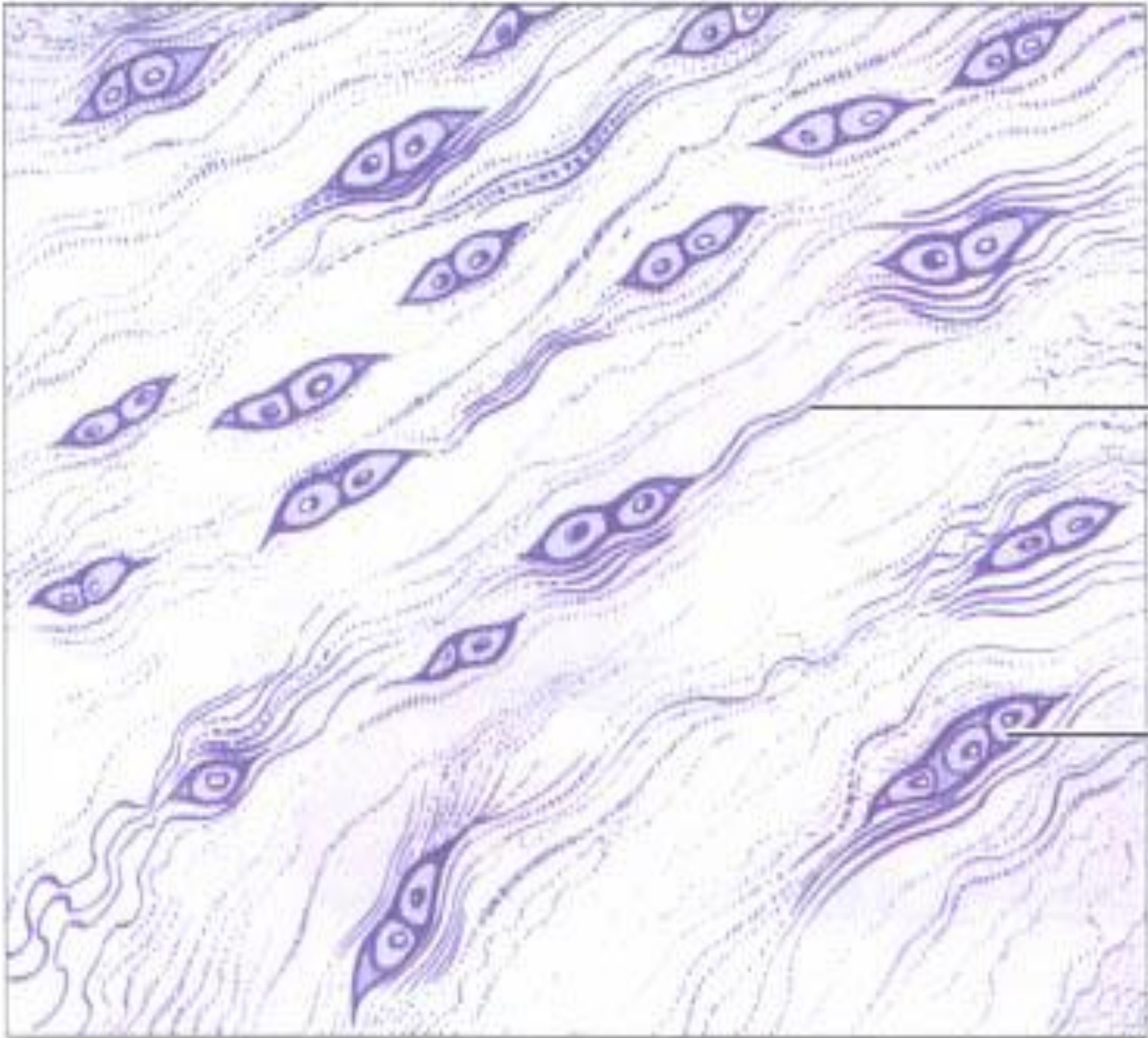
- Appears as a smooth bluish-white tissue.
- Chondrocytes are in small groups within cell nests and the matrix is solid and smooth.
- Found:
 - on the ends of long bones that form joints
 - forming the costal cartilages, which attach the ribs to the sternum
 - forming part of the larynx, trachea and bronchi.



Hyaline cartilage

b) Fibrocartilage

- Consists of dense masses of white collagen fibres in a matrix similar to that of hyaline cartilage with the cells widely dispersed.
- It's a tough, slightly flexible, supporting tissue found:
 - as pads between the bodies of the vertebrae, called the **intervertebral discs**
 - between the articulating surfaces of the bones of the knee joint, called **semilunar cartilages**
 - on the rim of the bony **sockets** of the hip and shoulder joints, deepening the cavities without restricting movement
 - as **ligaments** joining bones.



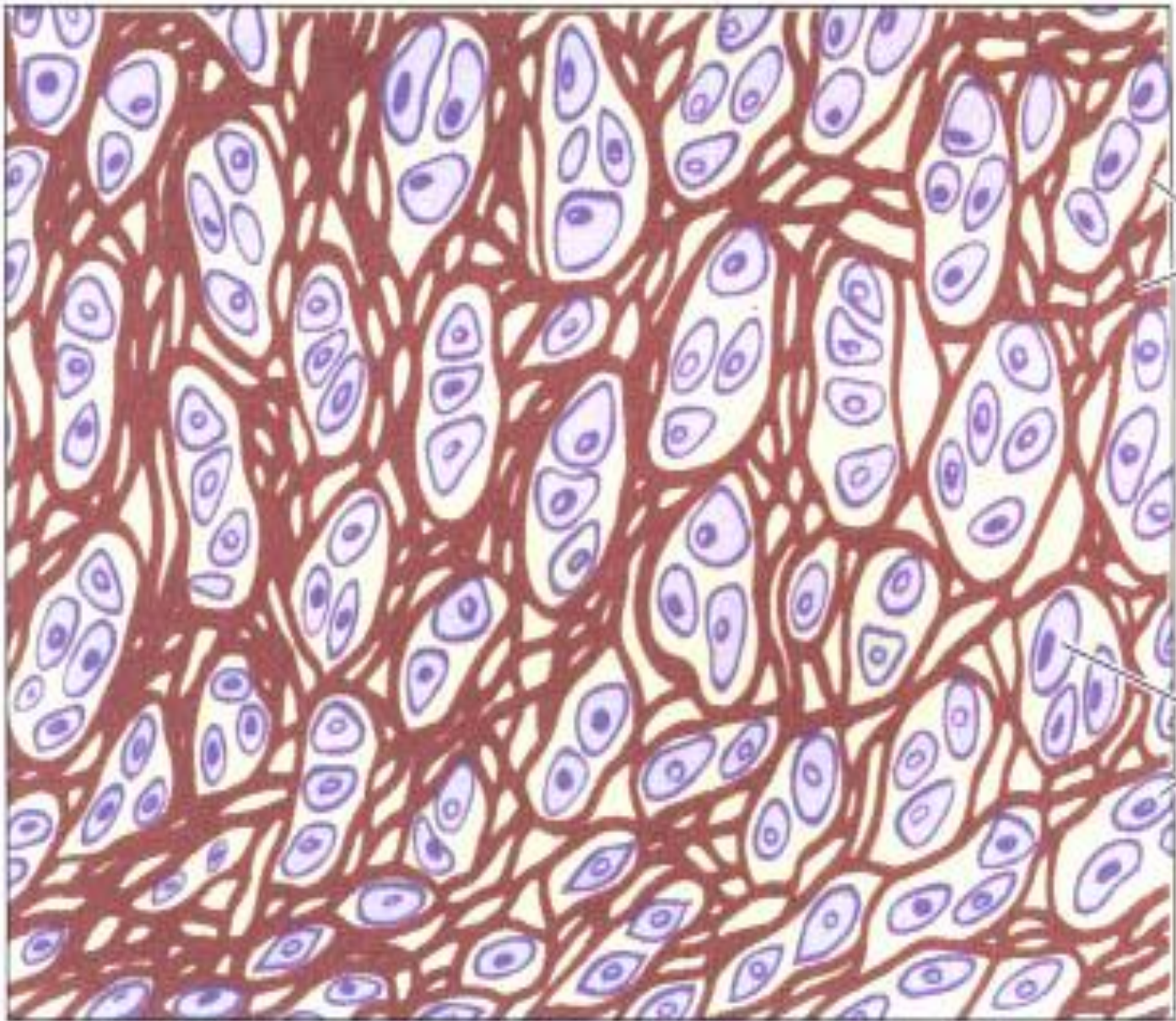
Collagen fibre

Chondrocyte

Fibrocartilage

c) Elastic cartilage

- Flexible tissue consisting of yellow elastic fibres lying in a solid matrix.
- Cells (chondrocytes) lie between the fibres.
- Forms:-
 - the pinna or lobe of the ear,
 - the epiglottis
 - part of the tunica media of blood vessel walls.



Elastic fibres

Chondrocytes

Elastic fibrocartilage

BONE

- Connective tissue with cells (osteocytes) surrounded by a matrix of collagen fibres that is strengthened by inorganic salts, especially calcium and phosphate. This provides bones with their characteristic strength and rigidity.
- 2 types:
 - **compact bone** — solid or dense appearance
 - **cancellous or spongy bone** — spongy or fine honeycomb appearance.

3. MUSCLE TISSUE

- Is a tissue with the capability to contract and relax thus providing movements.
- 3 types, consisting of specialized contractile cells:
 - skeletal muscle
 - smooth muscle
 - cardiac muscle.

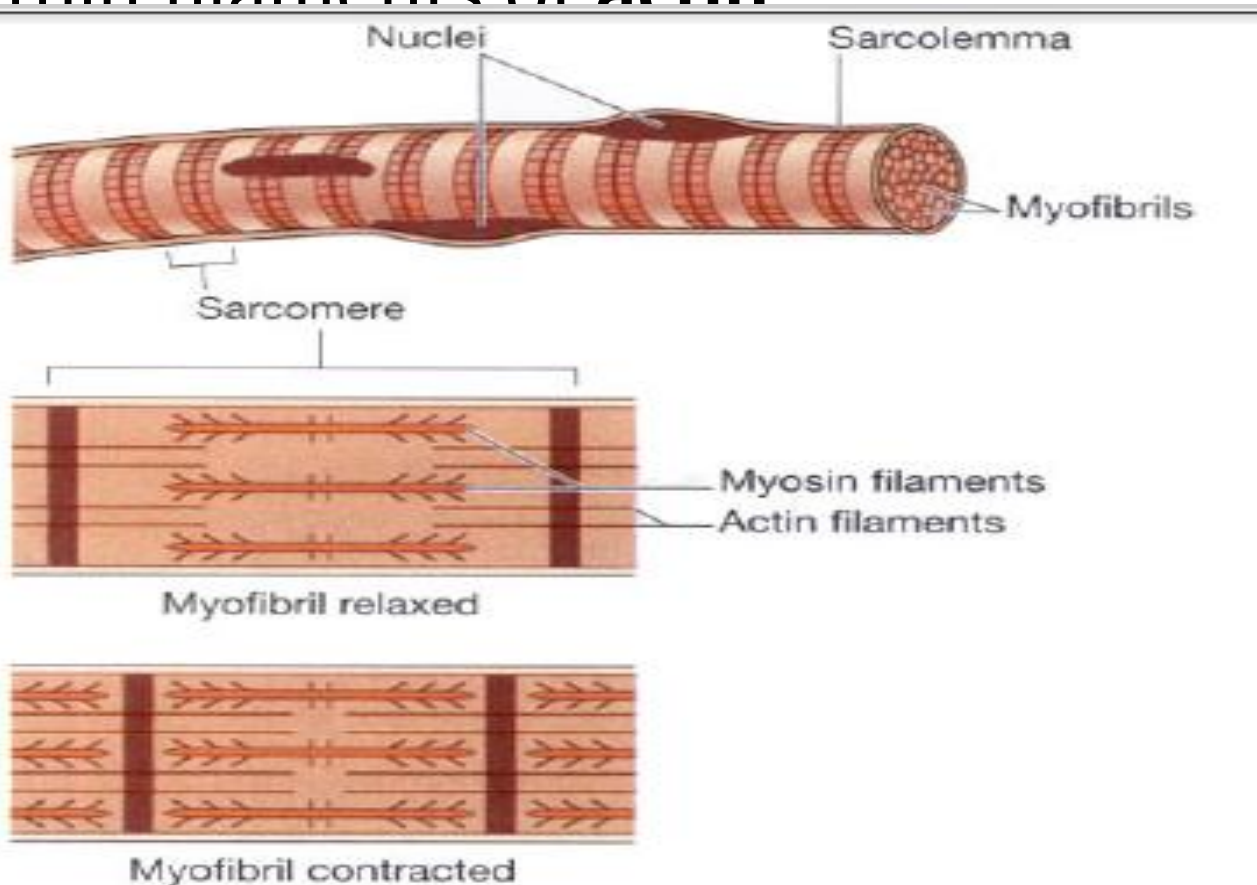
a) Skeletal muscle tissue

- Described as **skeletal, striated(striped)** or voluntary muscle.
- Called voluntary because contraction is under conscious control.
- Cells are cylindrical in shape and may be as long as 35 cm.
- Each cell, commonly called a **fibre**, has several nuclei situated just under the **sarcolemma** or cell membrane of each muscle fibre.
- Muscle fibres lie parallel to one another and microscopically, they show well-marked transverse dark and light bands, hence the name **striated** or **striped** muscle.

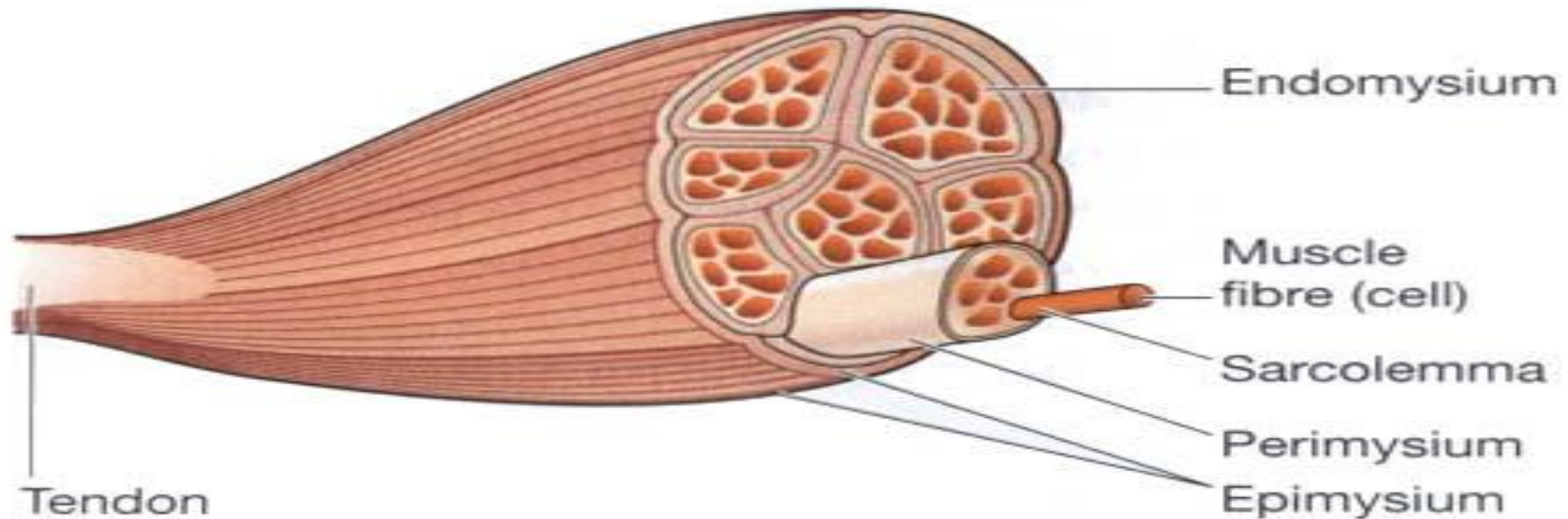
- Makes up the red part of flesh.
- Capable of stretching and contracting.
- **Sarcoplasm**, the cytoplasm of muscle fibres, contains:
 - i. bundles of **myofibrils**, which consist of filaments of contractile proteins including actin and myosin
 - ii. many **mitochondria**, which generate chemical energy (ATP) from glucose and oxygen by aerobic respiration
 - iii. **glycogen**, a carbohydrate store which is broken down into glucose when required
 - iv. **myoglobin**, a unique oxygen-binding protein molecule, similar to haemoglobin in red blood cells, which stores oxygen within muscle cells.

A myofibril has a repeating series of dark and light bands, consisting of units called **sarcomeres**.

- A sarcomere represents the smallest functional unit of a skeletal muscle fibre and consists of:
 - **thin filaments of actin**

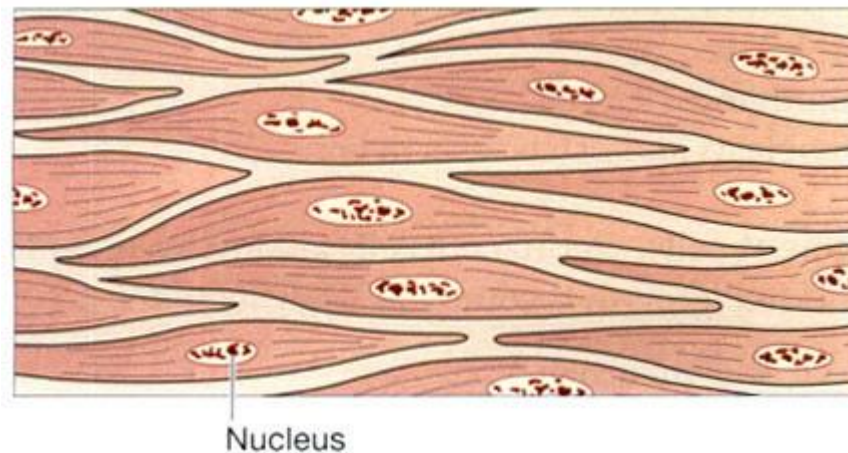


- A muscle consists of a large number of muscle fibres.
- In addition to the sarcolemma, each fibre is enclosed in and attached to fine fibrous connective tissue called **endomysium**.
- Small bundles of fibres are enclosed in **perimysium**, and the whole muscle in **epimysium**.

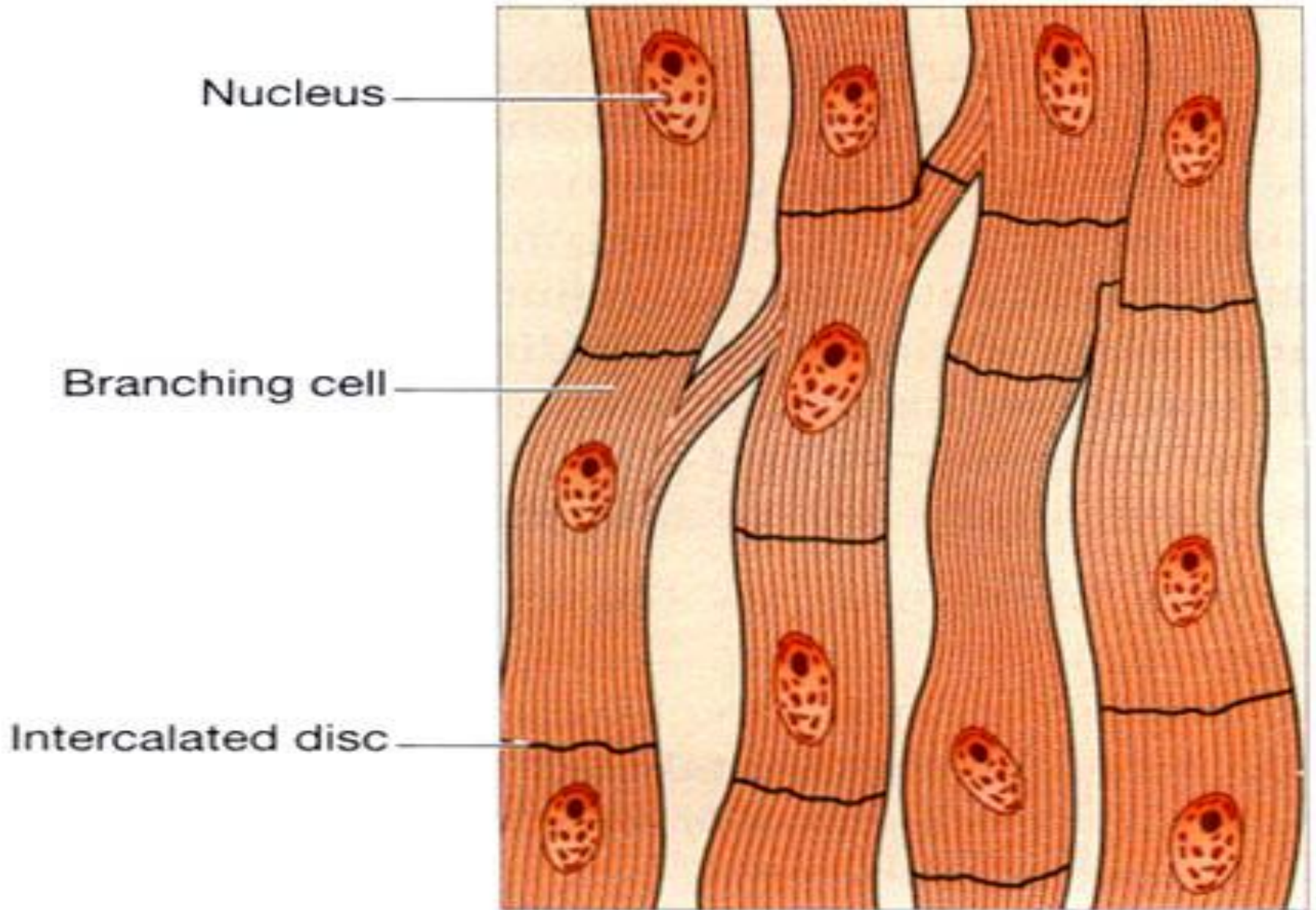


- **b) Smooth (Visceral) Muscle Tissue**
- Described as **non-striated, visceral or involuntary**.
- Not under **conscious control** and **has no striations**
- Found in the walls of hollow organs:
 - i. regulating the diameter of blood vessels and parts of the respiratory tract
 - ii. propelling contents of the ureters, ducts of glands and alimentary tract
 - iii. expelling contents of the urinary bladder and ureter
- Microscopically, the cells are spindle shaped with only one central nucleus.
- No distinct sarcolemma but a very fine membrane surrounds each fibre.
- Bundles of fibres form sheets of muscle.

It also has intrinsic capability to contract and relax. This is further controlled autonomic nervous impulses, hormones and some metabolic substances



- **c) Cardiac Muscle Tissue**
- Found exclusively in the wall of the heart.
- **Not under conscious control** but microscopically, cross-stripes characteristic of voluntary muscle can be seen. Each fibre (cell) has a nucleus and one or more branches.
- The ends of the cells and their branches are in very close contact with the ends and branches of adjacent cells. Microscopically these '**joints**', or **intercalated discs**, can be seen as lines which are thicker and darker than the ordinary cross-stripes.
- The end-to-end continuity of cardiac muscle cells has significance in relation to the way the heart contracts.
- A wave of contraction spreads from cell to cell across the intercalated discs which means that cells do not need to be stimulated individually.



Cardiac muscle fibers

NOTE:

- Muscle functions by alternate phases of contraction and relaxation thus producing movement of body parts or the body itself.
- Skeletal muscle fibres are stimulated by motor nerve impulses originating in the brain or spinal cord and ending at the neuromuscular junction.
- Smooth and cardiac muscle have the intrinsic ability to initiate contraction.
- The strength of contraction, e.g. lifting a weight, depends on the number of fibres contracting at the same time.
- Contraction of smooth muscle is slower and more sustained than skeletal muscle.
- In order to contract when it is stimulated, a muscle fibre must have an **adequate blood supply to provide sufficient oxygen**, calcium and nutritional materials and to remove waste products.

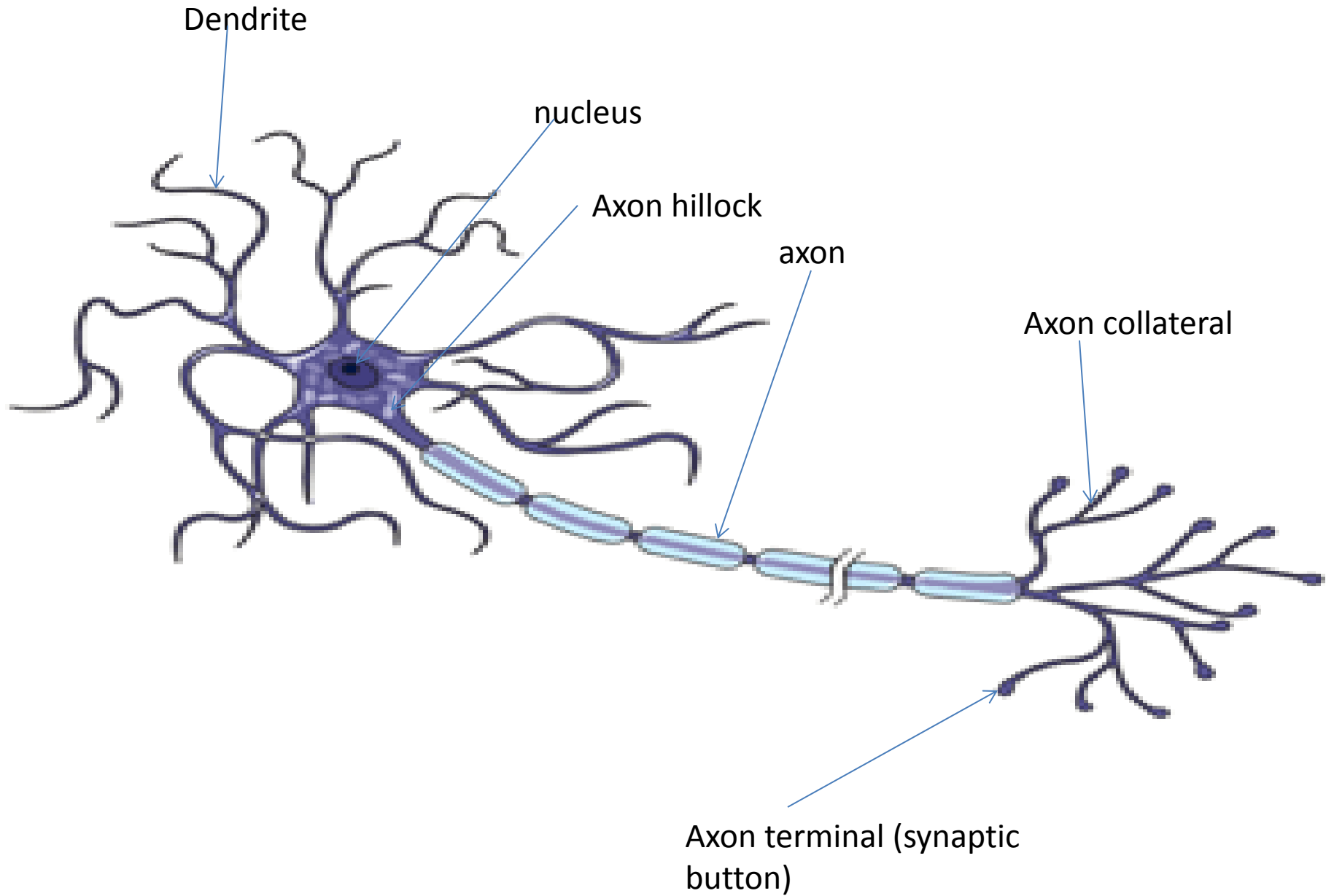
- Skeletal muscle tone (state of partial contraction) is essential for maintenance of posture in the sitting and standing positions. The muscle is stimulated to contract through a system of spinal reflexes.
- **Muscle fatigue:** occurs if a muscle is stimulated to contract at very frequent intervals; its response gradually becomes depressed and will in time cease.
- The chemical energy (ATP) which muscles require is usually derived from the breakdown (catabolism) of carbohydrate and fat.
- If an individual undertakes excessive exercise, the oxygen supply may be insufficient to meet the metabolic needs of the muscle fibres resulting in the accumulation of intermediate metabolic products, such as **lactic acid**.
- Where the breakdown process and the release of energy are complete, the waste products are **carbon dioxide and water**.

- Each skeletal muscle consists of a **fleshy part** made up of striped fibres and **tendinous parts** consisting of fibrous tissue, usually at both ends of the fleshy part.
- The muscle is attached to bone or skin by these tendons.
- When the tendinous attachment of a muscle is broad and flat it is called an **aponeurosis**.
- To be able to produce movement at a joint, a muscle or its tendon must stretch across the joint.
- The muscles of the skeleton are arranged in groups, some of which are **antagonistic to each other**.
- To produce movement at a joint, one muscle or group of muscles contracts while the antagonists relax; e.g. to bend the knee the muscles on the back of the thigh contract and those on the front relax.

NERVOUS TISSUE

- 2 types of tissue:
 - Excitable cells** — called **neurones**; they initiate, receive, conduct and transmit information.
 - Non-excitable cells (glial cells)**— support the neurones.

NB: TO BE DISCUSSED IN LATER SESSIONS



A neuron

TISSUE REGENERATION

- Extent of regeneration depends on the normal rate of physiological turnover of particular types of cell. Those with a rapid turnover regenerate most effectively.
- 3 categories:
 - a) Labile cells:** Cells in which replication is normally a continuous process.
 - Include cells in:
 - epithelium of e.g. skin, mucous membrane, secretory glands, ducts, uterus lining
 - bone marrow
 - blood
 - spleen and lymphoid tissue.

b) Stable cells: Cells that have retained the ability to replicate but do so infrequently.

- Include:
 - liver, kidney and pancreatic cells
 - fibroblasts
 - smooth muscle cells
 - osteoblasts and osteoclasts in bone.

c) Permanent cells: Cells that are unable to replicate after normal growth is complete.

- Include:
 - nerve cells (neurons)
 - skeletal and cardiac muscle.

MEMBRANES

- **Def:** sheets of epithelial tissue and their supporting connective tissue that cover or line internal structures or cavities.
- Main membranes are:
 - i. Mucous
 - ii. Serous
 - iii. Synovial
 - iv. Cutaneous

a) Mucous membrane

- Moist lining of the alimentary, respiratory and genitourinary tracts; known as the **mucosa**.
- Consists of epithelial cells, some of which produce a secretion called **mucus, a slimy tenacious fluid**.
- As the cells fill up with mucus they have the appearance of a goblet or flask and are known as **goblet cells**. The mucus is then released to the surface when the cell bursts
- Organs lined by mucous membrane have a moist slippery surface.
- Mucus protects the lining membrane **from drying**, and **mechanical and chemical injury**. In the respiratory tract it **traps inhaled foreign particles**, preventing them from entering the alveoli of the lungs.

b) Serous membrane

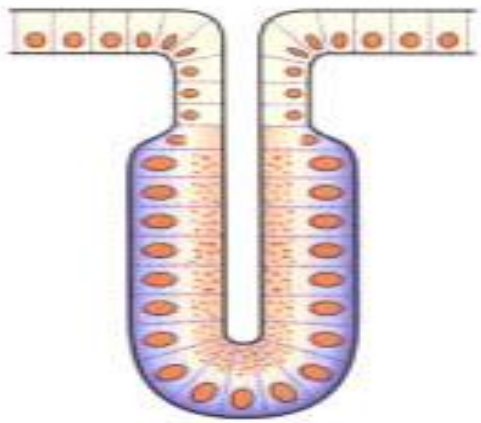
- Also called serosa; **secrete serous watery fluid.**
- Consist of a double layer of loose areolar connective tissue lined by simple squamous epithelium.
- The **parietal** layer lines a **cavity** and the **visceral** layer surrounds **organs within the cavity.**
- The 2 layers are separated by **serous fluid** secreted by the epithelium.
- Found lining cavities and organs i.e. sites like
 - i. **The pleura;** lining the thoracic cavity and surrounding the lungs
 - ii. **The pericardium;** lining the pericardial cavity and surrounding the heart
 - iii. **The peritoneum;** lining the abdominal cavity and surrounding abdominal organs.
- The **serous fluid** between the visceral and parietal layers enables an organ to **glide freely within the cavity without being damaged by friction between it and adjacent organs.**

c) Synovial membrane

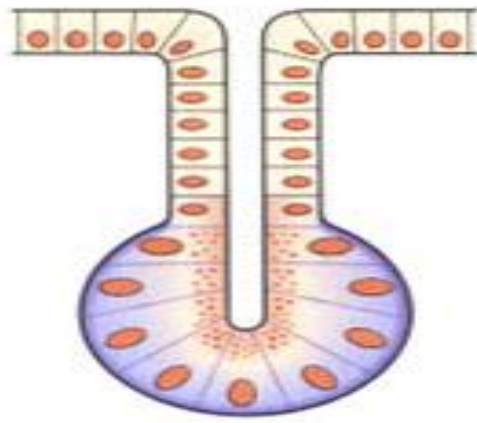
- Found lining the joint cavities and surrounding tendons, which could be injured by rubbing against bones, e.g. over the wrist joint.
- Made up of a layer of fine, flattened epithelial cells on a layer of delicate connective tissue (areolar CT and elastic fibres).
- Secretes clear, sticky, oily ***synovial fluid***, which acts as a **lubricant to the joints** and **helps to maintain their stability**.

GLANDS

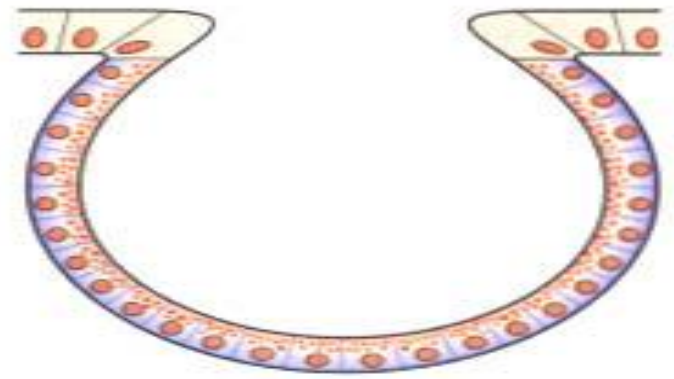
- **Def:** groups of epithelial cells which produce specialized secretions.
- **Types**
- **Exocrine glands:** glands that discharge their secretion on to the epithelial surface of an organ, either directly or through a duct. Vary in size, shape and complexity. Secrete *mucus, saliva, digestive juices* and *earwax*.
- **Endocrine (ductless) glands:** glands that discharge their secretions into blood and lymph; secrete hormones.



Tubular

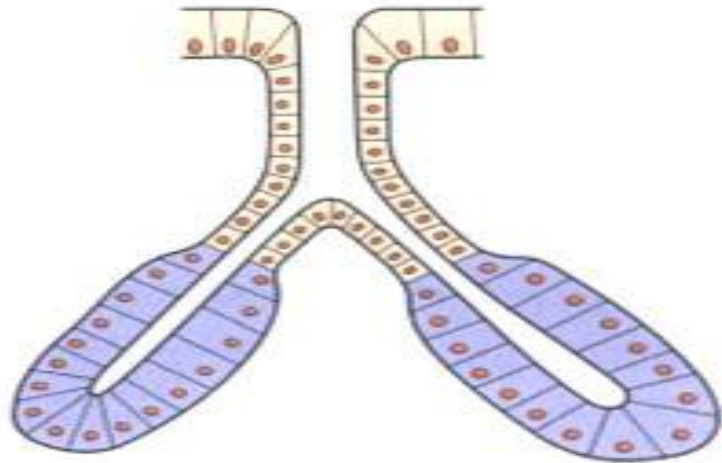


Alveolar (acinar)

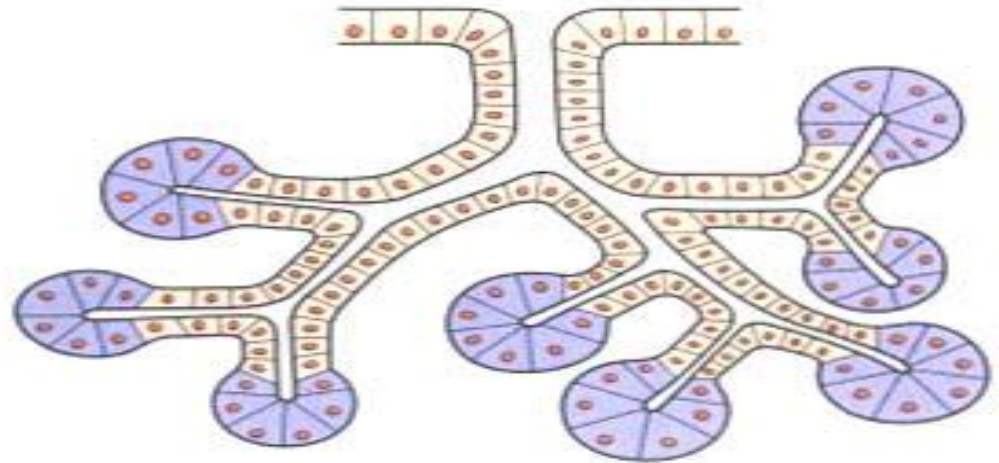


Saccular

A



Branched tubular



Branched alveolar (acinar)

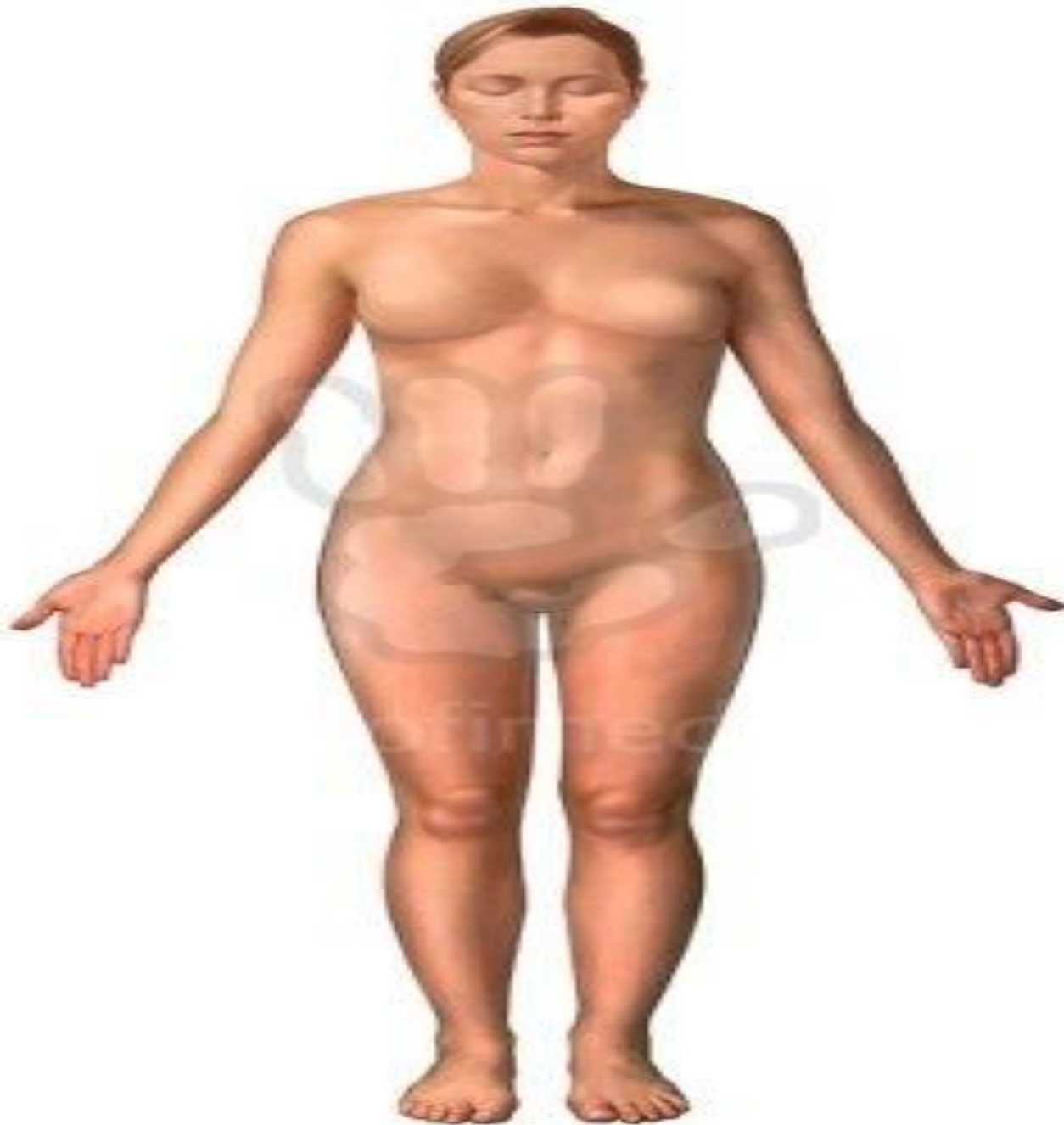
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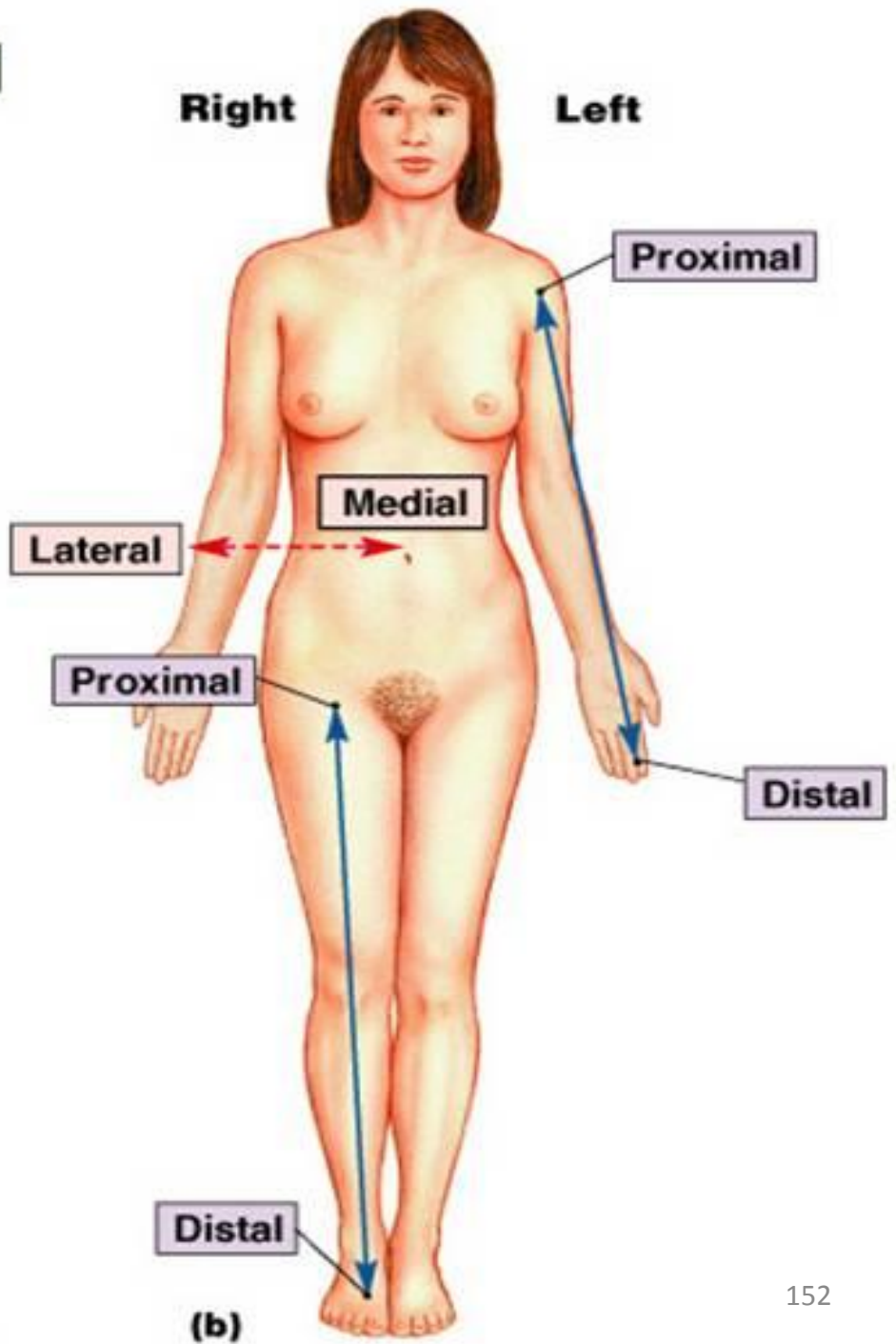
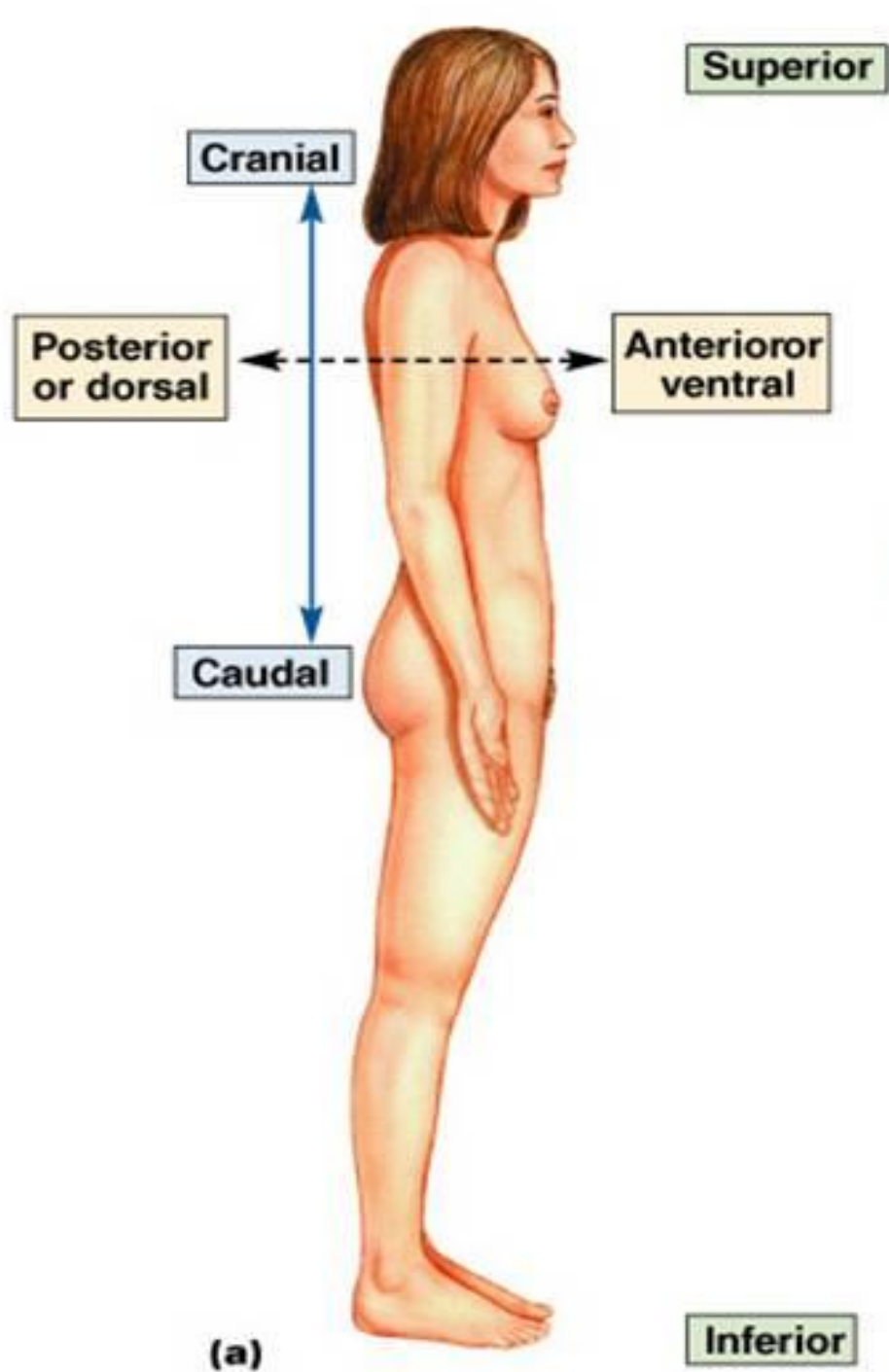
ORGANISATION OF THE BODY

ANATOMICAL TERMS

- **Anatomical position:** The body is in the upright position with the head facing forward, the arms at the sides with the palms of the hands facing forward and the feet together.
- **Anatomical Plane** - An imaginary surface formed by extension through any axis of the body or through two definite points on the body.

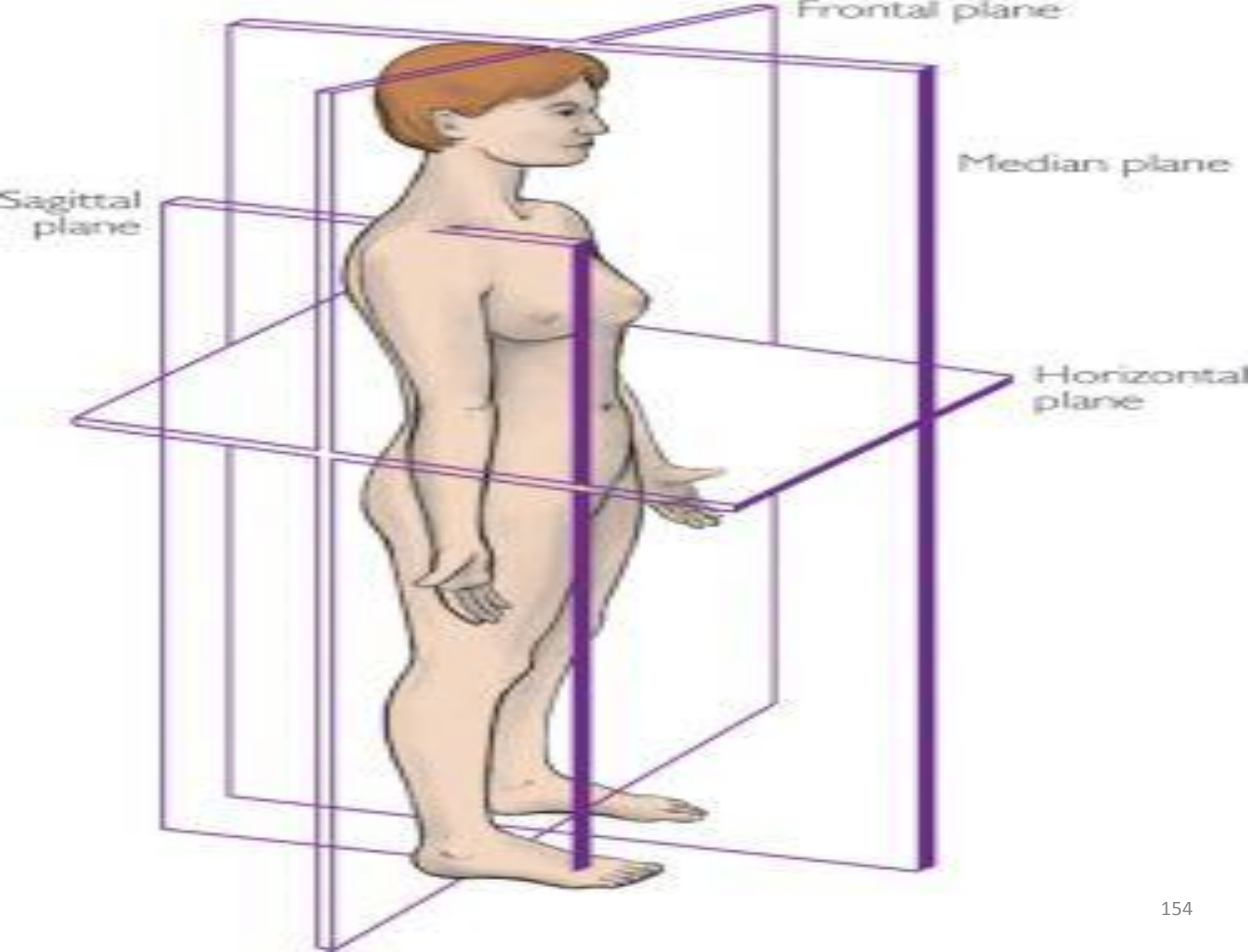
Anatomical position

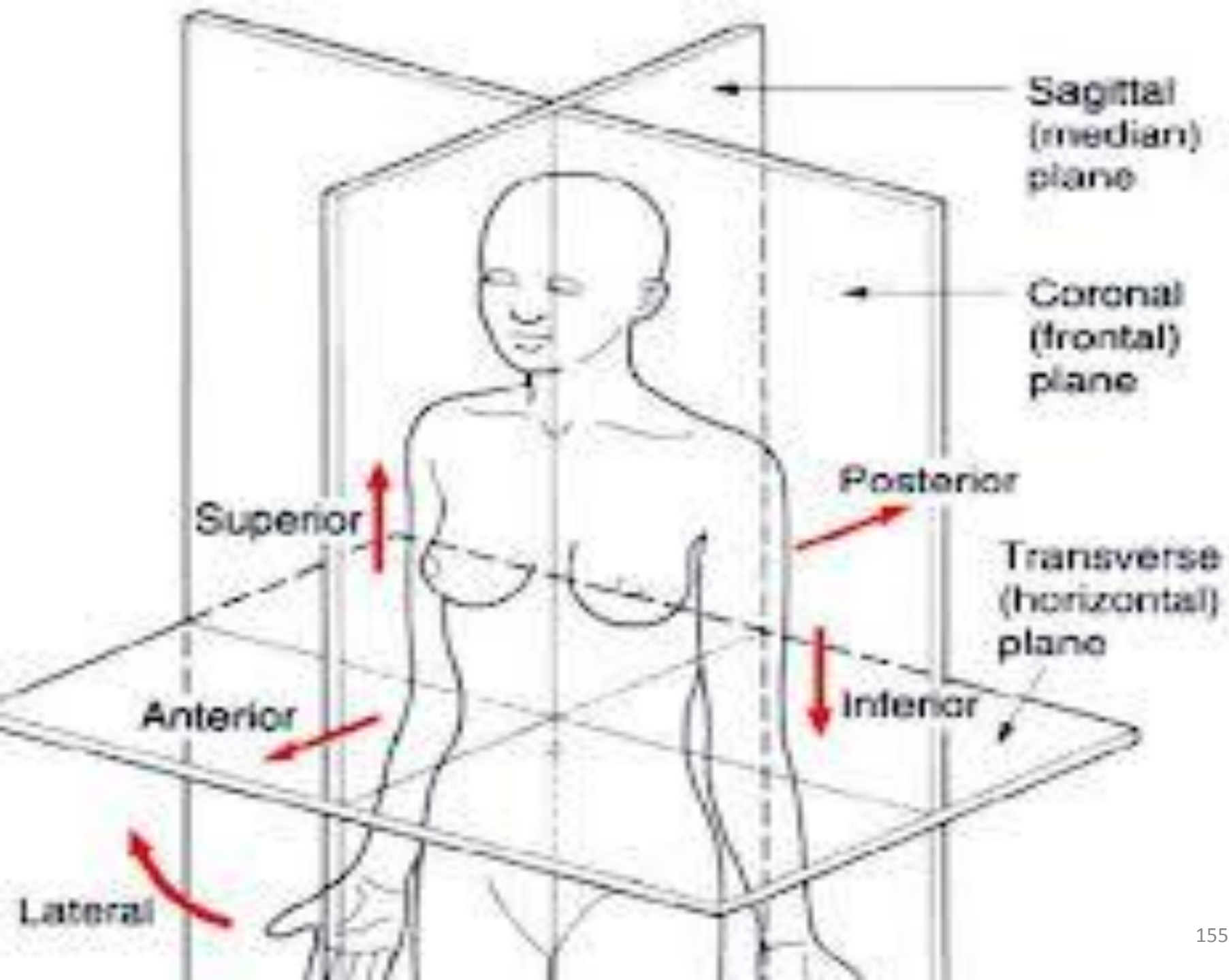


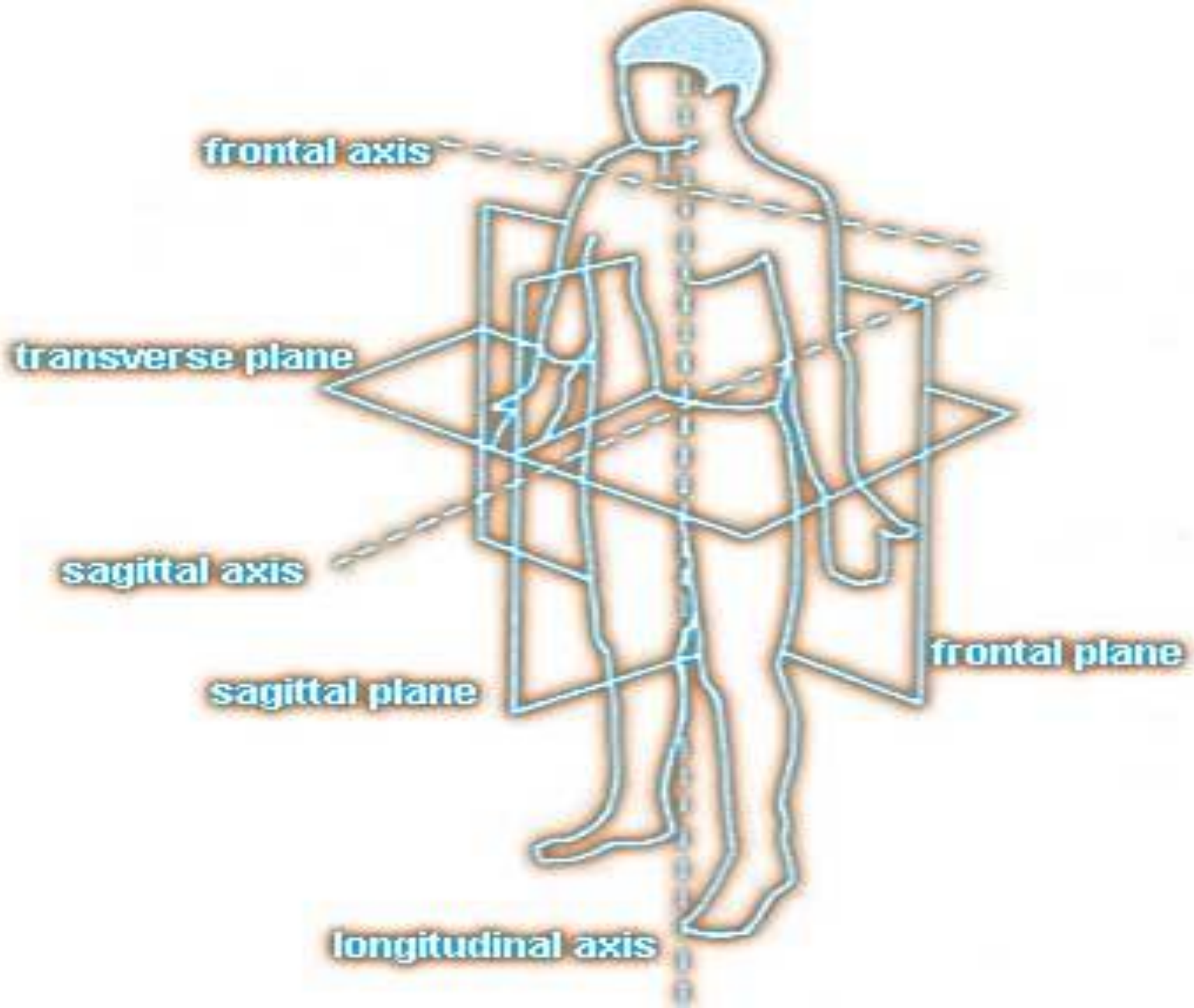


Anatomical planes

- **Coronal (frontal or lateral) Plane** - Plane running from left to right, dividing the body into a front and back portion.
- **Sagittal (anterior-posterior) Plane** - Plane that runs from front to back, cutting the body into a right and a left part.
 - **Parasagittal Plane:** Sagittal plane that divides the body into **unequal** right and left regions.
 - **Midsagittal (median) Plane** - Plane passing longitudinally through the middle of the body from front to back, dividing it into right and left halves.
- **Transverse** - Plane that runs across the body, dividing it into a top and bottom portion; also known as the horizontal plane.







Movement in Planes and Axis of Rotation

Describing Position and Movement

- A body movement can be described in terms of the anatomical plane through which it occurs and the anatomical axis around which it rotates.
- **The GENERAL RULE:** The axis of rotation is perpendicular to the plane of movement.

Anatomical Axis

- **Anatomical Axis**: Axis are used to describe how rotation of the muscles and bones take place.
- **Longitudinal** or **polar** axis: is in a “north-south” relationship to the anatomical position.
- **Horizontal** or **bilateral** axis: is in an “east-west” relationship to the anatomical position.
- **Antero-posterior** axis: is in a “front-to-back” relationship to the anatomical position.

3 Primary Axes of Rotation

1. Horizontal (Medio-Lateral) Axis:

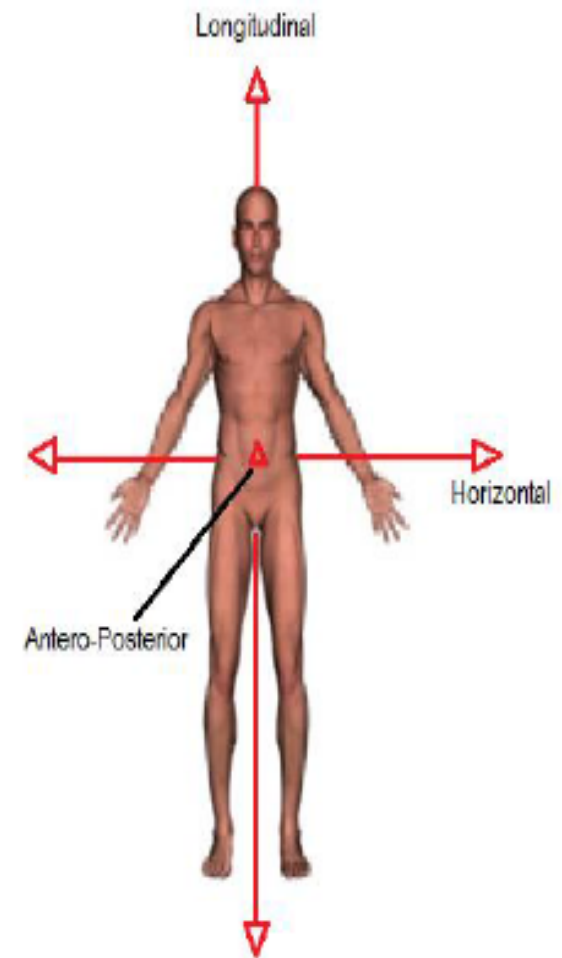
- Runs from side to side
- Perpendicular to Sagittal Plane
- Typically flexion/extension

2. Antero-Posterior (Sagittal) Axis:

- Runs from front to back
- Perpendicular to the Coronal Plane
- Typically abduction/adduction movements

3. Longitudinal (Vertical) Axis:

- Runs straight through the top of the head down between the feet
- Perpendicular to the Transverse Plane
- Typically a rotation type of movement



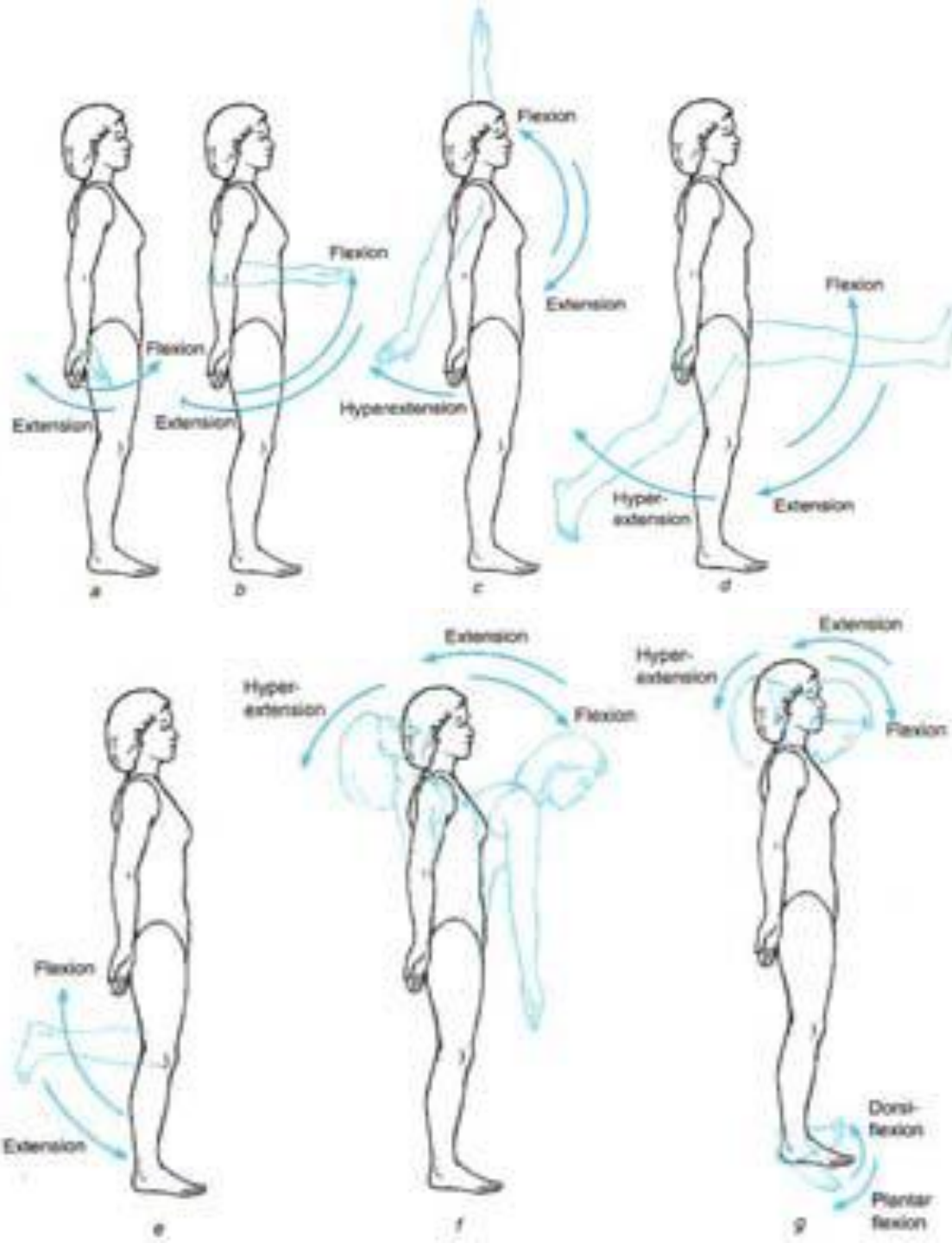
Terms of relative position and direction (6 pairs)

- **Lateral:** is away from or further from the midline
- **Medial:** is towards or closer to the midline
- **Proximal:** Closer to the trunk or point of attachment; top of limb segment.
- **Distal:** Away from the trunk or point of attachment; bottom of limb segment
- **Anterior: (ventral)** Towards the front of the body
- **Posterior: (dorsal)** Towards the back of the body

Ct...

- **Superior**: Towards the top of the body
- **Inferior**: Towards the bottom of the body
- **Deep**: Farther away from the surface of the body
- **Superficial**: Closer to the surface of the body
- **Plantar**: Towards the sole of the foot
- **Dorsum**: Uppermost surface of the foot

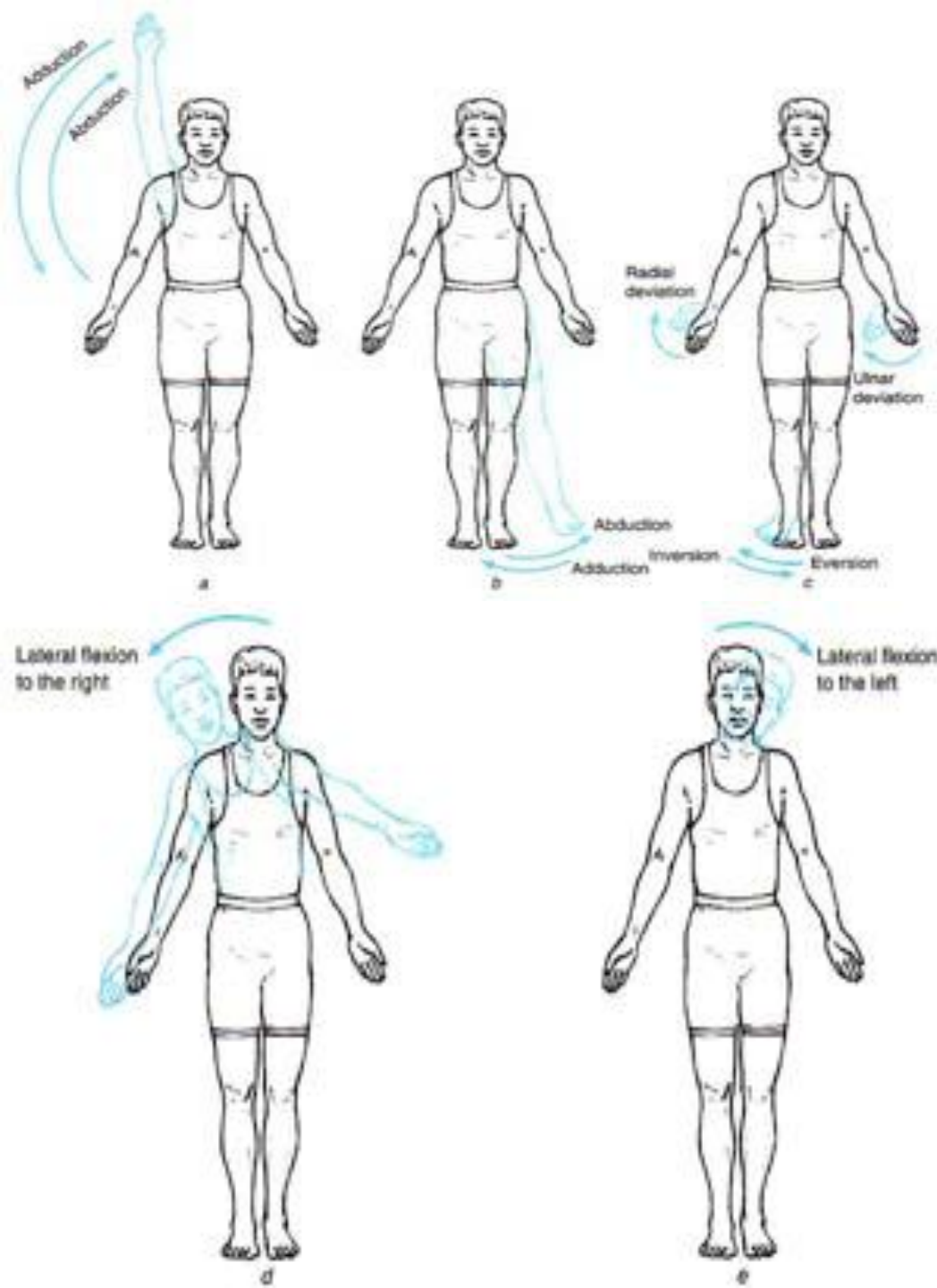
Movt. in sagittal plane



- **Flexion**: Decreasing angles between two segments
- **Extension**: Increasing angles between two segments
- **Hyperextension**: Increasing angles more than 180°
- Major Joints involved : **Wrist, Elbow, Shoulder, Hip, Knee, Trunk, Neck, & Ankle**

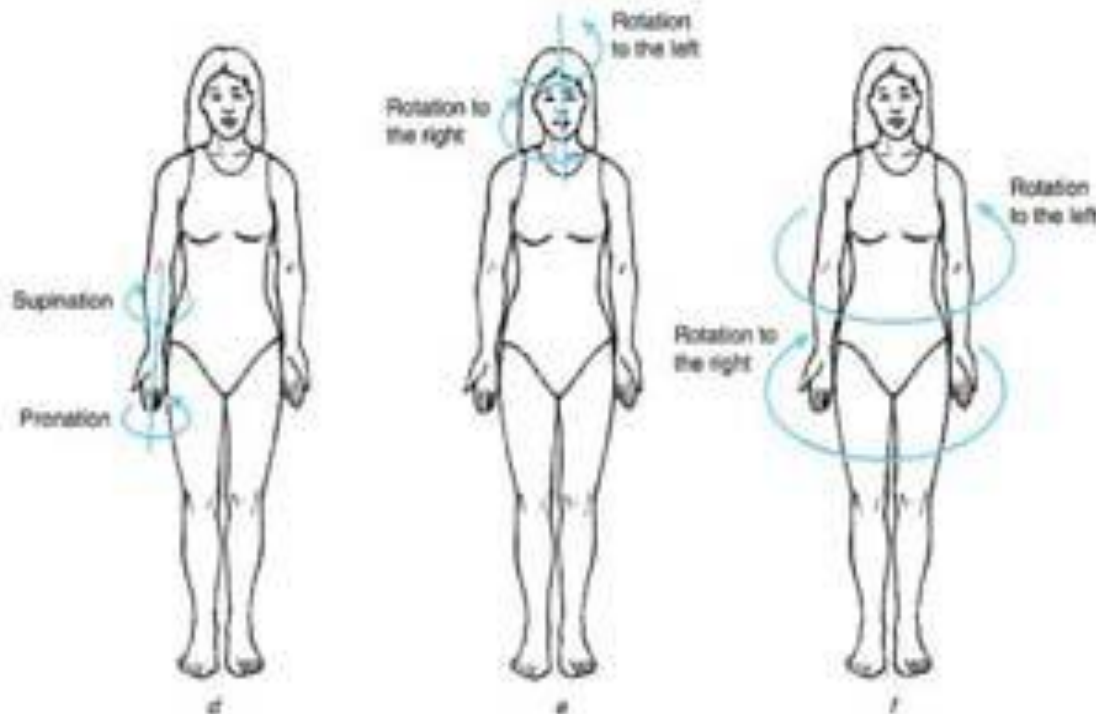
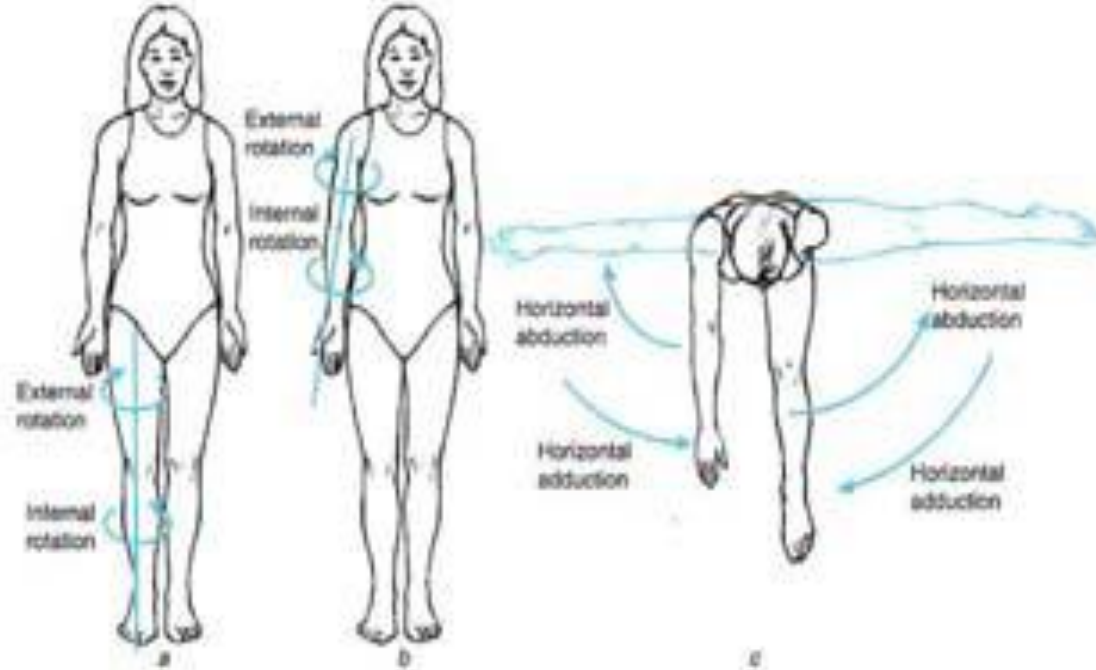
Movt. In frontal plane

- **Abduction** : Away from midline
- **Adduction**: Closer to midline
- **Radial/Ulnar deviation**
- **Inversion/Eversion**
- **Lateral flexion to R/L**
- **Elevation/Depression**
- **Upward/Downward rotation**
- Major Joints involved : **Shoulder, Hip, Wrist, Ankle, Trunk, Neck, & Scapula**



Movt. on transverse plane

- External/Internal rotation
- Horizontal abduction/adduction
- Pronation: Palm down
- Supination: Palm up
- Rotation to R/L
- Protraction/Retraction**
- Major joints involved: **Hip, Shoulder, Radioulnar, Neck, Trunk, & Scapula****



Helpful Hints....

- Axis of rotation is always perpendicular to the plane of movement.
- In the anatomical position, all flexion/extension occurs in the sagittal plane, all abduction/adduction occurs in the frontal plane, and all rotation occurs in the transverse plane.
- More involved movements are usually not in one specific plane but occur as a combination of motions from more than one plane e.g. circumduction of the shoulder joint.

Summary of the three planes and axes of rotation

Anatomical Plane	Perpendicular Axis
Sagittal (Medial)	Horizontal (Medio-Lateral)
Frontal (Coronal)	Antero-Posterior (Sagittal)
Transverse (Horizontal)	Longitudinal (Vertical)

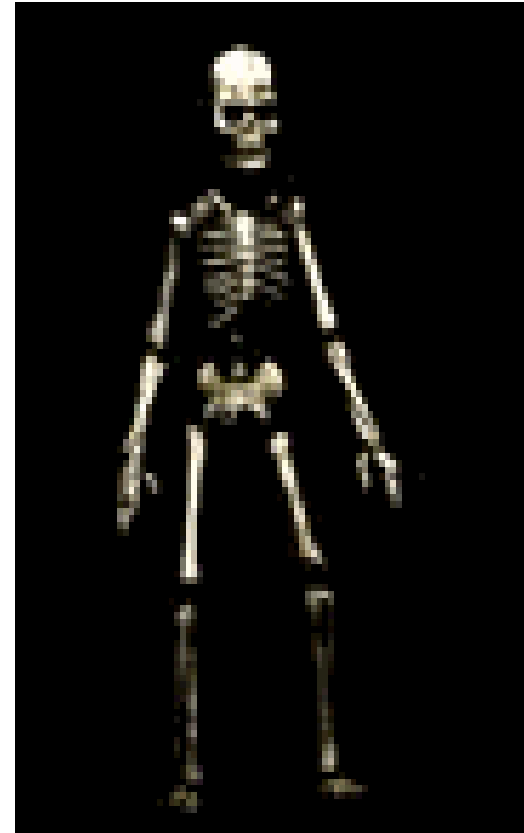
THE SKELETON

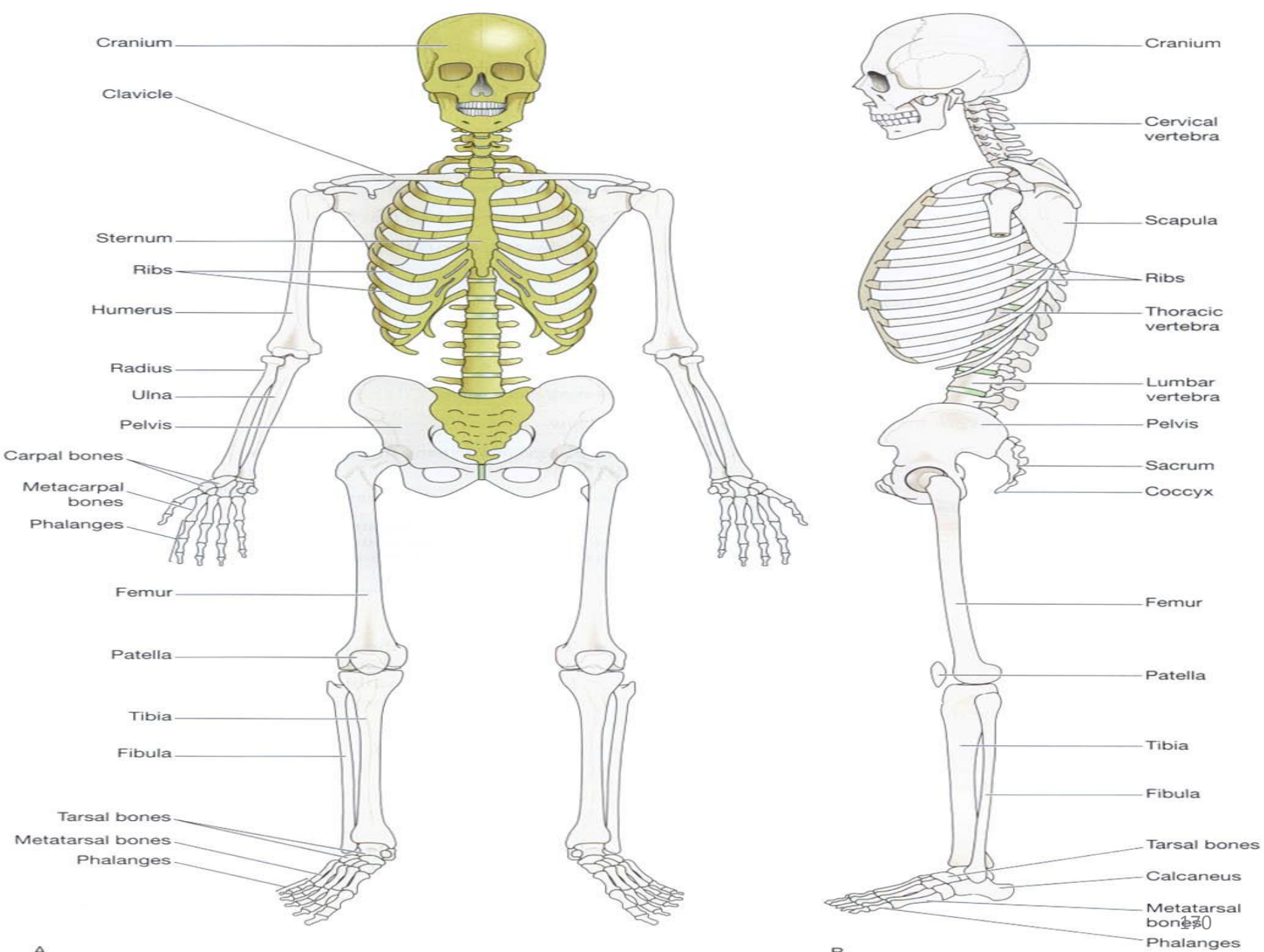
- Bony framework of the body.
- Forms the cavities and fossae that protect some structures, forms the joints and gives attachment to muscles.
- Made up of 206 bones
- Accounts for approx 14% of the body weight

Functions of the skeletal system:

- **Supports** tissues and provides a framework for our body.
- **Protects** organs e.g. rib cage, skull
- **Reservoir of minerals** such as phosphorus and calcium which may be used in time of need (repair and function).
- **Produces** Red & white blood cells & platelets.
- Provides the levers on which muscles pull to produce **movement.**

- Divided into 2 parts: **axial** and **appendicular**
- **Axial skeleton** (axis of the body) consists of:
 - skull
 - vertebral column
 - sternum or breast bone
 - ribs.
- **Appendicular skeleton** (appendages attached to the axis of the body) consists of:
 - the bones of the upper limbs, the two clavicles and the two scapulae
 - the bones of the lower limbs and the two innominate bones of the pelvis.





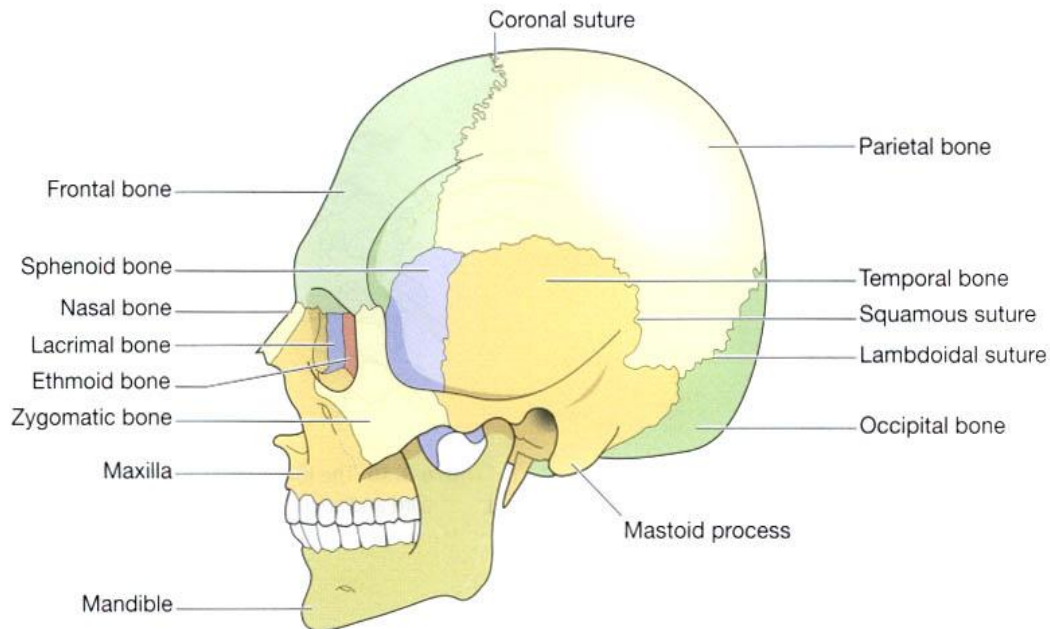
A

B

AXIAL SKELETON

1. Skull

- 2 parts,
 - the cranium, which contains the brain
 - the face.
- Consists of a number of bones which develop separately, but fuse together as they mature.
- The orbit is a bony cavity for the eye, formed by the frontal bone, ethmoid bone, lacrimal bone, maxilla, zygomatic bone, sphenoid bone, and temporal bone. The mandible is the lower jaw.



Functions of the skull

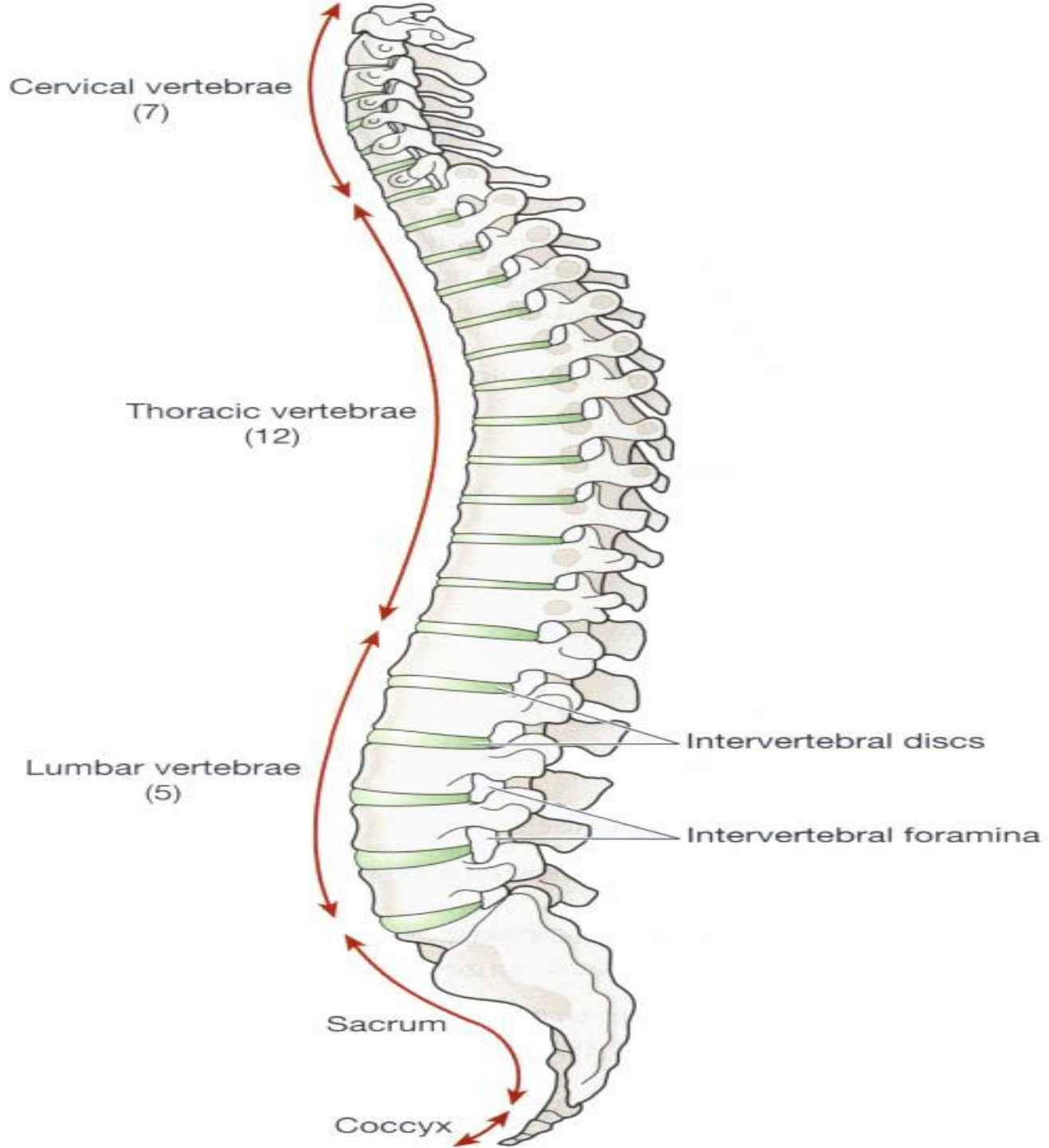
- 1) Protection of the delicate structure of the brain, eyes and inner ears
- 2) Maintaining patency of the nasal passages enabling breathing
- 3) Eating – movement of the mandible allows chewing

NB: various parts of the skull have specific functions

2. vertebral column

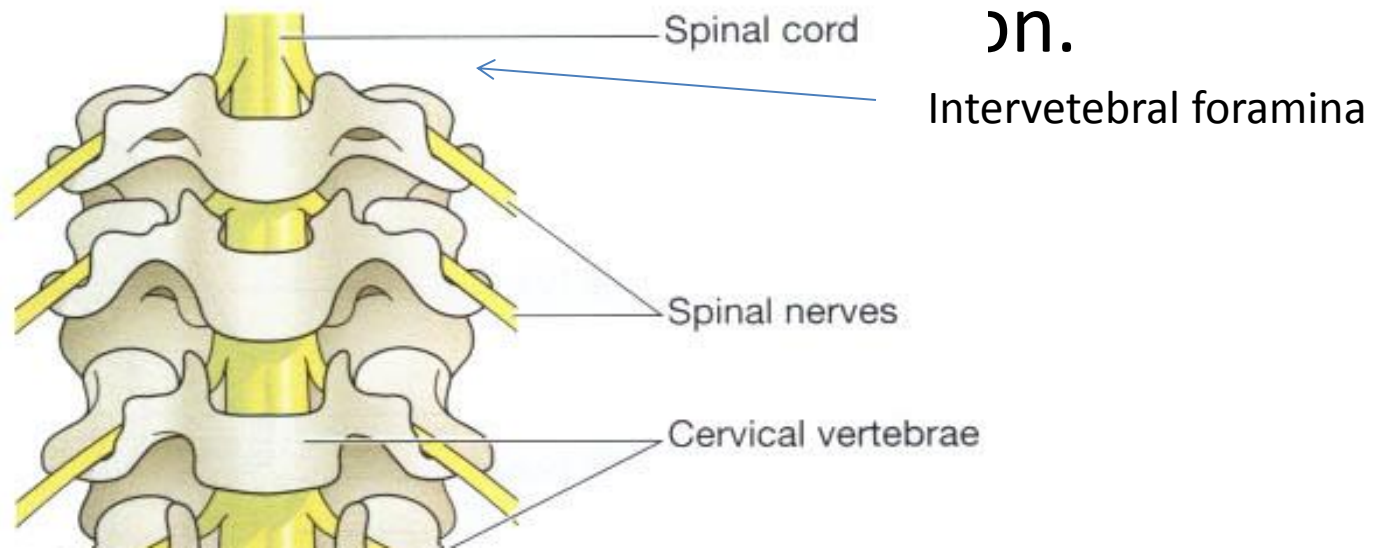
- Consists of 24 movable bones (vertebrae) plus the sacrum and coccyx. The bodies of the bones are separated from each other by **intervertebral discs, consisting of cartilage.**
- Has 5 parts and the bones of each part are numbered from above downwards.
 - 7 cervical
 - 12 thoracic
 - 5 lumbar
 - 1 sacrum (5 fused bones)
 - 1 coccyx (4 fused bones)

- The first **cervical** vertebra, called the **atlas**, articulates with the skull. Thereafter each vertebra forms a joint with the vertebrae immediately above and below. In the cervical and lumbar regions more movement is possible than in the thoracic region.
- The **sacrum** consists of five vertebrae fused into one bone which articulates with the fifth lumbar vertebra above, the coccyx below and an innominate (pelvic or hip) bone at each side.
- The **coccyx** consists of the four terminal vertebrae fused into a small triangular bone which articulates with the sacrum above.



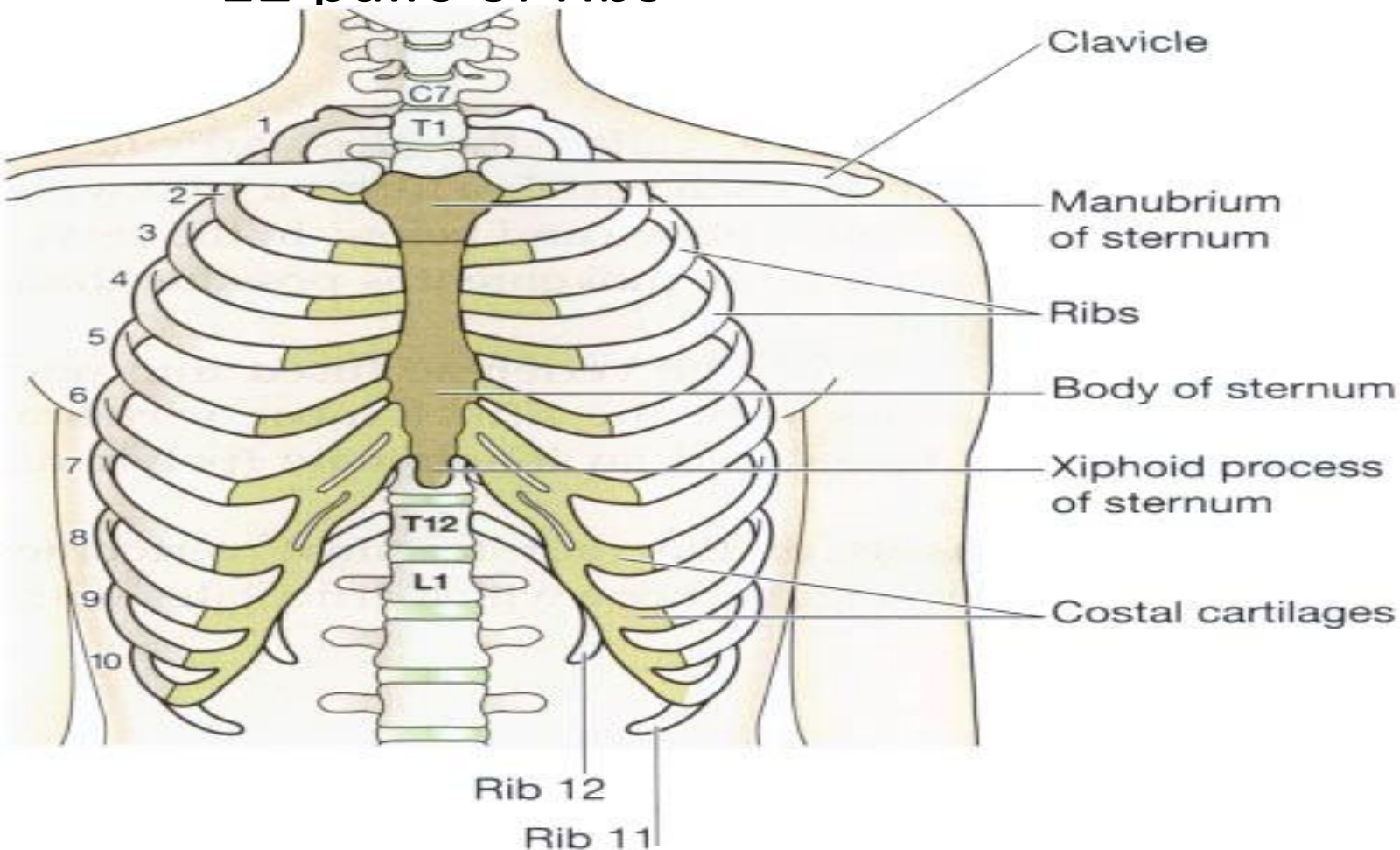
Functions of vertebral column

1. Protects the spinal cord. In each bone there is a hole or foramen (**vertebral foramen**) and collectively form a canal where the spinal cord lies.
2. Adjacent vertebrae form openings (intervertebral foramina) through which spinal nerves pass from the spinal cord to all parts of the body.
3. Articulates with ribs in the thoracic region forming joints



3. Thoracic cage

- The thoracic cage is formed by:
 - 12 thoracic vertebrae
 - 12 pairs of ribs



Functions of the thoracic cage

1. Protects the thoracic organs e.g the heart, lungs, large blood vessels and other structures.
2. Forms joints between the upper limbs and the axial skeleton. The upper part of the sternum, the manubrium, articulates with the clavicles forming the only joints between the upper limbs and the axial skeleton.
3. Gives attachment to the muscles of respiration:
 - **intercostal muscles** occupy the spaces between the ribs and when they contract the ribs move upwards and outwards, increasing the capacity of the thoracic cage, and inspiration (breathing in) occurs.
 - **the diaphragm** is a dome-shaped muscle which separates the thoracic and abdominal cavities. It is attached to the bones of the thorax and when it contracts it assists with inspiration.
4. Enables breathing (ventilation) to take place.

APPENDICULAR SKELETON

- The appendages are:
 - the upper limbs and the shoulder girdles
 - the lower limbs and the pelvic girdle
- A shoulder girdle is composed of a clavicle and a scapula
- The pelvic girdle is composed of the two innominate bones and the sacrum.

Functions of appendicular skeleton

- 1. *Voluntary movement.*** The bones, muscles and joints of the limbs are involved in voluntary movement; ranging from very fine movements to coordinated movements.
- 2. *Protection of delicate structures*** such as blood vessels and nerves that lie along the length of bones of the limbs (by the muscles and skin).

CAVITIES OF THE BODY

- 4 cavities:
 - cranial
 - thoracic
 - abdominal
 - pelvic.

a) Cranial cavity

- Contains the brain
- Boundaries formed by the bones of the skull:
 - ❖ Anteriorly — 1 frontal bone
 - ❖ Laterally — 2 temporal bones
 - ❖ Posteriorly — 1 occipital bone
 - ❖ Superiorly — 2 parietal bones
 - ❖ Inferiorly — 1 sphenoid and 1 ethmoid bone and parts of the frontal, temporal and occipital bones.

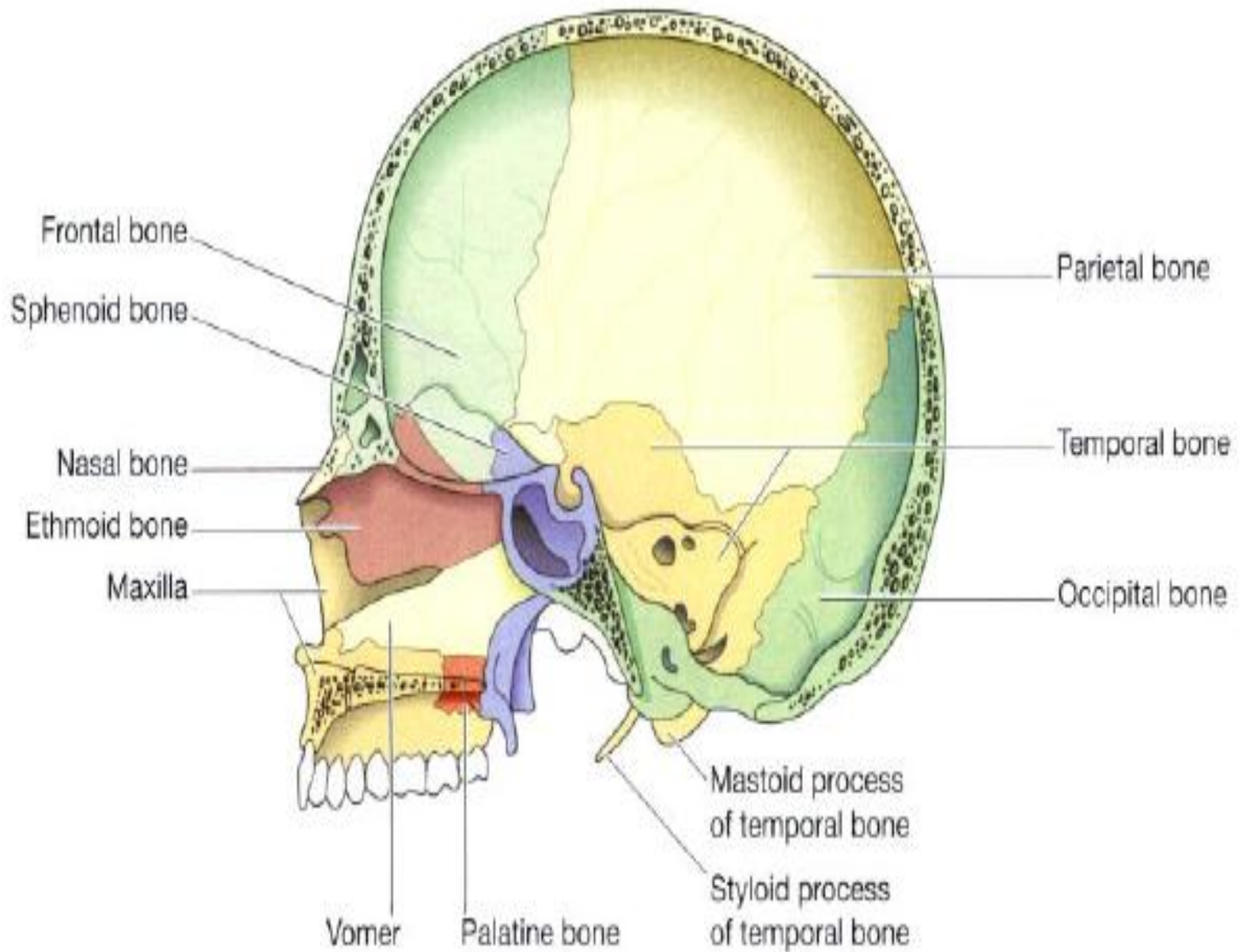


Figure 3.32 Bones forming the right half of the cranium and the face – viewed from the left.

b) Thoracic cavity

- Situated in the upper part of the trunk.
- Boundaries formed by a bony framework and supporting muscles :
 - ❖ Anteriorly — the sternum and costal cartilages of the ribs
 - ❖ Laterally — 12 pairs of ribs and the intercostal muscles
 - ❖ Posteriorly — the thoracic vertebrae and the intervertebral discs between the bodies of the vertebrae
 - ❖ Superiorly — the structures forming the root of the neck
 - ❖ Inferiorly — the diaphragm, a dome-shaped muscle.

Contents of thoracic cavity

1. the trachea, 2 bronchi, 2 lungs
 2. the heart, aorta, superior and inferior vena cava, numerous other blood vessels
 3. the oesophagus
 4. lymph vessels and lymph nodes
 5. nerves.
- The **mediastinum**: refers to the space between the lungs including the structures found there, such as the heart, oesophagus and blood vessels.

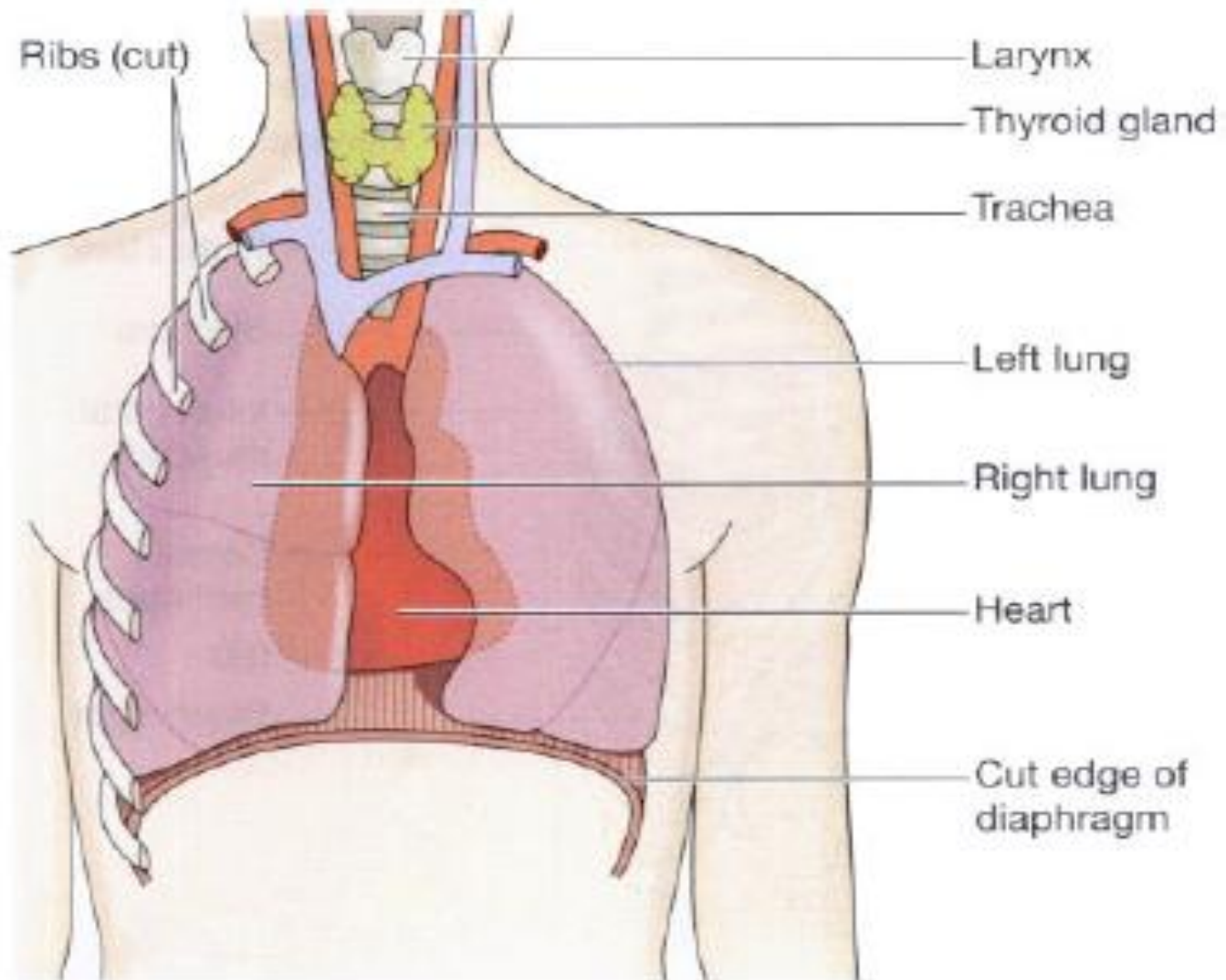
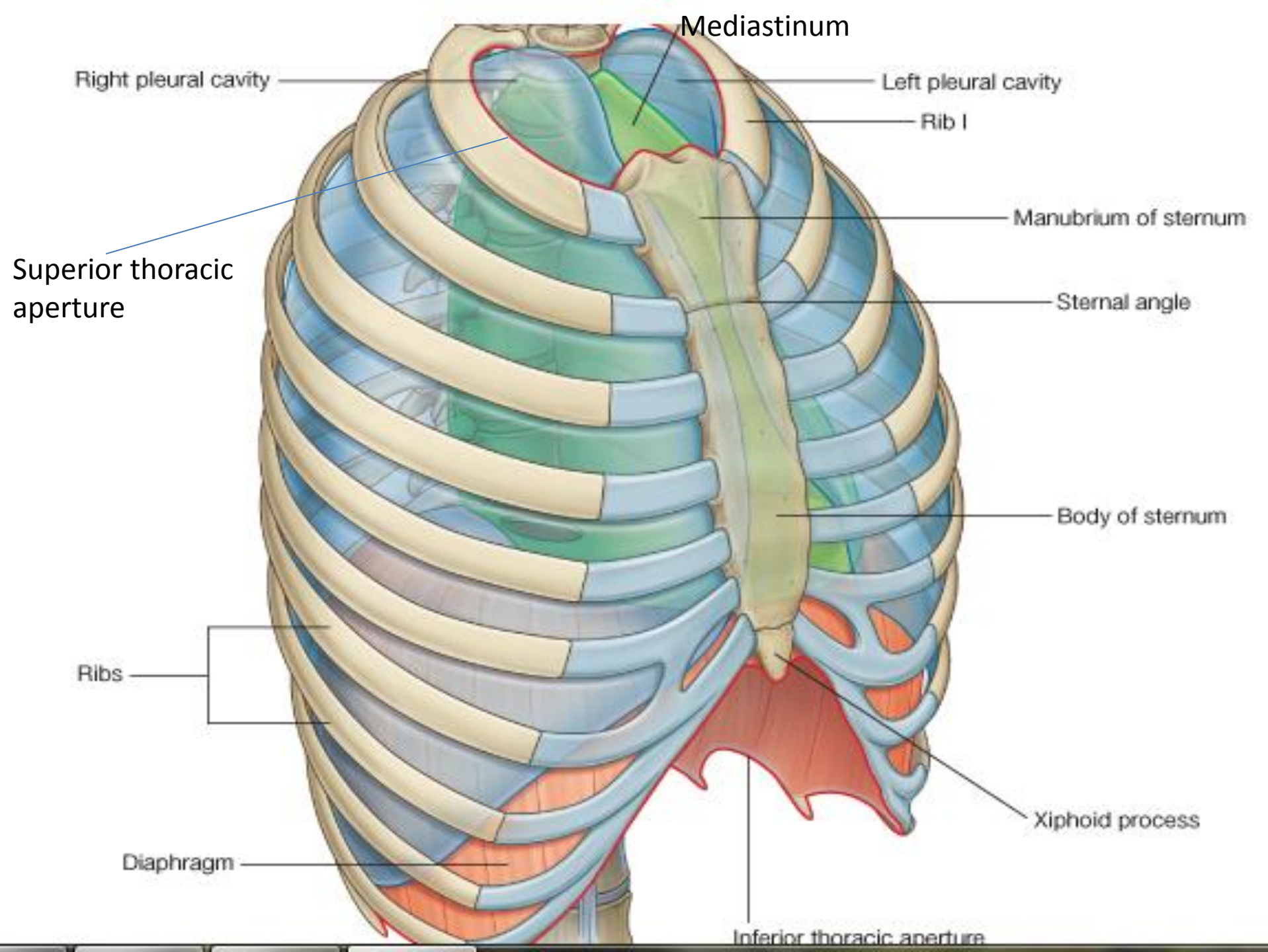
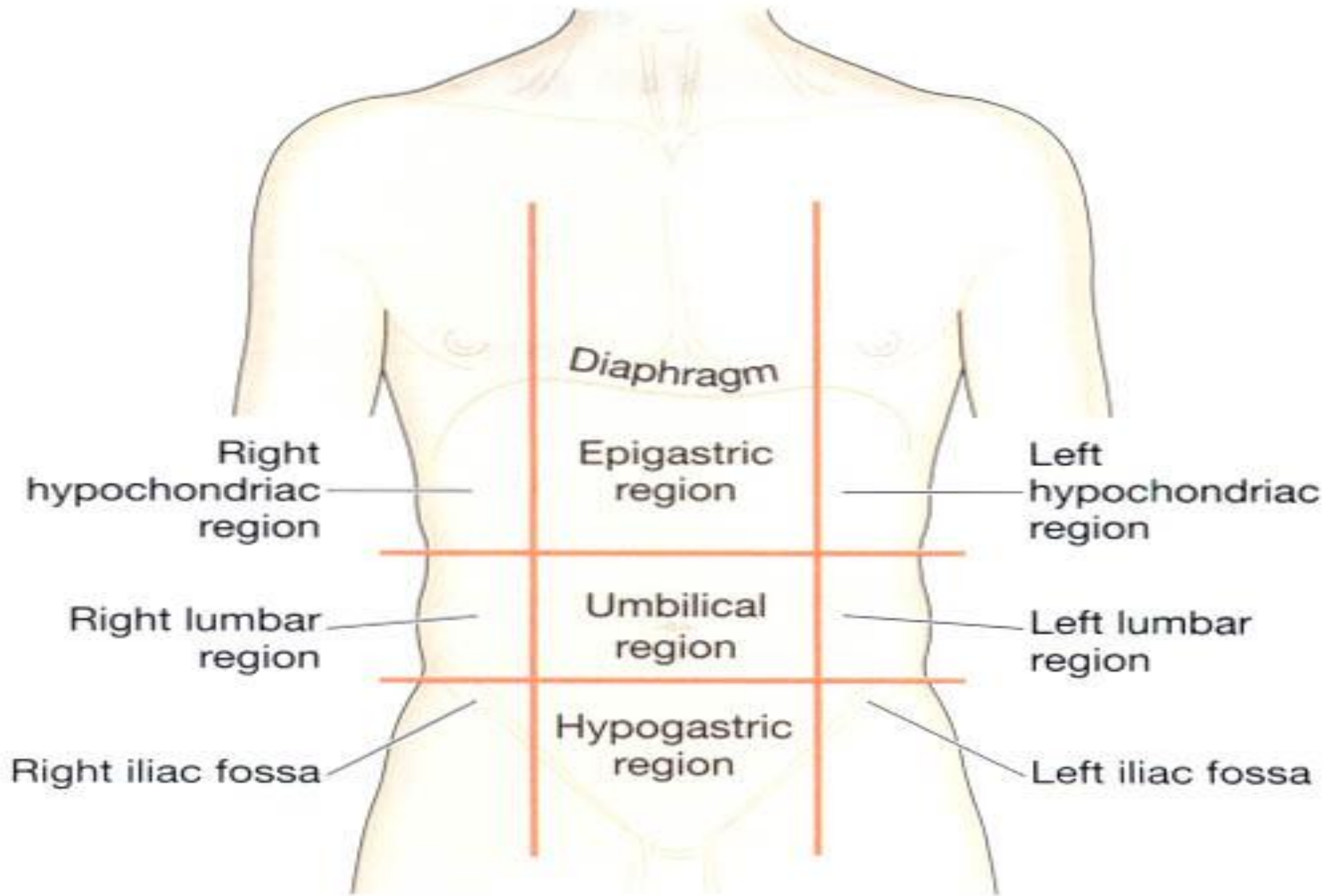


Figure 3.34 Some of the main structures in the thoracic cavity and the root of the neck.



c) Abdominal cavity

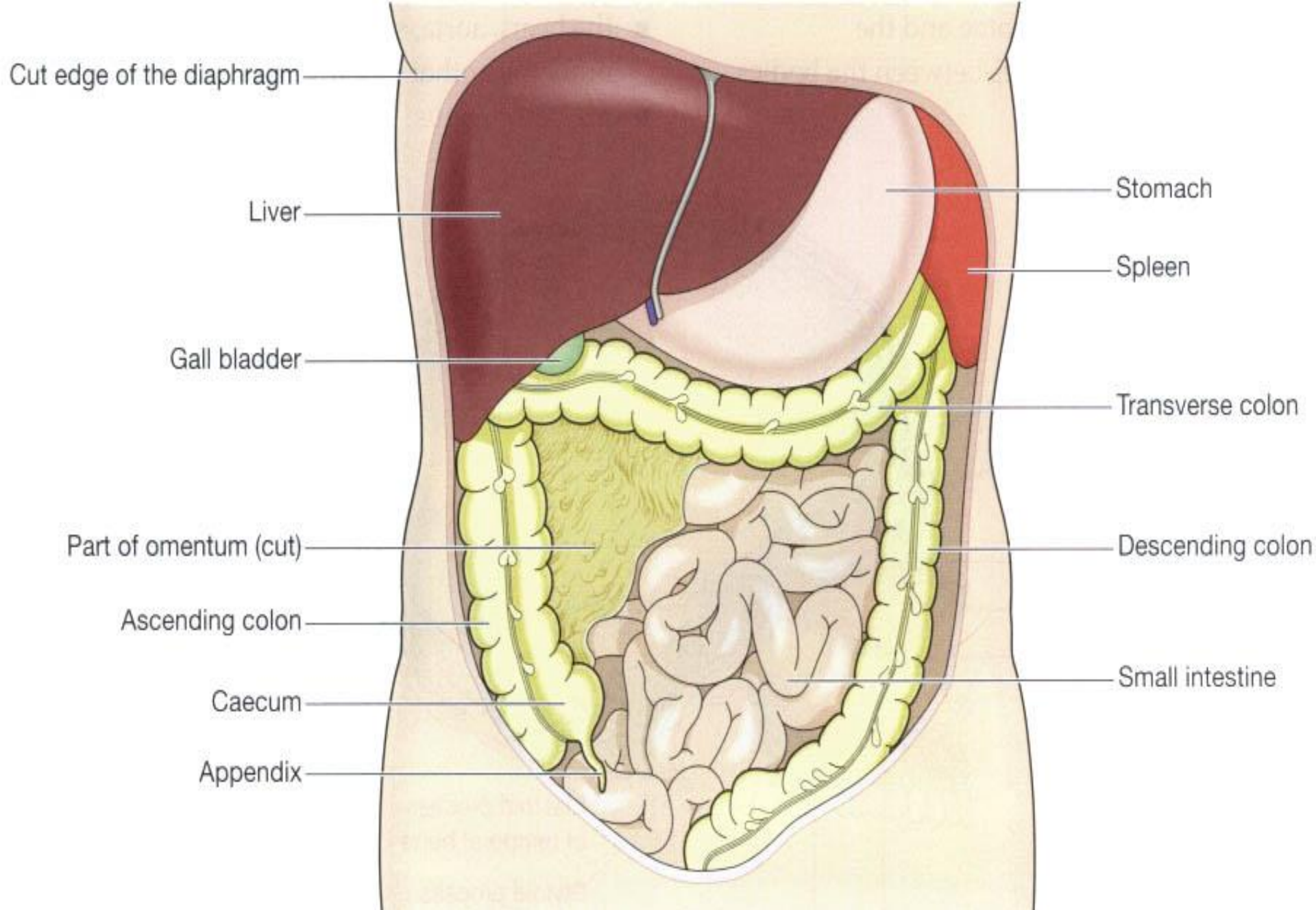
- Largest cavity in the body. It's oval in shape
- Situated in the main part of the trunk and its boundaries are:
 - ❖ Superiorly — the diaphragm, which separates it from the thoracic cavity
 - ❖ Anteriorly — the muscles forming the anterior abdominal wall
 - ❖ Posteriorly — the lumbar vertebrae and muscles forming the posterior abdominal wall
 - ❖ Laterally — the lower ribs and parts of the muscles of the abdominal wall
 - ❖ Inferiorly — the pelvic cavity with which it is continuous.
- To facilitate the description of the positions of the organs and structures it contains, the abdominal cavity is divided into the nine regions.



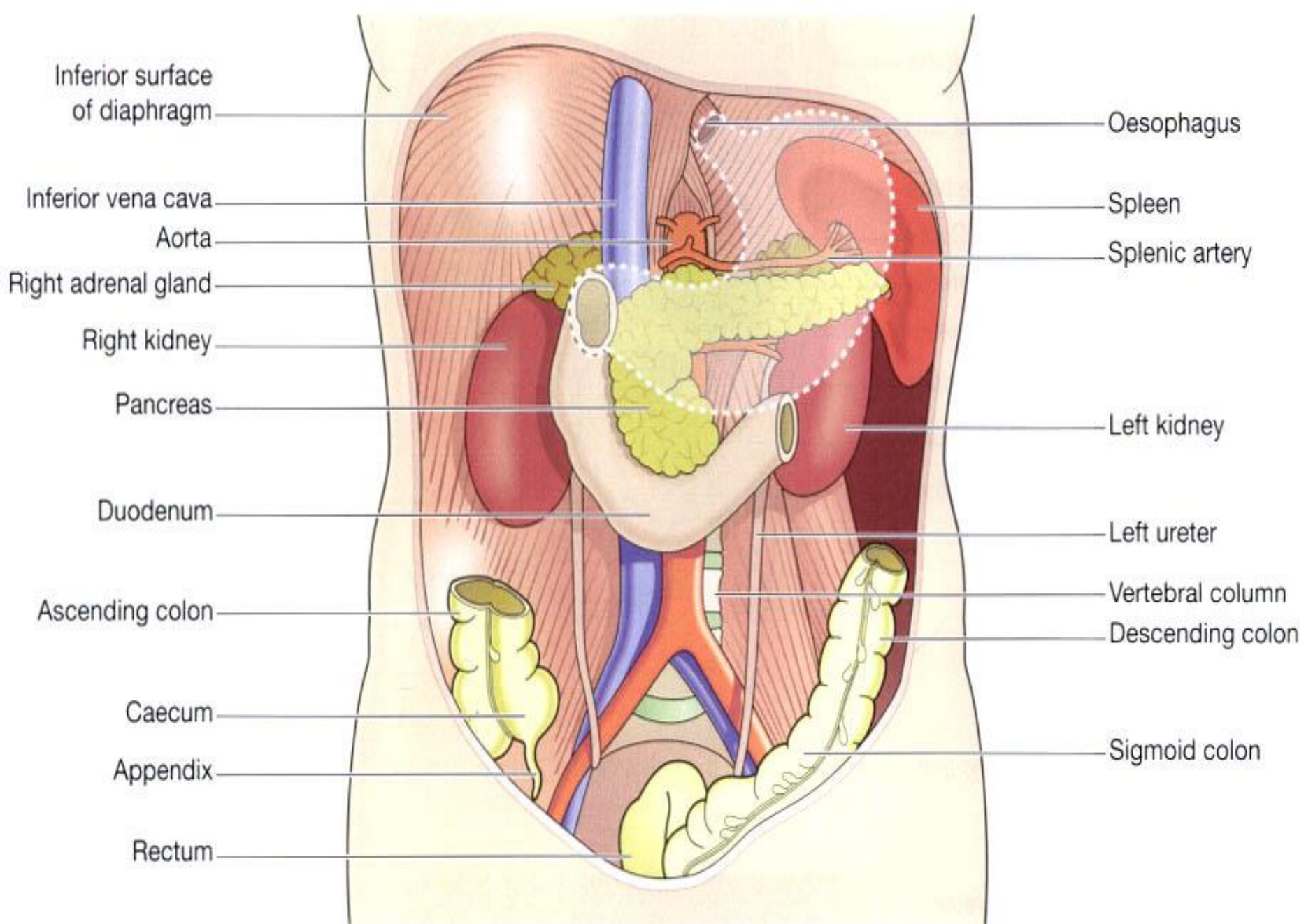
Regions of abdominal cavity

Contents of abdominal cavity

- Organs and glands involved in the digestion and absorption of food. These are:
 - the stomach, small intestine and most of the large intestine
 - the liver, gall bladder, bile ducts and pancreas.
- Other structures include:
 - the spleen
 - 2 kidneys and the upper part of the ureters
 - 2 adrenal (suprarenal) glands
 - numerous blood vessels, lymph vessels, nerves
 - lymph nodes.



Organs occupying anterior part of abdominal cavity



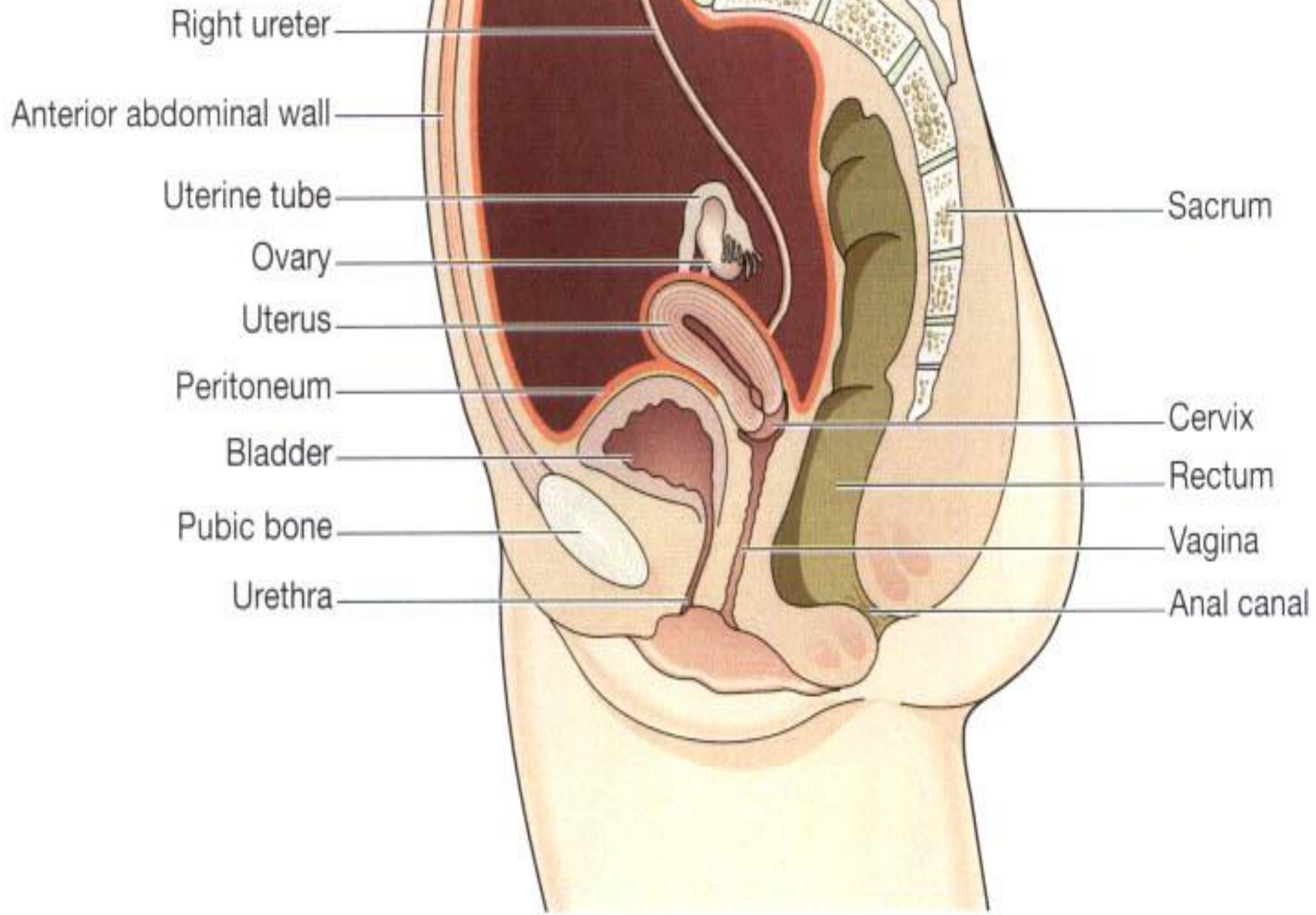
cavity

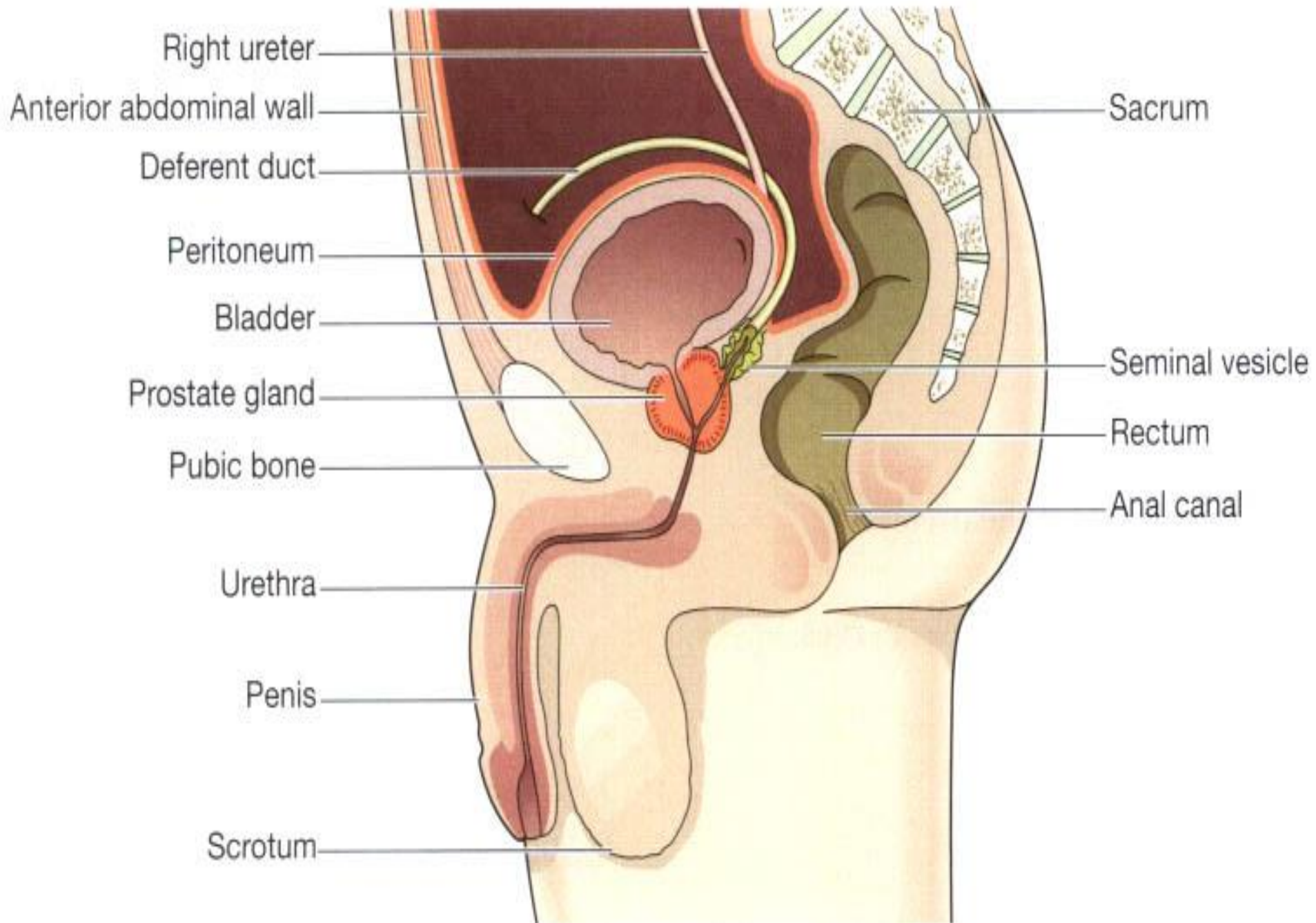
d) Pelvic cavity

- Roughly funnel shaped and extends from the lower end of the abdominal cavity.
- Boundaries are:
 - ❖ Superiorly — continuous with the abdominal cavity
 - ❖ Anteriorly — the pubic bones
 - ❖ Posteriorly — the sacrum and coccyx
 - ❖ Laterally — the innominate bones
 - ❖ Inferiorly — the muscles of the pelvic floor.

Contents of pelvic cavity

- a) sigmoid colon, rectum and anus
- b) some loops of the small intestine
- c) urinary bladder, lower parts of the ureters and the urethra
- d) in the female, the organs of the reproductive system: the uterus, uterine tubes, ovaries and vagina.
- e) in the male, some of the organs of the reproductive system: the prostate gland, seminal vesicles, spermatic cords, deferent ducts (vas deferens), ejaculatory ducts and the urethra (common to the reproductive and urinary systems)





Male reproductive organs

COMMUNICATION

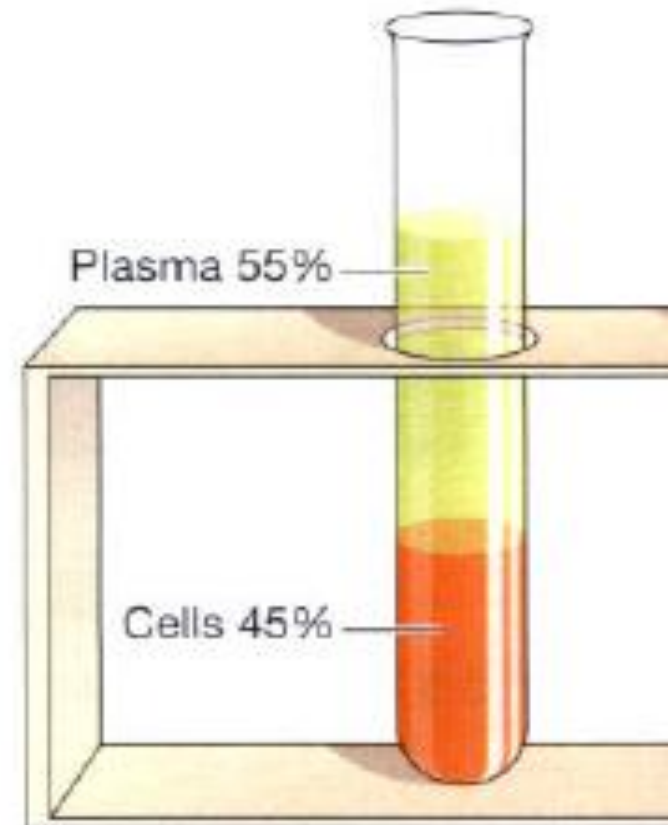
THE BLOOD

- Blood is a connective tissue.
- Provides means of communication between the cells of different parts of the body.
- Carries:
 - a) oxygen from the lungs to the tissues and carbon dioxide from the tissues to the lungs for excretion
 - b) nutrients from the alimentary tract to the tissues and cell wastes to the excretory organs, principally the kidneys
 - c) hormones secreted by endocrine glands to their target glands and tissues
 - d) heat produced in active tissues to other less active tissues
 - e) protective substances, e.g. antibodies, to areas of infection
 - f) clotting factors that coagulate blood, minimizing its loss from ruptured blood vessels.

- Blood makes up about 7% of body weight (about 5.6 litres in a 70 kg man).
- Proportion is less in women & greater in children, gradually decreasing until the adult level is reached.
- Blood in the blood vessels is in continual flow to maintain a fairly constant environment for the body cells.
- Blood volume and the concentration of its many constituents are kept within narrow limits by homeostatic mechanisms.

COMPOSITION OF BLOOD

- Composed of a straw-coloured transparent fluid, **plasma**, in which different types of **cells** are suspended.
- Composition
 - Plasma constitutes about 55%
 - Cells about 45% of blood volume



PLASMA

- Constituents are water (90 to 92%) and dissolved substances, including:
 - ▣ plasma proteins: albumins, globulins (including antibodies), fibrinogen, clotting factors
 - ▣ inorganic salts (mineral salts): sodium chloride, sodium bicarbonate, potassium, magnesium, phosphate, iron, calcium, copper, iodine, cobalt
 - ▣ nutrients, principally from digested foods, e.g. glucose, amino acids, fatty acids, glycerol and vitamins
 - ▣ waste materials, e.g. urea, uric acid, creatinine
 - ▣ hormones
 - ▣ enzymes, e.g. certain clotting factors
 - ▣ gases, e.g. oxygen, carbon dioxide, nitrogen.

Plasma proteins

- Make up about 7% of plasma
- Normally retained within the blood, because they are too big to escape through the capillary pores into the tissues.
- Largely responsible for creating the osmotic pressure of blood which keeps plasma fluid within the circulation.
- If plasma protein levels fall, because of either reduced production or loss from the blood vessels, osmotic pressure is also reduced, and fluid moves into the tissues (oedema) and body cavities.
- They are mainly formed in the liver and are responsible for the viscosity of plasma (mainly albumin and fibrinogen)
- Examples:
 - albumins,
 - globulins (including antibodies),
 - fibrinogen,
 - clotting factors

a) **Albumins:** Most abundant plasma proteins

Functions

- Maintain a normal plasma osmotic pressure (**main**).
- Act as carrier molecules for lipids and steroid hormones.

b) **Globulins:** Main functions include:

- ✓ Act as Antibodies (immunoglobulins), which are complex proteins produced by lymphocytes that play an important part in immunity. They bind to, and neutralise, foreign materials (antigens) such as micro-organisms .
- ✓ transportation of some hormones and mineral salts; e.g. **thyroglobulin** carries the hormone **thyroxine** and **transferrin** carries the **mineral iron**
- ✓ inhibition of some proteolytic enzymes, e.g. α_2 macroglobulin inhibits trypsin activity.

- c) Clotting factors:** substances essential for coagulation of blood.
- D). Fibrinogen:** Synthesised in the liver and is essential for blood coagulation.
- **Serum:** plasma from which clotting factors have been removed.
 - Plasma viscosity (thickness) is due to plasma proteins, mainly albumin and fibrinogen.
 - **Viscosity** is used as a measure of the body's response to some diseases.

Inorganic salts (mineral salts) (Electrolytes)

- Involved in
 - Cell formation,
 - contraction of muscles,
 - transmission of nerve impulses,
 - formation of secretions
 - maintenance of the balance between acids and alkalis.

Nutrients

- Food is digested in the alimentary tract and the resultant nutrients e.g. monosaccharides, amino acids, fatty acids, glycerol and vitamins, are absorbed.
- Together with mineral salts they are required by all body cells to
 - provide energy and heat,
 - Provide materials for repair and replacement,
 - Provide for the synthesis of other blood components and body secretions.

Organic waste products

- Urea, creatinine and uric acid are the waste products of protein metabolism. They are formed in the liver and conveyed in blood to the kidneys for excretion. Carbon dioxide, released by all cells, is conveyed to the lungs for excretion.

Hormones

- **Def:** Chemical compounds synthesized by endocrine glands. They pass directly from the cells of the glands into the blood which transports them to their target tissues and organs elsewhere in the body, where they influence cellular activity.

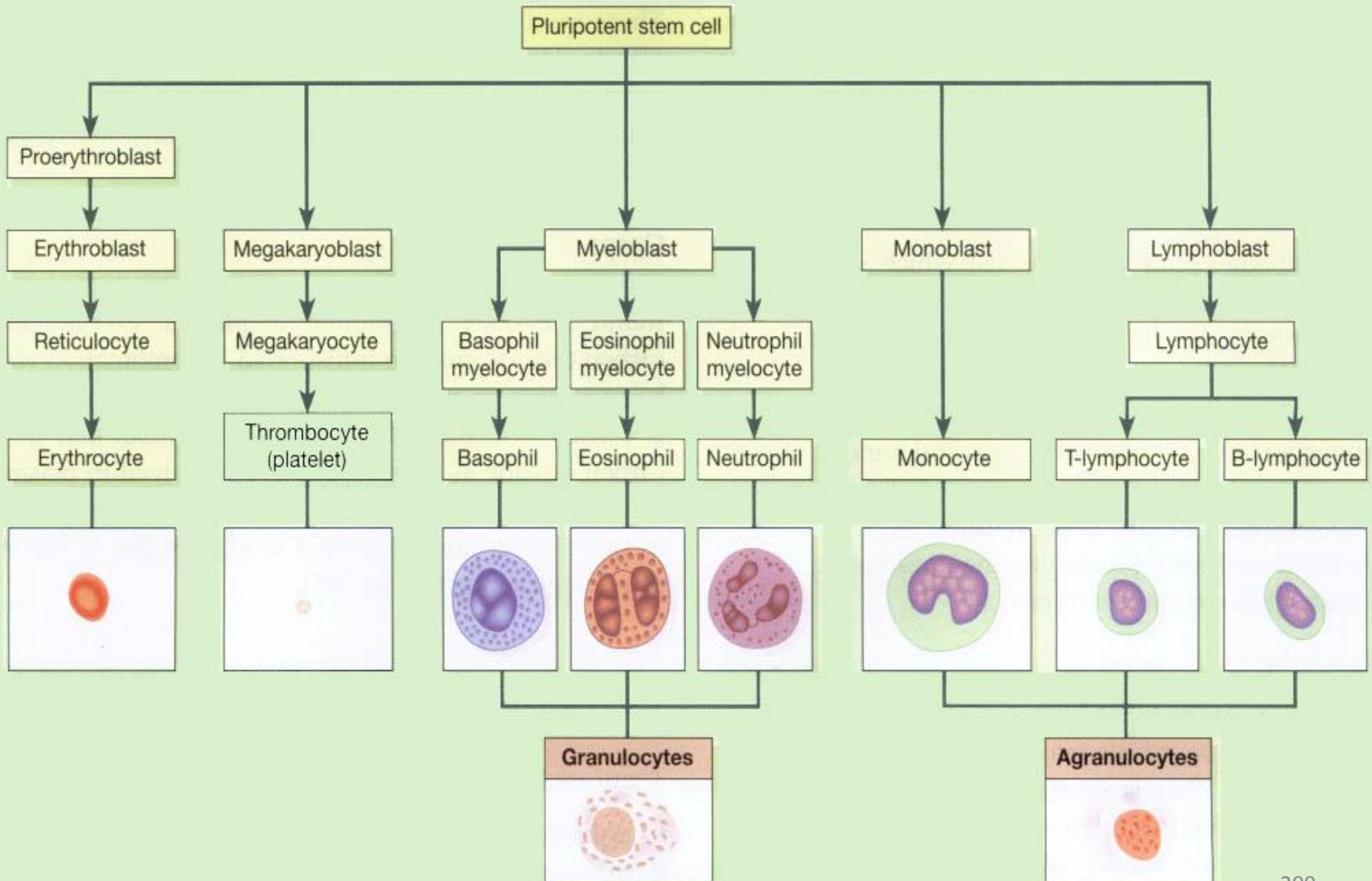
Gases

- Oxygen, carbon dioxide and nitrogen are transported round the body in solution in plasma. Oxygen and carbon dioxide are also transported in combination with hemoglobin in red blood cells.
- Most oxygen is carried in combination with hemoglobin and most carbon dioxide as bicarbonate ions dissolved in plasma.

CELLULAR CONTENT OF BLOOD

- 3 types of blood cells.
 - erythrocytes or red cells
 - thrombocytes or platelets
 - leukocytes or white cells.
- All blood cells originate from **pluripotent stem cells** and go through several developmental stages before entering the blood.
- **Haemopoiesis**: process of blood cell formation; takes place within red bone marrow.
- For the first few years of life, red marrow occupies the entire bone capacity and, over the next 20 years, is gradually replaced by fatty yellow marrow that has no erythropoietic function.
- In adults, hemopoiesis is confined to flat bones, irregular bones and the ends (epiphyses) of long bones, the main sites being the sternum, ribs, pelvis and skull.

HAEMOPOIESIS

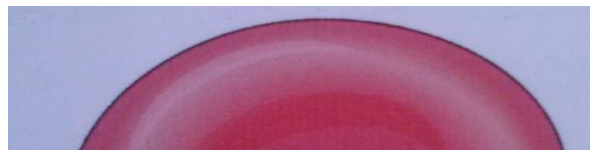


ERYTHROCYTES (Red Blood Cells)

- Circular biconcave non-nucleated discs with a diameter of about 7 micrometers whose main function is transport of gases

Characteristics (adaptations) of the R.B.C

- ✓ They are biconcave – to ↑ S.A for gaseous exchange
- ✓ They have a thin central portion – to allow fast entry and exit of gases
- ✓ They are flexible – so that they can squeeze thru narrow capillaries
- ✓ Contain no organelles – thus creating more room for Hb



r.b.c counts

- 1) Erythrocyte count:** number of erythrocytes per litre (l) or per cubic millimetre (mm³) of blood.
- 2) Packed cell volume (PCV) or haematocrit:** volume of red cells in 1 litre or 1 mm³ of whole blood.
- 3) Mean cell volume (MCV):** average volume of cells, measured in femtolitres (fl = 10⁻¹⁵ litre).
- 4) Haemoglobin:** weight of haemoglobin in whole blood, measured in grams per 100 ml.
- 5) Mean cell haemoglobin (MCH):** average amount of haemoglobin in each cell, measured in picograms (pg = 10⁻¹² gram).
- 6) Mean cell haemoglobin concentration (MCHC):** amount of haemoglobin in 100 ml of red cells.

Table 4.1 Erythrocytes – normal values

Measure	Normal values
Erythrocyte count	
Male	$4.5 \times 10^{12}/l$ to $6.5 \times 10^{12}/l$ (4.5 to 6.5 million/mm ³)
Female	$4.5 \times 10^{12}/l$ to $5 \times 10^{12}/l$ (4.5 to 5 million/mm ³)
Packed cell volume (PCV)	0.4 to 0.5 l/l (40 to 50/mm ³)
Mean cell volume (MCV)	80 to 96 fl
Haemoglobin (Hb)	
Male	13 to 18 g/100 ml
Female	11.5 to 16.5 g/100 ml
Mean cell haemoglobin (MCH)	27 to 32 pg/cell
Mean cell haemoglobin concentration (MCHC)	30 to 35 g/100 ml of cells

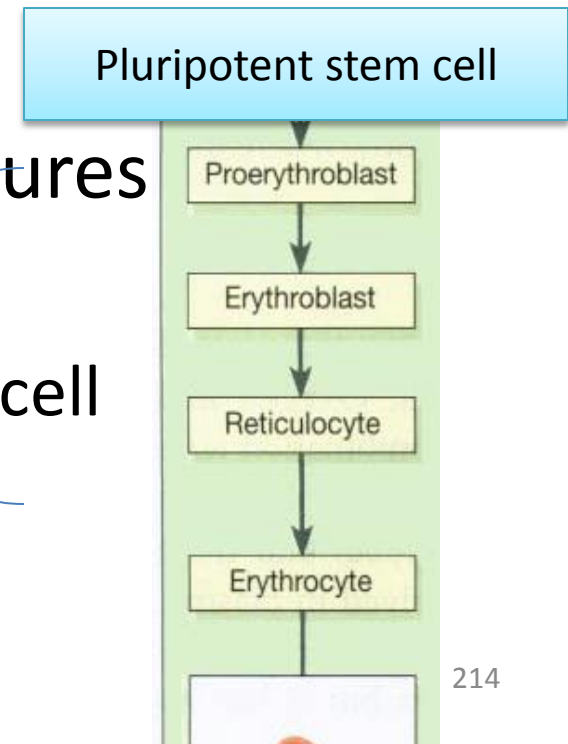
assignment

- Make notes on
 - Haemopoiesis: stages in development of blood cells (include the diagram on differentiation)
 - Normal values of cellular elements in human blood

Development and lifespan of erythrocytes

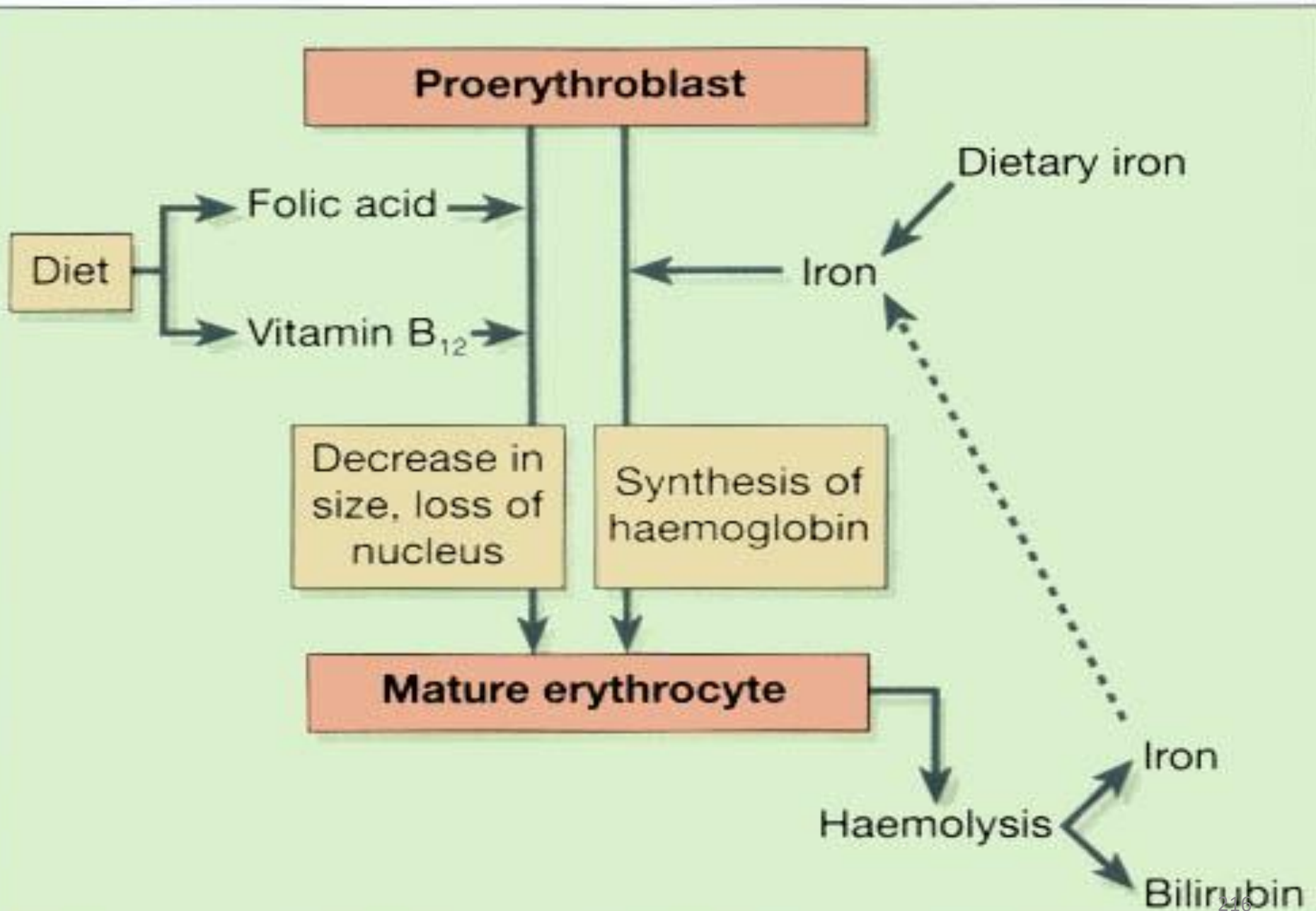
- Formed in red bone marrow, which is present in the **ends of long bones** and **in flat and irregular bones**.
- Life span in the circulation is about 120 days
- Process of development of red blood cells from pluripotent stem cells takes about 7 days and is called **erythropoiesis**.
- It is characterised by two main features
 - maturation of the cell
 - formation of haemoglobin inside the cell

MATURATION



- a) **Maturation of the cell:** During this process the cell decreases in size and loses its nucleus.
- These changes depend on the **presence of vitamin B12 and folic acid**. These are present in sufficient quantity in a normal diet containing dairy products, meat and green vegetables; excess is stored in the liver.
 - Absorption of vitamin B12 depends on a glycoprotein called **intrinsic factor** secreted by parietal cells in the gastric glands.
 - Together they form the **intrinsic factor-vitamin B12 complex (IF-B₁₂)**.
 - During its passage through the intestines, the bound vitamin is protected from enzymatic digestion, and is absorbed in the terminal ileum.
 - **Folic acid** is absorbed in the **duodenum and jejunum** where it undergoes change before entering the blood.
 - Deficiency of either vitamin B12 or folic acid leads to impaired red cell production.

Maturation of the erythrocyte



b) Formation of haemoglobin.

- Hb is a complex protein, consisting of **globin** and an iron-containing substance called **haem**, and is synthesised inside developing **erythrocytes in red bone marrow**.
- Hb in mature erythrocytes combines with oxygen to form **oxyhaemoglobin**, giving arterial blood its characteristic **red colour**.
- Hb is also involved, to a lesser extent, in the transport of carbon dioxide from the body cells to the lungs for excretion.
- Each Hb molecule contains four atoms of iron.
- Each atom can carry one molecule of oxygen, therefore one Hb molecule can carry up to four molecules of oxygen.
- Haemoglobin is said to be saturated when all its available binding sites for oxygen are filled.
- When oxygen levels are low, only partial saturation is possible.

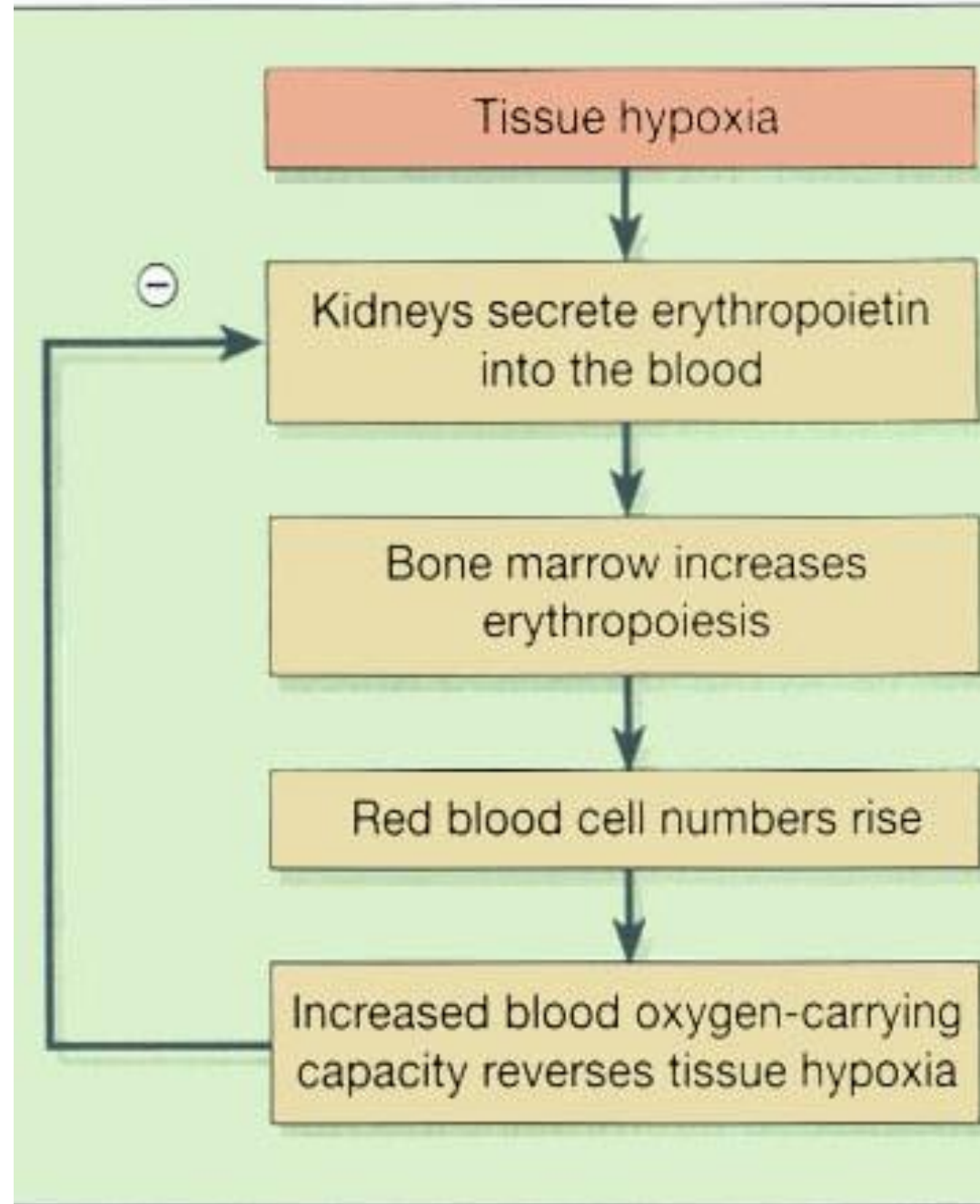
- Haemoglobin binds reversibly to oxygen to form Oxyhaemoglobin
- Oxygen presence in blood changes the colour of blood. Blood rich on oxygen is bright red while blood low in oxygen is dark bluish in colour coz its not saturated.
- Factors which increases release of oxygen from oxyhaemoglobin includes:-
 - Low pH
 - Low levels of oxygen in blood (hypoxia)
 - Temperature

Control of erythropoiesis

- Through homeostatic negative feedback mechanism; the bone marrow produces erythrocytes at the rate at which they are destroyed.
- Primary stimulus to increased erythropoiesis is **hypoxia** which occurs when:
 - oxygen-carrying power of blood is reduced by e.g. haemorrhage or excessive erythrocyte breakdown (haemolysis) due to disease
 - oxygen tension in the air is reduced, as at high altitudes.
- Hypoxia increases erythrocyte formation by stimulating the production of the hormone **erythropoietin**, mainly by the kidneys.

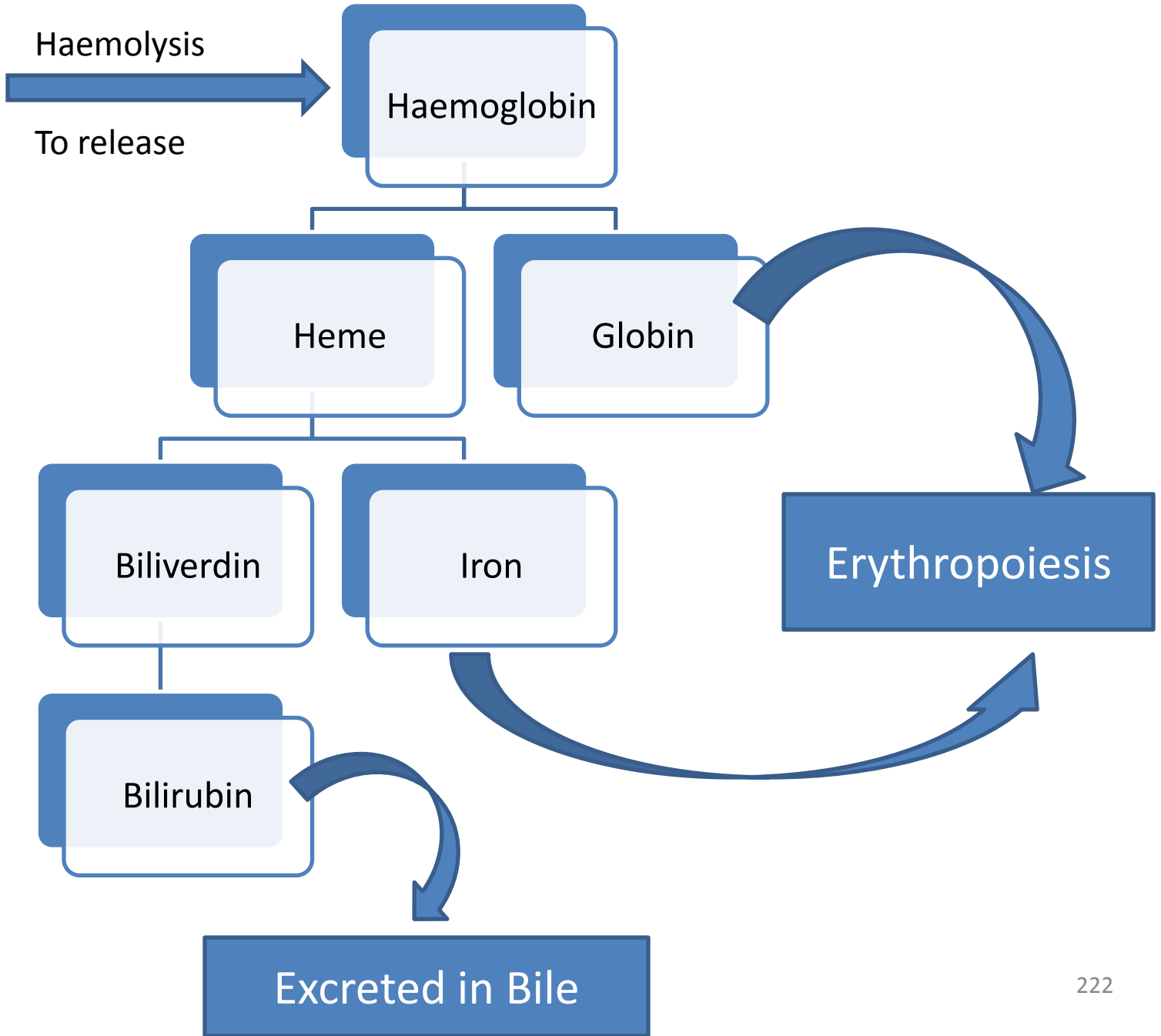
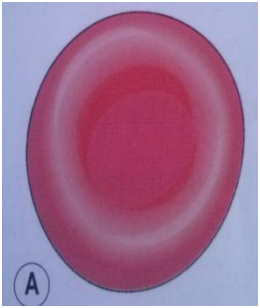
- Effects of erythropoietin
 - Increases production of proerythrocytes
 - Speeds up reticulocyte maturation
- And this \uparrow oxygen carrying capacity of blood and thus \downarrow hypoxia.
- When erythropoietin levels are low, red cell formation does not take place even in the presence of hypoxia, and anaemia develops.

Control of erythropoiesis



Destruction of erythrocytes

- Life span of erythrocytes is about 120 days
- Their breakdown/haemolysis, is by **phagocytic reticuloendothelial cells** found mainly in the **spleen, bone marrow** and **liver**.
- As erythrocytes age, changes in their cell membranes make them more susceptible to haemolysis (membranes become fragile).
- Iron released by haemolysis is retained in the body and reused in the bone marrow to form haemoglobin.
- **Biliverdin** is formed from the protein part of the erythrocytes.
- It is then reduced to the yellow pigment **bilirubin**, before it is bound to **plasma globulin** and transported to the liver. In the liver it is changed from a fat-soluble to a water-soluble form before it is excreted as a constituent of bile.



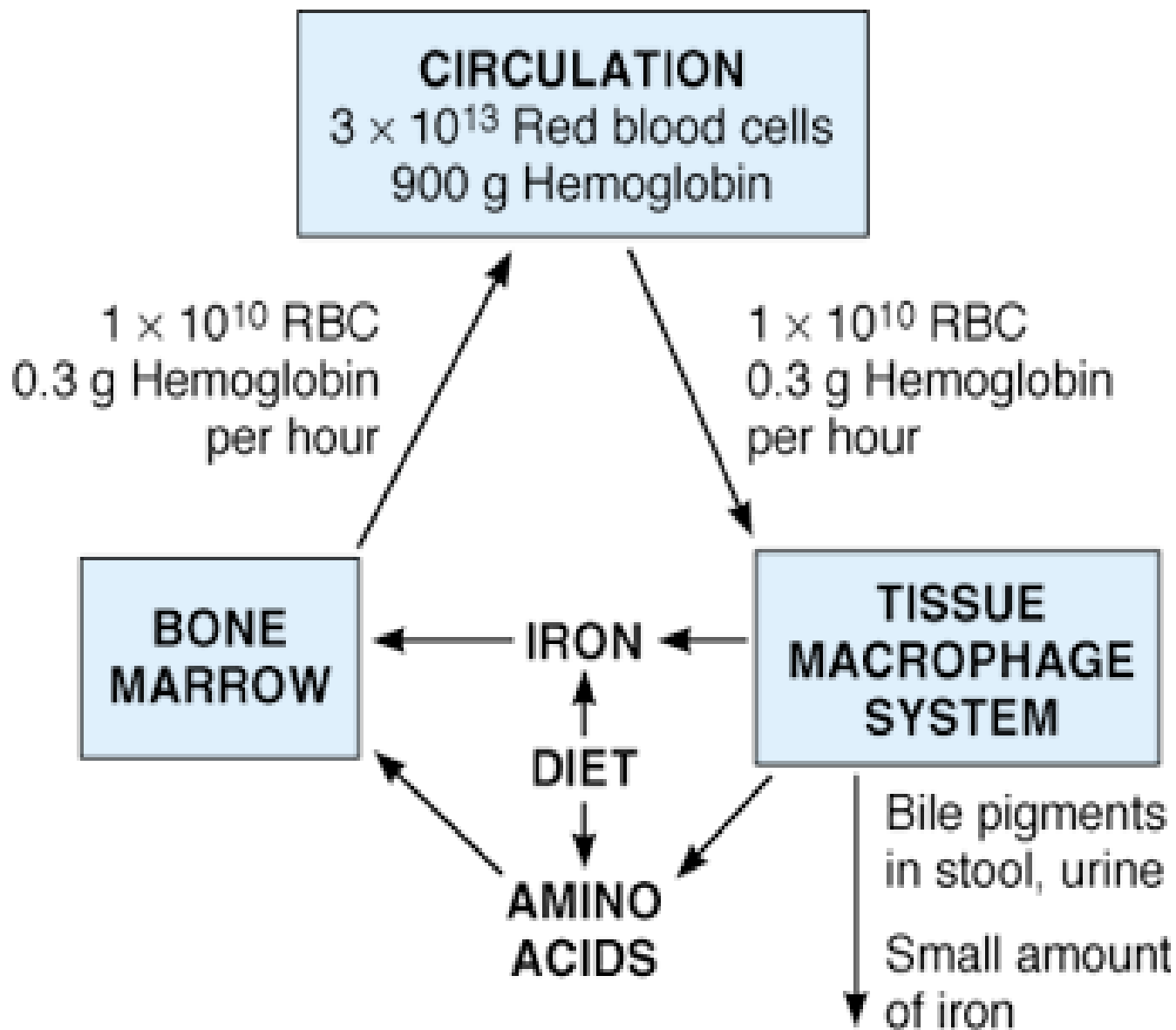


Figure 27-16. Red cell formation and destruction. RBC, red blood cells.

BLOOD GROUPS

- Antigens, found on the surfaces of individual's RBCs, which are inherited, determine the individual's blood group.
- In addition, individuals make antibodies to these antigens, but not to their own type of antigen, since if they did the antigens and antibodies would react causing a **transfusion reaction**.
- These antibodies circulate in the bloodstream and the ability to make them is genetically determined and not associated with acquired immunity.



- If individuals are transfused with blood of the same group, i.e. possessing the same antigens on the surface of the cells, their immune system will not recognise them as foreign and will not reject them.
- However, if they are given blood from an individual of a different blood type, i.e. with a different type of antigen on the red cells, their immune system will mount an attack upon them and destroy the transfused cells.
- This is the basis of the transfusion reaction; the two blood types, the donor and the recipient, are **incompatible**.
- **There are two important systems of blood grouping:**
 - ABO system**
 - Rhesus system**

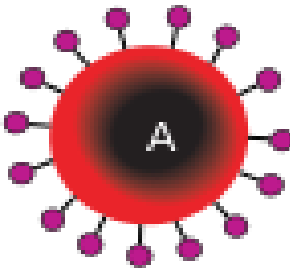
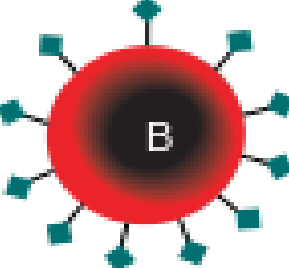
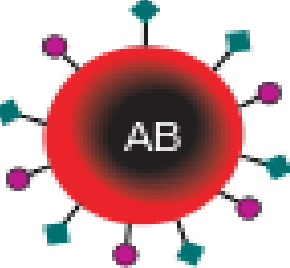
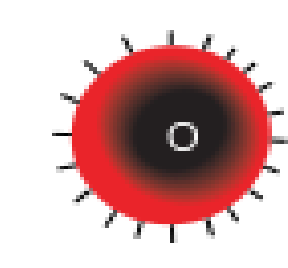






THE ABO SYSTEM

- About 55% of the population has either A-type antigens (blood group A), B-type antigens (blood group B) or both (blood group AB) on their red cell surface.
- The remaining 45% have neither A nor B type antigens (blood group O).
- The corresponding antibodies are called anti-A and anti- B.
- Blood group A individuals cannot make anti-A (and therefore do not have these antibodies in their plasma), since otherwise a reaction to their own cells would occur; they do, however, make anti-B.

- Blood group B individuals, for the same reasons, make only anti-A. Blood group AB make neither, and blood group O make both anti-A and anti-B .
- Because blood group AB people make neither anti-A nor anti-B antibodies, they are known as **universal recipients**: transfusion of either type A or type B blood into these individuals is safe, since there are no antibodies to react with them.
- Conversely, group O people have neither A nor B antigens on their red cell membranes, and their blood may be safely transfused into A, B, AB or O types; group O is known as the **universal donor**.

- WHEN ARE BLOOD GROUPS SAID TO BE COMPATIBLE? GIVE EXAMPLES**
- WHEN ARE BLOOD GROUPS SAID TO BE INCOMPATIBLE? GIVE EXAMPLES**

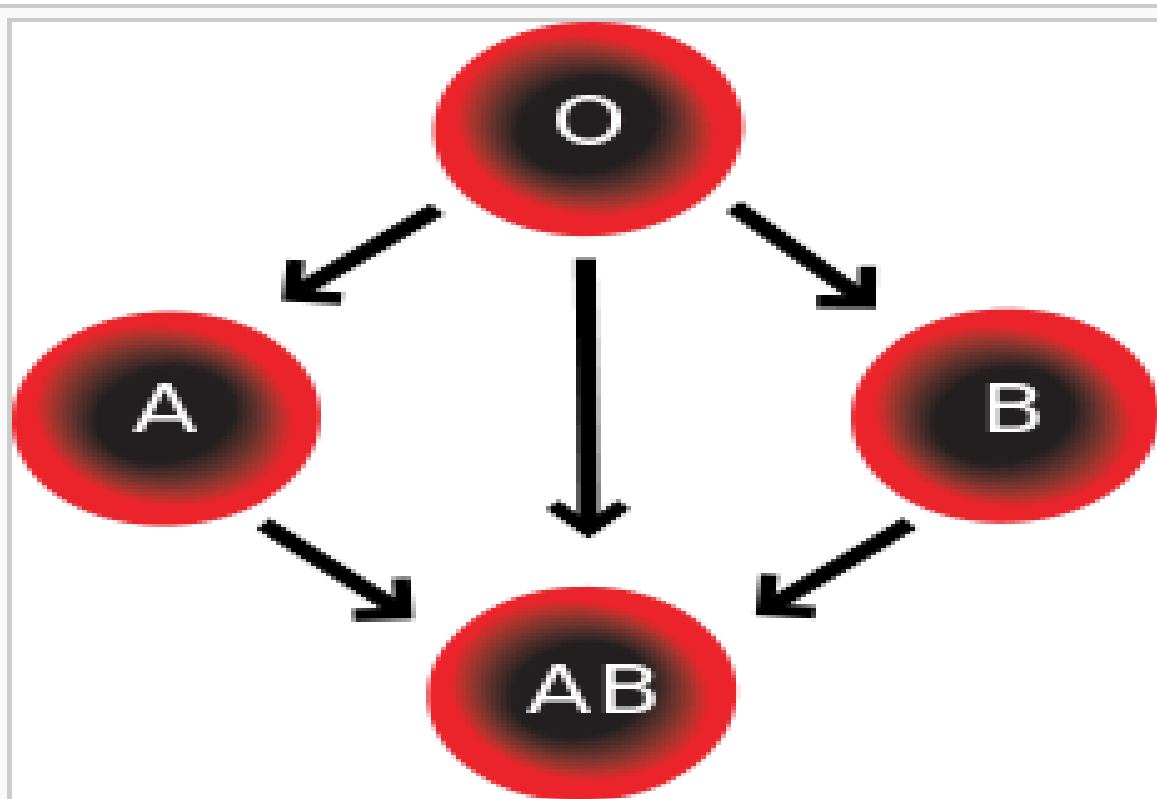
Abo system

	Group A	Group B	Group AB	Group O
Red blood cell type	 A	 B	 AB	 O
Antibodies in Plasma	 Anti-B	 Anti-A	None	 Anti-A and Anti-B
Antigens in Red Blood Cell	 A antigen	 B antigen	 A and B antigens	None

Blood type (or blood group) is determined, in part, by the ABO blood group antigens present on red blood cells.



Universal donor vs recipient

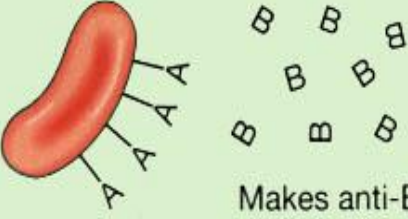
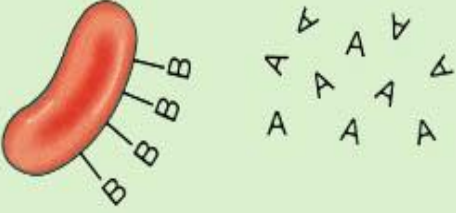
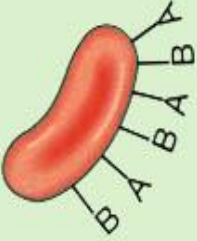
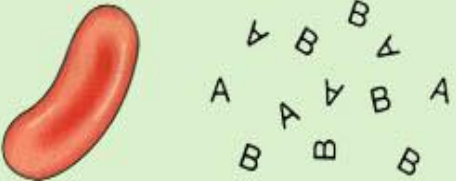


Red blood cell compatibility chart

In addition to donating to the same blood group; type O blood donors can give to A, B and AB; blood donors of types A and B can give to AB.

Plasma compatibility table^[25]

Recipient	Donor ^[1]			
	O	A	B	AB
O	✓	✓	✓	✓
A	✗	✓	✗	✓
B	✗	✗	✓	✓
AB	✗	✗	✗	✓

Blood group	Antigen + antibody(ies) present	As donor, is	As recipient, is
A	 <p>Antigen A</p> <p>Makes anti-B</p>	<p>Compatible with: A and AB</p> <p>Incompatible with: B and O, because both make anti-A antibodies that will react with A antigens</p>	<p>Compatible with: A and O</p> <p>Incompatible with: B and AB, because type A makes anti-B antibodies that will react with B antigens</p>
B	 <p>Antigen B</p> <p>Makes anti-A</p>	<p>Compatible with: B and AB</p> <p>Incompatible with: A and O, because both make anti-B antibodies that will react with B antigens</p>	<p>Compatible with: B and O</p> <p>Incompatible with: A and AB, because type B makes anti-A antibodies that will react with A antigens</p>
AB	 <p>Antigens A and B</p> <p>Makes neither anti-A nor anti-B</p>	<p>Compatible with: AB only</p> <p>Incompatible with: A, B and O, because all three make antibodies that will react with AB antigens</p>	<p>Compatible with all groups UNIVERSAL RECIPIENT</p> <p>AB makes no antibodies and therefore will not react with any type of donated blood</p>
O	 <p>Neither A nor B antigen</p> <p>Makes both anti-A and anti-B</p>	<p>Compatible with all groups UNIVERSAL DONOR</p> <p>O red cells have no antigens, and will therefore not stimulate anti-A or anti-B antibodies</p>	<p>Compatible with: O only</p> <p>Incompatible with: A, AB and B, because type O makes anti-A and anti-B antibodies</p>

The ABO system of blood grouping: antigens, antibodies and compatibility.

THE RHESUS SYSTEM

- Rhesus factor; it's a red blood cell membrane antigen.
- About 85% of people have this antigen; they are said to be Rhesus positive (Rh+) and do not therefore make anti-Rhesus antibodies.
- The remaining 15% have no Rhesus antigen (they are Rhesus negative, or Rh -).
- Rh - individuals are capable of making anti-Rhesus antibodies, but are stimulated to do so only in certain circumstances, e.g. in *pregnancy*, or *as the result of an incompatible blood transfusion*.

LEUKOCYTES (White Blood Cells)

- **Main function:** Defending the body against microbes and other foreign materials.
- Largest blood cells
- Account for about 1% of the blood volume.
- Contain nuclei and some have granules in their cytoplasm.
- 2 main types:
 - i. Granulocytes** (polymorphonuclear leukocytes)
 - neutrophils, eosinophils and basophils
 - ii. Agranulocytes**
 - monocytes and lymphocytes.

Granulocytes (polymorphonuclear leukocytes)

- **Granulopoiesis:** follow a common line of development through **myeloblast** to **myelocyte** before differentiating into 3 types.
- Have multilobed nuclei in their cytoplasm.
- Their names represent the dyes they take up when stained in the laboratory.
 - **Eosinophils;** red acid dye, eosin;
 - **Basophils;** alkaline methylene blue;
 - **Neutrophils** (purple); take up both dyes.



Basophil



Neutrophil



Eosinophil

The granulocytes (granular leukocytes)

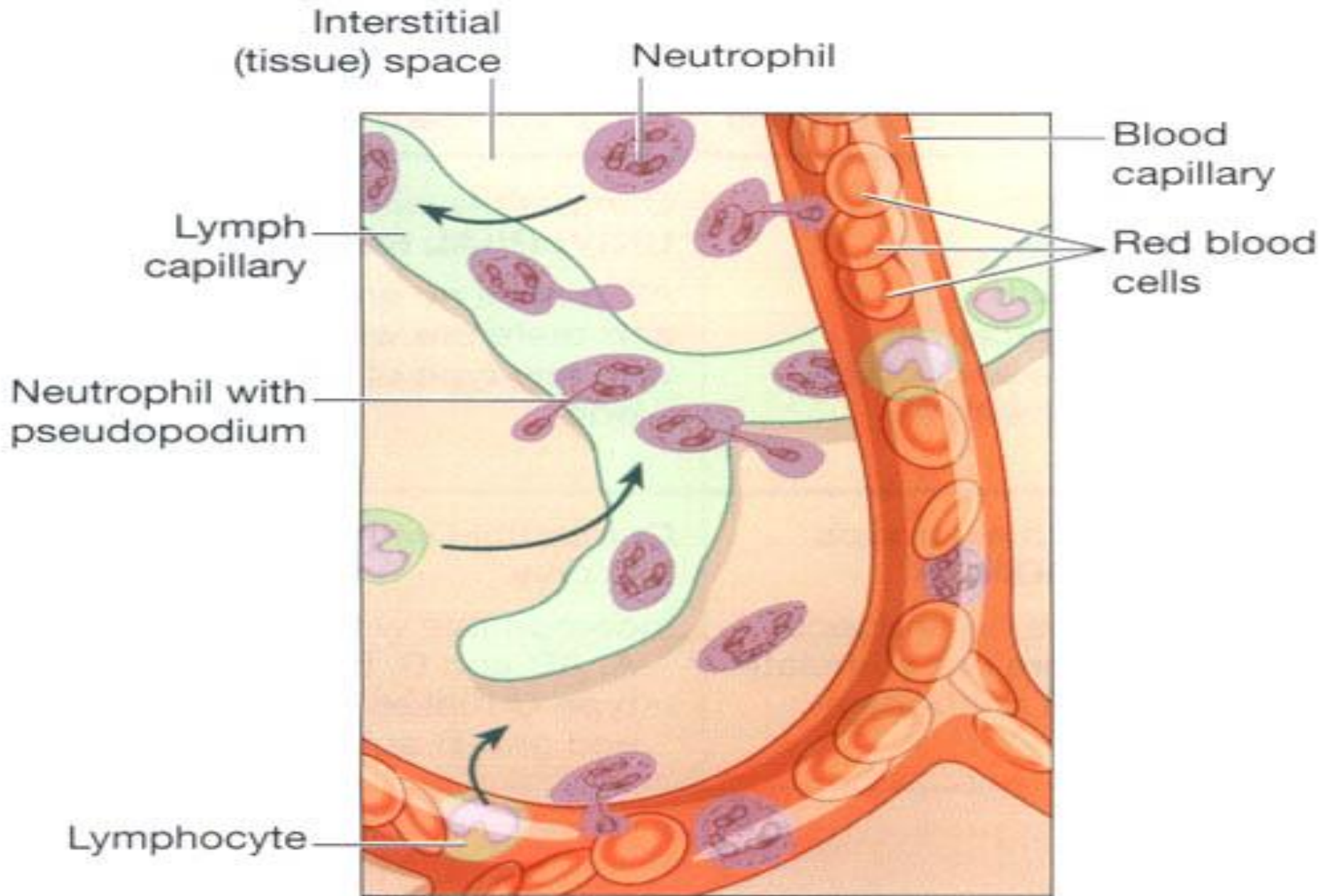
Assignment:

- Make notes on the numbers of different types of leucocytes in adult blood.
- Draw the structure of granulocytes

granulocytes

a) Neutrophils

- **Main function:** protect against any foreign material that gains entry to the body mainly microbes, and to remove waste materials, e.g. cell cells and debris.
- Attracted in large numbers to any area of infection by chemical substances, released by damaged cells, called **chemotaxins**.
- Pass through the capillary walls in the affected area by **amoeboid movement (diapedesis)**. Thereafter they engulf and kill the microbes by phagocytosis .
- Their granules are lysosomes that contain enzymes that digest the engulfed material and their nuclei may contain upto six lobes

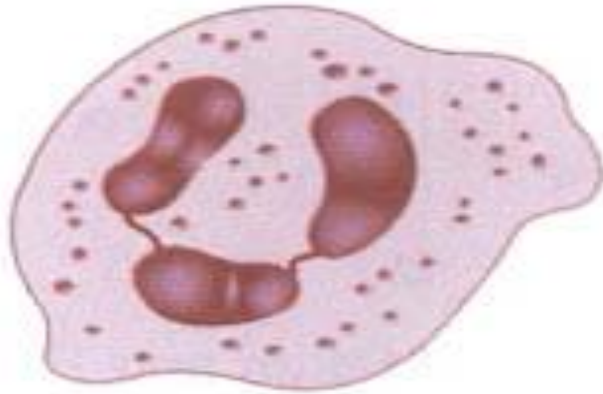


Amoeboid movement of leucocytes

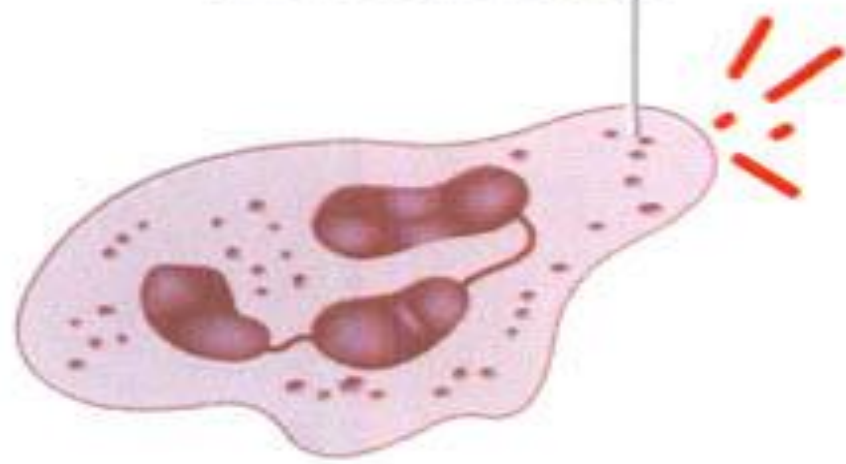
- Circulating neutrophils numbers increase (**neutrophilia**) in
 - Following strenuous exercise
 - The later stages of normal pregnancy.
- Numbers are also increased in:
 - ❖ Microbial infection
 - ❖ Tissue damage, e.g. inflammation, myocardial infarction, burns, crush injuries
 - ❖ Metabolic disorders, e.g. diabetic ketoacidosis, acute gout
 - ❖ Leukaemia
 - ❖ Heavy smoking
 - ❖ Use of oral contraceptives.

Phagocytic action of neutrophils

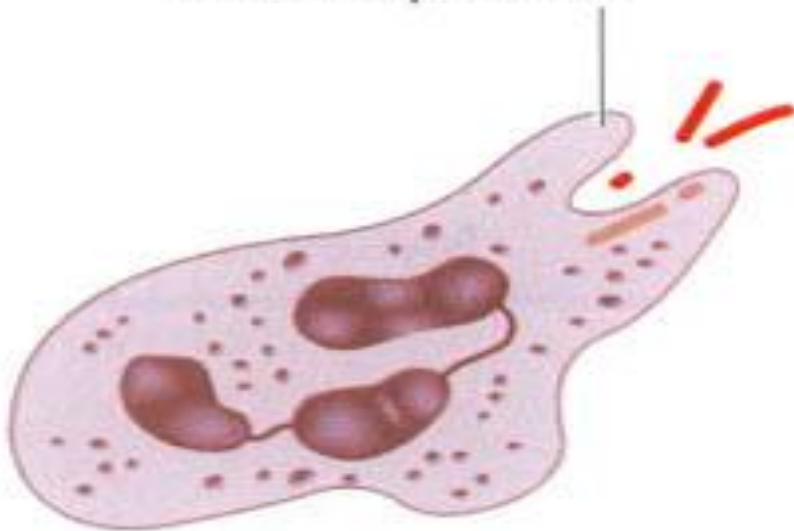
Microbes



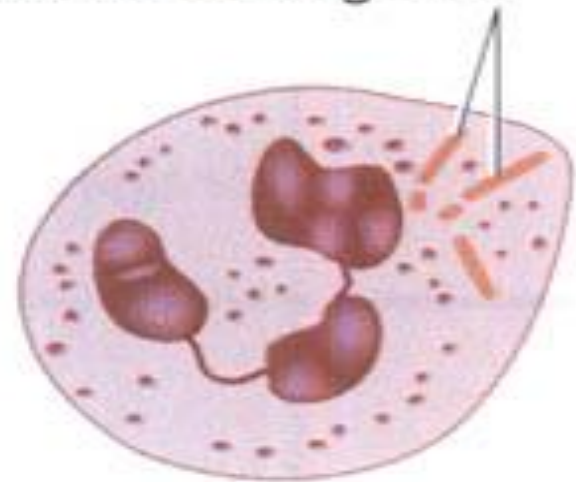
Pseudopodium



Pseudopodium



Microbes engulfed



b) Eosinophils

- **Main role:** elimination of parasites, such as worms, which are too big to be phagocytosed.
- Less active in phagocytosis than neutrophils.
- Equipped with certain toxic chemicals, stored in their granules, which they release when the eosinophil binds an infecting organism.
- Often found at sites of allergic inflammation, such as the asthmatic airway and skin allergies where they promote tissue inflammation by releasing their array of toxic chemicals, but they may also inhibit the inflammatory process through the release of other chemicals, such as an enzyme that breaks down histamine.
- **Eosinophilia** occurs in allergic disorders, parasitic infections, in leukaemia, systemic autoimmune disorders, HIV, etc

c) **Basophils**

- Closely associated with allergic reactions.
- Contain cytoplasmic granules packed with heparin (an anticoagulant), histamine (an inflammatory agent) and other substances that promote inflammation.
- Stimulus that causes basophils to release the contents of their granules is an **allergen** (an antigen that causes allergy).
- This binds to antibody-type receptors on the basophil membrane.
- **Mast cells**: basophils found in tissues and not in circulation.
- Mast cells release their granule contents within seconds of binding an allergen, which accounts for the rapid onset of allergic symptoms following exposure to ,e.g , pollen in hay fever.
- **Basophilia** occurs in: allergy and inflammation, DM, hypothyroidism, chicken pox, TB, leukemia, other cancers etc

assignment

- **Granulocytopenia** refers to a situation when granulocytes are abnormally low in the blood. List the common causes of;
 1. Neutropenia
 2. Eosinopenia
 3. Basopenia

AGRANULOCYTES

- Have a large nucleus
- Have no granules in their cytoplasm
- Make up 25% to 50% of all leukocytes
- Includes:
 - **Monocytes and**
 - **Lymphocytes**

a) Monocytes

- Are large mononuclear cells that originate in red bone marrow.
- Some circulate in the blood and are *actively motile* and *phagocytic* while others migrate into the tissues where they develop into **macrophages**.
- Both types of cell produce interleukin 1 which:
 - acts on the hypothalamus, causing the rise in body temperature associated with microbial infections
 - stimulates the production of some globulins by the liver
 - enhances the production of activated T-lymphocytes.
- Macrophages have important functions in inflammation and immunity.

The monocyte-macrophage system/ reticuloendothelial system,

- Consists of the body's complement of monocytes and macrophages.
- Some macrophages are mobile whereas others are fixed.
- Cells of this system include:
 - **histiocytes** in connective tissues
 - **microglia** in the brain
 - **Kupffer cells** in the liver
 - **alveolar macrophages** in the lungs
 - **sinus-lining macrophages** (reticular cells) in the spleen, lymph nodes and thymus gland
 - **mesangial cells** in the glomerulus of nephrons in the kidney
 - **osteoclasts** in bone.
 - **Langerhans cells** in the skin
 - **Synovial cells** in the joints

- Macrophages are actively phagocytic and if they encounter large amounts of foreign or waste material, they tend to multiply at the site and 'wall off the area, isolating the material.
- Other fnxs:
 - Linking the specific and non specific immunity
 - Involved in repair of body tissues
- Their numbers are increased in **microbial infections, collagen diseases and some non-infective bowel conditions.**

b) Lymphocytes

- Smaller than monocytes and have large nuclei.
- Circulate in the blood and are present in great numbers in lymphatic tissue such as lymph nodes and the spleen.
- Lymphocytes develop from pluripotent stem cells in **red bone marrow** and from **precursors in the lymphoid tissue**, then travel in the blood to lymphoid tissue elsewhere in the body where they are activated, i.e. they become immunocompetent which means they are able to respond to antigens (foreign material).
- Lymphocytes are usually activated in the lymphatic tissue (especially the **Thymus**) to produce two distinct types: ***T-lymphocytes*** and ***B-lymphocytes*** which have different functions

Agranulocytes



Lymphocyte



Monocyte

THROMBOCYTES (platelets)

- Very small non-nucleated discs derived from the cytoplasm of **megakaryocytes** in red bone marrow.
- Contain a variety of substances that promote blood clotting, which causes **haemostasis (cessation of bleeding)**.
- Normal blood platelet count is between $200 \times 10^9/L$ and $350 \times 10^9/L$ (200 000 to 350 000/mm³).
- Control of production is a **fall in platelet count(stimulus)** and **thrombopoietin (effector)**.
- Life span is between 8 and 11 days. They are mainly stored in the spleen rather than found in the circulation.
- Destroyed by macrophages, mainly in the spleen.

HAEMOSTASIS

Cessation of bleeding is achieved through the following processes:

- 1. Vasoconstriction.** When platelets come in contact with a damaged blood vessel, their surface becomes sticky and they adhere to the damaged wall.
 - They then release **serotonin** which constricts the vessel, reducing blood flow through it. **Thromboxanes**; released by the damaged vessel itself also cause vasoconstriction.
- 2. Platelet plug formation.** Adherent platelets clump to each other and release **adenosine diphosphate (ADP)**, which attract more platelets to the site.
 - Passing platelets stick to those already at the damaged vessel and they too release their chemicals.

Many platelets rapidly arrive at the site of vascular damage and quickly form a temporary seal — the **platelet plug** (within 6 minutes).

3. Coagulation (blood clotting).

- Results in formation of an insoluble thread-like mesh of **fibrin** which traps blood cells and is much stronger than the rapidly formed platelet plug. In the final stages of this process **prothrombin activator** acts on the plasma protein **prothrombin** converting it to **thrombin**.
- **Thrombin** then acts on **fibrinogen** converting it to **fibrin**.
- **Prothrombin activator** can be formed by two processes which often occur together: **the extrinsic** and **intrinsic pathways** .

- **Extrinsic pathway** occurs **rapidly** (within seconds) when there is tissue damage outside the circulation. Damaged tissue releases a complex of chemicals called **thromboplastin or tissue factor**, which initiates coagulation.
- **Intrinsic pathway** is **slower** (3-6 minutes) and is confined to the circulation. It is triggered by damage to a blood vessel lining (endothelium) and the effects of platelets adhering to it.
- After a time the clot shrinks, squeezing out serum.

Stages of blood clotting

Thromboplastin released by damaged tissue cells enters the blood

Platelets adhere to damaged blood vessel lining

Extrinsic pathway

Intrinsic pathway

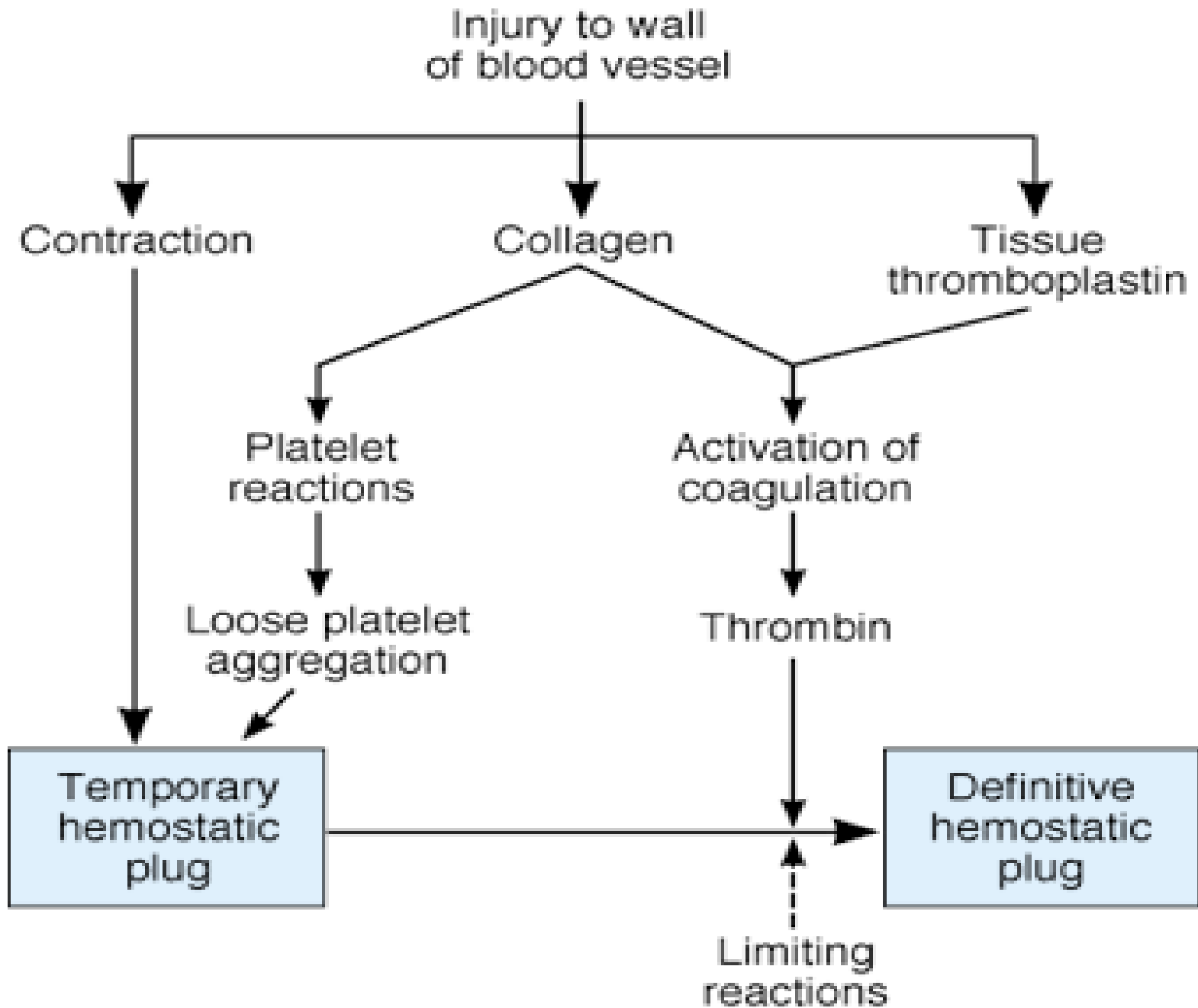
Prothrombin activator

Prothrombin → Thrombin

Fibrinogen → Loose fibrin threads

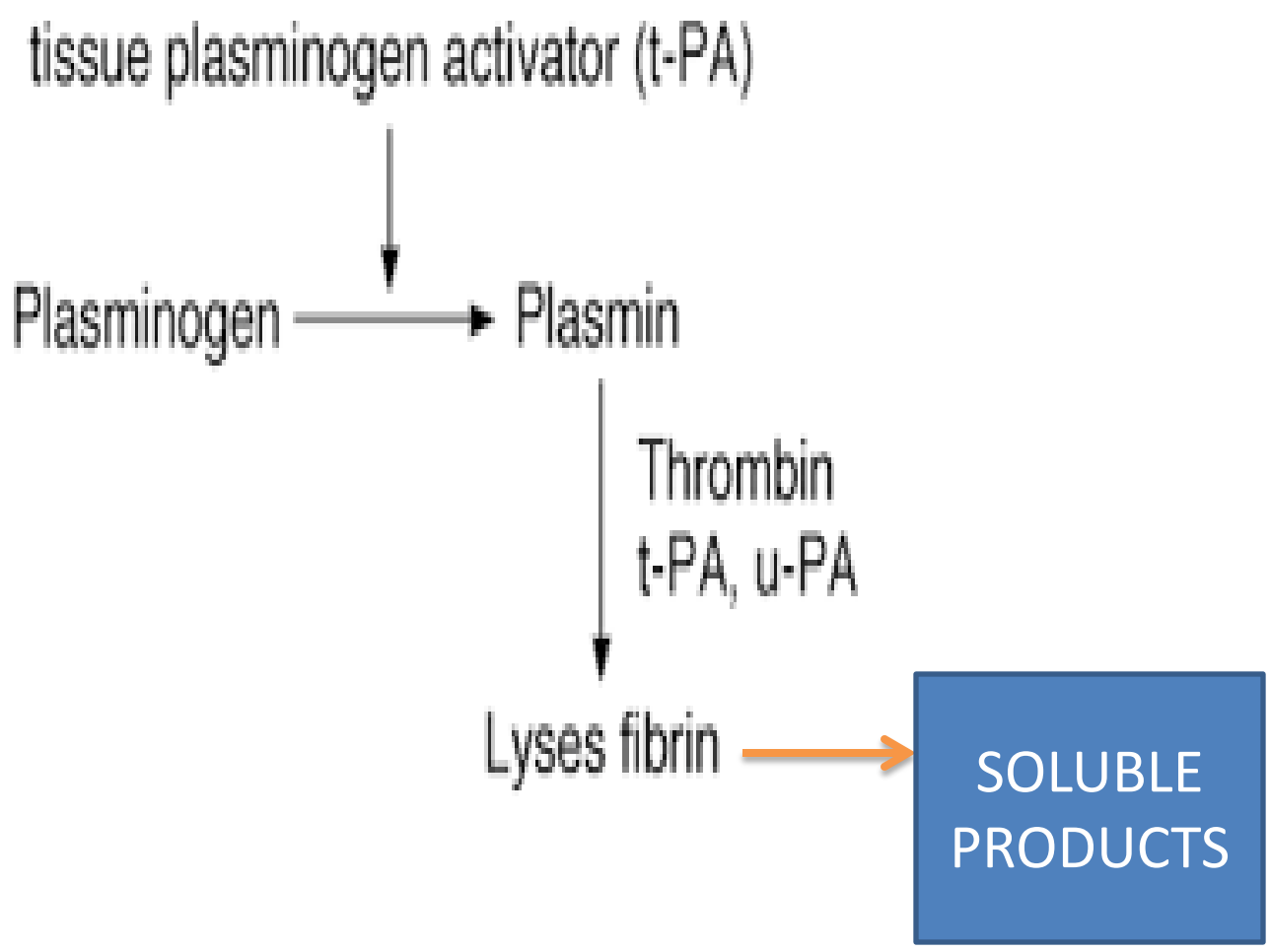
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Stabilised fibrin clot

Final common pathway



4. Fibrinolysis. After the clot has formed the process of removing it and healing the damaged blood vessel begins.

- An inactive substance called **plasminogen** is present in the clot and is converted to the enzyme **plasmin** by activators released from the damaged endothelial cells.
- **Plasmin** initiates the breakdown of fibrin to soluble products; removed by phagocytosis.
- As the clot is removed, the healing process restores the integrity of the blood vessel wall.



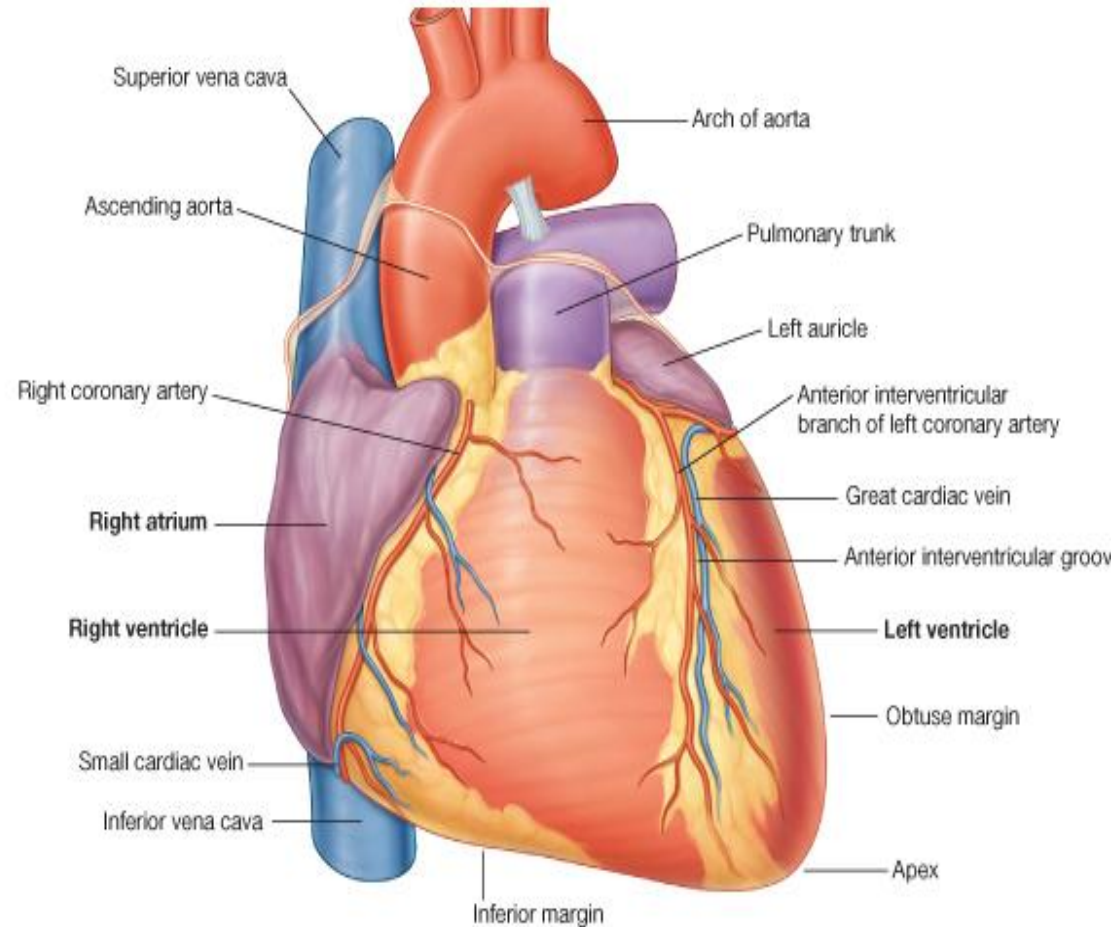
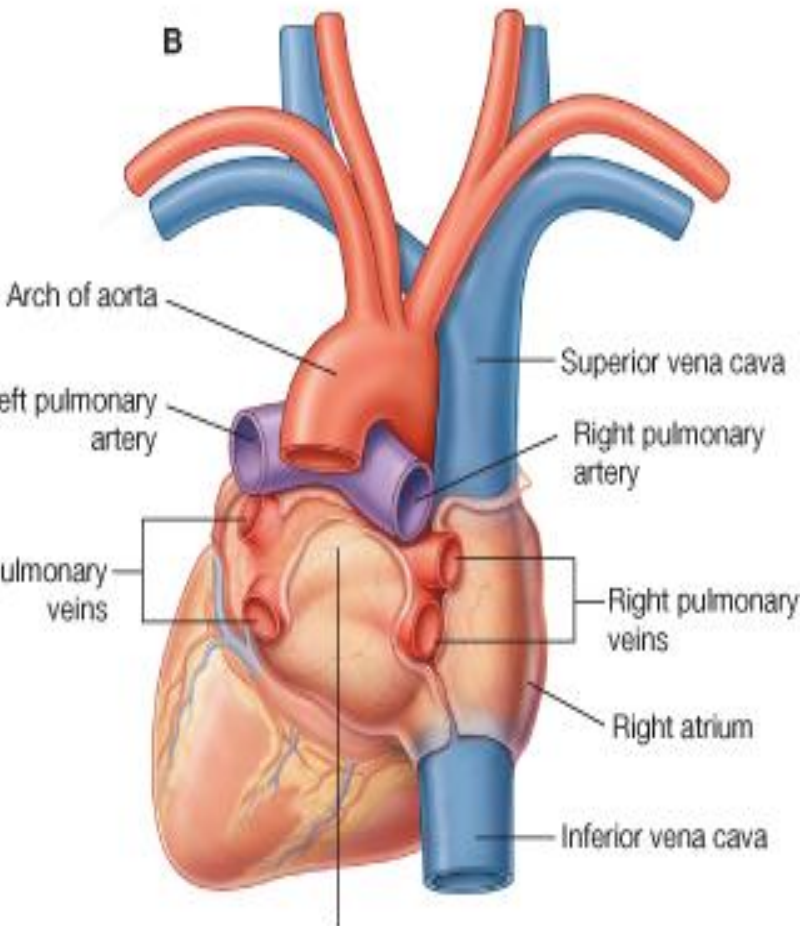
Assignment

1. List the clotting factors
2. Read and make notes on the Intrinsic and Extrinsic pathways of the clotting system
3. List four Vitamin K dependent factors

Control of coagulation

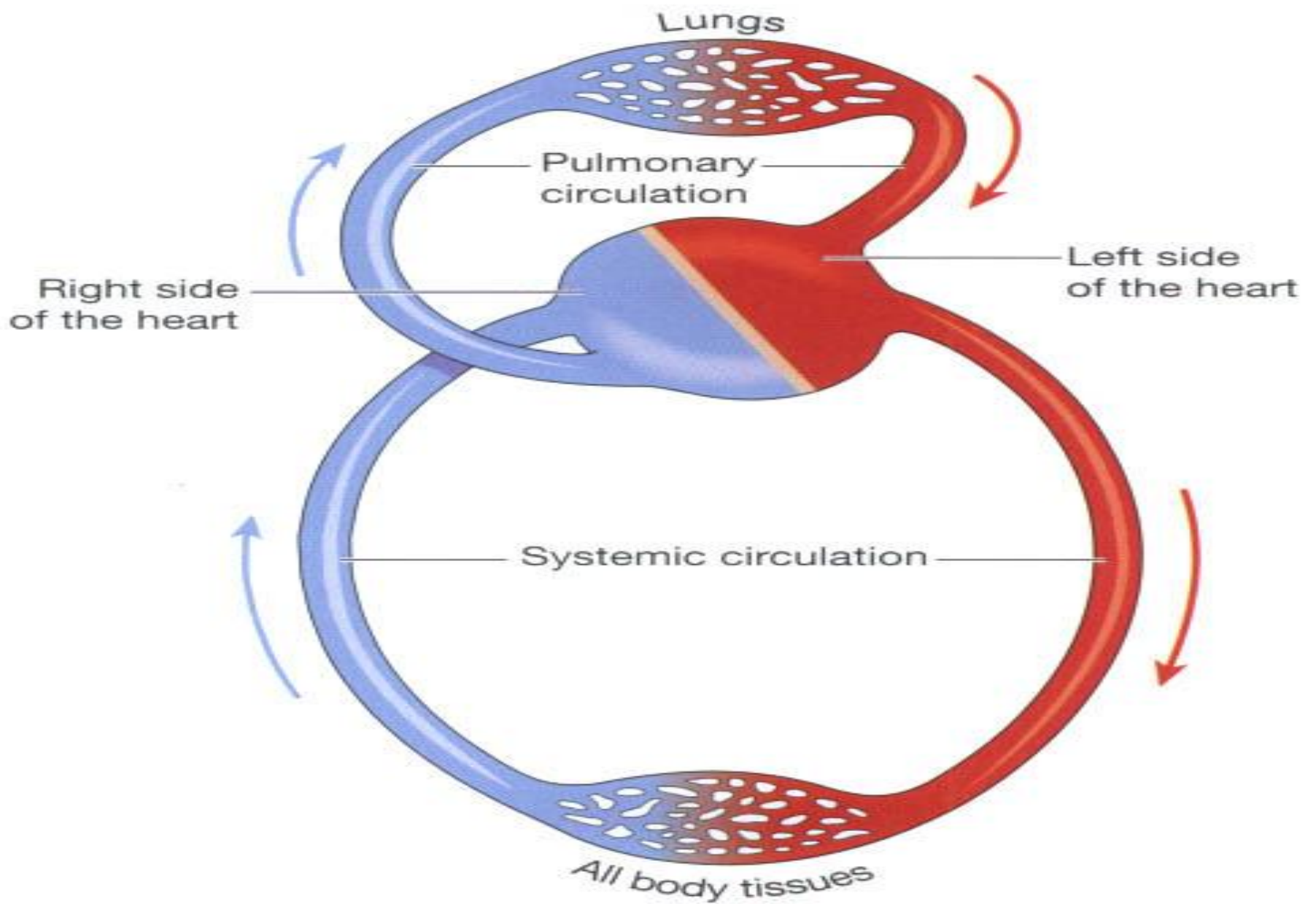
- A positive feedback mechanism promotes blood clotting since thrombin is a powerful stimulator of its own production.
- Main controls of coagulation are the:
 - Perfect smoothness of normal blood vessel lining: platelets do not adhere to this surface
 - Binding of thrombin to a special thrombin receptor on the cells lining blood vessels; once bound, thrombin is inactivated
 - Presence of natural anticoagulants, e.g. heparin, in the blood, which inactivate clotting factors.

CARDIOVASCULAR SYSTEM



introduction

- The cardiovascular system (CVS) is divided into two parts:
 - The heart (pump)
 - The blood vessels (pipes)
- The heart pumps blood into two systems of blood vessels namely;
 - i. The pulmonary circulation
 - ii. The systemic circulation
- Right side of the heart pumps blood to the lungs (**the pulmonary circulation**) where gas exchange occurs.
- Left side of the heart pumps blood into the **systemic circulation**; supplies rest of the body.



Relationship between pulmonary and systemic circulations²⁶³

Assignment

1. Draw a diagram showing the relationship between pulmonary and systemic circulations

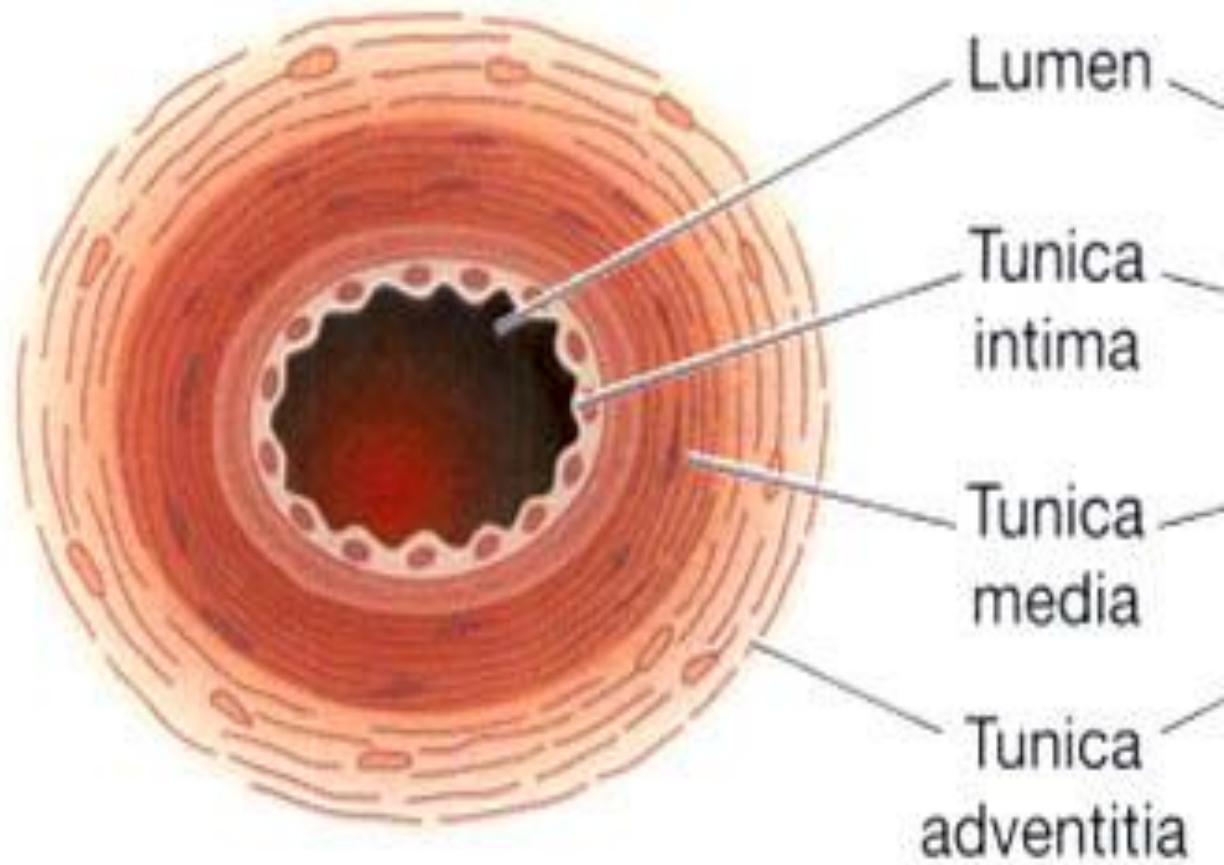
BLOOD VESSELS

SEE OBJECTIVES IN THE TEXT BOOK

- Blood vessels vary in **structure, size and function**
- **Types:**
 - **Arteries**
 - **Arterioles**
 - **Capillaries**
 - **Venules**
 - **Veins**

ARTERIES AND ARTERIOLES

- Blood vessels that transport blood away from the heart.
- Vary considerably in size
- Walls consist of 3 layers of tissue
 - **tunica adventitia** or outer layer of fibrous tissue
 - **tunica media** or middle layer of smooth muscle and elastic tissue
 - **tunica intima** or inner lining of squamous epithelium called *endothelium*.
- Amount of muscular and elastic tissue varies in the arteries depending upon their size.
 - Large arteries (elastic arteries); **tunica media** consists of **more elastic tissue** and **less smooth muscle**.
 - Arterioles (smallest arteries); **tunica media** consists almost entirely of **smooth muscle**.
- Arteries have **thicker walls** than veins; enables them to withstand high pressure of arterial blood.

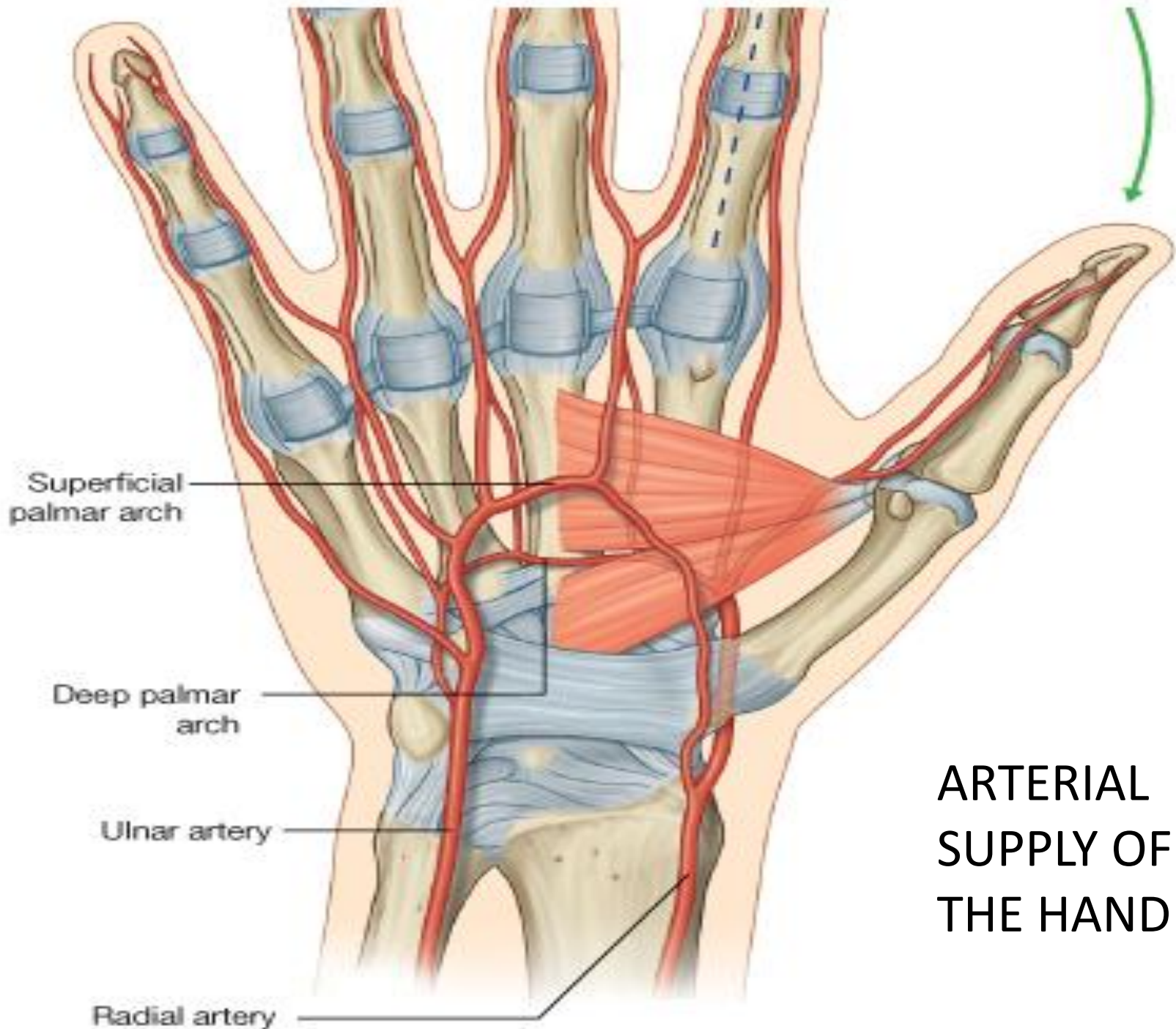


Artery

The tiny arteries are known as arterioles and since they cannot stretch, they offer resistance which determine systemic blood pressure. Are therefore known as *resistance vessels*.

ANASTOMOSES

- **Def:** arteries that form a link between main arteries supplying an area, e.g. the arterial supply to the palms of the hand and soles of the feet, the brain, the joints and, to a limited extent, the heart muscle.
- If one artery supplying the area is occluded anastomotic arteries provide a **collateral circulation**.
- This provides an adequate blood supply when the occlusion occurs gradually, giving the anastomotic arteries time to dilate.



ARTERIAL SUPPLY OF THE HAND

END-ARTERIES

- **Def:** arteries with no anastomoses or those beyond the most distal anastomosis, e.g. the branches from the circulus arteriosus (**circle of Willis**) in the brain or the central artery to the retina of the eye.
- When an end-artery is occluded the tissues it supplies die because there is no alternative blood supply.

CAPILLARIES

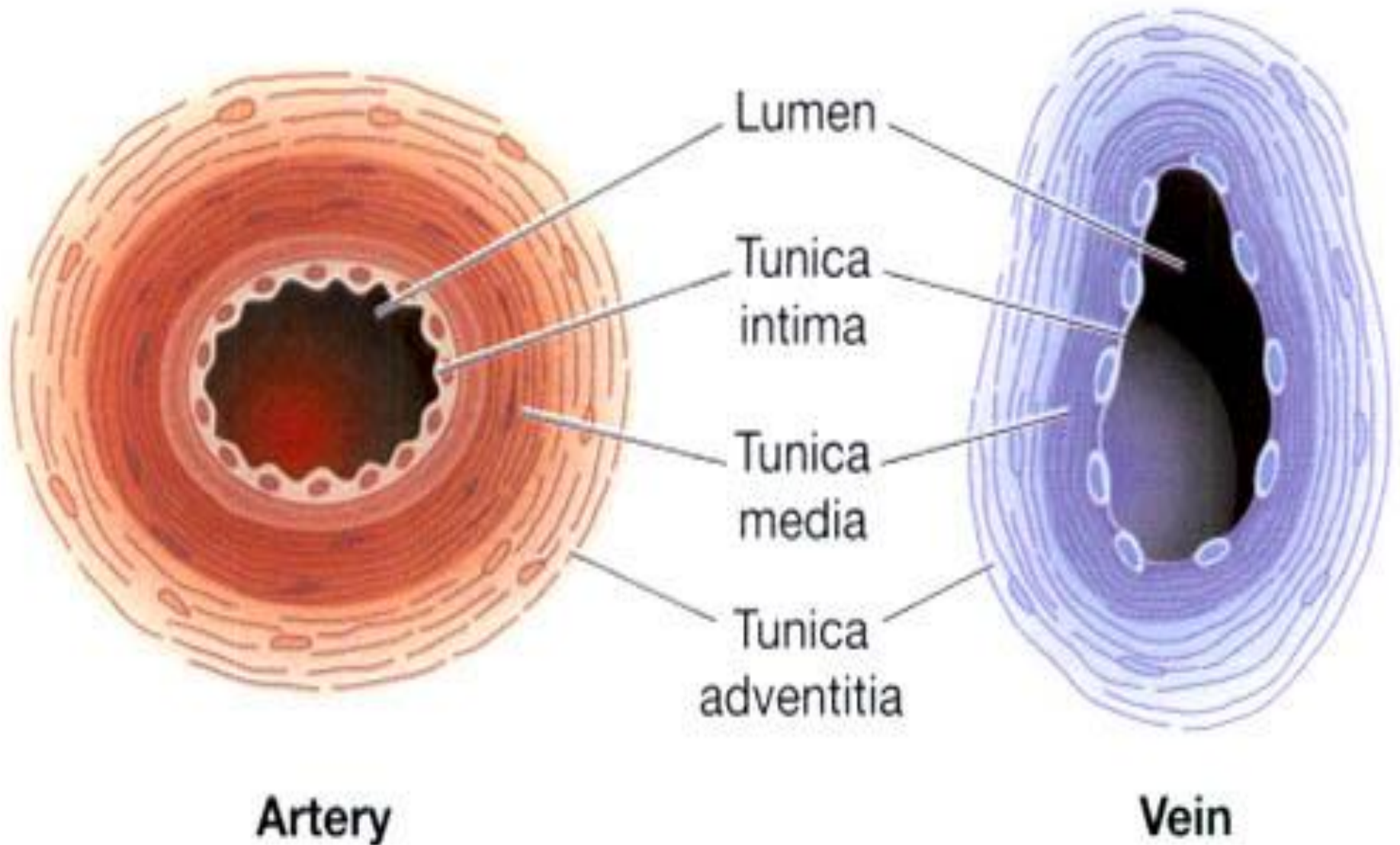
- **Def:** minute vessels formed from break up of smallest arterioles.
- Walls consist of a single layer of endothelial cells through which water and other small-molecule substances can pass.
- Form a vast network of tiny vessels which link smallest arterioles to smallest venules.
- Diameter; approximately **7 μm** .
- **Capillary bed:** site of exchange of substances between blood & tissue fluid.
- Blood entry into the capillary bed is guarded by ***precapillary sphincters*** that direct blood flow

SINUSOIDS

- Capillaries that are wider and leakier than normal capillaries
- Have extremely thin walls separating blood from the neighboring cells.
- Found in
 - bone marrow,
 - endocrine glands,
 - spleen
 - liver.
- Because of their larger lumen, BP in sinusoids is lower than in capillaries and there is a slower rate of blood flow.

VEINS AND VENULES

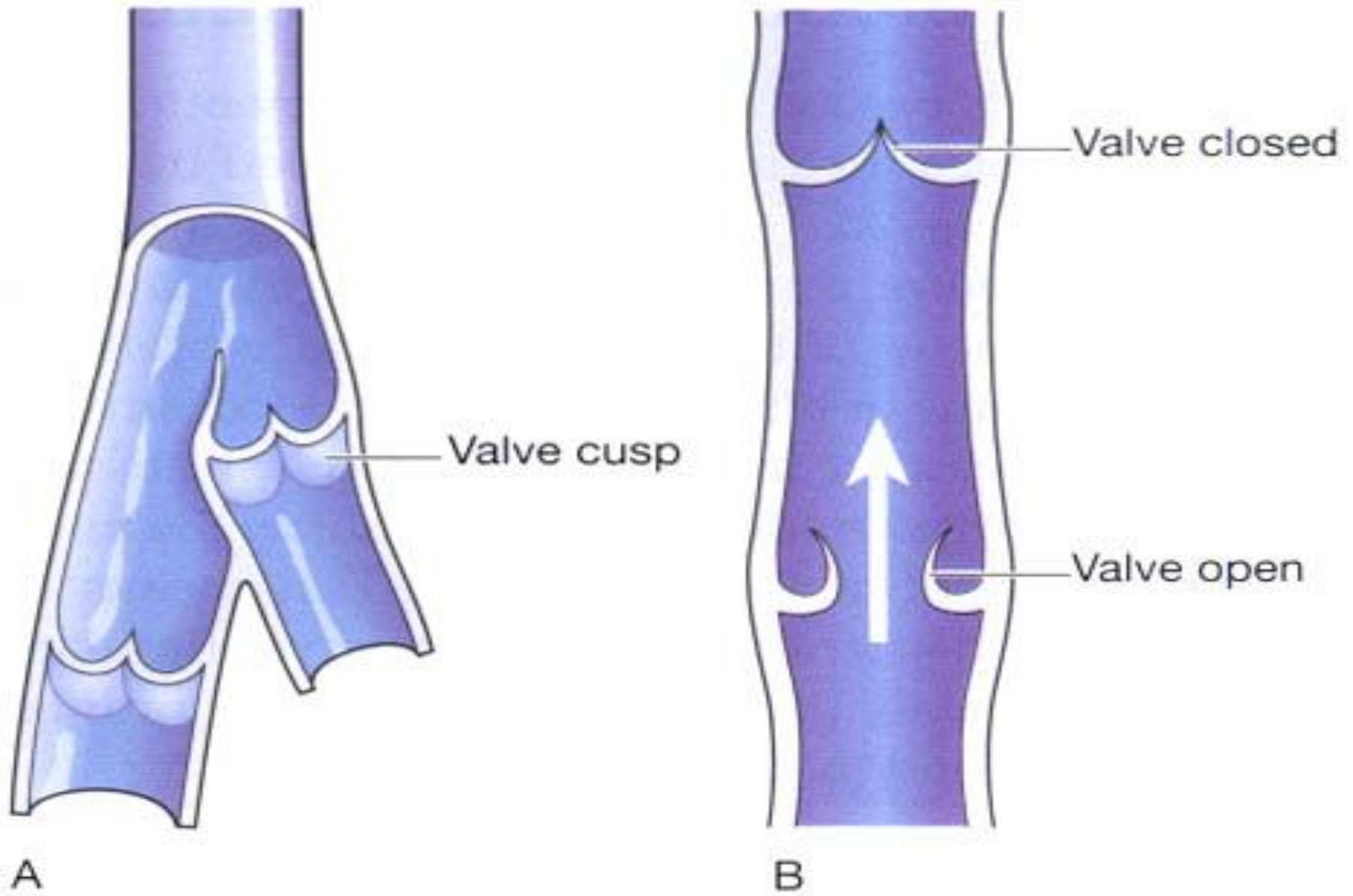
- **Veins:** blood vessels that return blood at low pressure to the heart.
- **Venules:** smallest veins
- Walls of the veins are thinner (because there is less muscle and elastic tissue in the tunica media than those of arteries) but have the same three layers of tissue.
- When cut, the veins collapse while the thicker-walled arteries remain open.
- When an artery is cut blood spurts at high pressure while a slower, steady flow of blood escapes from a vein.
- Veins are called **capacitance vessels** coz they are distensible and there4 have the capacity to hold a large proportion of blood



Structure of an artery and a vein

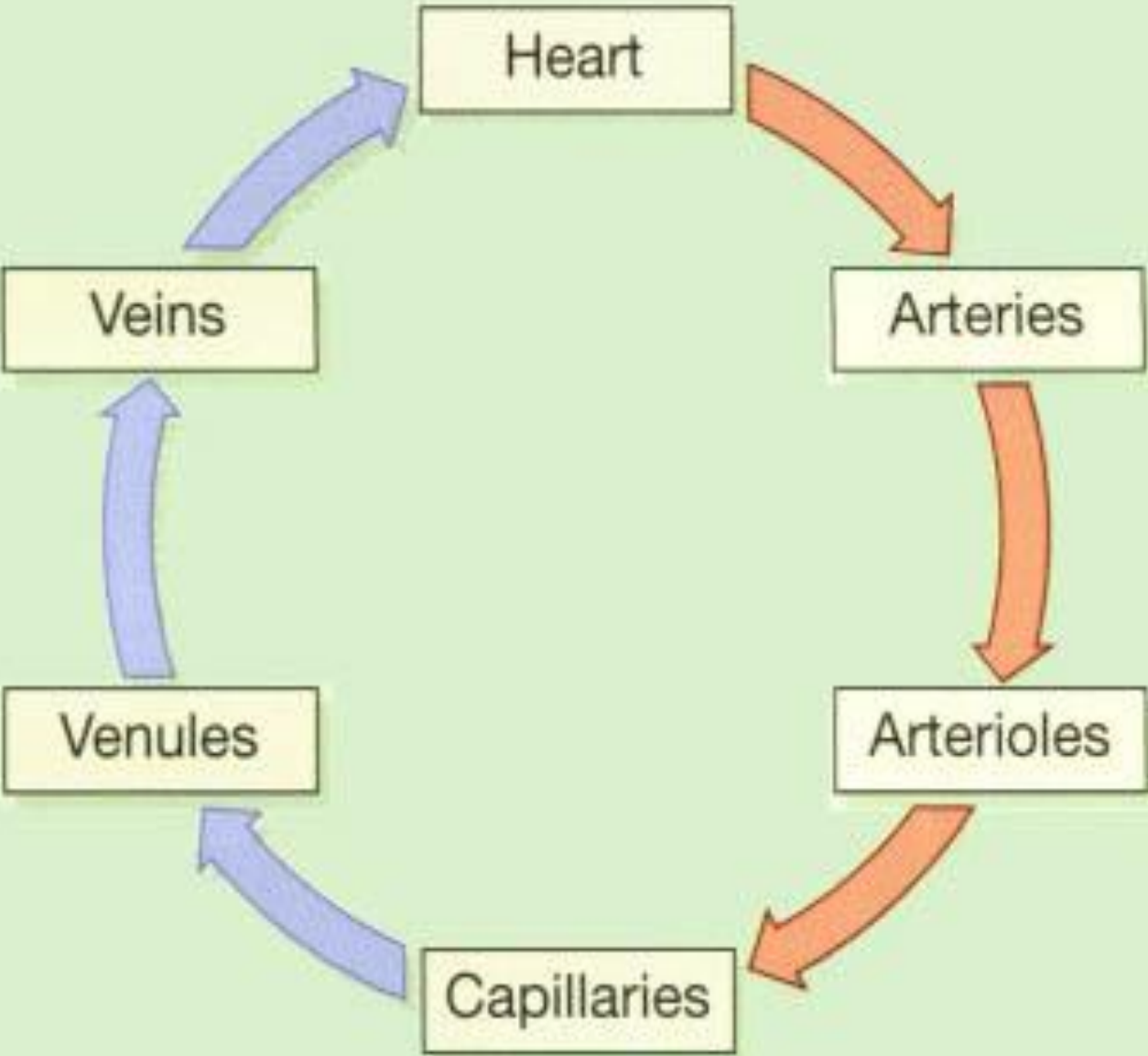
Valves

- Present in some veins
- Prevent backflow of blood, ensuring that it flows towards the heart.
- Formed by a fold of **tunica intima** strengthened by connective tissue.
- Cusps are **semilunar** in shape with the concavity towards the heart.
- Are abundant in limb veins, especially the lower limbs where blood must travel a considerable distance against gravity when the individual is standing.
- Absent in very small and very large veins in the thorax and abdomen.



The interior of a vein; valves and cusps

Relationship between the vascular network



Assignment

1. draw the cross-sectional structure of a vein and an artery

NB:

- Outer layers of tissue of thick-walled blood vessels receive their blood supply via a network of blood vessels called **vasa vasorum**.
- Vessels with thin walls and the endothelium receive oxygen and nutrients by diffusion from the blood passing through them.

Control of blood vessels diameter

- All blood vessels except capillaries have smooth muscle fibres in the tunica media which are supplied by nerves of autonomic nervous system (ANS).
 - The nerves arise from the **vasomotor centre** in the medulla oblongata and they change the diameter of the lumen of blood vessels, controlling the volume of blood they contain.
- **Medium-sized and small arteries** have more **muscle** than **elastic tissue** in their walls.
 - Thus, small arteries & arterioles respond to nerve stimulation whereas the diameter of large arteries varies according to the amount of blood they contain.

Vasodilatation & vasoconstriction

- Sympathetic nerves supply the smooth muscle of tunica media of blood vessels.
- Diameter of vessel lumen and tone of smooth muscle is determined by degree of sympathetic nerve stimulation.
- No parasympathetic nerve supply to most blood vessels.
- Decreased nerve stimulation causes smooth muscle to relax, thinning the vessel wall and enlarging the lumen (**vasodilatation**) and results in increased blood flow under less resistance. This increases the diameter while decreasing the pressure within blood vessels.
- When nervous activity is increased, smooth muscle of tunica media contracts and thickens (**vasoconstriction**). This decreases the diameter while increasing pressure within blood vessels

- Arterioles provide *peripheral resistance(PR)* (a major factor in BP regulation) to blood flow and thus called **resistance vessels**.
- Resistance to flow of fluids along a tube is determined by 3 factors:
 - Tube diameter;
 - Tube length;
 - Viscosity of fluid involved.

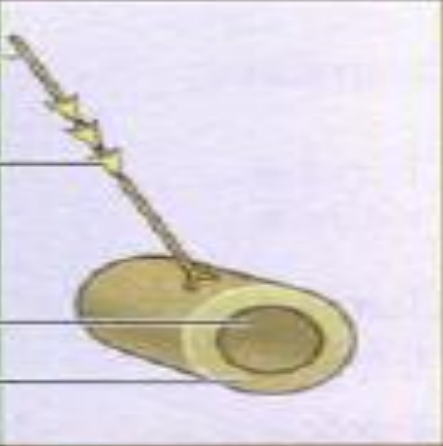

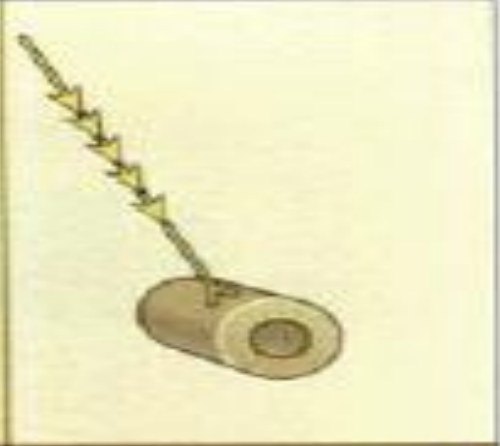
<p>Sympathetic nerve fibre</p> <p>Impulses in sympathetic fibre</p> <p>Lumen</p> <p>Vessel wall</p>			
	Resting situation	Vasodilatation	Vasoconstriction
Sympathetic stimulation	Moderate	Decreased	Increased
Smooth muscle	Moderate tone	Relaxed	Contracted
Thickness of vessel wall	Moderate	Thinner	Thicker
Diameter of lumen	Moderate	Increased	Decreased
Peripheral resistance in arterioles	Moderate	Decreased	Increased

Figure 5.5 The relationship between sympathetic stimulation and blood vessel diameter.

Autoregulation/Local regulation of Blood Flow

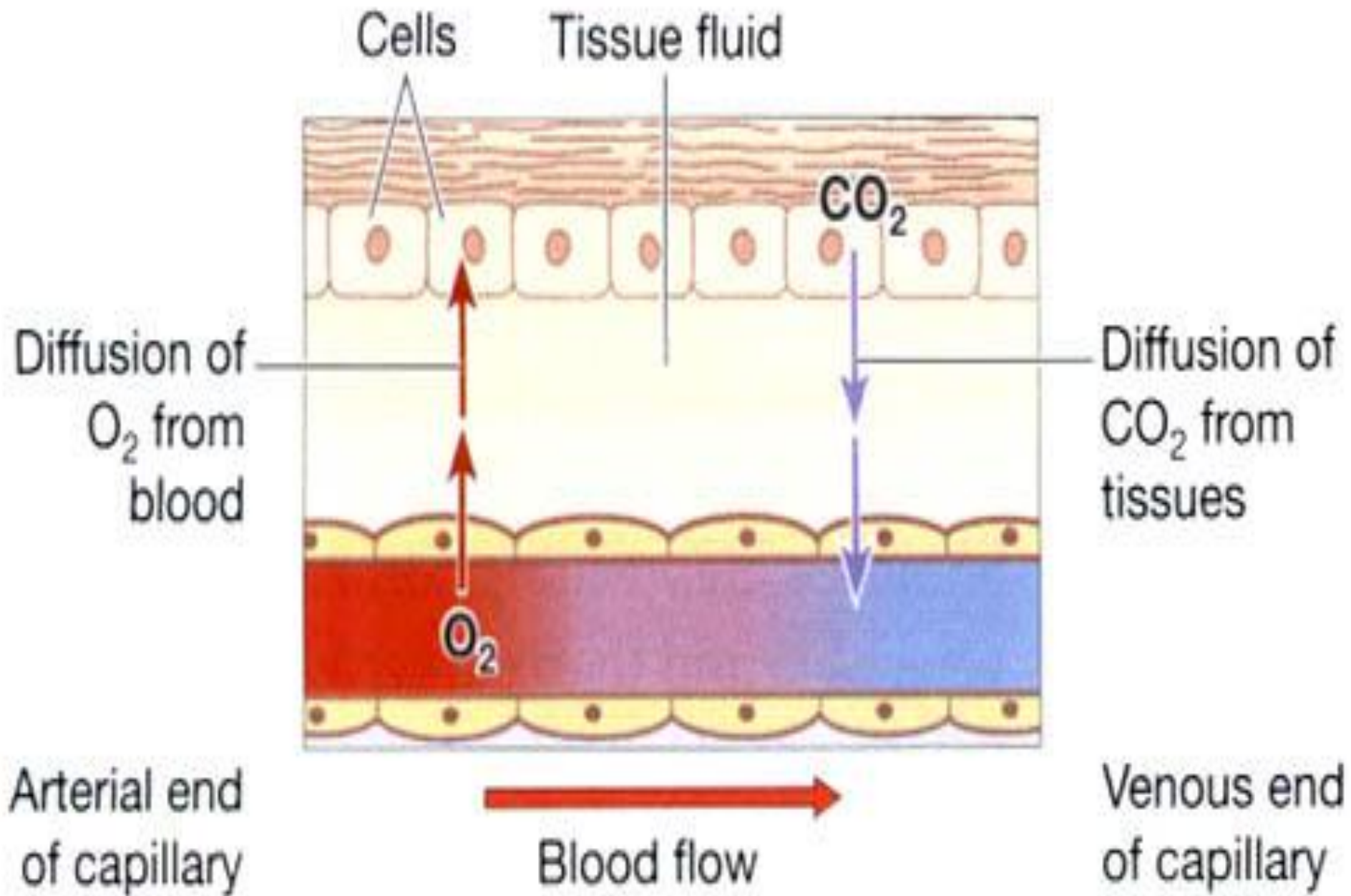
- Accumulation of metabolites in local tissues also influences the degree of dilatation of arterioles.
- This mechanism ensures that local blood flow is increased or decreased in response to tissue need.
- Main mechanisms involved in autoregulation includes:
 - Release of metabolic waste products e.g. CO₂ and lactic acid
 - Tissue temperature
 - Hypoxia
 - Release of vasodilator chemicals e.g. Nitric oxide
 - Activity of vasoconstrictor substances e.g. angiotensin 2 and epinephrine

Capillary exchange

Internal respiration

- **Def:** Exchange of gases between capillary blood and local body cells.
- Exchange in tissues takes place between blood at arterial end of capillaries & tissue fluid and then between the tissue fluid and the cells through diffusion.
- Oxygen is carried in the form of oxyhaemoglobin

- Oxyhaemoglobin is an unstable compound and breaks up (dissociates) easily to liberate oxygen which diffuse down its concentration gradient.
- Factors that increase dissociation include
 - hypoxia
 - raised temperature and
 - Low pH
- In active tissues there is an increased production of CO₂ and heat which leads to an increased availability of oxygen.
- CO₂ diffuses into blood down the concentration gradient towards the venous end of capillary.
- Blood transports CO₂ to lungs for excretion by 3 mechanisms:
 - dissolved in water of blood plasma — 7%
 - in chemical combination with sodium in the form of sodium bicarbonate — 70%
 - remainder in combination with Hb — 23%.



Exchange of gases in internal respiration

CELL NUTRITION

- Nutrients required by the cells of the body are transported in the blood plasma.
- Mechanism of the transfer of water and other substances from the blood capillaries depends mainly upon diffusion, osmosis & active transport.

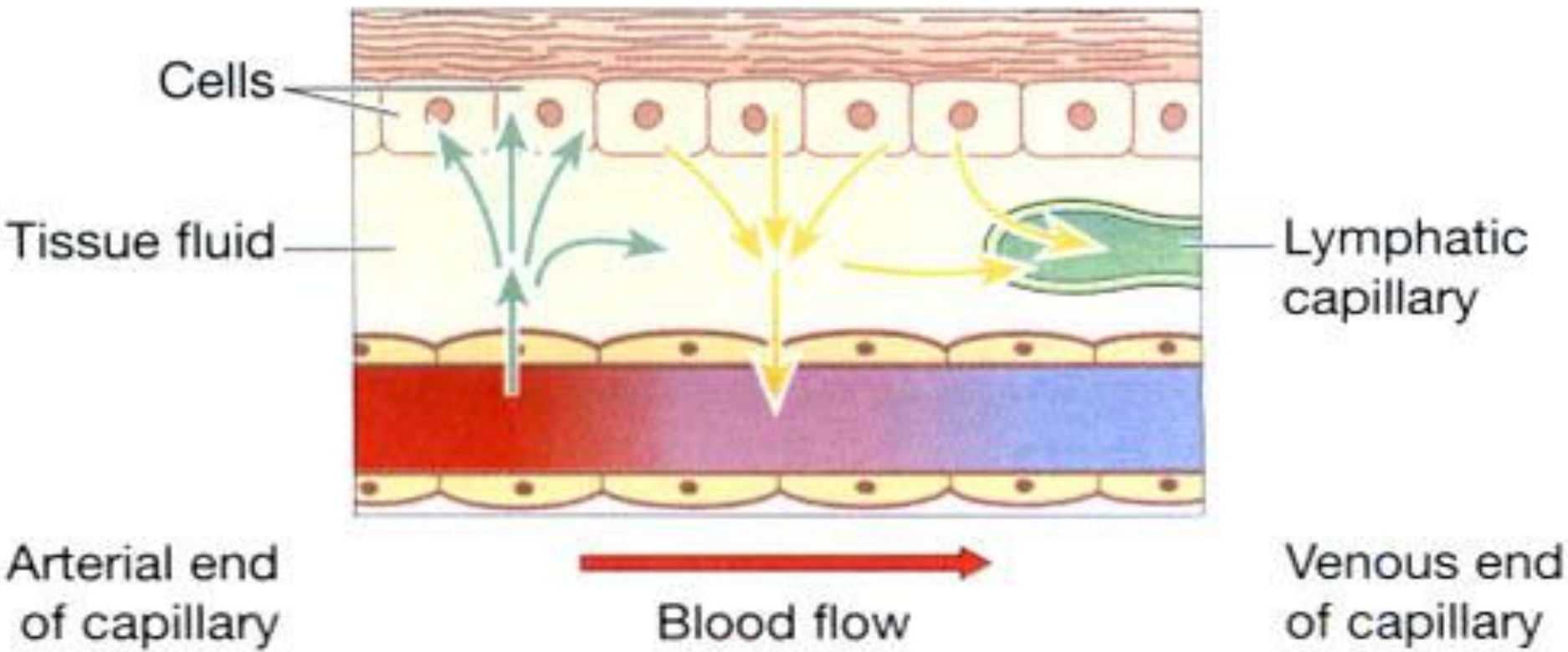
a) Diffusion



- Capillary walls consist of a single layer of epithelial cells that constitutes a semi-permeable membrane which allows substances with small molecules to pass through into tissue fluid, and retains large molecules in the blood.

- Diffusible substances include dissolved oxygen and CO₂, glucose, amino acids, fatty acids, glycerol, vitamins, mineral salts and water.

b) Osmosis

- Osmotic pressure across a semi-permeable membrane draws water from a dilute to a more concentrated solution in an attempt to establish a state of equilibrium.



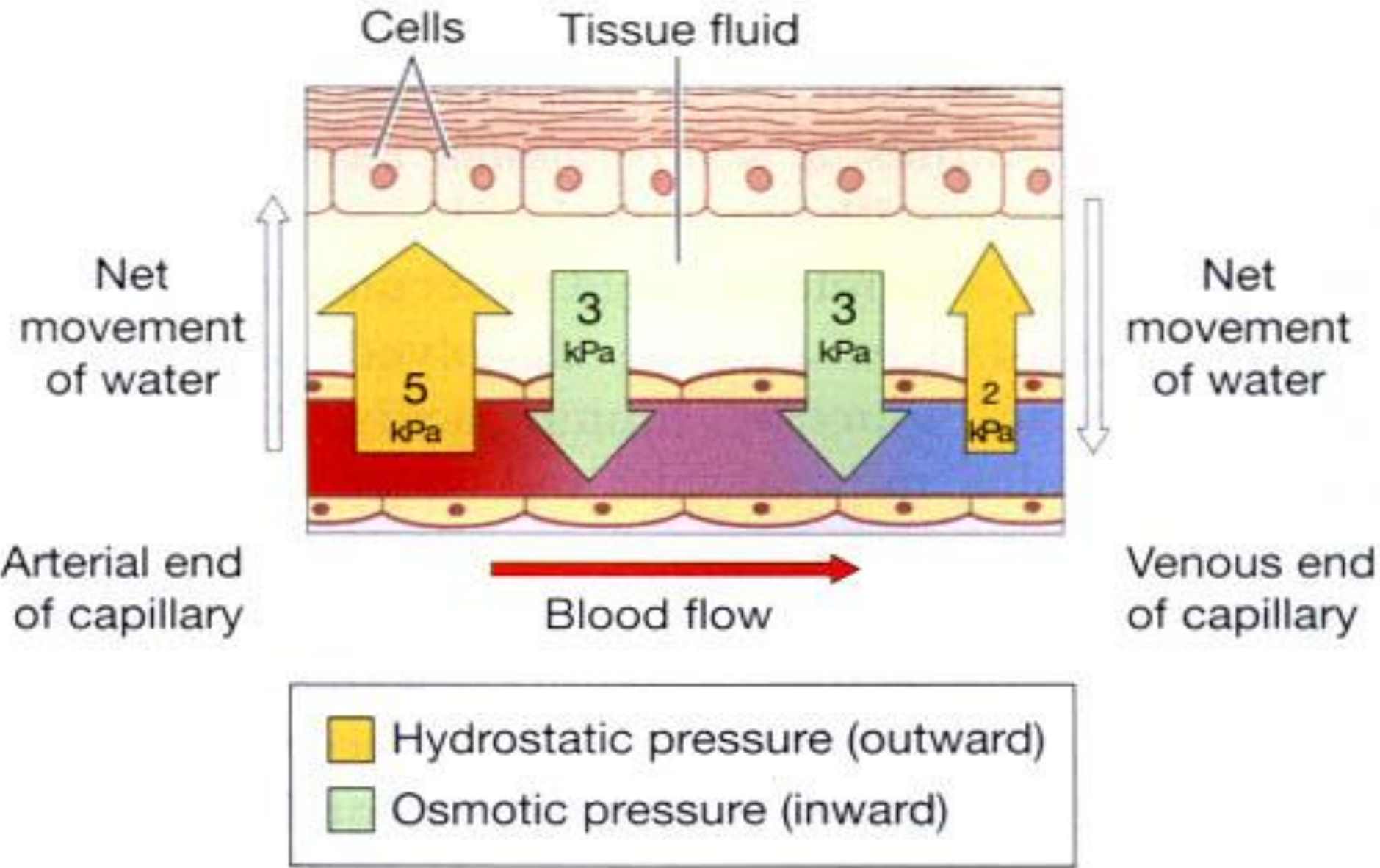
-  Movement of nutrients including oxygen
-  Movement of excess fluid and wastes, including carbon dioxide

Diffusion of nutrients and waste products b/n capillaries and cells

Capillary fluid dynamics

- At arterial end capillary BP, i.e. **hydrostatic pressure**, is about 35 mmHg (5 kPa).
 - Causes forward movement of blood and forces some water and solutes of small enough molecular size to pass out of capillaries into tissue spaces.
- **Osmotic pressure** in capillaries is about 25 mmHg (3.3 kPa).
 - Draws water into capillaries.
- Net **outward pressure** of 10 mmHg is the difference between hydrostatic & osmotic pressures.
- At venous end of capillaries hydrostatic pressure is reduced to about 15 mmHg (2 kPa) and the osmotic pressure remains the same, at 25 mmHg (3.3 kPa). Thus, net force moving water and solvents into capillaries is again the difference between the two pressures, i.e. 10 mmHg.

- As blood flows slowly through the large network of capillaries from arterial to the venous end, there is constant change.
- Not all water and cell waste products return to the blood capillaries.
- Excess is drained away from tissue spaces in the minute lymph capillaries which originate as blind-end tubes with walls similar to, but more permeable than, those of blood capillaries .
- Extra tissue fluid and some cell waste materials enter the lymph capillaries and are eventually returned to the bloodstream.



Effect of capillary pressures on water water movement between capillaries and cells.

THE HEART

Student's learning objectives

- At the end of the section, the student should be able to:
 - describe the structure of the heart and its position within the thorax
 - trace the circulation of the blood through the heart and the blood vessels of the body
 - outline the conducting system of the heart
 - relate the electrical activity of the cardiac conduction system to the cardiac cycle
 - describe the main factors determining heart rate and cardiac output.

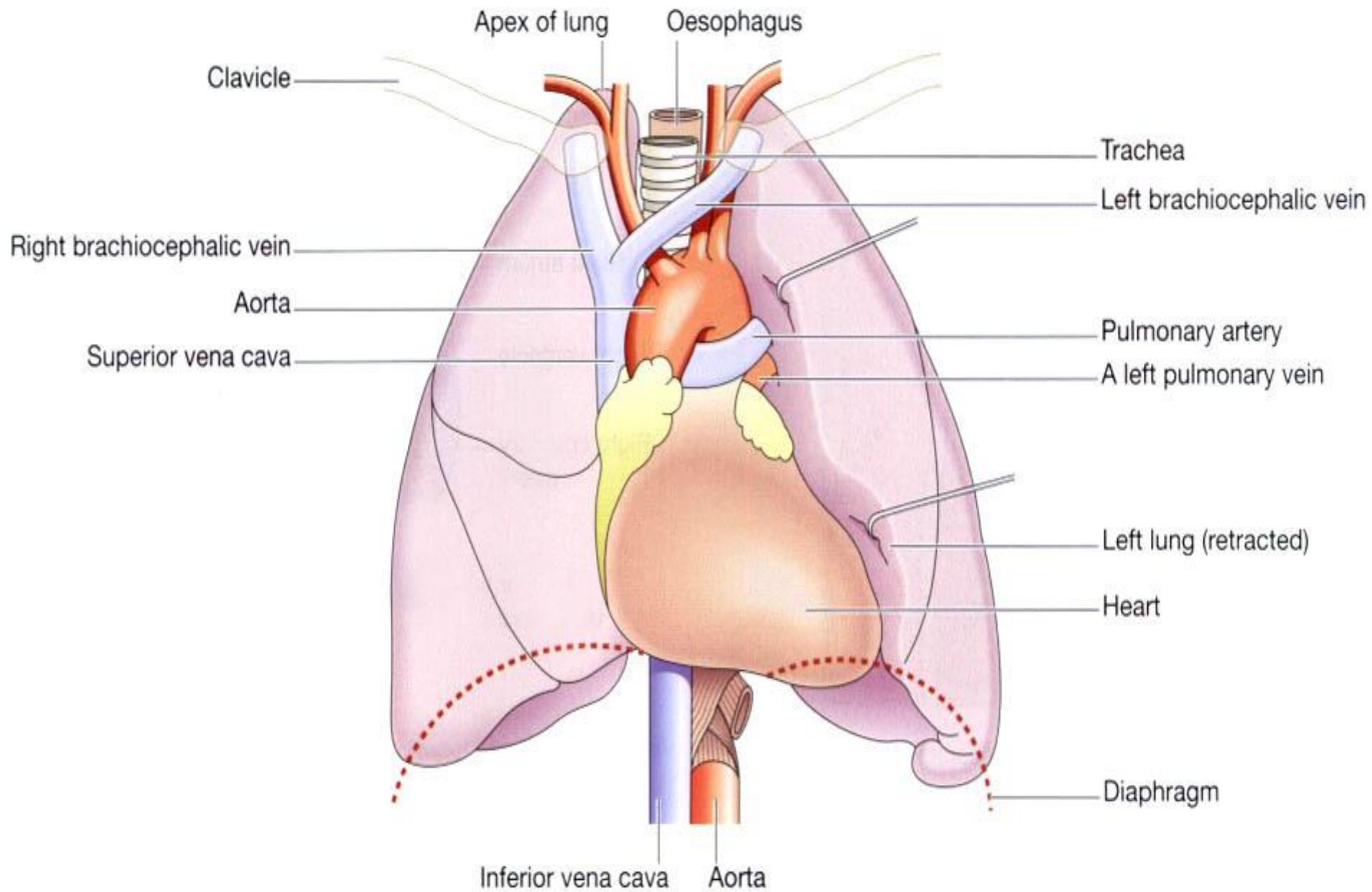
- Heart; roughly cone-shaped hollow muscular organ.
- It's about 10 cm long & about size of the owner's clenched fist.
- Weighs about 225 g in women and is heavier in men (about 310 g).

Position

- Lies in thoracic cavity in the mediastinum between the lungs.
- Lies obliquely, a little more to the left than right, and presents a **base above**, and an **apex below**.
- Apex is about 9 cm to the left of midline at the level of the 5th intercostal space, i.e. a little below the nipple and slightly nearer the midline. Base extends to the level of the 2nd rib.

Organs associated with the heart

- Inferiorly — apex rests on central tendon of diaphragm
- Superiorly — great blood vessels, i.e. aorta, superior vena cava, pulmonary artery & pulmonary veins
- Posteriorly — oesophagus, trachea, left and right bronchus, descending aorta, inferior vena cava and thoracic vertebrae
- Laterally — lungs; left lung overlaps left side of the heart
- Anteriorly — sternum, ribs and intercostal muscles



Anatomical relations

Structure

- Composed of 3 layers of tissue:
 - pericardium,
 - myocardium
 - endocardium.

a) Pericardium

- Made up of two sacs.
 - **Outer sac**; consists of **fibrous tissue**
 - **Inner sac**; continuous double layer of **serous** membrane.
- Outer fibrous sac is continuous with the tunica adventitia of the great blood vessels above and is adherent to the diaphragm below. It's inelastic, fibrous nature prevents over-distension of the heart.

- Outer layer of the serous membrane; **parietal pericardium**, lines the fibrous sac.
- Inner layer; **visceral pericardium/epicardium**, which is continuous with the parietal pericardium, is adherent to the heart muscle.
- Serous membrane consists of flattened epithelial cells.
 - Secretes serous fluid into the space between visceral and parietal layers ; allows smooth movement between them when the heart beats.
- Space between parietal & visceral pericardium is only a potential space.
 - The 2 layers are in close association, with only the thin film of serous fluid between them.

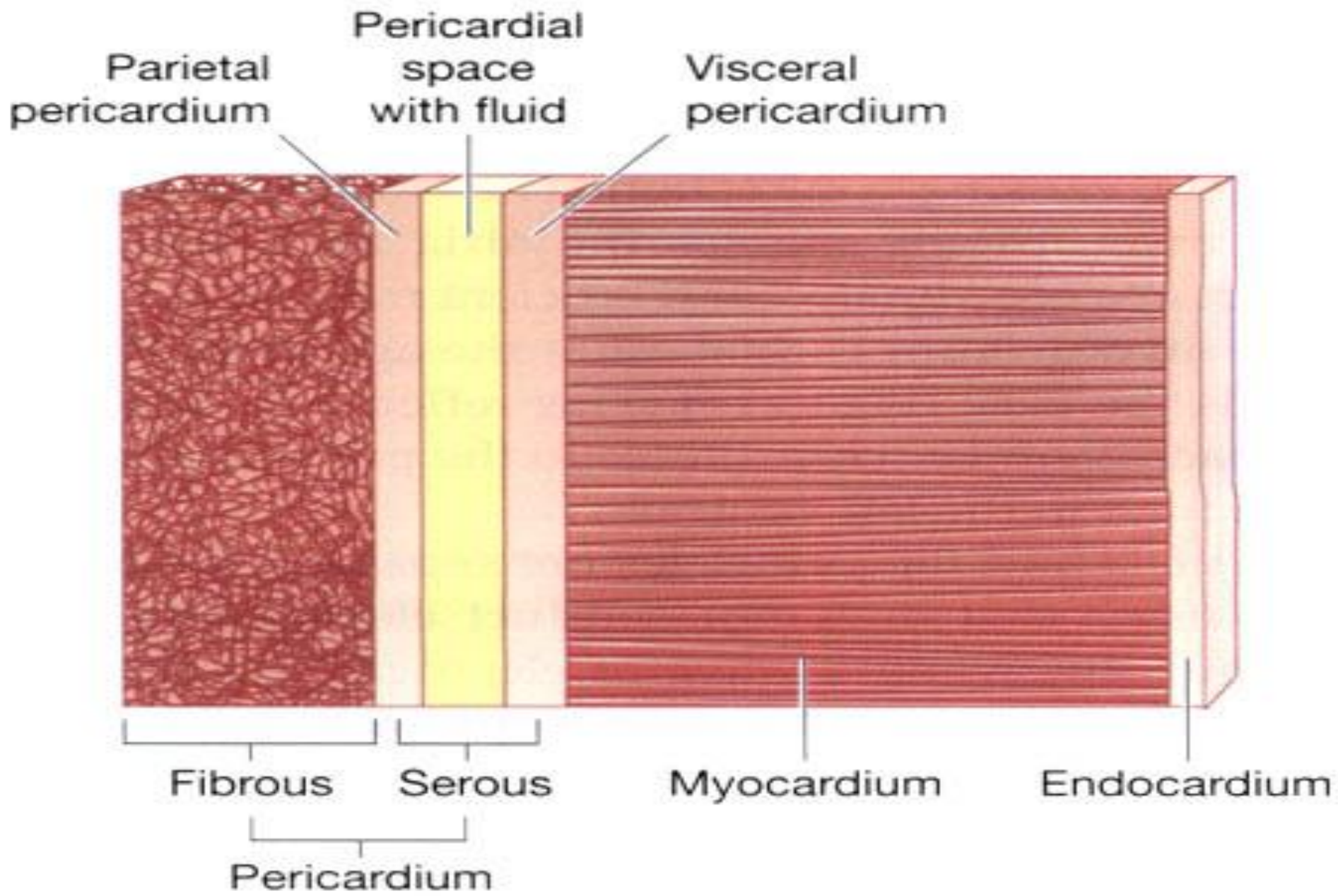
b) Myocardium

- Composed of specialized cardiac muscle found only in the heart.
- Not under voluntary control
- Each fibre (cell) has a nucleus & one or more branches.
- When an impulse is initiated it spreads from cell to cell via the branches and intercalated discs over the whole 'sheet' of muscle, causing contraction.
- The 'sheet' arrangement enables atria & ventricles to contract in a coordinated and efficient manner.
- Thickest at apex and thins out towards the base; reflecting amount of work each chamber contributes to pumping of blood.
 - Thickest in the left ventricle.

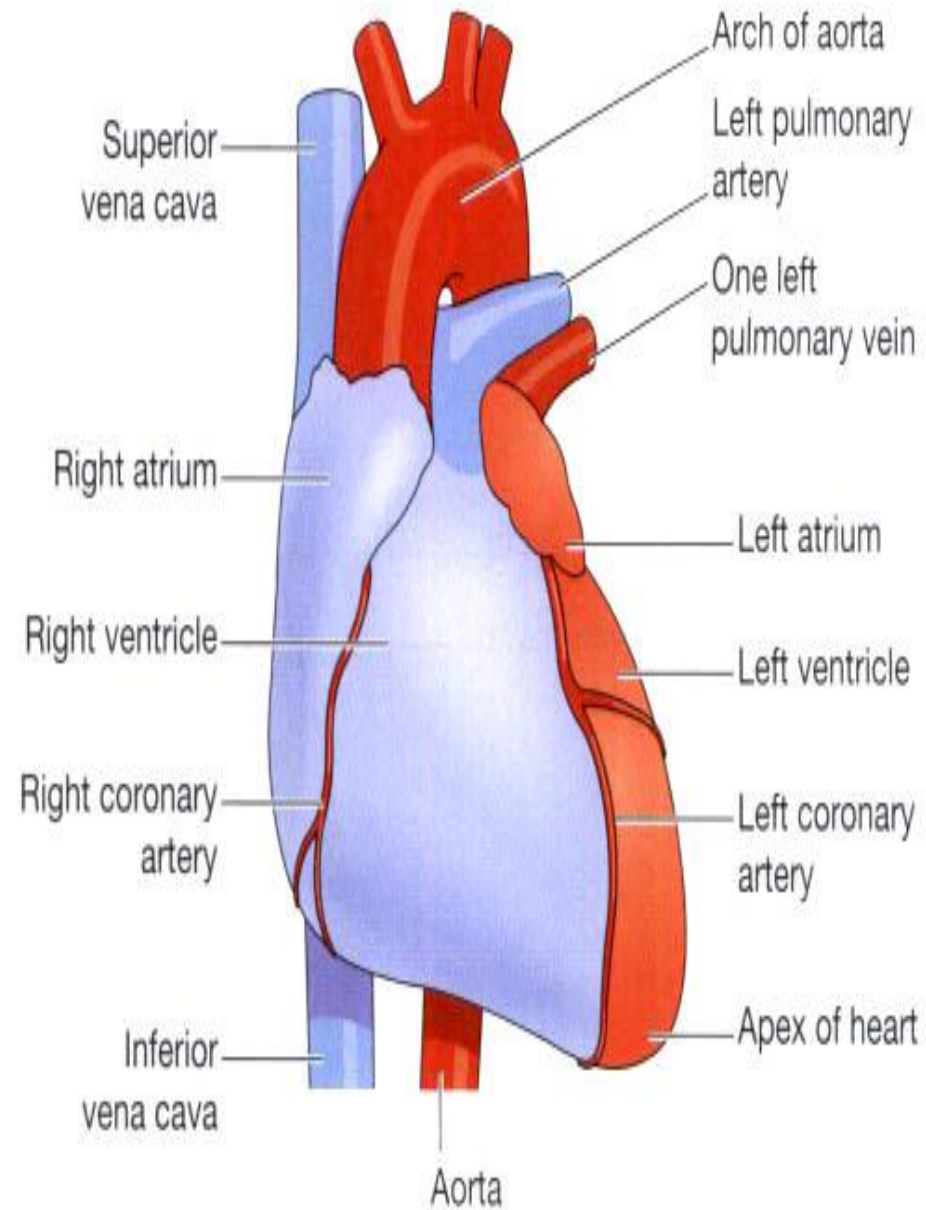
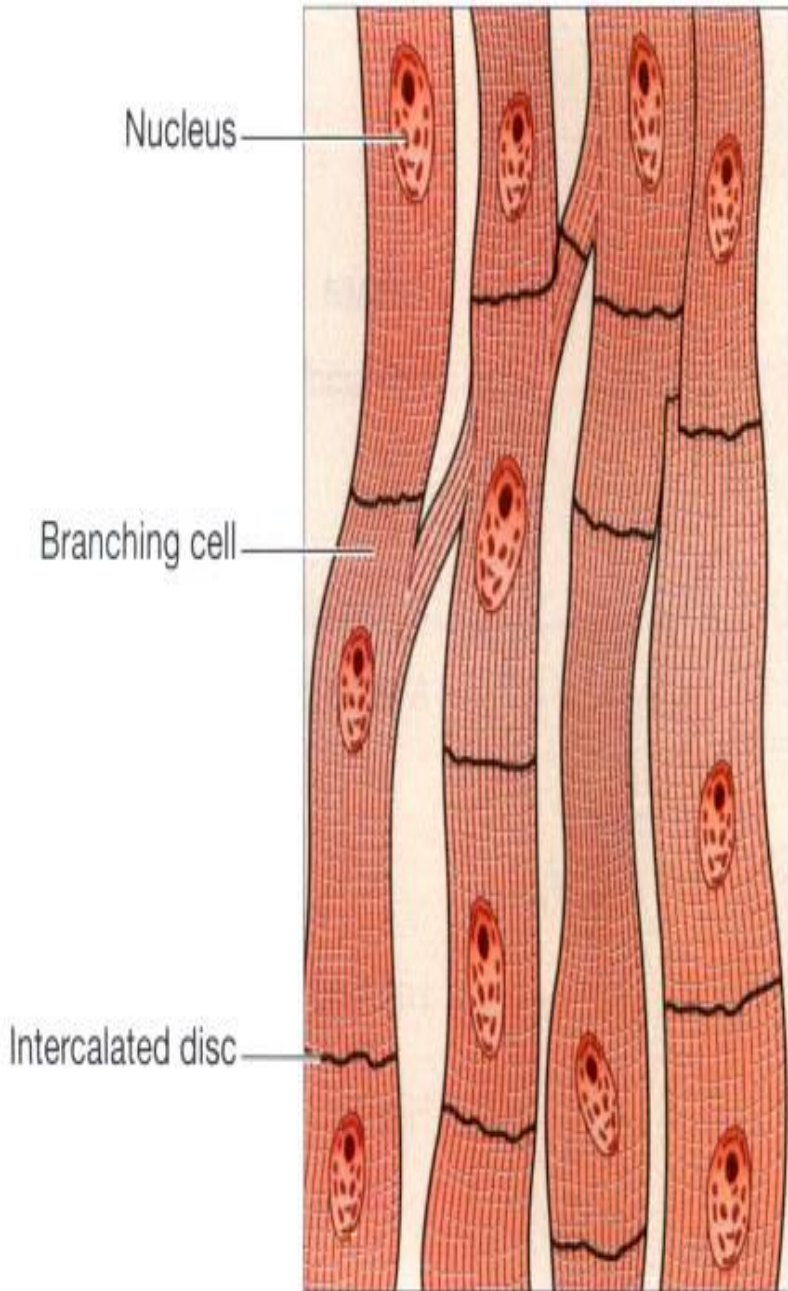
- Atria & ventricles are separated by a ring of fibrous tissue that does not conduct electrical impulses.
- Consequently, when a wave of electrical activity passes over the atrial muscle, it can only spread to the ventricles through the conducting system which bridges the fibrous ring from atria to ventricles.

c) Endocardium

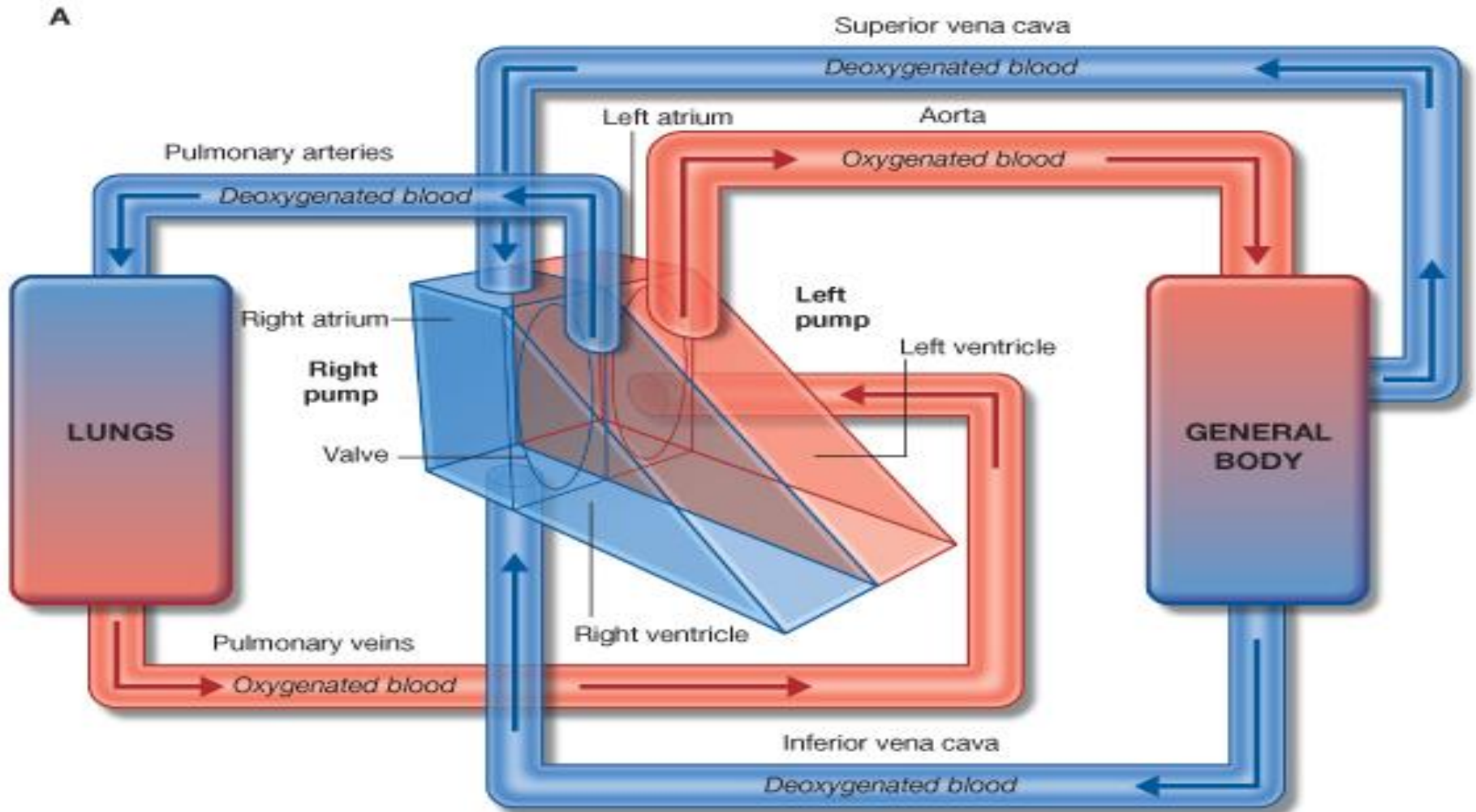
- Forms the lining of myocardium & heart valves.
- Thin, smooth, glistening membrane which permits smooth flow of blood inside the heart.
- Consists of flattened epithelial cells, continuous with the endothelium that lines the blood vessels.



Layers of the heart wall



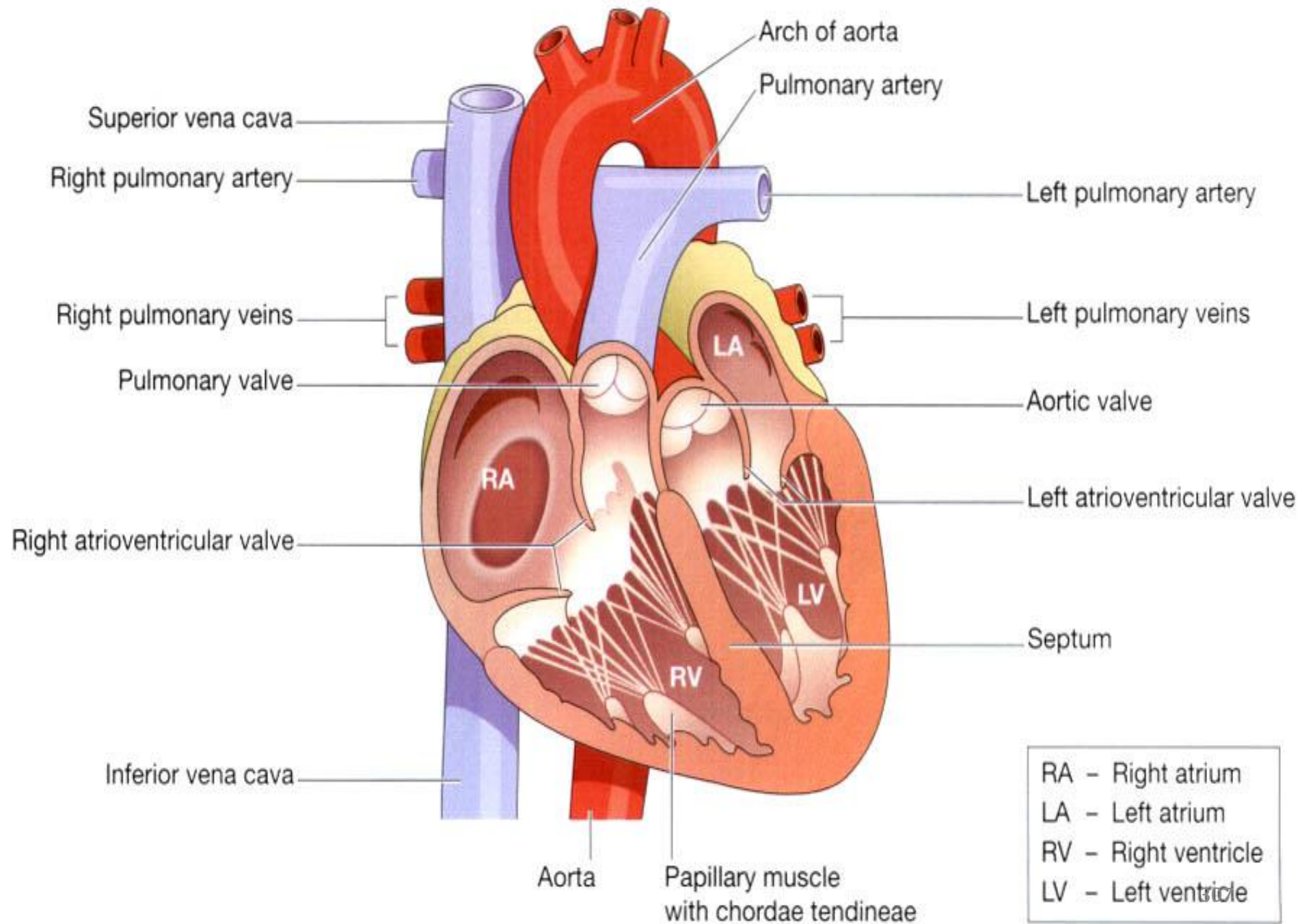
- Heart consists of 2 receiving chambers and 2 pumping chambers.
- Each chamber holds 60-70 mls of blood.



INTERIOR OF THE HEART

- Divided into a right and left side by a **septum**, a partition consisting of myocardium covered by endocardium.
- Each side is divided by an **atrioventricular valve** into an upper chamber, **atrium**, and a lower chamber, the **ventricle**.
- Atrioventricular valves are formed by double folds of endocardium strengthened by a little fibrous tissue.
- **Right atrioventricular valve (tricuspid valve)** has **3** flaps/cusps & **left atrioventricular valve (mitral valve)** has **2** cusps.
- Valves between atria & ventricles open and close passively according to changes in pressure in the chambers.
 - They open when the pressure in the atria is greater than that in the ventricles.

- During ventricular contraction, pressure in the ventricles rises above that in the atria and the valves snap shut preventing backward flow of blood.
- Valves are prevented from opening upwards into the atria by tendinous cords; **chordae tendineae**, which extend from the inferior surface of the cusps to little projections of myocardium covered with endothelium, called **papillary muscles**
- The septa and the atrioventricular valves divides the heart into four chambers, namely:
 - **Two upper chambers: Right and Left atrium**
 - **Two lower chambers: Right and Left Ventricles**
- **WHAT ARE THE FUNCTIONS OF EACH CHAMBER?**



Left atrio-ventricular valve

Atrium

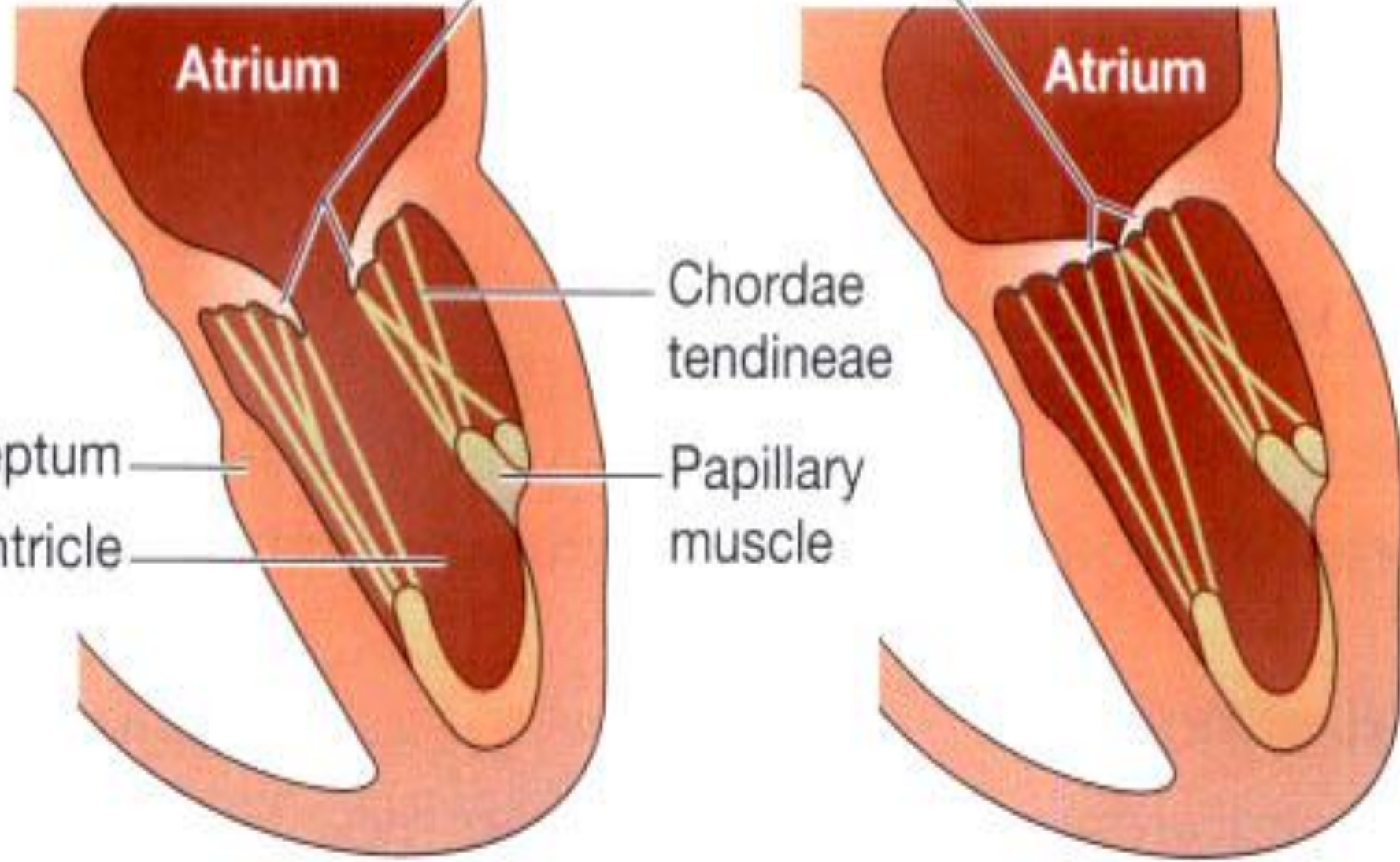
Atrium

Chordae tendineae

Septum

Papillary muscle

Ventricle

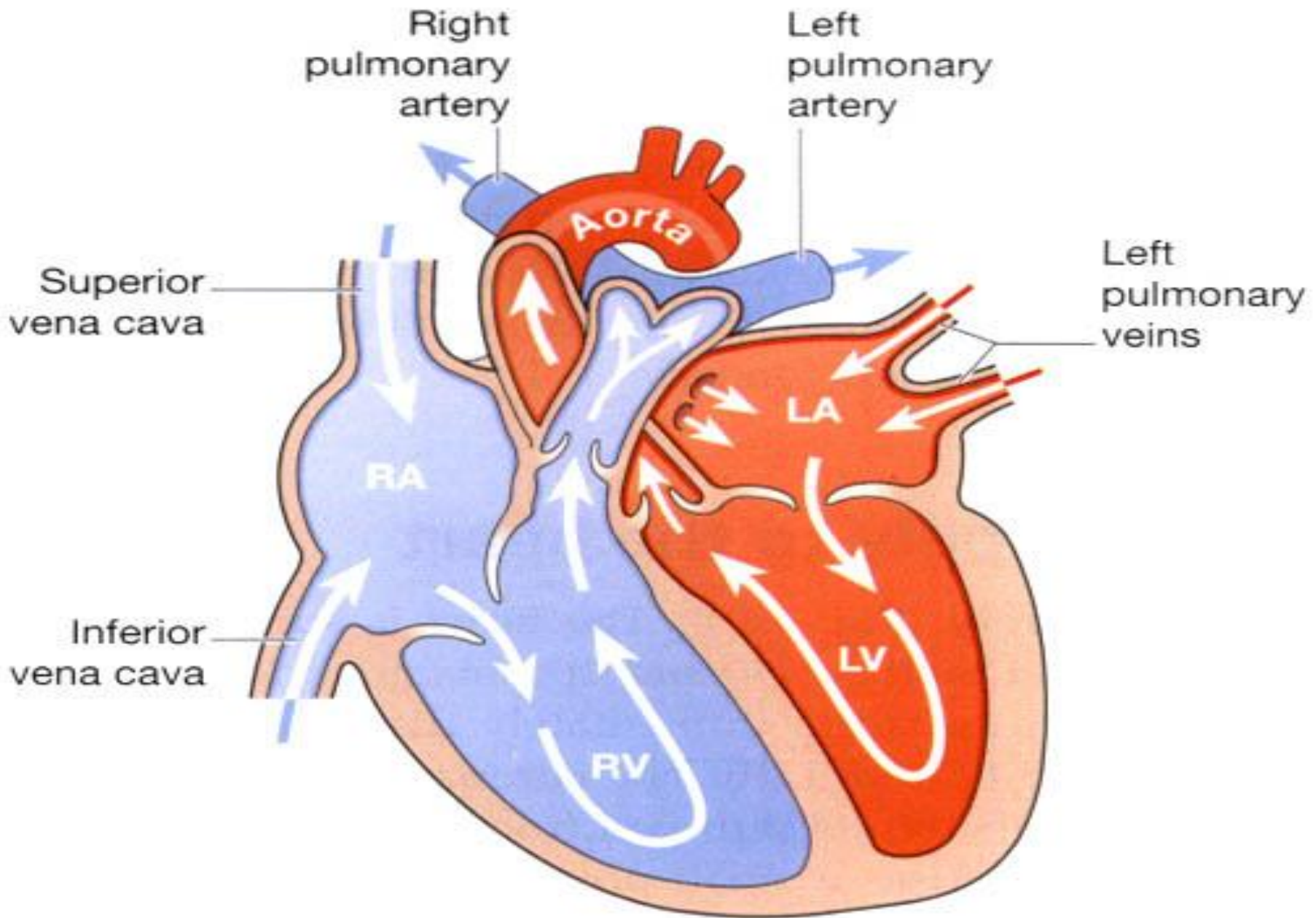


Valve closed.

Flow of blood through the heart

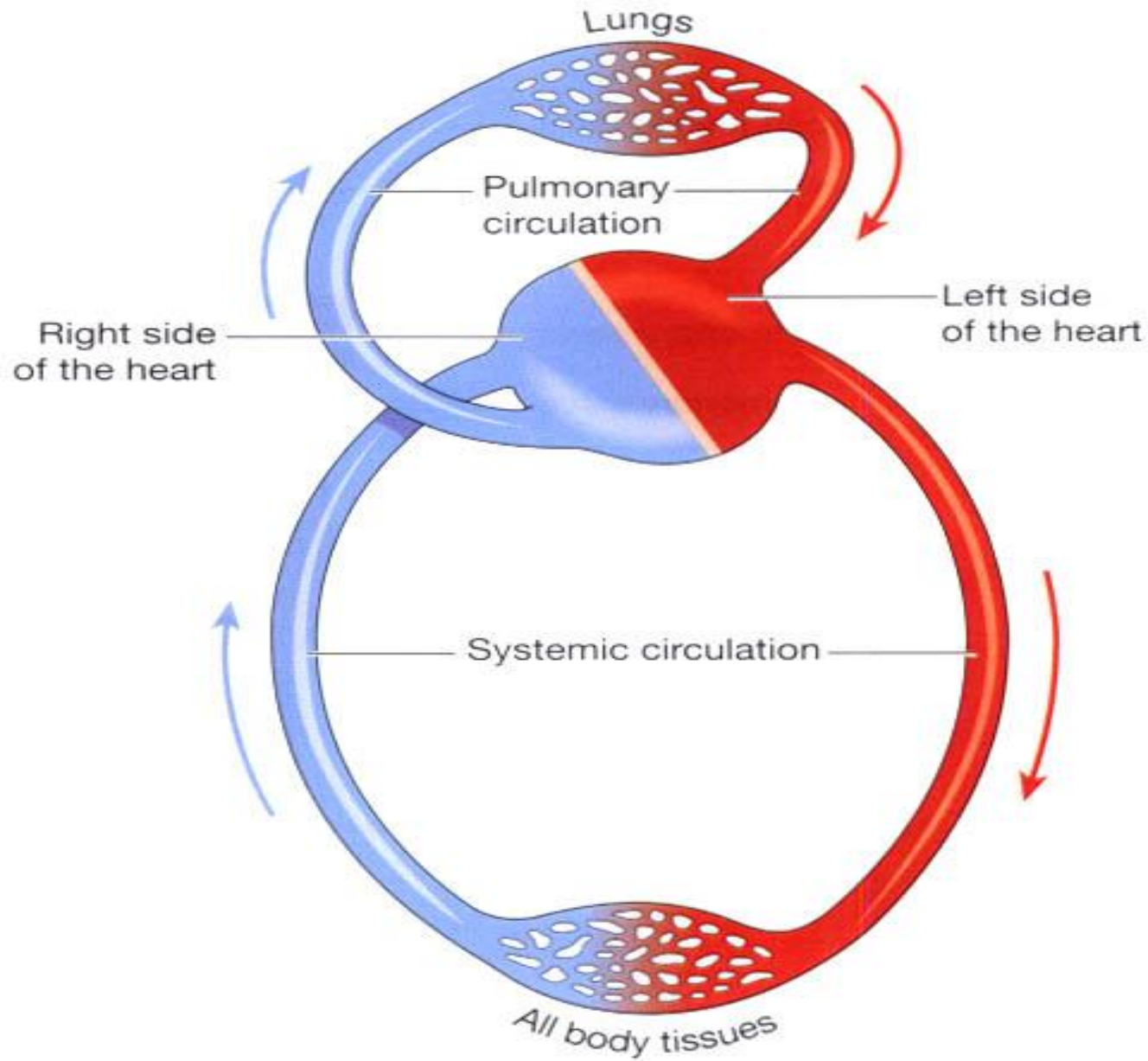
- 2 largest veins; **superior & inferior venacavae**, empty their contents into RA.
- This blood passes via **right atrioventricular valve** into RV, from there it is pumped into the **pulmonary artery/trunk (only artery in the body which carries deoxygenated blood)**.
- The **pulmonary valve** prevents back flow of blood into the RV when the ventricular muscle relaxes.

- After leaving the heart, pulmonary artery divides into **left & right pulmonary arteries**, which carry the venous blood to the lungs where exchange of gases takes place.
- **2 pulmonary veins** from each lung carry oxygenated blood back to LA.
- Blood then passes through **the left atrioventricular valve** into LV, and from there it is pumped into the **aorta**; first artery of general circulation.
- Opening of aorta is guarded by aortic valve, formed by 3 semi lunar cusps.



[Direction of blood flow through the heart](#)

- Thus, blood passes from right to left side of the heart via the lungs/pulmonary circulation.
- Both atria contract at the same time and followed by the simultaneous contraction of both ventricles.
- Muscle layer of atrial walls is very thin in comparison with that of the ventricles. The atria, usually assisted by gravity, only propel the blood through the atrioventricular valves into the ventricles, whereas the ventricles actively pump the blood to the lungs and round the whole body.
 - Muscle layer is thickest in the wall of the LV.
- **Pulmonary trunk** leaves the heart from the **upper** part of RV, & the aorta leaves from **upper** part of LV.



Relationship between systemic and pulmonary circulation ³¹³

Blood supply to the heart

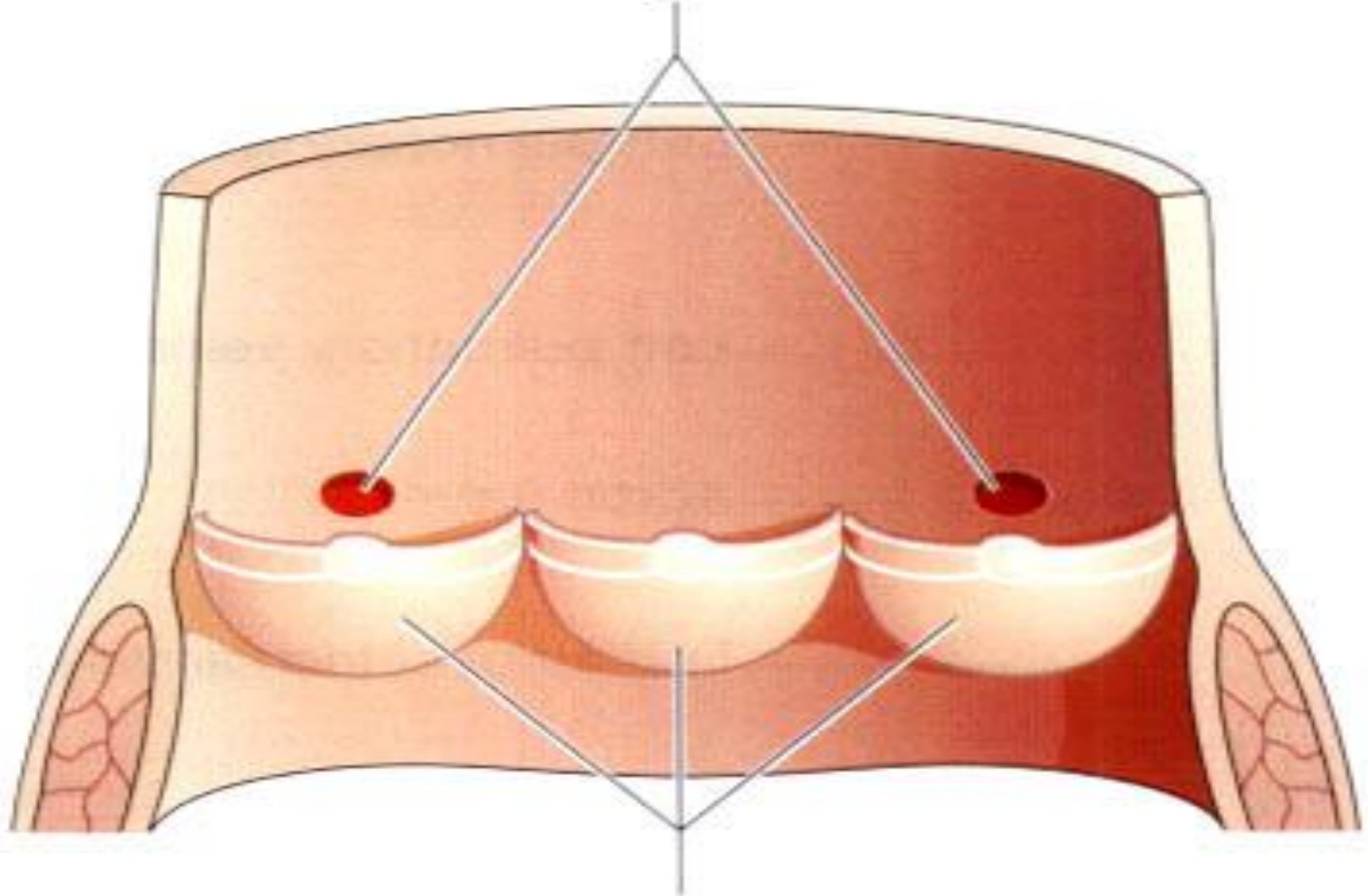
Arterial supply:

- Supplied by **Right** and **left coronary** arteries; which branch from the aorta immediately distal to the aortic valve.
- Coronary arteries receive about 5% of the blood pumped from the heart; highlighting the importance of the heart to body function.

Venous drainage.

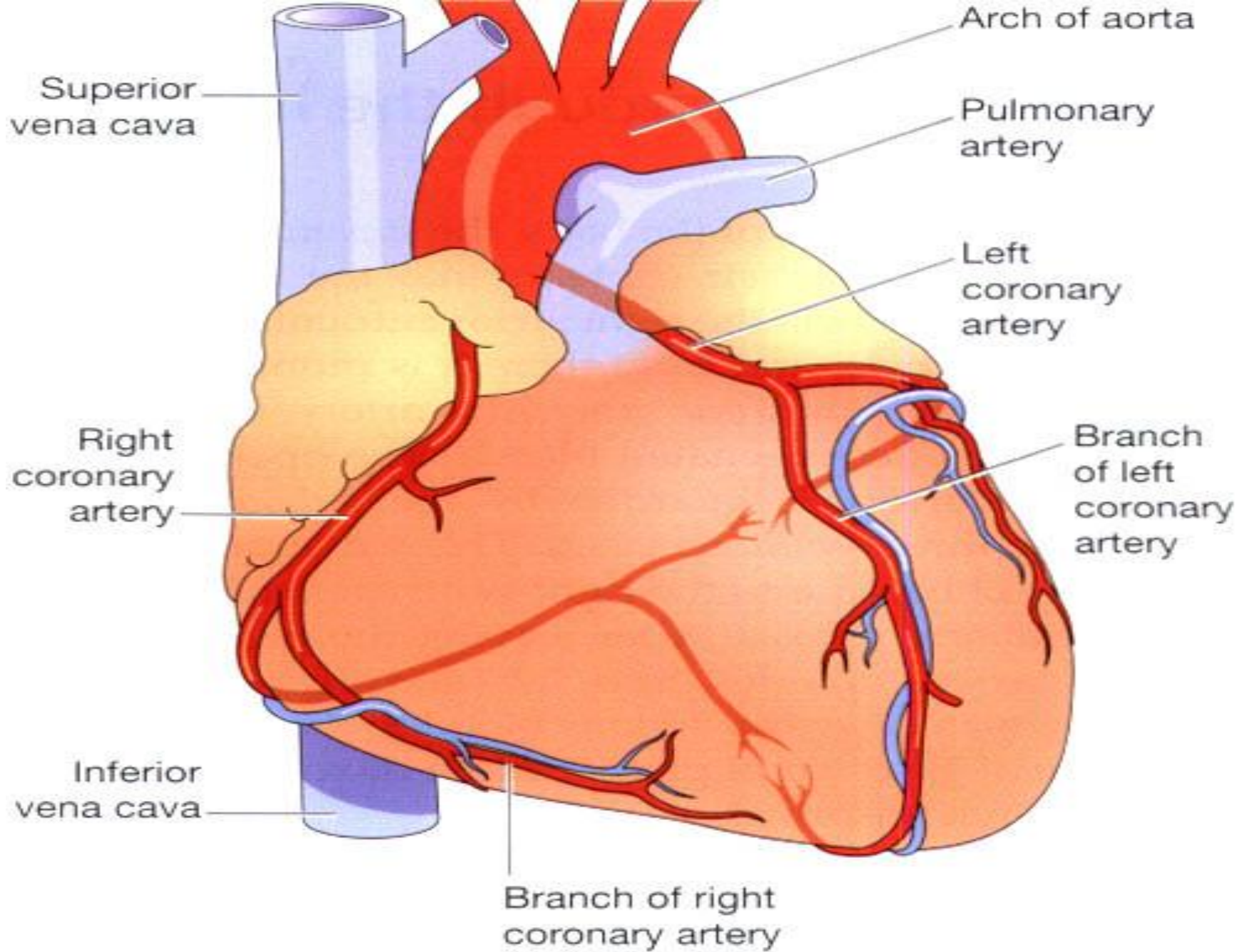
- Most of the venous blood is collected into ***cardiac veins*** that join to form the coronary sinus which opens into the RA.
- The remainder passes directly into the heart chambers through little venous channels.

Openings of
right and left
coronary arteries



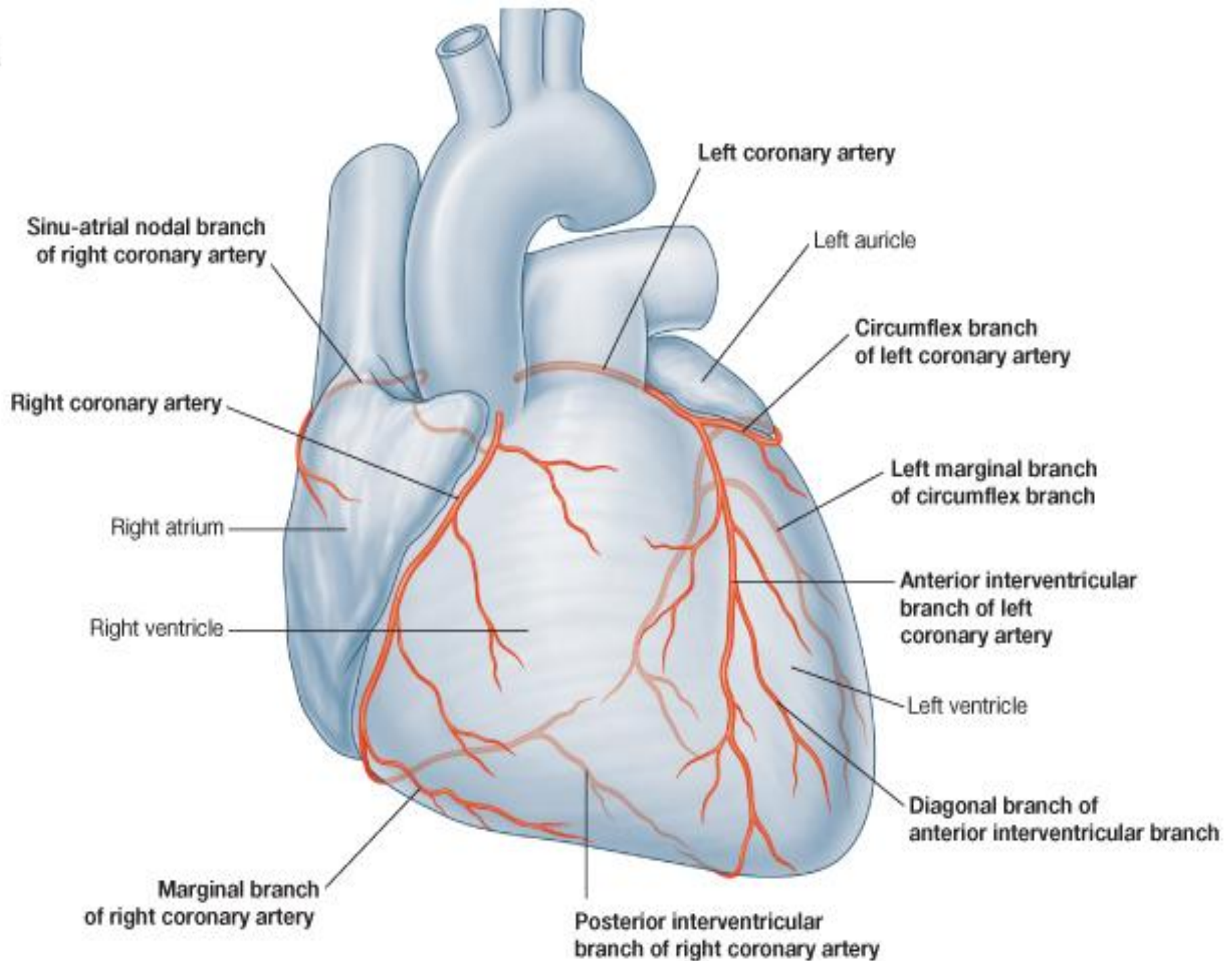
Semilunar cusps

Semilunar cusps of the aortic valve



Coronary arteries

A



Conducting system of the heart

- The heart is capable of generating its own electrical impulses and beating independently of nervous and hormonal control.
- However, the intrinsic system can be stimulated or depressed by **nerve impulses (parasympathetic vs sympathetic ctrl)** initiated in the brain and by circulating chemicals including hormones.
- There are specialized cells in the heart responsible for the generation and coordination of the transmission of electrical impulses to the other myocardial cells.
- X-tics of conduction cells:
 - Automaticity*: ability to initiate an electrical impulse
 - Excitability*: ability to respond to an electrical impulse
 - Conductivity*: ability to transmit an electrical impulse from one cell to another

Conducting cells

- Sinoatrial node (SAN)
 - Is the primary pacemaker (fires faster than any other cell)
 - Located at the junction of the superior vena cava and the right atrium
 - Normal firing rate at 60 to 80 impulses per minute
- Atrioventricular node (AVN)
 - Located in the right atrial wall near the tricuspid valve
 - Coordinates the incoming electrical impulses from the atria and, after a slight delay, relays the impulse to the ventricles. (WHY??)
 - Normal firing rate at 40 to 60 impulses per minute and forms the secondary pacemaker

Ct....

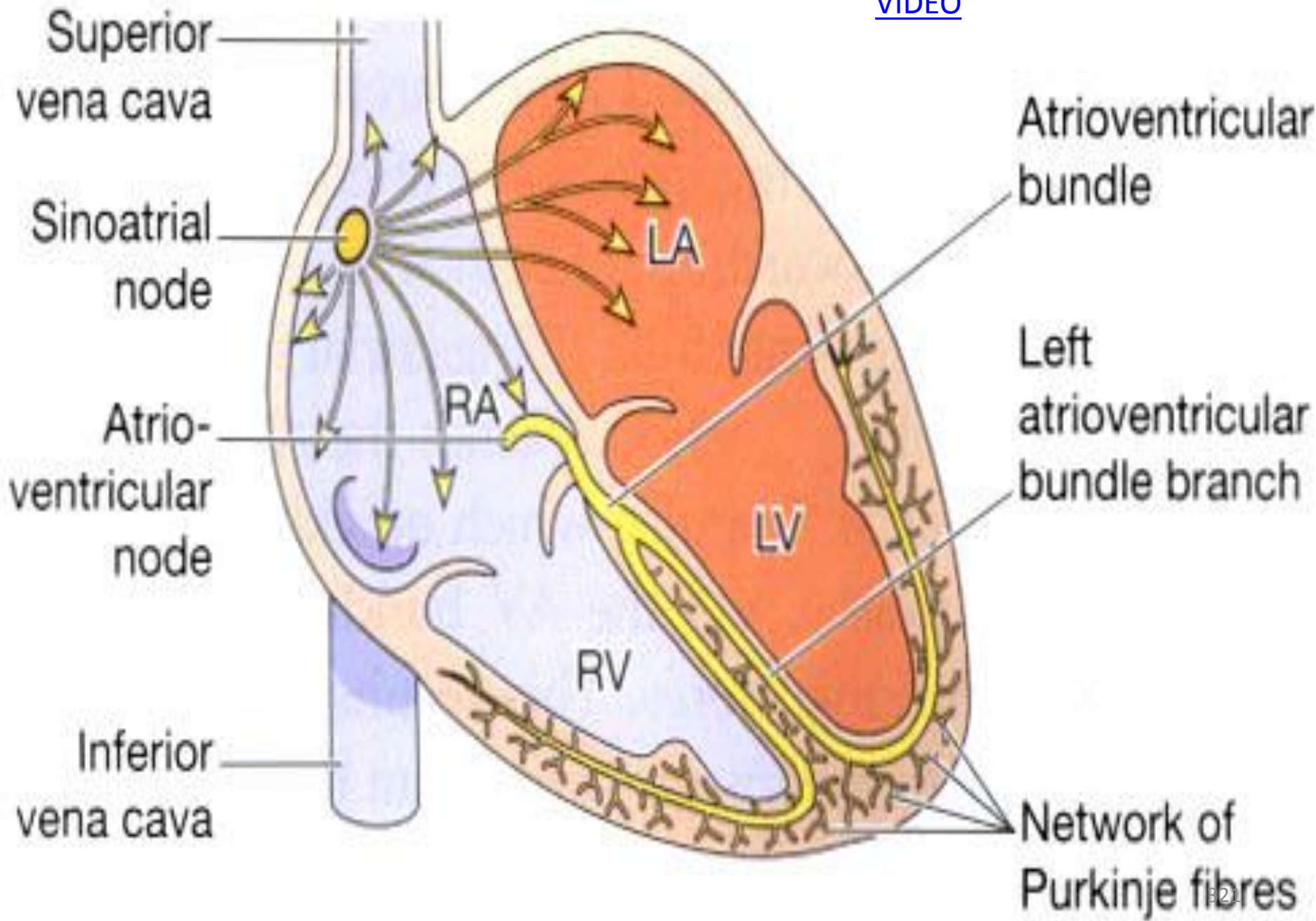
c) Atrioventricular bundle (AV bundle or bundle of His)

- Originates from the AV node.
- At the upper end of the ventricular septum, it divides into right and left bundle branches.

d) Purkinje fibres

- Within the ventricular myocardium the branches break up into fine fibres, called the **Purkinje fibres**.
- The AV bundle, bundle branches and Purkinje fibres convey electrical impulses from the AV node to the apex of the myocardium where the wave of ventricular contraction begins, then sweeps upwards and outwards, pumping blood into the pulmonary artery and the aorta.

[VIDEO](#)



Nerve supply to the heart

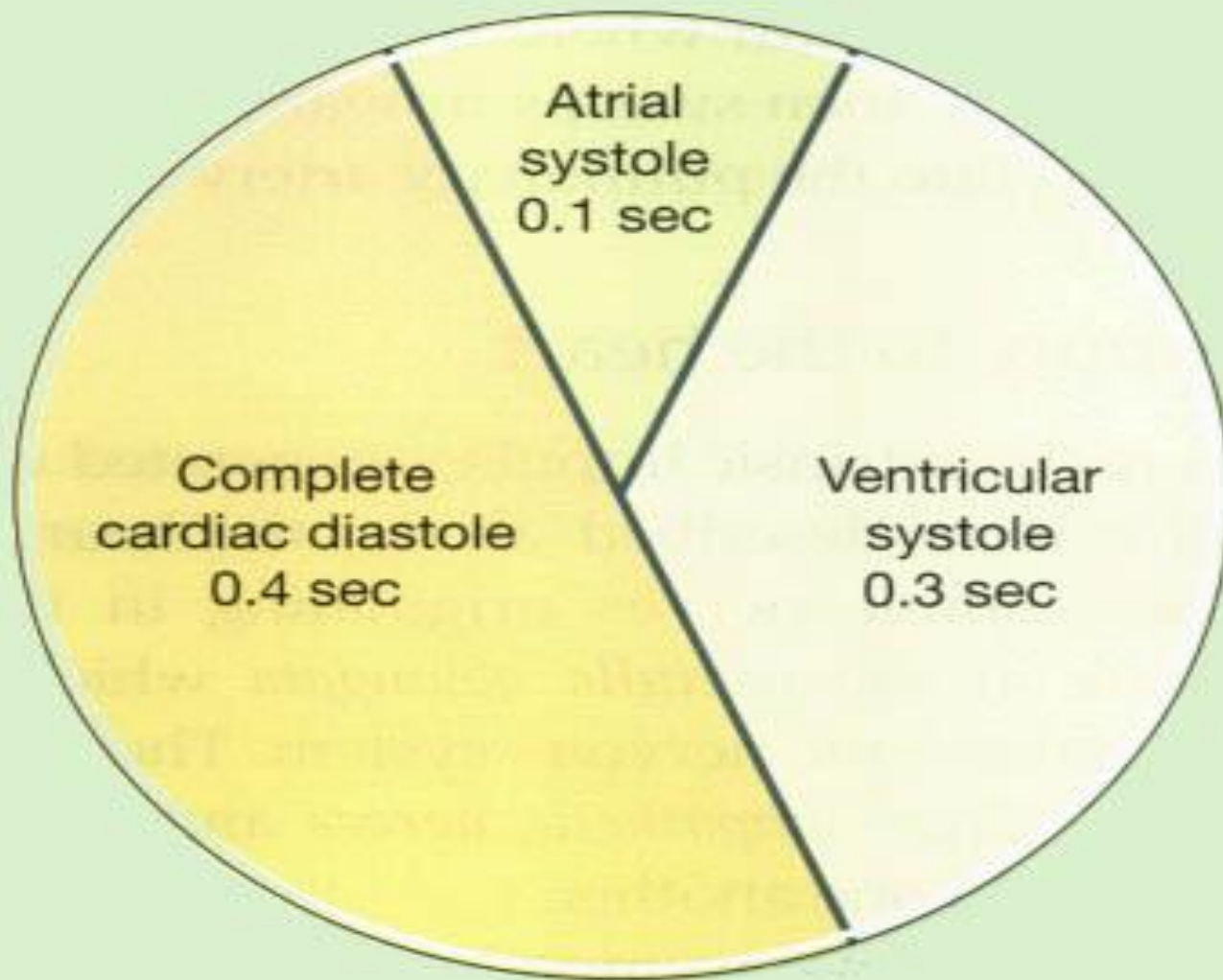
- The heart is innervated by nerves from the Autonomic nervous system (sympathetic and parasympathetic) that originates in the CV centre in medulla oblongata.
- The parasympathetic and sympathetic nerves have antagonistic actions.
 - The **vagus nerves** (parasympathetic) supply mainly the SA and AV nodes and atrial muscle. This stimulation reduces the rate at which impulses are produced, decreasing the rate and force of the heart beat.
 - The **sympathetic nerves** supply the SA and AV nodes and the myocardium of atria and ventricles. This stimulation increases the rate and force of the heart beat.

Cardiac cycle

- **Def:** series of events by which the heart acts as a pump.
- During each heartbeat, or cardiac cycle, the heart contracts and then relaxes.
- Period of contraction is called **systole** while that of relaxation is known as **diastole**.

Stages of the cardiac cycle

- Normal cardiac cycles per minute ranges from 60 to 80 (Average 74bpm). Each cycle lasts 0.8 seconds and consists of:
 - **atrial systole** — atrial contraction
 - **ventricular systole** — ventricular contraction
 - **complete cardiac diastole** — atrial & ventricular relaxation.



Total period of 1 cycle = 0.8 sec

Stages of a cardiac cycle

- Superior & inferior vena cava transport deoxygenated blood into RA at the same time as the 2 pulmonary veins convey oxygenated blood into LA.
- Atrioventricular valves are open and blood flows passively through to the ventricles.
- SA node triggers a wave of contraction that spreads over the myocardium of both atria, emptying the atria & completing ventricular filling (**atrial systole 0.1 s**).
- When the wave of contraction reaches the AV node it is stimulated to emit an impulse which quickly spreads to the ventricular muscle via the AV bundle, the bundle branches and Purkinje fibres.

- This results in a wave of contraction which sweeps upwards from heart's apex & across walls of both ventricles pumping blood into pulmonary artery & aorta (**ventricular systole, 0.3 s**).
- High pressure generated during ventricular contraction is greater than that in the atria and forces AV valves to close, preventing backflow of blood into the atria.
- After ventricular contraction there is complete cardiac diastole, **a period of 0.4 seconds**, when atria and ventricles are relaxed. During this time the myocardium recovers until it is able to contract again, and the atria refill in preparation for the next cycle.
- Heart valves & valves of the great vessels open & close according to the pressure within the chambers of the heart. AV valves are open while the ventricular muscle is relaxed during atrial filling & systole.

- When ventricles contract there is a gradual increase in the pressure in these chambers, and when it rises above atrial pressure, AV valves close.
- When ventricular pressure rises above that in the pulmonary artery and in the aorta, pulmonary & aortic valves open & blood flows into these vessels.
- When ventricles relax & pressure within them falls, the reverse process occurs. First, pulmonary & aortic valves close, then AV valves open & the cycle begins again.
 - This sequence of opening & closing valves ensures that blood flows in only one direction.

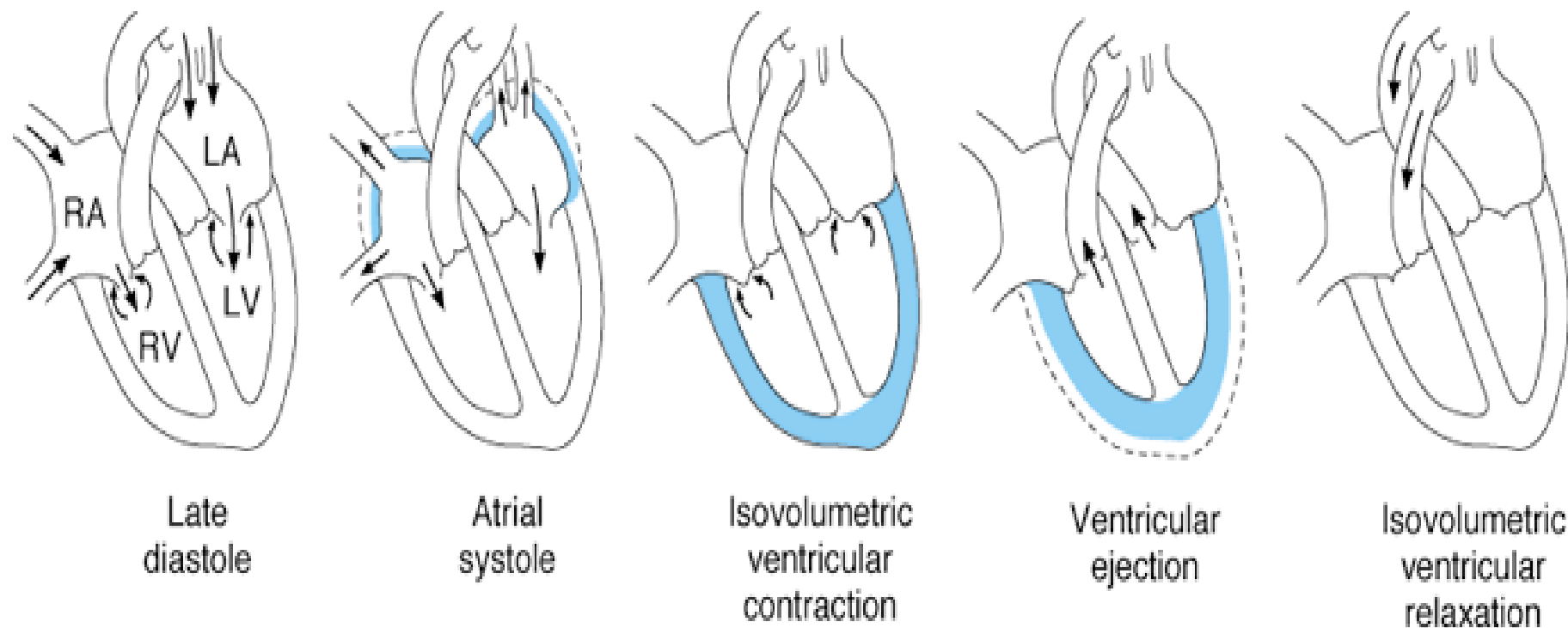
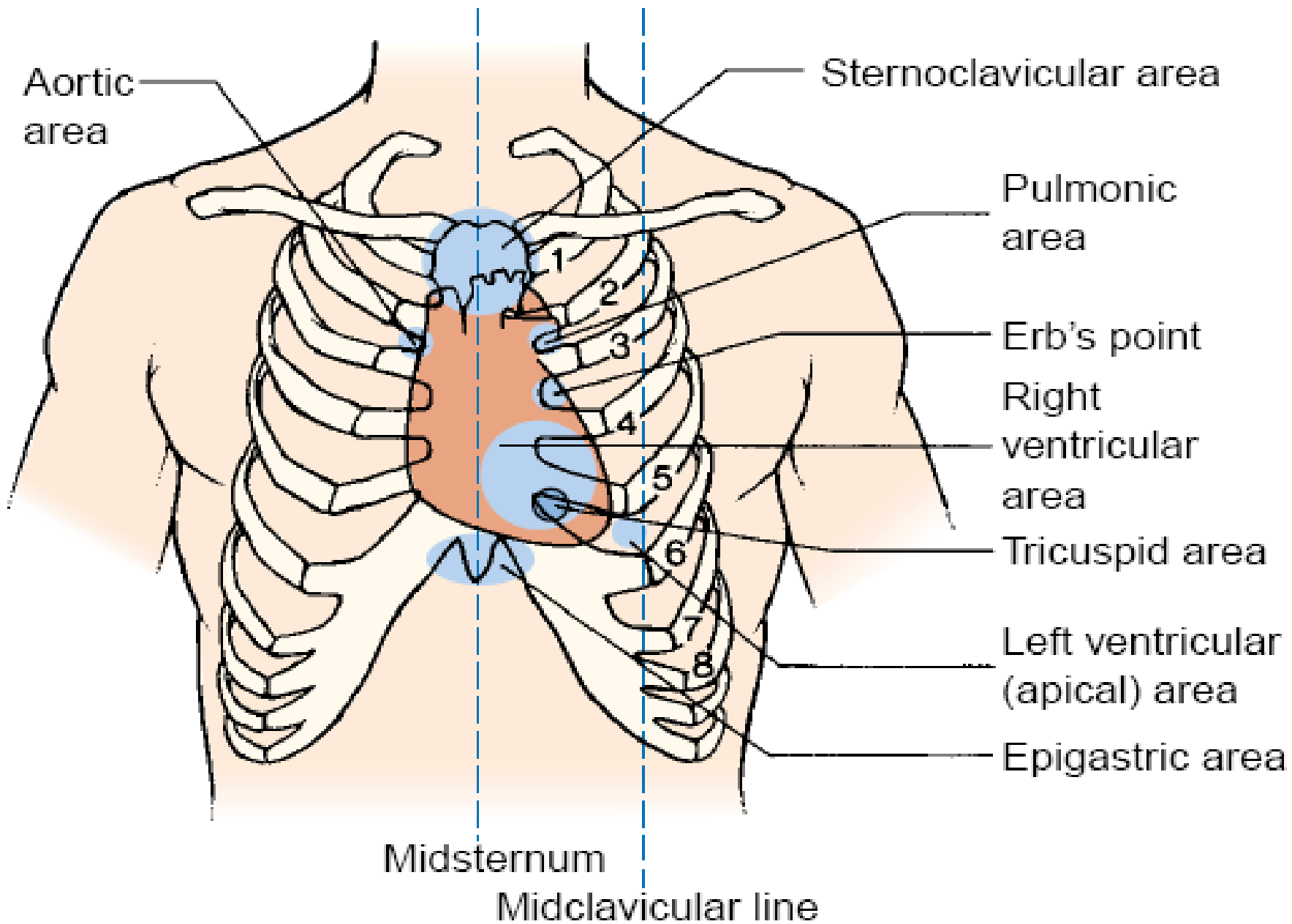


Figure 29-1. Blood flow in the heart and great vessels during the cardiac cycle. The portions of the heart contracting in each phase are indicated in color. RA and LA, right and left atria; RV and LV, right and left ventricles.

Heart sounds

- Heartbeat is heard a little below the left nipple and slightly nearer the midline.
- Heart sounds can be heard in the four auscultatory areas namely:
 - Aortic area – 2nd ICS to the right of the sternum
 - Pulmonic area - 2nd ICS to the left of the sternum
 - Tricuspid area – 4th and 5th ICS at the left lower border of the sternum
 - Mitral/Apical area – 5th ICS left MCL
- There are four heart sounds
- 2 sounds, separated by a short pause, can be clearly distinguished. Described as '**lub dup**'.



Aortic area

Sternoclavicular area

Pulmonic area

Erb's point

Right ventricular area

Tricuspid area

Left ventricular (apical) area

Epigastric area

Midsternum

Midclavicular line

1
2
3
4
5
6
7
8

aortic valve

pulmonary valve



tricuspid valve

**bicuspid (mitral)
valve**

aortic valve - 2nd-3rd
right interspace



pulmonic valve - 2nd-3rd
left interspace



tricuspid valve - left
sternal border



mitral valve
- apex



First heart sound (S1)

- Is made by closure of atrioventricular valves
- The heart sound is described as “lubb-dubb. **Lubb** represents S1
- Corresponds with the start of the ventricular systole
- It should be heard at all the sites and its louder at the apex
- Its usually louder and longer

Second heart sound (S2)

- Is made by closing of semi lunar valves
- S2 is **dubb** of the lubb-dubb heart sound
- Its heard in all sites and often louder at the base where aortic and pulmonic sites are auscultated
- Its usually softer and shorter than S1
- Corresponds with ventricular diastole

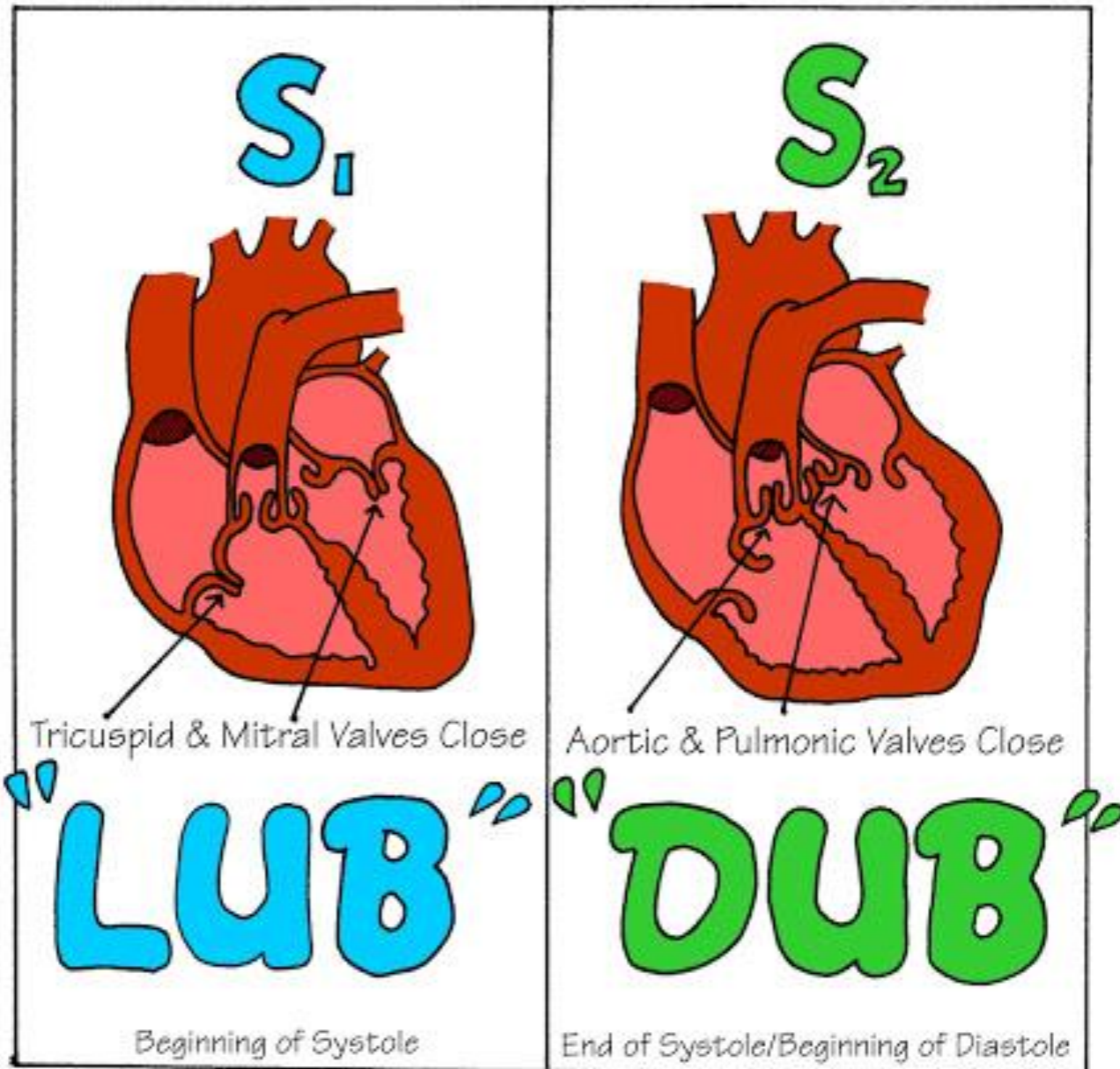
3rd heart sound

- Occurs shortly after S2
- Normal in children and young adults < 30yrs at the beginning of diastole
- Its heard over the apex with the bell (low pitch)
- S3 is **tu** of the lubb dub tu heart sound

Fourth heart sound (S4)

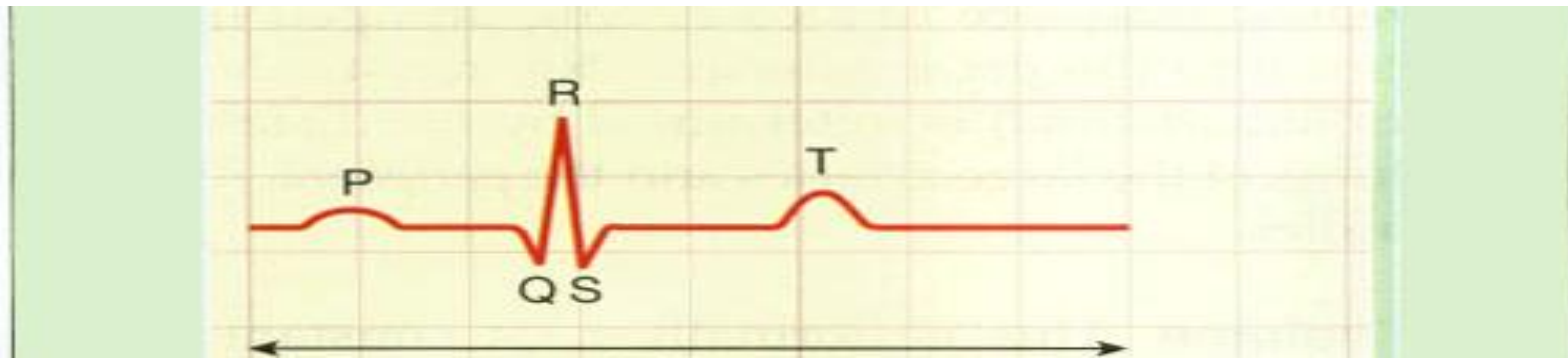
- Occurs just before S1
- Always abnormal
- It signifies a non compliant or stiff ventricle as in aortic stenosis, hypertensive heart, coronary artery disease, pulmonic stenosis, hypertension
- It sounds like tu lubb dubb
- Felt at the apex when patient is in left lateral position
- Both S3 and S4 occur in diastole

HEART SOUNDS



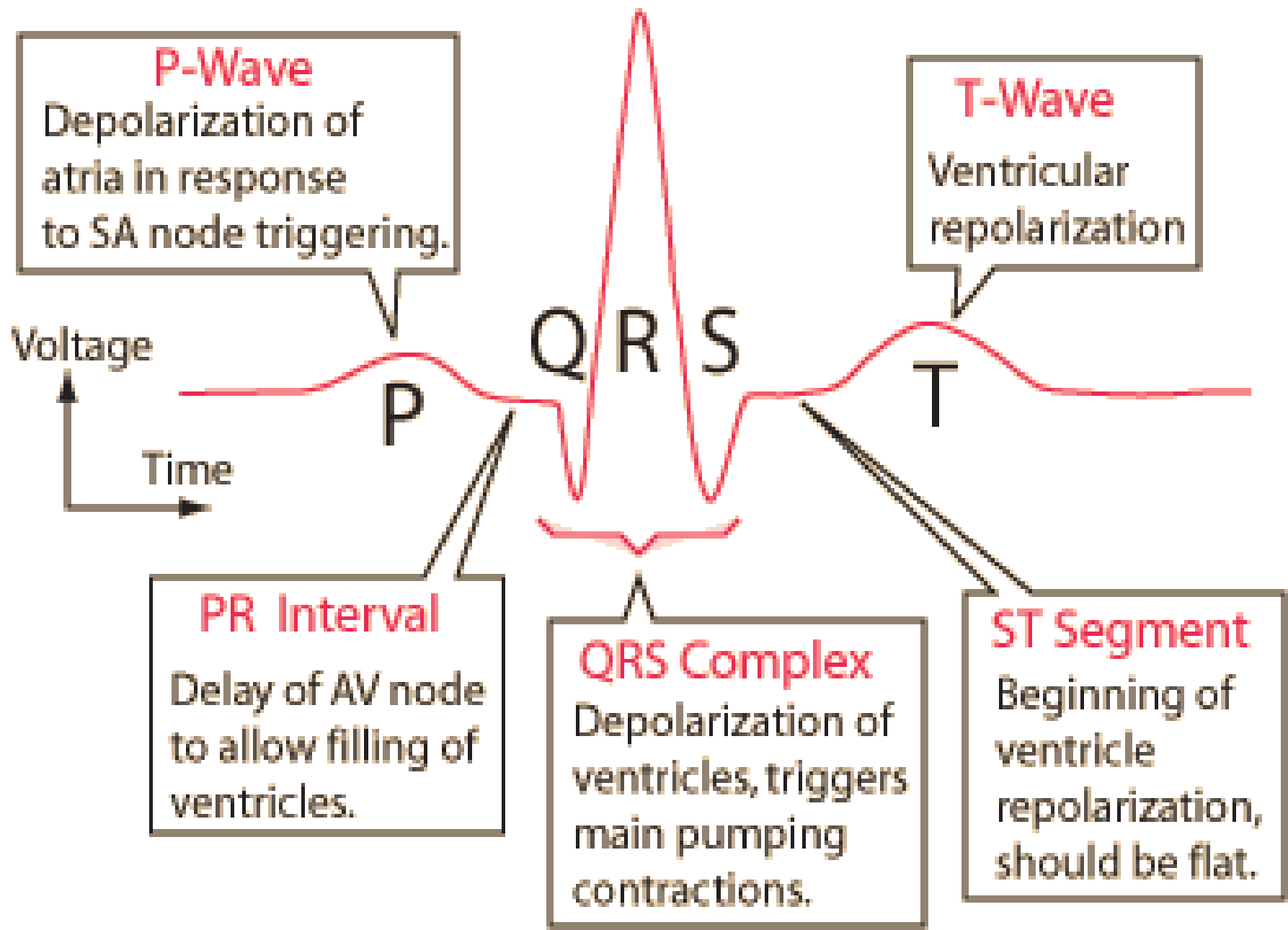
Electrical changes in the heart

- The pattern of electrical activity of the heart may be detected by electrodes placed on the skin and displayed on an oscilloscope screen or traced on paper. The apparatus used is an **electrocardiograph** and the tracing is an **electrocardiogram (ECG)**.
- The normal ECG tracing shows five waves named P, Q, R, S and T.
- The **P wave** arises when the impulse from the **SA node** sweeps over the **atria** (atrial depolarization)



- The **QRS complex** represents the very rapid spread of the impulse from the **AV node** through the AV bundle and the Purkinje fibres and the electrical activity of the ventricular muscle (ventricular depolarisation)
- The **T wave** represents the relaxation of the **ventricular muscle** (Ventricular repolarisation)
- **Sinus rhythm** refers to the ECG that originates from the SA node.
- The rate of sinus rhythm is 60 to 100 beats per minute. A faster heart rate is called **tachycardia** and a slower heart rate, **bradycardia**.





Cardiac output

- **Cardiac output** is the amount of blood ejected from each ventricle every minute. It's expressed in litres per minute (L/min)
- **Stroke volume:** The amount of blood expelled by each contraction of the ventricles
- **Cardiac output** is calculated by multiplying the stroke volume by the heart rate (measured in beats per minute):
- **Cardiac output (CO) = Stroke Volume(SV) x Heart rate(HR)**
- **In a healthy adult, SV = 70 mL and the HR = 72 bpm.**
- **\therefore CO = 70 x 72**
- **= 5040 mL/min**
- **\sim 5L/min**

- **Cardiac reserve:** the increase in cardiac output to meet demands e.g., exercise.
- When increased blood supply is needed to meet increased tissue requirements of oxygen and nutrients, heart rate and/or stroke volume can be increased.

Stroke volume

- Is determined by the volume of blood in the ventricles immediately before they contract, i.e. the **ventricular end-diastolic volume (VEDV)**, sometimes called **preload**.
- Preload depends on the amount of blood returning to the heart through the superior and inferior vena cava (**the venous return**).
- Factors that increase myocardial contraction include:
 - Increased preload
 - increased stimulation of the sympathetic nerves innervating the heart
 - hormones, e.g. adrénaline, noradrenaline, thyroxine.

Arterial blood pressure.

- This affects the stroke volume as it creates resistance to blood being pumped from the ventricles into the great arteries.
- This resistance (**afterload**) is determined by the distensibility, or elasticity, of the large arteries and the peripheral resistance of arterioles.

Blood volume.

- This is normally kept constant by the kidneys and if deficient the stroke volume, cardiac output and venous return decrease.

Venous return

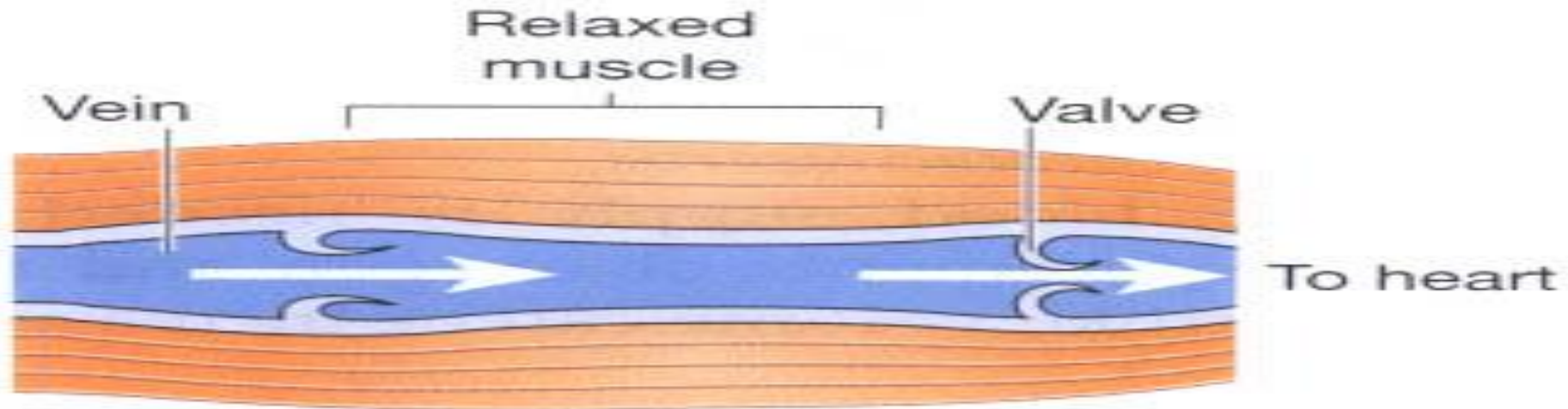
- Venous return is the major determinant of cardiac output.
- The force of contraction of the left ventricle ejecting blood into the aorta is not sufficient to return the blood through the veins and back to the heart.
- Other factors involved are:
 - a) The position of the body:** Gravity assists the venous return from the head and neck when standing or sitting and offers less resistance to venous return from the lower parts of the body when an individual is lying flat.

b) Muscular contraction:

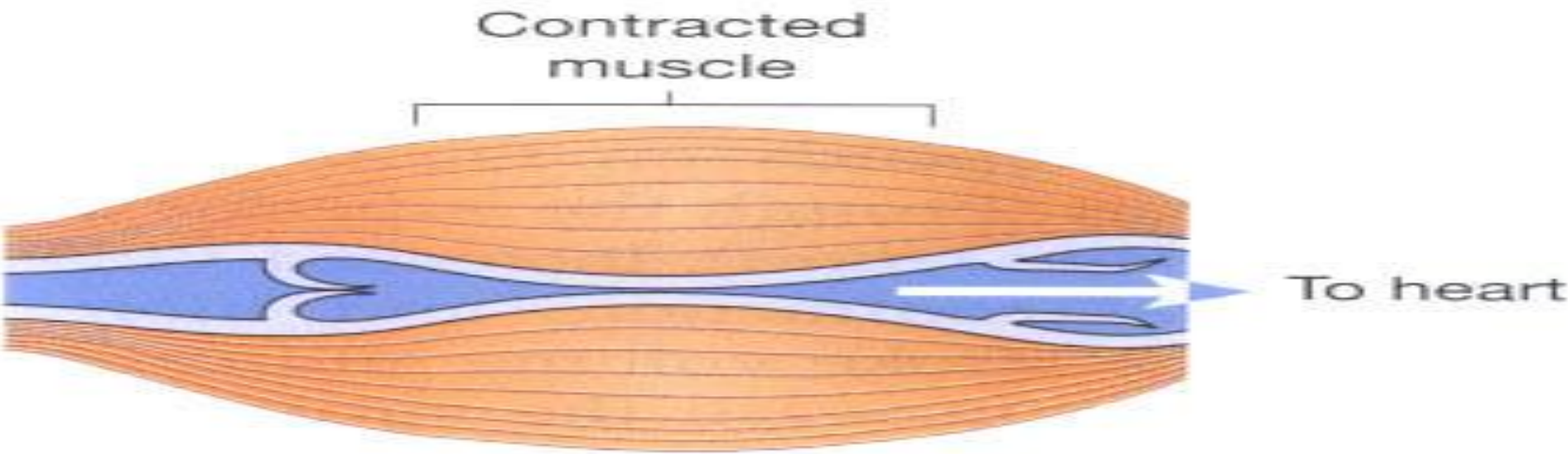
- Contraction of skeletal muscles surrounding the deep veins puts pressure on them, pushing blood towards the heart (skeletal muscle pump).

c) The respiratory pump: During inspiration the expansion of the chest creates a negative pressure within the thorax, assisting flow of blood towards the heart.

- In addition, when the diaphragm descends during inspiration, the increased intra-abdominal pressure pushes blood towards the heart.



Valves open



**Proximal valve open,
distal valve closed**

Blood flow through a vein; skeletal muscle contraction

Box 5.1 Summary of factors affecting cardiac output

$$\text{Cardiac output} = \text{Stroke volume} \times \text{Heart rate}$$

Factors affecting stroke volume:

- VEDV (ventricular end-diastolic volume)
- Venous return
 - position of the body
 - skeletal muscle pump
 - respiratory pump
- Strength of myocardial contraction
- Blood volume.

Factors affecting heart rate:

- Autonomic nerve stimulation
- Circulating chemicals
- Activity and exercise
- Emotional states
- Gender
- Age
- Body temperature
- Baroreceptor reflex.

Factors affecting heart rate

1. ANS; the rate at which the heart beats is a balance of sympathetic and parasympathetic activity; most important factor in determining heart rate.
2. Circulating chemicals. Hormones (catecholamines), secreted by the adrenal medulla, increase the heart rate. Thyroxine increases heart rate by its metabolic effect. Some drugs, dissolved gases and electrolytes in the blood may either increase or decrease the heart rate.
3. Position. When upright, the heart rate is usually faster than when lying down.
4. Exercise. Active muscles need more blood than resting muscles and this is achieved by an increased heart rate and selective vasodilatation.

5. Emotional states. During excitement, fear or anxiety the heart rate is increased.
6. Gender. The heart rate is faster in women than men.
7. Age. In babies heart rate is more rapid than in older children and adults.
8. Temperature. The heart rate rises and falls with body temperature.
9. Baroreceptor reflex.

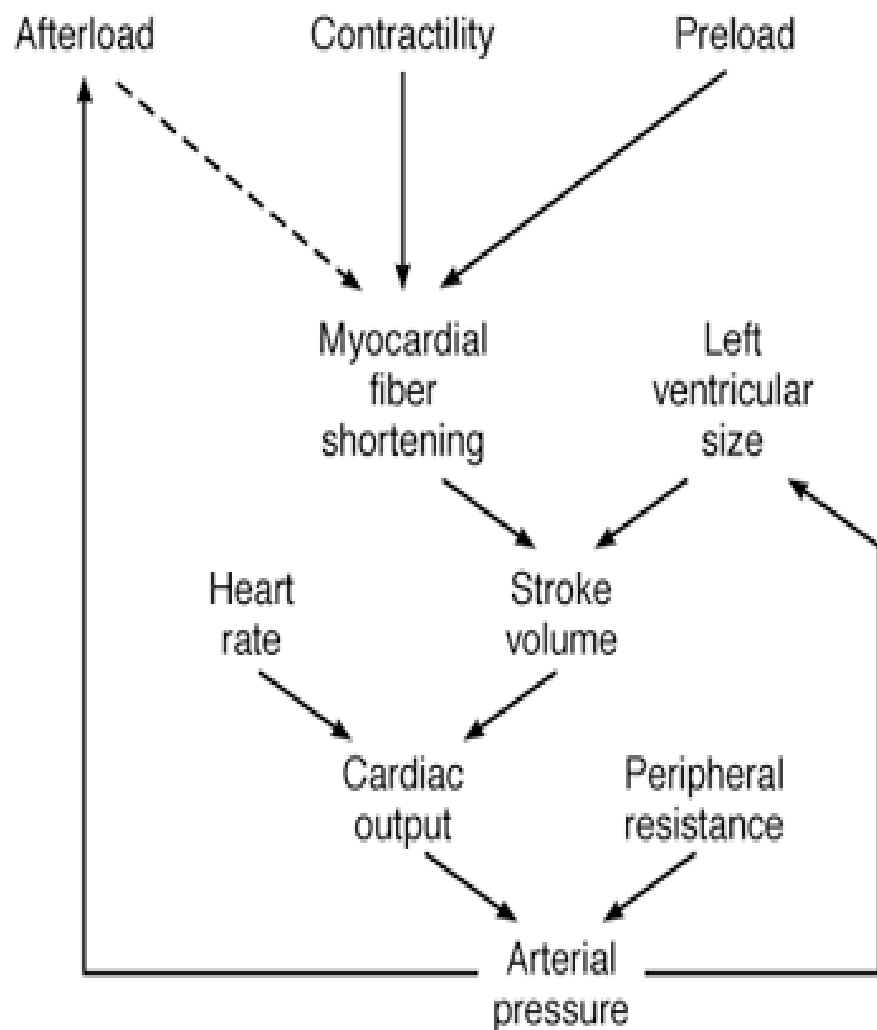


Figure 29-5. Interactions between the components that regulate cardiac output and arterial pressure. Solid lines indicate increases, and the dashed line indicates a decrease.

BLOOD PRESSURE

- **Def:** The force or pressure which the blood exerts on the walls of the blood vessels.
- Systemic arterial blood pressure maintains blood flow into and out of the organs. It results from the discharge of blood from the left ventricle into the already full aorta.
- Blood pressure is tightly controlled within normal limits
- It varies according to:
 - Time of the day
 - Posture
 - Gender
 - Age
- Arterial blood pressure is measured with a **sphygmomanometer** and is expressed with systolic pressure written above the diastolic pressure

Sytolic vs diastolic pressure

- **Systolic blood pressure:** pressure produced within the arterial system when the left ventricle contracts and pushes blood into the aorta. In adults...about 120 mmHg.
- **Diastolic blood pressure:** pressure within the arteries when complete cardiac diastole occurs and the heart is resting following the ejection of blood. Adultsabout 80 mmHg.
- **Pulse pressure:** difference between systolic and diastolic blood pressures.

$$BP = \frac{120}{80} \text{ mmHg}$$

Factors determining blood pressure

- Blood pressure is a product of Cardiac Output and Peripheral Resistance

Blood Pressure(BP) = Cardiac Output(CO) x
Peripheral Resistance (PR)

- **Cardiac Output**
- Determined by SV and HR
- Increase in CO raises both systolic and diastolic pressure.

Peripheral or arteriolar resistance

- Occurs mainly in the small arteries (arterioles)
- Constriction and dilatation of the arterioles are the main determinants of PR
- Vasoconstriction \uparrow BP while vasodilatation \downarrow BP

Autoregulation

- Some organs in the body are capable of adjusting blood flow and BP in the local blood vessels so as to avoid PR in the small blood vessels due to sudden increase in BP

Control of blood pressure

- 2 Mechanisms;
 - short-term control: mainly involves *baroreceptor reflex, chemoreceptors & circulating hormones*.
 - long-term control: involves *regulation of blood volume by kidneys & renin—angiotensin—aldosterone system*.
- **Short term Blood Pressure Regulation**
- **Cardiovascular centre (CVC)** in the medulla & pons of the brain stem receives, integrates & coordinates inputs from:
 - baroreceptors (pressure receptors)
 - chemoreceptors
 - higher centres in the brain.
- CVC sends autonomic nerves to heart & blood vessels & controls BP by slowing down or speeding up heart rate & by dilating or constricting blood vessels.

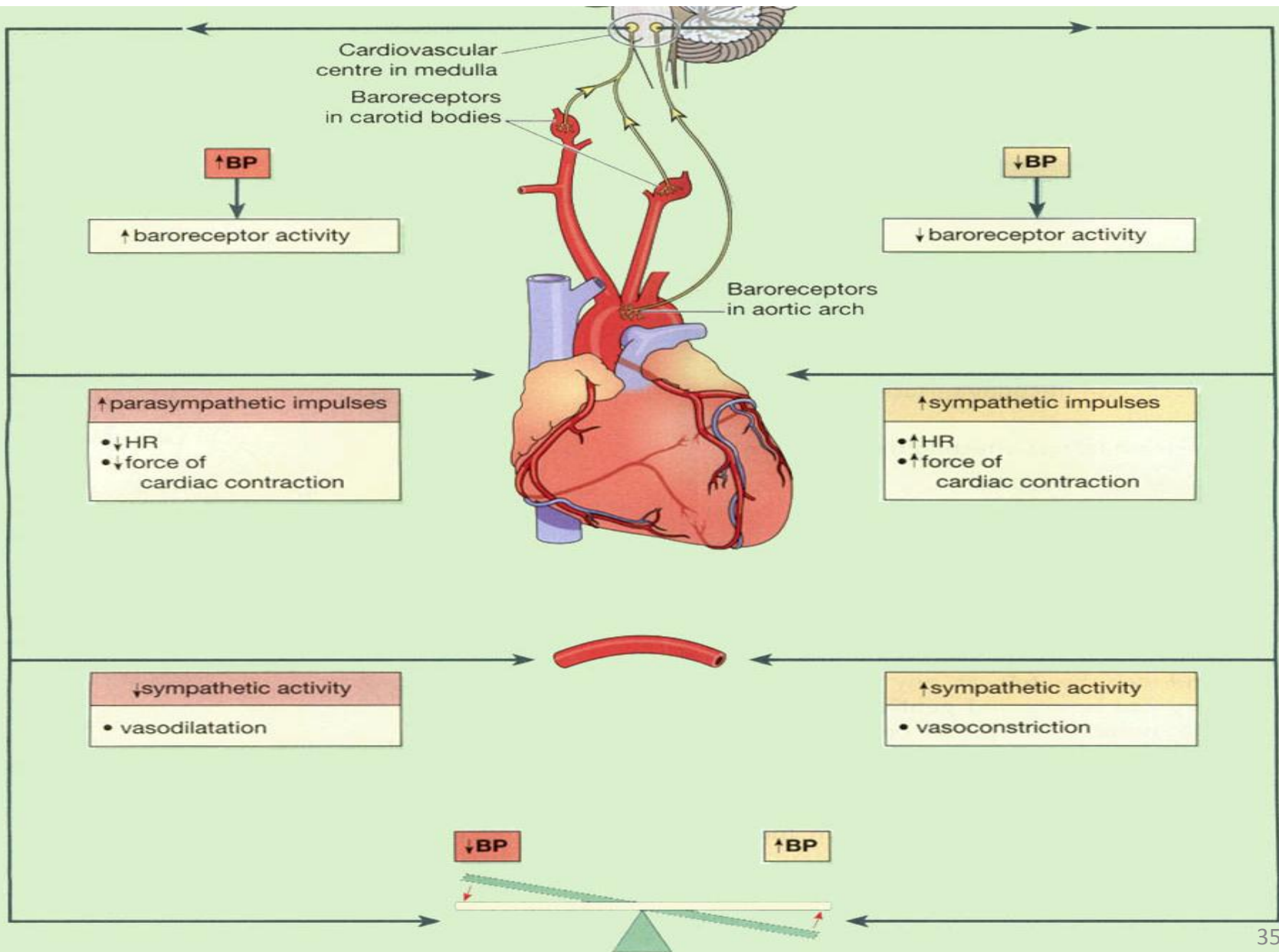
Table 5.1 The sympathetic and parasympathetic nervous systems

	Sympathetic stimulation	Parasympathetic stimulation
Heart	↑Rate ↑Strength of contraction	↓Rate ↓Strength of contraction
Blood vessels	Most constrict	There is little parasympathetic innervation to most blood vessels

Baroreceptors:

- **Def:** Nerve endings sensitive to pressure changes (stretch) within the vessel, situated aortic arch & in the carotid sinuses and are the body's principal moment-to-moment regulatory mechanism for controlling BP.
- A rise in BP in these arteries stimulates the baroreceptors, increasing their input to the CVC.
- CVC responds by increasing parasympathetic nerve activity to heart; slows the heart down. At the same time, sympathetic stimulation to the blood vessels is inhibited, causing vasodilatation.
- Net result is a fall in systemic BP.

- Conversely, if pressure within aortic arch & carotid sinuses falls, the rate of baroreceptor discharge also falls.
- CVC responds by increasing sympathetic drive to the heart to speed it up.
- Sympathetic activity in blood vessels is also increased, leading to vasoconstriction.
- Baroreceptor control of blood pressure is also called the ***baroreceptor reflex***

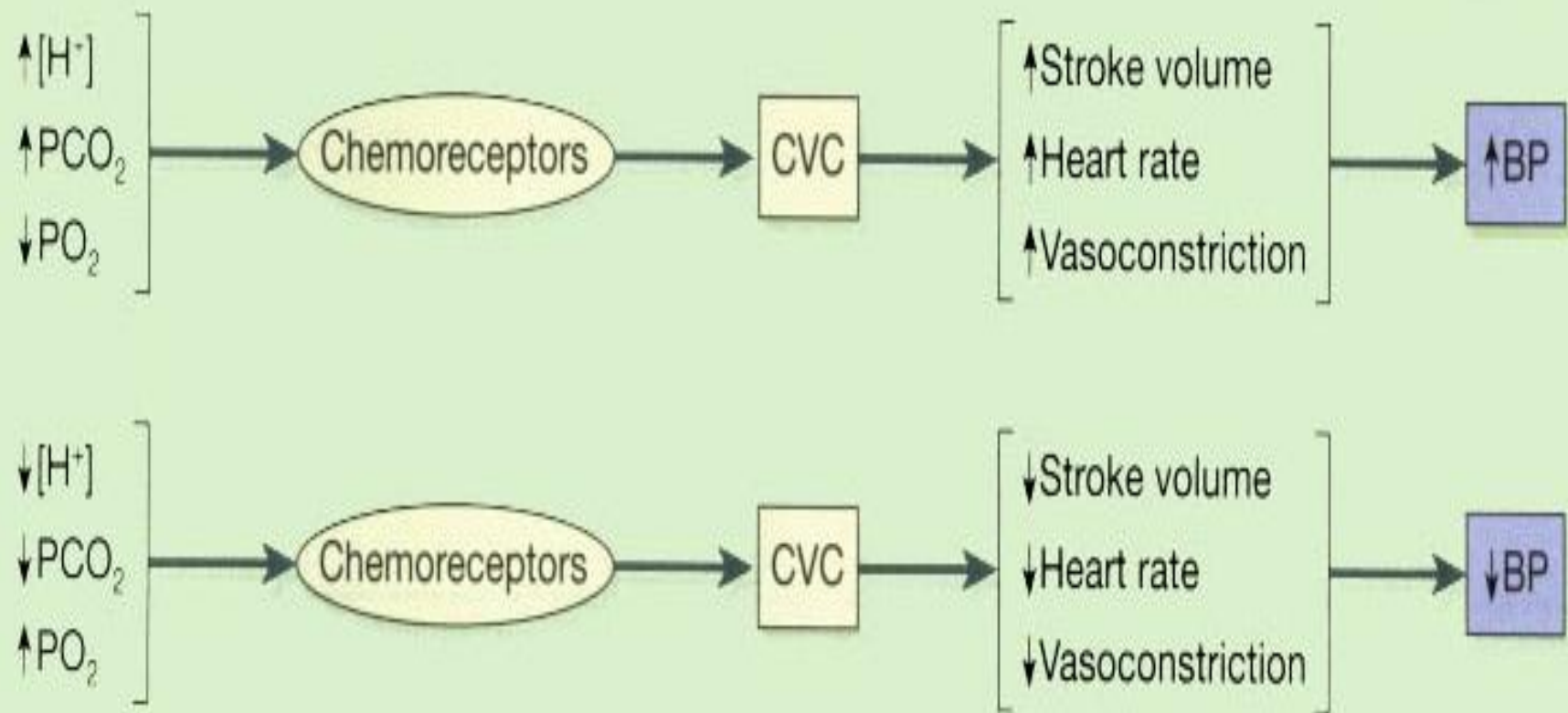


Chemoreceptors

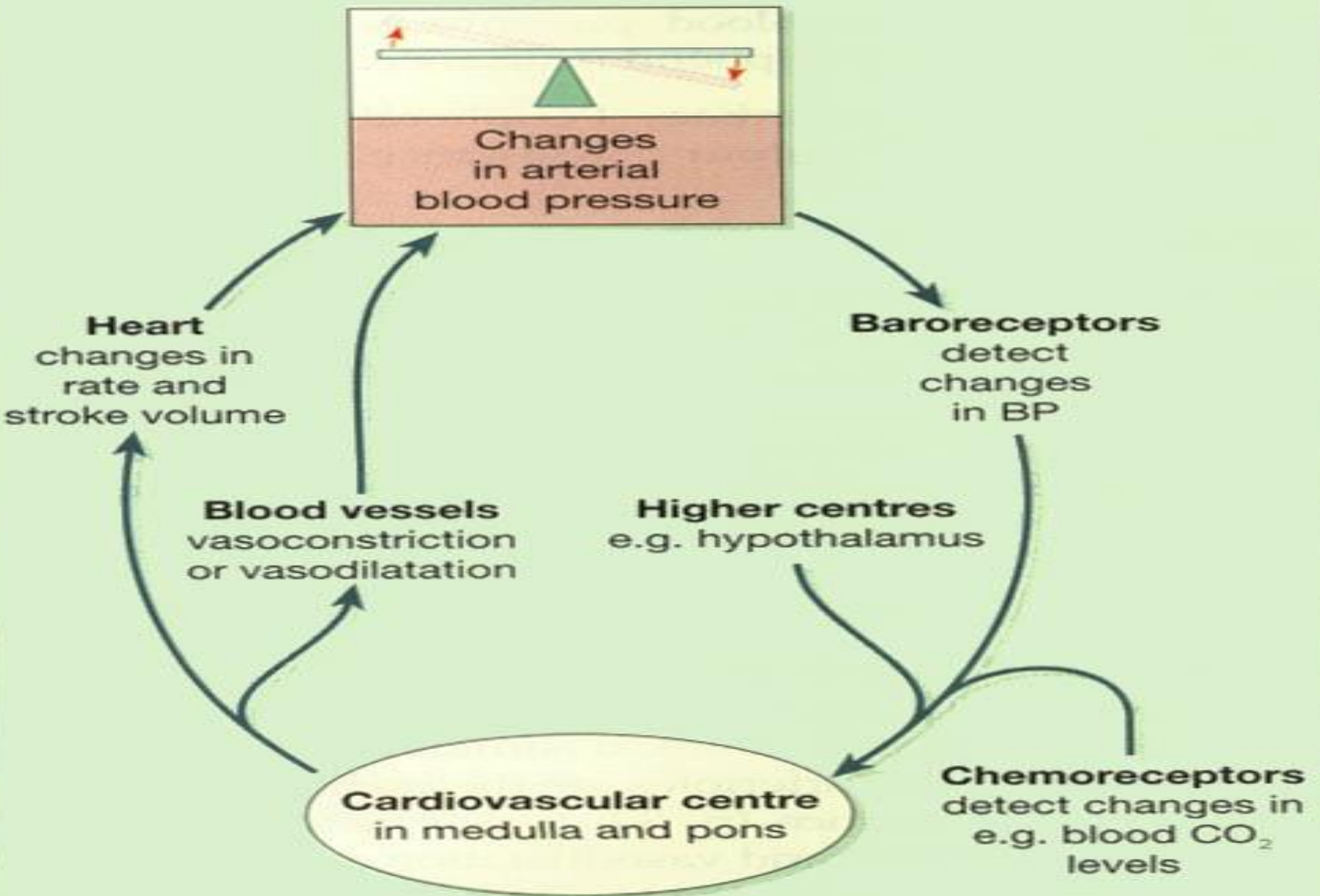
- **Def:** Nerve endings situated in the carotid & aortic bodies and primarily involved in control of respiration.
- Are sensitive to changes in the levels of CO₂, O₂ & pH.
- Their input to CVC influences its output only when severe disruption of respiratory function occurs or when arterial BP falls to less than 80 mmHg.

Higher centres in the brain

- Their input to CVC is influenced by emotional states e.g fear, anxiety, pain & anger that may stimulate changes in BP.
- Hypothalamus controls body temperature & influences the CVC which responds by adjusting the diameter of blood vessels in the skin.



Relationship between stimulation of chemoreceptors and arterial blood pressure.



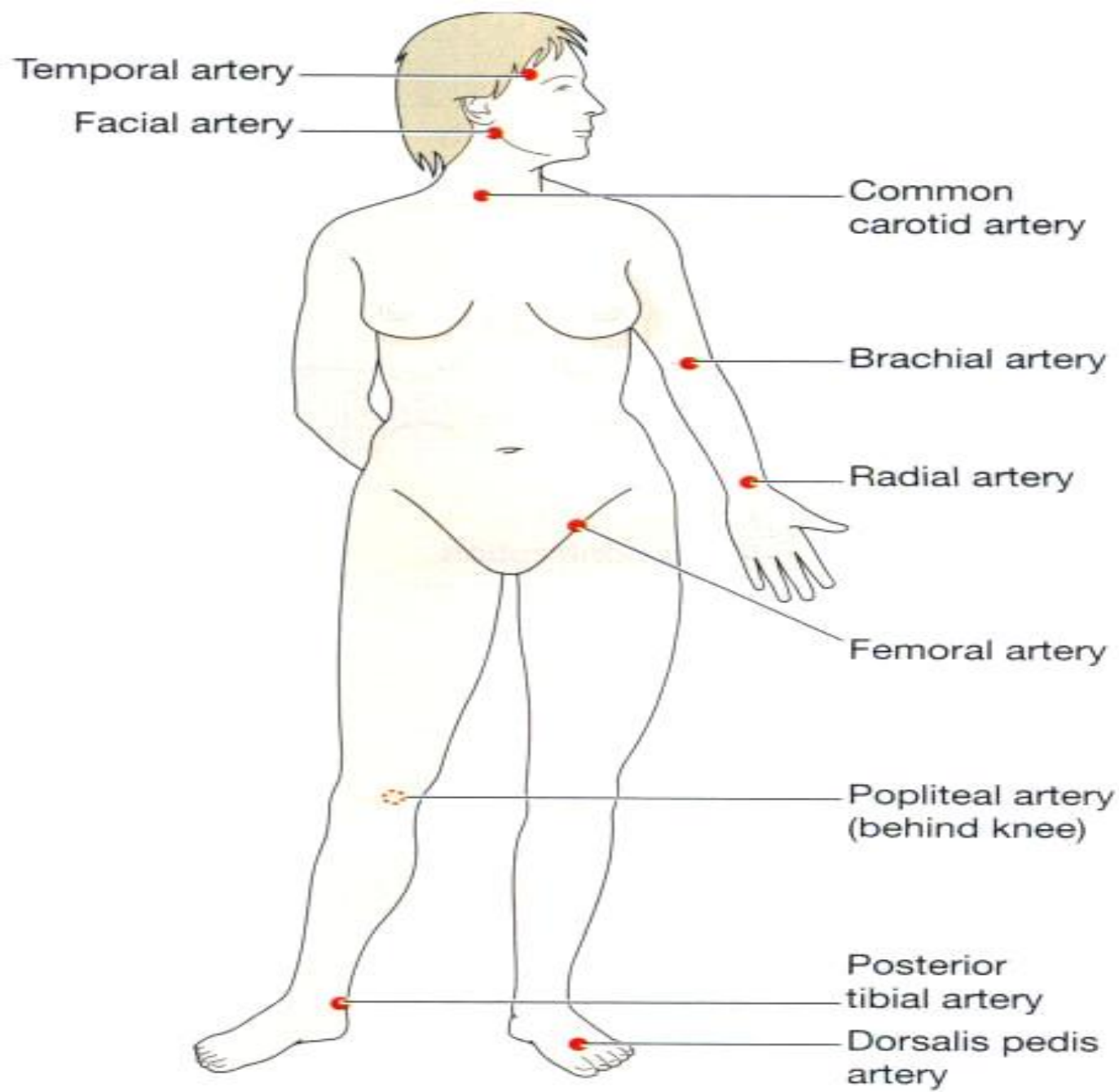
Mechanisms of blood pressure control

Long term BP regulation

- This control is exerted by
 - Renin-Angiotensin-Aldosterone System
 - Action of Antidiuretic Hormone (ADH)
- Both regulate blood volume which influences BP

PULSE

- **Def:** a wave of distension and elongation felt in an artery wall due to the contraction of the left ventricle during ventricular ejection.
- The pulse is felt at any point where a superficial artery can be pressed gently against a bone.
- No. of pulse beats per minute normally represents the heart rate and varies considerably in different people and in the same person at different times.
- Information obtained from the pulse includes:
 - rate at which the heart is beating
 - regularity with which the heartbeats occur,
 - volume or strength of the beat
 - tension — artery wall should feel soft & pliant under the fingers.



Main pulse points

Factors that affect the pulse rate

1. Narrowing or blockage of arteries supplying peripheral tissues; therefore blood is not pumped through them with each heartbeat
2. Failing or diseased heart therefore unable to generate enough force, with each contraction, to circulate blood to peripheral arteries.

NB: Under normal circumstances the pulse rate and the heart rate are identical (same)

CIRCULATION OF BLOOD

- Blood is circulated through two main systems:
 - Pulmonary circulation
 - Systemic or General Circulation

PULMONARY CIRCULATION

- Refers to the circulation of blood from RV of heart to lungs & back to LA.
- Pulmonary artery, carrying deoxygenated blood, leaves upper part of RV. It passes upwards & divides into left & right pulmonary arteries.
- Left pulmonary artery runs to the root of left lung where it divides into 2 branches, one passing into each lobe.
- Right PA passes to the root of right lung & divides into 2 branches.
 - larger branch carries blood to middle & lower lobes
 - smaller branch to the upper lobe.

- Within the lung these arteries subdivide into smaller arteries, arterioles & capillaries. Interchange of gases takes place between capillary blood & air in the lung's alveoli.
- In each lung capillaries containing oxygenated blood join up & form 2 veins.
- 2 pulmonary veins leave each lung, returning oxygenated blood to LA of the heart.
- During atrial systole this blood passes into LV & during ventricular systole it is forced into the aorta.

SYSTEMIC OR GENERAL CIRCULATION

- Blood pumped out from LV is carried by aortic branches around the body & returned to RA of the heart by superior & inferior venae cavae.

AORTA

- Begins at upper part of LV &, after passing upwards for a short way, it arches backwards and to the left.
- Descends behind the heart through the thoracic cavity a little to the left of thoracic vertebrae.
- At the level of 12th thoracic vertebra it passes behind the diaphragm then downwards in the abdominal cavity to the level of 4th lumbar vertebra, where it divides into **right & left common iliac arteries**.
- Gives off paired branches, e.g. right & left renal arteries supplying kidneys, & some or unpaired branches, e.g. coeliac artery as it descends.

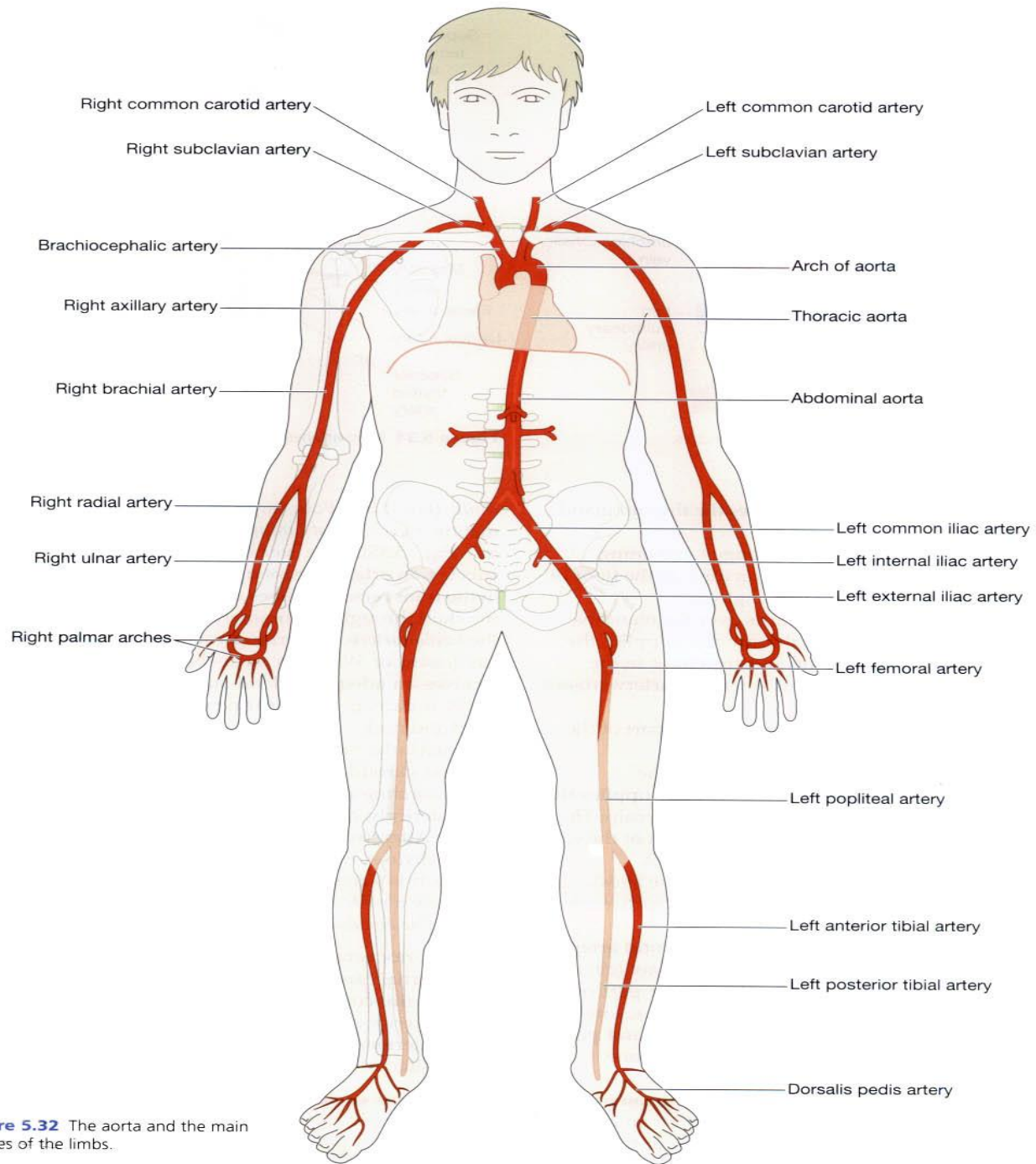


Figure 5.32 The aorta and the main arteries of the limbs.

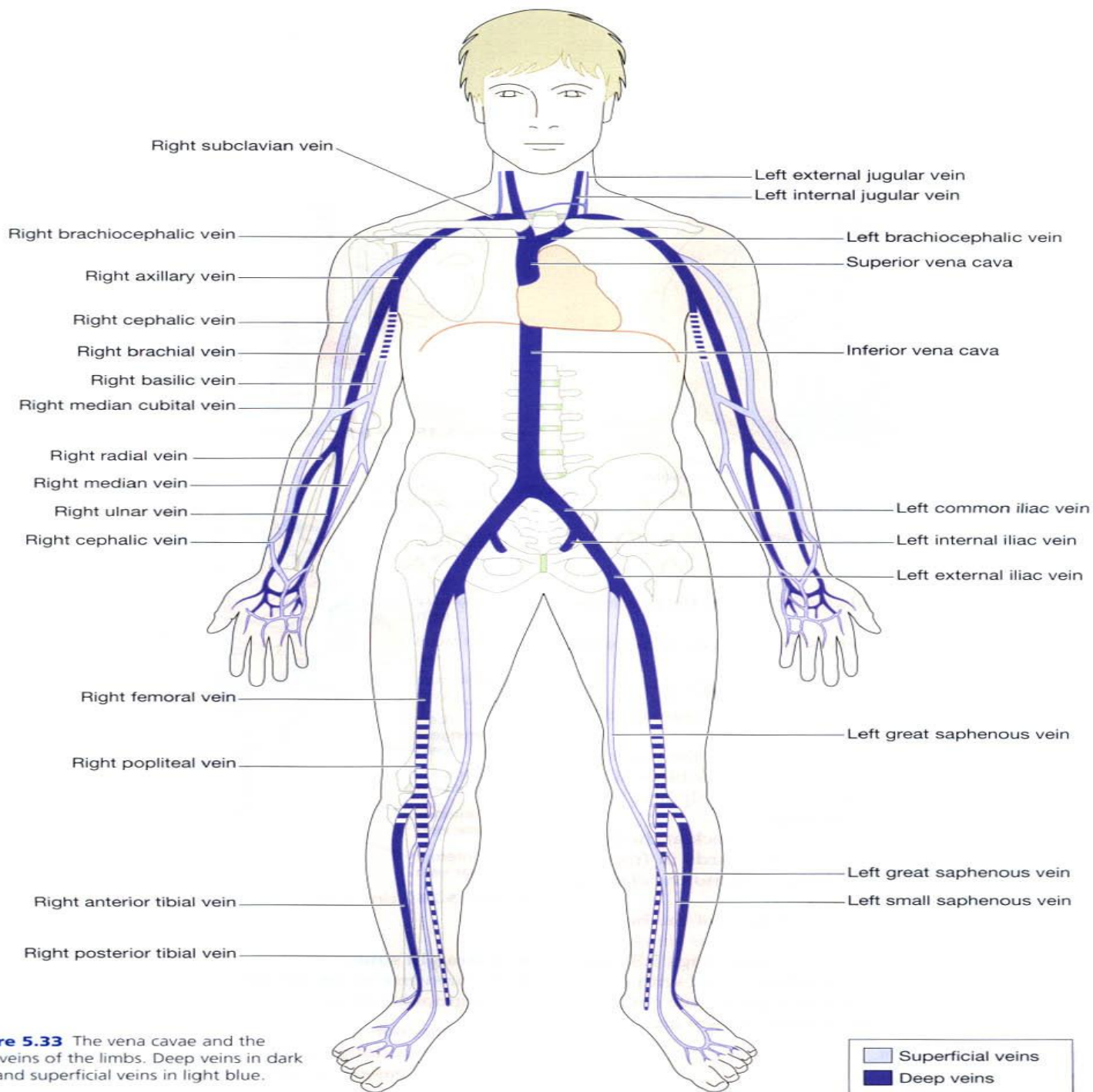
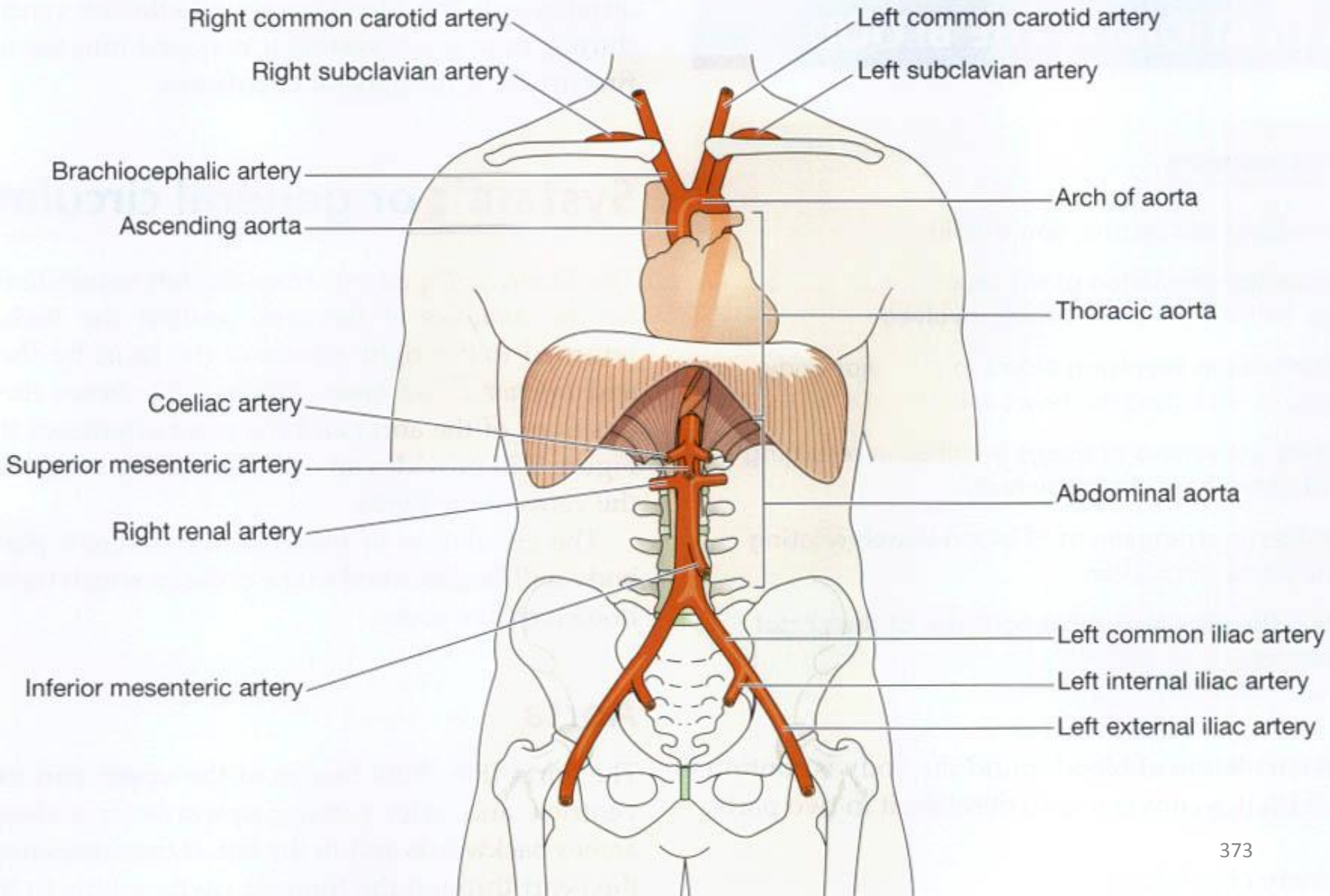


Figure 5.33 The vena cavae and the main veins of the limbs. Deep veins in dark blue and superficial veins in light blue.

Superficial veins
 Deep veins

Aorta and its branches



Thoracic aorta

- Part that lies above the diaphragm; has 3 parts:
 - ascending aorta
 - arch of the aorta
 - descending aorta in the thorax.

a) Ascending aorta:

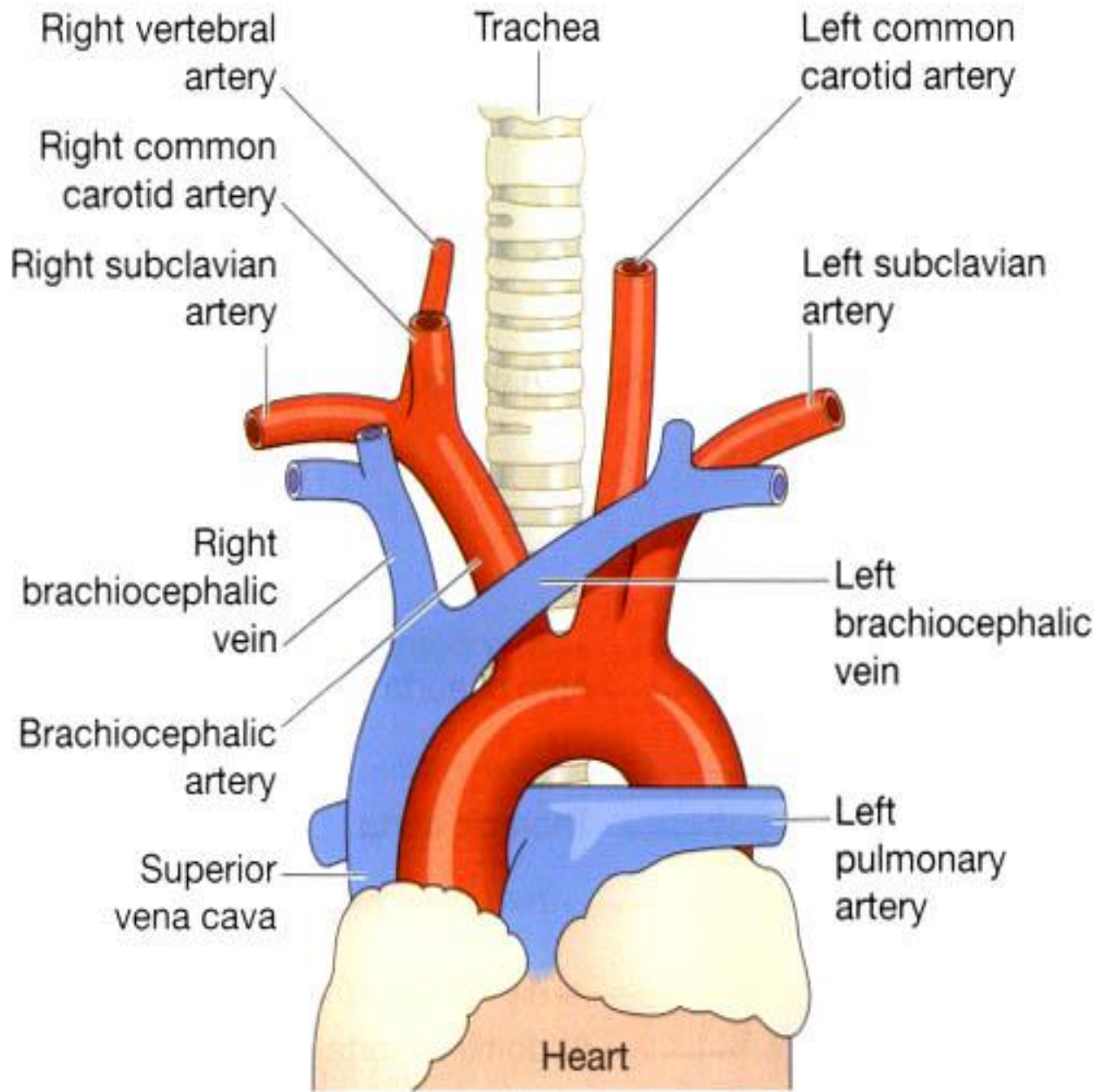
- About 5 cm long; lies behind the sternum.
- Gives off the right & left coronary arteries that supply the myocardium

b) Arch of the aorta: Continuation of ascending aorta.

- Begins behind the manubrium of the sternum & runs upwards, backwards & to the left in front of trachea.
- Then passes downwards to the left of trachea; continuous with descending aorta.

- Gives off 3 branches
 - ***brachiocephalic artery or trunk***; 4 to 5 cm long; passes obliquely upwards, backwards & to the right. At the level of sternoclavicular joint it divides into *right common carotid artery & right subclavian artery*.
 - ***left common carotid artery***
 - ***left subclavian artery***.

Aortic ar

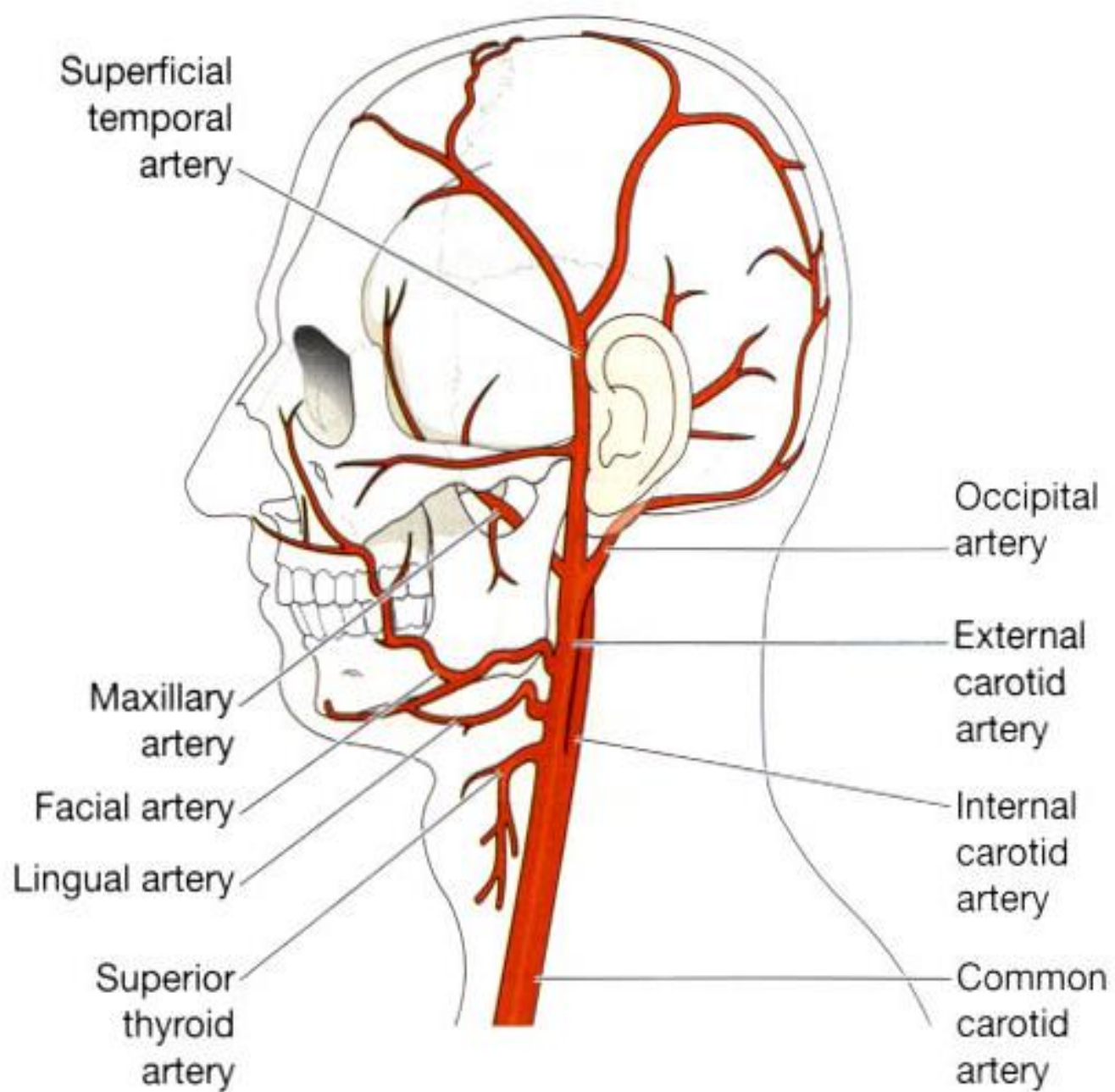


CIRCULATION OF BLOOD TO THE HEAD AND NECK

- The paired arteries supplying the head & neck are the ***common carotid arteries & vertebral arteries*** .

Carotid arteries.

- **Right common carotid artery** is a branch of brachiocephalic artery.
- **Left common carotid artery** arises directly from **arch of aorta**.
- Pass upwards on either side of neck & have the same distribution on each side.
- At the level of upper border of thyroid cartilage they divide into:
 - external carotid artery.
 - internal carotid artery.



Main arteries of the left side of the head and neck

- **Carotid sinuses** are slight dilatations at the point of division (bifurcation) of common carotid arteries into their internal & external branches.
- Walls of the sinuses are thin & contain numerous nerve endings (**baroreceptors**).
- **Carotid bodies (chemoreceptors)** are also found here.
- The resultant nerve impulses initiate reflex adjustments of respiration through the respiratory centre in medulla oblongata.

- **External carotid artery** supplies superficial tissues of head & neck, via a number of branches.
 - 1) **Superior thyroid artery** supplies thyroid gland & adjacent muscles.
 - 2) **Lingual artery** supplies the tongue, lining membrane of mouth, structures in the floor of mouth, tonsil & epiglottis.
 - 3) **Facial artery** passes outwards over the mandible just in front of angle of the jaw & supplies muscles of facial expression & structures in the mouth. The pulse may be felt where the artery crosses the jaw bone.

- 4) **Occipital artery** supplies posterior part of the scalp.
- 5) **Temporal artery** passes upwards over the zygomatic process in front of the ear & supplies the frontal, temporal & parietal parts of the scalp. The pulse may be felt in front of the upper part of the ear.
- 6) **Maxillary artery** supplies muscles of mastication. Branch of it; the middle meningeal artery, runs deeply to supply structures in the interior of the skull.

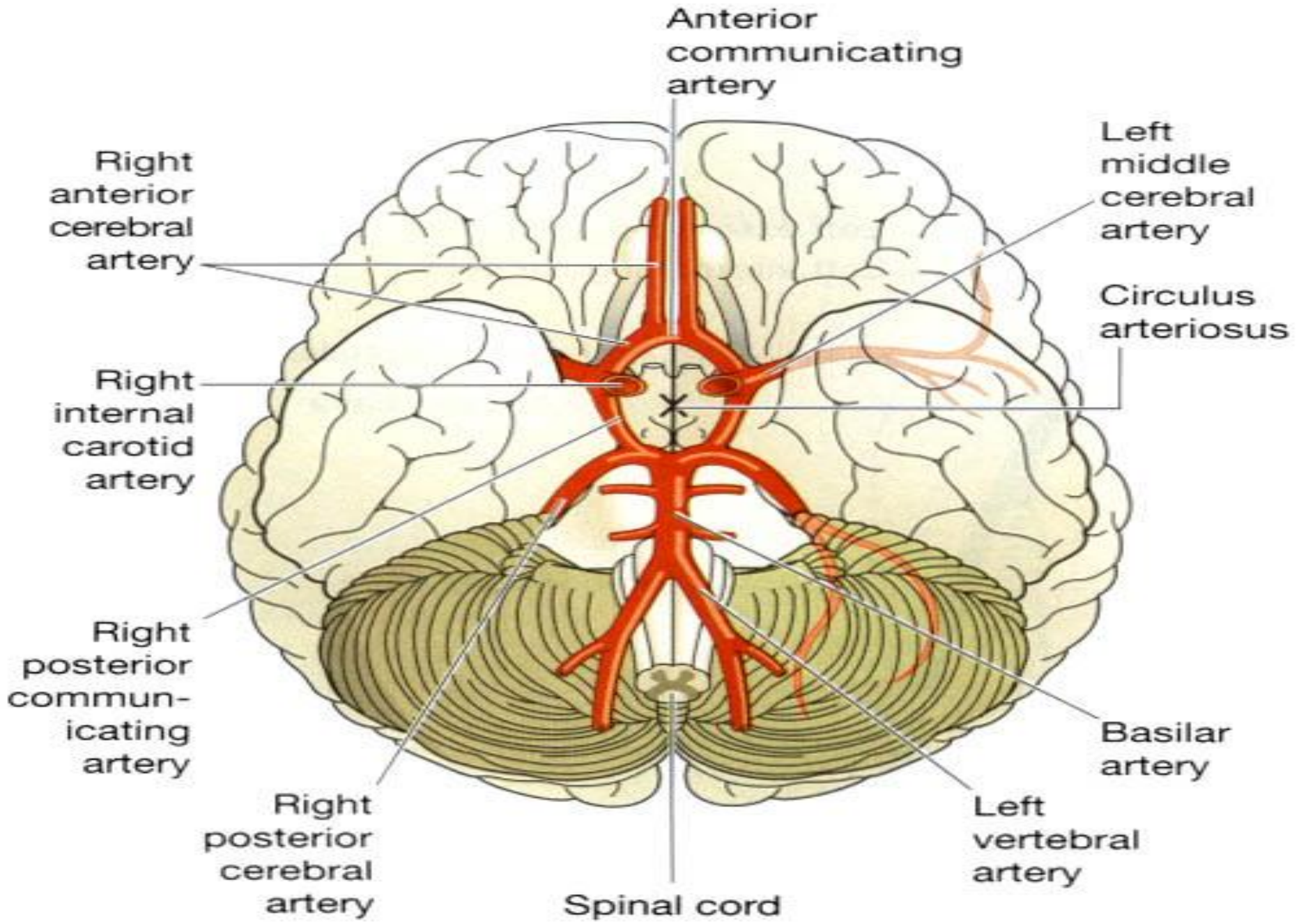
- Internal carotid artery.
- Major contributor to the circulus arteriosus.
- Has branches that supply eyes, forehead & nose.
- Ascends to skull's base & passes through the **carotid foramen** in the temporal bone.

Circulus arteriosus (circle of Willis)

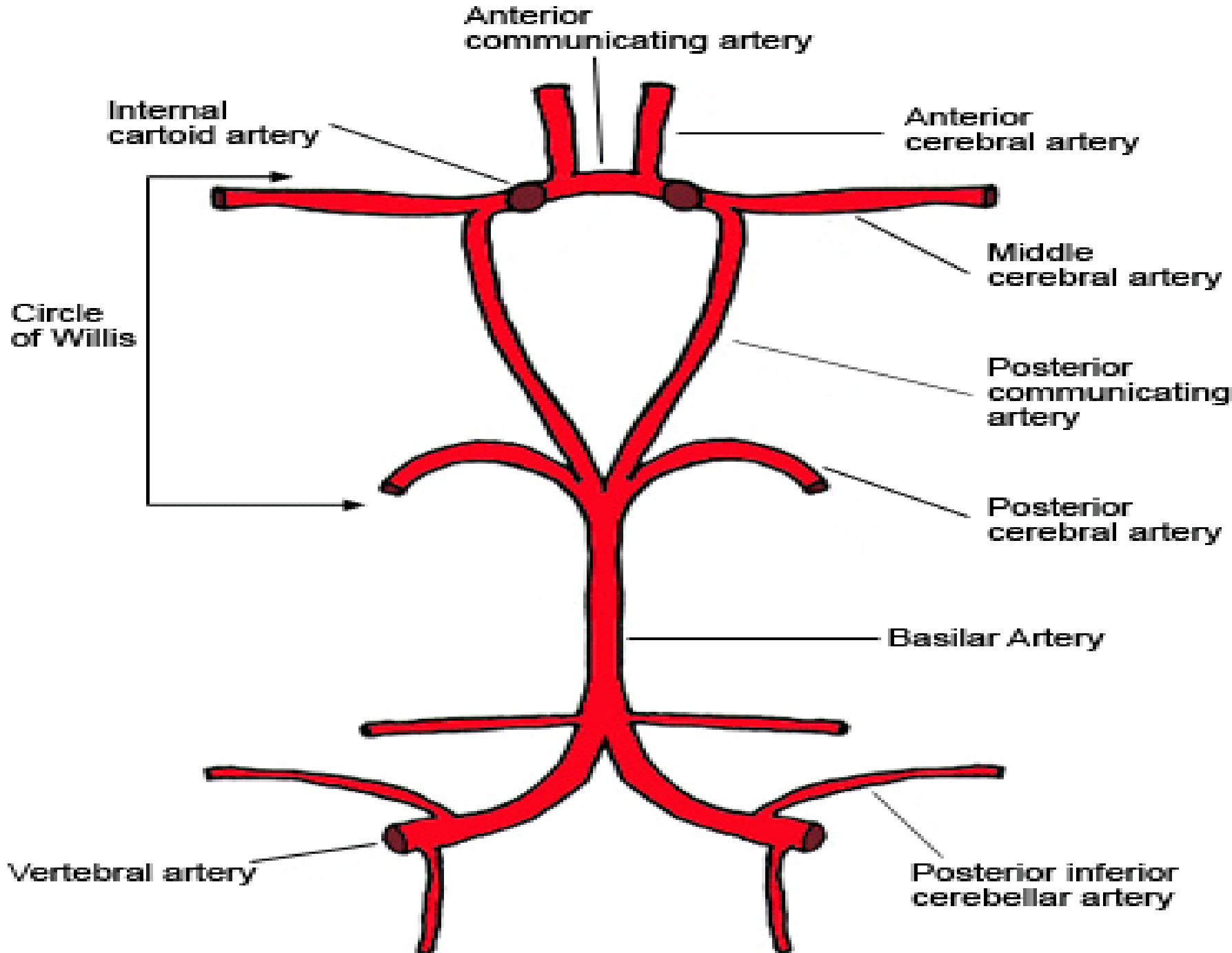
- Supplies greater part of the brain.
- 4 large arteries contribute to its formation:
 - two internal carotid arteries
 - two vertebral arteries

- **The vertebral arteries;** arise from **subclavian arteries**, pass upwards through the foramina in the transverse processes of cervical vertebrae, enter the skull through the foramen magnum, then join to form the **basilar artery**.
- Anteriorly, **2 anterior cerebral arteries** arise from the internal carotid arteries and are joined by the **anterior communicating artery**.
- Posteriorly, **2 vertebral arteries** join to form the **basilar artery**.
- Basilar artery divides to form **2 posterior cerebral arteries**, each of which is joined to the corresponding internal carotid artery by a **posterior communicating artery**, completing the circle.

- Circulus arteriosus is therefore formed by:
 - 2 anterior cerebral arteries
 - 2 internal carotid arteries
 - 1 anterior communicating artery
 - 2 posterior communicating arteries
 - 2 posterior cerebral arteries
 - 1 basilar artery.
- From this circle,
 - Anterior cerebral arteries pass **forward** to supply the **anterior part** of the brain,
 - **Middle cerebral arteries** pass **laterally** to supply the **sides of the brain**,
 - **Posterior cerebral arteries** supply **posterior part** of brain.
- **Branches of basilar artery** supply parts of **brain stem**.



Arteries forming circle of circle of Willis



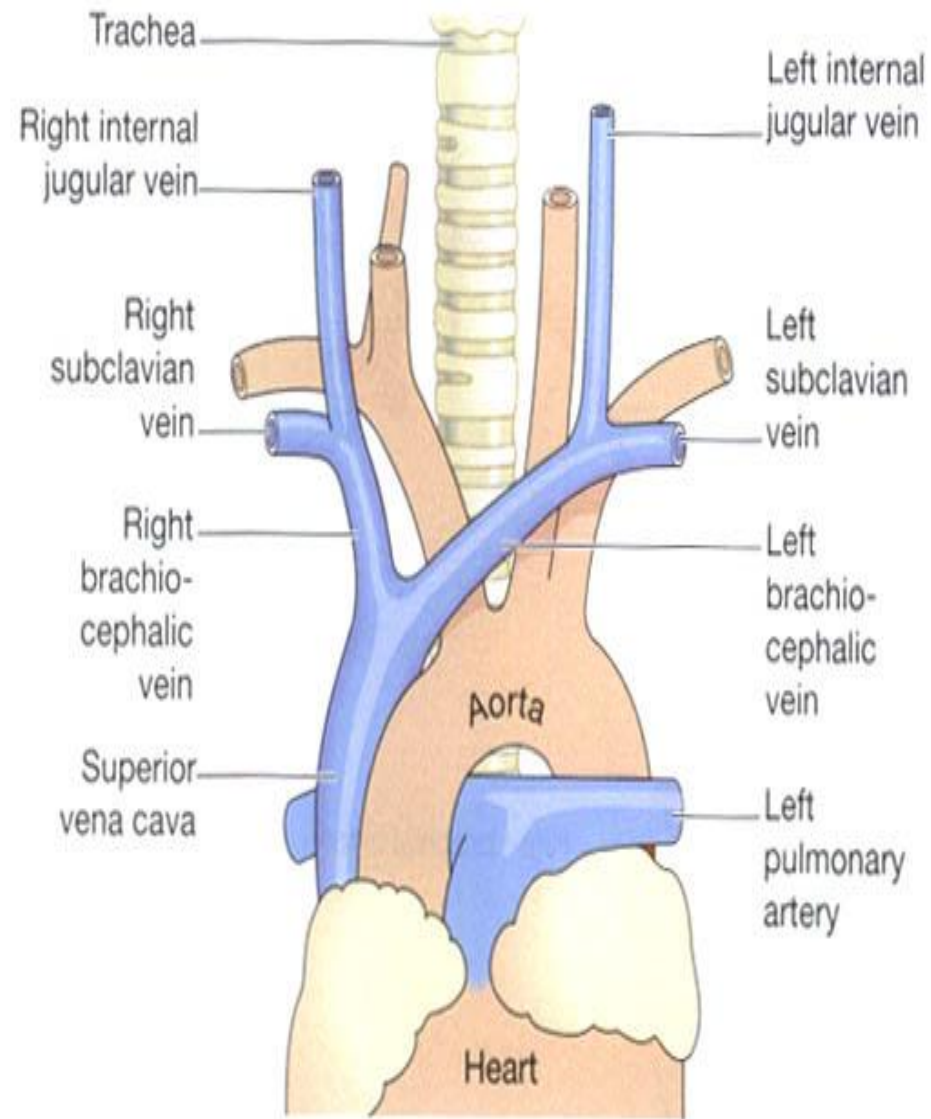
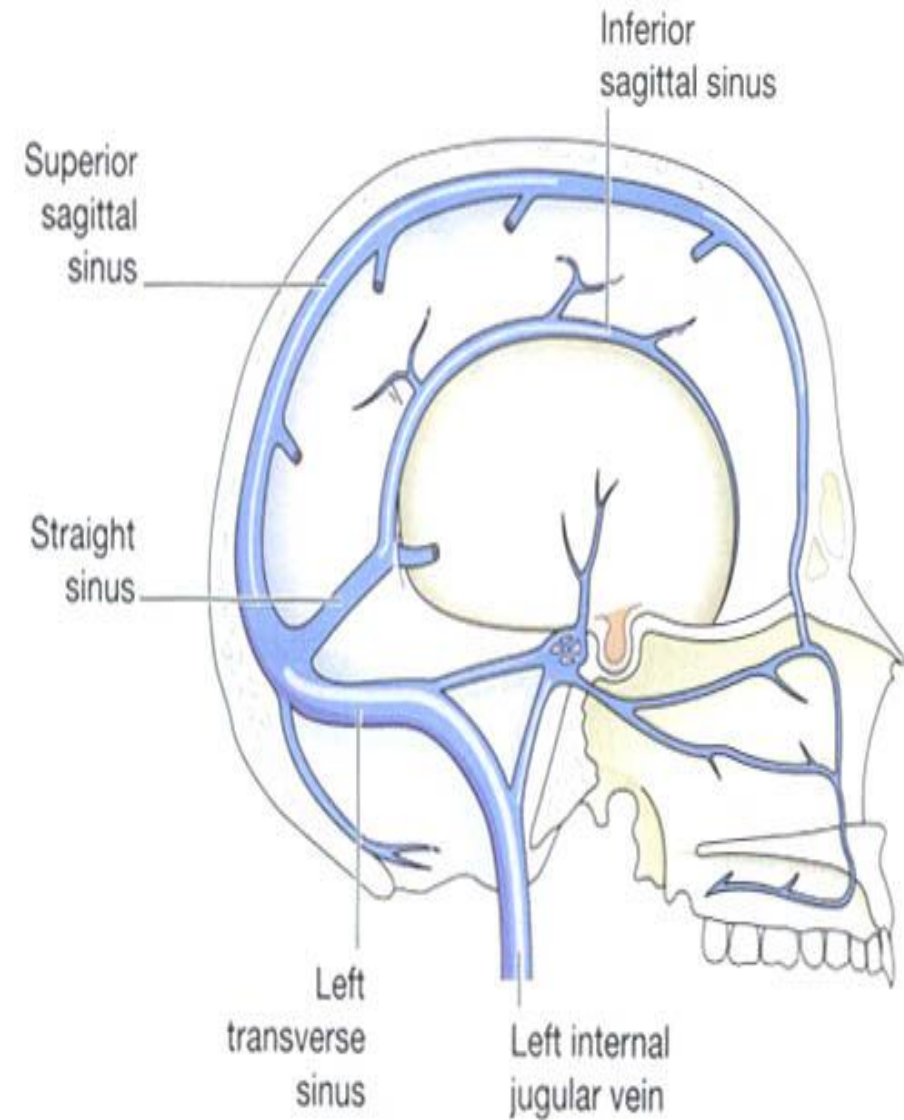
- Assignment:
- Draw a diagram showing the arteries that form the circle of Willis

Venous return from the head and neck

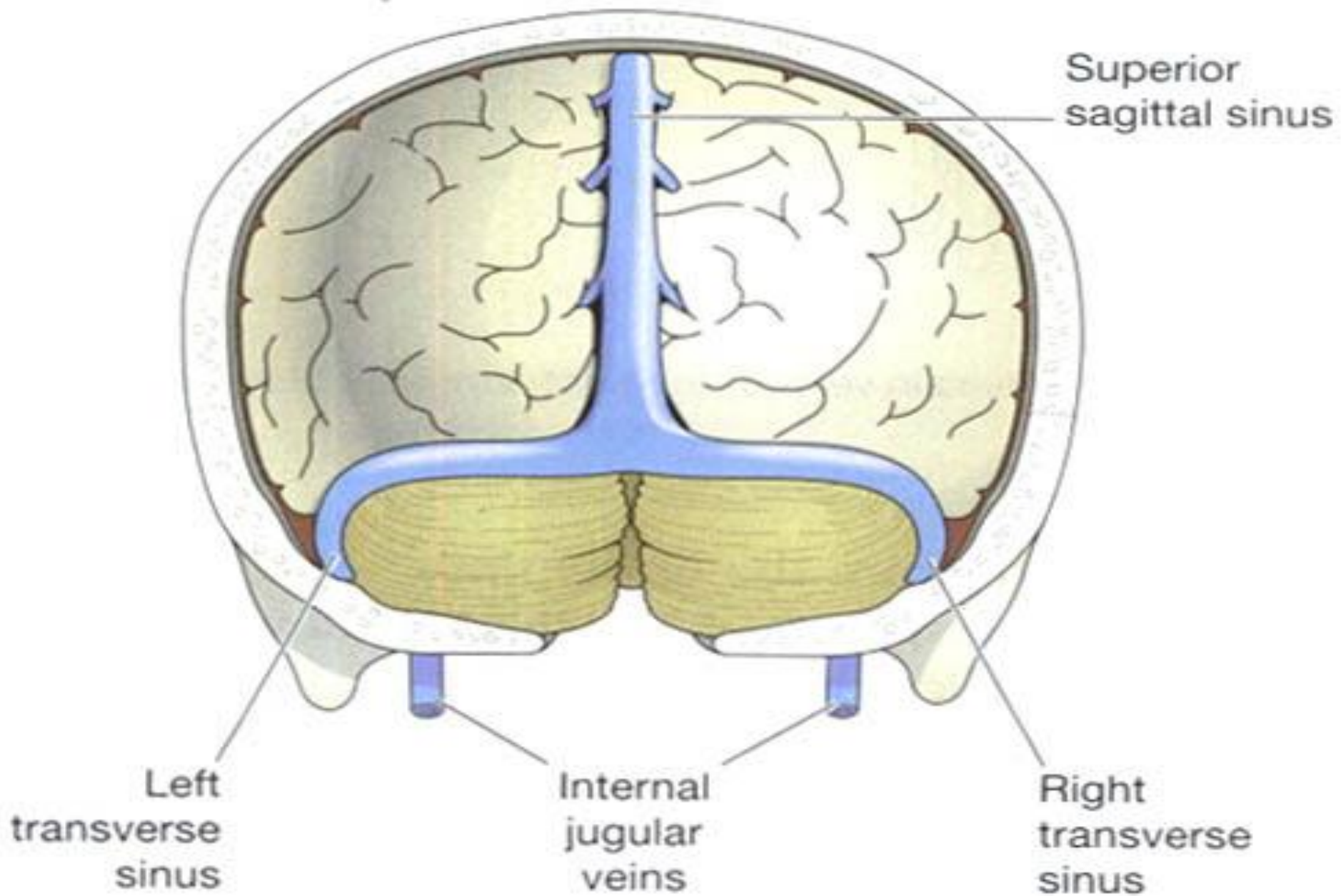
- Thru **deep & superficial** veins.
- Superficial veins; return venous blood from superficial structures of the face & scalp & unite to form the **external jugular vein**.
- External jugular vein begins in the neck at the level of angle of the jaw. Passes downwards in front of sternocleidomastoid muscle, then behind the clavicle before entering subclavian vein.
- Venous blood from deep areas of brain is collected into channels called **dural venous sinuses** (formed by layers of dura mater lined with endothelium).
- **Dura mater**: outer protective covering of the brain.

Main venous sinuses

- 1. Superior sagittal sinus:** carries venous blood from superior part of the brain. Begins in the frontal region and passes directly backwards in the skull's midline of to occipital region where it turns to the right side and continues as **right transverse sinus**.
- 2. Inferior sagittal sinus;** lies deep within the brain & passes backwards to form **straight sinus**.
- 3. Straight sinus;** runs backwards & downwards to become left transverse sinus.
- 4. Transverse sinuses;** begin in occipital region & run forward & medially in a curved groove of skull, to become continuous with **sigmoid sinuses**.
- 5. Sigmoid sinuses.** Each curves downwards & medially & lies in a groove in the mastoid process of temporal bone. Inferiorly it continues as **internal jugular vein**.

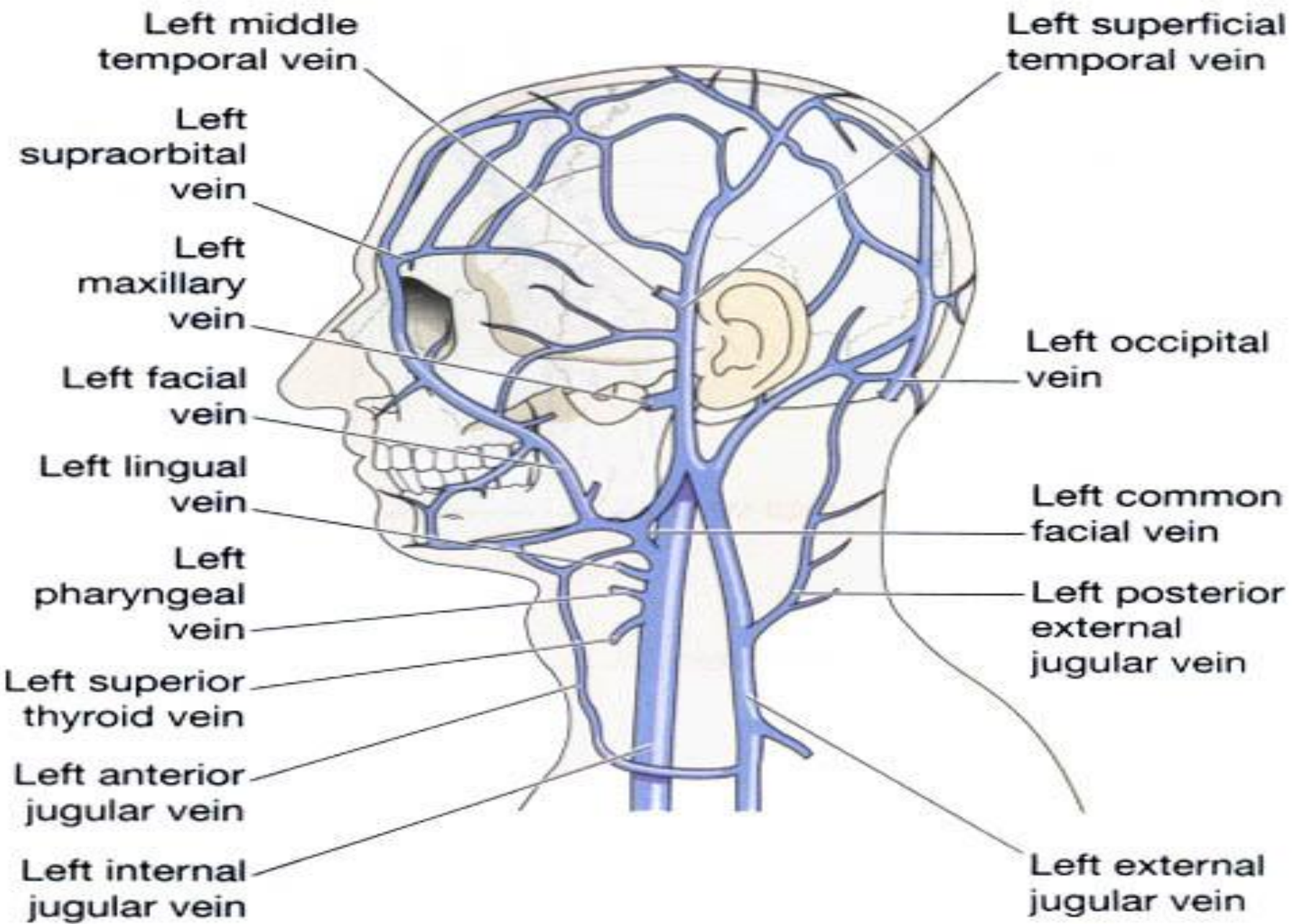


Venous sinuses of the brain viewed from the right; The superior vena cava and the veins which form it.



Venous sinuses of the brain viewed from above.

- 6. Internal jugular veins;** begin at jugular foramina in middle cranial fossa & each is the continuation of a sigmoid sinus. They run downwards in the neck behind **sternocleidomastoid** muscles. **Behind the clavicle** they unite with **subclavian veins**, carrying blood from upper limbs, forming brachiocephalic veins.
- 7. Brachiocephalic veins;** situated one on each side in the neck's root. Each is formed by union of internal jugular & subclavian veins. Left brachiocephalic vein is longer than the right & passes obliquely behind manubrium of the sternum, where it joins right brachiocephalic vein to form **superior vena cava**.
- 8. Superior vena cava,** drains all the venous blood from head, neck & upper limbs; about 7 cm long. Passes downwards along right border of sternum & ends in RA of the heart.



veins of the left side of the head and veins on the

left side of the neck & head

CIRCULATION OF BLOOD TO THE UPPER LIMB

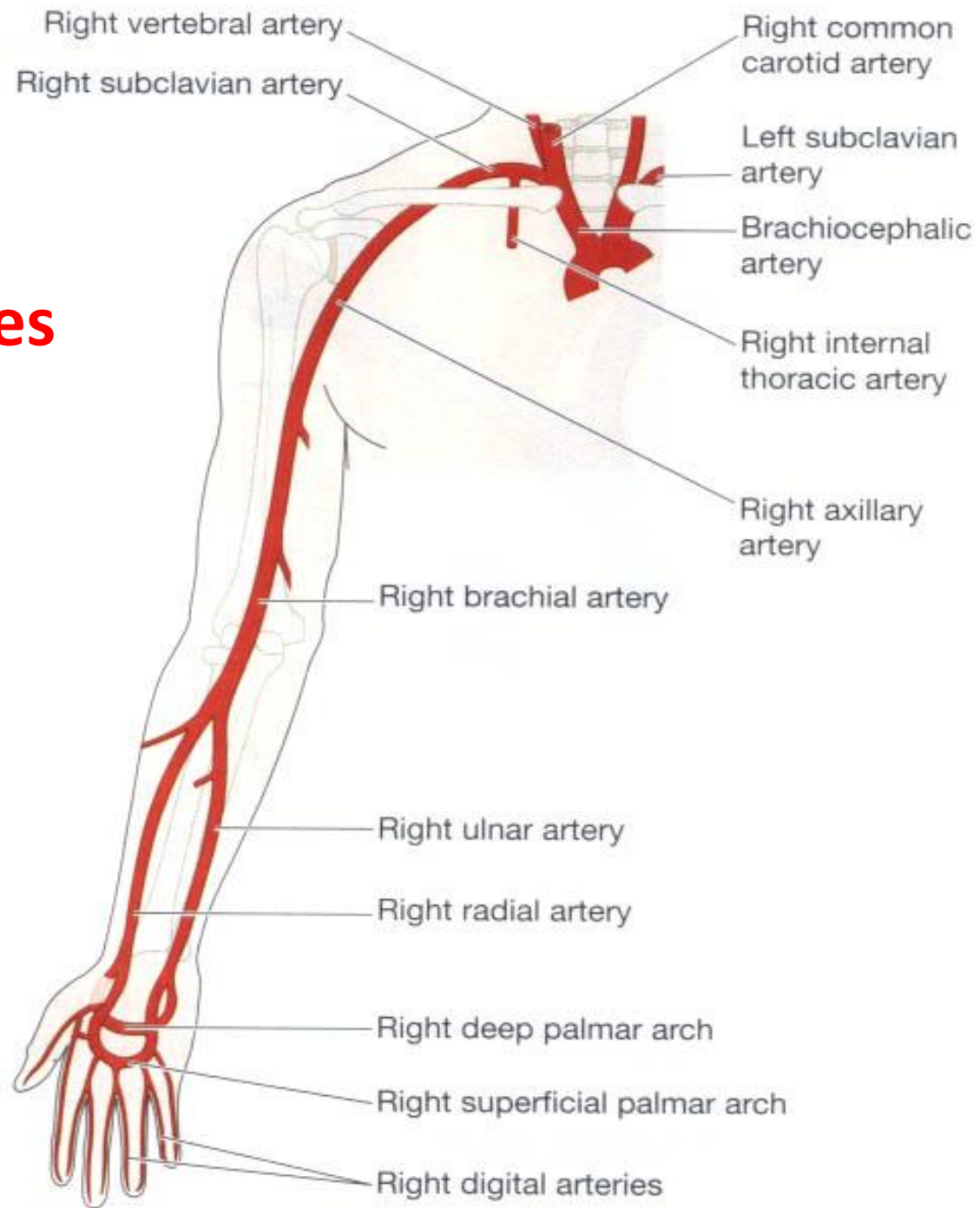
Arterial supply

a) Subclavian arteries.

- Right subclavian artery arises from brachiocephalic artery; the left branches from aortic arch.
- Slightly arched & pass behind the clavicles & over the first ribs before entering the axillae, where they continue as **axillary arteries**.
- Before entering the axilla, each subclavian artery gives off 2 branches:
 - **Vertebral artery**; passes upwards to supply the brain,
 - **Internal thoracic artery**; supplies breast & a number of structures in thoracic cavity.

- b) Axillary artery:** Continuation of subclavian artery; lies in the axilla. The first part lies deeply; then it runs more superficially to become **brachial artery**.
- c) Brachial artery:** runs down the medial aspect of upper arm, passes to the front of elbow & extends to about 1 cm below the joint, where it divides into **radial & ulnar arteries**.
- d) Radial artery:** passes down the radial or lateral side of forearm to the wrist. Just above the wrist, it lies superficially & can be felt in front of radius, where radial pulse is palpable. Then passes between first & second metacarpal bones & enters palm of the hand.
- e) Ulnar artery:** runs downwards on the ulnar or medial aspect of forearm to cross the wrist & pass into the hand.
- f) Deep and superficial palmar arches:** are anastomoses between radial & ulnar arteries, from which palmar metacarpal & palmar digital arteries arise to supply structures in the hand & fingers.

Main Arteries of the Right arm



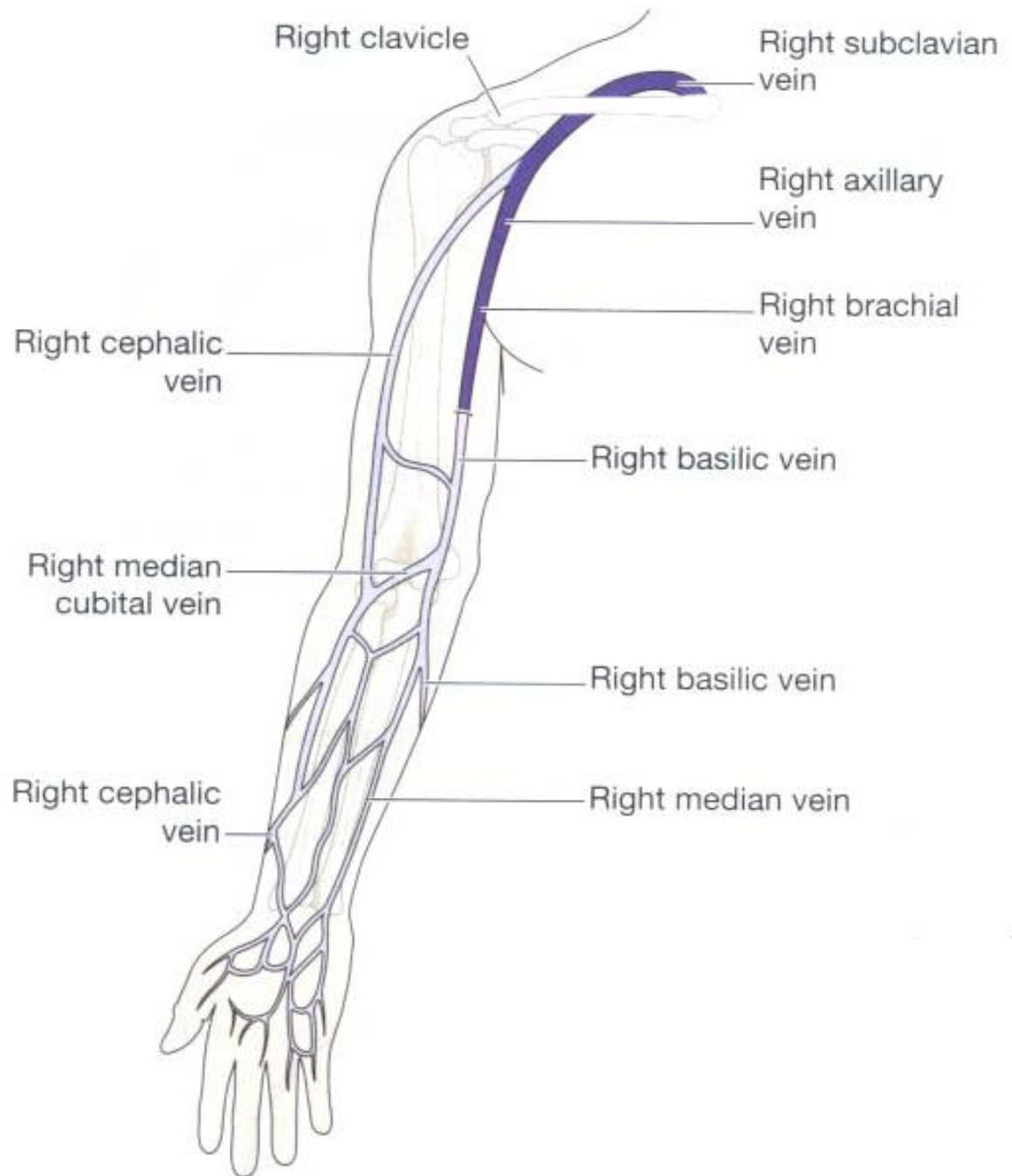
Venous return from the upper limb

- Divided into 2 groups:
 - deep
 - superficial veins
- Deep veins follows the course of arteries & have the same names:
 - palmar metacarpal veins
 - deep palmar venous arch
 - ulnar and radial veins
 - brachial vein
 - axillary vein
 - subclavian vein.

- **Superficial veins** begin in the hand. They are:
 - cephalic vein
 - basilic vein
 - median vein
 - median cubital vein.
- **Cephalic vein:** begins at the back of hand then winds round the radial side to the anterior aspect of forearm.
- In front of the elbow, it gives off a large branch, the **median cubital vein**, which slants upwards & medially to join **basilic vein**.
- After crossing elbow joint, cephalic vein passes up lateral aspect of arm & in front of shoulder joint to end in **axillary vein**.
- Throughout its length, it receives blood from superficial tissues on lateral aspects of hand, forearm & arm.

- **Basilic vein:** begins at the back of hand on the ulnar aspect, ascends on the medial side of forearm & upper arm then joins axillary vein. Receives blood from medial aspect of hand, forearm & arm.
- **Median vein:** small vein that is not always present. Begins at the palmar surface of hand, ascends on the front of the forearm & ends in the **basilic vein** or **the median cubital vein**.
- **Brachiocephalic vein:** formed when subclavian & internal jugular veins unite.
- **Superior vena cava:** formed when the 2 brachiocephalic veins unite. Drains all the venous blood from head, neck & upper limbs & terminates in the right atrium. About 7 cm long & passes downwards along the right border of the sternum.

Main veins of the right arm

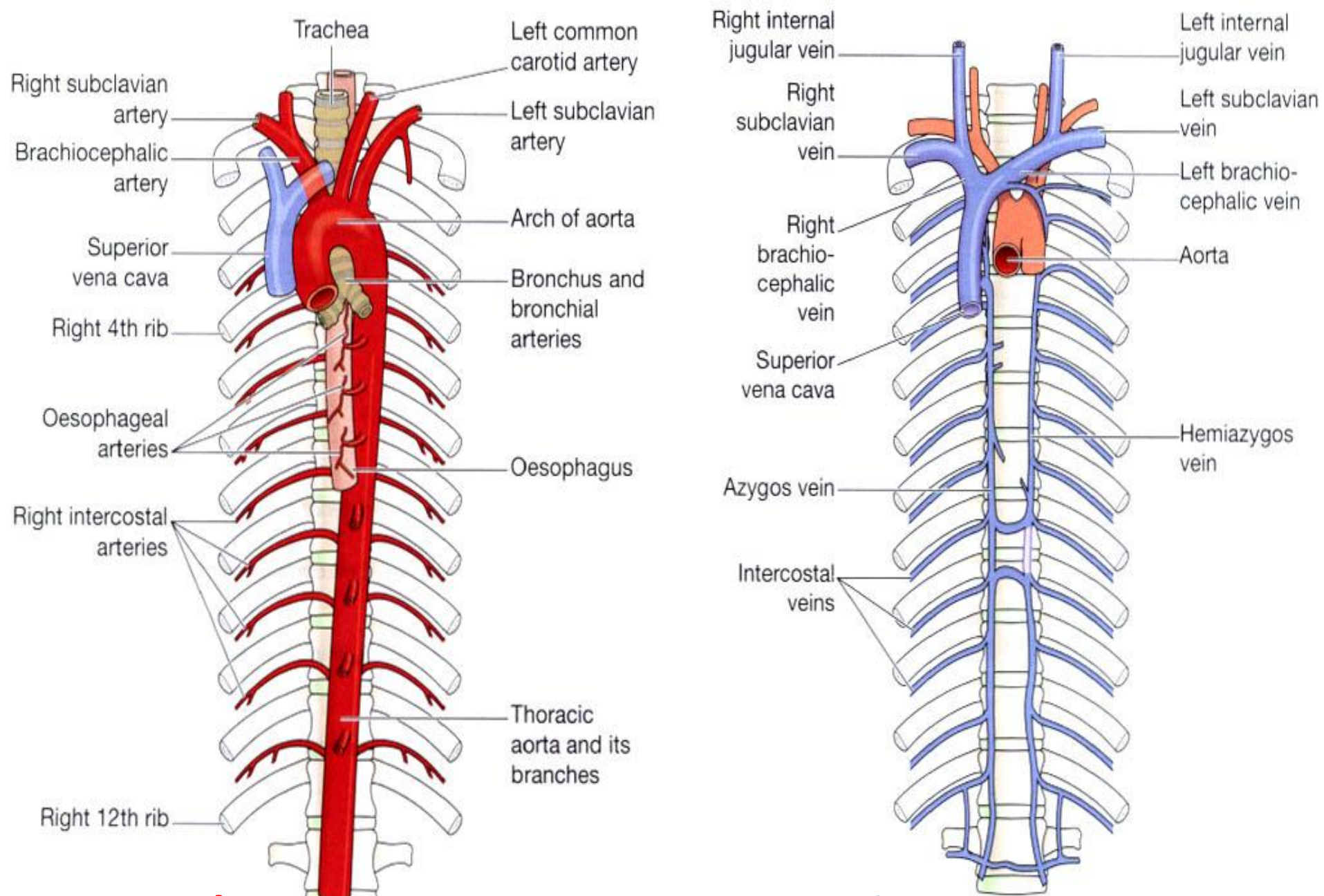


DESCENDING AORTA IN THE THORAX

- Continuous with aortic arch; begins at the level of **4th thoracic** vertebra.
- Extends downwards on anterior surface of bodies of thoracic vertebrae to the level of **12th thoracic** vertebra, where it passes behind the diaphragm to become **abdominal aorta**.
- Gives off many paired branches which supply walls of thoracic cavity & organs within the cavity, including:
 - **bronchial arteries:** supply bronchi & their branches, connective tissue in the lungs & lymph nodes at the root of the lungs
 - **oesophageal arteries:** supply oesophagus
 - **intercostal arteries** that run along the inferior border of the ribs & supply intercostal muscles, some muscles of thorax, ribs, skin & its underlying connective tissues.

Venous return from the thoracic cavity

- Mostly by **azygos vein & hemiazygos vein.**
- Main veins which join them are the
 - **bronchial,**
 - **oesophageal &**
 - **intercostal veins.**
- **Azygos vein** joins the **superior vena cava**
- **Hemiazygos vein** joins the **left brachiocephalic vein.**

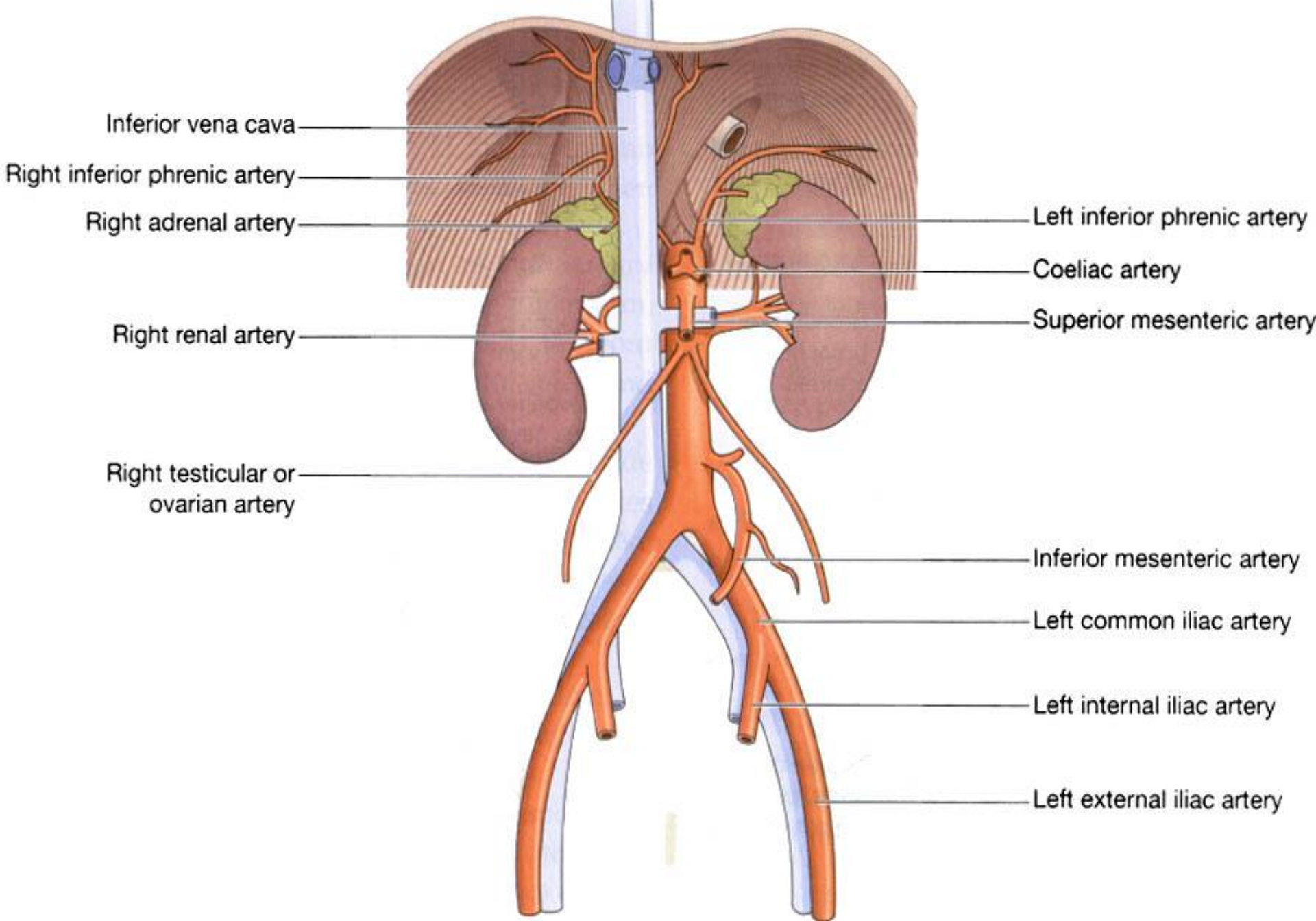


The aorta & superior venacava

and their main branches in the thorax

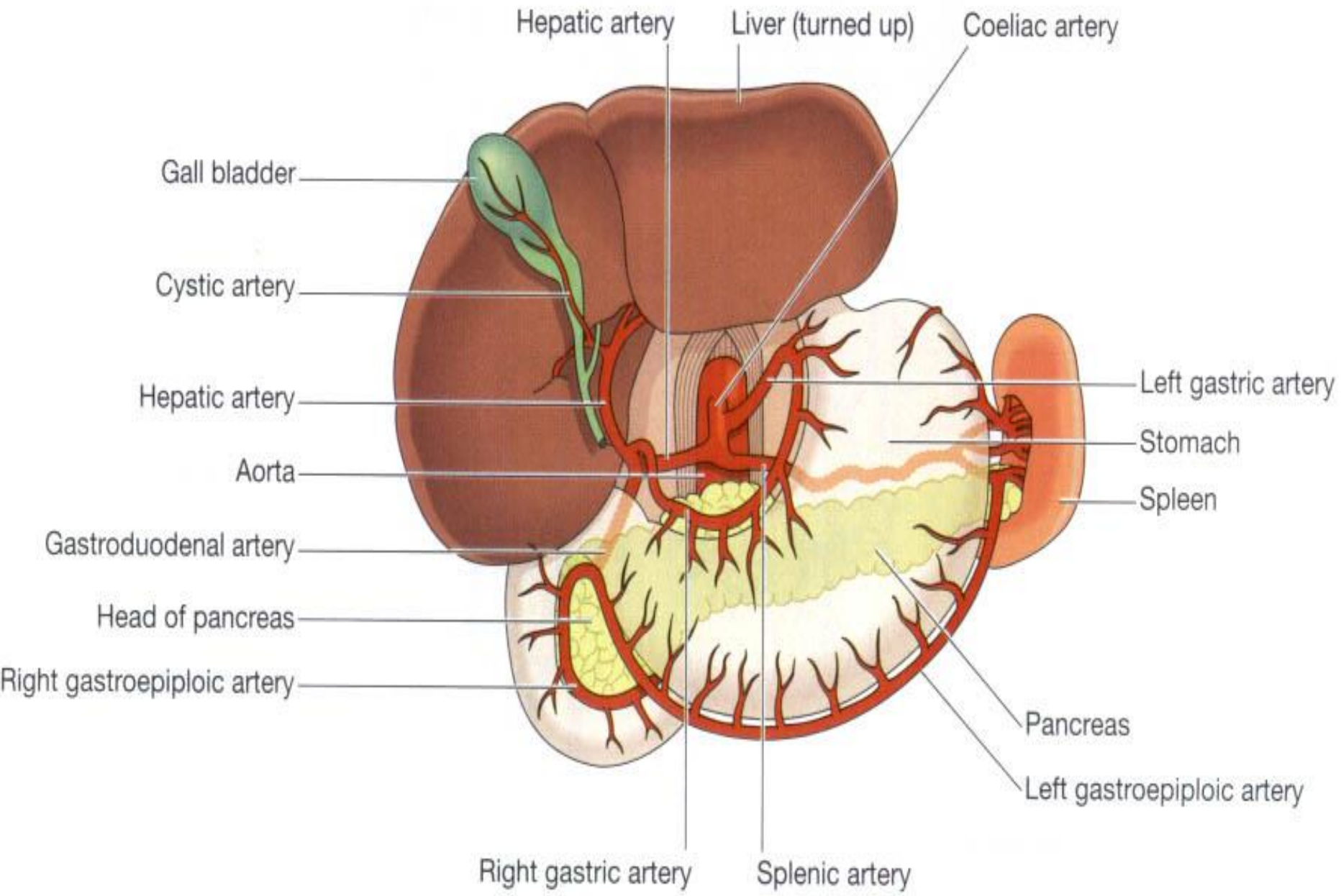
ABDOMINAL AORTA

- Continuation of thoracic aorta.
- Begins at the level of the 12th thoracic vertebra and descends in front of bodies of vertebrae to the level of the 4th **lumbar** vertebra, where it divides into **right & left common iliac** arteries.



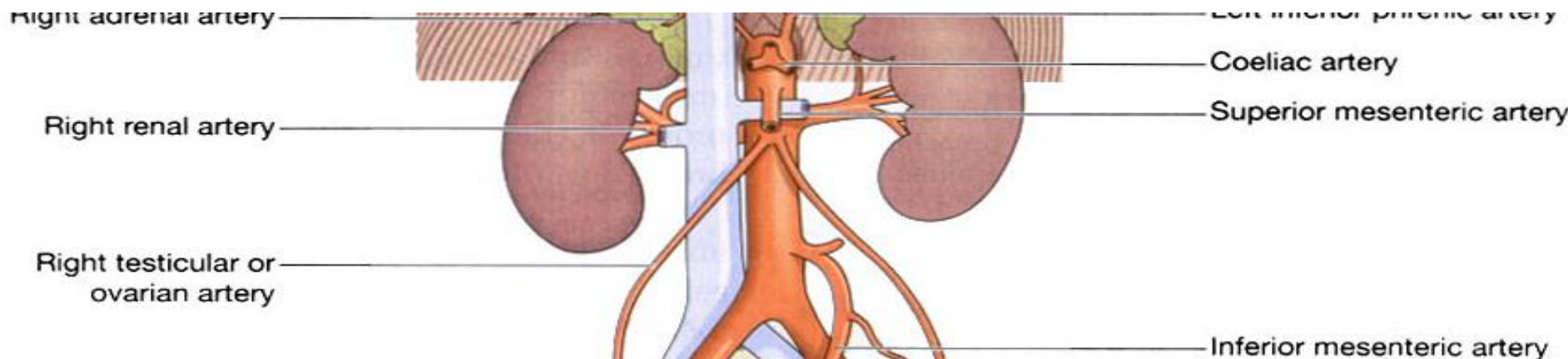
Abdominal aorta and its branches

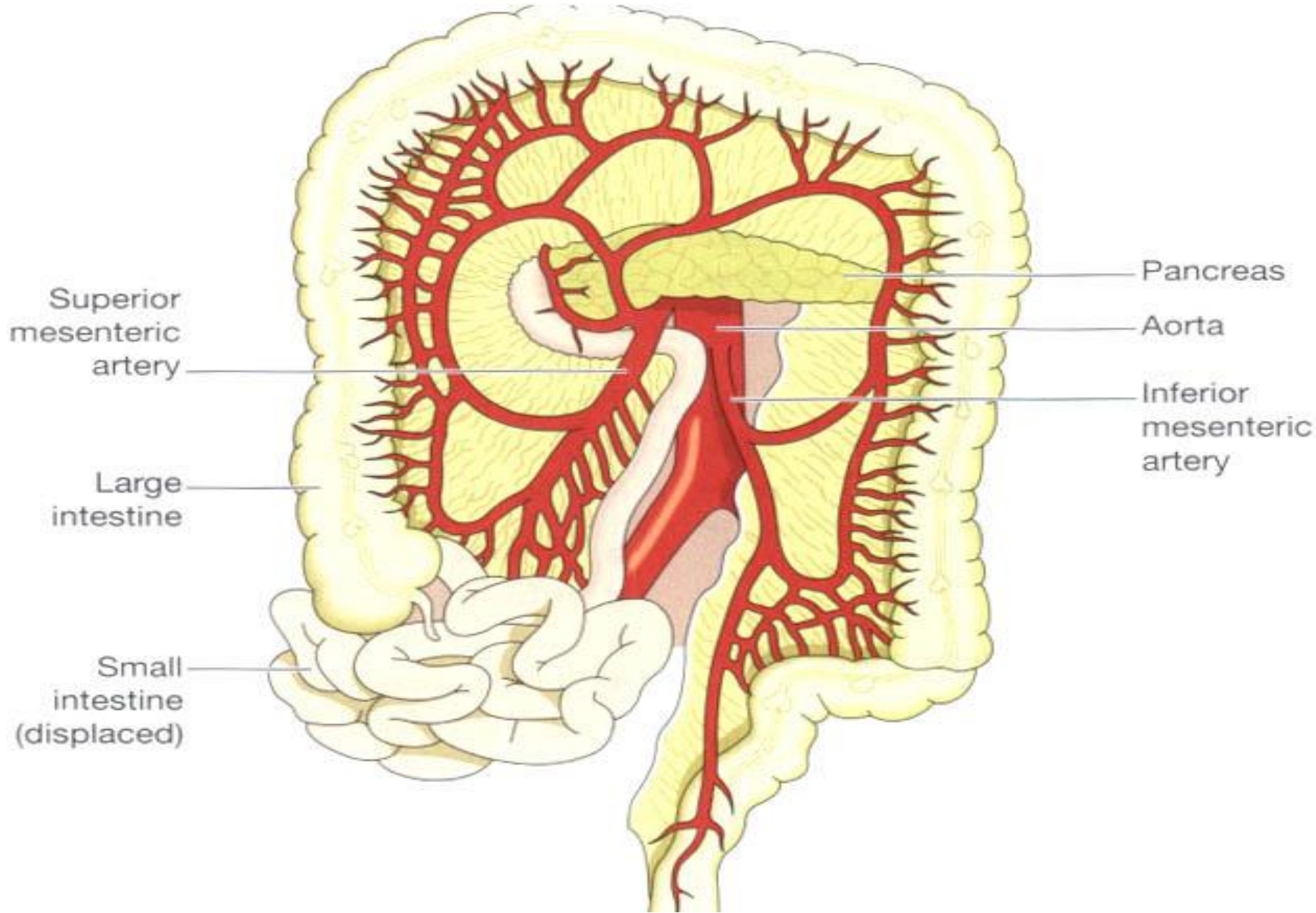
- Gives off paired & some unpaired branches.
- **Paired branches**
 - **Inferior phrenic** arteries; supply diaphragm.
 - **Renal arteries**; supply kidneys & give off branches, suprarenal arteries, to supply adrenal glands.
 - **Testicular arteries**; supply testes -male.
 - **Ovarian arteries**; supply ovaries -female.
- Testicular & ovarian arteries are much longer than the other paired branches because the testes & ovaries begin their development in the kidney region.
- **Unpaired branches**
 1. **Coeliac artery**: short thick artery about 1.25 cm long. Arises immediately below the diaphragm & divides into 3 branches:
 - **left gastric artery**: supplies stomach
 - **splenic artery**: supplies pancreas & spleen
 - **hepatic artery**: supplies liver, gall bladder & parts of the stomach, duodenum & pancreas.



The coeliac artery and its branches.

- 2. Superior mesenteric artery;** branches from aorta between the coeliac artery & renal arteries.
- Supplies the **whole of small intestine & proximal half** of the large intestine.
- 3. Inferior mesenteric artery** arises from aorta about 4 cm above its division into the common iliac arteries.
- Supplies the **distal half** of the large intestine and part of the rectum.





The superior and inferior mesenteric arteries and their branches.

Venous return from the abdominal organs

- **Inferior vena cava**; formed when **right & left common iliac** veins join at the level of the body of the 5th lumbar vertebra.
 - Largest vein in the body
 - Conveys blood from all parts of the body below the diaphragm to the RA of the heart.
 - Passes through the **central tendon of the diaphragm** at the level of **8th thoracic** vertebra.
- Paired testicular, ovarian, renal & adrenal veins join the inferior vena cava.
- Blood from the remaining organs in the abdominal cavity passes through the liver via the portal circulation before entering the inferior vena cava.

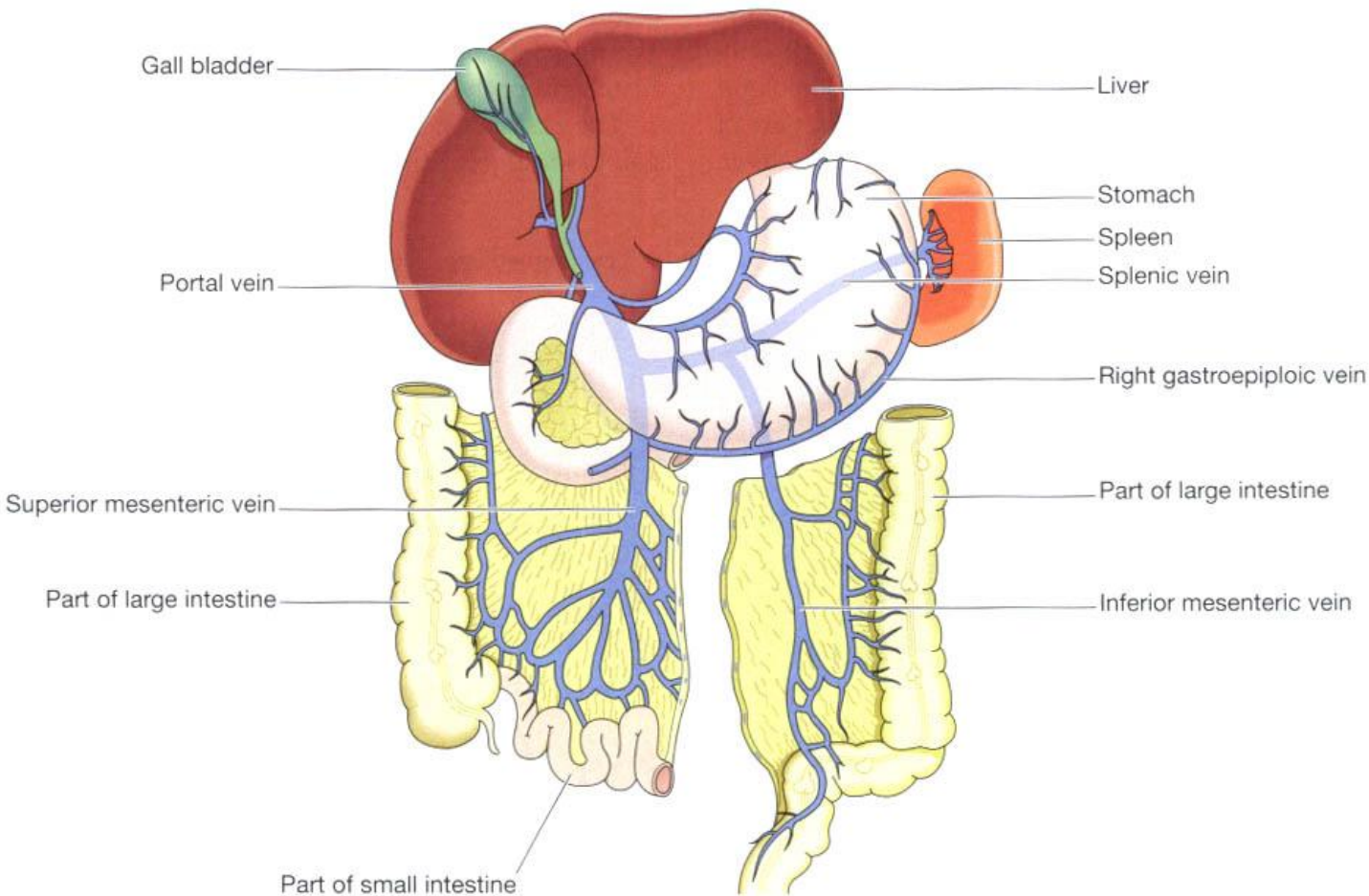
PORTAL CIRCULATION

- Venous blood passes from the capillary beds of the abdominal part of the digestive system, the spleen and pancreas to the liver.
- It passes through a second capillary bed, the **hepatic sinusoids**, in the liver before entering the general circulation via the inferior vena cava.
- Thus, blood with a high concentration of nutrients, absorbed from the stomach and intestines, goes to the liver first where some modifications takes place.

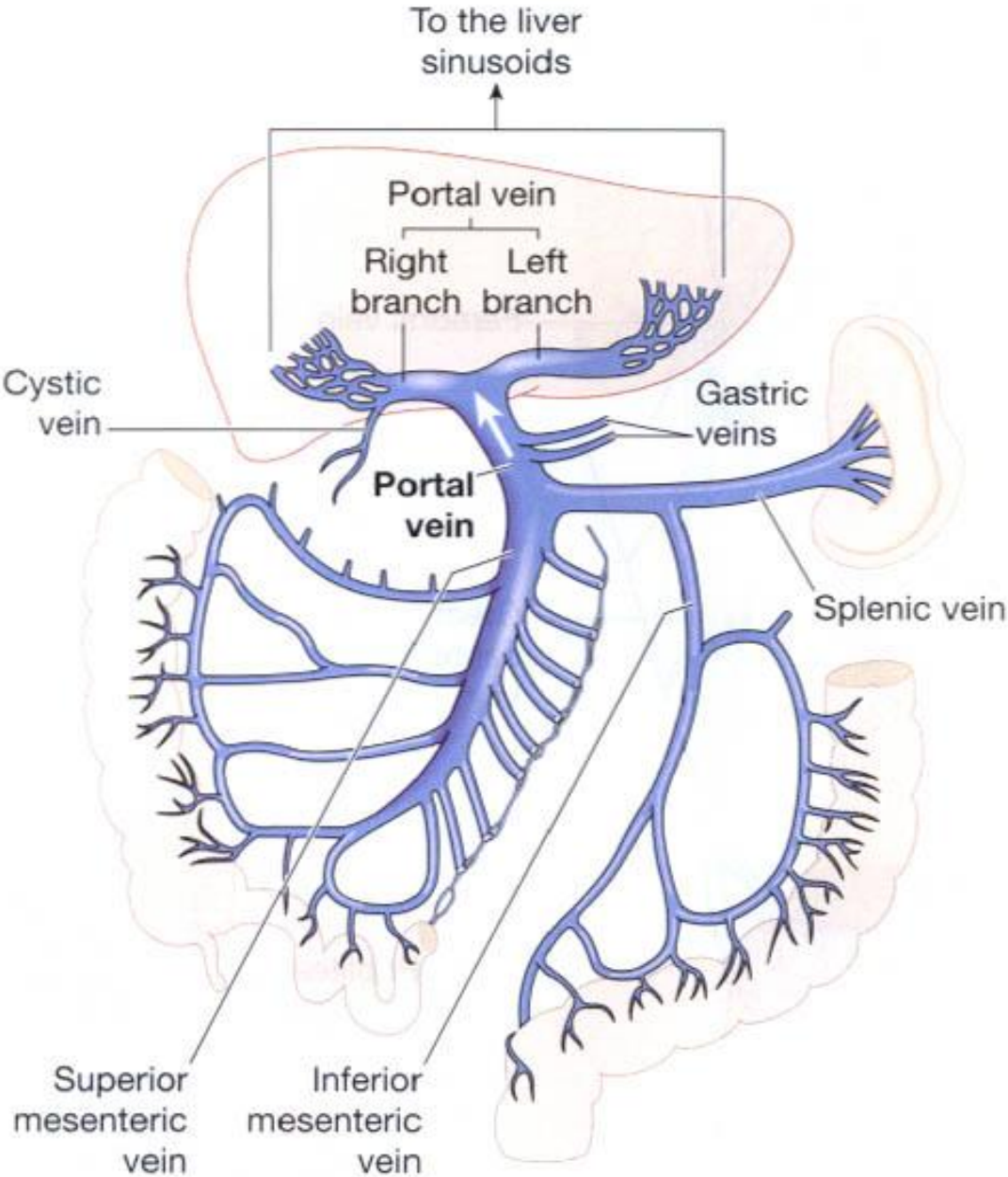
Portal vein

- Formed by union of several veins namely:
 - i. Splenic vein:** drains blood from spleen, pancreas & part of the stomach.
 - ii. Inferior mesenteric vein:** returns venous blood from the rectum, pelvic & descending colon of large intestine. Joins splenic vein.
 - iii. Superior mesenteric vein:** returns venous blood from the small intestine & proximal parts of large intestine (caecum, ascending & transverse colon). Joins with splenic vein to form the portal vein.
 - iv. Gastric veins:** drain blood from the stomach & distal end of the oesophagus, then join the portal vein.
 - v. Cystic vein:** drains venous blood from gall bladder joins the portal vein.

Venous drainage from abdominal organs and formation of portal vein



Portal vein: Origin and termination



CIRCULATION OF BLOOD TO THE PELVIS & LOWER LIMB

Arterial supply

a) Common iliac arteries.

- Right & left common iliac arteries are formed when the abdominal aorta divides at the level of **4th lumbar vertebra**.
- In front of the sacroiliac joint each divides into:
 - internal iliac artery
 - external iliac artery.
- **Internal iliac artery** runs medially to supply the organs within the pelvic cavity.
 - In females, one of the largest branches is **uterine artery** which provides the main arterial blood supply to reproductive organs.
- **External iliac artery** runs obliquely downwards and passes behind the inguinal ligament into the thigh where it becomes the femoral artery.

b) Femoral artery

- begins at the midpoint of inguinal ligament & extends downwards in front of the thigh; then turns medially and eventually passes round the medial aspect of femur to enter the popliteal space where it becomes **popliteal** artery;
- supplies blood to the **structures of the thigh** and **some superficial pelvic & inguinal structures.**

c) Popliteal artery;

- passes through the popliteal fossa behind the knee.
- Supplies the structures in this area, including knee joint.
- At the lower border of the popliteal fossa it divides into the **anterior & posterior tibial arteries.**

d) Anterior tibial artery

- passes forwards between tibia & fibula
- Supplies structures in the front of leg.
- Lies on the tibia, runs in front of ankle joint & continues over the dorsum (top) of the foot as **dorsalis pedis** artery.

e) Dorsalis pedis artery

- passes over the dorsum of the foot, supplying blood to the structures in this area.
- Ends by passing between the first & second metatarsal bones into the sole of the foot where it contributes to the formation of the **plantar arch**.

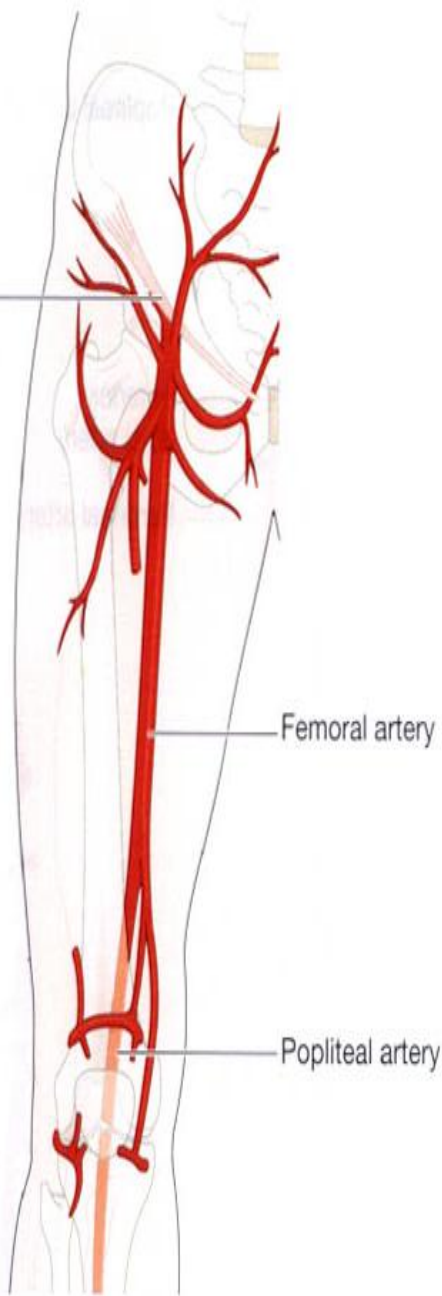
f) Posterior tibial artery

- Runs downwards & medially on the back of the leg.
- Near its origin it gives off the **peroneal** artery which supplies the lateral aspect of the leg.
- In the lower part it becomes superficial and passes medial to the ankle joint to reach the sole of the foot where it continues as **plantar** artery.

g) Plantar artery

- Supplies structures in the sole of foot.
- Together, with its branches & **dorsalis pedis** artery; form the plantar arch from which the **digital branches** arise to supply the toes.

Inguinal ligament



Femoral artery

Popliteal artery

External iliac artery

Superficial epigastric artery

Sartorius muscle

Superficial circumflex iliac artery

Femoral artery

midway between anterior superior iliac spine and pubic symphysis inferior to inguinal ligament

Superficial external pudendal artery

Deep external pudendal artery

Deep artery of thigh

Vastus medialis muscle

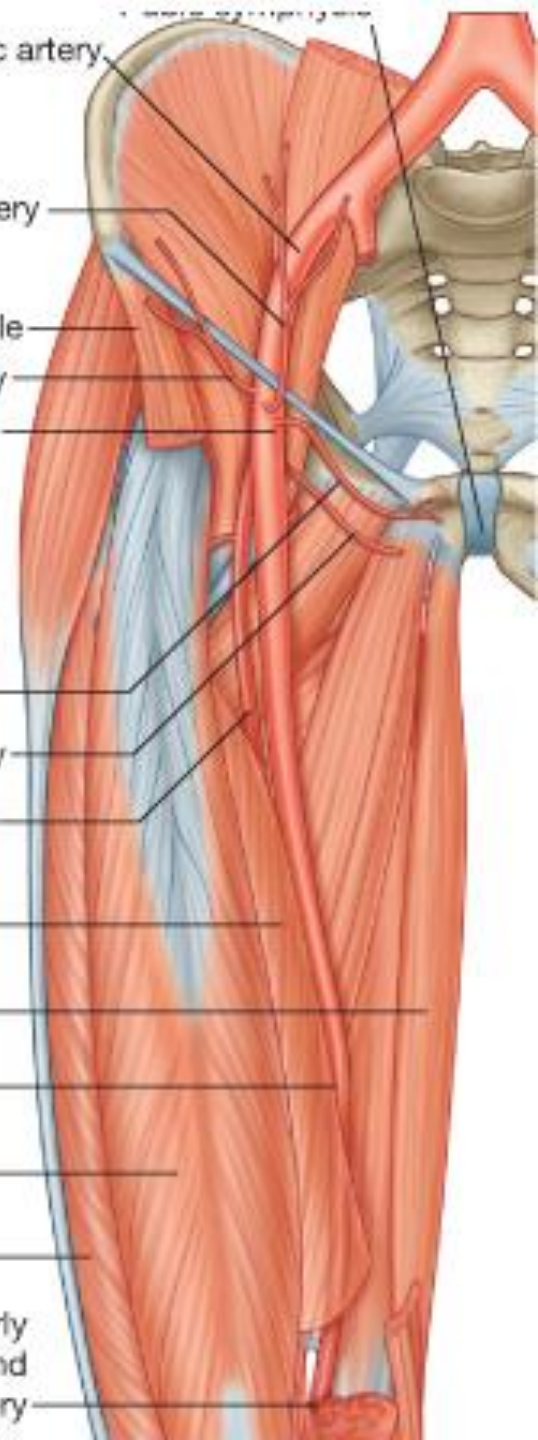
Gracilis muscle

Artery in adductor canal

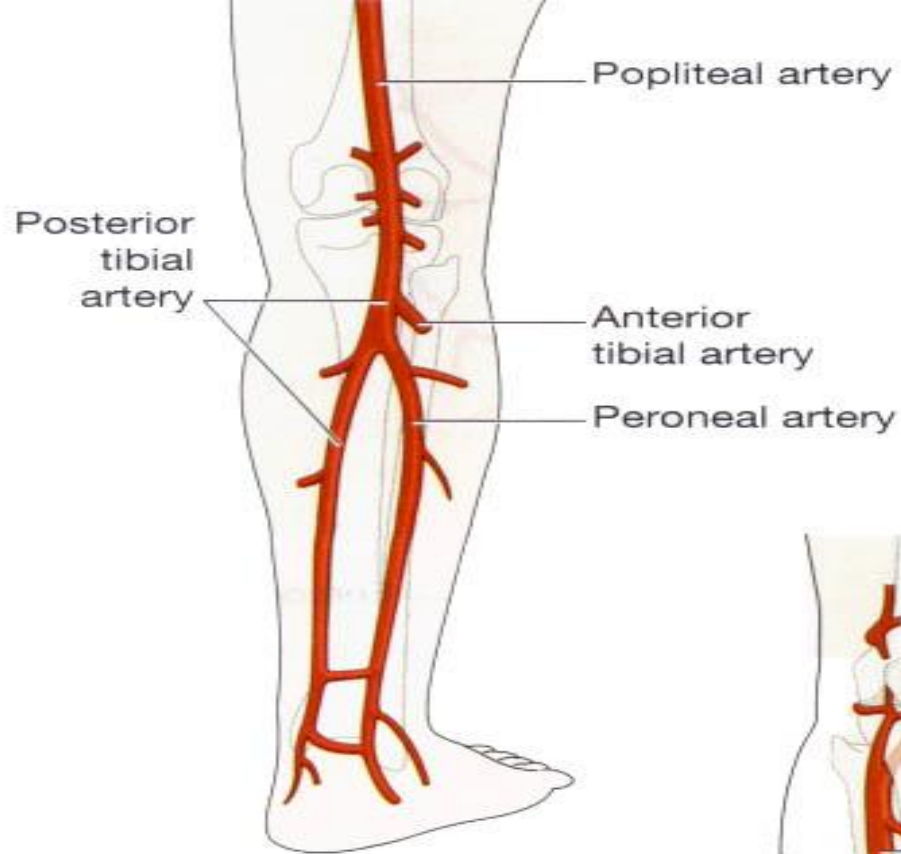
Rectus femoris muscle

Vastus lateralis muscle

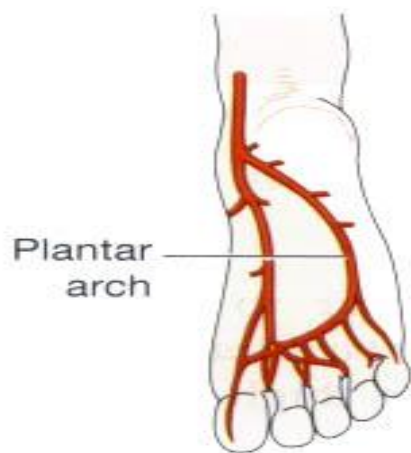
Artery passes posteriorly through adductor hiatus and becomes popliteal artery



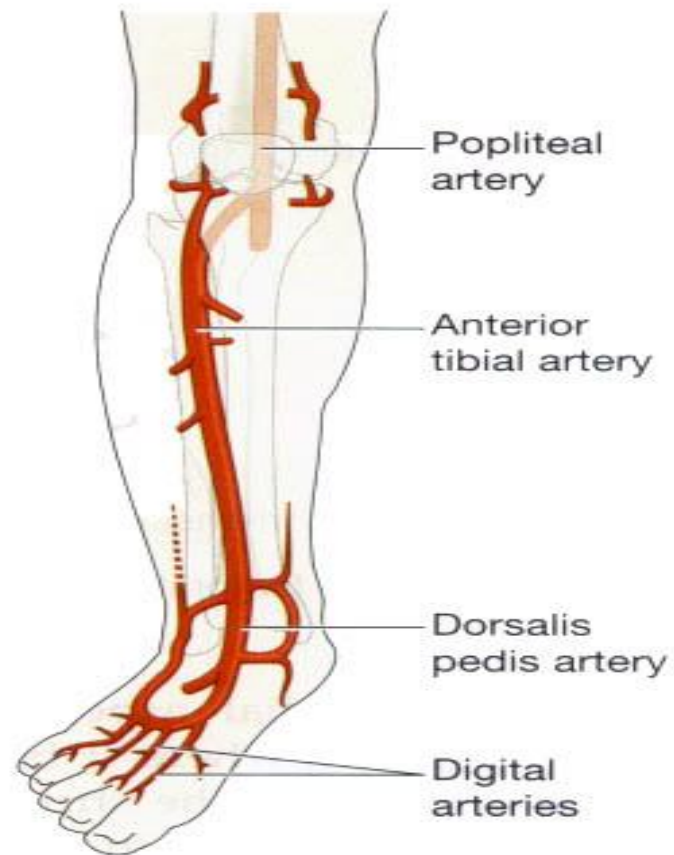
Femoral artery and its main brabnches



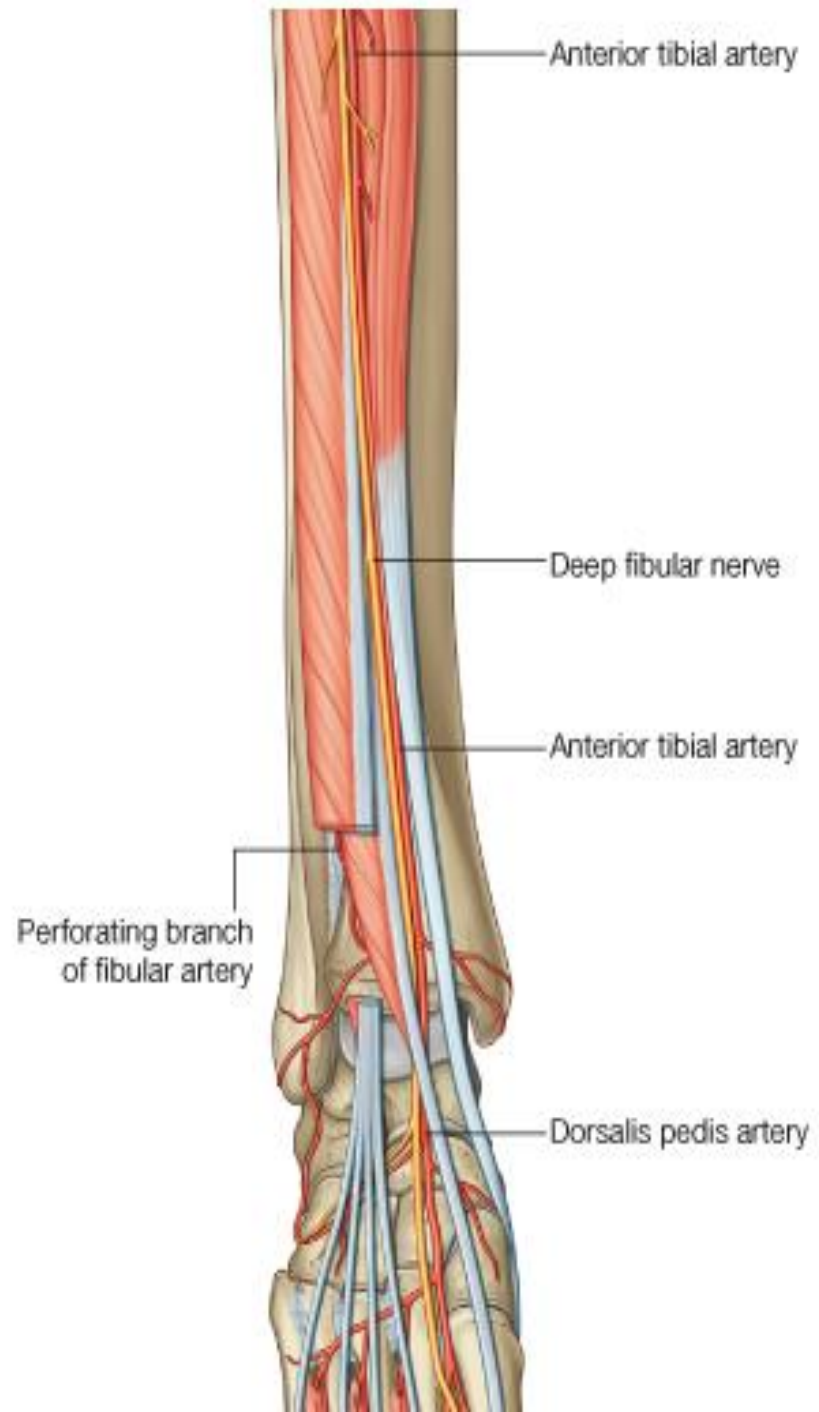
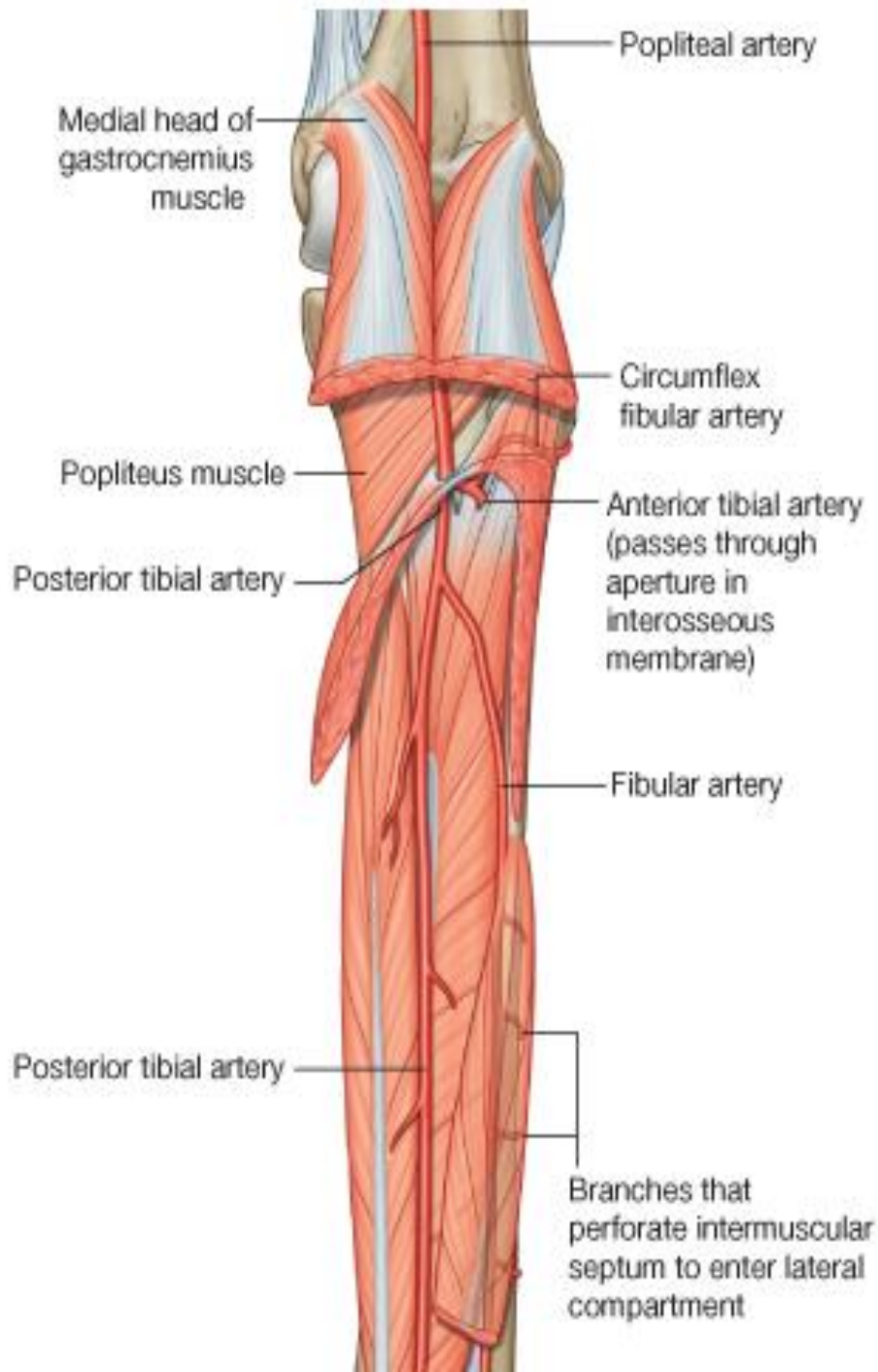
Posterior view



Inferior view



Anterior view



Venous return

- Both deep and superficial veins.
- Blood entering the superficial veins passes to the deep veins through **communicating veins**.

a) Deep veins.

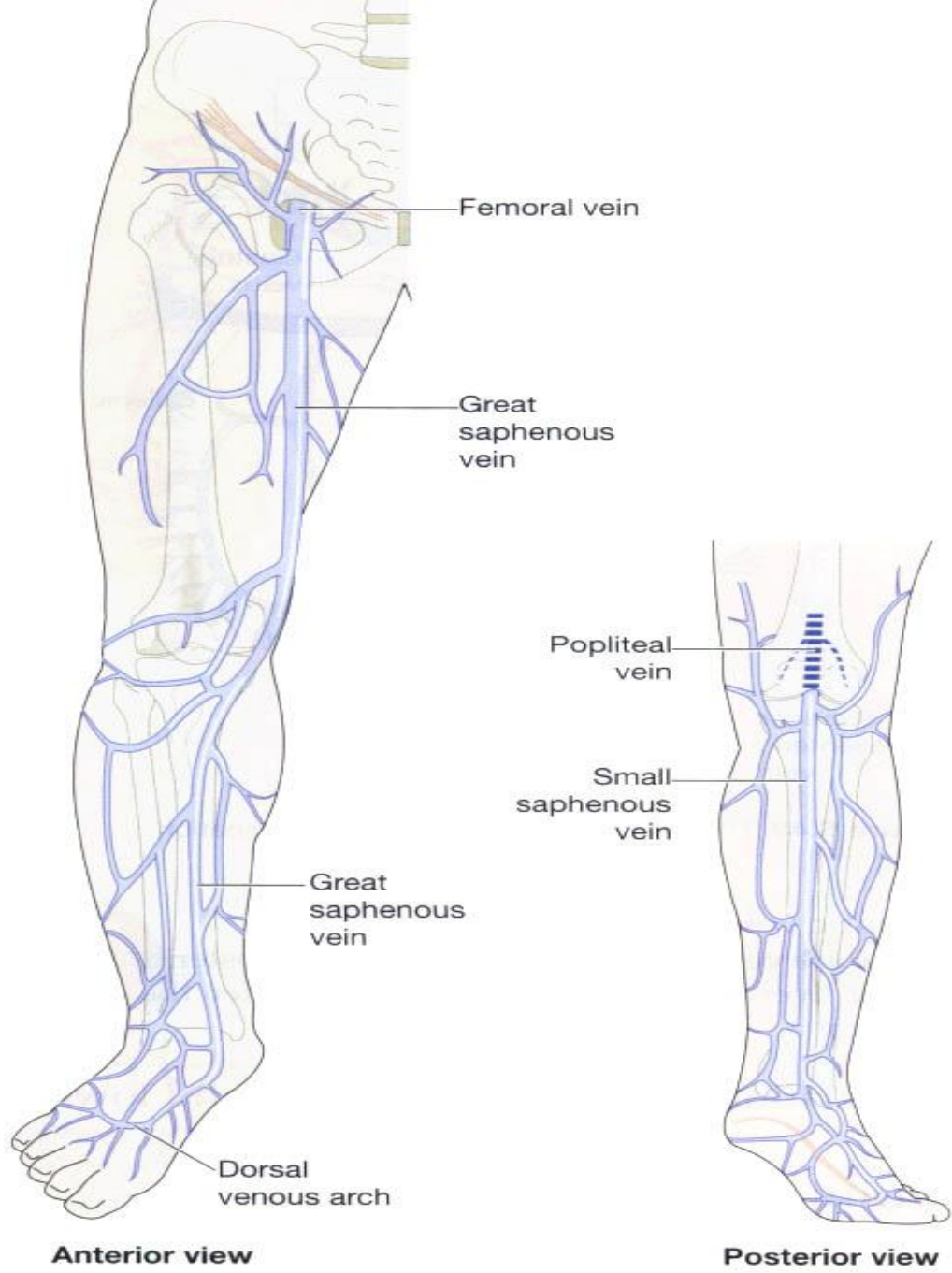
- Accompany the arteries and their branches and have the same names. They are:
 - digital veins
 - plantar venous arch
 - posterior tibial vein
 - anterior tibial vein
 - popliteal vein
 - femoral vein
 - external iliac vein
 - internal iliac vein
 - common iliac vein.

- **Femoral vein:** ascends in the thigh to the level of the inguinal ligament where it becomes the **external iliac vein**.
- **External iliac vein:** enters the pelvis lying close to the femoral artery. It passes along the brim of the pelvis and at the level of the sacroiliac joint it is joined by the **internal iliac vein** to form the **common iliac vein**.
- The **internal iliac vein** receives tributaries from several veins which drain the organs of the pelvic cavity.
- The two common iliac veins begin at the level of the **sacroiliac joints**. They ascend obliquely and end a little to the right of the body of the 5th lumbar vertebra by uniting to form the **inferior vena cava**.

b) Superficial veins.

- 2 main superficial veins
 - small saphenous vein
 - great saphenous vein.
- **Small saphenous vein**
 - begins behind the ankle joint where many small veins which drain the dorsum of the foot join together.
 - Ascends superficially along the back of the leg and in the popliteal space it joins the popliteal vein (a deep vein).

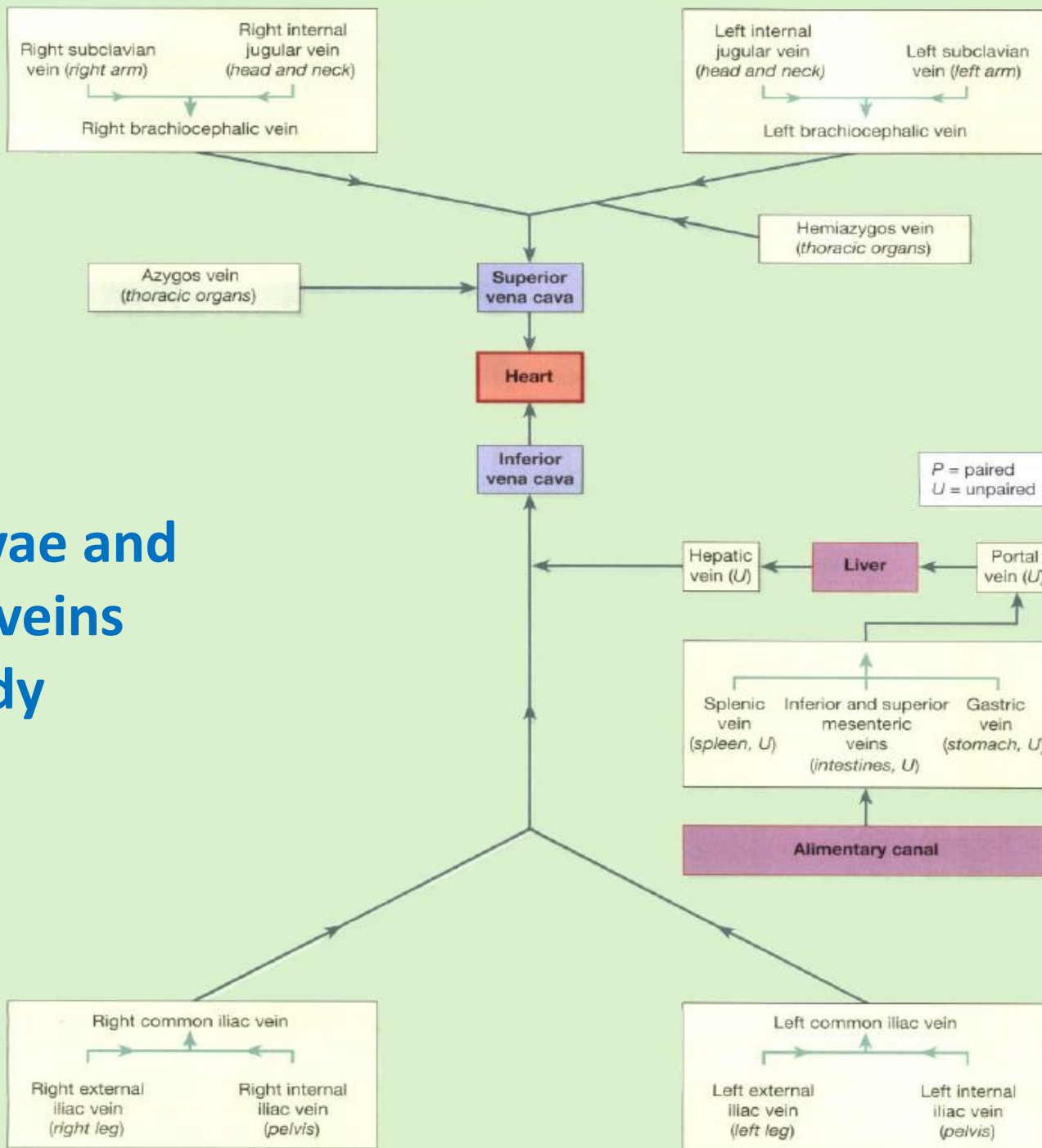
- **Great saphenous vein**
 - Longest vein in the body.
 - Begins at the medial half of the dorsum of the foot and runs upwards, crossing the medial aspect of the tibia and up the inner side of the thigh.
 - Joins the femoral vein just below the inguinal ligament.



Superficial veins of the leg

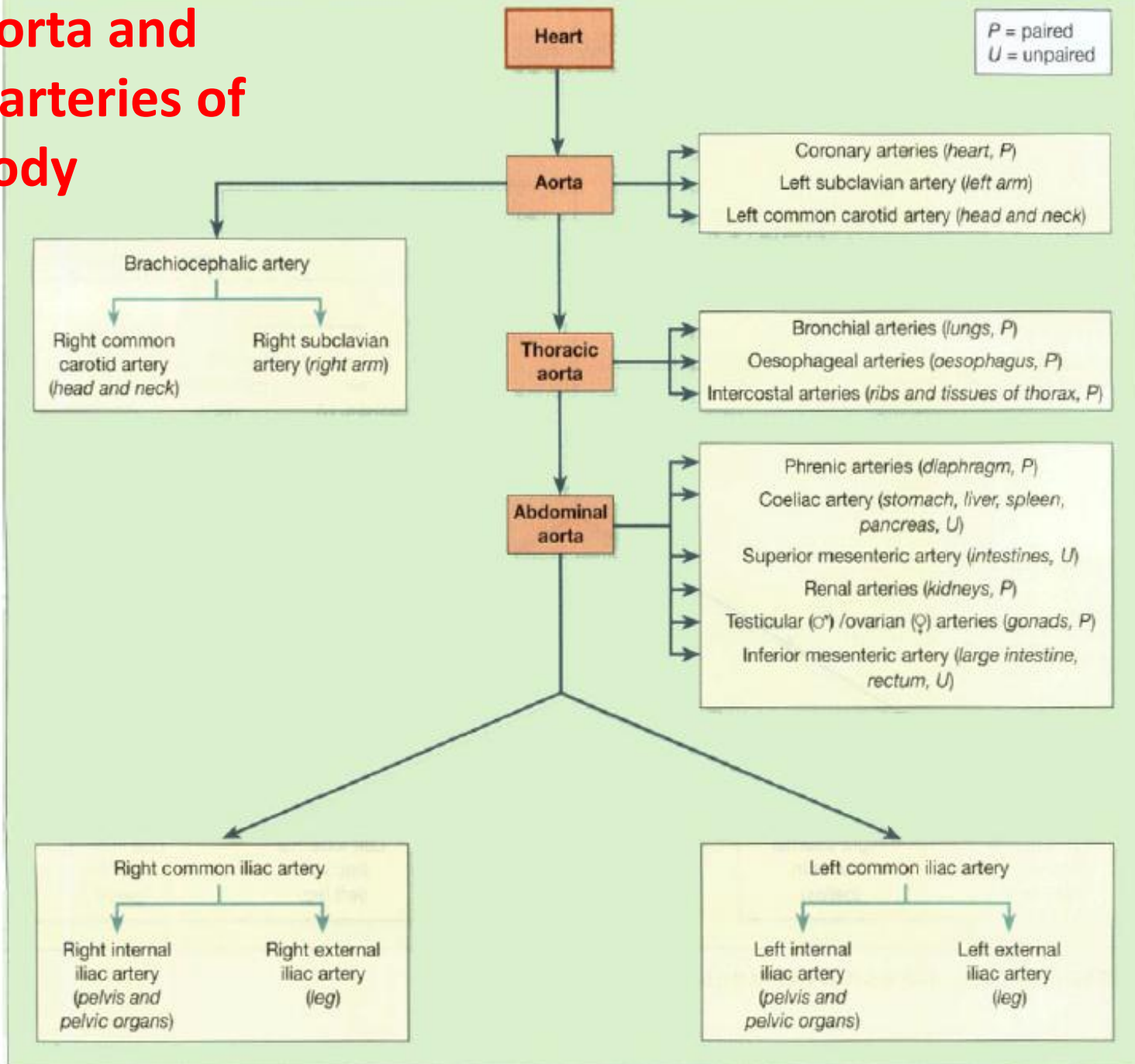
Fetal circulation

- ASSIGNMENT
- Read and make notes note fetal circulation using the following sub-headings;
 - Placenta and its functions
 - Diagram of fetal circulation
 - Fetal adaptations
 - Changes at birth



Venae cavae and the main veins of the body

The aorta and main arteries of the body



THE LYMPHATIC SYSTEM

- The lymphatic system drains tissue fluid which diffuses into the lymph capillaries at the tissue level.
- It consists of:
 - **lymph**
 - **lymph vessels**
 - **lymph nodes**
 - **lymph organs, e.g. spleen & thymus**
 - **diffuse lymphoid tissue, e.g. tonsils**
 - **bone marrow.**

Function of lymphatic system

- 1. Tissue drainage:** it usually drains excess tissue fluid back into the CVS that is not returned via the venous system. It drains around 3-4 litres of fluid thus preventing oedema and maintaining blood volume.
- 2. Absorption in the small intestine.** Fat and fat-soluble materials, e.g. fat-soluble vitamins, are absorbed into the central lacteals (lymphatic vessels) of the villi.
- 3. Immunity.** Lymphatic organs are concerned with production & maturation of lymphocytes; WBCs that are primarily responsible for provision of immunity.

LYMPH

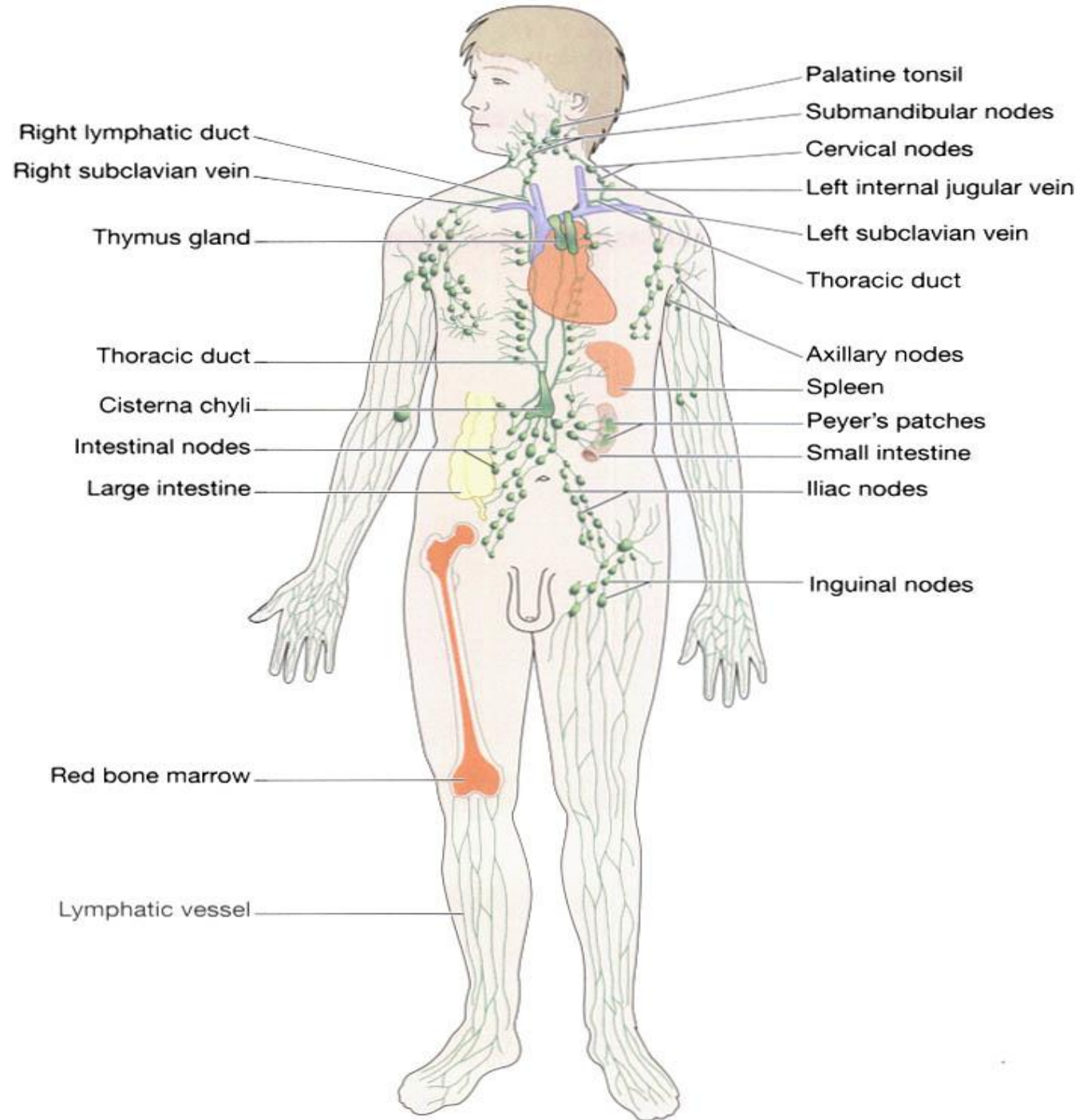
- **Lymph:** clear watery fluid, similar in composition to plasma, with exception of plasma proteins, & identical in composition to interstitial fluid.
- Lymph
 - transports plasma proteins that seep out of the capillary beds back to the bloodstream.
 - Carries away larger particles, e.g. bacteria & cell debris from damaged tissues, which can then be filtered out & destroyed by the lymph nodes.
 - contains lymphocytes, which circulate in the lymphatic system allowing them to patrol the different regions of the body.
- In the lacteals of small intestine, fats absorbed into the lymphatics give the lymph (chyle), a milky appearance.

LYMPH VESSELS

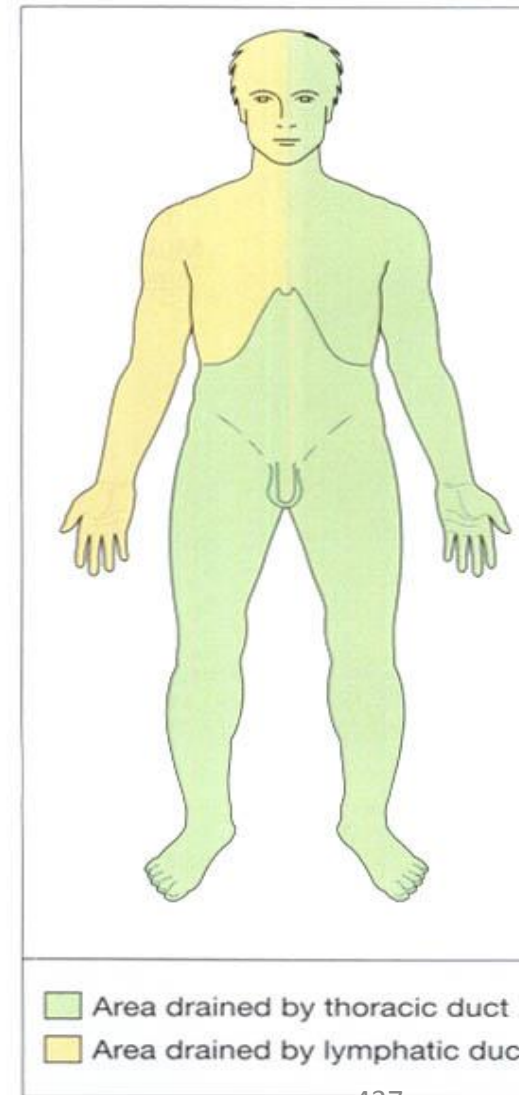
- **Lymph capillaries**
 - Originate as blind-end tubes in the interstitial spaces.
 - Have same structure as blood capillaries, but their walls are more permeable to all interstitial fluid constituents, including proteins and cell debris.
 - Tiny capillaries join up to form larger lymph vessels.
 - All body tissues have a network of lymphatic vessels, with the exception of CNS, **bones & the most superficial layers of the skin.**
- **Larger lymph vessels**
 - Their walls are about the same thickness as those of small veins & have the same layers of tissue
 - Have numerous cup-shaped valves which ensure that lymph flows in one way only, i.e. towards the thorax

- Movement of lymph is by intrinsic ability of the muscle tissue in the walls of the large lymph vessels to contract rhythmically (the lymphatic pump).
- Movement is also aided by contraction of adjacent muscles & pulsation of large arteries.
- Lymph vessels become larger as they join together, eventually forming 2 large ducts, the
 - thoracic duct
 - right lymphatic duct, that empty lymph into the subclavian veins.

- **Thoracic duct**
 - Begins at **cisterna chyli**; a dilated lymph channel situated in front of the bodies of the first **two lumbar** vertebrae.
 - About 40 cm long
 - Opens into **left subclavian** vein
 - Drains lymph from both legs, pelvic & abdominal cavities, left half of thorax, head & neck & the left arm.
- **Right lymphatic duct**
 - Dilated lymph vessel about 1 cm long.
 - Lies in the root of the neck
 - Opens into the **right subclavian** vein.
 - Drains lymph from the right half of thorax, head & neck & the right arm



A



B

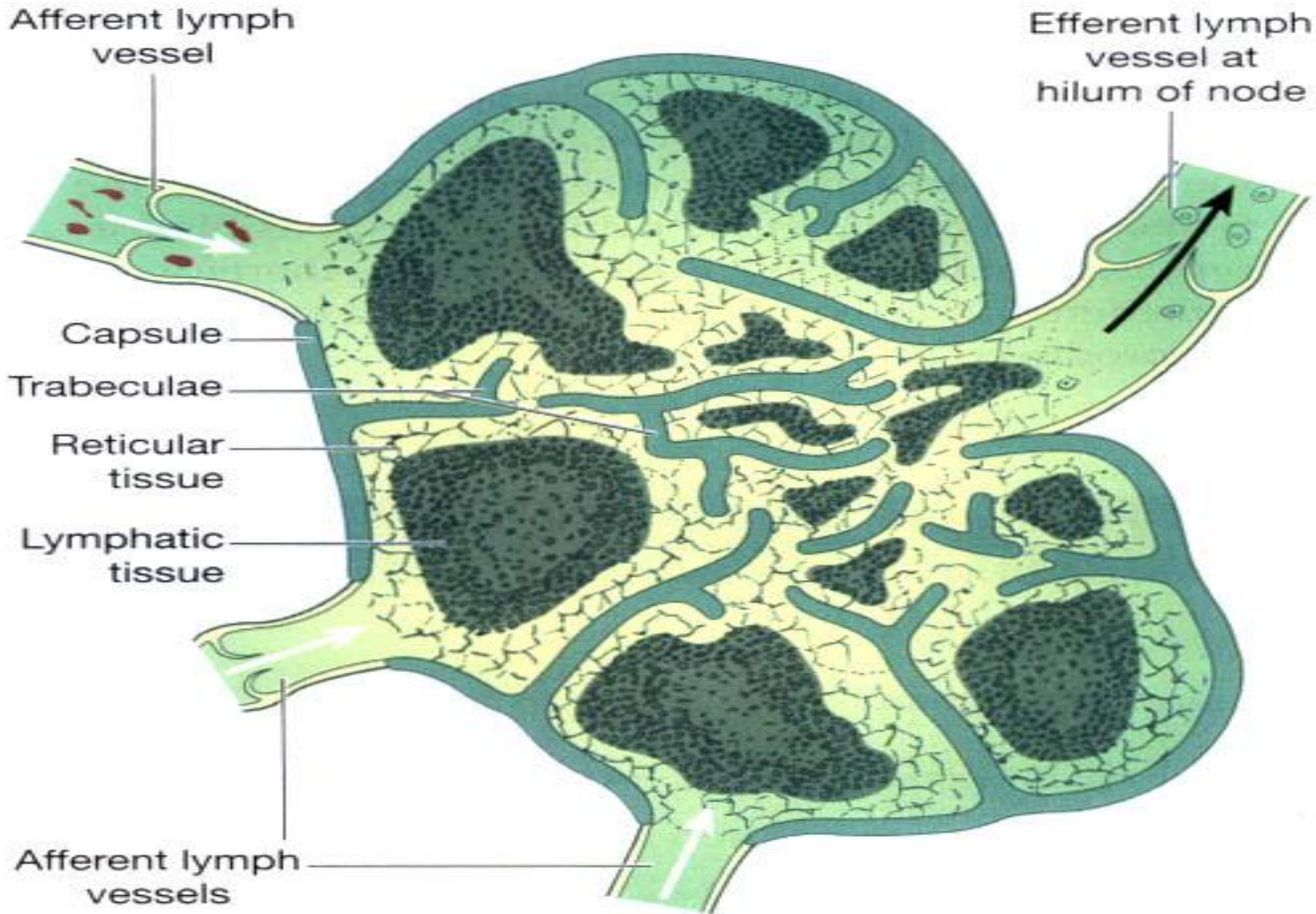
LYMPHATIC ORGANS AND TISSUES

a) Lymph nodes

- Oval or bean-shaped organs that lie, often in groups, along the length of lymph vessels.

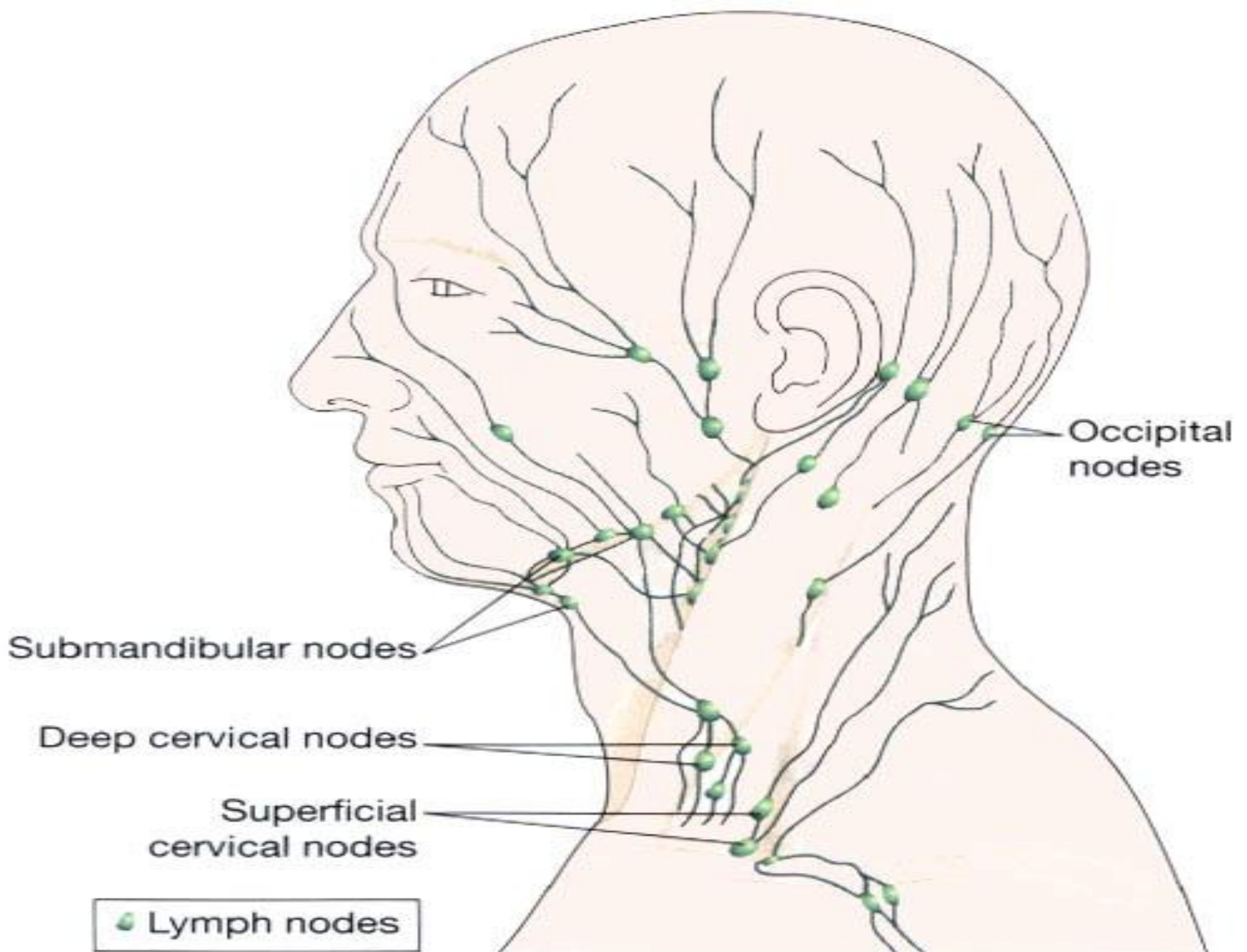
Structure

- Have an outer capsule of fibrous tissue which dips down into the node substance forming partitions, or trabeculae.
- The main substance consists of reticular & lymphatic tissue containing many lymphocytes & macrophages.
- Upto 4 or 5 afferent lymph vessels may enter a lymph node while only 1 efferent vessel carries lymph away from the node.
- Each node has a concave surface called the **hilum** where an artery enters & a vein & the efferent lymph vessel leave.
- Arranged in deep & superficial groups.



Section of a lymph node.

- Lymph from
 - **head & neck** passes through **deep and superficial cervical nodes**
 - **upper limbs** passes through nodes situated in the elbow region then through the **deep and superficial axillary nodes**.
 - Most of breast passes through the axillary nodes
 - **Organs and tissues** in the thoracic cavity drains through groups of nodes that are situated close to the mediastinum, large airways, oesophagus and chest wall.
 - **Pelvic & abdominal cavities** passes through many lymph nodes before entering the **cisterna chyli**.
 - **Lower limbs** drains through deep & superficial nodes including groups of nodes behind the knee and in the groin (**inguinal nodes**).



Lymph nodes: face and neck

Functions Of Lymph Nodes

a) Filtering & phagocytosis

- Lymph is filtered by reticular & lymphoid tissue as it passes through lymph nodes.
- Organic material is destroyed in lymph nodes by macrophages and antibodies.
- Some inorganic inhaled particles cannot be destroyed by phagocytosis and hence remain inside the macrophages, either causing no damage or killing the cell.
- Material not filtered off and dealt with in one lymph node passes on to successive nodes and by the time lymph enters the blood it has usually been cleared of foreign matter and cell debris. In some cases where phagocytosis of microbes is incomplete they may stimulate inflammation and enlargement of the node (*lymphadenopathy*).

b) Proliferation of lymphocytes

- Activated T- and B-lymphocytes multiply in lymph nodes.

b) SPLEEN

- Largest lymph organ
- Formed by reticular & lymphatic tissue.
- Lies in the **left hypochondriac** region of abdominal cavity between fundus of stomach and diaphragm.
- **Purplish** in colour
- Varies in size in different individuals, but is usually about 12 cm long, 7 cm wide and 2.5 cm thick.
- Weighs about 200 g.

- Organs associated with the spleen
 - ❖ Superiorly & posteriorly — diaphragm
 - ❖ Inferiorly — left colic flexure of large intestine
 - ❖ Anteriorly — fundus of stomach
 - ❖ Medially — pancreas & left kidney
 - ❖ Laterally — separated from the 9th, 10th and 11th ribs and the intercostal muscles by the diaphragm

Gastric impression

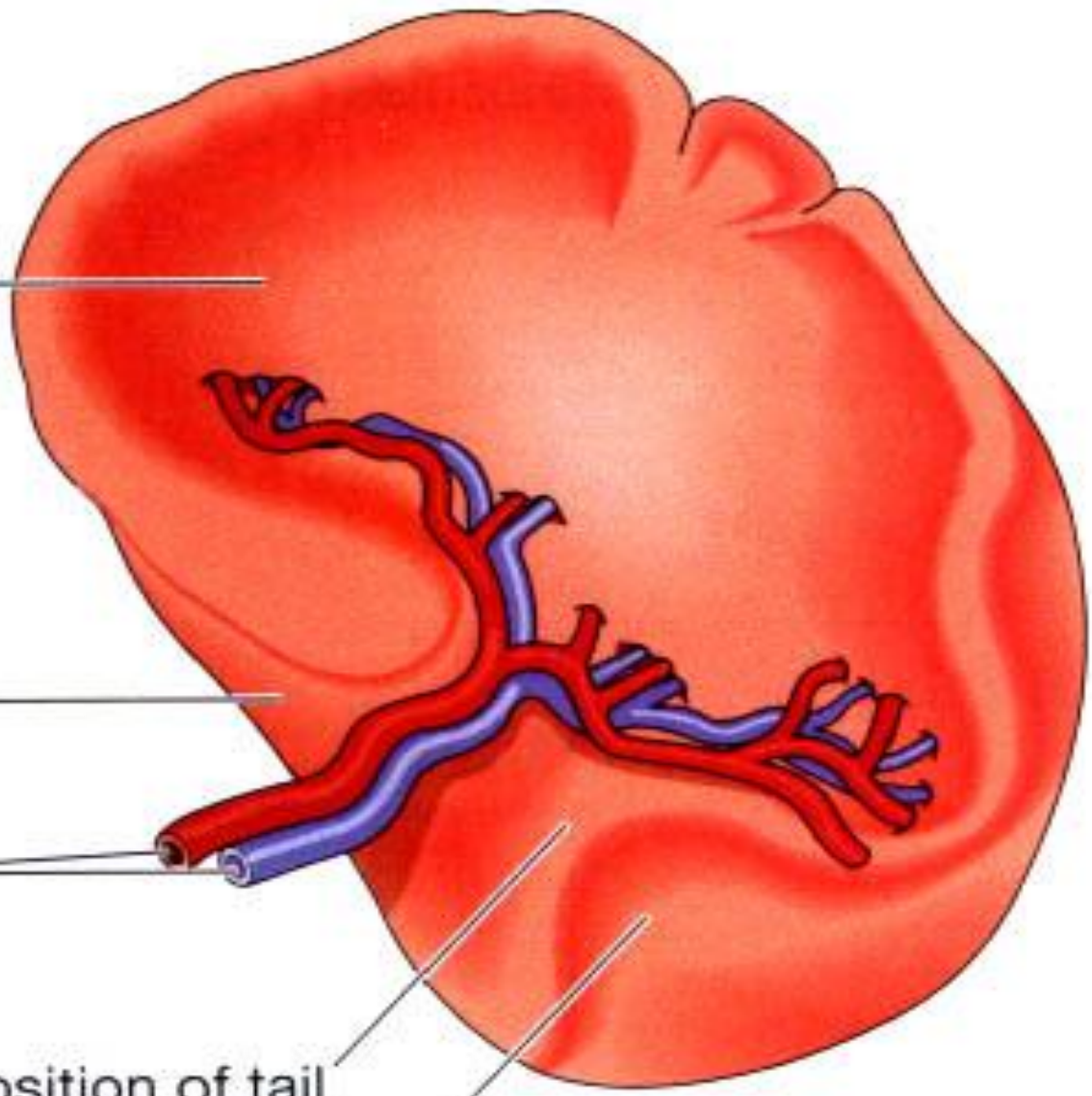
Renal impression

Splenic artery
and vein

Position of tail
of pancreas

Colic impression

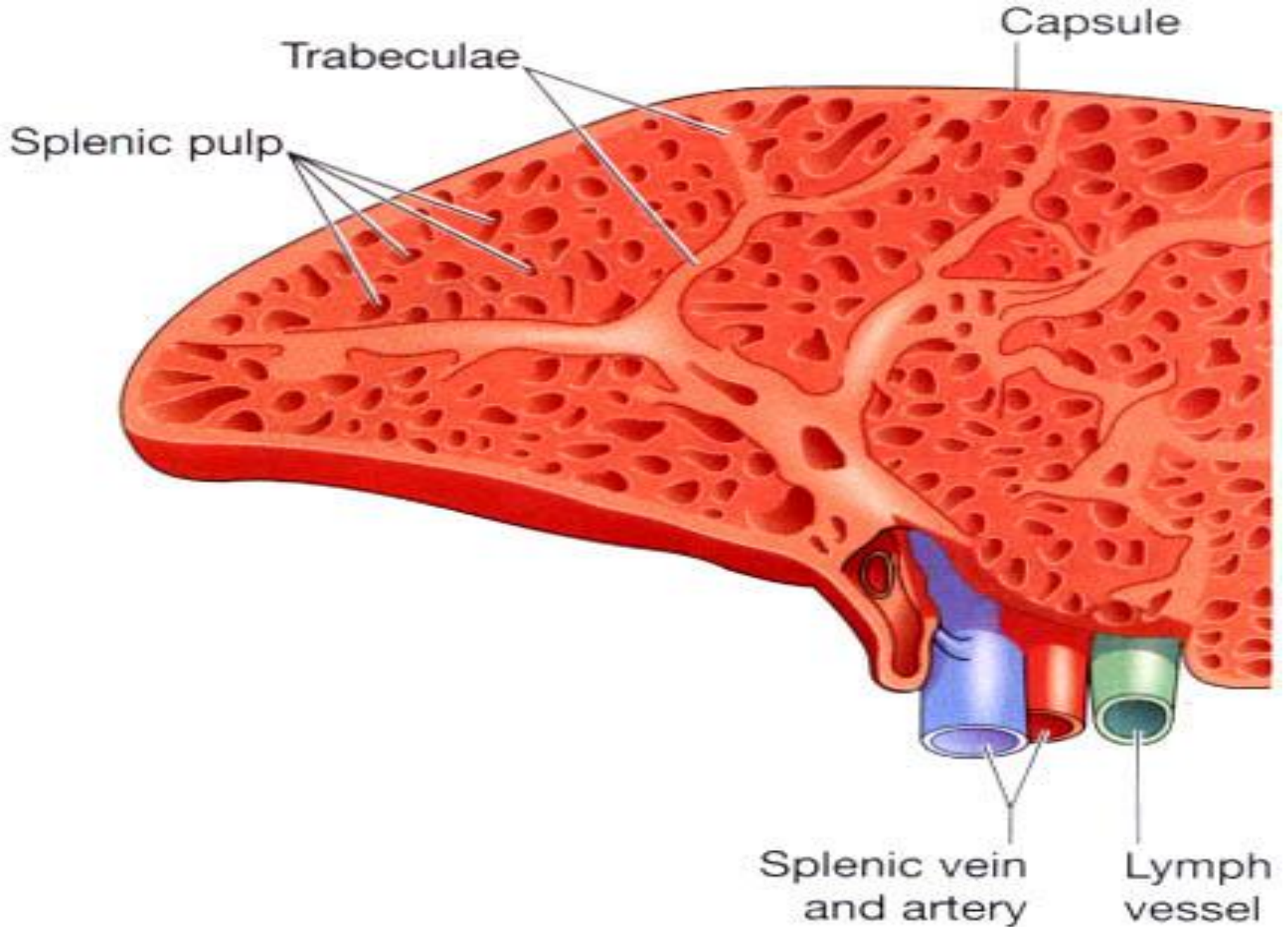
The spleen



Structure

- Slightly oval in shape with the hilum on the lower medial border.
- Anterior surface is covered with peritoneum.
- Enclosed in a fibroelastic capsule that dips into the organ, forming **trabeculae**.
- The cellular material, consisting of lymphocytes and macrophages, is called **splenic pulp**, and it lies between the trabeculae.
- **Red pulp**; part bathed with **blood** &
- **White pulp**; areas of lymphatic tissue where there are sleeves of **lymphocytes** & **macrophages** around blood vessels.

- Structures entering & leaving the spleen at the hilum are:
 - i. splenic artery: branch of coeliac artery
 - ii. splenic vein: branch of portal vein
 - iii. lymph vessels (efferent only)
 - iv. nerves



A section of the spleen

Functions Of The Spleen

- 1) Phagocytosis:** Breaks down old or abnormal blood cells and some bacteria. The by products is transported to the liver.
- 2) Storage of blood:** Contains up to 350 ml of blood & in response to sympathetic stimulation can rapidly return a large part of this volume to the circulation, e.g. in haemorrhage.
- 3) Immune response:** Contains T- & B-lymphocytes, which are activated by the presence of antigens, e.g. infection. Lymphocyte proliferation during serious infection can cause splenomegaly (enlargement).
- 4) Erythropoiesis:** Spleen & liver are important sites of fetal blood cell production & spleen can also fulfill this function in adults in times of great need.

c) THYMUS GLAND

- Lies in the upper part of mediastinum behind the sternum & extends upwards into the root of the neck.
- Weighs about 10 to 15 g at birth
- Grows until the individual reaches puberty, when it begins to atrophy (shrink).
- Maximum weight, at puberty, is between 30 & 40g
- Associated with
 - Anteriorly —sternum & upper 4 costal cartilages
 - Posteriorly —aortic arch & its branches, brachiocephalic veins, trachea
 - Laterally —lungs
 - Superiorly — structures in the root of the neck
 - Inferiorly — heart

Structure

- Consists of 2 lobes joined by areolar tissue.
- Lobes are enclosed by a fibrous capsule which dips into their substance, dividing them into lobules that consist of an irregular branching framework of epithelial cells & lymphocytes.

Function

- Maturation and activation of T-Lymphocytes which then leave thymus & enter blood and lymphoid tissues.
- Maturation of thymus & other lymphoid tissue is stimulated by **thymosin**, a hormone secreted by the epithelial cells that form the framework of the thymus gland.
- **NB:** shrinking of the gland begins in adolescence and with increasing age, the effectiveness of T-lymphocyte response to antigens decline.

d) Mucosa-associated lymphoid tissue (MALT)

- These are collections of lymphoid tissues found throughout the body, at strategically placed locations
- Contain B- & T-lymphocytes, which have migrated from bone marrow & thymus.
- Have no afferent lymphatic vessels, don't filter lymph, & are therefore not exposed to diseases spread by lymph.
- MALT is found throughout the GIT, respiratory tract & in GUT, all systems of the body exposed to the external environment.
- Main groups of MALT are the ***tonsils & Peyer's patches***.
- **Tonsils:** located in the mouth & throat; destroy swallowed & inhaled antigens
- **Peyer's patches:** large collections of lymphoid tissue found in the small intestine; intercept swallowed antigens.

THE NERVOUS SYSTEM

introduction

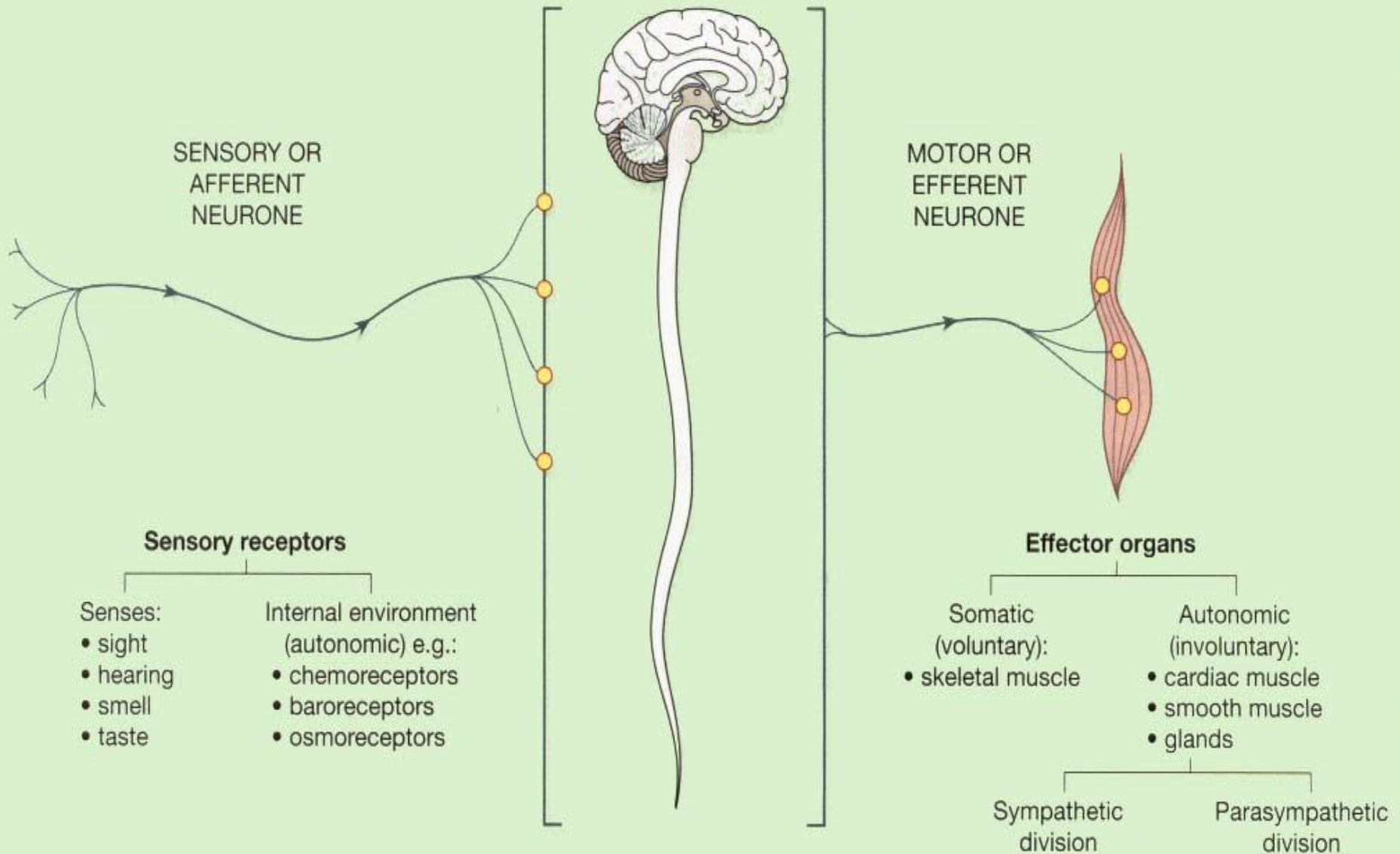
- Nervous system detects and responds to changes inside and outside the body.
- Controls important aspects of body function and maintains homeostasis together with the endocrine system.
- Nervous system stimulation provides an immediate response while endocrine activity is slower and more prolonged.
- Consists of the ***brain***, the ***spinal cord*** and ***peripheral nerves***.
- Response to changes in the internal environment maintains homeostasis and regulates involuntary functions, e.g. blood pressure and digestive activity.
- Response to changes in the external environment maintains posture and other voluntary activities.

Intro.....

- Nervous system is divided into two main areas:
 - **Central Nervous System (CNS)**; the brain and the spinal cord
 - **Peripheral Nervous System (PNS)**; all the nerves outside the brain and spinal cord.

INTRO....

- PNS comprises of paired cranial and sacral nerves; some are sensory (afferent), some are motor (efferent) and some mixed.
- ∴ has two functional parts:
 - the sensory division
 - the motor division
- Motor division is involved in activities that are:
 - voluntary —the somatic nervous system(movement of voluntary muscles)
 - involuntary — the autonomic nervous system (ANS) (functioning of smooth and cardiac muscle and glands) which has 2 parts: ***sympathetic*** and ***parasympathetic***



Functional components of the nervous system.

NEURONES

- **Neurones** are nerve cells.
- Each neurone consists of a **cell body** and its **processes**, one **axon** and many **dendrites**.
- **Nerves**: group/bundle of axons and/or dendrites of many neurons bound together.
- Neurones cannot divide and for survival they need a continuous supply of oxygen and glucose and can only synthesize chemical energy (ATP) from glucose.
- Neurones generate and transmit **electrical impulses** called **action potentials** which are similar to small electrical impulses.
- Some neurones initiate nerve impulses while others act as '**relay stations**' where impulses are passed on and sometimes redirected.

Properties of neurones

- Have the characteristics of irritability and conductivity.
- **Irritability:** ability to initiate nerve impulses in response to stimuli from:
 - outside the body, e.g. touch, light waves
 - inside the body, e.g. a change in the CO₂ concentration in the blood alters respiration.
- **Conductivity:** ability to transmit an impulse.

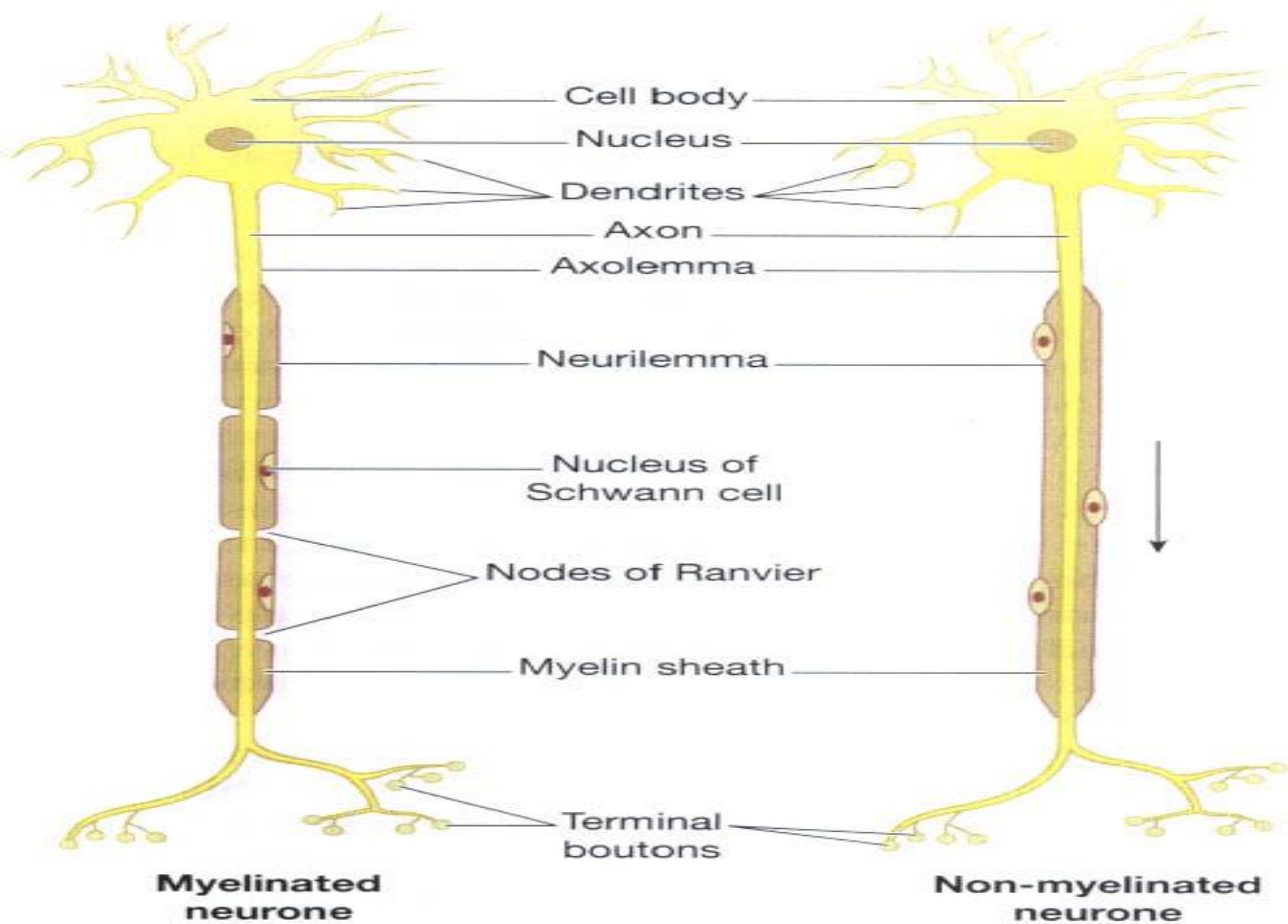
Structure of a neuron

a) Cell bodies

- Form the grey matter of the nervous system
- Found at the periphery of the brain and in the centre of the spinal cord.
- **Nuclei:** Groups of cell bodies in the CNS
- **Ganglia:** groups of cell bodies in the PNS.

b) Axons and dendrites

- **Def:** Extensions of cell bodies and form the white matter of the nervous system.
- **Axons** are found **deep in the brain** and in groups, called **tracts**, at the **periphery** of the spinal cord.
- Are referred to as **nerves** or **nerve fibres** outside the brain and spinal cord.



Structure of neurones

Axons

- Each nerve cell has only one axon, carrying nerve impulses away from the cell body.
- Usually longer than the dendrites, sometimes as long as 100 cm.
- They begin at the ***axon hillock*** near the cell body

Structure of an axon

- Has a membrane known as **axolemma** which encloses the cytoplasmic extension of the cell body.

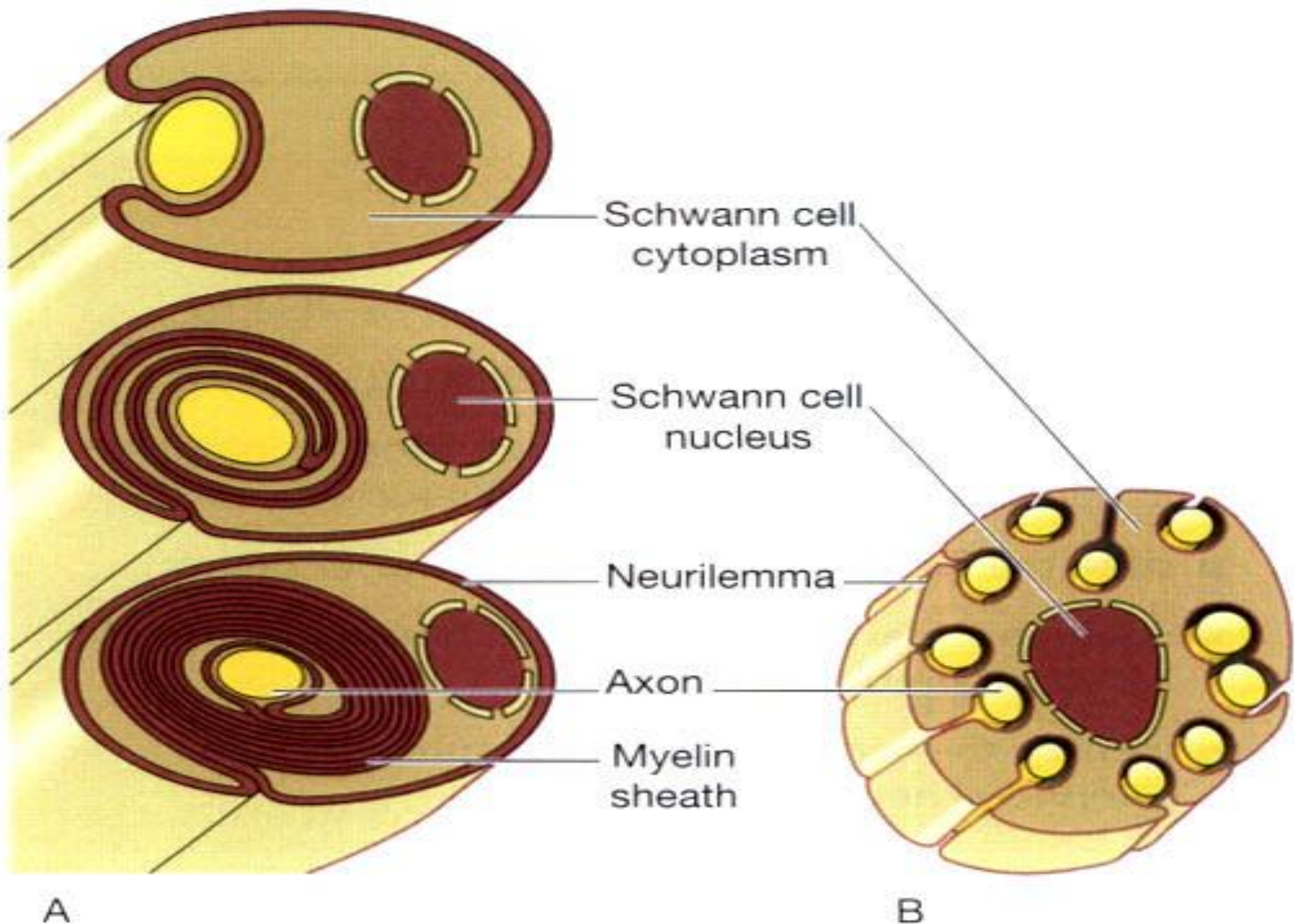
Myelinated neurones

- Are neurones whose axons are surrounded by a **Myelin sheath** which consists of series of Schwann cells arranged along the length of the axon;
- Myelin sheath is found in large axons and those of peripheral nerves.

- The outermost layer of Schwann cell plasma membrane is the **Neurilemma**
- There are tiny areas of exposed axolemma between adjacent Schwann cells called **Nodes of Ranvier** which assist the rapid transmission of nerve impulses.

Non-myelinated neurones

- Postganglionic fibres and some small fibres in the CNS are non-myelinated.
- A number of axons are found embedded in Schwann cell plasma membranes.
- Adjacent Schwann cells are in close association and there is no exposed axolemma.
- Speed of transmission of nerve impulses is significantly slower in non-myelinated fibres.



Nerve fibres; myelinated and non-myelinated

Dendrites

- **Def:** Many short processes that receive and carry incoming impulses towards cell bodies.
- Have the same structure as axons but they are usually shorter and branching.
- In **motor** neurones they form part of **synapses**
- In **sensory** neurones they form the sensory **receptors** that respond to stimuli.

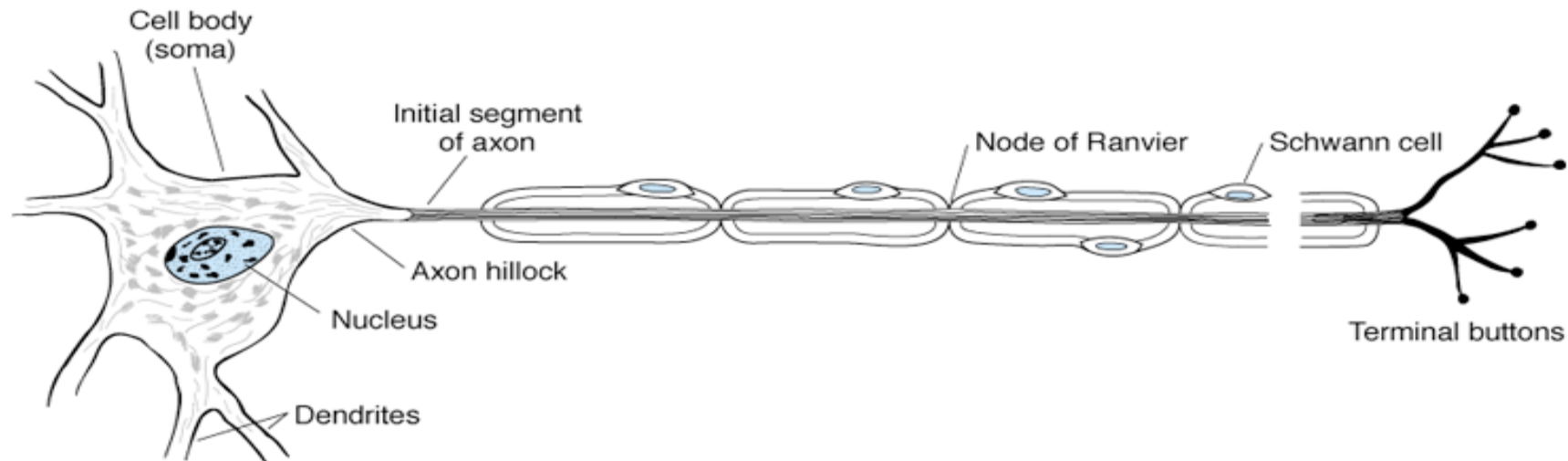
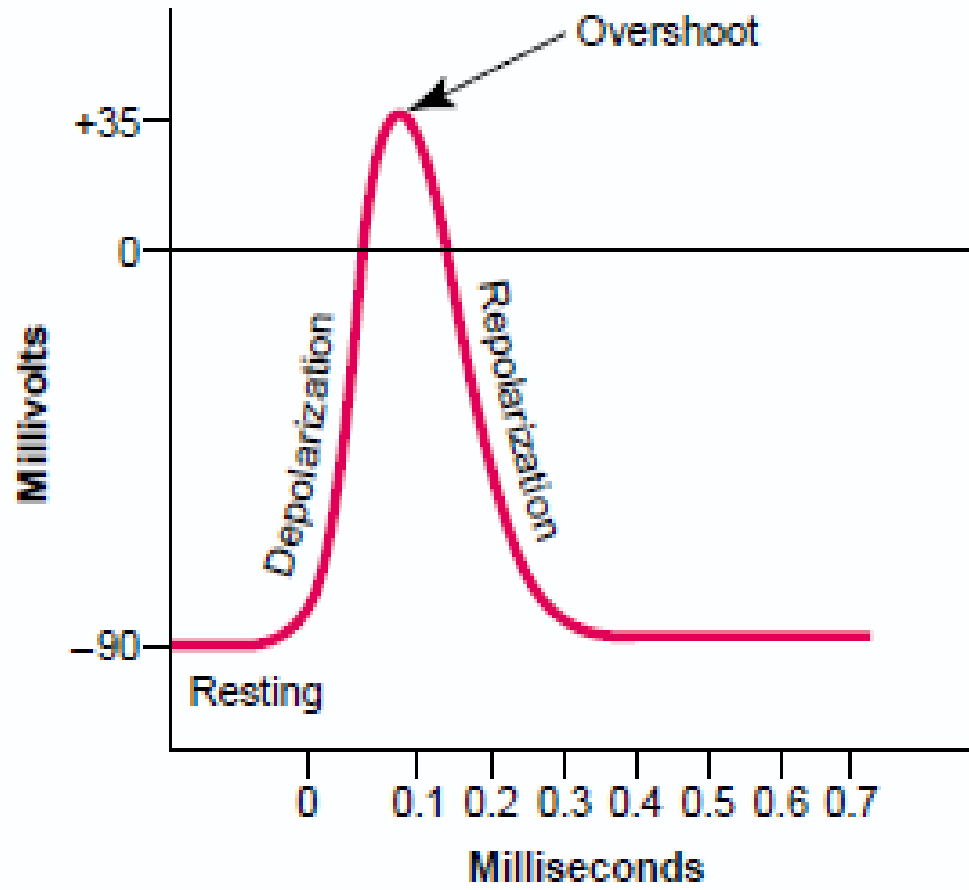


Figure 2-2. Motor neuron with myelinated axon.

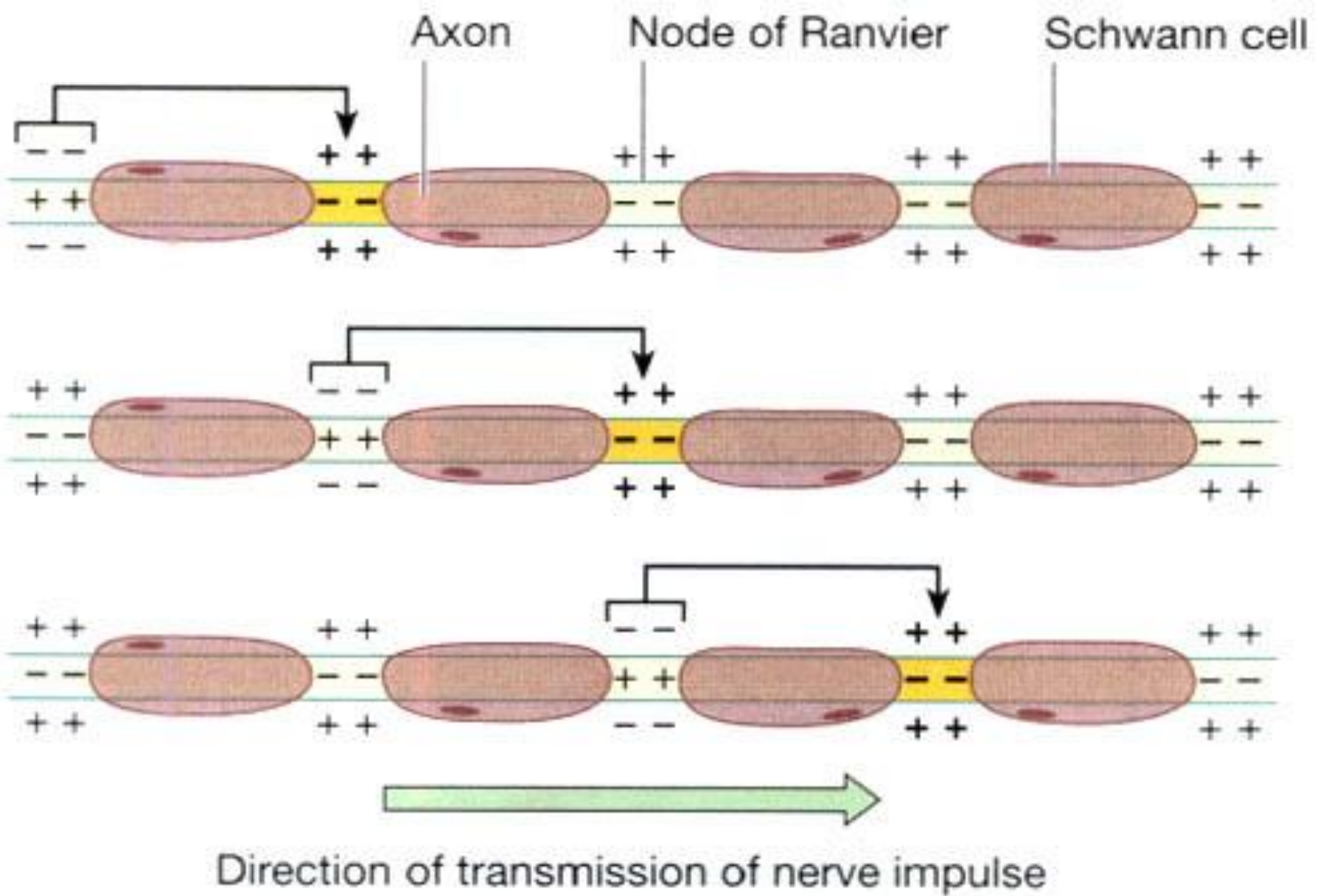
The nerve impulse (action potential)

- An impulse is initiated by
 - stimulation of sensory nerve endings
 - passage of an impulse from another nerve.
- Transmission of the impulse (action potential) is due to movement of ions across the nerve cell membrane.
- In the **resting state** the nerve cell membrane is polarized due to differences in the concentrations of ions across the plasma membrane.
- There is a different electrical charge on each side of the membrane, called the **resting membrane potential**.
- At rest, the charge on the outside is **positive** and inside it is **negative**.
- Principal ions involved are:
 - sodium (Na^+); the main extracellular cation
 - potassium (K^+); the main intracellular cation.

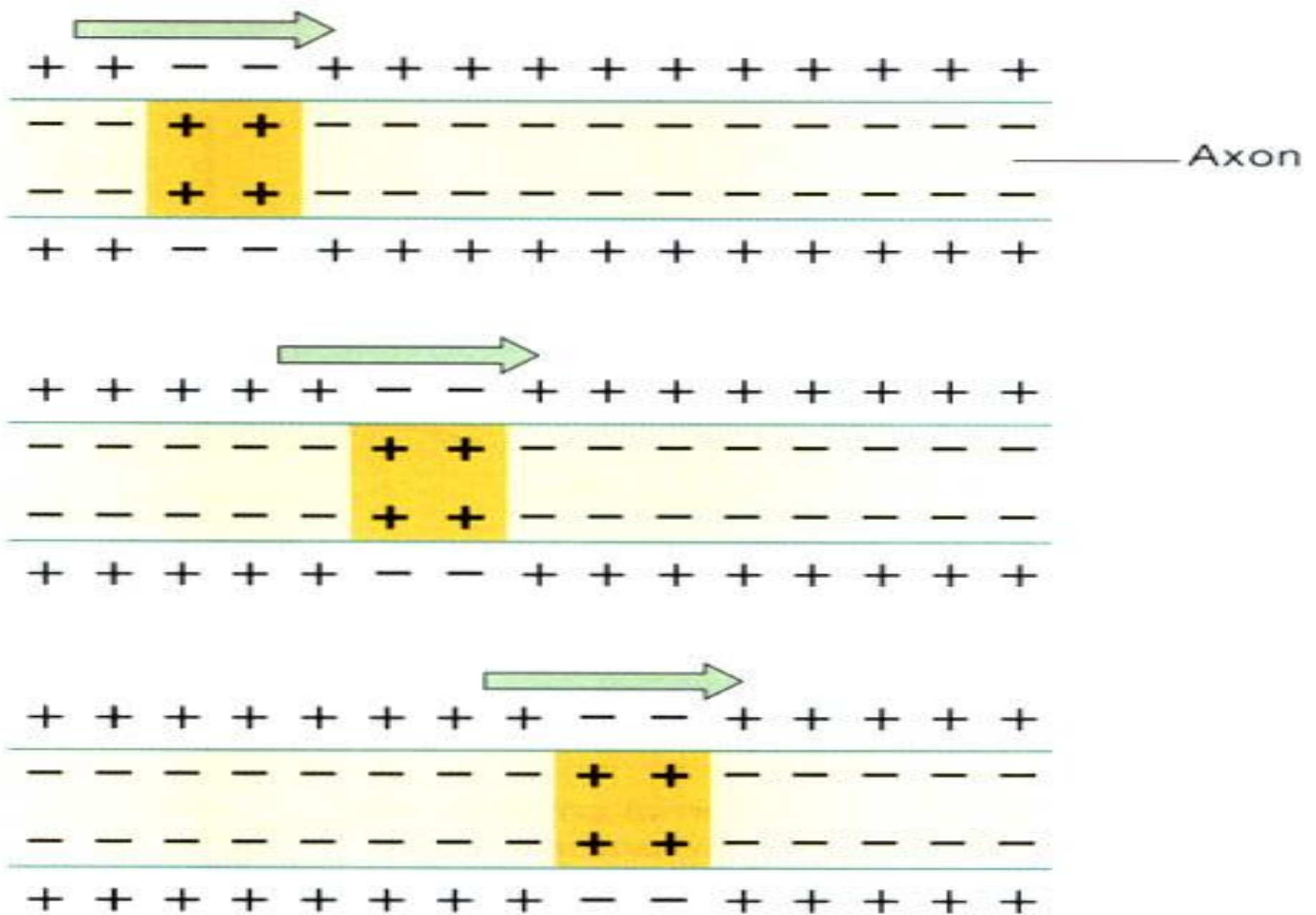
- In the **resting state** there is a continual tendency for these ions to diffuse along their concentration gradients, i.e. K^+ outwards and Na^+ into cells. When stimulated, the permeability of the nerve cell membrane to these ions changes.
- Initially **Na^+ floods into** the neurone from the ECF causing **depolarisation**, creating a nerve impulse or action potential.
- The nerve impulse passes from the point of stimulation in one direction only, i.e. away from the point of stimulation towards the area of resting potential.
- **Repolarisation** immediately follows and **K^+ floods out** of the neurone and the movement of these ions returns the membrane potential to its resting state. This is called the **refractory period** during which restimulation is not possible.
- As the neurone returns to its original resting state, the action of the sodium pump expels Na^+ from the cell in exchange for K^+ .



- Insulating properties of the myelin sheath (in myelinated neurones) prevent the movement of ions. Therefore electrical changes across the membrane can only occur at the nodes of Ranvier.
- When an impulse occurs at one node, depolarisation passes along the myelin sheath to the next node so that the flow of current appears to 'leap' from one node to the next (***saltatory conduction***) is propagation of action potentials along myelinated axons from one node of Ranvier to the next node, increasing the **conduction** velocity of action potentials.
- Speed of conduction depends on the diameter of the neurone: **the larger the diameter, the faster the conduction.**
- Myelinated fibres conduct impulses faster than unmyelinated fibres because saltatory conduction is faster than the complete conduction, or ***simple propagation***.
- Fastest fibres can conduct impulses to, e.g., skeletal muscles at a rate of 130 metres per second while the slowest impulses travel at 0.5 metres per second.



Saltatory conduction of an impulse in a myelinated nerve fibre.



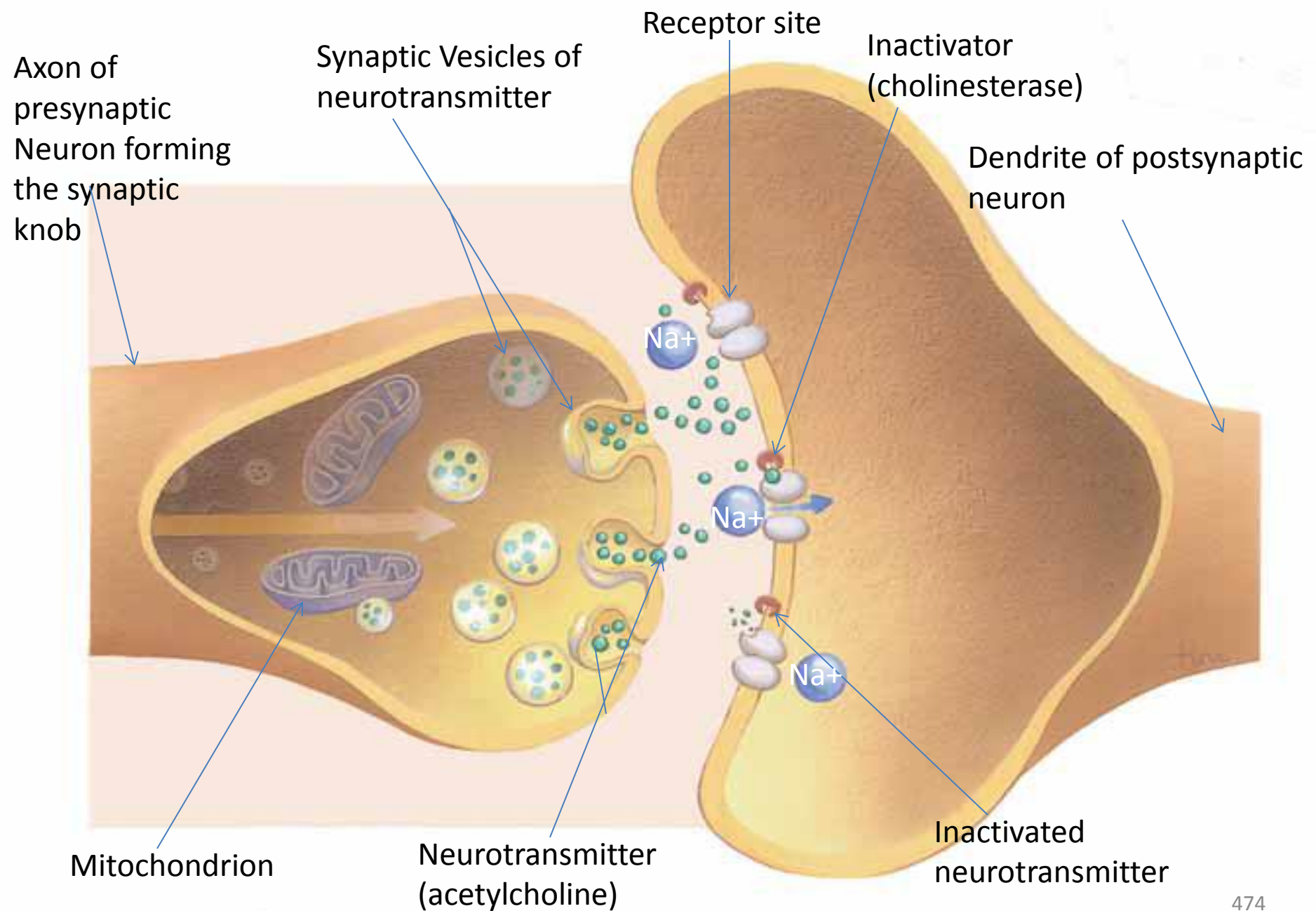
Simple propagation of an impulse in a non-myelinated nerve fibre.⁴⁷¹

THE SYNAPSE AND NEUROTRANSMITTERS

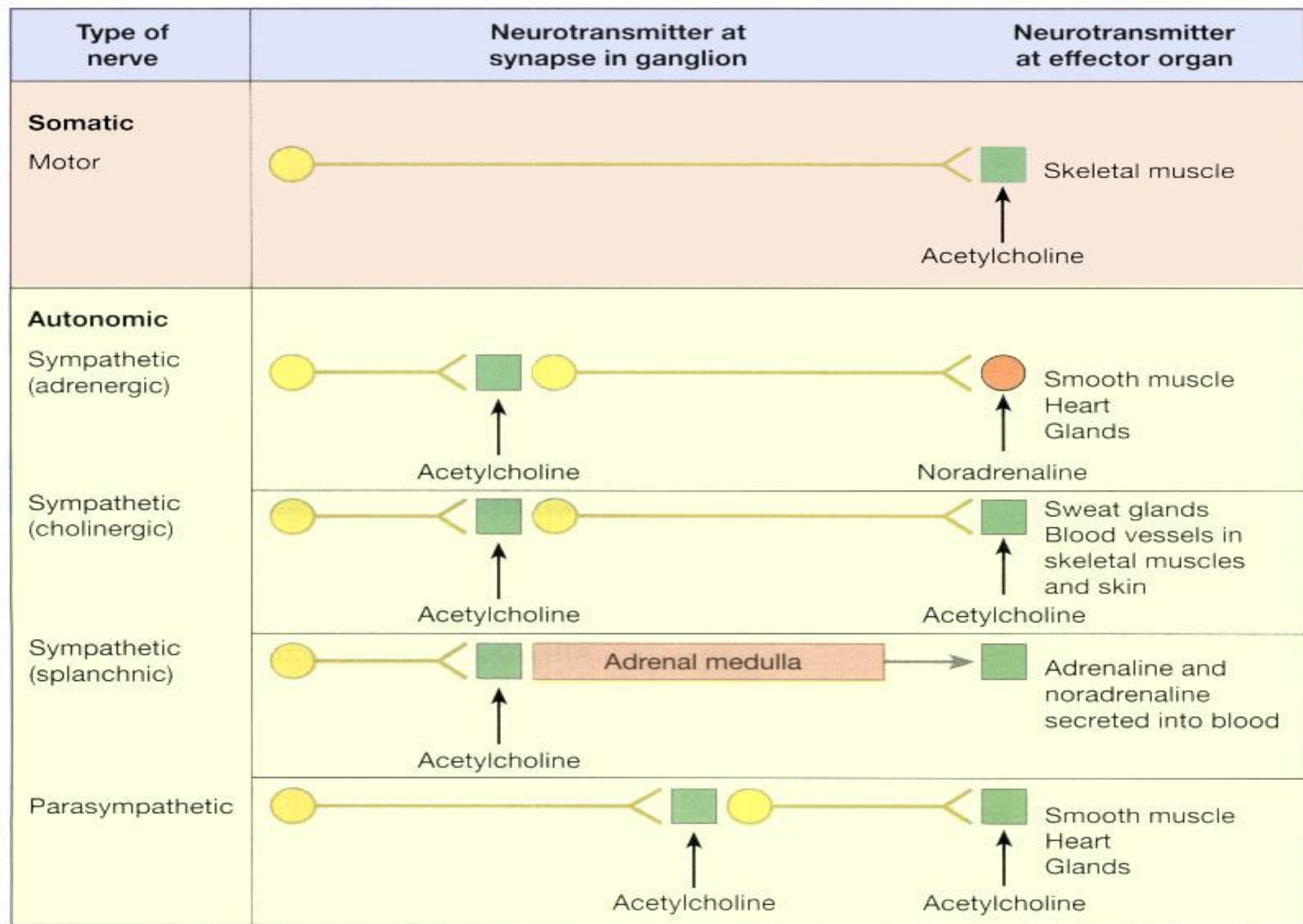
- **Synapse:** point at which the nerve impulse passes from one neurone to another one. Two neurones make up a synapse.
- The axon of the **presynaptic neurone** breaks up into minute branches which terminate in small swellings called **synaptic knobs, or terminal boutons**.
- Synaptic knobs are in close proximity to the dendrites and the cell body of the **postsynaptic neurone**. The space between them is the **synaptic cleft**.
- Ends of synaptic knobs have spherical **synaptic vesicles** containing, a **neurotransmitter**, which is released into synaptic clefts.
- **Neurotransmitters** are synthesized by nerve cells, actively transported along the axons and stored in the synaptic vesicles. They are released by exocytosis in response to the action potential and diffuse across the synaptic cleft.

- They act on specific receptor sites on the postsynaptic membranes.
- Their action is short lived. Immediately they have stimulated the postsynaptic neurone or effector organ, such as a muscle fibre, they are either
 - inactivated by enzymes or
 - taken back into the synaptic knob.
- Usually neurotransmitters have an **excitatory effect** at the synapse but they are sometimes **inhibitory**.

DIAGRAM OF A SYNAPSE



- Neurotransmitters include:
 - noradrenaline,
 - gamma amino- butyric acid (GABA),
 - acetylcholine,
 - dopamine,
 - serotonin (5-hydroxytryptamine),
 - enkephalins,
 - endorphins
 - Substance P.



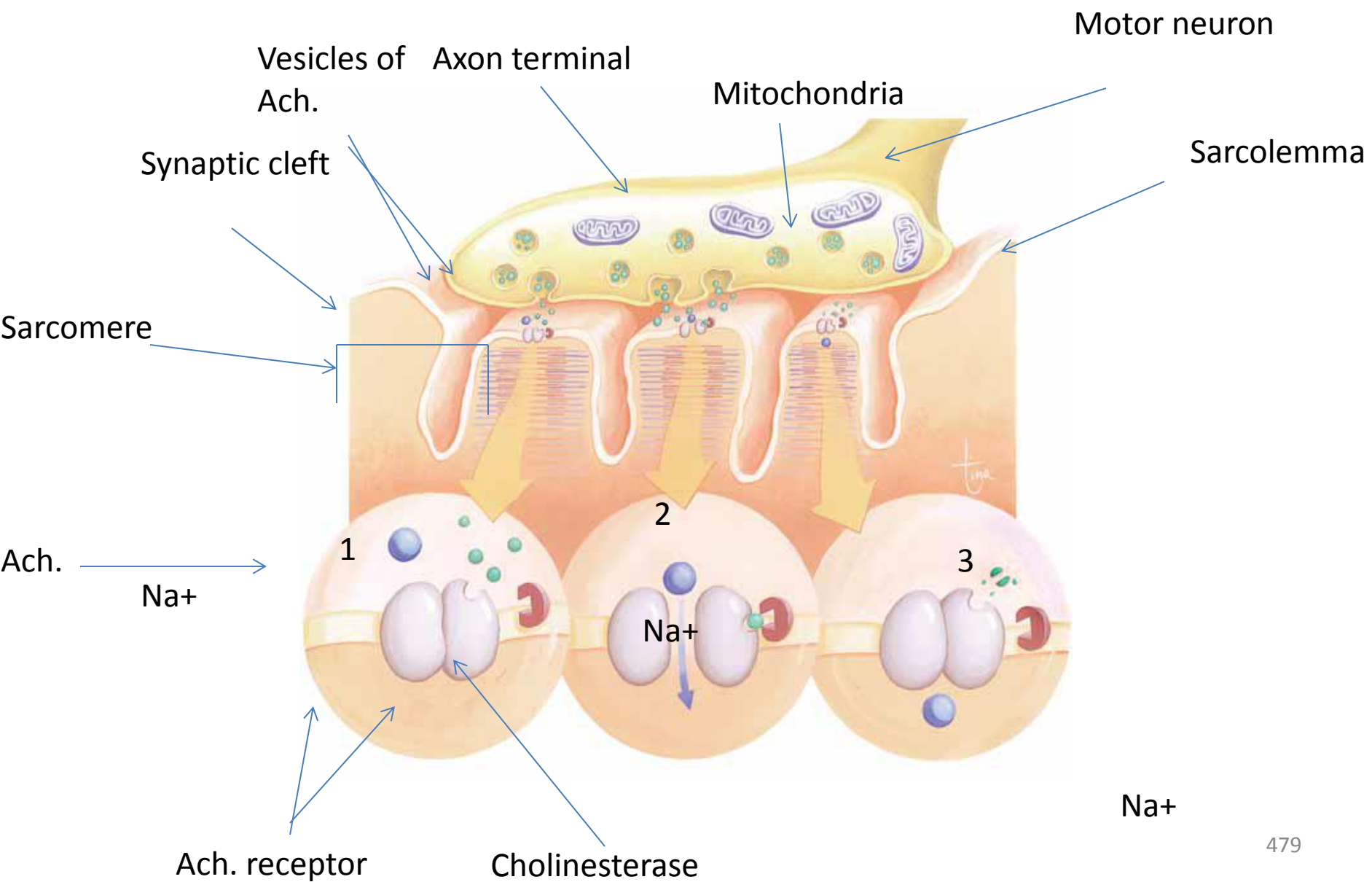
Neurotransmitters at synapses in the PNS

The neuromuscular junction

- **Somatic nerves** carry impulses directly to the synapses at skeletal muscles: the **neuromuscular junctions**.
- These are motor nerve ending where motor neuron terminates on the muscle.
- Axons of motor neurones, conveying impulses to skeletal muscle to produce contraction, divide into fine filaments terminating in minute pads called **motor end-plates**.
- At the point where the nerve reaches the muscle, the myelin sheath is absent and the fine filament passes to a sensitive area on the surface of the muscle fibre.
- **Axon terminal:** enlarged tip of the motor neuron contains sacs of the neurotransmitter **acetylcholine**.

- The membrane of the muscle fiber is the **sarcolemma**, which contains receptor sites for acetylcholine, & an inactivator called **cholinesterase**.
- **Motor unit** is constituted by the group of muscle fibres and the motor end-plates of the nerve fibre that supplies them.
- Endings of autonomic nerves supplying smooth muscle and glands, branch near their effector structure and release a neurotransmitter which stimulates or depresses the activity of the structure.

Neuromuscular junction, (1) Acetylcholine is about to bond to the ACh receptor in the sarcolemma. (2) Channel opens to allow Na ions into the muscle cell. (3) Cholinesterase inactivates acetylcholine.



NERVES

A nerve consists of numerous neurones collected into bundles

TYPES

a) **Sensory or afferent nerves**

- Transmit action potentials (information) generated by sensory receptors on the body to the spinal cord which is then carried to the brain.

Sensory receptors are specialised nerve endings that respond to different stimuli (changes). Various types to include:

- i) **Somatic, cutaneous or common senses:** Originate in the skin. They are: pain, touch, heat and cold.
- Sensory nerve endings in the skin are fine branching filaments without myelin sheaths.

- ii) **Proprioceptor senses.** Originate in muscles and joints and contribute to the maintenance of balance and posture.
- iii) **Special senses.** Sight, hearing, smell, touch and taste .
- iv) **Autonomic afferent nerves.** Originate in internal organs, glands and tissues, e.g. baroreceptors, chemoreceptors, and are associated with reflex regulation of involuntary activity and visceral pain.

b) Motor or efferent nerves

- Originate in the brain, spinal cord and autonomic ganglia and transmit impulses to the effector organs: muscles and glands.
- 2 types:
 - somatic nerves: involved in voluntary movement and reflexes
 - autonomic nerves: involved in cardiac and smooth muscle contraction and glandular secretion

c) Mixed nerves

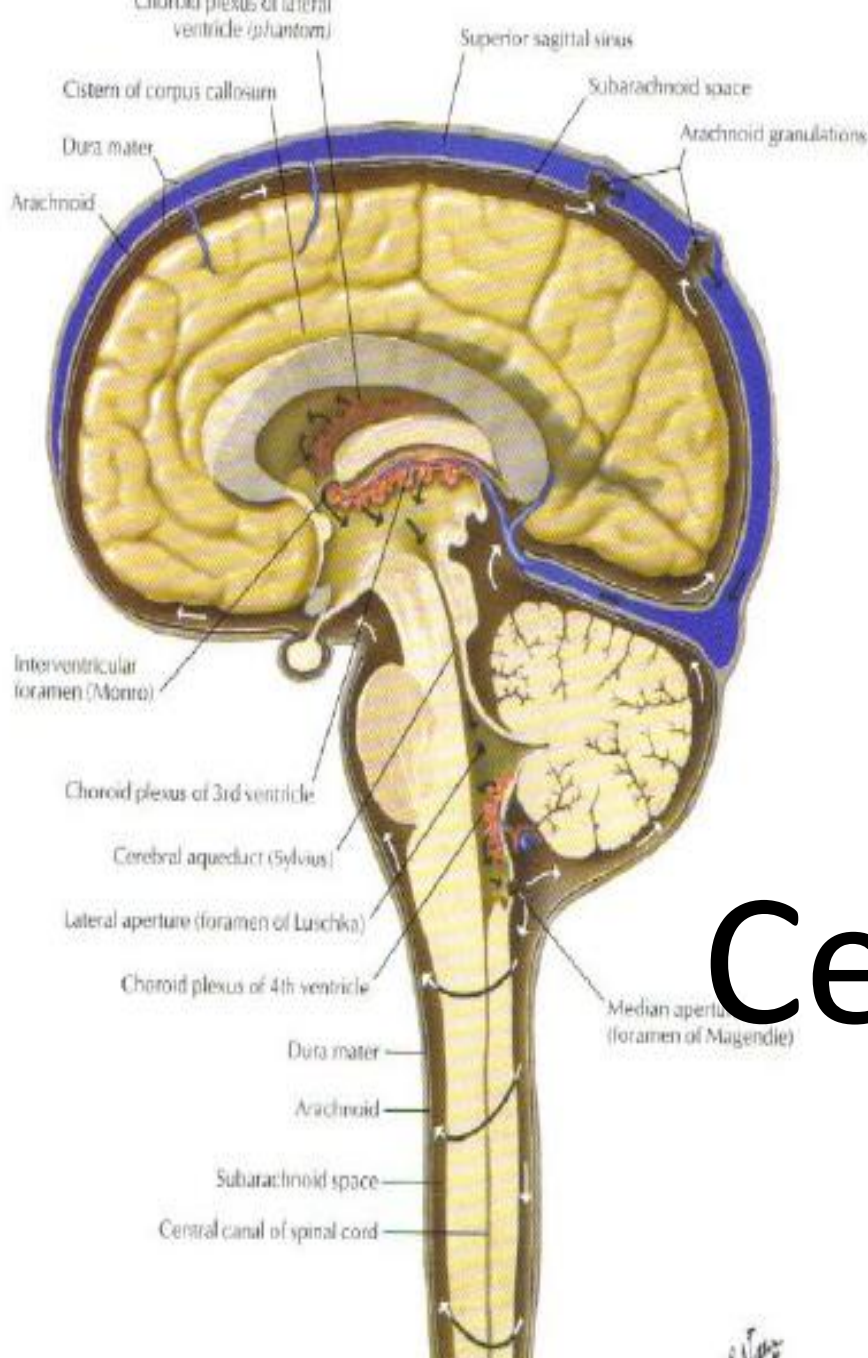
- Occur outside the spinal cord, when sensory and motor nerves are enclosed within the same sheath of connective tissue e.g. sciatic nerve

Neuroglia

- Neurones of the CNS are supported by 4 types of non-excitabile **glial** cells that make up a quarter to a half of the volume of brain tissue.
- Unlike nerve cells these continue to replicate throughout life. They are
 - **astrocytes,**
 - **oligodendrocytes,**
 - **microglia**
 - **ependymal cells.**

Neuroglia

Name	Function
Astrocytes (star shaped with fine branching processes which have swellings called foot processes)	Support neurons, help maintain K ⁺ level, contribute to the blood-brain barrier (BBB)
Oligodendrocytes	Produce the myelin sheath to electrically insulate neurons of the CNS, provide support
Microglia	Capable of movement and phagocytosis of pathogens and damaged tissue
Ependymal cells	Line the ventricles of the brain; many of the cells have cilia; involved in circulation of CSF



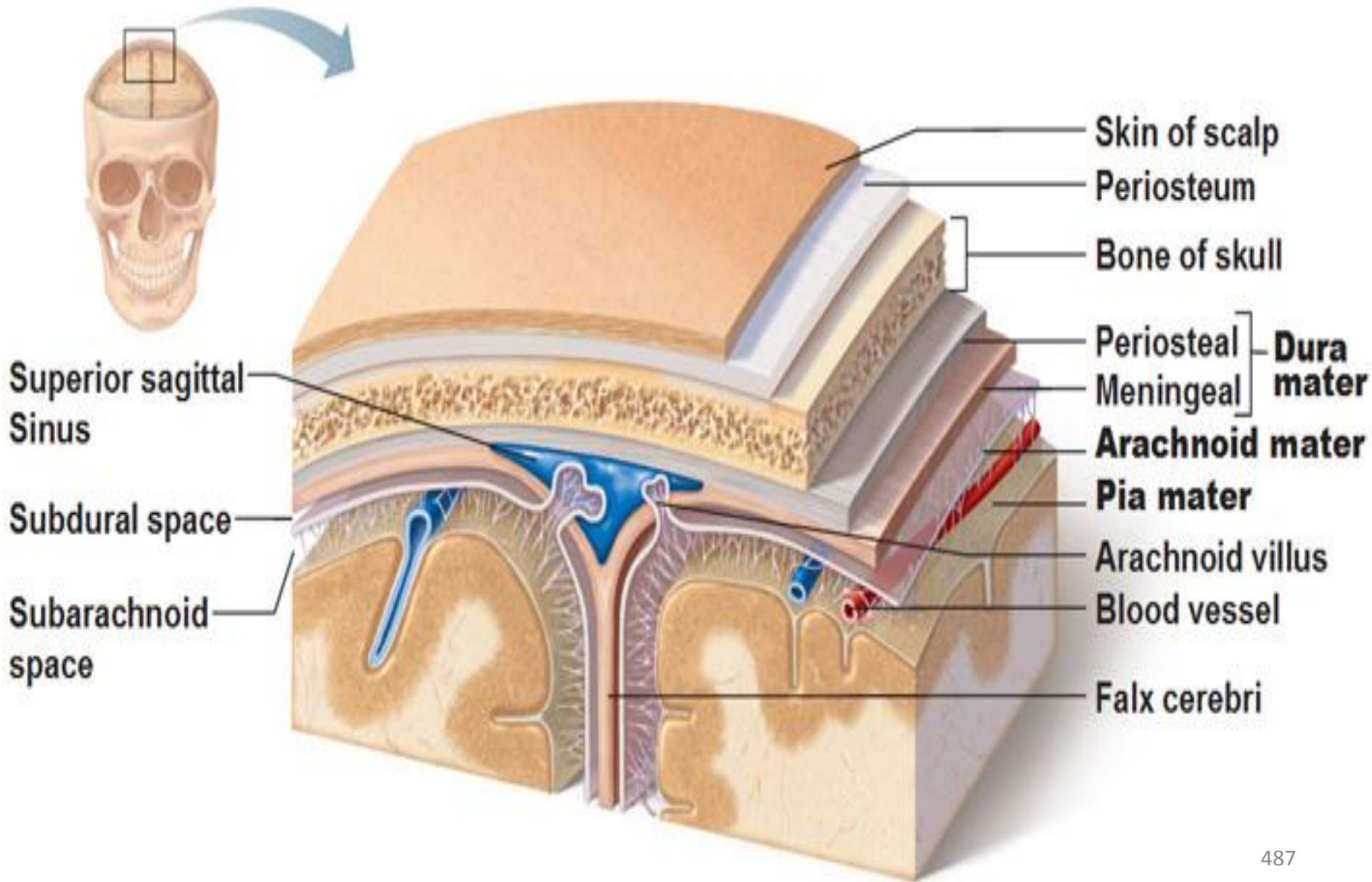
Central nervous system

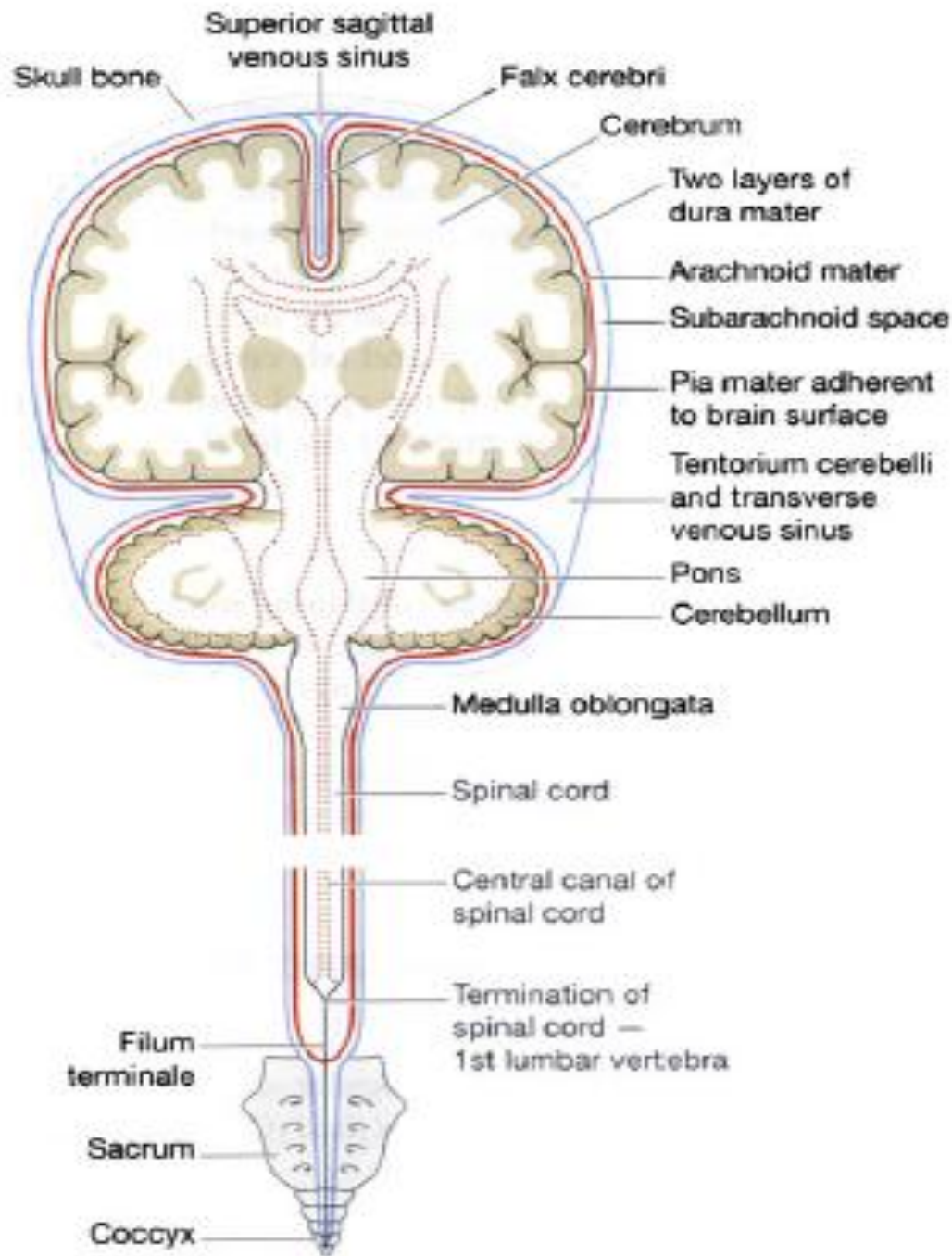
The Central nervous System consists of the brain and the spinal cord

THE MENINGES

- These are tissue membranes that cover the brain and spinal cord.
- Has 3 layers of tissue named from outside inwards; they are:
 - ❖ dura mater
 - ❖ arachnoid mater
 - ❖ pia mater.
- **Dura and arachnoid** maters are separated by a potential space, the **subdural space**.
- **Arachnoid and pia** maters are separated by the **subarachnoid** space, containing **cerebrospinal fluid**.

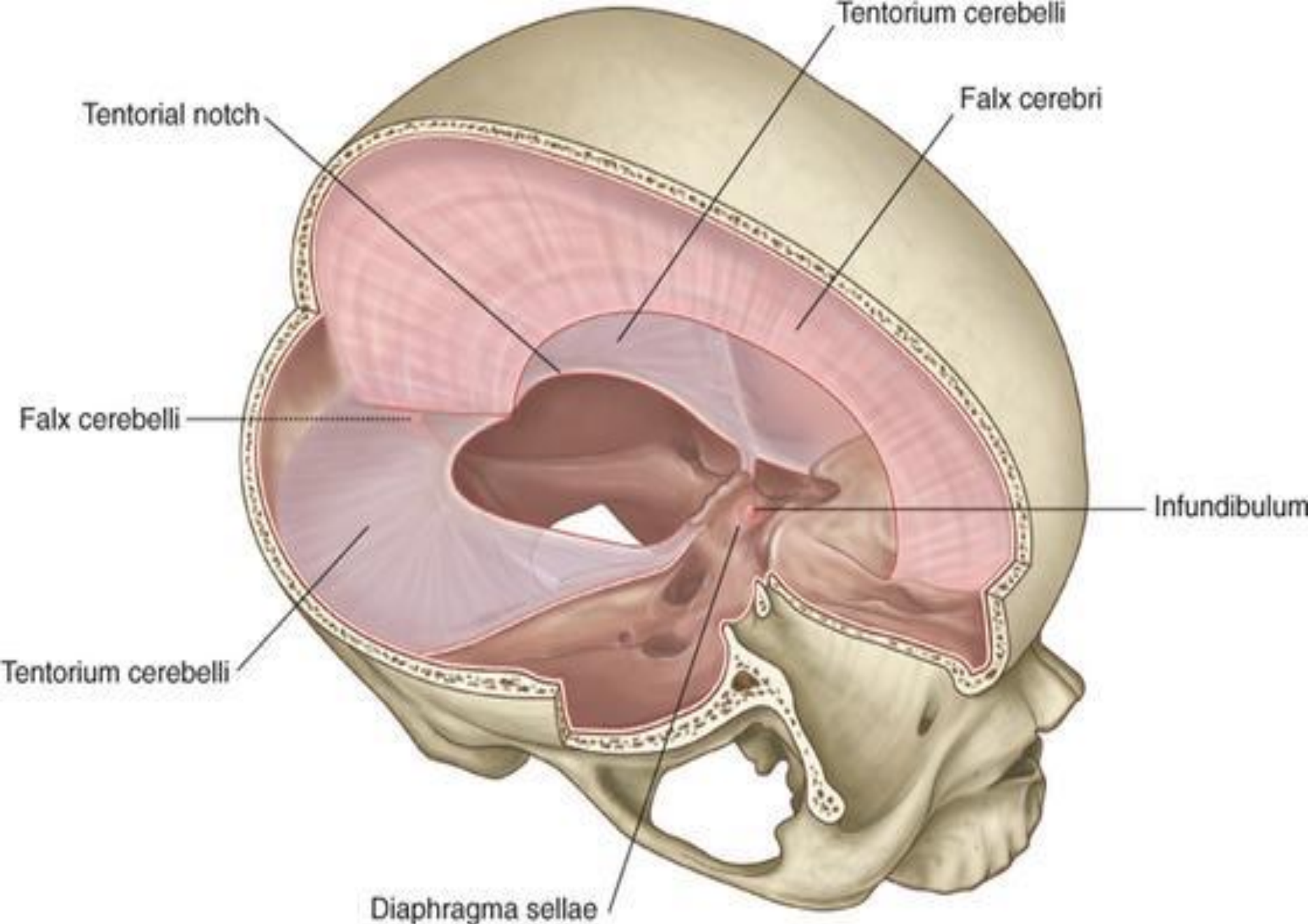
The Dura Mater





a) Dura mater

- i) **Cerebral dura mater** consists of two layers of dense fibrous tissue.
- **Outer** layer takes the place of the **periosteum** on the inner surface of the skull bones and the **inner** layer provides a protective covering for the brain.
 - Only a potential space exists between the two layers except where the inner layer sweeps inwards between the **cerebral** hemispheres to form the **falx cerebri**; between the **cerebellar** hemispheres to form the **falx cerebelli**; and between the **cerebrum** and **cerebellum** to form the **tentorium cerebelli**.
 - Venous blood from the brain drains into venous sinuses between the layers of dura mater. The **superior sagittal sinus** is formed by the **falx cerebri**, and the **tentorium cerebelli** forms the **straight** and **transverse sinuses**.



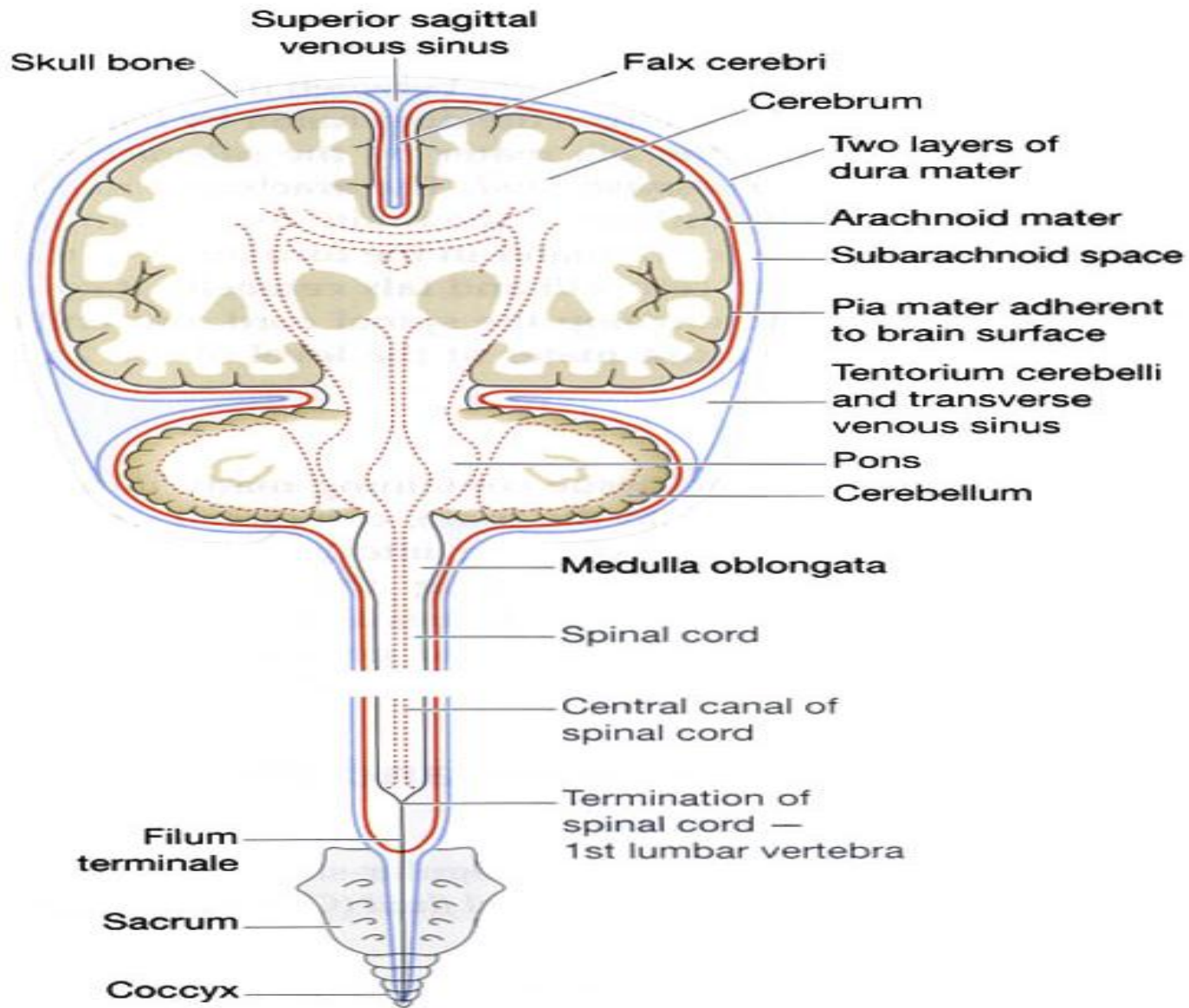
- ii) **Spinal dura mater** forms a loose sheath round the spinal cord, extending from the **foramen magnum** to the **second sacral vertebra**; encloses the **filum terminale** and fuses with the periosteum of the coccyx.
- It is an extension of the inner layer of cerebral dura mater and is separated from the periosteum of the vertebrae and ligaments within the neural canal by the **epidural** or **extradural** space, containing blood vessels and areolar tissue.
 - Nerves entering and leaving the spinal cord pass through the epidural space.
 - Dyes, used for diagnostic purposes, and local anaesthetics or analgesics to relieve pain, may be injected into the epidural space.

b) Arachnoid mater

- Delicate serous membrane that lies between the dura and pia maters.
- Separated from the dura mater by the **subdural space**, and from the pia mater by the **subarachnoid space**, containing **cerebrospinal fluid**.
- Passes over the convolutions of the brain and accompanies the inner layer of dura mater in the formation of the **falx cerebri**, **tentorium cerebelli** and **falx cerebelli**.
- Continues downwards to envelop the spinal cord and ends by merging with the dura mater at the level of the **2nd sacral vertebra**.

c) Pia mater

- Fine connective tissue containing many minute blood vessels.
- Adheres to the brain, completely covering the convolutions and dipping into each fissure.
- Continues downwards surrounding the spinal cord.
- Beyond the end of the cord it continues as the **filum terminale**, pierces the arachnoid tube and goes on, with the dura mater, to fuse with the periosteum of the coccyx.



Ventricles of the brain and the cerebrospinal fluid

- The brain contains 4 irregular-shaped cavities called **Ventricles** containing *cerebrospinal fluid (CSF)*.
- They are:
 - right lateral ventricle
 - left lateral ventricle
 - third ventricle
 - fourth ventricle.

a) The lateral ventricles

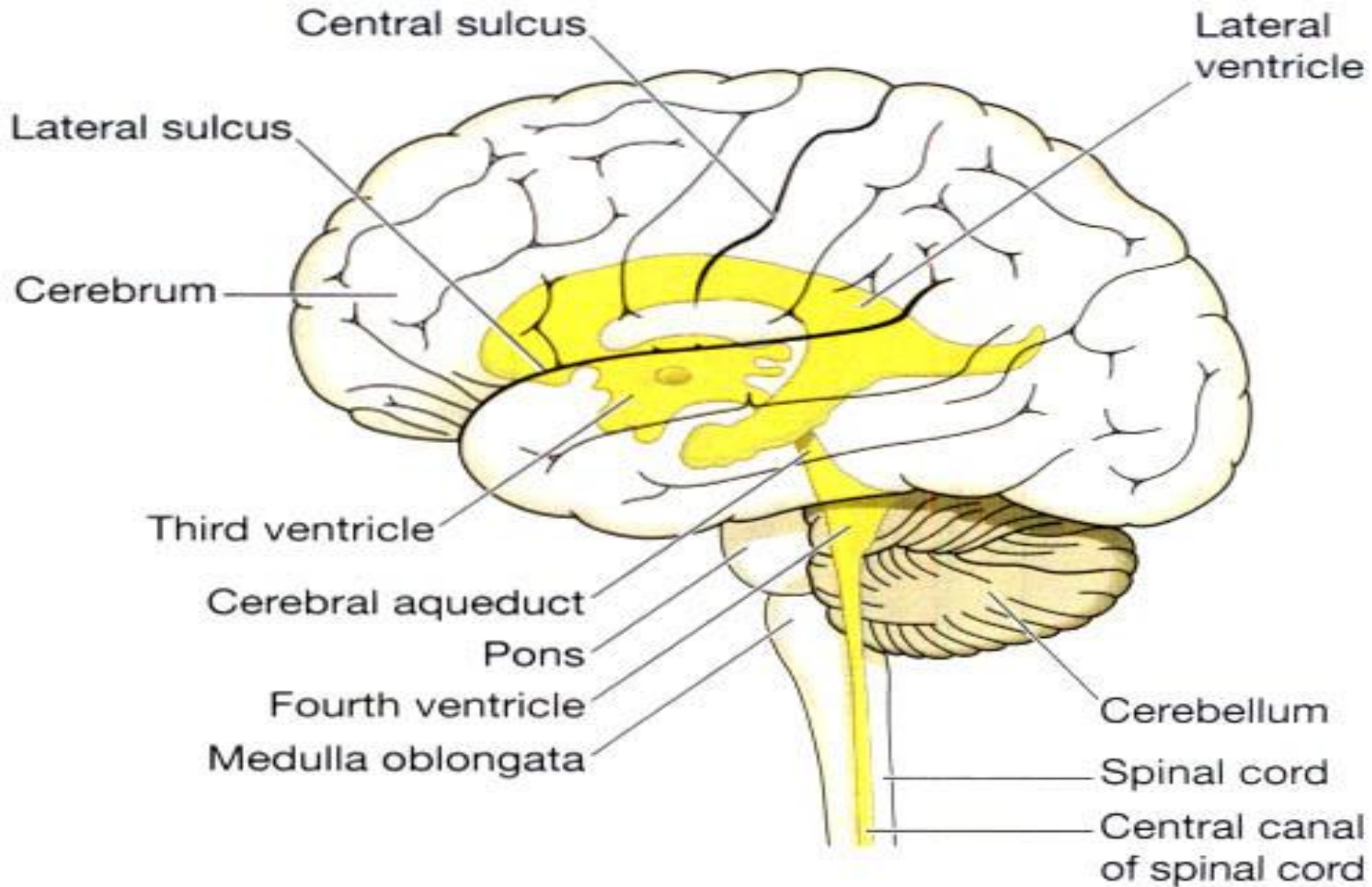
- Lie within the cerebral hemispheres, one on each side of the median plane just below the corpus callosum.
- Separated from each other by a thin membrane, the **septum lucidum**, and are lined with **ciliated epithelium**
- Communicate with the third ventricle by **interventricular foramina**.

b) The third ventricle

- Situated below the lateral ventricles between the two parts of the thalamus.
- Communicates with the fourth ventricle by a canal, the **cerebral aqueduct** or aqueduct of the midbrain.

c) The fourth ventricle

- Diamond-shaped cavity situated below and behind the third ventricle, between the cerebellum and pons.
- Continuous below with the central canal of the spinal cord and communicates with the subarachnoid space by foramina in its roof.
- CSF enters the subarachnoid space through these openings and through the open distal end of the central canal of the spinal cord.

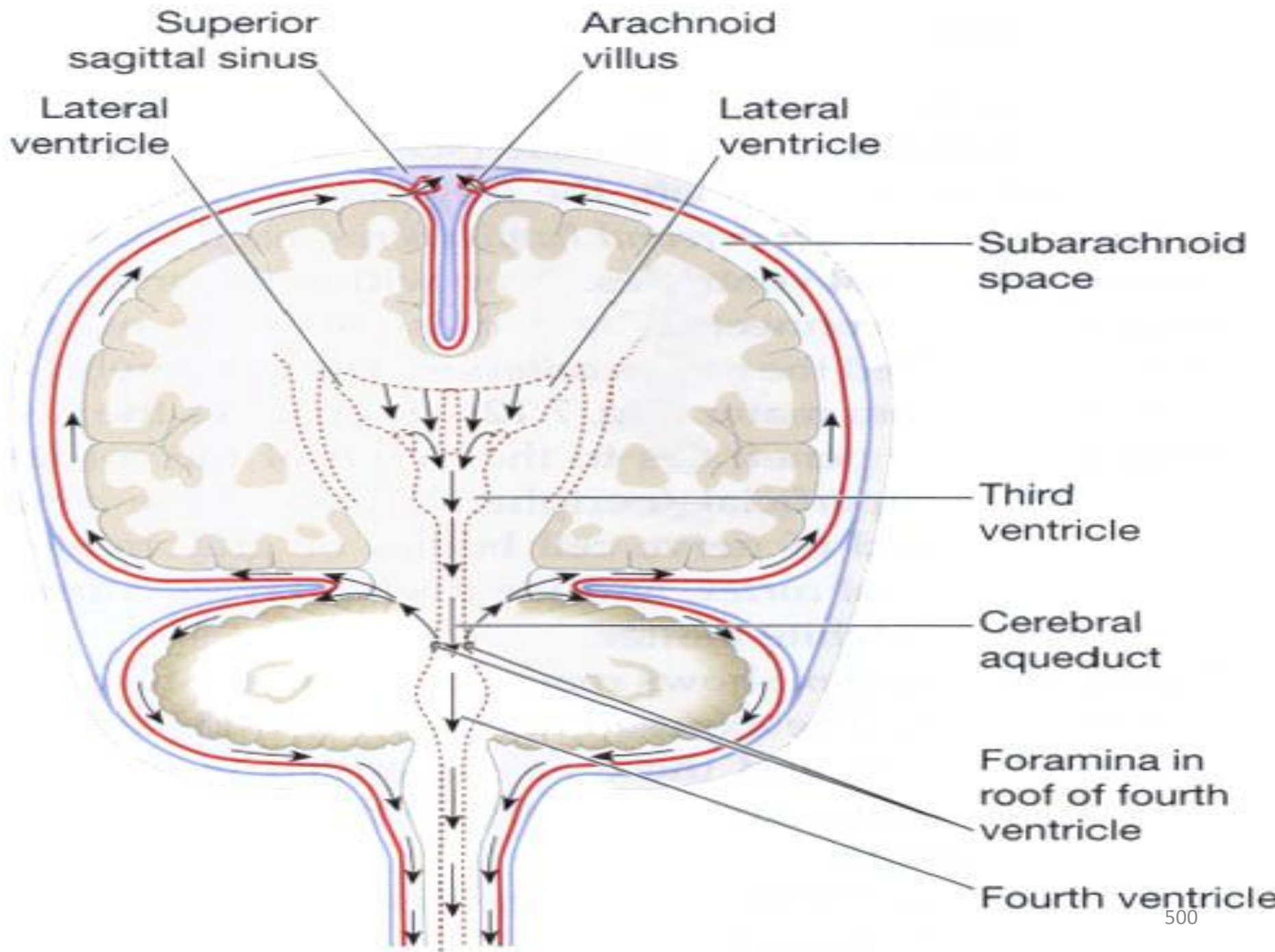


The positions of the ventricles of the brain (in yellow) ⁴⁹⁷

CEREBROSPINAL FLUID

- CSF is secreted into each ventricle of the brain by **choroid plexuses**; a capillary network that forms cerebrospinal fluid from blood plasma.
- CSF passes back into the blood through tiny diverticula of arachnoid mater, called **arachnoid villi** (arachnoid granulations), that project into the venous sinuses.
- The movement of CSF from the subarachnoid space to venous sinuses depends upon the difference in pressure on each side of the walls of the arachnoid villi, which act as one-way valves.
- When CSF pressure is higher than venous pressure, CSF passes into the blood and when the venous pressure is higher the arachnoid villi collapse, preventing the passage of blood constituents into the CSF.
- There may also be some reabsorption of CSF by cells in the walls of the ventricles.

- From the roof of the fourth ventricle CSF flows through foramina into the subarachnoid space and completely surrounds the brain and spinal cord.
- CSF movement is aided by pulsating blood vessels, respiration and changes of posture.
- CSF is secreted continuously at a rate of about **0.5 ml per minute, i.e. 720 ml per day.**
- The amount around the brain and spinal cord remains fairly constant at about **150ml**, which means that absorption keeps pace with secretion.
- CSF pressure may be measured using a vertical tube attached to a lumbar puncture needle. It remains fairly constant at about **10 cm H₂O** when the individual is **lying** on his side and about **30 cm H₂O** when **sitting up.**



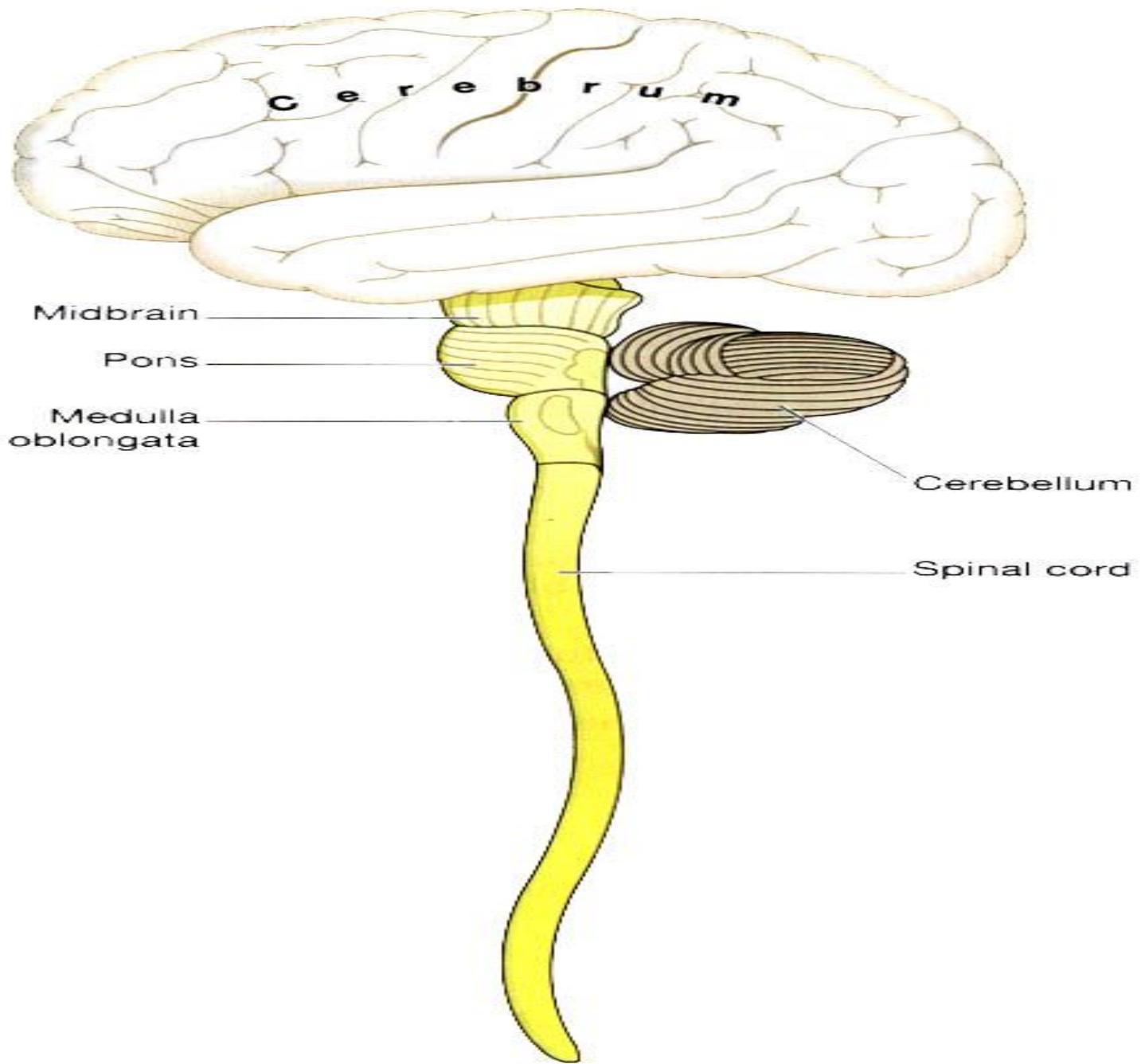
- If the brain is enlarged by, e.g. haemorrhage or tumour, some compensation is made by a reduction in the amount of CSF.
- When the volume of brain tissue is reduced, such as in degeneration or atrophy, the volume of CSF is increased.
- CSF is a clear, slightly alkaline fluid with a specific gravity of 1.005, consisting of:
 - water
 - mineral salts
 - glucose
 - plasma proteins: small amounts of albumin and globulin
 - Creatinine (small amounts)
 - Urea (small amounts)
 - a few leukocytes.

Functions of CSF

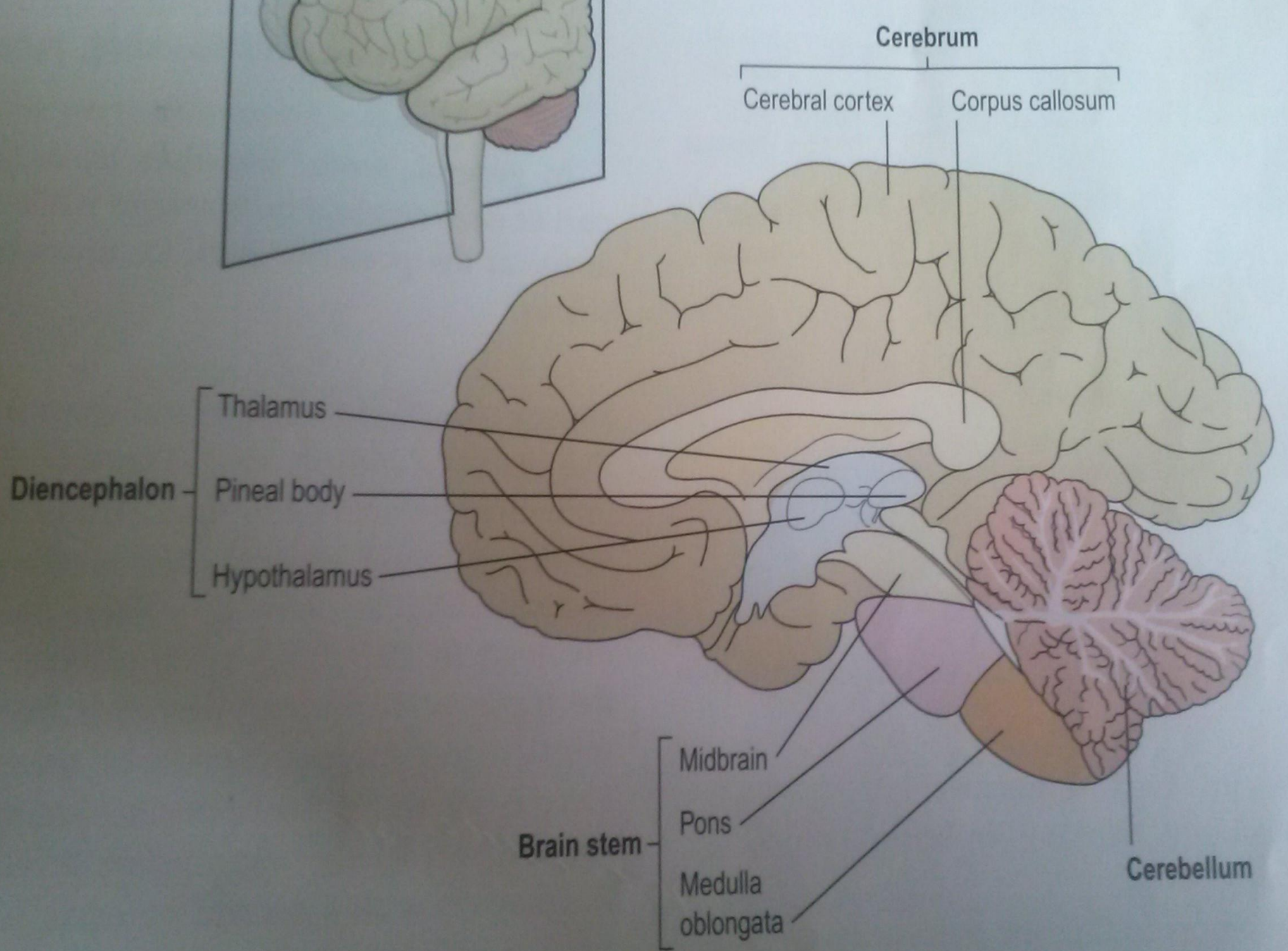
1. It is involved in the exchange of substances, for example, nutrients between the CSF and the nerve cells.
2. It keeps the brain and spinal cord moist.
3. It is a shock absorber for the brain, spinal cord and nerves.
4. It supports the brain and spinal cord and protects them by maintaining pressure around the delicate structures in a uniform manner.

THE BRAIN

- Constitutes about one-fiftieth of the body weight and lies within the cranial cavity.
 - The parts are
 - ☐ Cerebrum
 - ☐ Thalamus
 - ☐ hypothalamus
 - ☐ midbrain
 - ☐ pons
 - ☐ medulla oblongata
 - ☐ cerebellum.
-
- The diencephalon
- Brain Stem

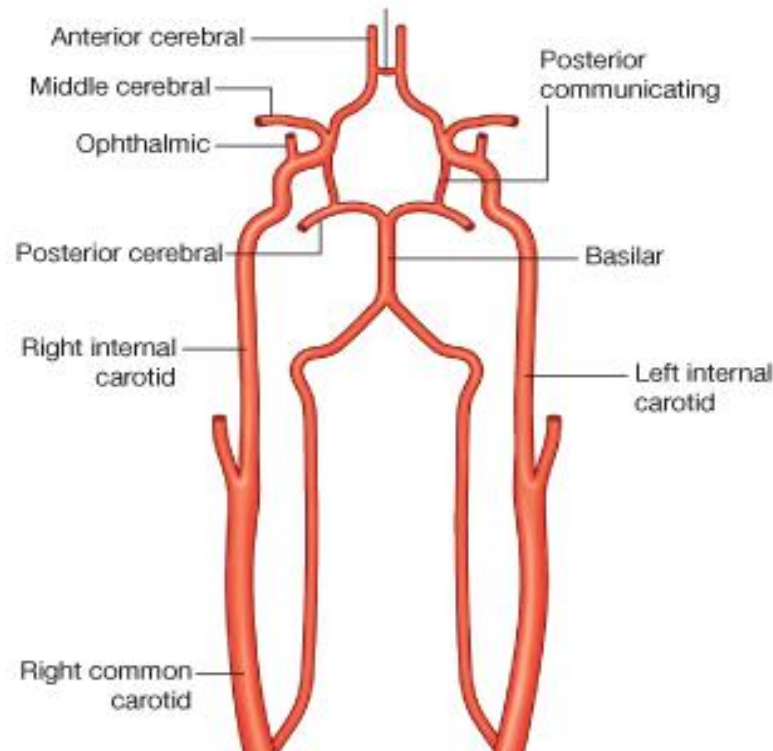


CNS



Blood supply to the brain

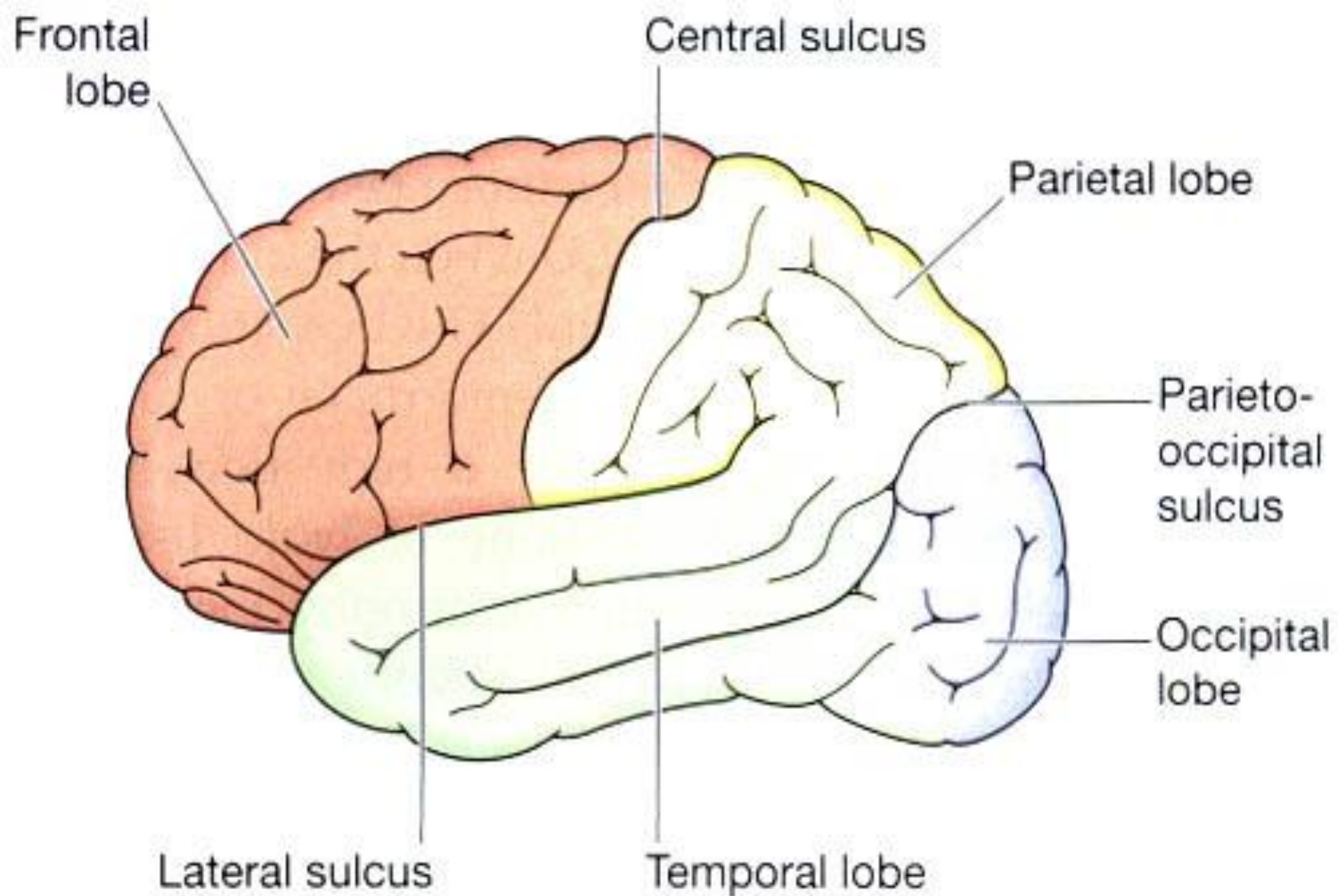
- By circulus arteriosus
- Receives about 15% of the cardiac output, approximately 750 ml of blood per minute.



CEREBRUM

- Largest part of the brain & occupies the anterior and middle cranial fossae.
- Divided by a deep cleft, the **longitudinal cerebral fissure**, into *right* and *left cerebral hemispheres*, each containing one of the lateral ventricles.
- Deep within the brain, the hemispheres are connected by a mass of white matter (nerve fibres) called the **corpus callosum**.
- **Falx cerebri**, formed by the dura mater; separates the two hemispheres and penetrates to the depth of the corpus callosum.
- Superficial (peripheral) part of the cerebrum is composed of nerve cell bodies or **grey matter**, forming the **cerebral cortex**, and the deeper layers consist of nerve fibres or **white matter**.
- Cerebral cortex shows many infoldings of varying depth.
- Exposed areas of the folds are the **gyri** or convolutions and these are separated by **sulci** or **fissures**.
- Convolutions greatly increase the surface area of the cerebrum.

- Cerebral cortex is divided into lobes that have the same names as the cranial bones under which they lie:
 - frontal
 - parietal
 - temporal
 - occipital.
- Boundaries of the lobes are marked by deep sulci (fissures).
- These are the
 - central,
 - lateral and
 - parieto-occipital sulci

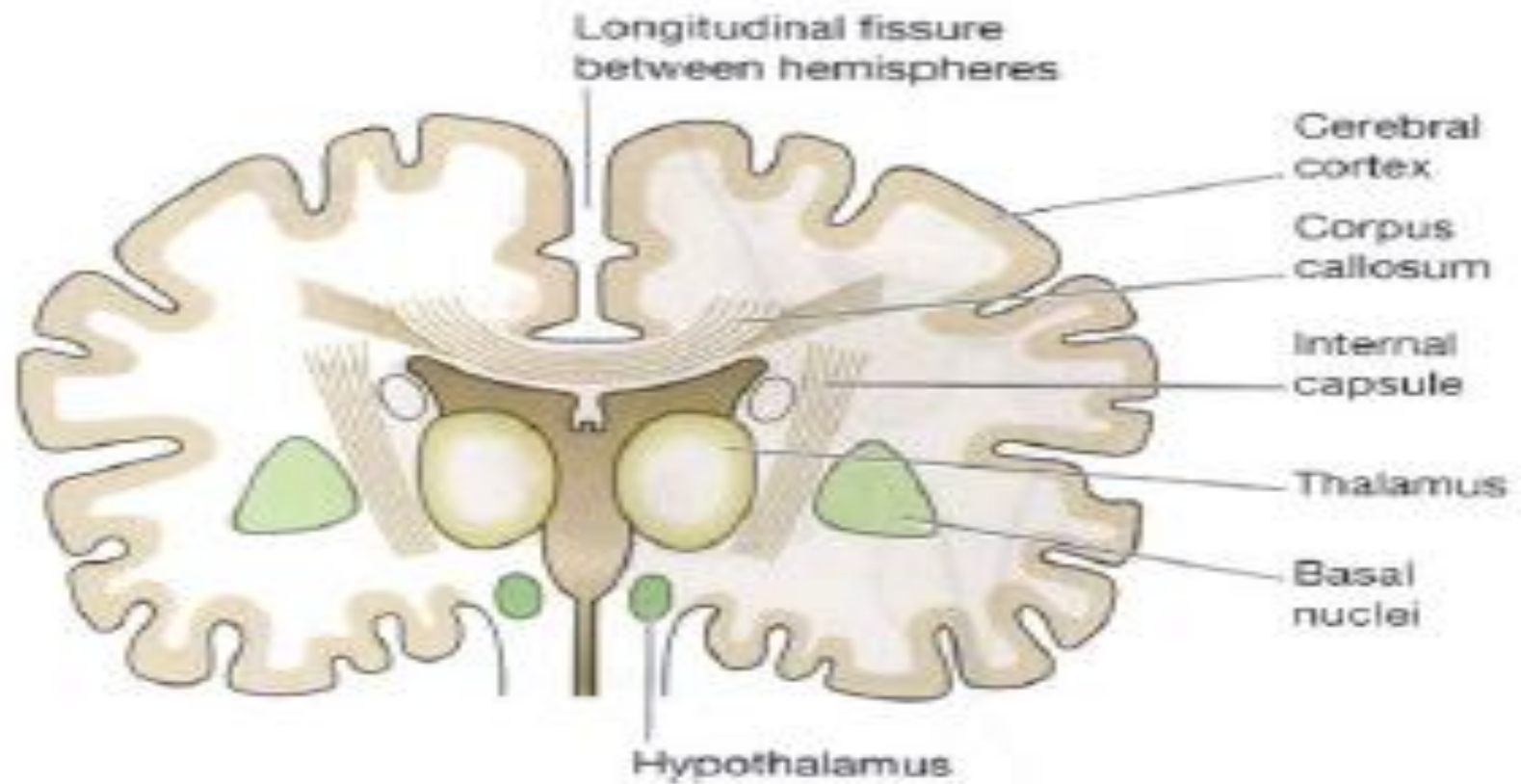


The lobes and sulci of the cerebrum.⁵⁰⁹

Cerebral Tracts and Basal Ganglia

- The surface of the cerebral cortex is composed of grey matter (nerve cell bodies).
- Within the cerebrum the lobes are connected by masses of nerve fibres, or tracts, which make up the white matter of the brain.
- Afferent and efferent fibres linking the different parts of the brain and spinal cord are;
 - **Association (arcuate) tracts:** connect different parts of a cerebral hemisphere by extending from one gyrus to another, some of which are adjacent and some distant.
 - **Commissural tracts:** connect corresponding areas of the two cerebral hemispheres; the largest and most important commissure is the **corpus callosum**.
 - **Projection tracts:** connect the cerebral cortex with grey matter of lower parts of the brain and with the spinal cord, e.g. the internal capsule.

- **Internal capsule** is a projection tract that lies deep within the brain between the basal nuclei (ganglia) and the thalamus.
- Many nerve impulses passing to and from the cerebral cortex are carried by fibres that form the internal capsule.
- Motor fibres within the internal capsule form the ***pyramidal tracts (corticospinal tracts)*** that cross over (decussate) at the medulla oblongata.
- Motor fibres that do not pass thru the internal capsule form the ***extrapyramidal tracts***



Functions of the cerebral cortex

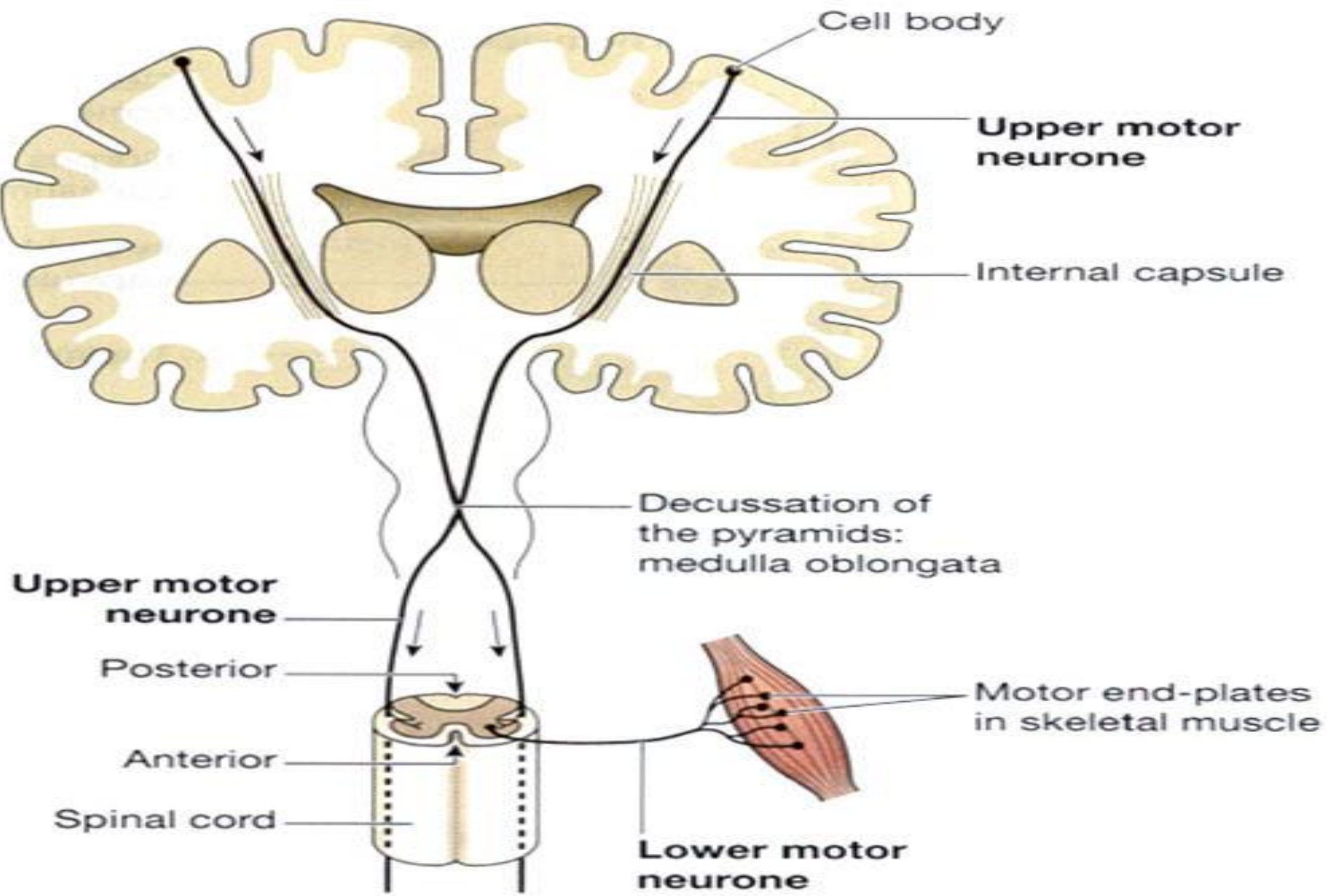
1. Mental activities involved in memory, intelligence, sense of responsibility, thinking, reasoning, moral sense and learning.
2. Sensory perception, including the perception of pain, temperature, touch, sight, hearing, taste and smell
3. Initiation and control of skeletal (voluntary) muscle contraction.

Functional areas of the cerebrum

A) Motor areas of the cerebrum

a) The primary motor area.

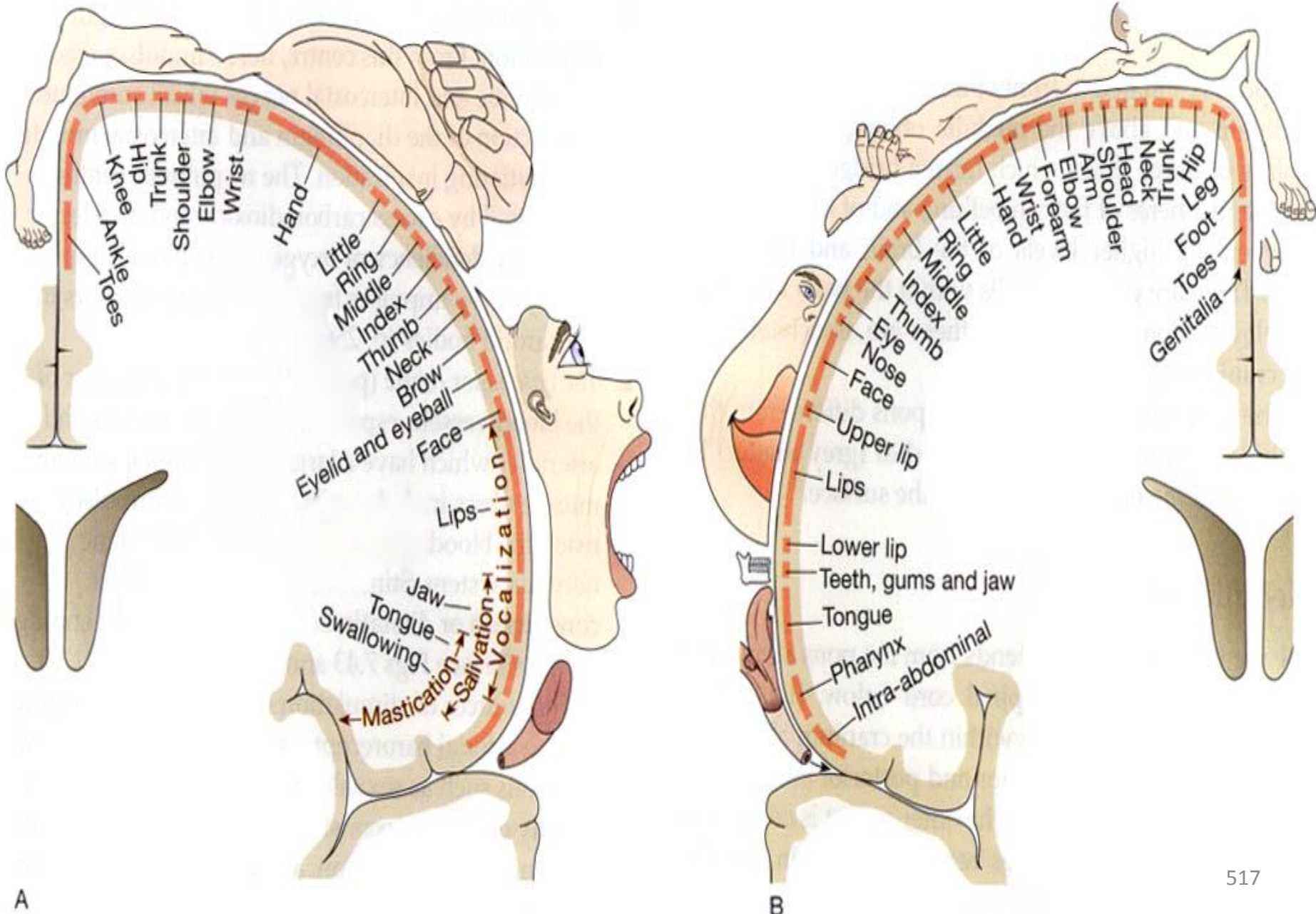
- Lies in the frontal lobe immediately anterior to the central sulcus.
- Its cell bodies control skeletal muscle activity
- The pathway to the muscle has two neurones: the upper motor neurone and the lower motor neurone
- The upper motor neurone passes downwards through the internal capsule to the medulla oblongata where it crosses to the opposite side then descends in the spinal cord.
- In the spinal cord the nerve impulse crosses a synapse to stimulate a second neurone which terminates at the motor end-plate of a muscle fibre thus, the motor area of the right hemisphere of the cerebrum controls voluntary muscle movement on the left side of the body and vice versa.



The motor nerve pathways: upper & lower motor neurones.⁵¹⁵

- Damage to either of these neurones may result in paralysis
- In the motor area of the cerebrum the body is represented upside down, i.e. the cells nearest the vertex control the feet and those in the lowest part control the head, neck, face and fingers.
- The sizes of the areas of cortex representing different parts of the body are proportional to the **complexity of movement** of the body part, not to its size.
- **b) Broca's area:** lies in the frontal lobe just above the lateral sulcus and it controls the movements necessary for speech.
- It is dominant in the left hemisphere in right-handed people and vice versa.

The motor homunculus showing body representation in the motor area of the cerebrum (A) & sensory area (B) of the cerebrum



Sensory area of the cerebrum

- a) **The somatosensory area.** Lies behind the central sulcus. Perceives sensations of pain, temperature, pressure and touch, knowledge of muscular movement and the position of joints (**proprioception**)
- The sensory area of the right hemisphere receives impulses from the left side of the body and vice versa.
 - The size of the areas representing different parts of the body is proportional to the extent of sensory innervation, e.g. the large area for the face is consistent with the extensive sensory nerve supply by the three branches of the trigeminal nerves (5th cranial nerves).

- b) The auditory (hearing) area.** Lies immediately below the lateral sulcus within the temporal lobe.
- The cells receive and interpret impulses transmitted from the inner ear by the cochlear (auditory) part of the vestibulocochlear nerves (8th cranial nerves).
- c) The olfactory (smell) area.** Lies deep within the temporal lobe where impulses from the nose via the olfactory nerves (1st cranial nerves) are received and interpreted.
- d) The taste area.** Lies just above the lateral sulcus in the deep layers of the sensory area. This is the area where impulses from special nerve endings in taste buds in the tongue and in the lining of the cheeks, palate and pharynx are perceived as taste.

- g) The visual area.** Lies behind the parieto-occipital sulcus and includes the greater part of the occipital lobe.
- The optic nerves (2nd cranial nerves) pass from the eye to this area which receives and interprets the impulses as visual impressions.

Longitudinal fissure
between hemispheres

Cerebral
cortex

Corpus
callosum

Internal
capsule

Thalamus

Basal
nuclei

Hypothalamus

Premotor area

Motor area

Central sulcus

Sensory area

Sensory
speech area

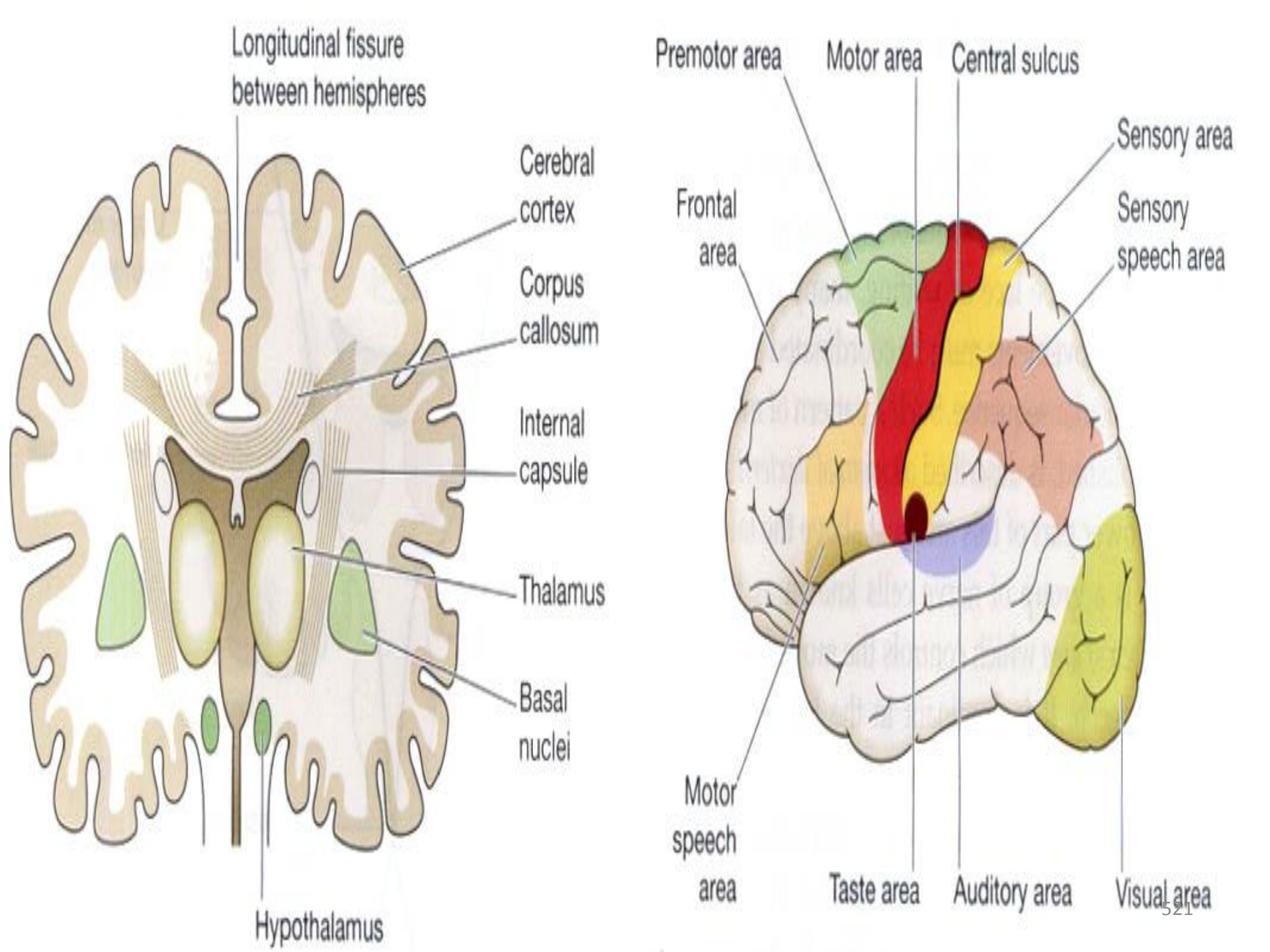
Frontal
area

Motor
speech
area

Taste area

Auditory area

Visual area



Association areas

These are areas that are connected to other functional areas of the cortex and their main function is to receive, coordinate and interpret impulses from the sensory and motor areas thus permitting higher cognitive abilities.

a) The prefrontal area. Lies in the frontal lobe immediately anterior to the motor area.

- The cells exert a controlling influence over the motor area, ensuring an orderly series of movements.
- When a pattern of movement is established, it's described as **manual dexterity**.

b) The frontal area. Extends anteriorly from the premotor area to include the remainder of the frontal lobe.

- It is a large area
- More highly developed in humans than in other animals.
- Communications between this and the other regions in the cerebrum are responsible for
 - the behavior,
 - character
 - emotional state of the individual.

c) The sensory speech (Wernicke's) area.

Situated in the lower part of the parietal lobe and extends into the temporal lobe.

- Spoken word is perceived here.
- There is a dominant area in the left hemisphere in right-handed people and vice versa.

diencephalon

- Deep within the cerebral hemispheres there are groups of cell bodies called nuclei which act as relay stations where impulses are passed from one neurone to the next in a chain.
- Important masses of grey matter include:
 - thalamus
 - hypothalamus.

a) Thalamus. Consists of 2 masses of grey and white matter situated within the cerebral hemispheres just below the corpus callosum, one on each side of the third ventricle. Sensory input from **the skin, viscera and special sense organs** is transmitted to the thalamus before redistribution to the cerebrum.

b) Hypothalamus. Situated below and in front of the thalamus, immediately above the ***pituitary gland***. It's linked to the posterior lobe of the pituitary gland by nerve fibres and to the anterior lobe by a complex system of blood vessels.

It therefore controls output of hormones from the pituitary gland

- Hypothalamus also controls:
 - the autonomic nervous system
 - appetite and satiety
 - thirst and water balance
 - body temperature
 - emotional reactions, e.g. pleasure, fear, rage
 - sexual behaviour including mating and child rearing
 - biological clocks or circadian rhythms, e.g. sleeping and waking cycles, body temperature and secretion of some hormones.

BRAIN STEM

a) Midbrain

- Situated around the cerebral aqueduct between the cerebrum above and the pons below.
- Consists of nuclei and nerve fibres (tracts) which connect the cerebrum with lower parts of the brain and with the spinal cord.
- The nuclei act as relay stations for the ascending and descending nerve fibres.

b) Pons

- Situated in front of the cerebellum, below the midbrain and above the medulla oblongata.
- Consists mainly of nerve fibres which form a bridge between the two hemispheres of the cerebellum, and of fibres passing between the higher levels of the brain and the spinal cord.

- Has nuclei which act as relay stations and some of these are associated with the cranial nerves.
- The anatomical structure of the pons differs from that of the cerebrum in that the cell bodies (grey matter) lie deeply and the nerve fibres are on the surface.

c) Medulla oblongata

- Extends from the pons above and is continuous with the spinal cord below.
- It is about 2.5 cm long and it lies just within the cranium above the foramen magnum.
- Its anterior and posterior surfaces are marked by central fissures.

- The outer aspect is composed of white matter which passes between the brain and the spinal cord, and grey matter lies centrally.
- Some cells constitute relay stations for sensory nerves passing from the spinal cord to the cerebrum.
- The **vital centres**, consisting of nuclei associated with autonomic reflex activity, lie in its deeper structure. These are the:
 - cardiac centre
 - respiratory centre
 - vasomotor centre
 - reflex centres of vomiting, coughing, sneezing and swallowing.

- Special features of the medulla oblongata include:
 1. **Decussation (crossing) of the pyramids.** Motor nerves descending from the motor area in the cerebrum to the spinal cord in the pyramidal (corticospinal) tracts cross from one side to the other.
 2. **Sensory decussation.** Some of the sensory nerves ascending to the cerebrum from the spinal cord cross from one side to the other in the medulla.
 3. **The cardiovascular centre** controls the rate and force of cardiac contraction. It also controls the BP.
 4. **The respiratory centre** controls the rate and depth of respiration. From this centre, nerve impulses pass to the phrenic and intercostal nerves which stimulate contraction of the diaphragm and intercostal muscles, thus initiating inspiration.

4. **The vasomotor centre** controls the diameter of the blood vessels. The sources of stimulation of the vasomotor centre are the arterial baroreceptors, body temperature and emotions.
5. **Reflex centres.** When irritating substances are present in the stomach or respiratory tract, nerve impulses pass to the medulla oblongata, stimulating the reflex centres which initiate the reflex actions of vomiting, coughing and sneezing to expel the irritant.

- **d) Reticular formation**
- **Def:** a collection of neurones in the core of the brain stem, surrounded by neural pathways which conduct ascending and descending nerve impulses between the brain and the spinal cord.

Functions

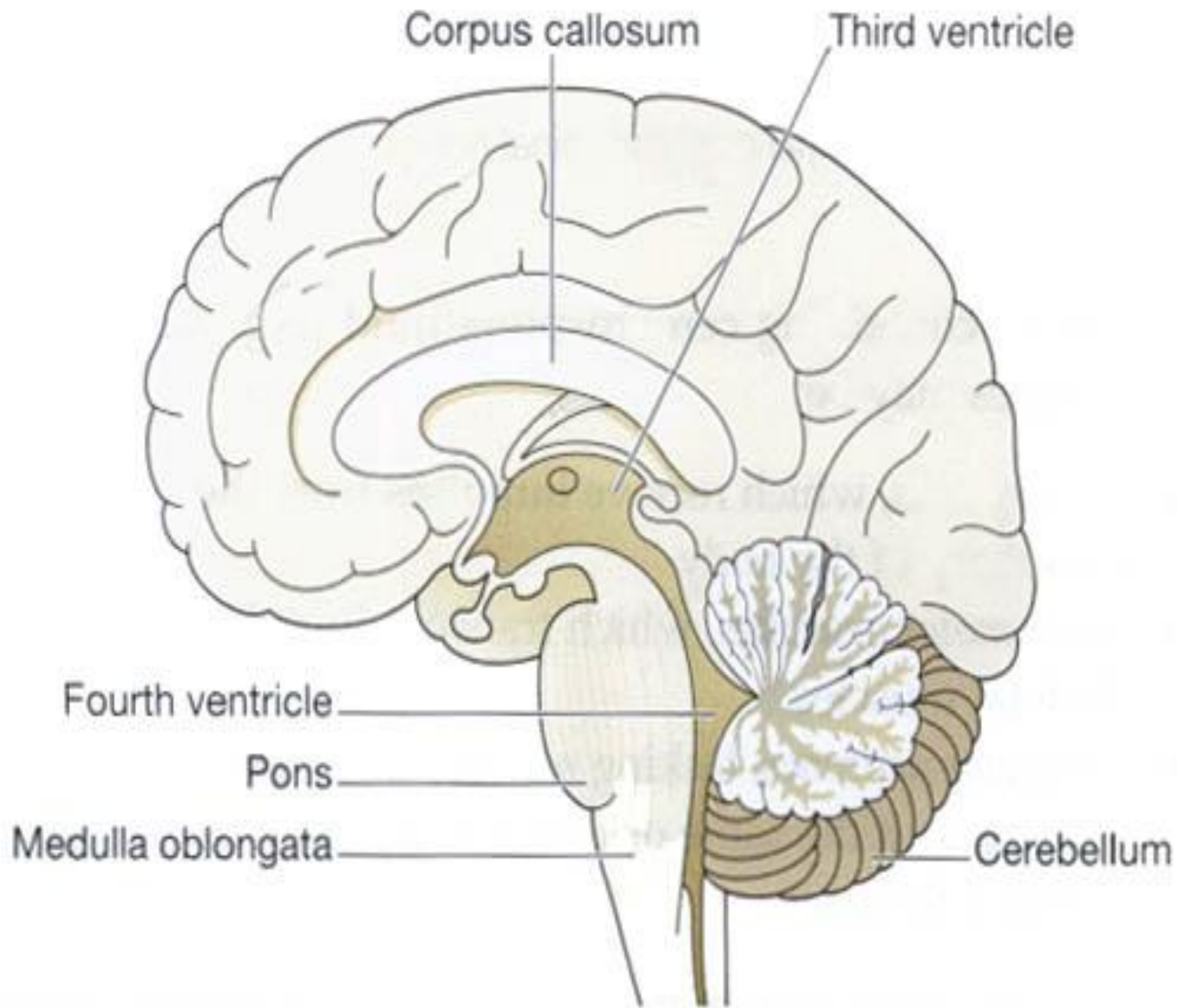
1. coordination of skeletal muscle activity associated with voluntary motor movement and the maintenance of balance
2. coordination of activity controlled by the autonomic nervous system, e.g. CVS, Resp and GIT activity
3. selective awareness that functions through the **reticular activating system (RAS)** which selectively blocks or passes sensory information to the cerebral cortex.

CEREBELLUM

- Situated behind the pons and immediately below the posterior portion of the cerebrum occupying the posterior cranial fossa.
- Ovoid in shape and has two hemispheres, separated by a narrow median strip called the *vermis*. Grey matter forms the surface of the cerebellum, and the white matter lies deeply.

Functions

- i. Maintenance of balance and posture
 - ii. Coordination of voluntary movements
 - iii. Motor learning
 - iv. Cognitive functions esp language
- NB: Damage to the cerebellum results in clumsy uncoordinated muscular movement, staggering gait and inability to carry out smooth, steady, precise movements.



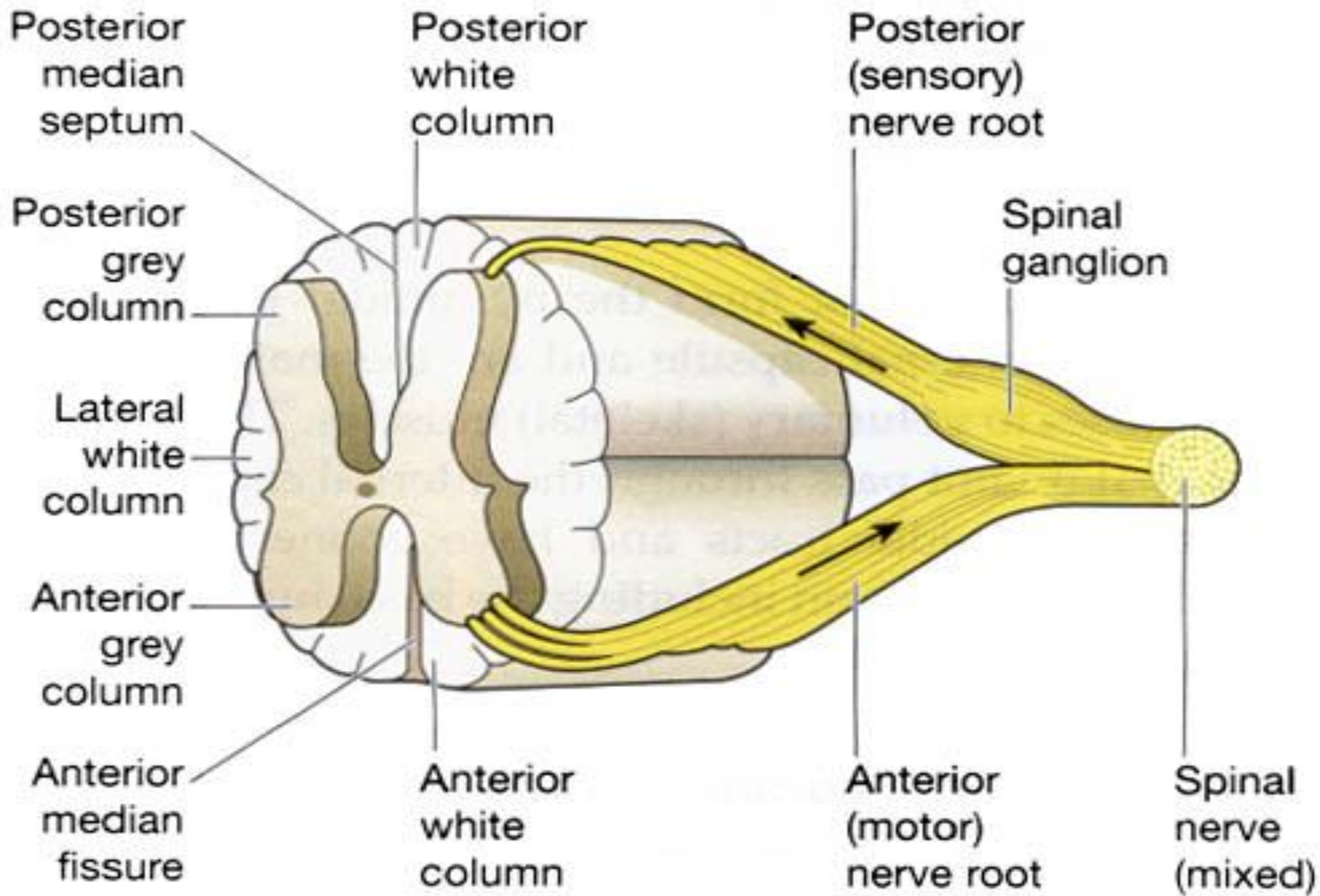
Cerebellum and associated structures

SPINAL CORD

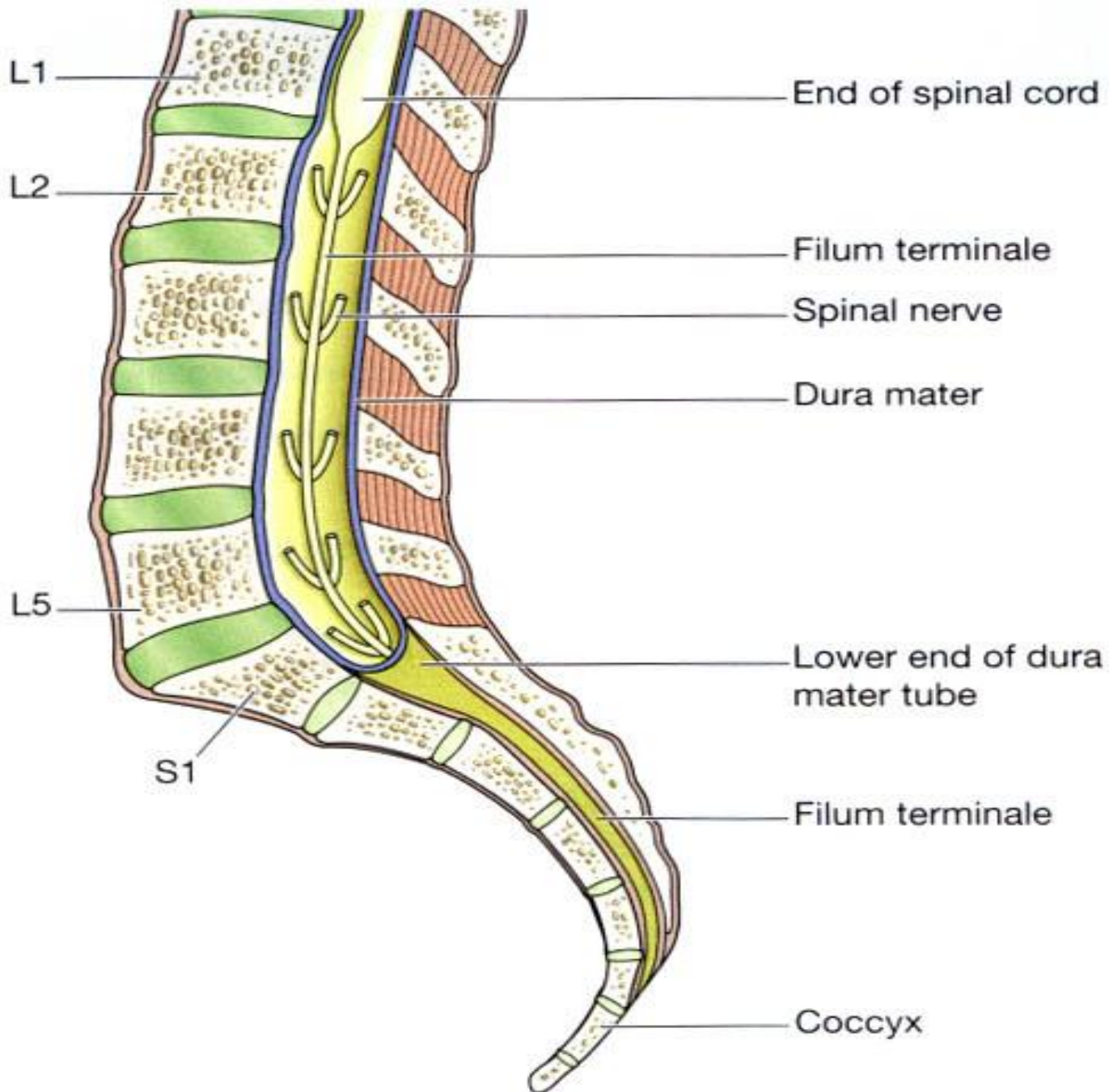
Def: the elongated, almost cylindrical part of the central nervous system, which is suspended in the vertebral canal surrounded by the meninges and cerebrospinal fluid.

- Continuous above with the medulla oblongata and extends from the upper border of the atlas to the lower border of the 1st lumbar vertebra (L1)
See Fig 7.27, page 155
- Its approximately 45 cm long in an adult male.
- When a specimen of cerebrospinal fluid is required it is taken from a point below the level of the 2nd lumbar vertebra (lumbar puncture).

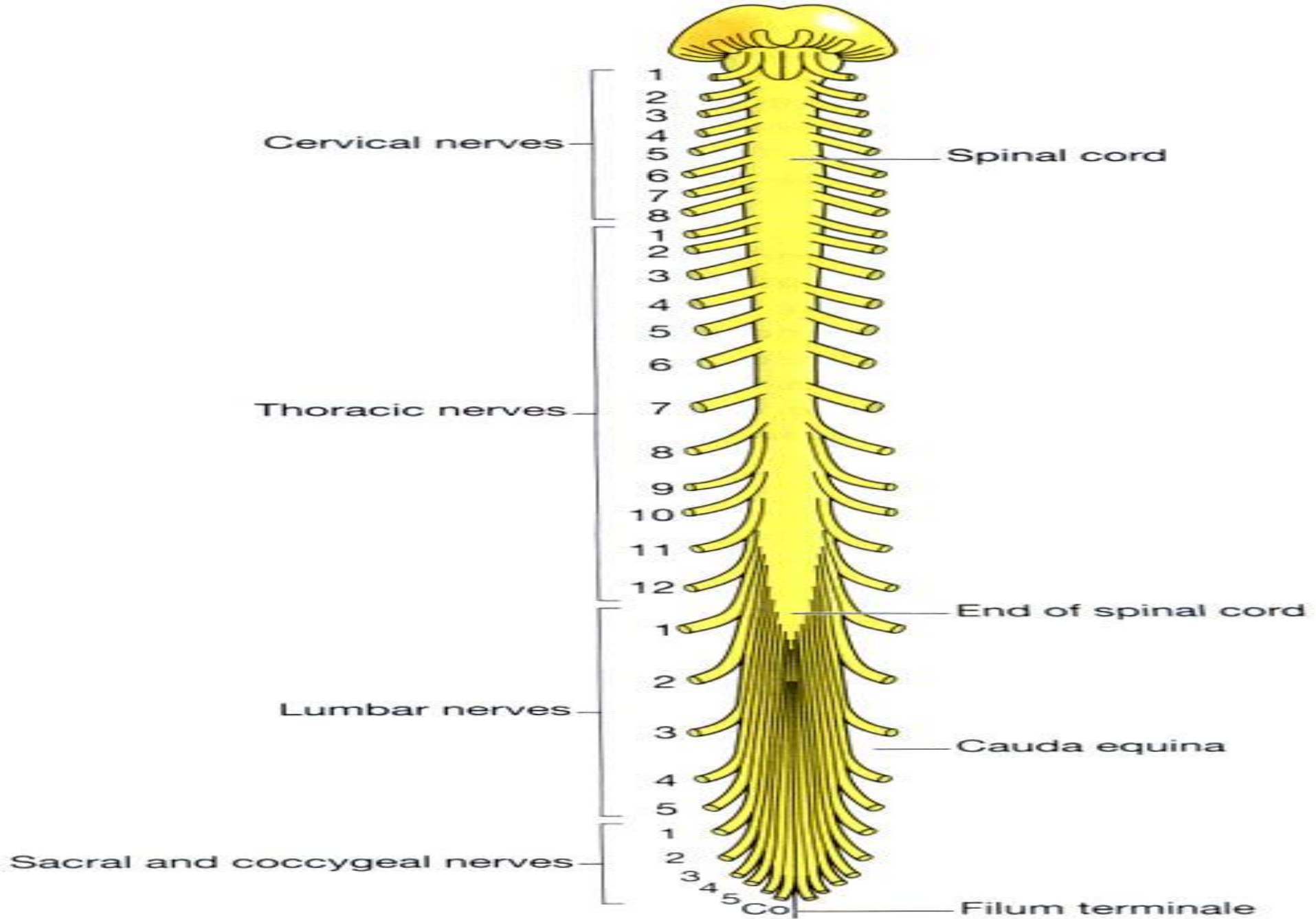
- **Spinal reflexes** control activities of the SC that are independent of the brain. To facilitate these there are extensive neurone connections between sensory and motor neurones at the same or different levels in the cord.
- The spinal cord is incompletely divided into two equal parts, anteriorly by a short, shallow **anterior median fissure** and posteriorly by a deep narrow septum, the **posterior median septum**.
- The SC is composed of grey matter in the centre surrounded by white matter supported by neuroglia..



spinal cord showing nerve roots on one side.



Section of the vertebral canal



Spinal cord and spinal nerves

Grey matter of the sc

- It's arrangement resembles the shape of the letter H, having **two posterior, two anterior** and **two lateral columns**
- The area of grey matter lying transversely is the **transverse commissure** and it is pierced by the central canal, an extension from the fourth ventricle, containing cerebrospinal fluid.
- The cell bodies may be:
 - **sensory cells**, which receive impulses from the periphery of the body
 - **lower motor neurones**, which transmit impulses to the skeletal muscles
 - **connector neurones**, linking sensory and motor neurones, at the same or different levels, which form spinal reflex arcs.
- At each point where nerve impulses are passed from one neurone to another there is a synapse.

Posterior columns of grey matter

- These are composed of nuclei stimulated by **sensory impulses from the periphery of the body**. The nerve fibres of these cells contribute to the formation of the **white matter** of the cord and transmit the sensory impulses **upwards to the brain**.

Anterior columns of grey matter

- These are composed of nuclei of the lower motor neurones which are stimulated by the axons of the upper motor neurones or by the cell bodies of connector neurones linking the anterior and posterior columns to form reflex arcs.
- The **posterior root (spinal) ganglia** are composed of cell bodies which lie just outside the spinal cord on the pathway of the sensory nerves. All sensory nerve fibres pass through these ganglia. Their only function is to promote the onward movement of nerve impulses.

White matter of the sc

- Arranged in three columns or tracts;
 - anterior,
 - posterior
 - lateral.
- These tracts are formed by sensory nerve fibres ascending to the brain, motor nerve fibres descending from the brain and fibres of connector neurones.
- Tracts are often named according to their points of origin and destination, e.g. spinothalamic, corticospinal.

Sensory nerve tracts in the spinal cord

- a.k.a. afferent or ascending tracts
 - Two main sources of sensation transmitted to the brain via the spinal cord.
- 1. The skin.** Cutaneous receptors, are stimulated by pain, heat, cold and touch including pressure. Nerve impulses generated are conducted by three neurones to the sensory area in the opposite hemisphere of the cerebrum where the sensation and its location are perceived . Crossing to the other side, or decussation, occurs either at the level of entry into the cord or in the medulla.

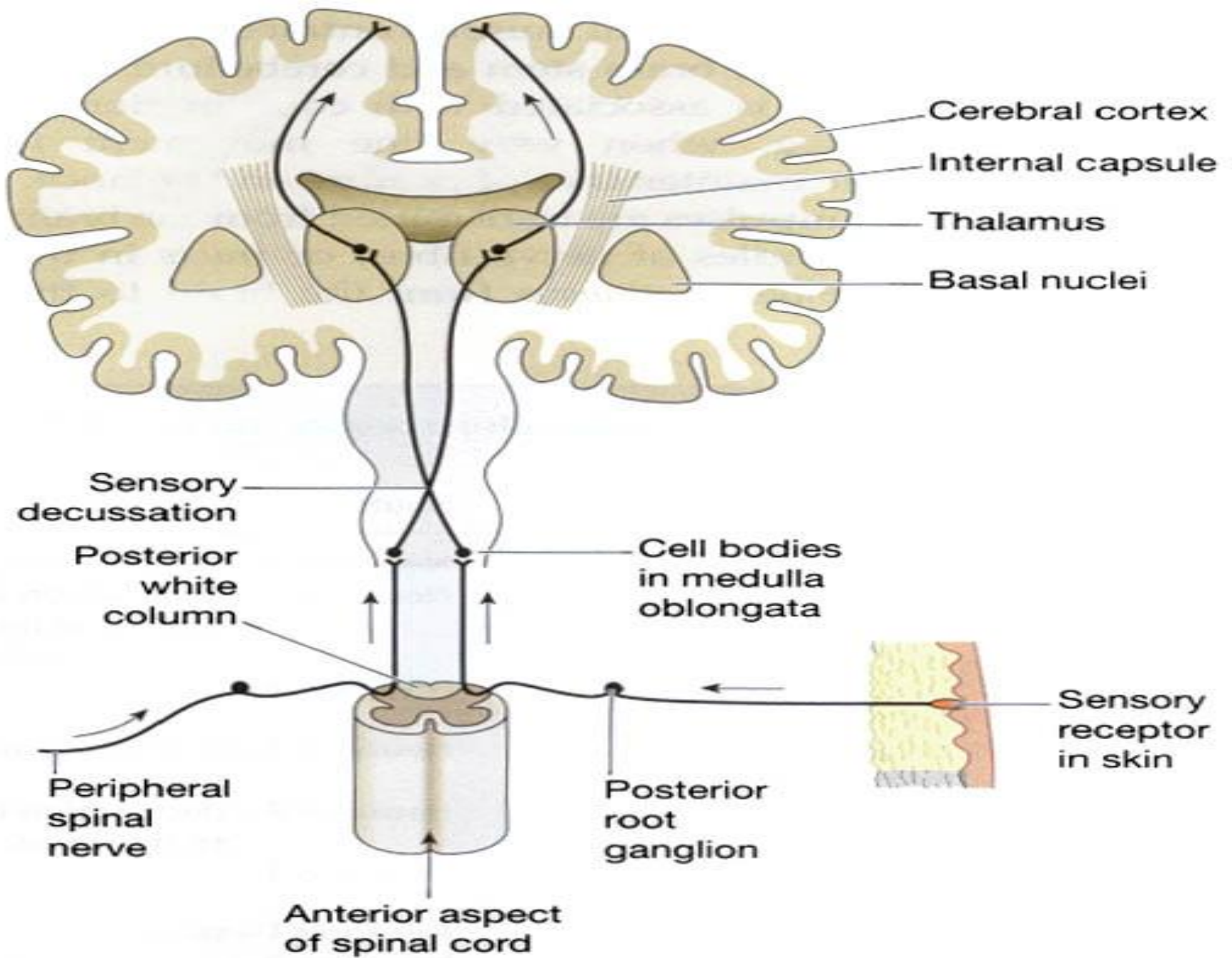
Ct.....

2. The tendons, muscles and joints.

Proprioceptors are stimulated by stretch.

Together with impulses from the eyes and the ears they are associated with the maintenance of balance and posture and with perception of the position of the body in space.

- These nerve impulses have two destinations:
 - by a three-neurone system the impulses reach the sensory area of the opposite hemisphere of the cerebrum
 - by a two-neurone system the nerve impulses reach the cerebellar hemisphere on the same side.



sensory nerve pathways from the skin to the cerebrum.

Motor nerve tracts in the sc

- a.k.a efferent / descending tracts
- Are neurones which transmit nerve impulses away from the brain.
- Motor neurone stimulation results in:
 - contraction of skeletal (striated, voluntary) muscle
 - contraction of smooth (involuntary) muscle, cardiac muscle and the secretion by glands controlled by nerves of the autonomic nervous system

Voluntary muscle movement

- The contraction of the muscles which move the joints is, in the main, under conscious (voluntary) control.
- However, some nerve impulses which affect skeletal muscle contraction are initiated in the midbrain, brain stem and cerebellum which is under unconscious control.

- This involuntary activity is associated with coordination of muscle activity, e.g. when very fine movement is required and in the maintenance of posture and balance.
- Motor nerve tracts are either:
 - pyramidal (corticospinal)
 - extrapyramidal.
- The motor fibres that form the pyramidal tracts travel through the **internal capsule** and are the **main pathway** for impulses to voluntary (skeletal) muscles.
- Those motor fibres that do not pass through the internal capsule form the **extrapyramidal** tracts.

The upper motor neurone.

- Has its cell body (Betz's cell) in the primary motor area of the cerebrum. The axons pass through the internal capsule, pons and medulla.
- In the spinal cord they form the **lateral corticospinal tracts** of white matter and the fibres terminate in close association with the cell bodies of the lower motor neurones in the **anterior columns of grey matter**.
- Axons of these upper motor neurones make up the **pyramidal tracts** and decussate in the **medulla oblongata**, forming the **pyramids**.

The lower motor neurone.

- Has its cell body in the **anterior horn of grey matter in the spinal cord.**
- Its axon emerges from the spinal cord by the ***anterior root***, joins with the incoming sensory fibres and forms the mixed spinal nerve which passes through the ***intervertebral foramen***.
- Near its termination in muscle the axon branches into a variable number of tiny fibres which form motor end-plates.

Involuntary muscle movement

Upper motor neurones.

- Have their cell bodies in the **midbrain, brain stem, cerebellum** or **spinal cord**.
- They influence muscle activity in relation to the:
 - maintenance of posture and balance,
 - coordination of muscle movement
 - the control of muscle tone.

Spinal reflexes.

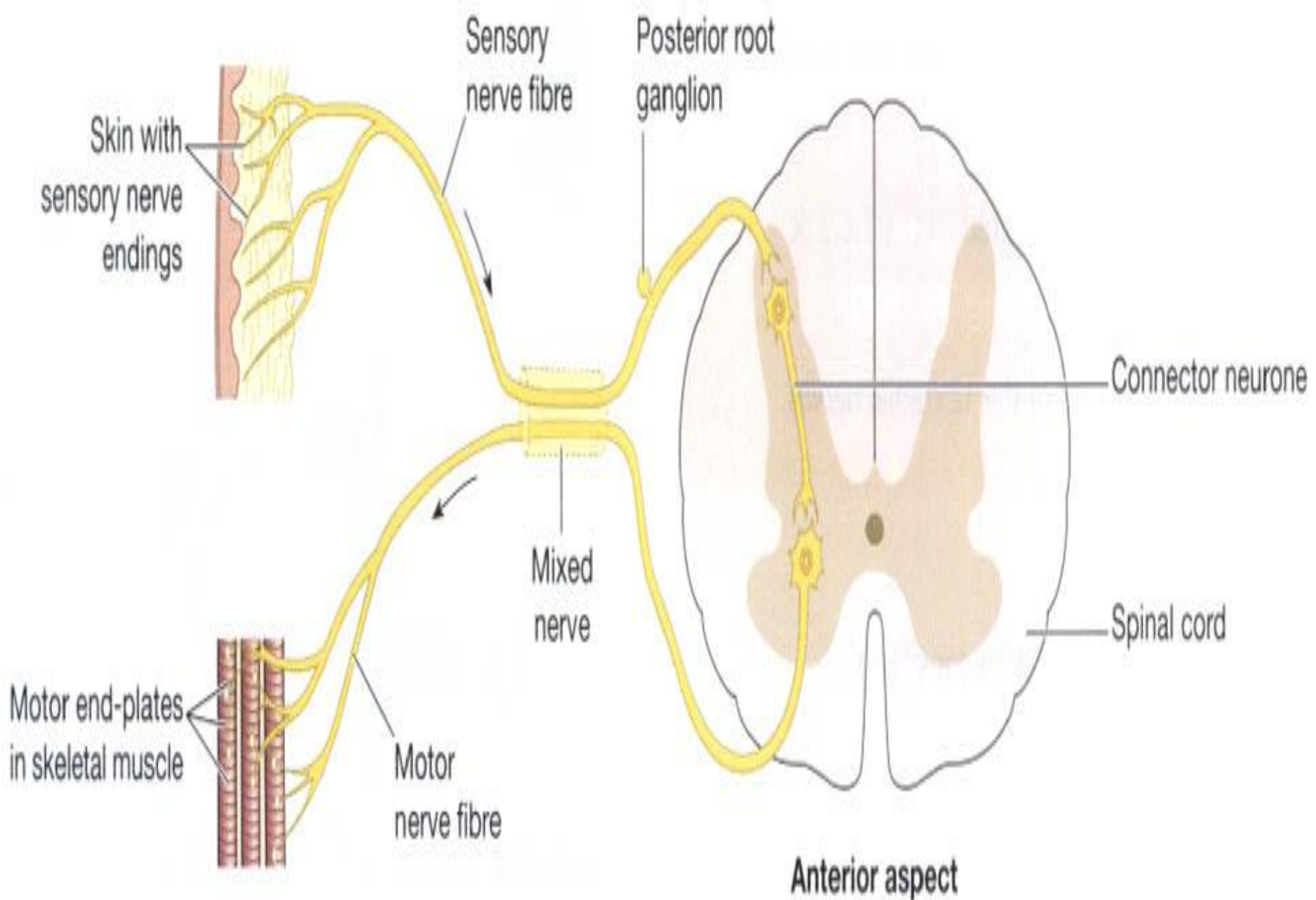
- Consist of three elements:
 - sensory neurones
 - connector neurones in the spinal cord
 - lower motor neurones.

In the **simplest reflex arc** there is only one of each.

- **A reflex action** is an involuntary immediate motor response to a sensory stimulus.
- Many connector and motor neurones may be stimulated by afferent impulses from a small area of skin, e.g. the pain impulses initiated by touching a very hot surface. These stimulate connector and lower motor neurones in the cord which results in the contraction of many skeletal muscles of the hand, arm and shoulder, and the removal of the finger.
- Reflexes of this type are invariably protective but they can on occasion be inhibited. E.g., if it is a precious plate that is very hot when lifted every effort will be made to overcome the pain to prevent dropping it!

Reflex arc

- Def: pathway that nerve impulses travel when a reflex is elicited.
- Has 5 essential parts:
 1. **Receptors**—detect a change (the stimulus) & generate impulses.
 2. **Sensory neurons**—transmit impulses from receptors to the CNS.
 3. **Central nervous system**—contains one or more synapses.
 4. **Motor neurons**—transmit impulses from the CNS to the effector.
 5. **Effector**—performs its characteristic action.



A simple reflex arc

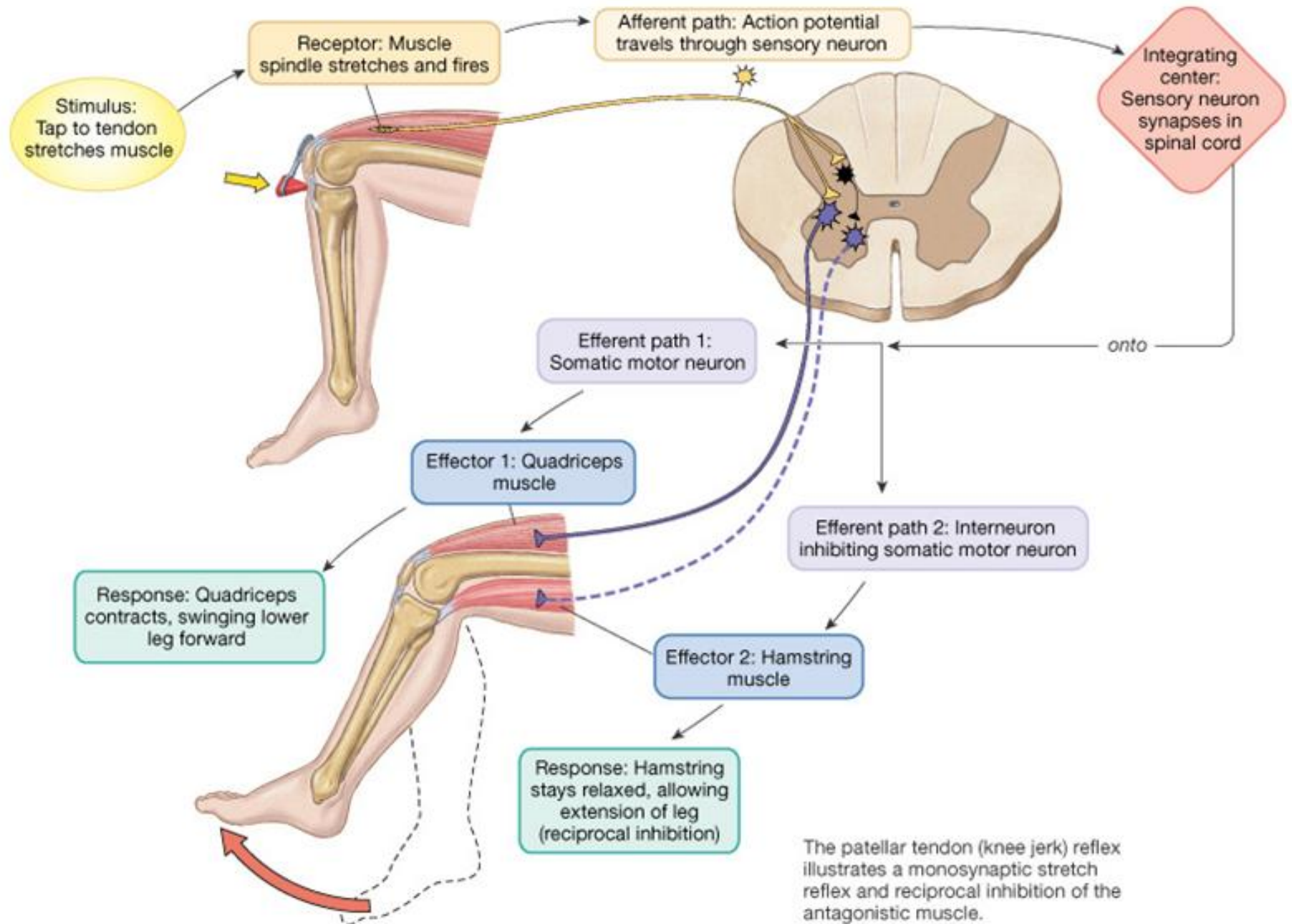
Stretch reflexes.

- Only 2 **neurones** are involved.
- The cell body of the lower motor neurone is stimulated by the sensory neurone.
- There is no connector neurone involved.
- E.g, the **knee jerk**; by tapping the tendon just below the knee when it is bent, the sensory nerve endings in the tendon and in the thigh muscles are stretched.
- This is used as a **test of the integrity of the reflex arc**. This type of reflex has a protective function —it prevents excessive joint movement that may damage tendons, ligaments and muscles.

Autonomic reflexes:

- Include pupillary light reflex when the pupil immediately constricts in response to bright light

Stretch Reflex



PERIPHERAL NERVOUS SYSTEM

Intro....

- Consists of:
 - 31 pairs of spinal nerves
 - 12 pairs of cranial nerves
 - autonomic nervous system.
- Most of PNS nerves are mixed nerves

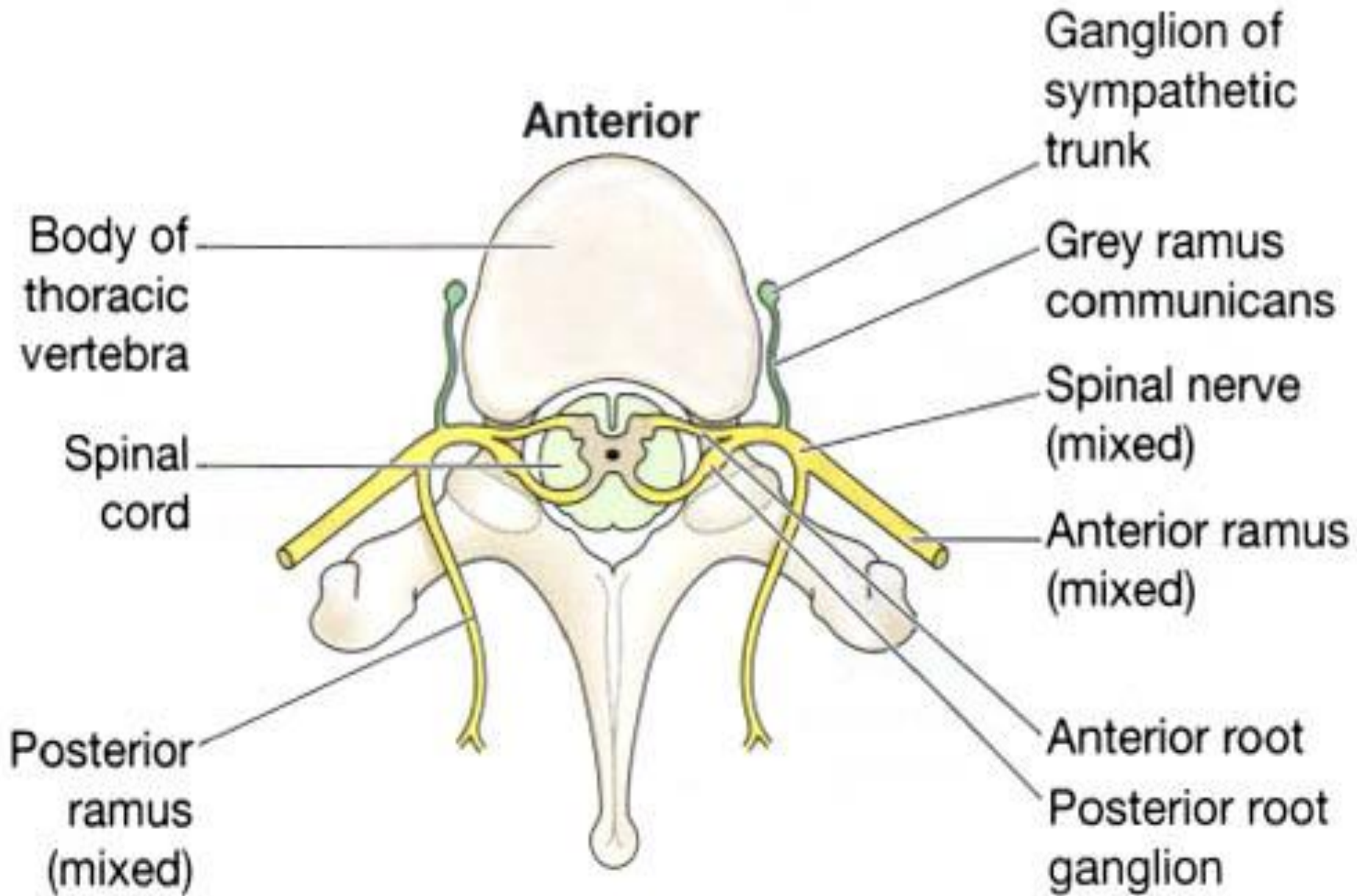
Spinal nerves

- Named and grouped according to the vertebrae with which they are associated.
 - 8 cervical
 - 12 thoracic
 - 5 lumbar
 - 5 sacral
 - 1 coccygeal.
- QUESTION? Why are Cervical nerves 8?
- Lumbar, sacral and coccygeal nerves leave the spinal cord near its termination at the level of the first lumbar vertebra, and extend downwards inside the vertebral canal in the subarachnoid space, forming a sheaf of nerves; the **cauda equina**.

NERVE ROOTS

- **Anterior nerve root:** consists of **motor nerve** fibres which are the axons of the nerve cells in the **anterior column of grey matter** in the spinal cord and, in the thoracic and lumbar regions; **sympathetic nerve** fibres which are the axons of cells in the **lateral columns of grey matter**.
- **Posterior nerve root** consists of **sensory nerve** fibres.
- Sensory nerve fibres pass through **posterior root ganglion** before entering the spinal cord.
- **Dermatome:** the area of skin supplied by each nerve
- Each nerve is formed by the union of anterior (motor) and posterior (sensory) nerve roots and there4 is a mixed nerves

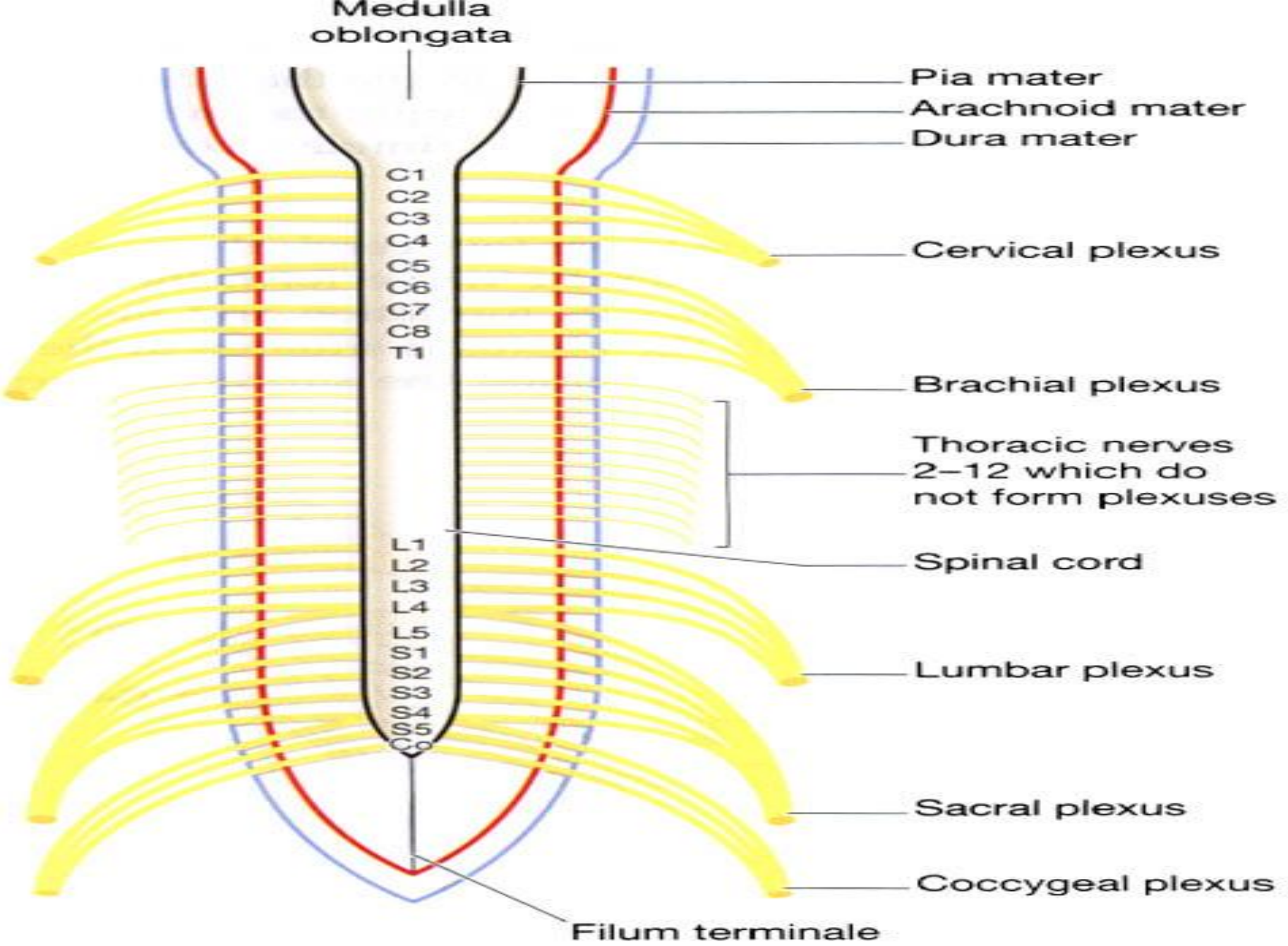
- For a very short distance after leaving the spinal cord the nerve roots have a covering of dura and arachnoid mater. These terminate before the two roots join to form the mixed spinal nerve. **The nerve roots have no covering of pia mater.**
- **Branches of Spinal Nerves**
- Immediately after emerging from the intervertebral foramen each spinal nerve divides into a **ramus communicans**, a **posterior ramus** and an **anterior ramus**.
- The rami communicans are part of **preganglionic sympathetic neurones of the ANS**.
- **Posterior rami** pass backwards and divide into **medial** and **lateral** branches to supply skin and muscles of relatively small areas of the posterior aspect of the head, neck and trunk.
- **Anterior rami** supply the **anterior** and **lateral** aspects of the neck, trunk and the upper and lower limbs.



Relationship btw sympathetic and mixed spinal nerves

plexuses

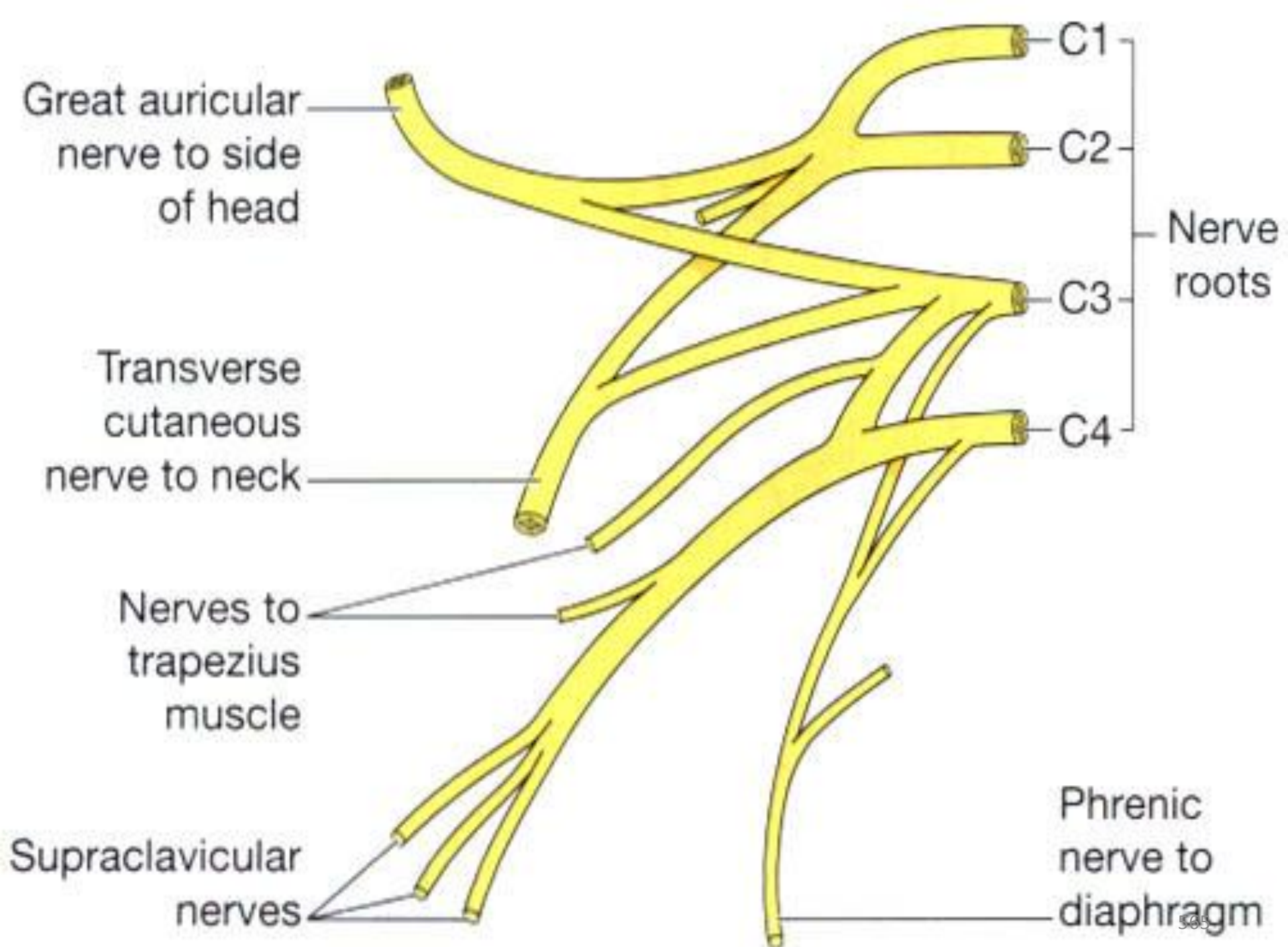
- In the cervical, lumbar and sacral regions the **anterior rami** unite near their origins to form plexuses before proceeding to supply skin, bones, muscles and joints of a particular area.
- Thus, these structures have a nerve supply from more than one spinal nerve and therefore damage to one spinal nerve does not cause loss of function of a region.
- In the **thoracic region** the **anterior rami** do not form plexuses.
- The 5 large plexuses of mixed nerves the:
 - cervical plexuses
 - brachial plexuses
 - lumbar plexuses
 - sacral plexuses
 - coccygeal plexuses.



Spinal cord, nerves and plexuses formed

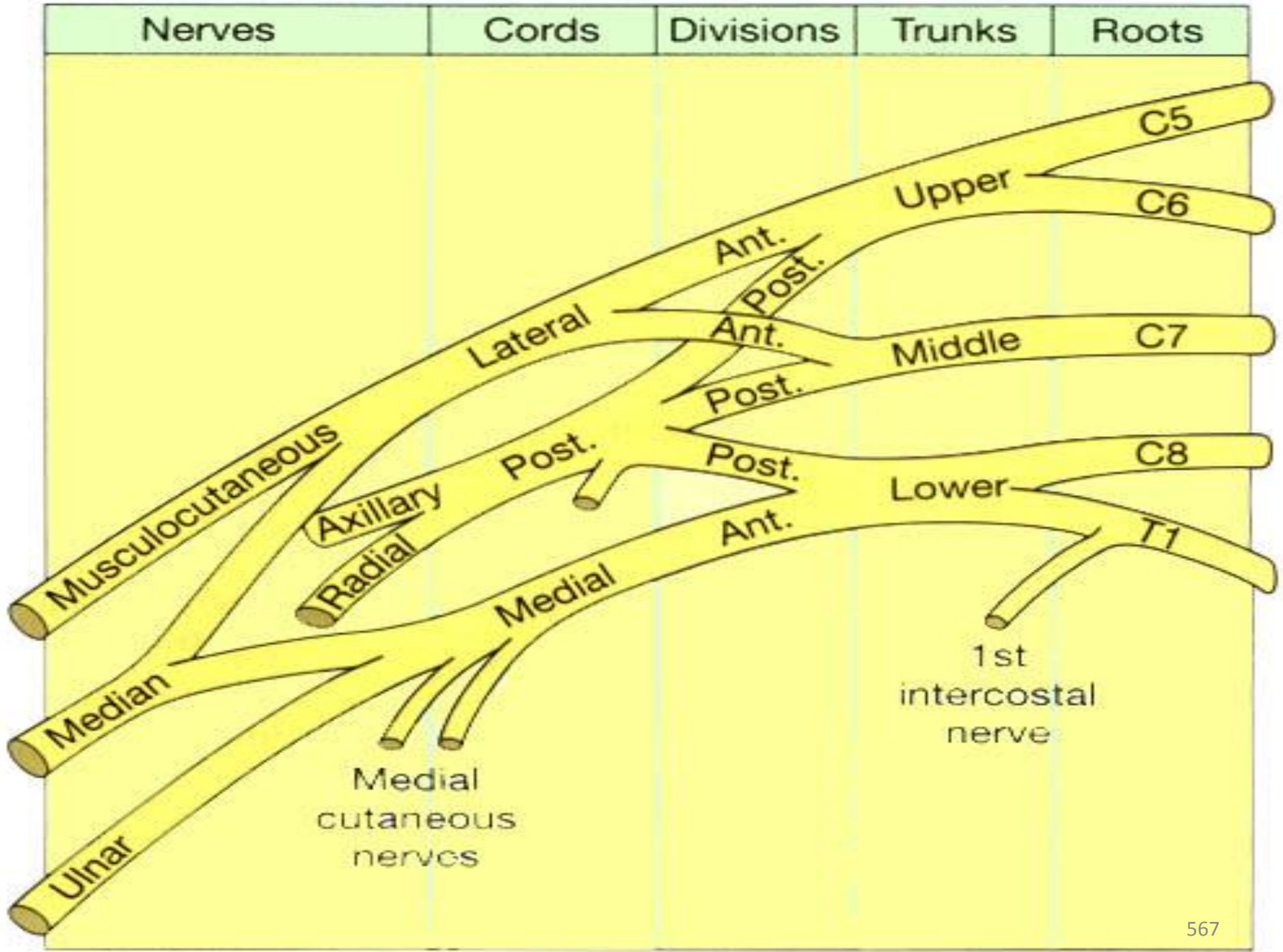
Cervical plexus

- Formed by the anterior rami of the first 4 cervical nerves.
- Lies opposite the 1st, 2nd, 3rd and 4th cervical vertebrae under the protection of the **sternocleidomastoid** muscle.
- **Superficial branches** supply
 - structures at the back & side of the head
 - skin of the front of the neck to the level of the sternum.
- **Deep branches** supply
 - muscles of the neck, e.g. sternocleidomastoid & trapezius.
- **Phrenic nerve** originates from **C3,4 and 5** and passes downwards through the thoracic cavity to supply **muscle of the diaphragm.**



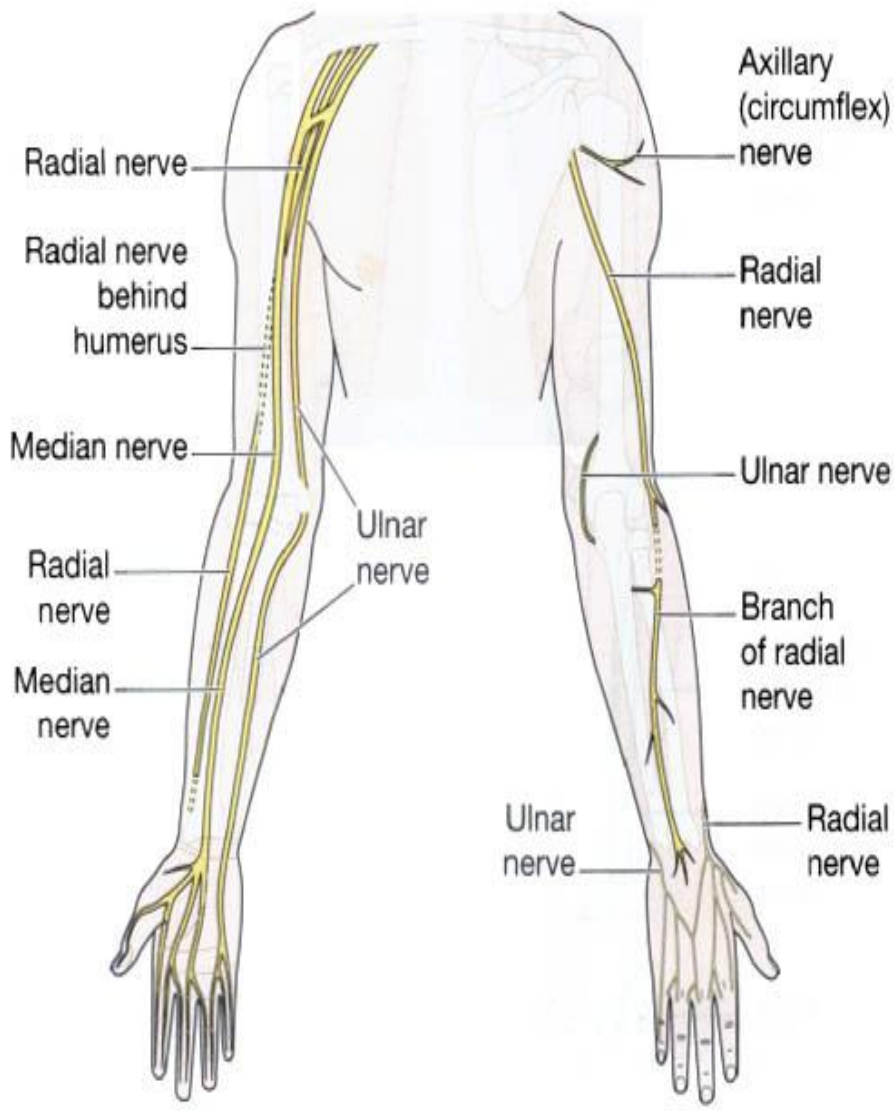
Brachial plexus

- Formed by
 - **anterior rami** of the **lower 4 cervical nerves &**
 - large part of the **first thoracic** nerve.
- Situated in the neck and shoulder above and behind the subclavian vessels and in the axilla.
- Its branches supply the **skin, muscles of the upper limbs & some of the chest muscles.**
- 5 large nerves and a number of smaller ones emerge from this plexus:
 - axillary (circumflex) nerve: C5, 6
 - radial nerve: C5, 6, 7, 8, T1
 - musculocutaneous nerve: C5, 6, 7
 - median nerve: C5, 6, 7, 8, T1
 - ulnar nerve: C7, 8, T1
 - medial cutaneous nerve: C8, T1.



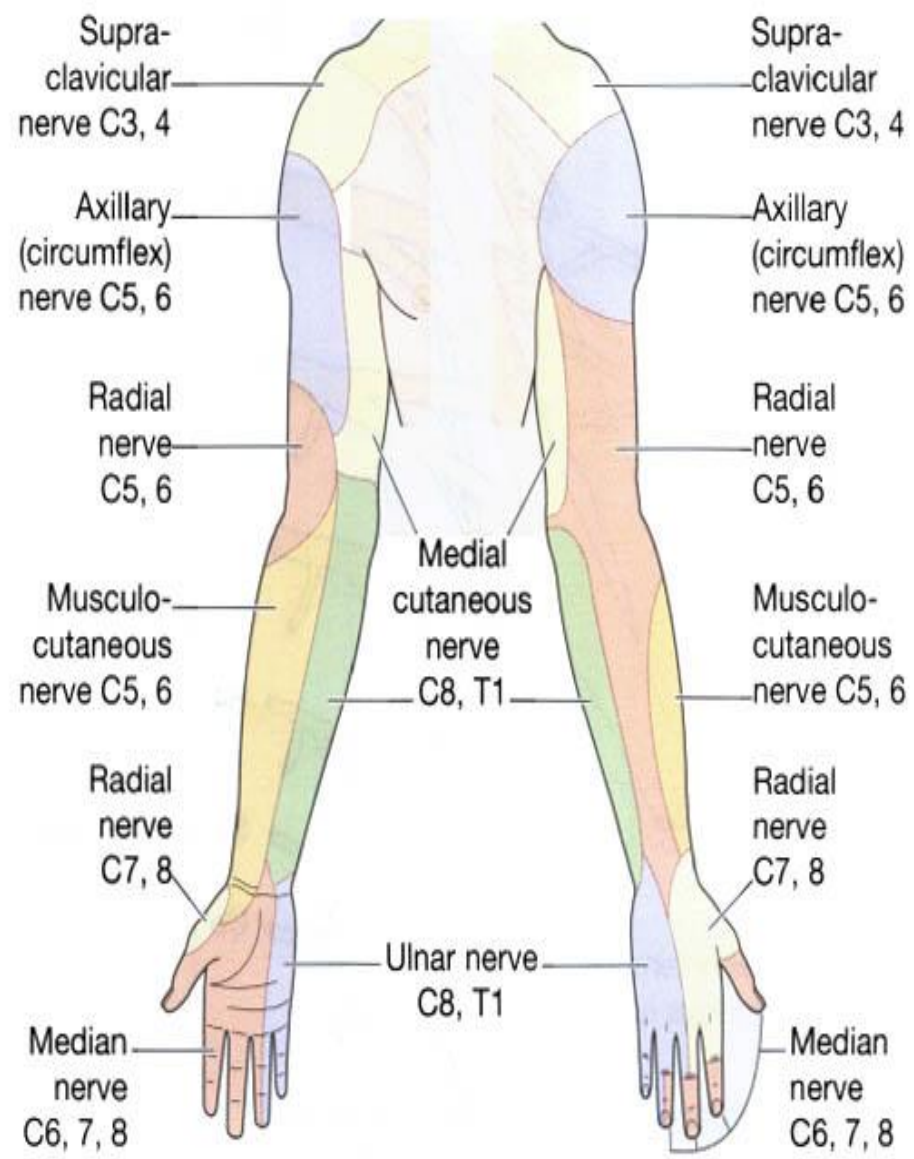
- **Axillary nerve** supplies:
 - deltoid muscle,
 - shoulder joint & overlying skin.
- **Radial nerve** Supplies:
 - triceps muscle,
 - extensors of the wrist and finger joints.
 - skin of the thumb, the first two fingers and the lateral half of the third finger.
- **Musculocutaneous nerve** Supplies the
 - muscles of the upper arm
 - skin of the forearm.

- **Median nerve:** passes down the midline of the arm in close association with the brachial artery to supply:
 - the **muscles of the front of the forearm.**
 - **small muscles** and the **skin of the front of the thumb**, the **first two fingers** and the **lateral half of the third finger.**
- **Ulnar nerve:** descends through the upper arm lying medial to the brachial artery.
 - passes behind the medial epicondyle of the humerus to supply the **muscles on the ulnar aspect of the forearm.**
 - supplies
 - **muscles in the palm of the hand**
 - **skin of the whole of the little finger** and the **medial half of the third finger.**



Anterior view

Posterior view



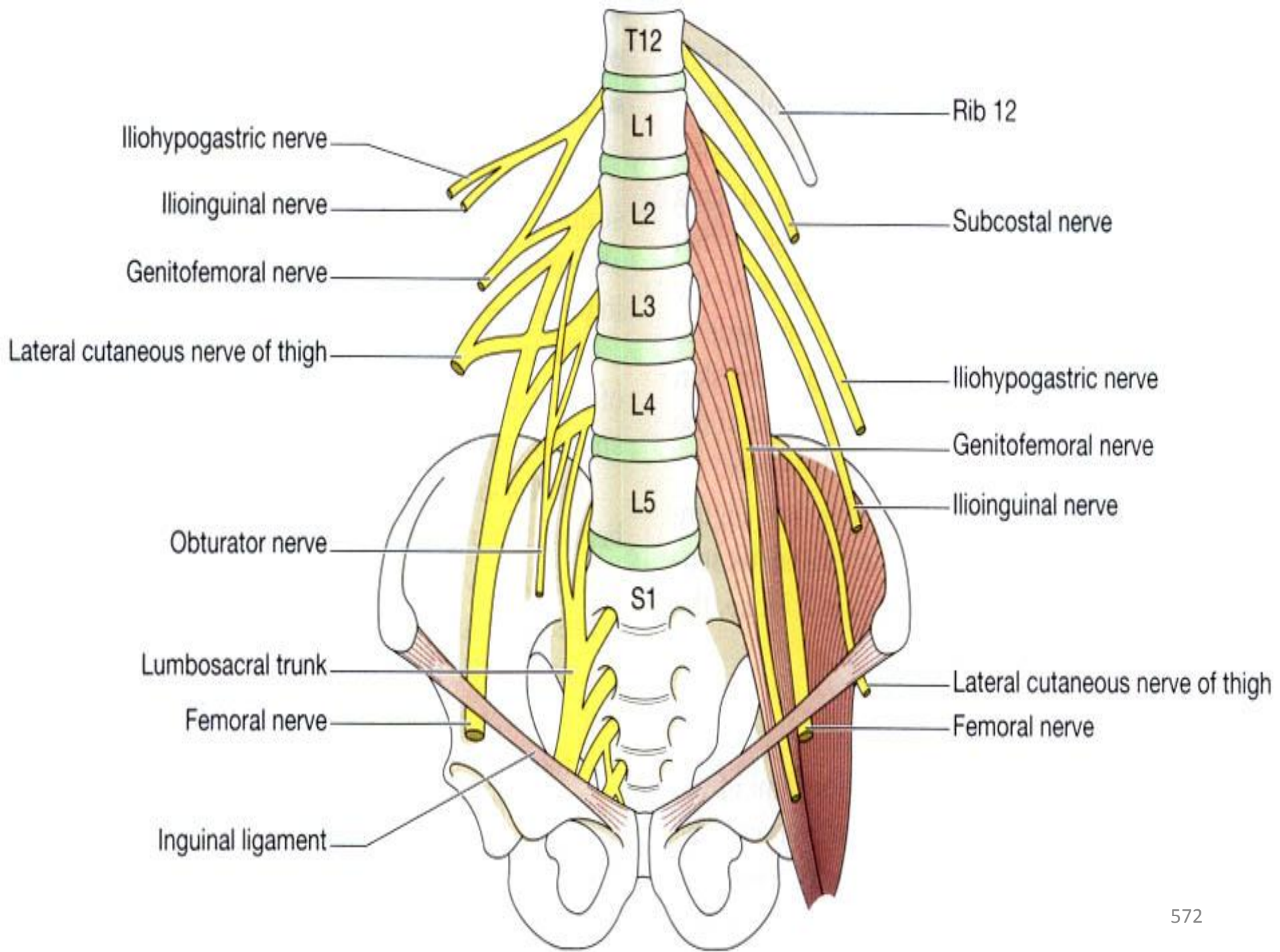
Anterior view

Posterior view

Main nerves of the arm, distribution & origins of cutaneous nerves

LUMBAR PLEXUS

- Formed by
 - **anterior rami** of the **first 3** &
 - part of the **4th lumbar** nerves.
- Situated in front of the transverse processes of the lumbar vertebrae and behind the psoas muscle.
- Main branches & their nerve roots are:
 - ❖ iliohypogastric nerve: L1
 - ❖ ilioinguinal nerve: L1
 - ❖ genitofemoral: L1, 2
 - ❖ lateral cutaneous nerve of thigh: L2, 3
 - ❖ femoral nerve: L2, 3,4
 - ❖ obturator nerve: L2, 3, 4
 - ❖ lumbosacral trunk: L4, 5.



- **Iliohypogastric, ilioinguinal and genitofemoral nerves supply**
 - **muscles and the skin in the area of *the lower abdomen, upper and medial aspects of the thigh* and the *inguinal region*.**
- **Lateral cutaneous nerve of the thigh supplies**
 - ***skin of the lateral aspect of the thigh*** including part of the anterior and posterior surfaces.
- **Femoral nerve;** one of the larger branches which passes behind the inguinal ligament to enter the thigh in close association with the femoral artery.
 - divides into **cutaneous and muscular** branches to **supply the skin and the muscles of the front of the thigh.**
 - One branch, the **saphenous nerve**, supplies the **medial aspect of the leg, ankle and foot.**

- **Obturator nerve** supplies
 - **Adductor muscles** of the **thigh**
 - **skin of the medial aspect of the thigh.**
 - ends just above the level of the knee joint.
- **Lumbosacral trunk** descends into the pelvis and makes a contribution to the **sacral plexus.**

Sacral plexus

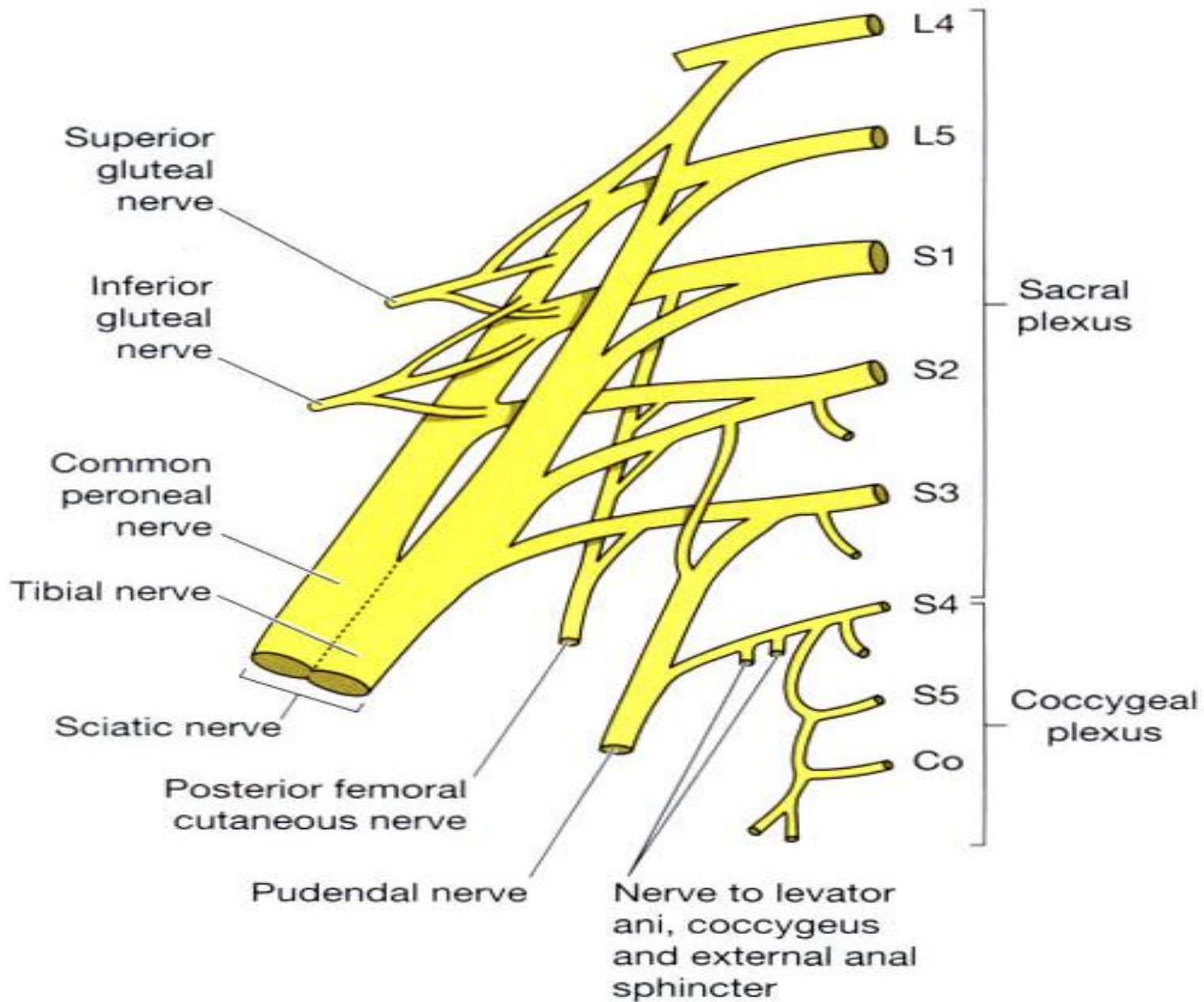
- Formed by
 - anterior rami of the lumbosacral trunk &
 - the 1st, 2nd & 3rd sacral nerves.
- Lies in the **posterior wall** of the pelvic cavity.
- Divides into a number of branches, supplying
 - muscles and skin of the pelvic floor,
 - muscles around the hip joint and the pelvic organs.
- Provides the sciatic nerve which contains fibres **from L4, 5, S1, 2, 3.**

- **Sciatic nerve**
 - largest nerve in the body.
 - about 2 cm wide at its origin.
 - passes through the **greater sciatic foramen** into the buttock then descends through the posterior aspect of the thigh supplying the **hamstring muscles**.
 - At the level of the **middle of the femur** it divides to form
 - **tibial &**
 - **common peroneal** nerves.
- **Tibial nerve**
 - descends through the popliteal fossa to the posterior aspect of the leg where it supplies **muscles and skin**.
 - passes under the medial malleolus to supply **muscles and skin of the sole of the foot and toes**.
 - main branch is the **sural nerve** which supplies
 - **tissues in the area of the heel,**
 - **lateral aspect of the ankle &**
 - **a part of the dorsum of the foot.**

- **Common peroneal nerve**
 - descends obliquely along the lateral aspect of the popliteal fossa
 - winds round the neck of the fibula into the front of the leg where it divides into the **deep peroneal (anterior tibial)** and the **superficial peroneal (musculocutaneous) nerves** which supply the skin and muscles of the **anterior aspect of the leg** and **the dorsum of the foot and toes.**
- **Pudendal nerve (S2, 3, 4).** The branches supplies
 - **external anal sphincter,**
 - **external urethral sphincter and adjacent skin.**
 - **Genitalia**
 - **Skin around the perineum**

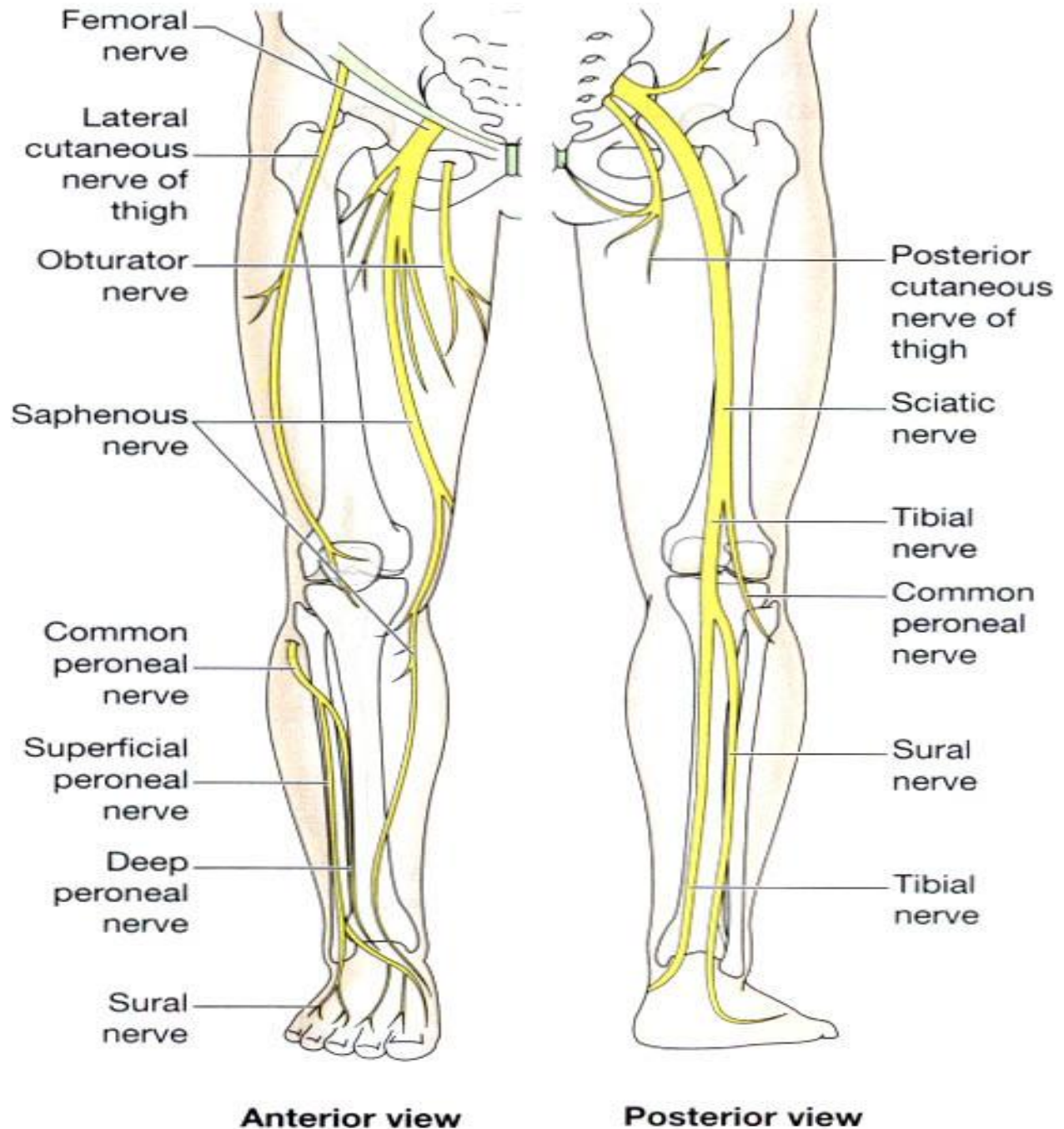
Coccygeal plexus

- Very small plexus
- Formed by **part of the 4th & 5th sacral** and the **coccygeal nerves**.
- Nerves from this plexus supply
 - skin in the area of the coccyx
 - levators ani and coccygeus muscles of the pelvic floor
 - external anal sphincter.



Sacral & coccygeal plexuses

The main nerves of the legs



Ilioinguinal nerve L1

Posterior rami S1, 2, 3

Subcostal nerve T12

Subcostal nerve T12

Genitofemoral nerve L1, 2

Iliohypogastric nerve L1

Lateral cutaneous nerve of thigh L2, 3

Posterior rami L1, 2, 3

Obturator L2, 3, 4

Lateral cutaneous nerve of thigh L2, 3

Medial and intermediate cutaneous nerves L2, 3

Posterior cutaneous nerve S1, 2, 3

Lateral cutaneous nerve of calf of leg L5, S1, 2

Obturator nerve L2, 3, 4

Medial cutaneous nerve of thigh L2, 3

Superficial peroneal (musculocutaneous) nerve L4, 5, S1

Saphenous nerve L3, 4

Lateral cutaneous nerve of calf L4, 5, S1 of leg

Sural nerve S1, 2

Sural nerve L5, S1, 2

Deep peroneal nerve L4, 5

Tibial nerve S1, 2

Anterior view

Posterior view

Distribution and origins of the cutaneous nerves of the leg.

Thoracic nerves

- Do not form plexuses.
- Are 12 pairs; first 11 are the **intercostal nerves**, 12th pair are the **subcostal nerves**.
- They pass between the ribs supplying them, the intercostal muscles and overlying skin.
- **7th to the 12th thoracic** nerves also supply the **muscles and the skin of the posterior and anterior abdominal walls**.

Cranial nerves

Def: 12 pairs of nerves originating from nuclei in the inferior surface of the brain, some sensory, some motor and some mixed.

- They are:

I. Olfactory

II. Optic

III. Oculomotor

IV. Trochlear

V. Trigeminal

VI. Abducent

VII. Facial

VIII. Vestibulocochlear (auditory)

IX. Glossopharyngeal

X. Vagus

XI. Accessory

XII. Hypoglossal

FUNCTIONAL TYPES

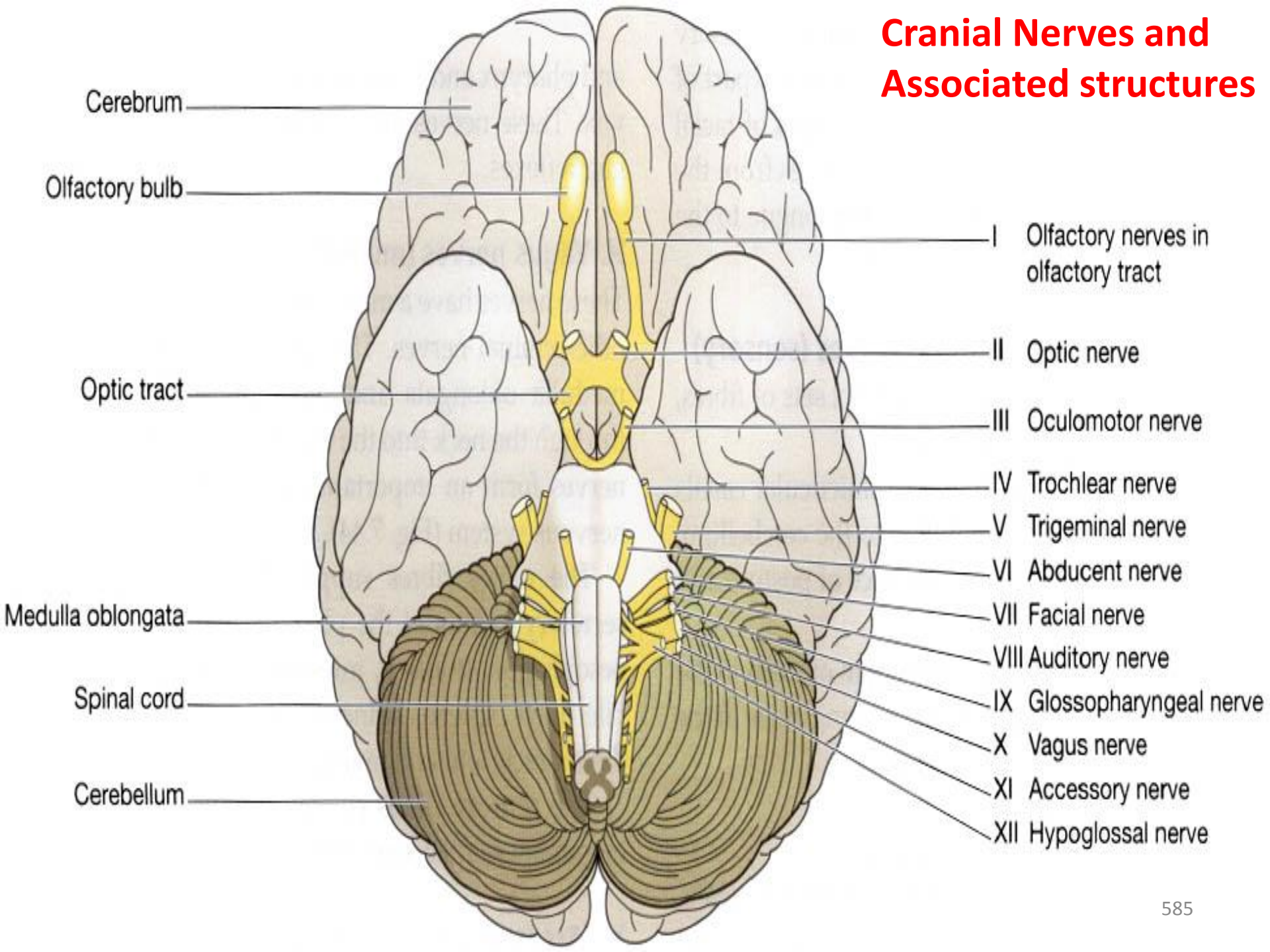
Motor Cranial nerves	Sensory cranial nerves	Mixed cranial nerves
III	I	V
IV	II	VII
VI	VIII	IX
XI		X
XII		

MNEMONICS:

CRANIAL NERVES: **Oh Oh Oh Tiny Tits Are Fun And Give Virgins Awkward Hips**

FUNCTIONAL TYPES: **Some Say Marry Money But My Brother Says Big Brains Matter More (S- Sensory, M-Motor, B-Both Sensory and Motor)**

Cranial Nerves and Associated structures



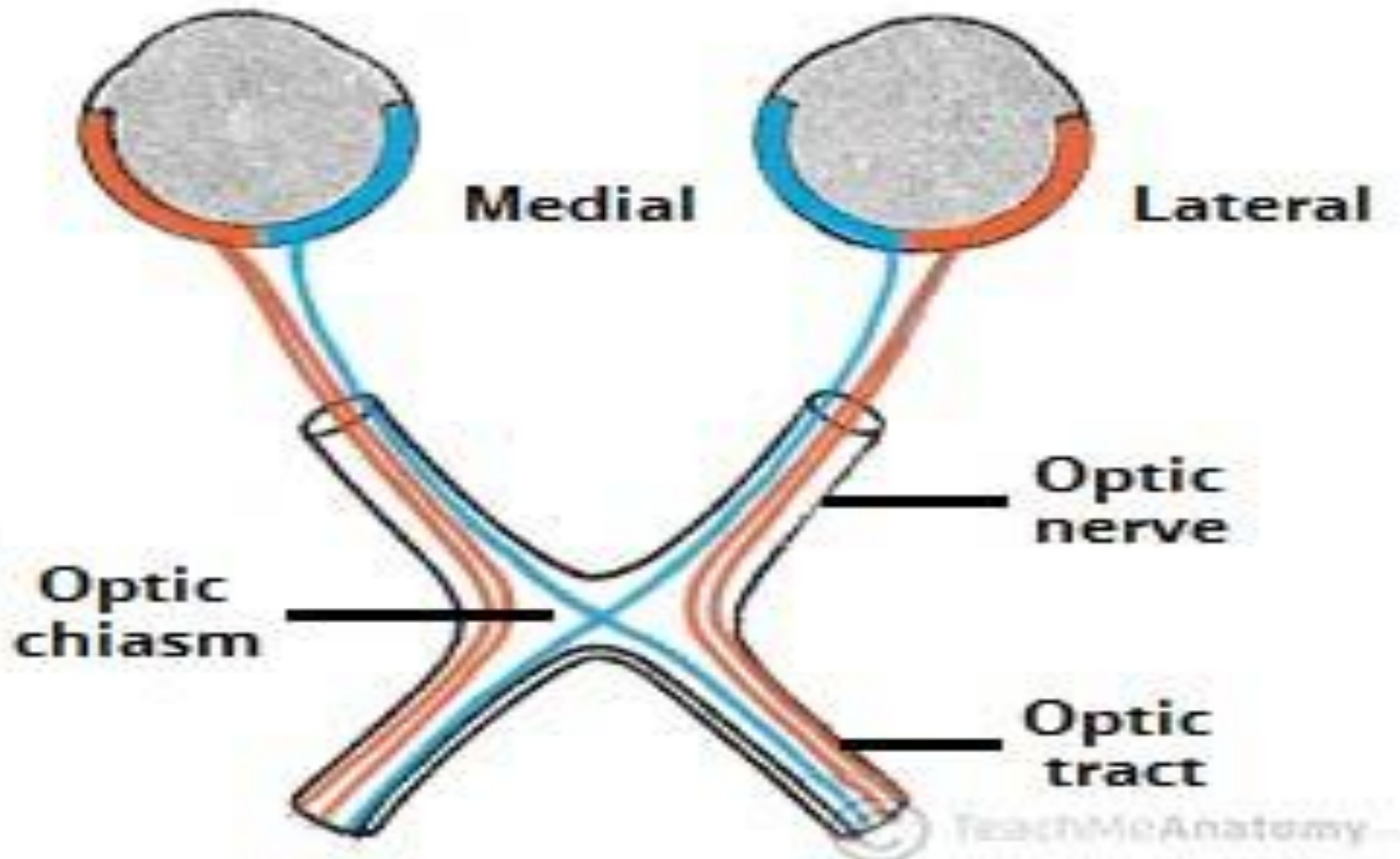
I. Olfactory nerves (sensory)

- Originate in the upper part of the mucous membrane of the nasal cavity
- pass upwards through the ***cribriform plate of the ethmoid bone*** and then go to the olfactory bulb, proceed backwards as the olfactory tract, to the **temporal lobe** of the cerebrum.
- **Function:** the sense of smell.

II. Optic nerves (sensory)

- Originate in the retina of the eyes.
- Pass through the ***optic foramina of the sphenoid bone*** into the cranial cavity and join at the optic chiasma, then proceed backwards as the optic tracts to the **lateral geniculate bodies** of the thalamus.

OPTIC CHIASMMA



- Impulses pass from these to the centre for sight in the occipital lobes of the cerebrum and to the cerebellum.
- In the **occipital lobe**, **sight** is perceived
- In the **cerebellum**, impulses from the eyes contribute to the maintenance of balance, posture and orientation of the head in space.
- **Function:** sense of sight

III. Oculomotor nerves (motor)

- Arise from nerve cells near the cerebral aqueduct.
- They supply:
 - 4 extraocular muscles that move the eyeball
 - **the superior, medial and inferior recti** and **the inferior oblique muscle.**
 - Intraocular (intrinsic) muscles:
 - **ciliary muscles**; alter the shape of the lens, changing its refractive power
 - **circular muscles** of the iris; constrict the pupil
 - the **levator palpebrae** muscle; raises the upper eyelid.

IV. Trochlear nerves (motor)

- Arise from nerve cells near the cerebral aqueduct.
- Supply the **superior oblique muscles** of the eyes.

V. Trigeminal nerves (mixed)

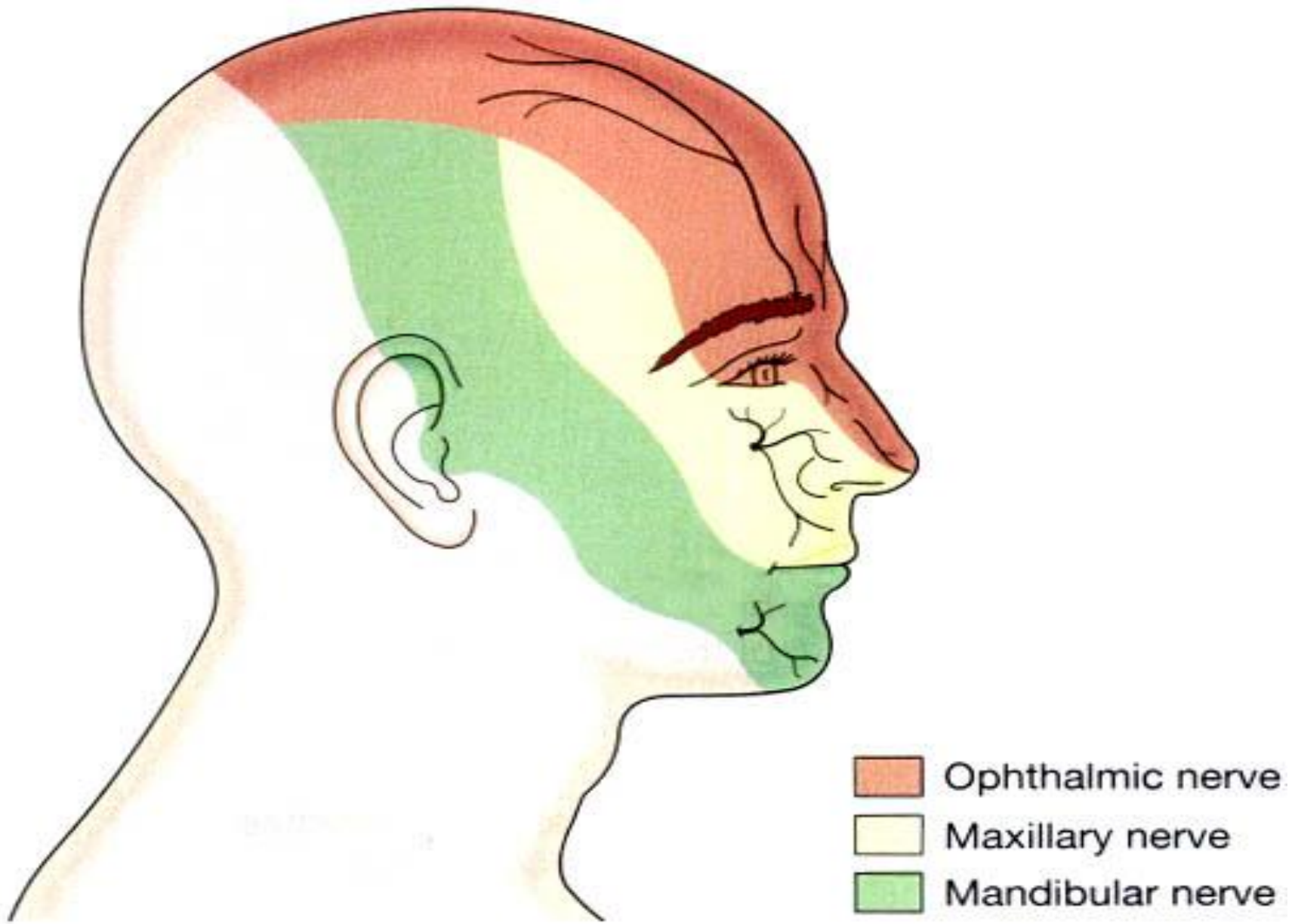
- Among the largest of the cranial nerves.
- Have 3 main branches.
 - **Ophthalmic nerves; sensory only**
 - supply the lacrimal glands, conjunctiva of the eyes, forehead, eyelids, anterior aspect of the scalp and mucous membrane of the nose.

– **Maxillary nerves; sensory only**

- supply the cheeks, upper gums, upper teeth and lower eyelids.

– **Mandibular nerves; both sensory and motor.**

- largest of the 3 divisions
- supply the teeth and gums of the lower jaw, pinnae of the ears, lower lip and tongue.
- motor fibres supply the **muscles of mastication.**



Cutaneous distribution of the main branches of the right trigeminal nerve.

VI. Abducens nerves (motor)

- Arise from a nuclei lying under the floor of the fourth ventricle.
- supply the **lateral rectus** muscles of the eyeballs.

VII. Facial nerves (mixed)

- Arises from nerve cells in the lower part of the pons.
- **motor** fibres supply the **muscles of facial expression**.
- **sensory** fibres convey impulses from the taste buds in the **anterior two-thirds of the tongue**.

VIII. Vestibulocochlear (auditory) nerves (sensory).

- 2 distinct sets of fibres
 - **Vestibular nerves**
 - arise from the semicircular canals of the inner ear and **convey impulses to the cerebellum.**
 - Associated with the maintenance of **posture and balance.**
 - **Cochlear nerves**
 - originate in the **organ of Corti** in the inner ear
 - **convey impulses to the hearing areas** in the cerebral cortex where sound is perceived.

IX. Glossopharyngeal nerves (mixed)

- Arise from nuclei in the medulla oblongata.
- **Motor fibres** stimulate the **muscles of the tongue and pharynx** and **the secretory cells of the parotid (salivary) glands.**

- **Sensory fibres** convey impulses to the cerebral cortex from
 - **posterior third of the tongue,**
 - **tonsils and pharynx**
 - **taste buds in the tongue and pharynx.**
- Are essential for the swallowing and gag reflexes.

X. Vagus nerves (mixed)

- Have a more extensive distribution than any other cranial nerves.
- Arise from nerve cells in the medulla oblongata and other nuclei, and pass down through the neck into the thorax and the abdomen.
- Form an important part of the parasympathetic nervous system .

- **Motor fibres** supply
 - smooth muscles and secretory glands of the pharynx, larynx, trachea, heart, oesophagus, stomach, intestines, pancreas, gall bladder, bile ducts, spleen, kidneys, ureter and blood vessels in the thoracic and abdominal cavities.
- **Sensory fibres** convey impulses from the lining membranes of the same structures to the brain.

XI. Accessory nerves (motor)

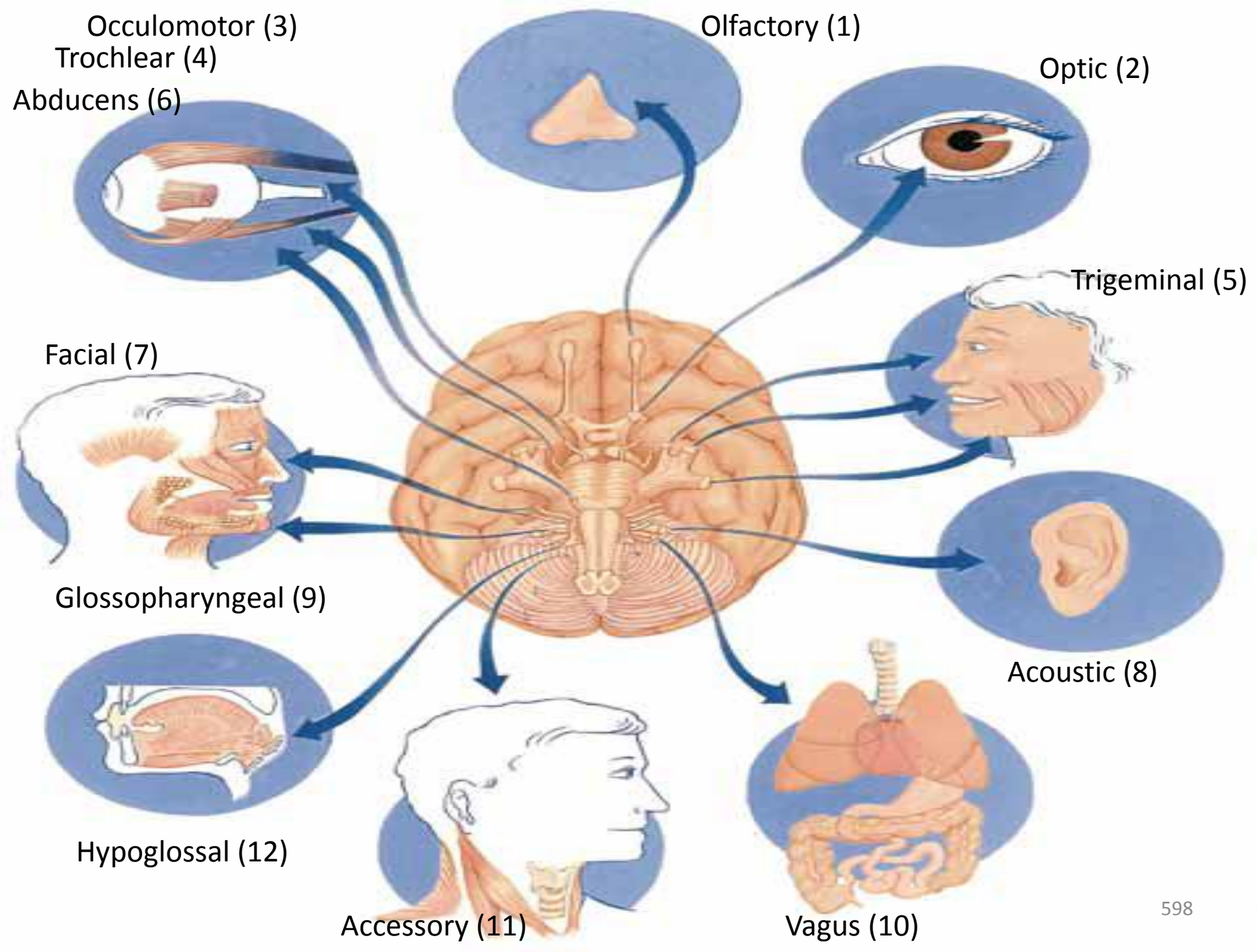
- Arise from cell bodies in the medulla oblongata and in the spinal cord.
- Supply the **sternodeiomylohyoid & trapezius** muscles.
- Branches join the vagus nerves and supply the pharyngeal and laryngeal muscles.

XII. Hypoglossal nerves (motor)

- Arise from nuclei in the medulla oblongata.
- Supply the muscles of the tongue and muscles surrounding the hyoid bone and contribute to swallowing and speech.

Table 7.3 Summary of the cranial nerves

Name and no.	Central connection	Peripheral connection	Function
I. Olfactory (sensory)	Smell area in temporal lobe of cerebrum through olfactory bulb	Mucous membrane in roof of nose	Sense of smell
II. Optic (sensory)	Sight area in occipital lobe of cerebrum Cerebellum	Retina of the eye	Sense of sight Balance
III. Oculomotor (motor)	Nerve cells near floor of aqueduct of midbrain	Superior, inferior and medial rectus muscles of the eye Ciliary muscles of the eye Circular muscle fibres of the iris	Moving the eyeball Focusing Regulating the size of the pupil
IV. Trochlear (motor)	Nerve cells near floor of aqueduct of midbrain	Superior oblique muscles of the eye	Movement of the eyeball
V. Trigeminal (mixed)	Motor fibres from the pons Sensory fibres from the trigeminal ganglion	Muscles of mastication Sensory to gums, cheek, lower jaw, iris, cornea	Chewing Sensation from the face
VI. Abducent (motor)	Floor of fourth ventricle	Lateral rectus muscle of the eye	Movement of the eye
VII. Facial (mixed)	Pons	Sensory fibres to the tongue Motor fibres to the muscles of the face	Sense of taste Movements of facial expression
VIII. Vestibulocochlear (sensory) (a) Vestibular (b) Cochlear	Cerebellum Hearing area of cerebrum	Semicircular canals in the inner ear Organ of Corti in cochlea	Maintenance of balance Sense of hearing
IX. Glossopharyngeal (mixed)	Medulla oblongata	Parotid gland Back of tongue and pharynx	Secretion of saliva Sense of taste Movement of pharynx
X. Vagus (mixed)	Medulla oblongata	Pharynx, larynx; organs, glands ducts, blood vessels in the thorax and abdomen	Movement and secretion
XI. Accessory (motor)	Medulla oblongata	Sternocleidomastoid, trapezius, laryngeal and pharyngeal muscles	Movement of the head, shoulders, pharynx and larynx
XII. Hypoglossal (motor)	Medulla oblongata	Tongue	Movement of tongue



AUTONOMIC NERVOUS SYSTEM

ANS

- Controls the functions of the body carried out 'automatically', i.e. initiated in the brain below the level of the cerebrum.
- Effector organs are:
 - smooth muscle
 - cardiac muscle
 - Glands .
- **Efferent (motor) nerves** of ANS arise from nerve cells in the brain and emerge at various levels between the midbrain and the sacral region of the spinal cord and travel together with the peripheral nerves.

- ANS is divided into 2 divisions; having both structural & functional differences.
 - sympathetic (thoraco-lumbar outflow)
 - parasympathetic (cranio-sacral outflow).
- They normally work in an opposing manner.
- Sympathetic activity tends to predominate in stressful situations and parasympathetic activity during rest.
- Each division has 2 efferent neurones in its peripheral pathways between the CNS & effector organs.
- These are:
 - the preganglionic neurone
 - the postganglionic neurone.

- Cell body of the preganglionic neurone is in the brain or spinal cord.
- Its axon terminals synapse with the cell body of the postganglionic neurone in an autonomic ganglion outside the CNS.
- The postganglionic neurone conducts impulses to the effector organ.

SYMPHATHETIC NERVOUS SYSTEM

The preganglionic neurone.

- Has its cell body in the **lateral column of grey matter** in the spinal cord between the levels of the 1st thoracic & 2nd or 3rd lumbar vertebrae.
- Nerve fibre leaves the cord by the anterior root & terminates either in the **lateral chain of sympathetic ganglia** or passes through it to one of the **prevertebral ganglia**.
- **Acetylcholine** is the neurotransmitter.

The postganglionic neurone.

- Has its cell body in a ganglion and terminates in the organ or tissue supplied.
- **Noradrenaline** is usually the neurotransmitter.

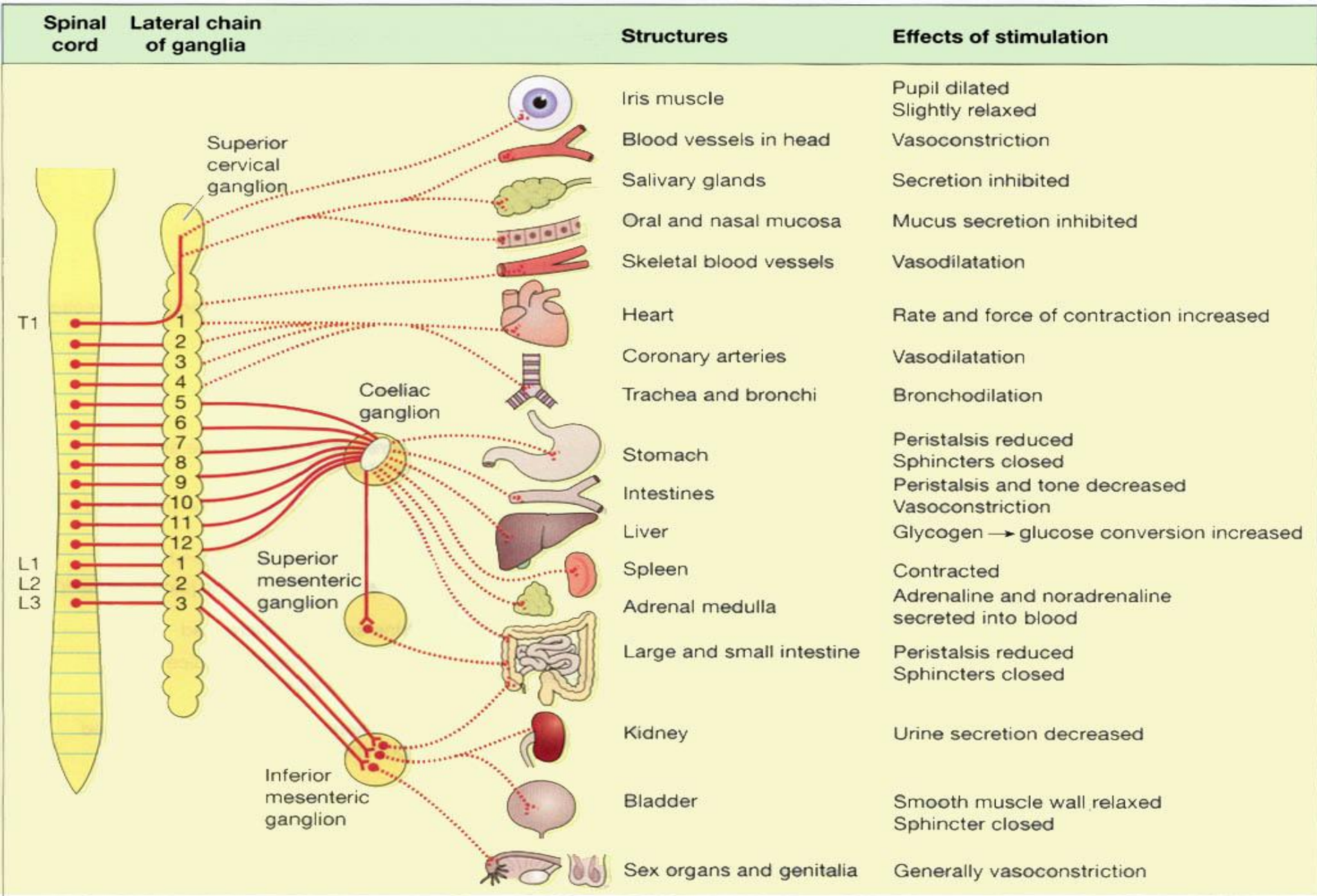
Sympathetic ganglia

a) The lateral chains of sympathetic ganglia.

- Chains of ganglia which extend from the upper cervical level to the sacrum, one chain lying on each side of the bodies of the vertebrae.
- The ganglia are attached to each other by nerve fibres.
- There is **no parasympathetic supply to the**
 - sweat glands,
 - skin and
 - blood vessels of skeletal muscles.

b) Prevertebral ganglia.

- 3 in number;
- Situated in the abdominal cavity close to the origins of arteries of the same names:
 - coeliac ganglion
 - superior mesenteric ganglion
 - inferior mesenteric ganglion.
- Consist of nerve cell bodies rather diffusely distributed among a network of nerve fibres which form plexuses.
- Preganglionic sympathetic fibres pass through the lateral chain to reach these ganglia.



Sympathetic outflow; Solid red lines - preganglionic fibres; broken lines - postganglionic fibres.

PARASYMPHATHETIC NERVOUS SYSTEM

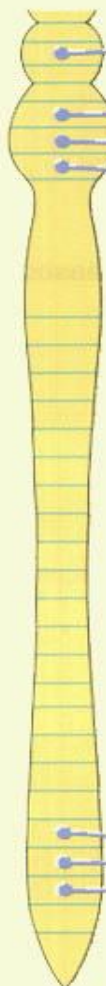
- Has two neurones (pre and postganglionic) and the primary neurotransmitter at both synapses is **acetylcholine**.

The preganglionic neurone.

- Has its cell body either in the brain or in the spinal cord.
- Those originating in the brain are the cranial nerves **III, VII, IX** and **X**, arising from nuclei in the midbrain and brain stem, and their nerve fibres terminate outside the brain.
- Cell bodies of the sacral outflow are in the lateral columns of grey matter at the distal end of the spinal cord. Their fibres leave the cord in sacral segments 2, 3 and 4 and synapse with postganglionic neurones in the walls of pelvic organs.

The postganglionic neurone.

- Has its cell body either in a ganglion or in the wall of the organ supplied.

Spinal cord	Cranial nerve numbers	Ganglia	Structures	Effects of stimulation	
	III	Ciliary	Iris muscle	Pupil constricted Contracted	
	VII	Pterygopalatine	Lacrimal gland	Tear secretion increased	
			Salivary glands: submandibular sublingual	Saliva secretion increased	
			parotid gland	Saliva secretion increased	
	IX	Submandibular	Heart	Rate and force of contraction decreased	
	X		Coronary arteries	Vasoconstriction	
			Otic	Trachea and bronchi	Bronchoconstriction
			Stomach	Secretion of gastric juice and peristalsis increased	
			Small intestine	Digestion and absorption increased	
			Liver and gall bladder	Blood vessels dilated Secretion of bile increased	
			Pancreas	Secretion of pancreatic juice increased	
			Kidney	Urine secretion increased	
			Small intestine	Secretion of intestinal juice and peristalsis increased	
			Large intestine	Secretions and peristalsis increased Sphincter relaxed	
			Bladder	Muscle of wall contracted Sphincters relaxed	
Sex organs and genitalia			Male: erection Female: variable; depending on stage in cycle		

Parasympathetic outflow; Solid blue lines-preganglionic fibres;broken lines-postganglionic fibres

Functions of ans

1. Sympathetic stimulation prepares the body to deal with exciting and stressful situations. Mobilises the body for 'fight or flight' (catecholamines).
2. Parasympathetic stimulation tends to slow down body processes except digestion and absorption of food and the functions of the genitourinary systems.
3. The 2 systems function together maintaining
 - ✓ regular heartbeat,
 - ✓ normal temperature &
 - ✓ an internal environment compatible with the immediate external surroundings.

Effects of ANS

a) Cardiovascular system

Sympathetic	Parasympathetic
<p>↑ HR and heart contraction</p> <p>Dilates coronary arteries</p> <p>Vasodilatation of vessels in skeletal muscle</p> <p>↑ PR and thus BP</p> <p>Accelerates blood coagulation</p>	<p>↓ HR and force of contraction</p> <p>Constricts coronary arteries</p>

b) Respiratory system

- **Sympathetic stimulation**
 - Causes dilatation of the airways (bronchodilation)
 - Increases oxygen intake and carbon dioxide output
- **Parasympathetic stimulation**
 - Produces constriction of the bronchi.

c) Digestive and urinary systems

- Sympathetic stimulation

- ***Liver***: increased conversion of glycogen to glucose
- ***Adrenal glands*** are stimulated to secrete adrenaline & noradrenaline.
- ***Stomach and small intestine***: inhibits peristalsis and production of digestive juices
- ***Urethral and anal sphincters***: the muscle tone of the sphincters is increased, inhibiting micturition and defecation.
- **Bladder** wall relaxes.
- ***Metabolic rate*** is greatly increased.

- **Parasympathetic stimulation**
 - ***Stomach and small intestine:*** rate of digestion & absorption of food is increased.
 - ***Pancreas:*** increased secretion of pancreatic juice & insulin .
 - **Urethral and anal sphincters;** Relaxation of internal sphincters thus allowing micturition and defecation to occur.in both cases there is voluntary relaxation of the external sphincters.
 - Liver: increased secretion of bile
 - No effect on adrenal glands and metabolic rate

d) Eye

- **Sympathetic stimulation**
 - Dilatation of the pupil.
 - Causes retraction of the levator palpebral muscles thus opening the eyes wide and giving the appearance of alertness and excitement.
 - Slight relaxation of the ciliary muscle that adjusts the thickness of the lens.
- **Parasympathetic stimulation**
 - Pupillary constriction
 - Eyelids tend to close, giving the appearance of sleepiness.
 - Ciliary muscles contracts facilitation near vision

e) Skin

- **Sympathetic stimulation**
 - Causes increased secretion of sweat
 - Produces contraction of the **arrector pili** (the muscles in the hair follicles of the skin), giving the appearance of 'goose pimples/flesh'.
 - Causes constriction of the blood vessels preventing heat loss.
- There is no parasympathetic nerve supply to the skin.
- Some sympathetic fibres are adrenergic, causing vasoconstriction, and some are cholinergic, causing vasodilatation

AFFERENT IMPULSES FROM VISCERA

- Impulses transmitted by autonomic afferents are associated with:
 - visceral reflexes, usually at an unconscious level, e.g. cough, blood pressure
 - sensation of, e.g., hunger, thirst, nausea, sexual sensation, rectal and bladder distension
 - visceral pain.

Visceral pain

- Def: A sensation of dull, poorly located pain from the viscera (internal organs)
- Experienced when:
 - visceral nerves are stretched
 - large number of fibres are stimulated
 - there is ischaemia and local accumulation of metabolites
 - the sensitivity of nerve endings to painful stimuli is increased, e.g. during inflammation.

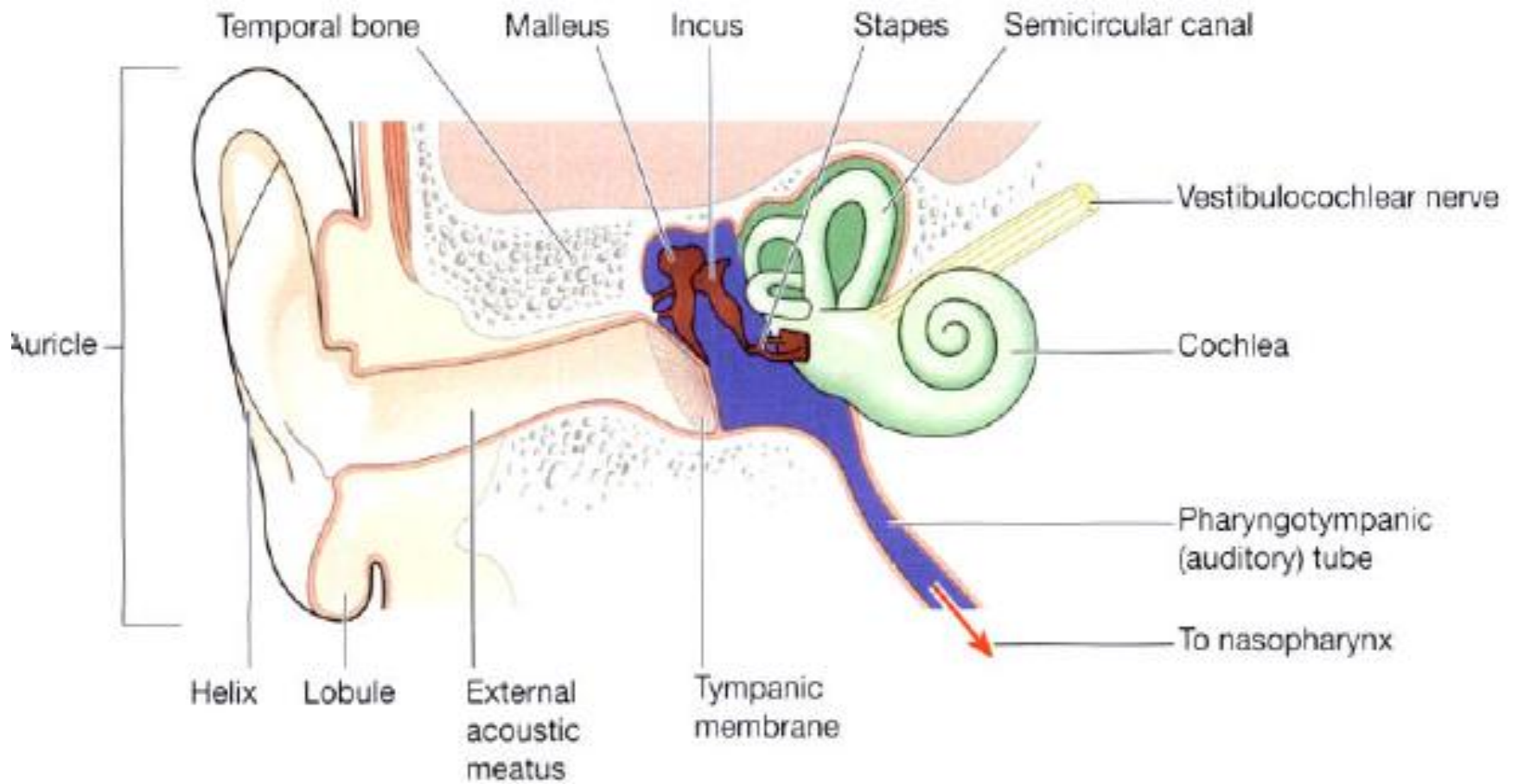
Referred pain

- Def: Refers to visceral pain that is projected and felt as cutaneous pain.
- Occurs when sensory fibres from the viscera enter the same segment of the spinal cord as somatic nerves, i.e. those from the superficial tissues.
- Sensory nerve from this organs stimulates the closely associated nerve in the spinal cord and it transmits the impulses to the sensory area in the cerebral cortex where the pain is perceived as originating in the area supplied by the somatic nerve.

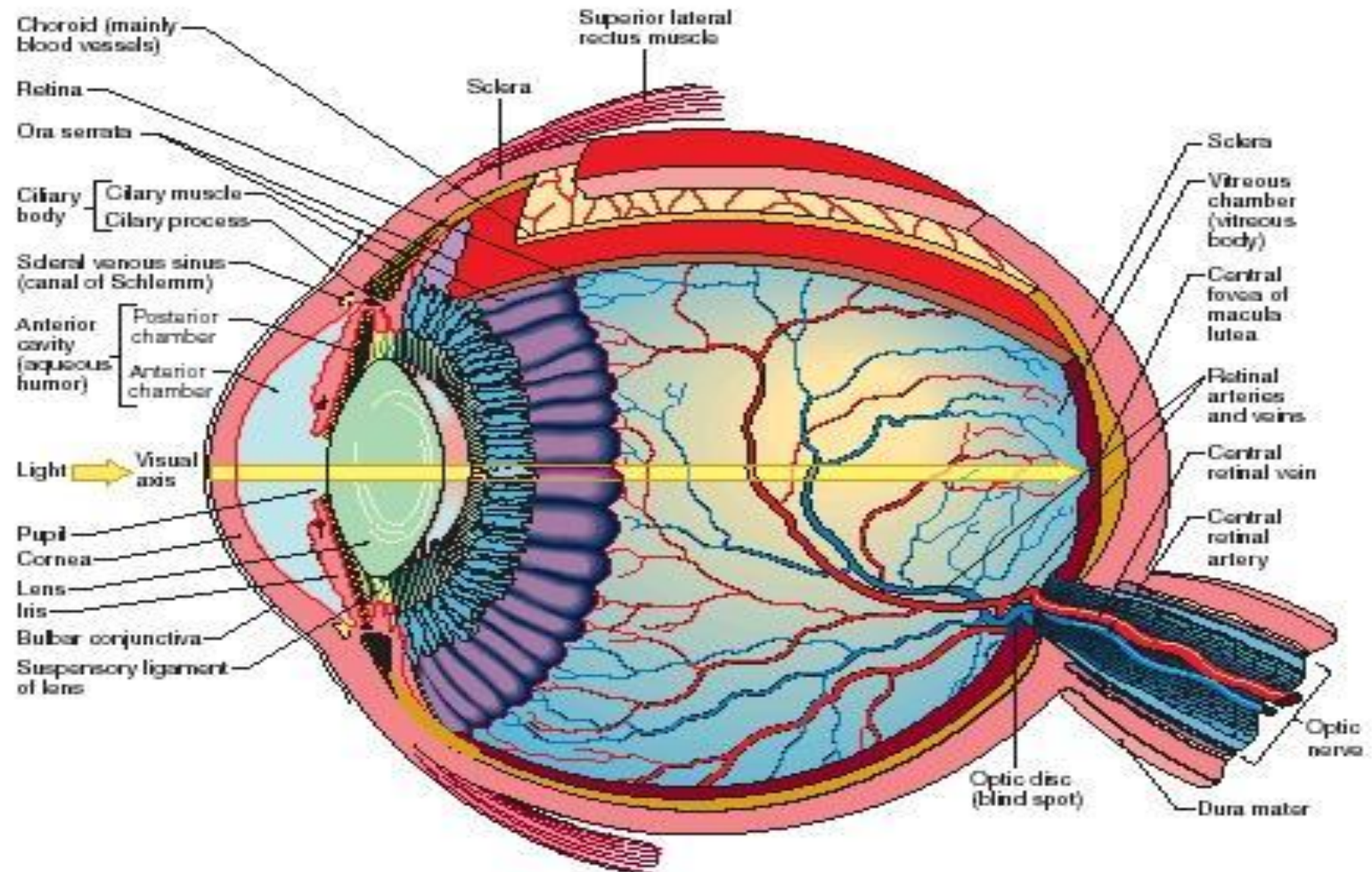
Table 7.4 Referred pain

<u>Tissue of origin of pain</u>	<u>Site of referred pain</u>
Heart	Left shoulder
Liver } Biliary tract }	Right shoulder
Kidney } Ureter }	Loin and groin
Uterus	Low back
Male genitalia	Low abdomen
Prolapsed intervertebral disc	Leg

THE SPECIAL SENSES



Vertical section of the right eye, shown from the nasal side



intro

- There are five special senses:
 - i. Hearing
 - ii. Sight
 - iii. Smell
 - iv. Taste
 - v. Touch
- Hearing, sight, smell and taste have specialized sensory receptors

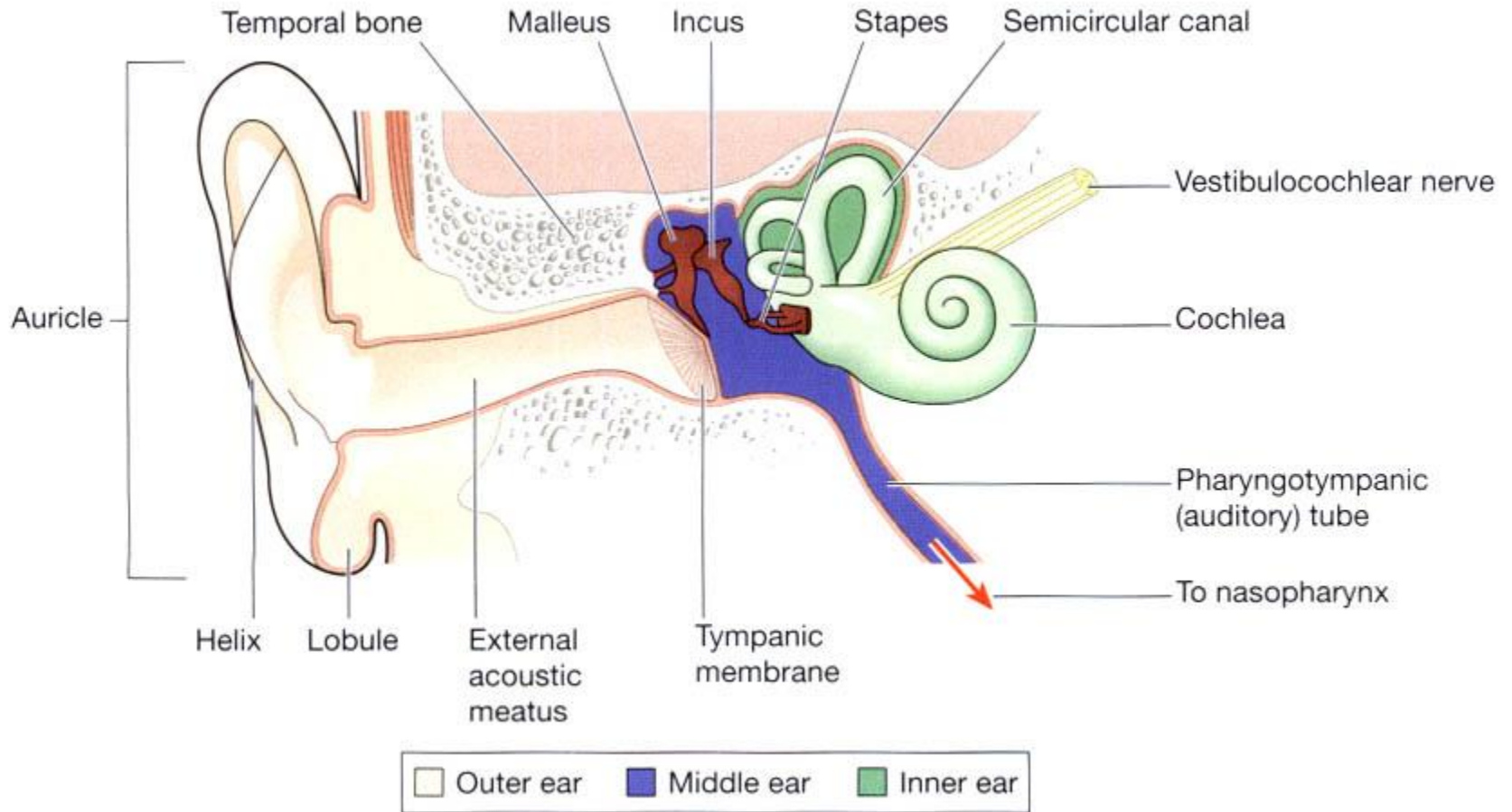
Hearing and THE EAR

- The ear is the organ of hearing.
- Supplied by cochlear part of 8th CN; stimulated by vibrations caused by sound waves.
- Except the auricle (pinna), structures forming it are encased within petrous portion of the temporal bone

Structure

- 3 distinct parts:
 - outer ear
 - middle ear (tympanic cavity)
 - inner ear.

Parts of the ear



OUTER EAR

- Consists of auricle & external acoustic meatus.

a) Auricle

- Expanded portion projecting from side of head.
- Composed of **fibroelastic cartilage** covered with skin.
- Deeply grooved & ridged; most prominent outer ridge: **helix**.
- **Lobule (earlobe)**: soft pliable part at lower extremity, composed of fibrous & adipose tissue richly supplied with blood.

b) External acoustic meatus (auditory canal)

- Slightly 'S'-shaped tube about 2.5 cm long extending from auricle to tympanic membrane (eardrum).
- **Lateral third; cartilaginous**; remainder is a canal in the **temporal bone**.

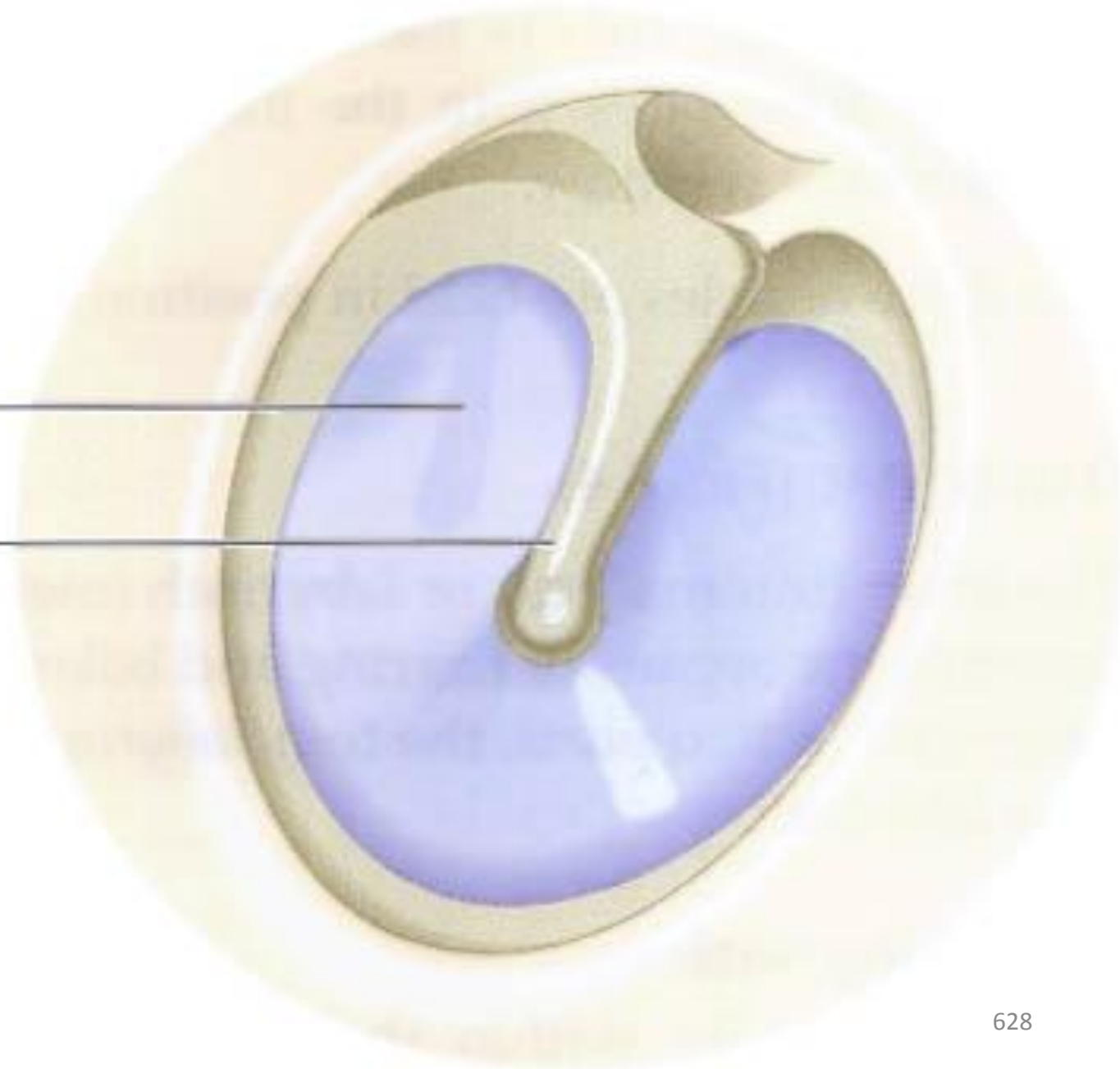
- Lined with skin containing hairs
- Has numerous sebaceous & ceruminous glands in skin of lateral third.
- **Ceruminous glands:** modified sweat glands that secrete cerumen (earwax), a sticky material containing lysozyme and immunoglobulins.
- Foreign materials are prevented from reaching the tympanic membrane by wax, hairs & curvature of meatus.
- Movements of temporomandibular joint during chewing & speaking 'massage' the cartilaginous meatus, moving wax towards the exterior.

- The **tympanic membrane** (eardrum):
 - completely separates external acoustic meatus from middle ear.
 - oval-shaped with slightly broader edge upwards
 - Formed by 3 types of tissue:
 - outer covering of hairless skin,
 - middle layer of fibrous tissue
 - inner lining of mucous membrane continuous with that of middle ear.

Tympanic membrane

Long process
of incus

Handle of
malleus



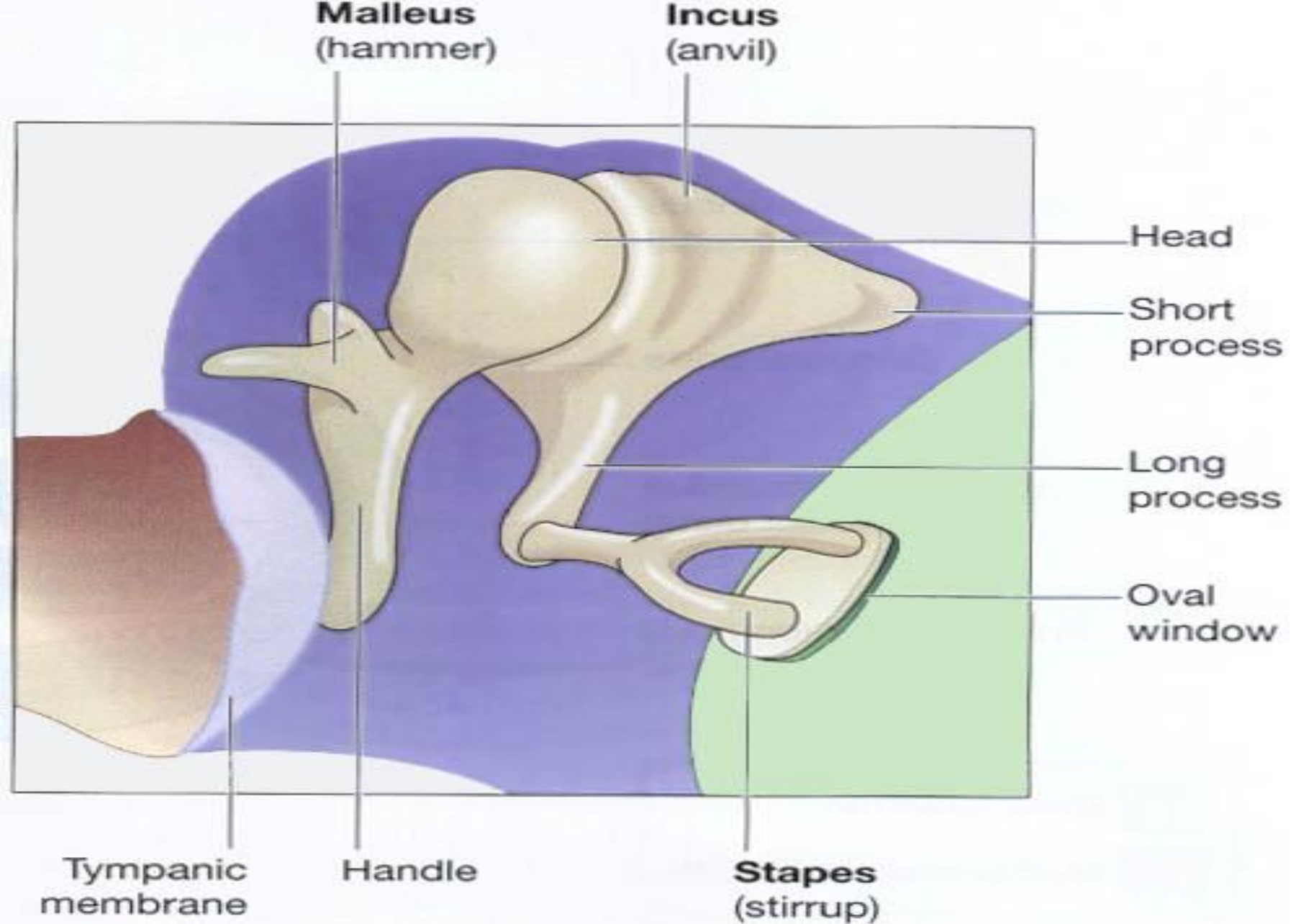
MIDDLE EAR (tympanic cavity)

- Irregular-shaped air-filled cavity within the temporal bone
- The cavity, its contents & air sacs which open out of it are lined with either **simple squamous** or **cuboidal epithelium**.
- **Boundaries;**
 - **Lateral wall;** formed by tympanic membrane.
 - **Roof and floor;** formed by temporal bone.
 - **Posterior wall;** formed by temporal bone with openings leading to mastoid antrum through which air passes to air cells within the mastoid process.
 - **Medial wall;** thin layer of temporal bone with 2 openings:
 - oval window
 - round window

- Oval window is occluded by **stapes** & round window, by a fine sheet of fibrous tissue.
- Air reaches the cavity through **pharyngotympanic (auditory/Eustachian) tube** which extends from the nasopharynx.
 - Its about 4 cm long; lined with ciliated epithelium.
- Presence of air at atmospheric pressure on both sides of tympanic membrane is maintained by the pharyngotympanic tube & enables the membrane to vibrate when sound waves strike it.
- Pharyngotympanic tube is normally closed but when there is unequal pressure across the tympanic membrane it is opened by swallowing or yawning and the ears 'pop', equalising the pressure again.

Auditory ossicles

- 3 very small bones extending across middle ear from tympanic membrane to the oval window.
- Form a series of movable joints with each other & with medial wall of the cavity at the oval window.
- Named according to their shapes.
- **The malleus.** Lateral hammer-shaped bone.
 - Handle is in contact with tympanic membrane
 - Head forms a movable joint with incus.
- **The incus.** Middle anvil-shaped bone.
 - Its body articulates with malleus, long process with stapes, and it's stabilised by the short process, fixed by fibrous tissue to posterior wall of tympanic cavity.
- **The stapes.** Medial stirrup-shaped bone.
 - Its head articulates with incus; its footplate fits into oval window.
- Held in position by fine ligaments.



Auditory ossicles

INNER (INTERNAL) EAR/ LABYRINTH

- Contains organs of hearing & balance.
- 2 parts, ***bony labyrinth*** & ***membranous labyrinth***.

a) Bony labyrinth

- Cavity within temporal bone lined with periosteum.
- Larger than, & encloses, membranous labyrinth.
- Between bony & membranous labyrinth is a layer of watery fluid called **perilymph** and within membranous labyrinth is a watery fluid called **endolymph**.
- Consists of:
 - 1 vestibule
 - 1 cochlea
 - 3 semicircular canals.

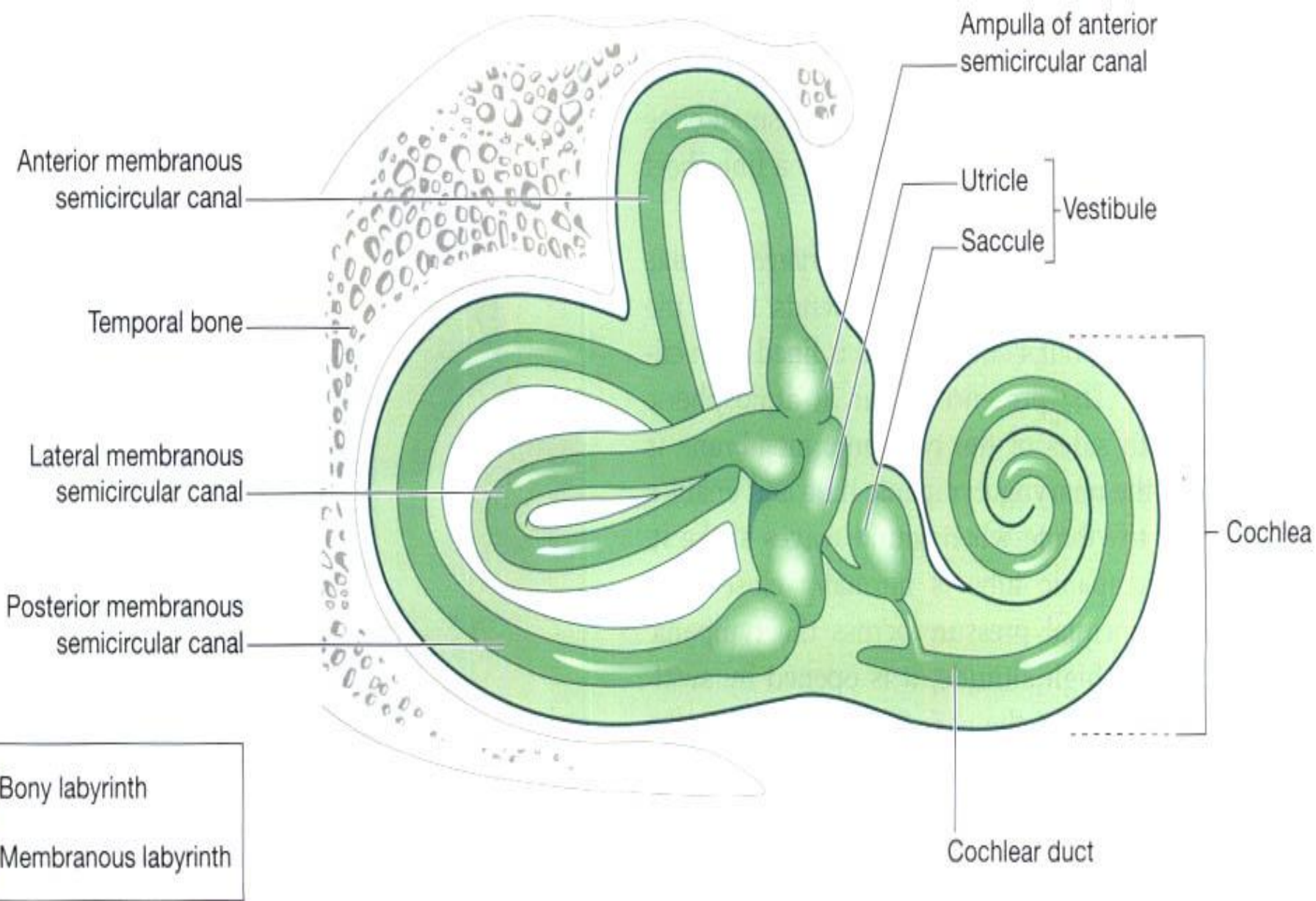
- **Vestibule:** Is the expanded part nearest middle ear.
 - Contains oval & round windows in its lateral wall and two membranous sacs: *utricle* and *sacculle* that are important in balance.
- **Cochlea:** resembles a snail's shell.
 - Has a broad base where it is continuous with the vestibule & a narrow apex, & it spirals round a central bony column.
- **Semicircular canals:** these are 3 tubes arranged so that one is situated in each of the 3 planes of space.
 - Continuous with vestibule.

b) Membranous labyrinth

- Contains endolymph & lies within its bony counterpart.
- Comprises:
 - vestibule; contains utricle & saccule
 - cochlea
 - 3 semicircular canals.

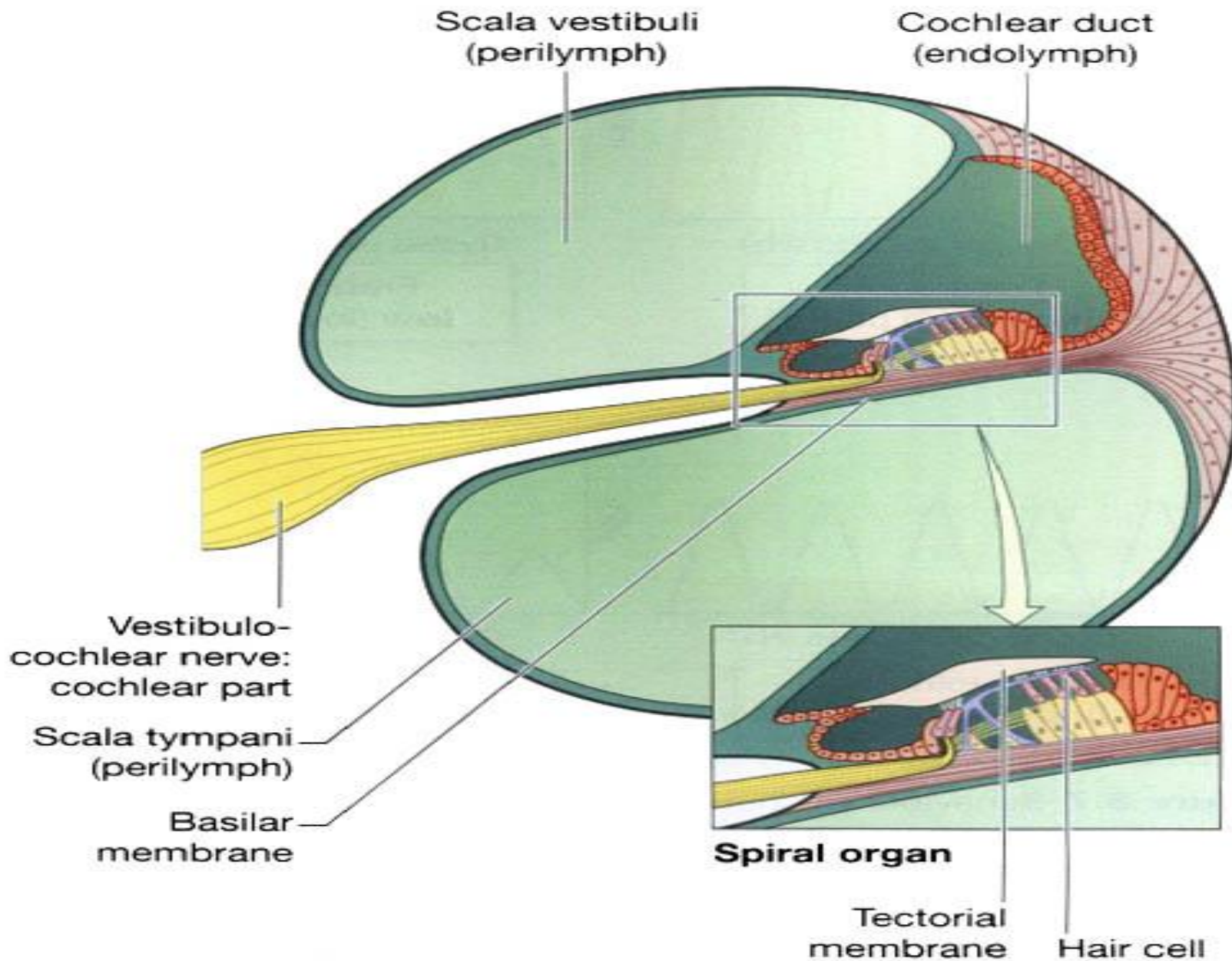
The cochlea

- Contains 3 compartments: the
 - scala vestibuli
 - scala media, or cochlear duct
 - scala tympani.
- In cross-section, bony cochlea has 2 compartments containing perilymph:
 - scala vestibuli; originates at oval window,
 - scala tympani; ends at round window.
- The 2 compartments are continuous with each other.



Inner ear; membranous labyrinth within bony labyrinth

- **Cochlear duct** is part of membranous labyrinth; triangular in shape.
- On the **basilar membrane**, or base of the triangle, there are supporting cells & specialised cochlear hair cells containing auditory receptors.
 - These cells form **spiral organ (of Corti)**: sensory organ that responds to vibration by initiating nerve impulses that are then perceived as hearing by the brain.
- Auditory receptors are dendrites of efferent nerves that combine forming **cochlear (auditory) part** of 8th CN

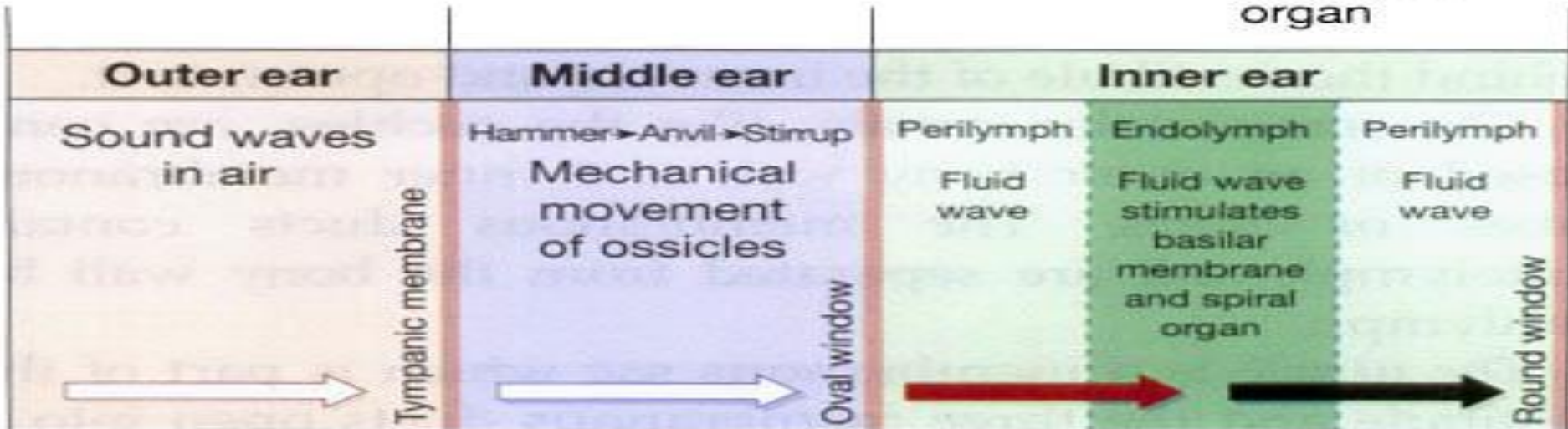
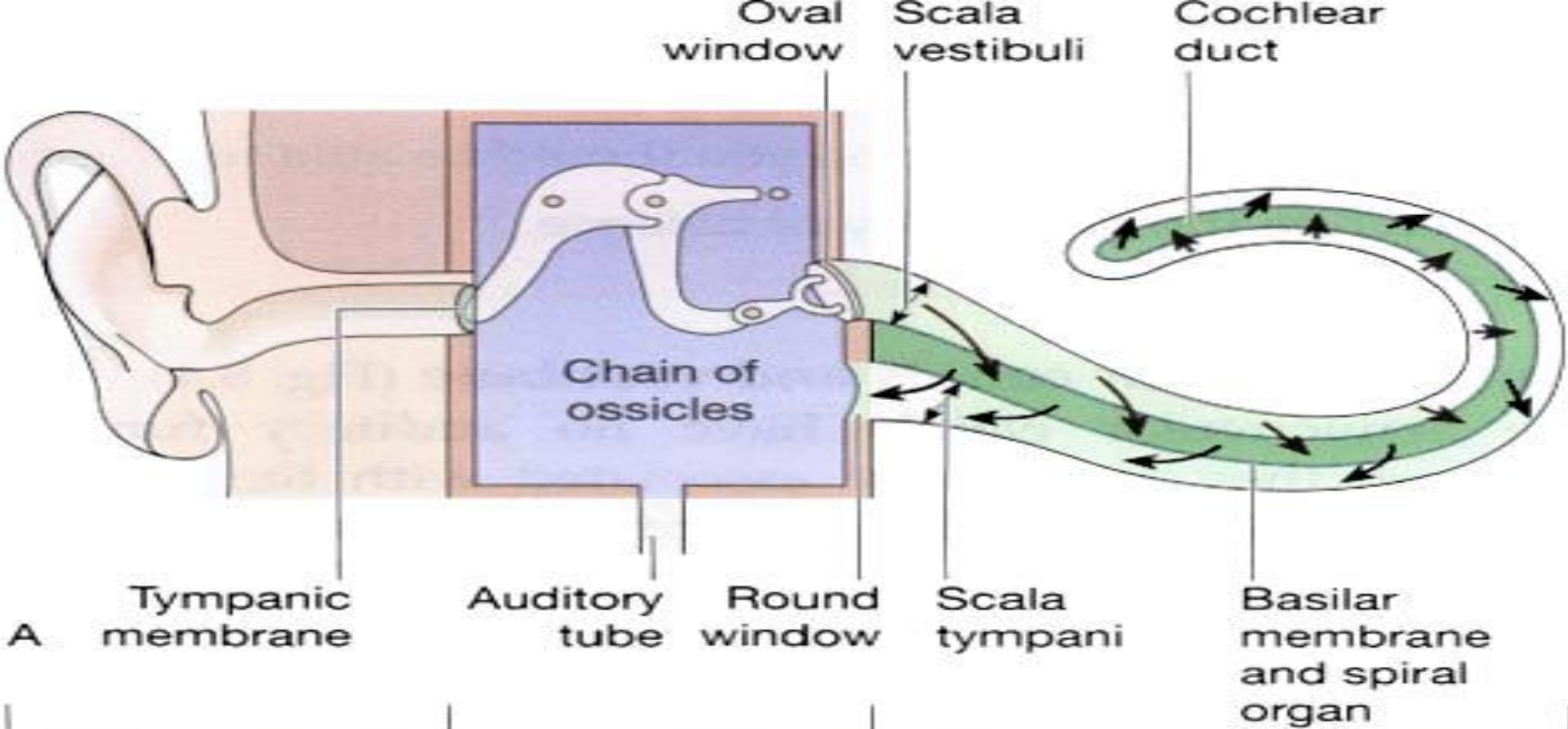


Cochlea; showing spiral organ (of Corti)

Physiology of hearing

- Every sound produces **sound waves/vibrations in the air**, which travel at about 332 metres (1088 feet) per second.
- Auricle concentrates the waves & directs them along the auditory meatus causing tympanic membrane to vibrate.
- Tympanic membrane vibrations are transmitted & amplified through the middle ear by movement of ossicles.
- At their medial end, footplate of stapes rocks to & fro in the oval window, setting up fluid waves in the perilymph of the scala vestibuli.

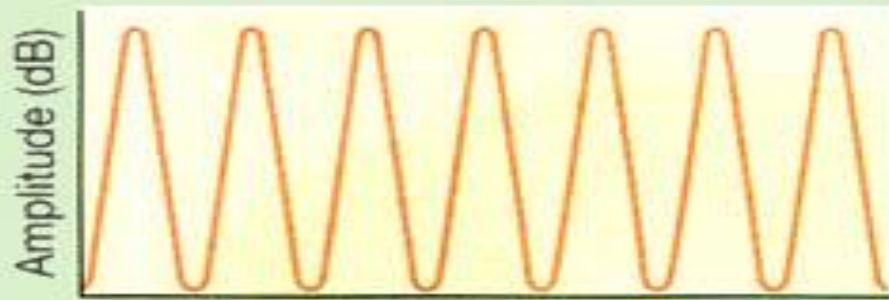
- Some of the force of these waves is transmitted along the length of the scala vestibuli & scala tympani, but most of the pressure is transmitted into cochlear duct.
- This causes a corresponding wave motion in the endolymph, resulting in vibration of basilar membrane & stimulation of auditory receptors in the hair cells of the spiral organ.
- Nerve impulses generated pass to the brain in cochlear portion of 8th CN which transmits the impulses to the hearing area in the cerebrum where sound is perceived & to various nuclei in the pons & midbrain.
- The fluid wave is finally expended into the middle ear by vibration of the membrane of the round window.



Passage of sound waves

Properties of sound waves

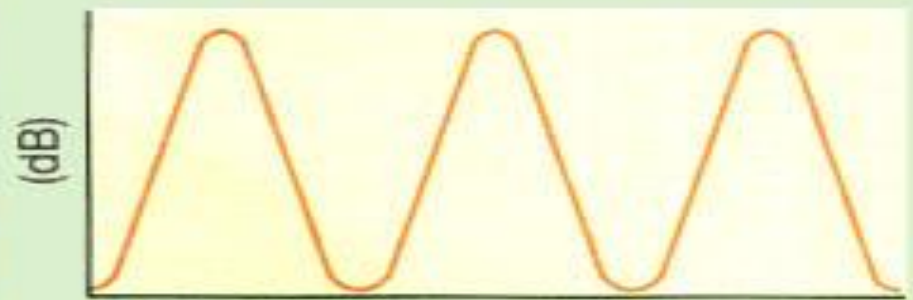
- *pitch and volume*/intensity
- Pitch: determined by frequency of the sound waves
 - measured in hertz (Hz).
- Volume: depends on amplitude of the sound waves
 - measured in decibels (dB).



Cycles per second (Hz)

Frequency:

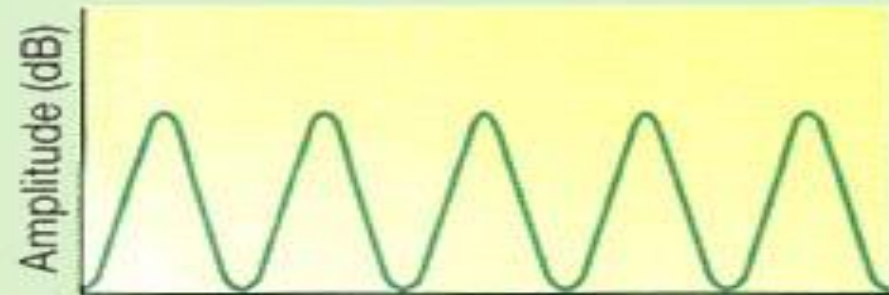
high (high pitch)



Cycles per second (Hz)

Frequency:

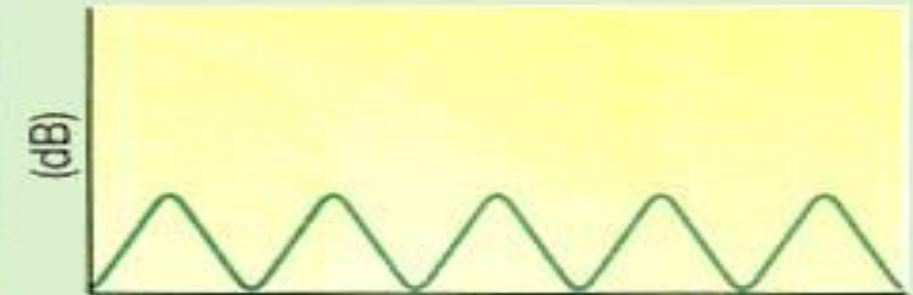
low (low pitch)



Cycles per second (Hz)

Amplitude:

high (high volume)



Cycles per second (Hz)

Amplitude:

low (low volume)

Behaviour of sound waves; A. difference in frequency but same amplitude, B. difference in amplitude but same frequency

Balance and the ear

- **The semicircular canals & vestibule**
- Semicircular canals have no auditory function. They provide information about the position of head in space, contributing to maintenance of posture & balance.
 - Situated above & behind vestibule of inner ear & open into it.
 - Like cochlea, SCC are composed of an outer bony wall & inner membranous tubes/ducts. Membranous ducts contain endolymph & are separated from the bony wall by perilymph.
- **Utricle:** membranous sac which is part of the vestibule
 - The 3 membranous ducts open into it at their dilated ends, ampullae.
- **Saccule:** part of vestibule
 - communicates with utricle & cochlea.
- In the walls of the utricle, saccule & ampullae; are fine specialised epithelial cells with minute projections called **hair cells**. Amongst the hair cells are sensory nerve endings which combine forming vestibular part of 8th CN.

Physiology of balance

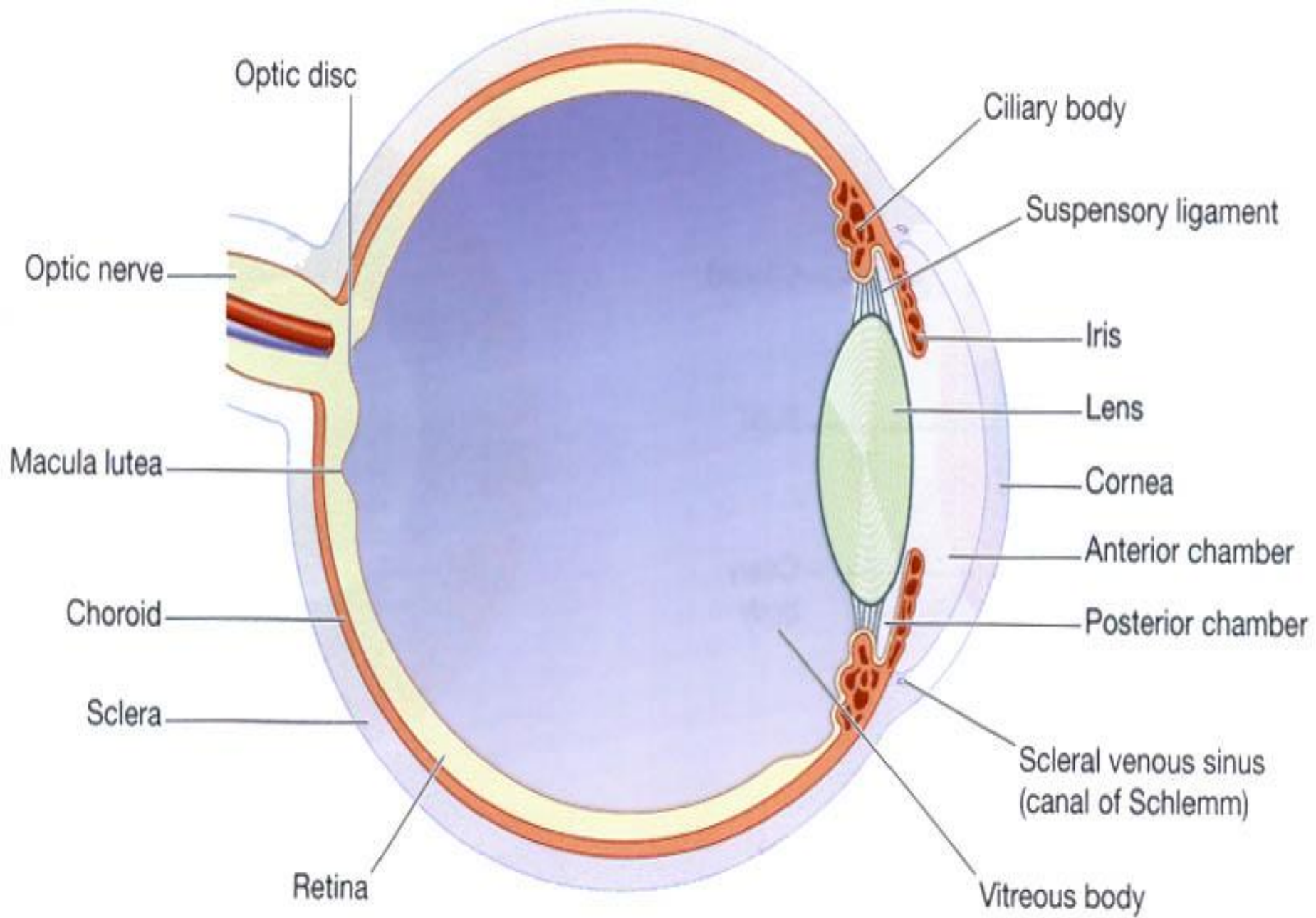
- Carried out by semicircular canals & vestibule (utricle & saccule).
- Any change in head's position causes movement in the perilymph & endolymph, which bends the hair cells & stimulates sensory nerve endings in the utricle, saccule & ampullae.
- Resultant nerve impulses are transmitted by vestibular nerve which joins cochlear nerve forming 8th CN. The vestibular branch passes first to the ***vestibular nucleus***, then to the ***cerebellum***.
- Cerebellum also receives nerve impulses from the eyes & proprioceptors in the skeletal muscles & joints.
- The impulses are coordinated & efferent nerve impulses pass to the cerebrum & to skeletal muscles; results in
 - awareness of body position, maintenance of upright posture & fixing of the eyes on the same point, independently of head movements.

THE EYE

- Organ of sight
- Situated in orbital cavity and supplied by ***optic nerve (2nd CN)***.
- Almost spherical in shape; about 2.5 cm in diameter.
- Space between eye & orbital cavity; occupied by adipose tissue.
- Bony walls of orbit & fat; protect the eye from injury.
- The 2 eyes are structurally separate but some of their activities are coordinated so that they function as a pair.

Structure of the eye

- 3 layers of tissue in their walls.
 - outer fibrous layer: **sclera & cornea**
 - middle vascular layer or uveal tract: **choroid, ciliary body & iris**
 - inner nervous tissue layer: **retina.**
- Structures inside the eyeball
 - lens,
 - aqueous fluid (humour)
 - vitreous body (humour).

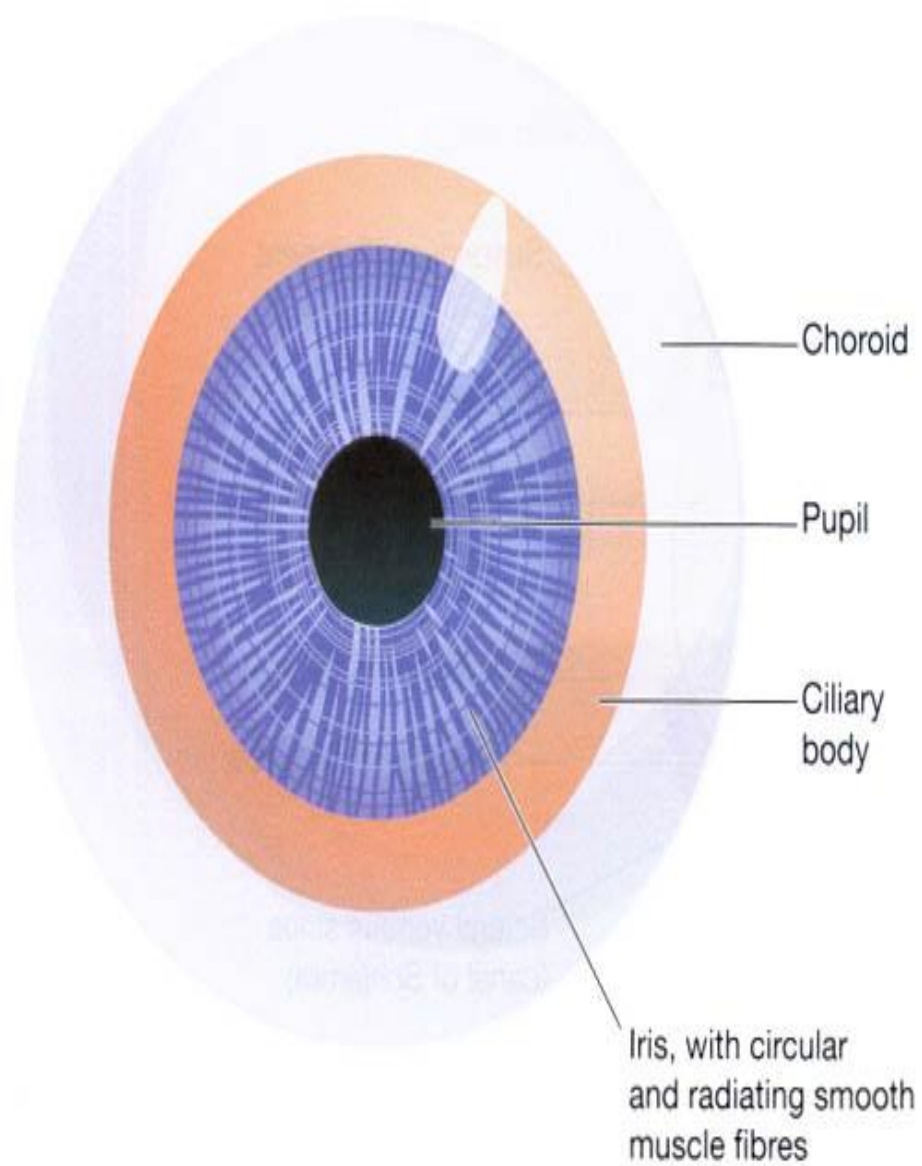


The eye

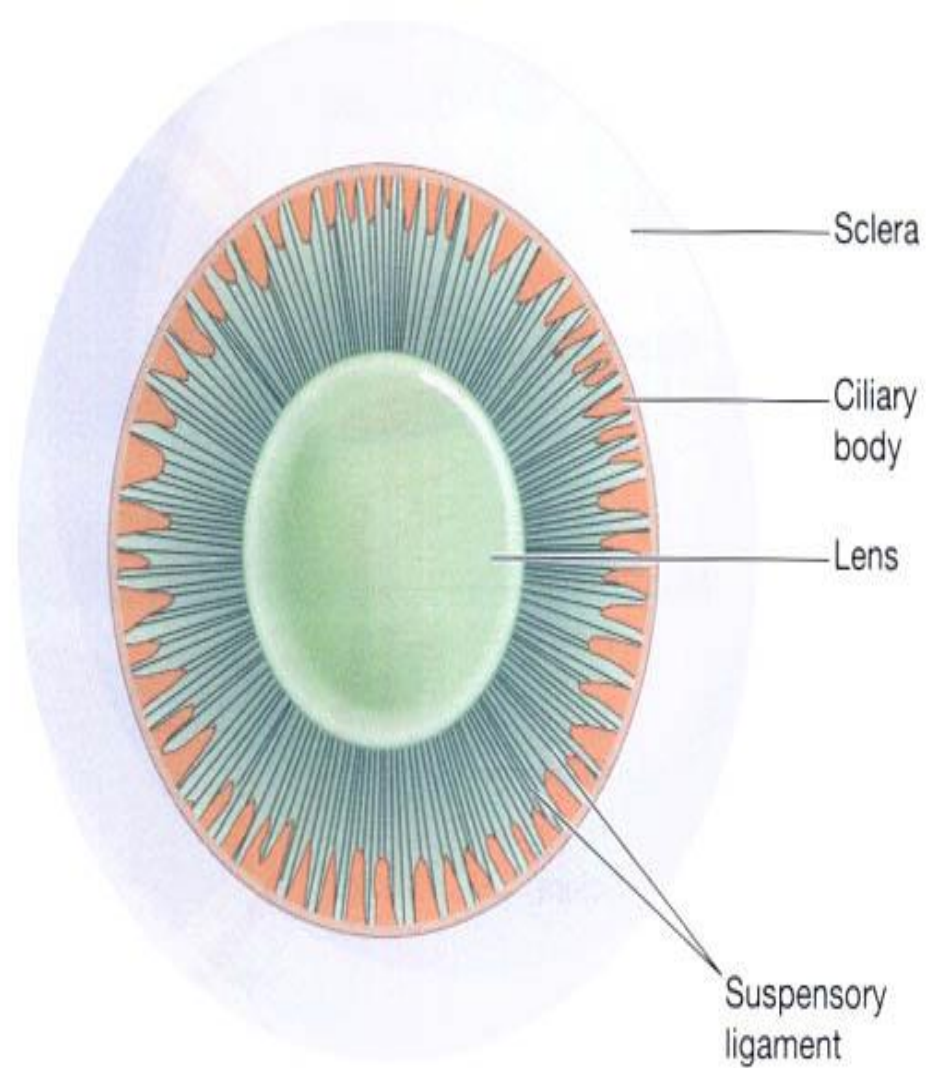
- **Sclera and cornea**
- ***Sclera*** or white of the eye forms the outermost layer of tissue of posterior & lateral aspects of eyeball
 - Consists of a firm fibrous membrane that maintains eye's shape & gives attachment to extraocular/extrinsic muscles of eye
- Anteriorly continues as a clear transparent epithelial membrane known as the ***cornea***.
- Light rays pass through the cornea to reach the retina.
- Cornea is convex anteriorly and is involved in refracting (bending) light rays to focus them on retina.

- **Choroid**
- Lines posterior 5/6 of inner surface of sclera.
- Very rich in blood vessels and deep chocolate brown in colour. Light enters the eye through the pupil, stimulates nerve endings in the retina; then absorbed by the choroid.
- **Ciliary body**
- Is the anterior continuation of choroid consisting of ciliary muscle (smooth muscle fibres) & secretory epithelial cells.
- Gives attachment to suspensory ligament of the lens
- Its Contraction & relaxation changes the thickness of lens which refracts light rays entering the eye to focus them on the retina.
- Epithelial cells secrete aqueous fluid into anterior segment of eye and cornea (anterior & posterior chambers).
- It is Supplied by parasympathetic branches of 3rd CN and Stimulation causes contraction of smooth muscle & accommodation of the eye

- **Iris**
- Visible coloured part of eye
- Extends anteriorly from ciliary body, lying behind cornea and in front of lens.
- It divides anterior segment of eye into anterior & posterior chambers which contain aqueous fluid secreted by the ciliary body.
- Its circular body is composed of pigment cells & 2 layers of smooth muscle fibres, one circular & the other radiating
- In the centre is an aperture known as the **pupil**.
- It is Supplied by
 - Parasympathetic nerves which constricts pupil
 - Sympathetic nerves which dilates pupil.
- Its colour is genetically determined & depends on the number of pigment cells present.
 - Albinos have no pigment cells
 - People with blue eyes have fewer than those with brown eyes.



The choroid, ciliary body and iris



Lens and suspensory ligaments

- **Lens**
- Highly elastic circular biconvex body, lying immediately behind the pupil.
- Consists of fibres enclosed within a capsule
- Suspended from ciliary body by suspensory ligament.
- Its thickness is controlled by ciliary muscle through the suspensory ligament.
- Refracts light rays reflected by objects in front of eye.
- It is the only structure in the eye that can vary its refractory power; achieved by changing its thickness.
 - When the ciliary muscle contracts, it moves forward, releasing its pull on the lens, increasing its thickness.
 - The nearer is the object being viewed, the thicker the lens becomes to allow focusing.

- **Retina**
- Innermost layer of the wall of eye
- Extremely delicate structure and is well adapted for stimulation by light rays.
- Composed of several layers of nerve cell bodies & their axons, lying on a pigmented layer of epithelial cells which attach it to the choroid.
- The light sensitive layer consists of sensory receptor cells: **rods & cones** that contain photosensitive pigments that convert light rays into nerve impulses
- It lines about three-quarters of eyeball & thickest at the back & thins out anteriorly to end just behind the ciliary body.
- Near the centre of posterior part is **macula lutea**, or **yellow spot**. Here, there is a little depression called **fovea centralis**, consisting of only **cones**

- Towards the anterior part of retina there are fewer cone- than rod-shaped cells.
- About 0.5 cm to the nasal side of macula lutea all the nerve fibres of the retina converge to form the ***optic nerve***.
- Small area of retina where the optic nerve leaves the eye is **optic disc** or **blind spot** and has no light sensitive cells.

Blood supply to the eye

- Arterial blood: ***ciliary arteries & central retinal artery***.
 - Branches of ***ophthalmic artery***, one of the branches of internal carotid artery.
- Venous drainage: by a no. of veins, including the ***central retinal vein***, which eventually empty into a deep venous sinus.

NB: Central retinal artery & vein are encased in the optic nerve, entering the eye at the optic disc.

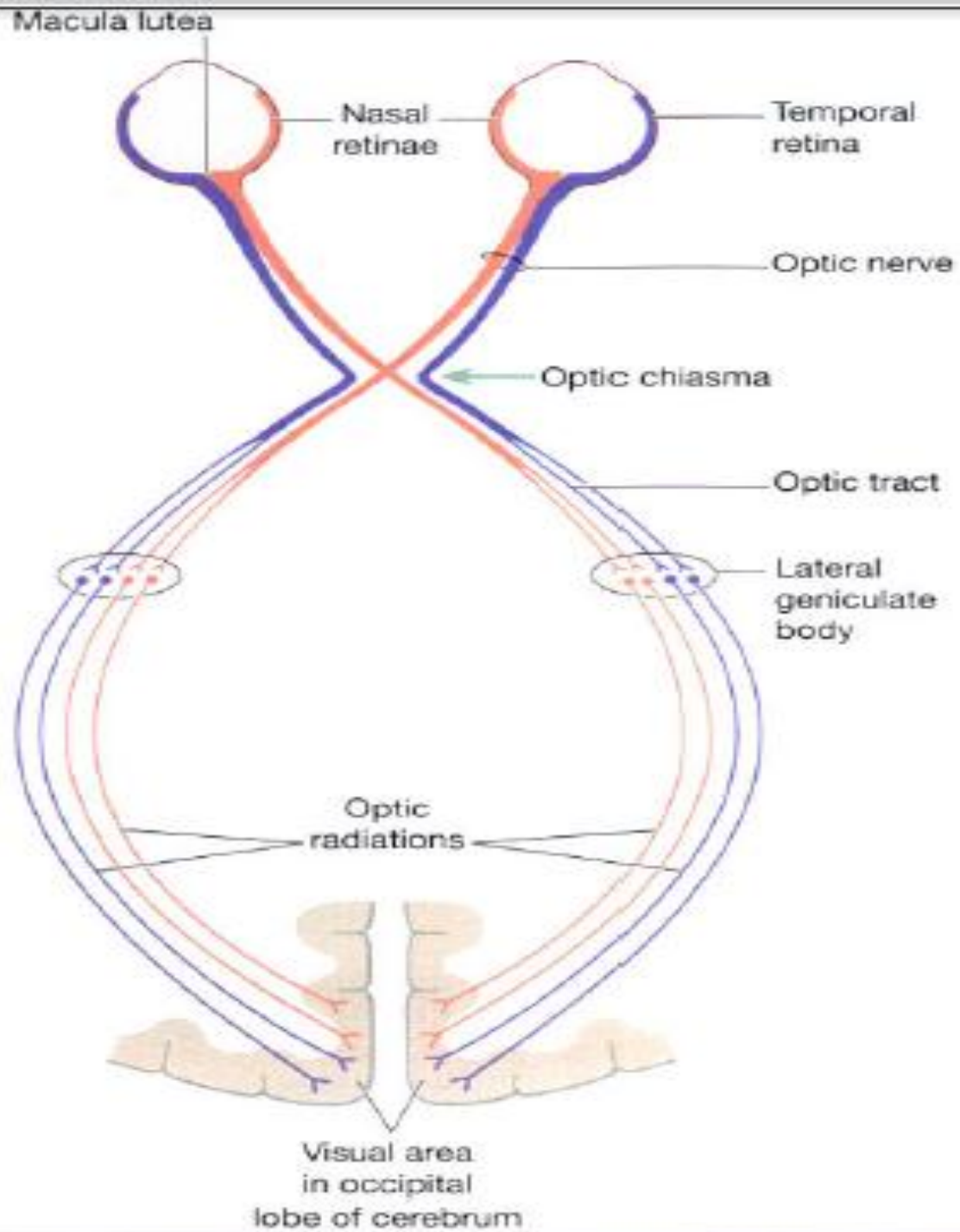
Interior of the eye

- **Anterior segment** of the eye (space between the cornea and the lens) is incompletely divided into **anterior & posterior** chambers by **iris**.
- Both chambers contain a clear aqueous fluid (humour) secreted into the posterior chamber by ciliary glands.
 - Circulates in front of lens, through the pupil into the anterior chamber & returns to the venous circulation through **scleral venous sinus (canal of Schlemm)** in the angle between the iris & cornea.
- Intraocular pressure (IOP) remains fairly constant between 1.3 & 2.6 kPa (10 to 20 mmHg).
 - increased IOP causes glaucoma.

- Aqueous fluid supplies nutrients & removes waste from transparent structures in the front of eye that have no blood supply, i.e. cornea, lens & lens capsule.
- Behind the lens & filling posterior segment (cavity) of the eyeball is vitreous body (humour).
 - soft, colourless, transparent, jelly-like substance composed of 99% water, some salts & mucoprotein.
 - Maintains sufficient intraocular pressure to support the retina against the choroid & prevent the eyeball walls from collapsing.
- The eye keeps its shape because of the intraocular pressure exerted by the vitreous body & aqueous fluid.

- **Optic nerves**
- Fibres originate in retina and converge forming optic nerve about 0.5 cm to the nasal side of macula lutea.
- The nerve pierces the choroid & sclera to pass backwards & medially through orbital cavity. Then passes through the optic foramen of sphenoid bone, backwards & medially to meet the nerve from the other eye at the **optic chiasma**.
- **Optic chiasma**
- Situated immediately in front of & above pituitary gland.
- Nerve fibres of the optic nerve from the nasal side of each retina cross over to the opposite side.
- Fibres from temporal side do not cross but continue backwards on the same side.
- Crossing over provides both cerebral hemispheres with sensory input from each eye.

- **Optic tracts**
- These are the pathways of the optic nerves, posterior to the optic chiasma. Each tract consists of the nasal fibres from the retina of one eye and the temporal fibres from the retina of the other.
- The optic tracts pass backwards through the cerebrum to synapse with nerve cells of the *lateral geniculate bodies of the thalamus*. From there the nerve fibres proceed backwards and medially as the *optic radiations to terminate in the visual area of the cerebral cortex* in the occipital lobes of the cerebrum.



Physiology of sight

- Clear vision is dependent on three processes:
 - Refraction of the light rays
 - Changing of the size of the pupils
 - Accomodation
- They are all coordinated

Refraction of light rays

- When light rays pass from a medium of one density to a medium of a different density they are **refracted or bent**; for example in the eye the biconvex lens bends and focuses light rays
- This principle is used to focus light on the retina. Before reaching the retina light rays pass successively through the conjunctiva, cornea, aqueous fluid, lens and vitreous body.
- Abnormal refraction within the eye is corrected using biconvex or biconcave lenses
- Light is refracted by the lens and on the brain the image of the perceived object is actually upside down.

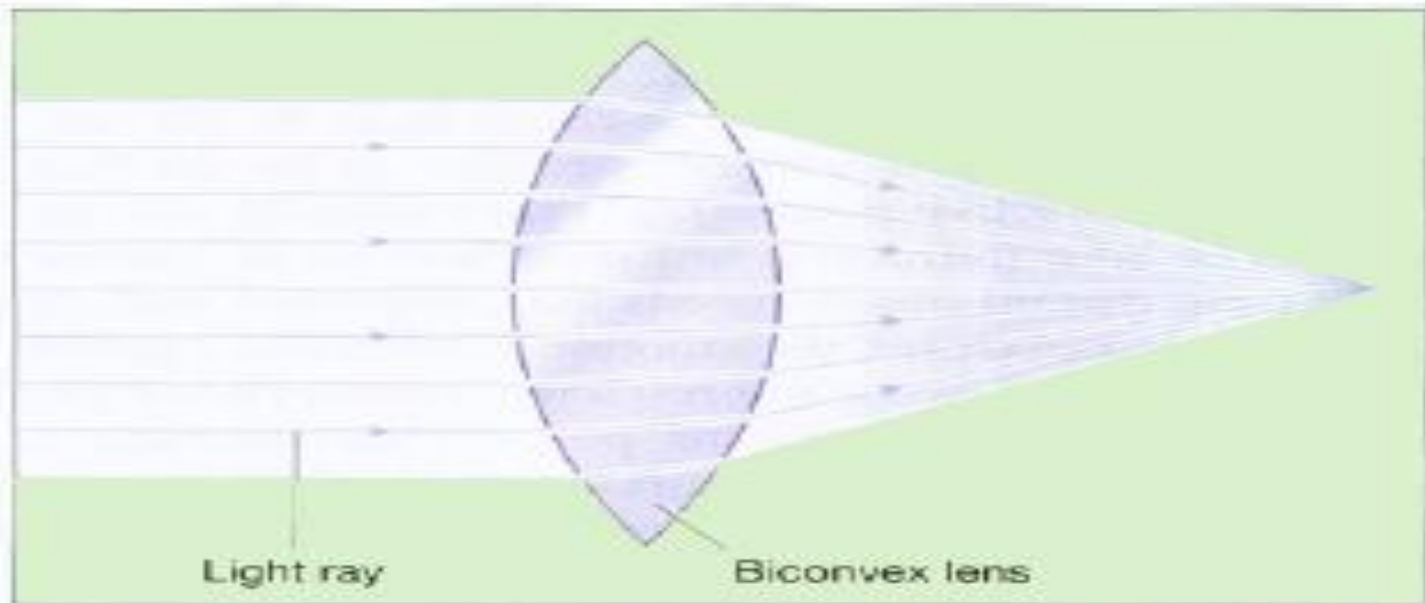


Figure 8.16 Refraction of light rays passing through a biconvex lens.

- The lens is there⁴ responsible for focusing the images on the retina thru refraction of the lights. Distant objects need least refraction while closer objects needs increased refraction.
- The refraction is effected by the ciliary muscles: to \uparrow they contract and to \downarrow they relax.

Pupil size

- Pupil size influences accommodation by controlling the amount of light entering the eye. In a bright light the pupils are constricted. In a dim light they are dilated. This protects the retina (from bright light) or increases clarity of images (in dim light)
- The size changes is effected by the iris: contraction of circular fibres causes pupil constriction while contraction of radiating fibres causes pupil dilatation.
- Its under sympathetic(dilatation) and parasympathetic (constriction) control

accomodation

- Required in order for the eye to focus on near objects. In accomodation, there must be:
 - Constriction of the pupils
 - Convergence
 - Changing of the power of lens
- Constriction of the pupils: reduces the width of the beam of light entering the eye so that it passes through the central curved part of the lens.
- Convergence: Extraocular muscles move the eyes and to obtain a clear image they rotate the eyes so that they *converge on the object viewed*.

- The nearer an object is to the eyes the greater the eye rotation needed to achieve convergence, e.g. an individual focusing near the tip of his nose appears to be 'cross-eyed'.
- If convergence is not complete the eyes are focused on different objects or on different points of the same object. There are then two images sent to the brain and this leads to double vision, *diplopia*.
- **Changing the power of the lens.**
- Changes in the thickness of the lens are made to focus light on the retina. The amount of adjustment depends on the distance of the object from the eyes, i.e. the lens is thicker for near vision and at its thinnest when focusing on objects at more than 6 metres' distance
- Looking at near objects 'tires' the eyes more quickly, owing to the continuous use of the ciliary muscle. The lens loses its elasticity and stiffens with age, a condition known as **presbyopia**

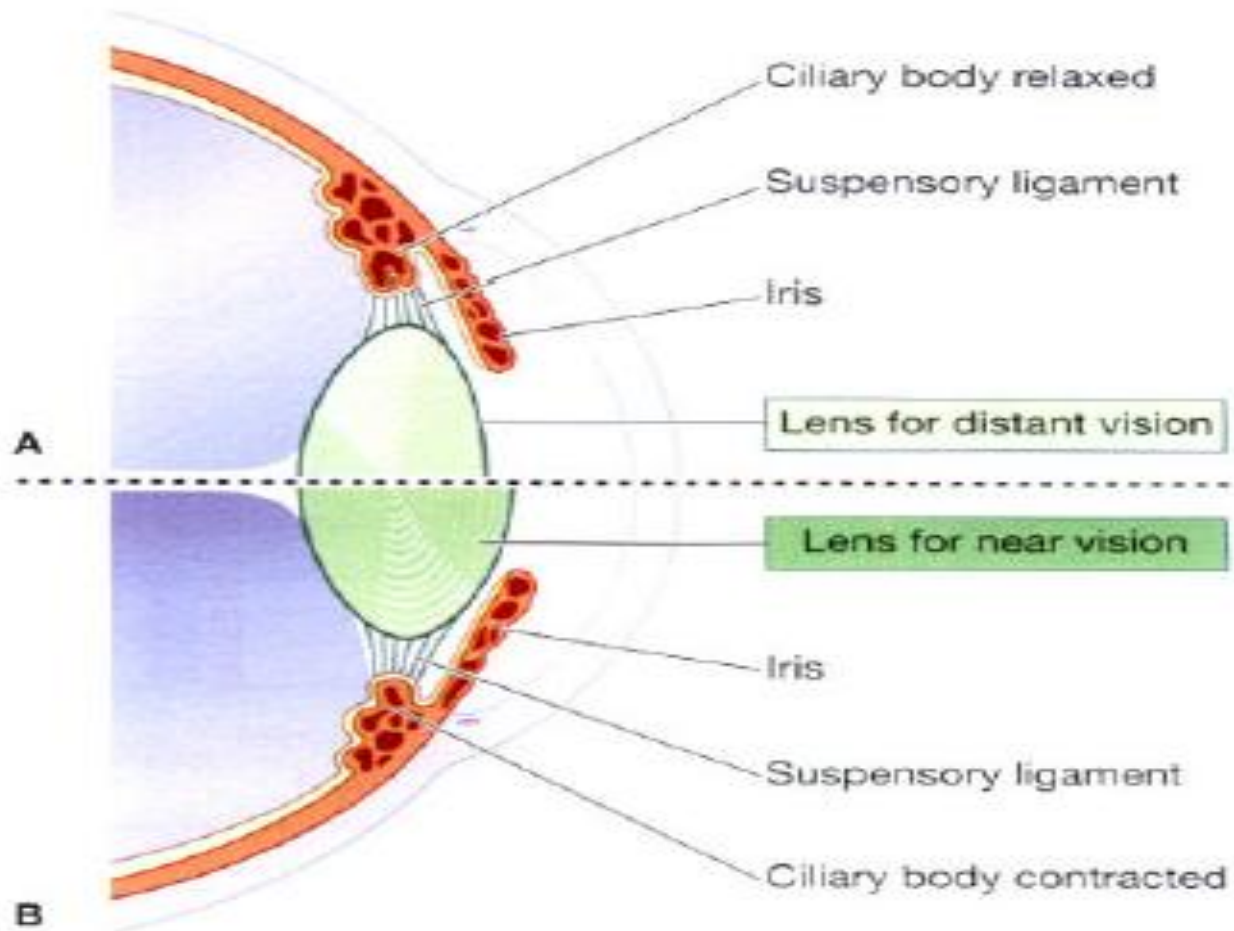


Figure 8.17 The shape of the lens: A. Distant vision. B. Near vision.

Functions of the retina

- The retina is the *photosensitive part of the eye* and contains the lightsensitive nerve cells called *rods and cones*.
- Light rays cause chemical changes in photosensitive pigments in these cells and they generate nerve impulses which are conducted to the occipital lobes of the cerebrum via the optic nerves
- The rods are more sensitive than the cones. They are stimulated by low-intensity or dim light, e.g. by the dim light in the interior of a darkened room.
- *The cones are sensitive to bright light and colour.* The different wavelengths of visible light stimulate photosensitive pigments in the cones, resulting in the perception of different colours. In bright light the light rays are focused on the macula lutea. (colour blindness)

- The rods are more numerous towards the periphery of the retina. *Visual purple (rhodopsin)* is a photosensitive pigment present only in the rods. It is bleached (degraded) by bright light and is quickly regenerated when an adequate supply of vitamin A is available

Dark adaptation

- When exposed to bright light, the rhodopsin within the sensitive rods is completely degraded. This is not significant until the individual moves into a darkened area where the light intensity is insufficient to stimulate the cones, and temporary visual impairment results whilst the rhodopsin is being regenerated within the rods, 'dark adaptation'.
- When regeneration of rhodopsin occurs, normal sight returns.

Binocular vision

- Binocular or stereoscopic vision enables 3D views although each eye 'sees' a scene slightly differently. There is an overlap of visual fields in the middle but the left eye sees more on the left than can be seen by the other eye and vice versa. The images from the two eyes are fused in the cerebrum so that only one image is perceived.
- Binocular vision provides a much more accurate assessment of one object relative to another, e.g. its distance, depth, height and width. People with monocular vision may find it difficult, for example, to judge the speed and distance of an approaching vehicle.

Extraocular muscles

- Includes muscles of the eyelids and those that move the eye ball
- Are 6 in number
 - 4 straight (recti) muscles and
 - 2 oblique muscles
- Namely
 - medial rectus
 - lateral rectus
 - superior rectus
 - inferior rectus
 - superior oblique
 - inferior oblique.

Table 8.1 Extrinsic muscles of the eye: their actions and cranial nerve supply

Name	Action	Cranial nerve supply
Medial rectus	Rotates eyeball inwards	Oculomotor nerve (3rd cranial nerve)
Lateral rectus	Rotates eyeball outwards	Abducent nerve (6th cranial nerve)
Superior rectus	Rotates eyeball upwards	Oculomotor nerve (3rd cranial nerve)
Inferior rectus	Rotates eyeball downwards	Oculomotor nerve (3rd cranial nerve)
Superior oblique	Rotates eyeball downwards and outwards	Trochlear nerve (4th cranial nerve)
Inferior oblique	Rotates eyeball upwards and outwards	Oculomotor nerve (3rd cranial nerve)

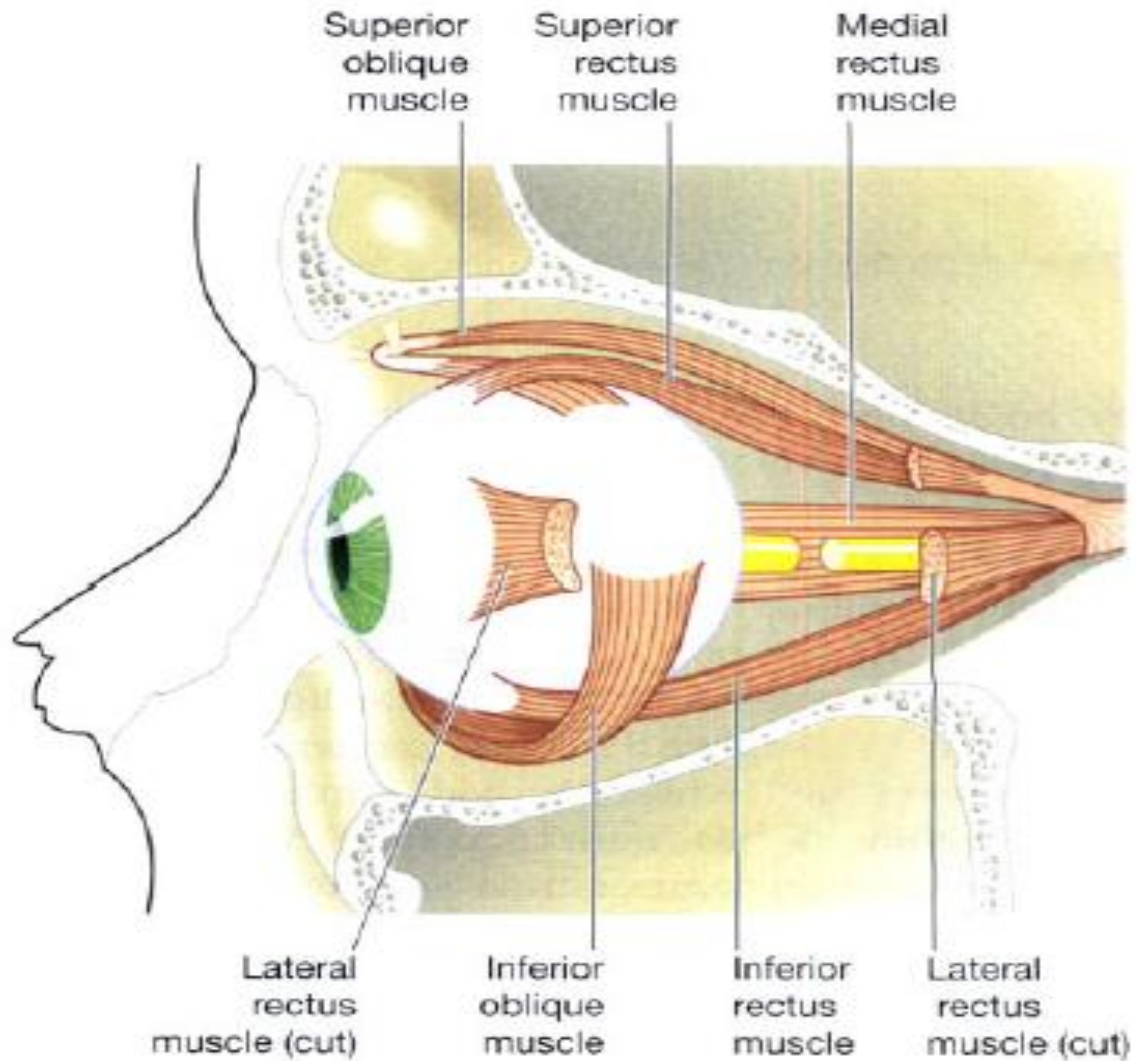


Figure 8.20 The extrinsic muscles of the eye.

Accessory organs of the eye

- **Eyebrows**: composed of hair that protect the eyeball from sweat, dust and other foreign bodies
- **Eyelids (palpebrae)**: movable folds of tissue found above and below the front of each eye. They also have the eyelashes (short curved hair). The layers of the eyelids are:
 - Thin skin
 - Loose areolar tissue (CT)
 - Two muscles (orbicularis oculi and levator palpebrae superioris)
 - Dense CT (tarsal plate)
 - A lining of conjunctiva

- **Conjunctiva** is a fine transparent membrane which lines the eyelids and the front of the eyeball . Where it lines the eyelids it consists of highly vascular columnar epithelium. Corneal conjunctiva consists of avascular stratified epithelium.
- When the eyelids are closed the conjunctiva becomes a closed sac. It protects the delicate cornea and the front of the eye.
- The medial and lateral angles of the eye where the upper and lower lids come together are called respectively the *medial canthus* and the *lateral canthus*.

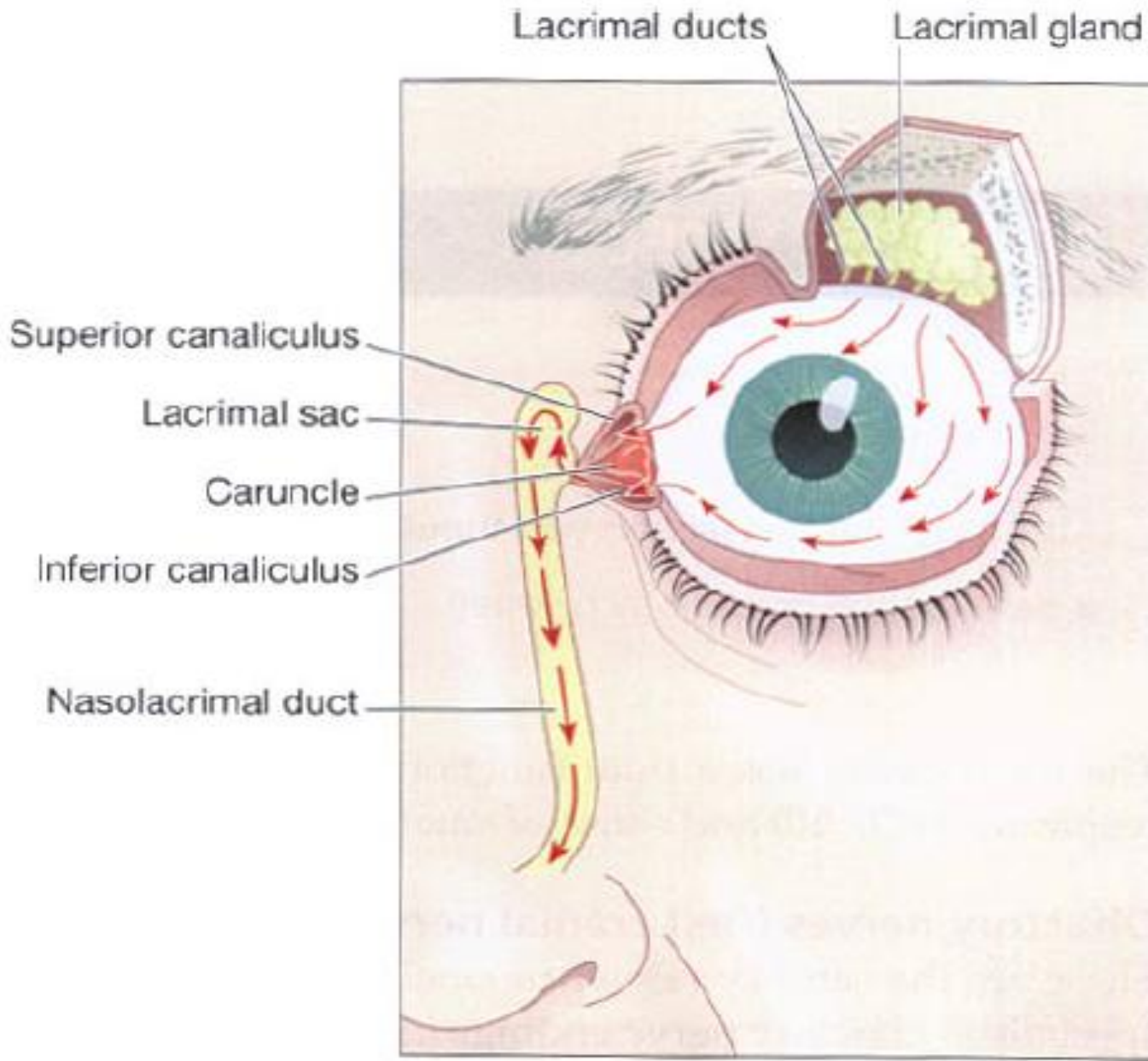
- **Eyelid margins**
- Along the edges of the lids there are numerous *sebaceous glands*, some with ducts opening into the hair follicles of the eyelashes and some on to the eyelid margins between the hairs.
- *Tarsal glands (meibomian glands)* are modified sebaceous glands embedded in the tarsal plates with ducts that open on to the inside of the free margins of the eyelids. They secrete an oily material, spread over the conjunctiva by blinking, which delays evaporation of tears.

- Functions of eyelids and eyelashes
 - Reflex closure of the lids occurs when the conjunctiva or eyelashes are touched, when an object comes close to the eye or when a bright light shines into the eye — this is called the *conjunctival or corneal reflex*.
 - Blinking at about 3- to 7-second intervals spreads tears and oily secretions over the cornea, preventing drying.
- When the *orbicularis oculi contracts, the eyes close*. When the *levator palpebrae contract the eyelids open*

Lacrimal apparatus

- For each eye this consists of:
 - i. 1 lacrimal gland and its ducts
 - ii. 2 lacrimal canaliculi
 - iii. 1 lacrimal sac
 - iv. 1 nasolacrimal duct.
- *The lacrimal glands are exocrine glands situated in recesses in the frontal bones on the lateral aspect of each eye just behind the supraorbital margin. The glands secrete tears composed of water, mineral salts, antibodies, and lysozyme.*
- The tears leave the lacrimal gland by several small ducts and pass over the front of the eye under the lids towards the medial canthus where they drain into the **two lacrimal canaliculi**; the opening of each is called the **punctum**. The two canaliculi lie one above the other, separated by a small red body, the **caruncle**.

- The tears then drain into the *lacrima sac* which is the upper expanded end of the *nasolacrima duct*. This is a membranous canal approximately 2 cm long, extending from the lower part of the lacrima sac to the nasal cavity, opening at the level of the inferior concha.
- Normally the rate of secretion of tears keeps pace with the rate of drainage. When a foreign body or other irritant enters the eye the secretion of tears is greatly increased and the conjunctival blood vessels dilate.
- Secretion of tears is also increased in emotional states, e.g. crying, laughing



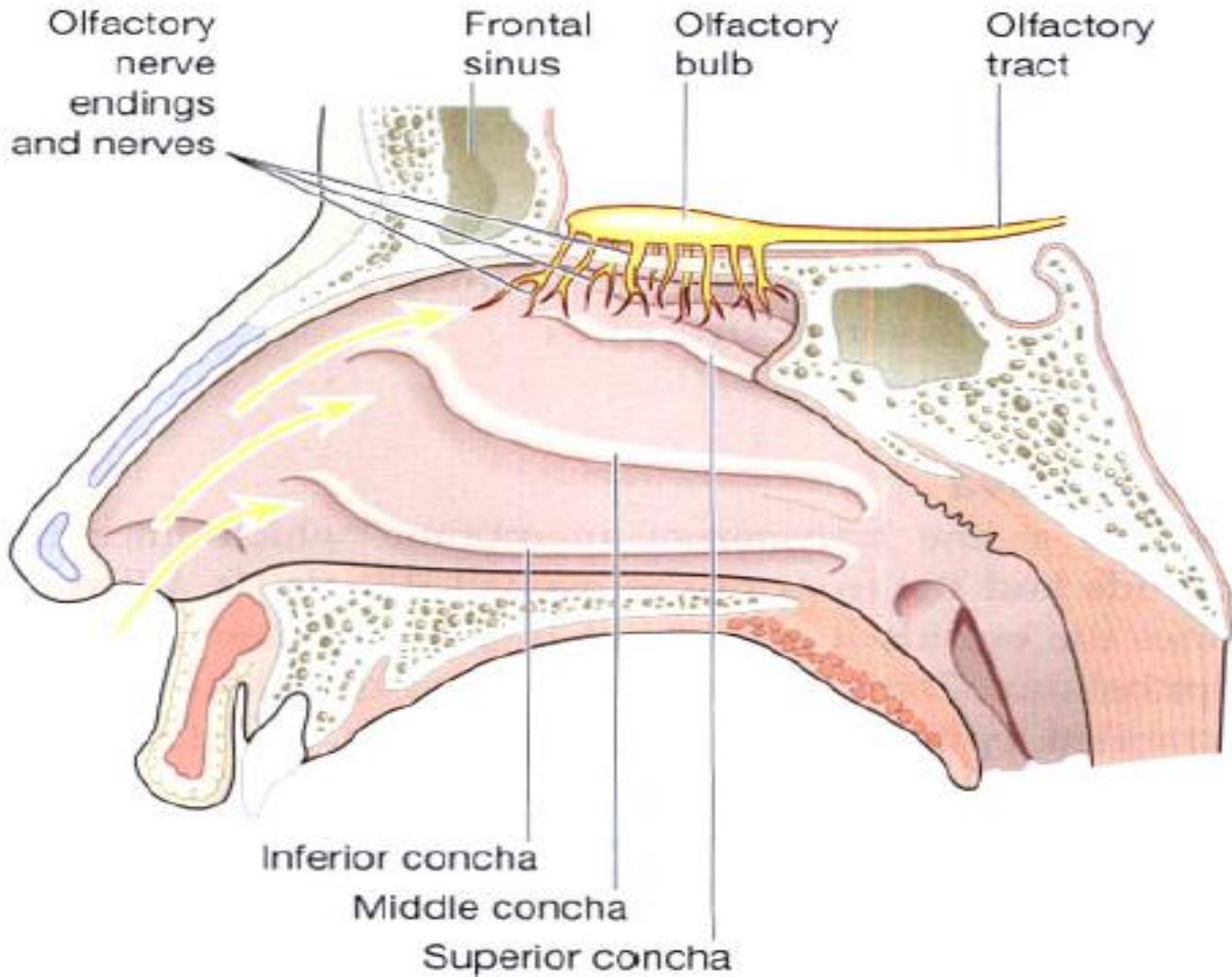
Functions

- i. Washing away irritating materials, e.g. dust, grit
- ii. The bacteriocidal enzyme lysozyme prevents microbial infection
- iii. Its oiliness delays evaporation and prevents drying of the conjunctiva
- iv. Nourishment of the cornea.

Sense of SMELL

- The nasal cavity has a dual function: a passageway for respiration and sense of smell (olfaction).
- Sensory nerves of smell originates from chemoreceptors in the mucous membrane of the roof of the nasal cavity above the superior nasal conchae

Olfactory Structures



Physiology of smell

- All odorous materials give off volatile molecules, which are carried into the nose with the inhaled air and stimulate the olfactory chemoreceptors when dissolved in mucus.
- The air entering the nose is warmed and convection currents carry eddies of inspired air to the roof of the nasal cavity.
- 'Sniffing' concentrates volatile molecules in the roof of the nose. This increases the number of olfactory receptors stimulated and thus the perception of the smell.

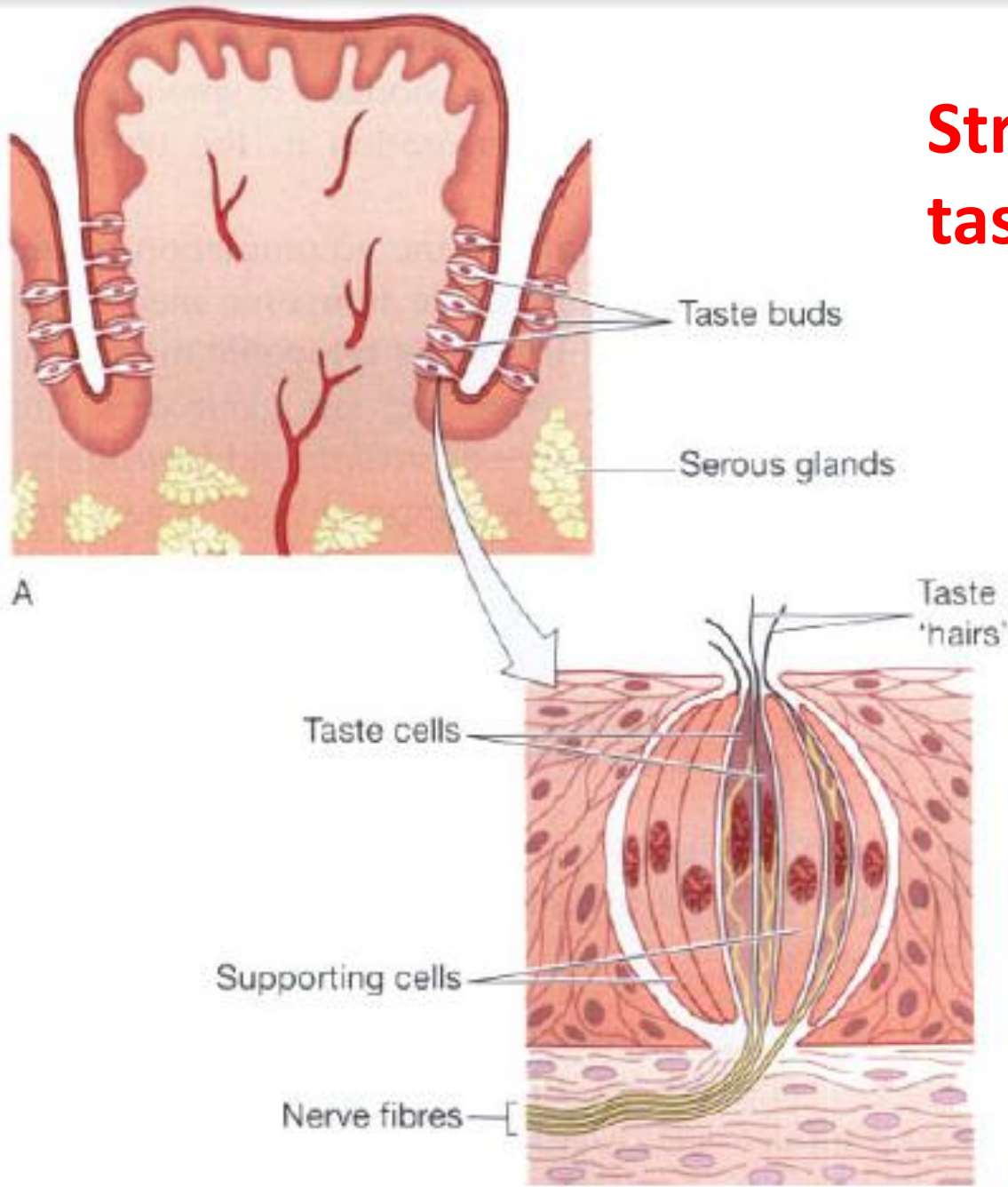
NB:

- Inflammation of the nasal mucosa prevents odorous substances from reaching the olfactory area of the nose, causing loss of the sense of smell (*anosmia*). The usual cause is the common cold.
- *Adaptation*. When an individual is continuously exposed to an odour, perception of the odour decreases and ceases within a few minutes.

Sense of TASTE

- A.k.a Gustation
- Closely linked with olfaction and it also involves stimulation of chemoreceptors by dissolved chemicals
- Taste buds contain chemoreceptors that are found on the papillae of the tongue and widely distributed in the epithelia of the tongue, soft palate, pharynx and the epiglottis. They consist of small sensory nerve endings of the glossopharyngeal, facial and vagus nerves (cranial nerves VII, IX and X).
- Some of the cells have hair-like microvilli on their free border, projecting towards tiny pores in the epithelium. The sensory receptors are stimulated by chemicals that enter the pores dissolved in saliva.

Structure of taste buds



- Nerve impulses are generated and conducted along the glossopharyngeal, facial and vagus nerves before synapsing in the medulla and thalamus.
- Their final destination is the *taste area* in the parietal lobe of the cerebral cortex where taste is perceived

Physiology of taste

- Four fundamental sensations of taste have been described — sweet, sour, bitter and salt. Some tastes consistently stimulate taste buds in specific parts of the tongue:
 - Sweet and salty, mainly at the tip
 - Sour, at the sides
 - Bitter, at the back.
- The sense of taste triggers salivation and the secretion of gastric juice (Ch. 12). It also has a protective function, e.g. when foul-tasting food is eaten then reflex gagging or vomiting may be induced.

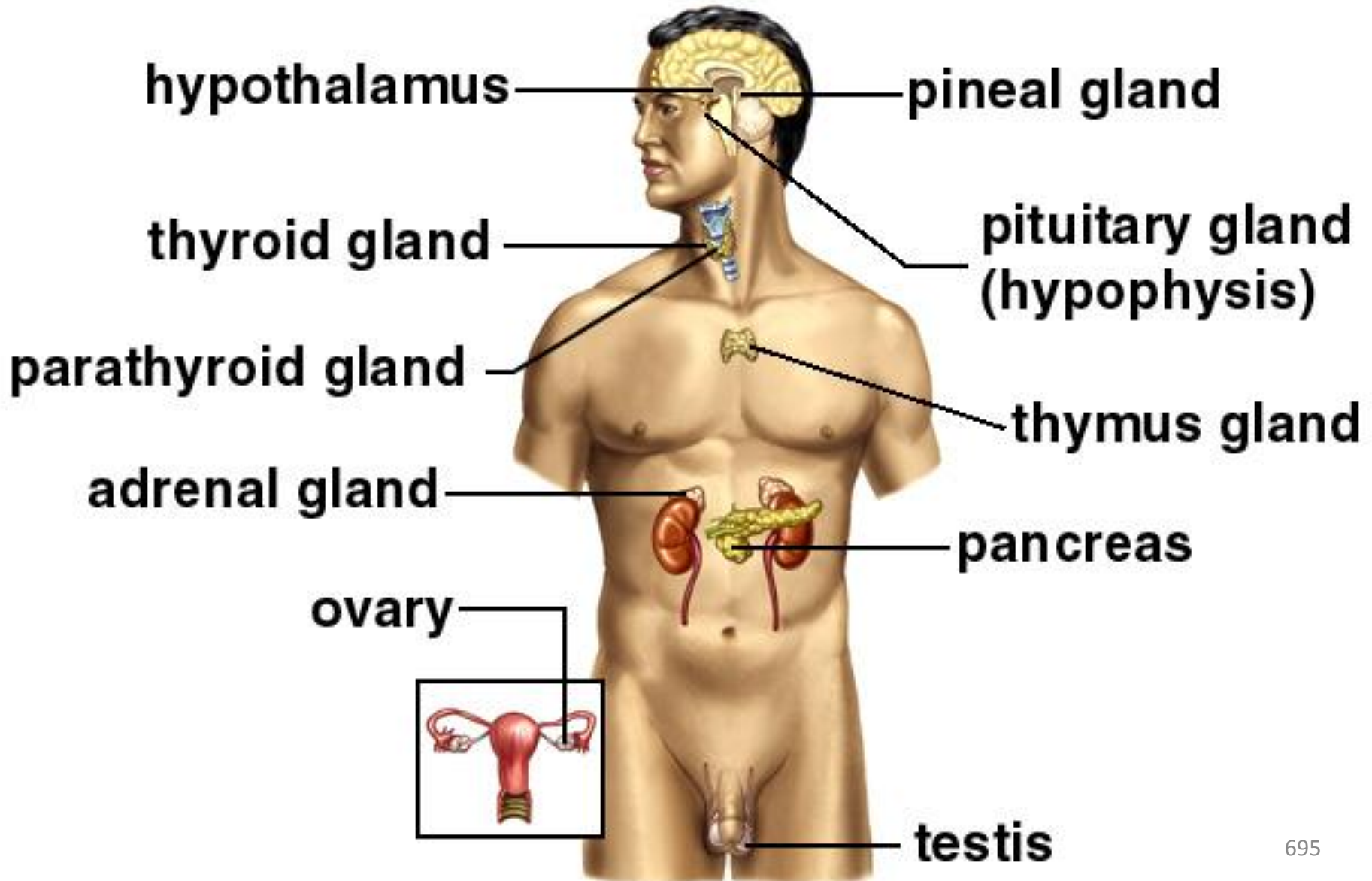
THE ENDOCRINE SYSTEM

ENDOCRINE SYSTEM

- Consists of glands widely separated from each other with no direct anatomical links.
- Endocrine glands
 - consist of groups of secretory cells surrounded by an extensive network of capillaries which facilitates diffusion of hormones from the secretory cells into the bloodstream.
 - are ductless because the hormones are secreted and diffuse directly into the bloodstream.
- A hormone is formed in one organ or gland and carried in the blood to another organ (target organ or tissue), where it influences cellular activity, especially growth and metabolism.
- Most hormones are synthesized from amino acids (amines, polypeptides and proteins; or are cholesterol-based lipids (steroids)).

- Endocrine glands are:
 - ✓ 1 pituitary gland
 - ✓ 1 thyroid gland
 - ✓ 4 parathyroid glands
 - ✓ 2 adrenal (suprarenal) glands
 - ✓ the pancreatic islets (islets of Langerhans)
 - ✓ 1 pineal gland or body
 - ✓ 1 thymus gland
 - ✓ 2 ovaries in the female
 - ✓ 2 testes in the male.

The Endocrine System



- When a hormone arrives at its target cell, it binds to a specific **receptor**, where it acts as a switch influencing chemical or metabolic reactions inside the cell.
- Receptors for
 - **water-soluble** hormones are situated on the **cell membrane**
 - **lipid-soluble** hormones are **inside the cell**.
- A hormone is released in response to a specific stimulus and usually its action reverses or negates the stimulus through a **negative feedback mechanism**.
- A **positive feedback mechanism** is amplification of the stimulus and increasing release of the hormone until a particular process is complete and the stimulus ceases, e.g. release of oxytocin during labour

Box 9.1 Examples of lipid-soluble and water-soluble hormones

Lipid-soluble hormones

Steroids

e.g. glucocorticoids,
mineralocorticoids

Thyroid hormones

Water-soluble hormones

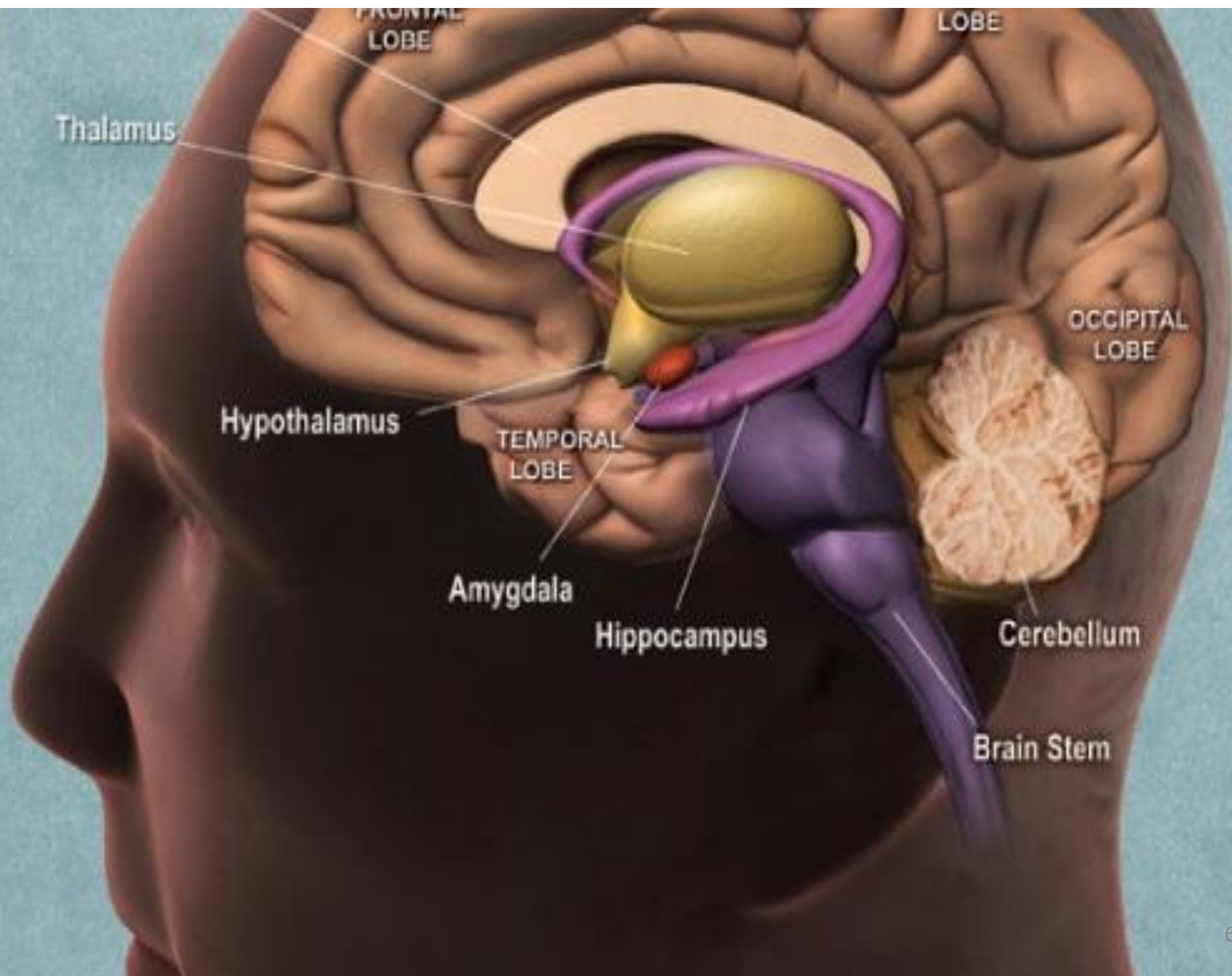
Adrenaline,
noradrenaline

Insulin

Glucagon

PITUITARY GLAND AND HYPOTHALAMUS

- They act as a unit, regulating the activity of most of the other endocrine glands.
- **Pituitary gland (Hypophysis)**
 - lies in the hypophyseal fossa of the sphenoid bone below the hypothalamus, to which it is attached by a stalk.
 - Pea-sized, weighs about 500 mg & consists of 3 distinct parts that originate from different types of cells.
 - **Anterior pituitary (adenohypophysis)** is an up growth of glandular epithelium from the pharynx
 - **Posterior pituitary (neurohypophysis)** is a down growth of nervous tissue from the brain. A network of nerve fibres exists between the **hypothalamus** and the **posterior pituitary**.
 - **Intermediate lobe**; a thin strip between the 2 lobes.



Blood supply

- **Arterial blood.**
 - Branches from the internal carotid artery.
 - Anterior lobe; supplied indirectly by blood that has already passed through a capillary bed in the hypothalamus but the posterior lobe is supplied directly.
- **Venous blood.**
 - Comes from both lobes, containing hormones, and leaves the gland in short veins that enter the venous sinuses between the layers of dura mater.

Influence of hypothalamus on pituitary gland

a) The anterior pituitary.

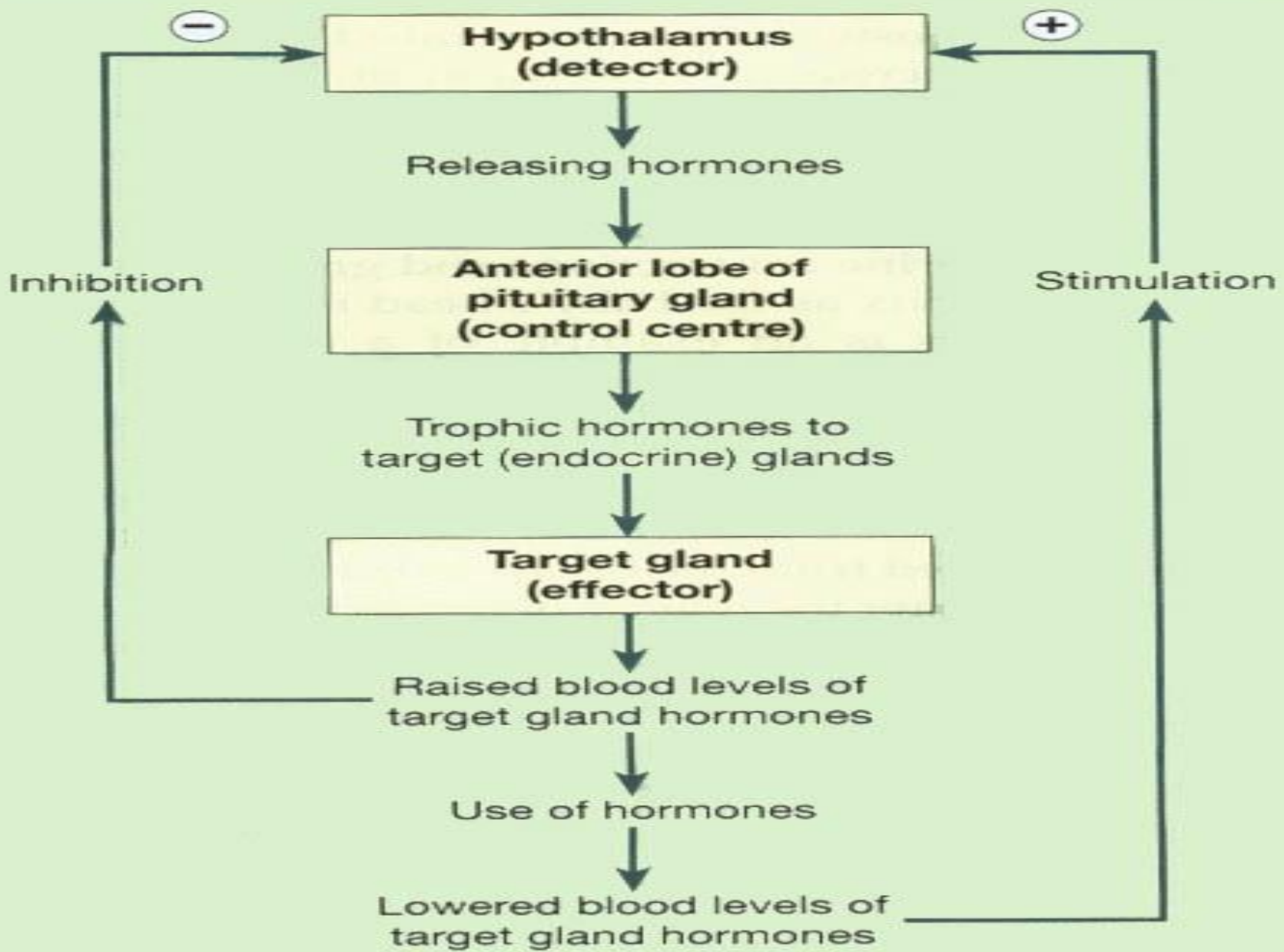
- Supplied indirectly with arterial blood that has already passed through a capillary bed in the hypothalamus.
- This network forms part of the **pituitary portal system**, which transports blood from the hypothalamus to the anterior pituitary where it enters thin-walled vascular sinusoids and is in very close contact with the secretory cells.
- The blood
 - Provides oxygen and nutrients,
 - Transports releasing and inhibiting hormones secreted by the hypothalamus; which influence secretion and release of other hormones formed in the anterior pituitary.

b) The posterior pituitary.

- Formed from nervous tissue and consists of nerve cells surrounded by supporting cells called **pituicytes**.
- These neurones have their cell bodies in the **supraoptic & paraventricular nuclei** of the hypothalamus and their axons form a bundle known as the **hypothalamo-hypophyseal tract**.
- Posterior pituitary hormones are synthesized in the nerve cell bodies, transported along the axons and then stored in vesicles within the axon terminals.
- Their release by **exocytosis** is triggered by nerve impulses from the hypothalamus.

ANTERIOR PITUITARY

- Release of an anterior pituitary hormone is controlled by a **negative feedback mechanism**.
- When there is a low level of a hormone in the blood supplying the hypothalamus it produces the appropriate releasing hormone which stimulates release of a trophic hormone by the anterior pituitary.
- This in turn stimulates the target gland to produce and release its hormone.
- As a result the blood level of that hormone rises and inhibits the secretion of releasing factor by the hypothalamus.

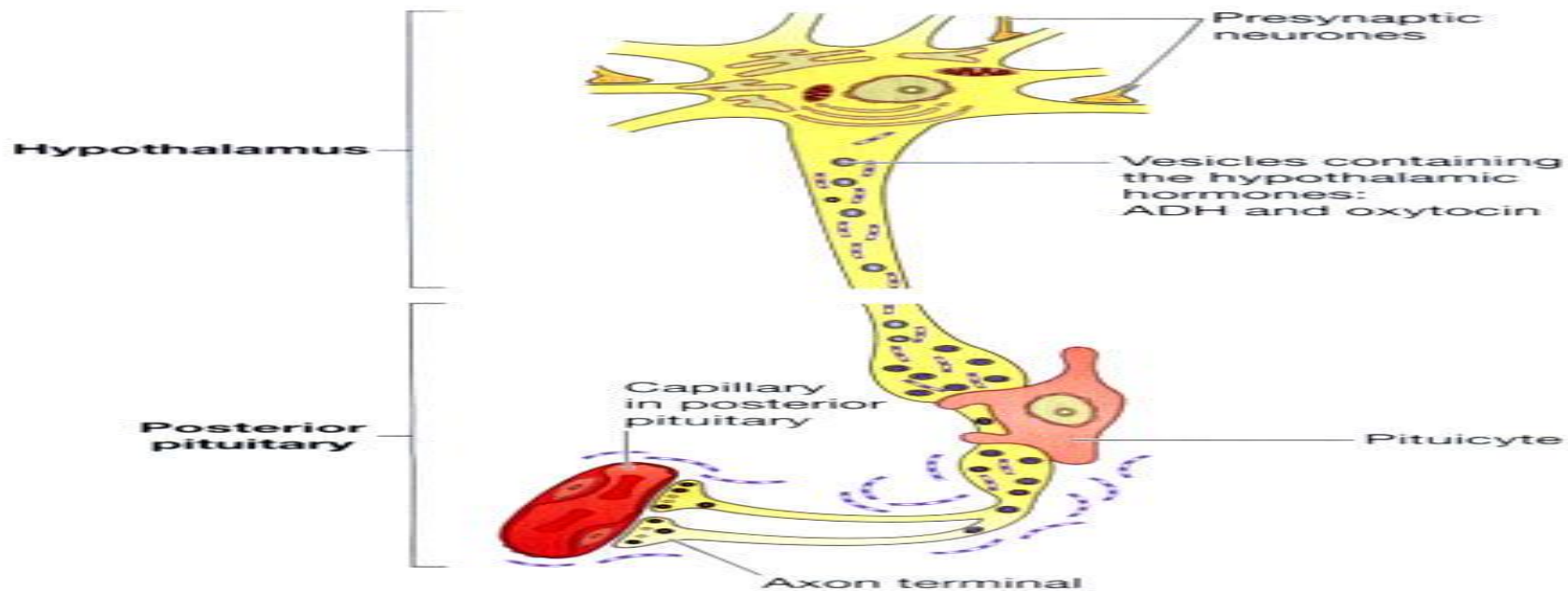
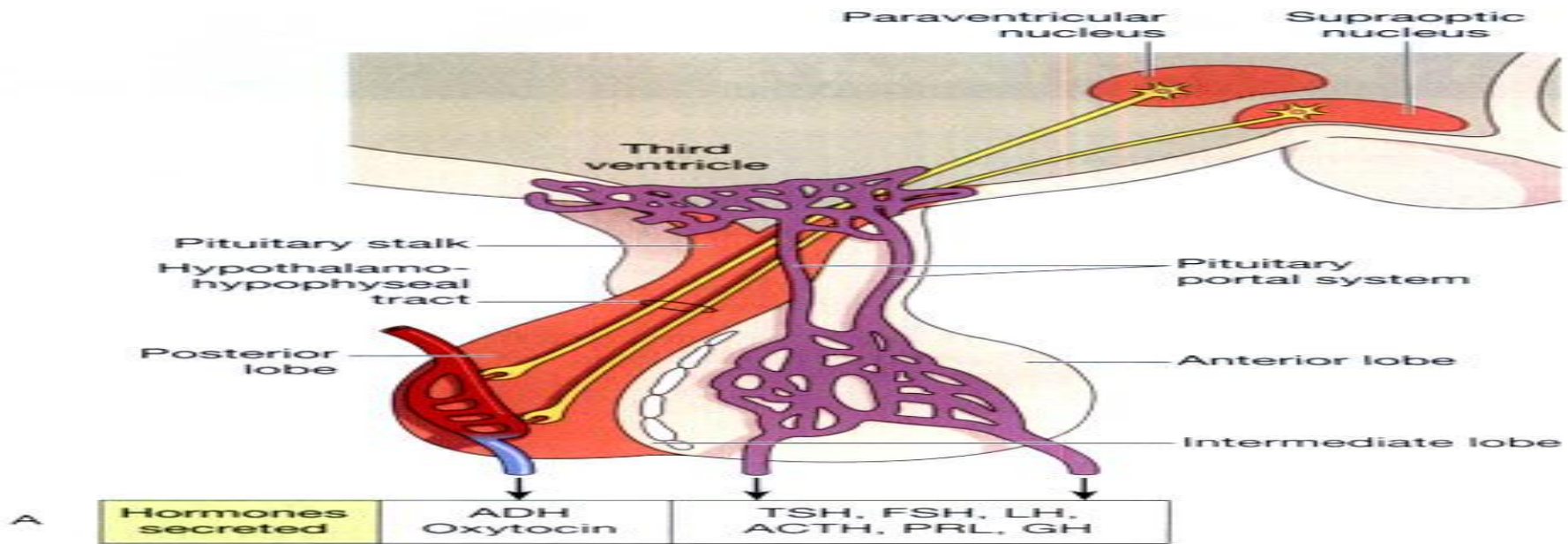


Negative feedback mechanism

Table 9.1 Hormones of the hypothalamus, anterior pituitary and their target tissues

Hypothalamus	Anterior pituitary	Target gland or tissue
GHRH	GH	Most tissues Many organs
GHRIH	GH inhibition TSH inhibition	Thyroid gland Pancreatic islets Most tissues
TRH	TSH	Thyroid gland
CRH	ACTH	Adrenal cortex
PRH	PRL	Breast
PIH	PRL inhibition	Breast
LHRH or GnRH	FSH LH	Ovaries and testes Ovaries and testes

- GHRH = growth hormone releasing hormone
- GH = growth hormone (somatotrophin)
- GHRIH = growth hormone release inhibiting hormone (somatostatin)
- TRH = thyroid releasing hormone
- TSH = thyroid stimulating hormone
- CRH = corticotrophin releasing hormone
- ACTH = adrenocorticotrophic hormone
- PRH = prolactin releasing hormone
- PRL = prolactin (lactogenic hormone)
- PIH = prolactin inhibiting hormone (dopamine)
- LHRH = luteinising hormone releasing hormone
- GnRH = gonadotrophin releasing hormone
- FSH = follicle stimulating hormone
- LH = luteinising hormone



The pituitary gland; Synthesis and storage of antidiuretic hormone and oxytocin.

a) **Thyroid stimulating hormone (TSH)**

- Synthesized by the anterior pituitary
- Its release is stimulated by TRH from the hypothalamus.
- Stimulates growth and activity of the thyroid gland, which secretes the hormones **thyroxine (T4)** and **triiodothyronine (T3)**.
- Release is lowest in the early evening and highest during the night.

b) **Adrenocorticotrophic hormone (corticotrophin, ACTH)**

- Corticotrophin releasing hormone (CRH) from the hypothalamus promotes the synthesis and release of ACTH by the anterior pituitary.
- Increases the concentration of cholesterol and steroids within the adrenal cortex and the output of steroid hormones, especially **cortisol**.

- ACTH levels are highest at about 8 a.m. and fall to their lowest about midnight, although high levels sometimes occur at midday and 6 p.m (circadian rhythm).
- It is associated with the sleep pattern and adjustment to changes takes several days, following, e.g., shift work changes, travel to a different time zone (jet lag).
- Other factors that stimulate secretion include
 - hypoglycaemia,
 - exercise
 - other stressors, e.g. emotional states and fever.

c) Growth hormone (GH)

- Most abundant hormone synthesized by the anterior pituitary.
- **Functions**
 - ✓ Stimulates growth and division of most body cells but especially those in the bones and skeletal muscles.
 - ✓ Regulates aspects of metabolism in many organs, e.g. liver, intestines and pancreas;
 - ✓ Stimulates protein synthesis;
 - ✓ Promotes breakdown of fats;
 - ✓ Increases blood glucose levels .

- Its release is stimulated by growth hormone releasing hormone (GHRH) and suppressed by growth hormone release inhibiting hormone (GHRIH) both of which are secreted by the hypothalamus.
- Secretion of GH is greater at night during sleep.
 - Hypoglycaemia, exercise and anxiety also stimulate release.
 - The daily amount secreted peaks in adolescence and then declines with age.
- Inhibition of GH secretion occurs by a negative feedback mechanism when the blood level rises and also when **GHRIH (somatostatin)** is released by the hypothalamus.
- GHRIH also suppresses secretion of
 - TSH
 - gastrointestinal secretions, e.g. gastric juice, gastrin and cholecystokinin

d) Prolactin

- Stimulates lactation (milk production) and has a direct effect on the breasts immediately after parturition (childbirth).
- Its blood level is stimulated by prolactin releasing hormone (PRH) released from the hypothalamus and it is lowered by prolactin inhibiting hormone (PIH, dopamine) and by an increased blood level of prolactin.
- After birth, suckling stimulates prolactin secretion and lactation. The resultant high blood level is a factor in reducing the incidence of conception during lactation.
- Together with oestrogens, corticosteroids, insulin and thyroxine; is involved in initiating and maintaining lactation.
- Secretion is related to sleep, i.e. it is raised during any period of sleep, night or day.
- Emotional stress increases production.

e) Gonadotrophins

- Secreted by the anterior pituitary in response to luteinising hormone releasing hormone (LHRH)/ gonadotrophin releasing hormone (GnRH).
- In both males and females these are:
 - follicle stimulating hormone (FSH)
 - luteinising hormone (LH).
- **In both sexes.** FSH stimulates production of gametes (ova or spermatozoa).
- **In females.** LH and FSH are involved in secretion of the hormones oestrogen and progesterone during the menstrual cycle.
- **In males.** LH (**interstitial cell stimulating hormone**) (ICSH) stimulates the interstitial cells of the testes to secrete the hormone testosterone.

Table 9.2 Summary of the hormones secreted by the anterior pituitary gland and their functions

Hormone	Function
Growth hormone (GH)	Regulates metabolism, promotes tissue growth especially of bones and muscles
Thyroid stimulating hormone (TSH)	Stimulates growth and activity of thyroid gland and secretion of T_3 and T_4
Adrenocorticotrophic hormone (ACTH)	Stimulates the adrenal cortex to secrete glucocorticoids
Prolactin (PRL)	Stimulates milk production in the breasts
Follicle stimulating hormone (FSH)	Stimulates production of sperm in the testes, stimulates secretion of oestrogen by the ovaries, maturation of ovarian follicles, ovulation
Luteinising hormone (LH)	Stimulates secretion of testosterone by the testes, stimulates secretion of progesterone by the corpus luteum

POSTERIOR PITUITARY

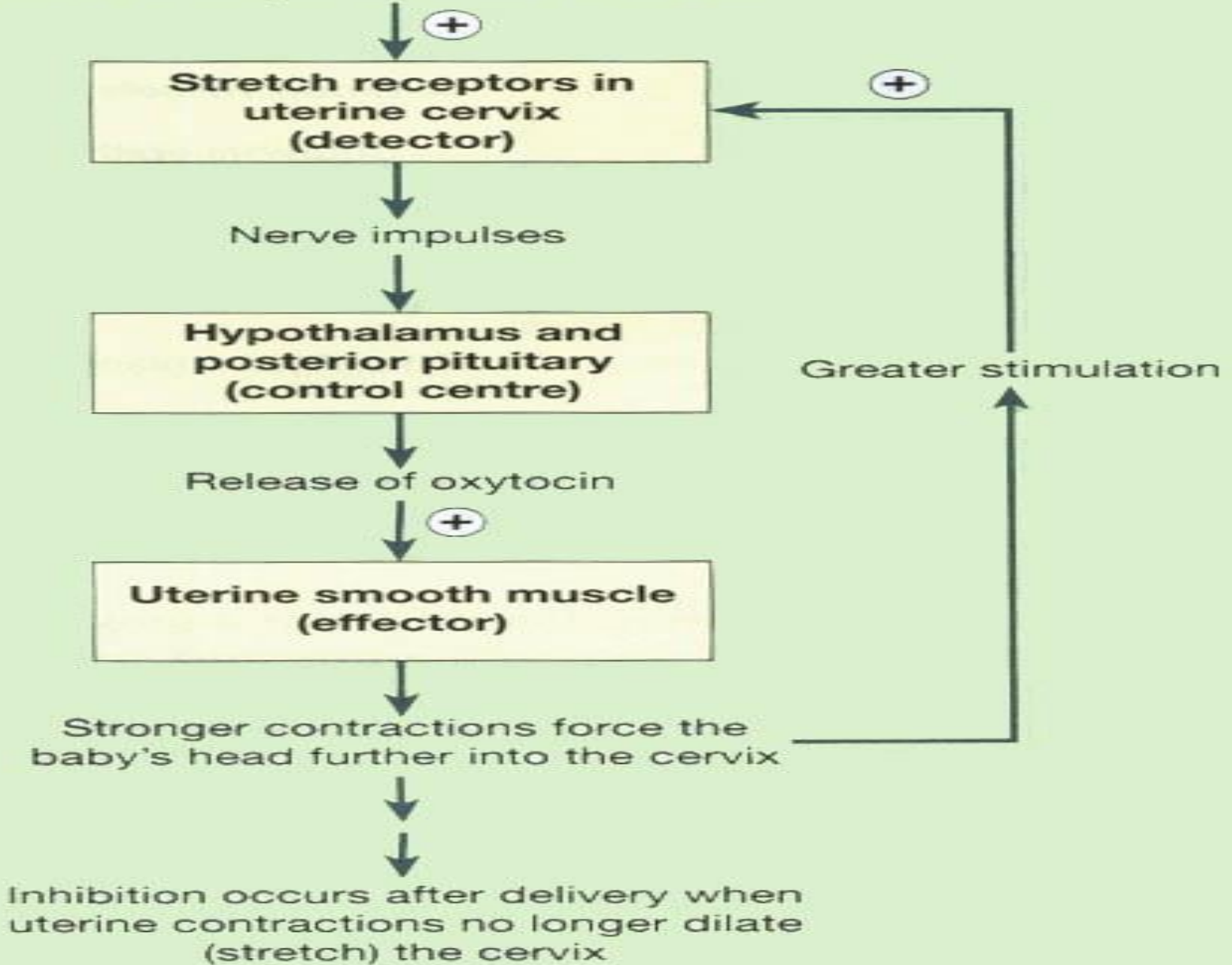
- Releases oxytocin and antidiuretic hormone (ADH or vasopressin); hormones synthesized in the hypothalamus.
- The hormones act directly on non-endocrine tissue and their release by **exocytosis** is stimulated by nerve impulses from the hypothalamus.

a) Oxytocin

- Stimulates 2 target tissues during and after parturition (childbirth): **uterine smooth muscle and the muscle cells of the lactating breast.**
- During parturition increasing amounts of oxytocin are released into the bloodstream in response to increasing distension of sensory stretch receptors in the uterine cervix by the baby's head.

- Sensory impulses are generated and travel to the control centre in the hypothalamus, stimulating the posterior pituitary to release more oxytocin.
- In turn this stimulates more forceful uterine contractions and greater stretching of the uterine cervix as the baby's head is forced further downwards (positive feedback mechanism).
- The process of milk ejection also involves a positive feedback mechanism. Suckling generates sensory impulses that are transmitted from the breast to the hypothalamus.
- The impulses trigger the release of oxytocin from the posterior pituitary and oxytocin stimulates contraction of the myoepithelial cells around the glandular cells and ducts of the lactating breast to contract, ejecting milk.
- Suckling also inhibits the release of prolactin inhibiting hormone (PIH), prolonging prolactin secretion and lactation.

In labour, uterine contractions force the baby's head into the cervix



Positive feedback mechanism; oxytocin

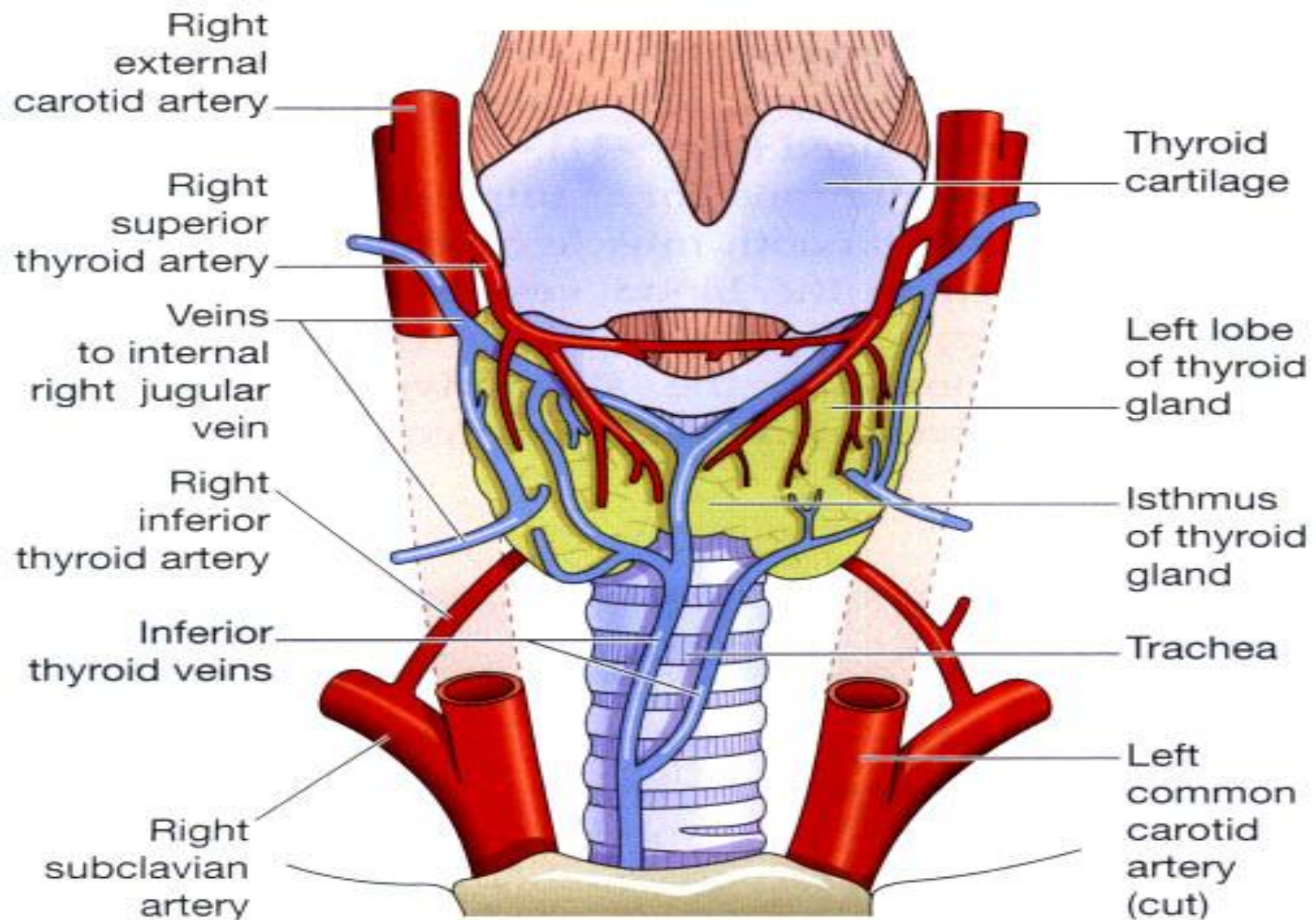
b) Antidiuretic hormone (ADH) or vasopressin

- **Main effect:** to reduce urine output.
- Increases the permeability to water of the distal convoluted and collecting tubules of the nephrons of the kidneys. As a result the reabsorption of water from the glomerular filtrate is increased.
- Amount of ADH secreted is influenced by the osmotic pressure of the blood circulating to the osmoreceptors in the hypothalamus.
- As the osmotic pressure rises, the secretion of ADH increases. More water is therefore reabsorbed and the urine output is reduced, thus the body retains more water and the rise in osmotic pressure is reversed.
- Conversely, when the osmotic pressure of the blood is low, e.g., after a large fluid intake, secretion of ADH is reduced, less water is reabsorbed and more urine is produced .
- At high concentrations, e.g., after severe blood loss, ADH causes smooth muscle contraction, especially vasoconstriction in the blood vessels of the skin and abdominal organs. This has a pressor effect, raising systemic blood pressure.

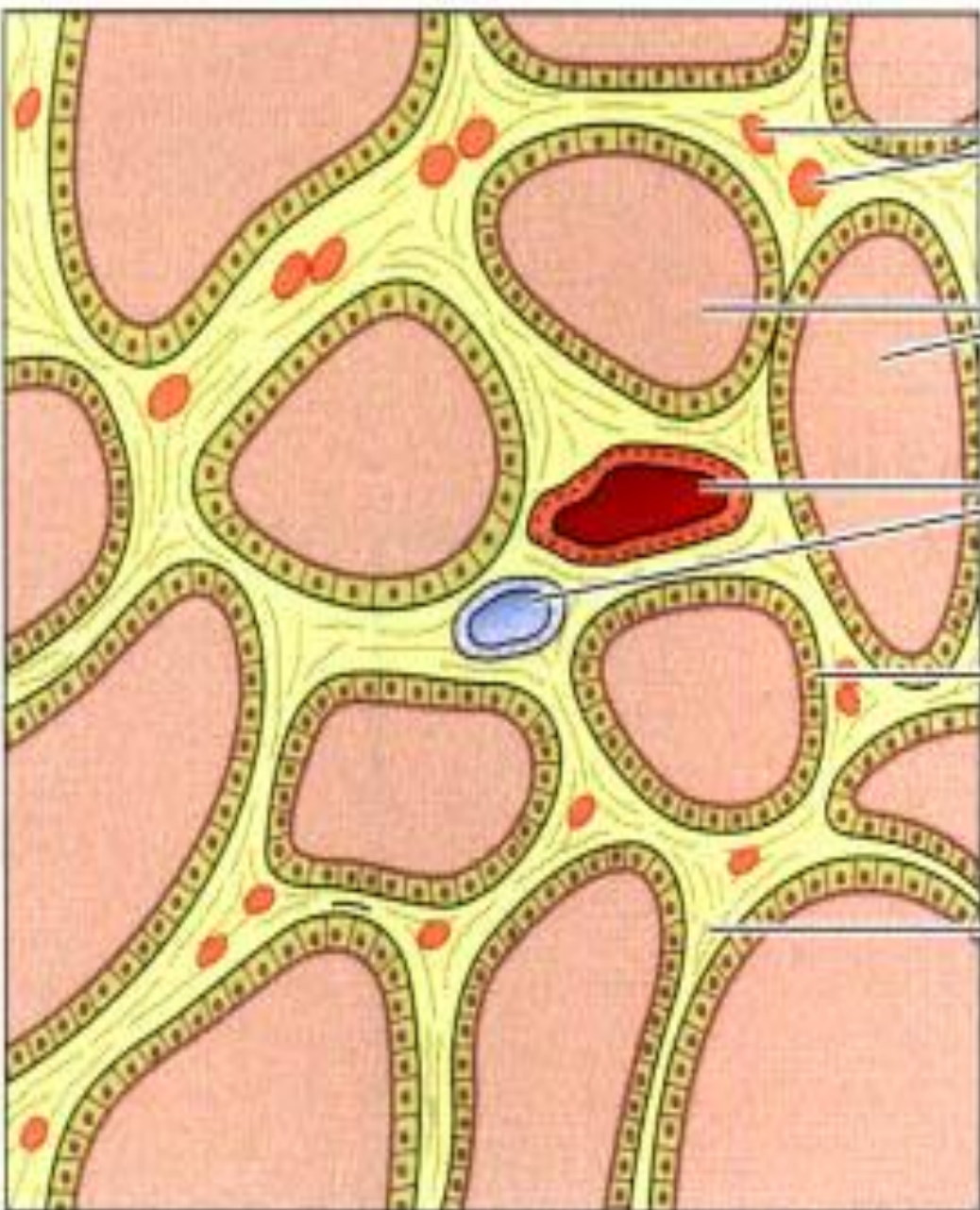
THYROID GLAND

- Situated in the neck in front of the larynx and trachea at the level of the 5th, 6th and 7th cervical and 1st thoracic vertebrae.
- Highly vascular gland; weighs about 25 g & is surrounded by a fibrous capsule.
- Has 2 lobes, one on either side; joined by a narrow **isthmus**, lying in front of the trachea.
- Lobes are roughly cone-shaped, about 5 cm long & 3 cm wide.
- Arterial blood is through the
 - **Superior &**
 - **inferior thyroid arteries.**

- Venous return; by the **thyroid veins** which drain into the internal jugular veins.
- 2 parathyroid glands lie against the posterior surface of each lobe
- **Recurrent laryngeal nerve** passes upwards close to the lobes of the gland and on the right side it lies near the inferior thyroid artery.
- The gland is composed of **cuboidal epithelium** that forms spherical follicles; which secrete and store colloid, a thick sticky protein material (thyroglobulin).
- Between the follicles there are other cells found singly or in small groups: **parafollicular cells (C-cells)**, which secrete the hormone **calcitonin**.



Thyroid gland and associated structures



- Parafollicular cells
- Follicles filled with colloid
- Blood vessels
- Cuboidal epithelium (follicular cells)
- Interlobular connective tissue

Microscopic structure

- Assignment:
 - draw the microscopic structure of thyroid gland
 - Make notes on the regulation of the secretion of thyroxine (T_4) and triiodothyronine (T_3).

i) Thyroxine and triiodothyronine

- Iodine is essential for the formation of the thyroid gland hormones; **thyroxine (T4)** & **tri-iodothyronine (T3)**.
- Body's main sources of iodine are
 - seafood,
 - vegetables grown in iodine-rich soil
 - iodinated table salt in the diet.
- **Iodine trapping:** process by which thyroid gland selectively takes up iodine from the blood
- Thyroid hormones are synthesized as large precursor molecules called **thyroglobulin**.
- Release of T3 & T4 into the blood is regulated by TSH.

- Secretion of TSH is stimulated by the **TRH** from the hypothalamus.
- Secretion of TRH is stimulated by
 - exercise,
 - stress,
 - malnutrition,
 - low plasma glucose
 - sleep.
- Increased levels of T3 and T4; decrease TSH secretion and vice versa .
- When the iodine supply is deficient, excess TSH is secreted and there is proliferation of thyroid gland cells and enlargement of the gland.
- Secretion of T3 and T4 begins about the 3rd month of fetal life and is increased at puberty and in women during the reproductive years, especially during pregnancy.

- Thyroid hormones enter the target cells and regulate the expression of genes in the nucleus.
- T3 and T4 affect most cells of the body by:
 - increasing the basal metabolic rate and heat production
 - regulating metabolism of carbohydrates, proteins and fats.
- T3 and T4
 - may enhance effect of other hormones (adrenaline & noradrenaline).
 - are essential for physical growth and mental development
 - helps in regulating the metabolic rate of all body cells.
 - increase protein and bone turnover.

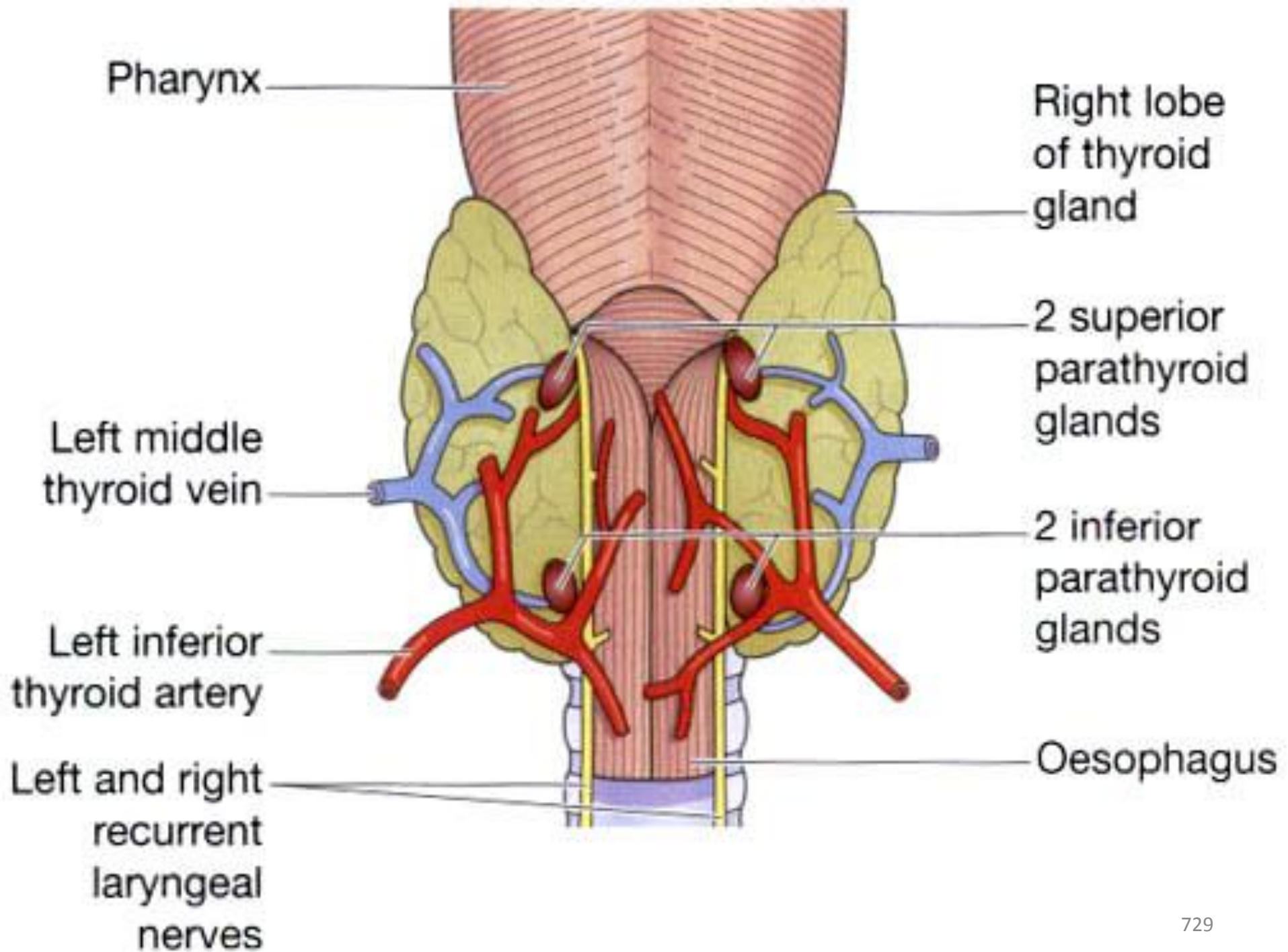
ii) Calcitonin

- Secreted by the parafollicular (C-cells).
- **Functions**
 - Acts on bone and the kidneys to reduce the blood calcium (Ca^{2+}) level when it is raised.
 - Reduces the reabsorption of calcium from bones
 - Inhibits reabsorption of calcium by the renal tubules.
- Its effect is antagonistic to that of **parathyroid hormone (PTH, parathormone)**; secreted by parathyroid glands.
- Release of calcitonin is stimulated by an increase in the blood calcium level.
- Important during childhood when bones undergo considerable changes in size and shape.

PARATHYROID GLANDS

- 4 parathyroid glands, 2 embedded in the posterior surface of each lobe of the thyroid gland
- Surrounded by fine connective tissue capsules.
- Cells forming the glands are spherical in shape and are arranged in columns with channels containing blood between them.
- Secrete **parathyroid hormone (PTH, parathormone)**.
- Secretion is regulated by the blood level of calcium. When this falls, secretion of PTH is increased and vice versa.
- **Main function** of PTH is to increase the blood calcium level when it is low.

- This is achieved by
 - indirectly increasing the amount of calcium absorbed from the small intestine and reabsorbed from the renal tubules.
 - If these sources provide inadequate supplies then PTH stimulates osteoclasts (bone-destroying cells) and resorption of calcium from bones.
- PTH & calcitonin from the thyroid gland act in a complementary manner to maintain blood calcium levels within the normal range.
- This is needed for:
 - muscle contraction
 - blood clotting
 - nerve impulse transmission.



ADRENAL/SUPRARENAL GLANDS

- 2, one situated on the upper pole of each kidney enclosed within the renal fascia .
- Are about 4 cm long & 3 cm thick.
- **Arterial blood supply;** by branches from the abdominal aorta and renal arteries.
- **Venous return;** by suprarenal veins.
 - **right gland** drains into the **inferior vena cava** &
 - **left gland** into the **left renal vein**.
- Composed of 2 parts.
 - outer part; **cortex**
 - inner part; **medulla**.
- Adrenal cortex is essential to life but the medulla is not.

Adrenal cortex

- Produces 3 groups of steroid hormones from cholesterol collectively called **adrenocorticoids** (corticosteroids, corticoids).
- They are:
 - glucocorticoids
 - mineralocorticoids
 - sex hormones (androgens).
- a) Glucocorticoids** e.g., Cortisol (hydrocortisone), corticosterone and cortisone
- Essential for life, regulating metabolism & responses to stress.
- Secretion is stimulated by
 - ACTH from the anterior pituitary
 - stress.

- In non-stressful conditions secretion has marked circadian variations. The highest level of hormones occurs between 4 a.m. and 8 a.m. and the lowest, between midnight and 3 a.m.
- **Effects of glucocorticoids**
 - ✓ gluconeogenesis (formation of new sugar from, e.g. protein) and hyperglycaemia.
 - ✓ lipolysis (breakdown of triglycerides into fatty acids and glycerol for energy production)
 - ✓ stimulating breakdown of protein, releasing amino acids, which can be used for synthesis of other proteins, e.g. enzymes, or for energy (ATP) production
 - ✓ promoting absorption of sodium and water from renal tubules (a weak mineralocorticoid effect).

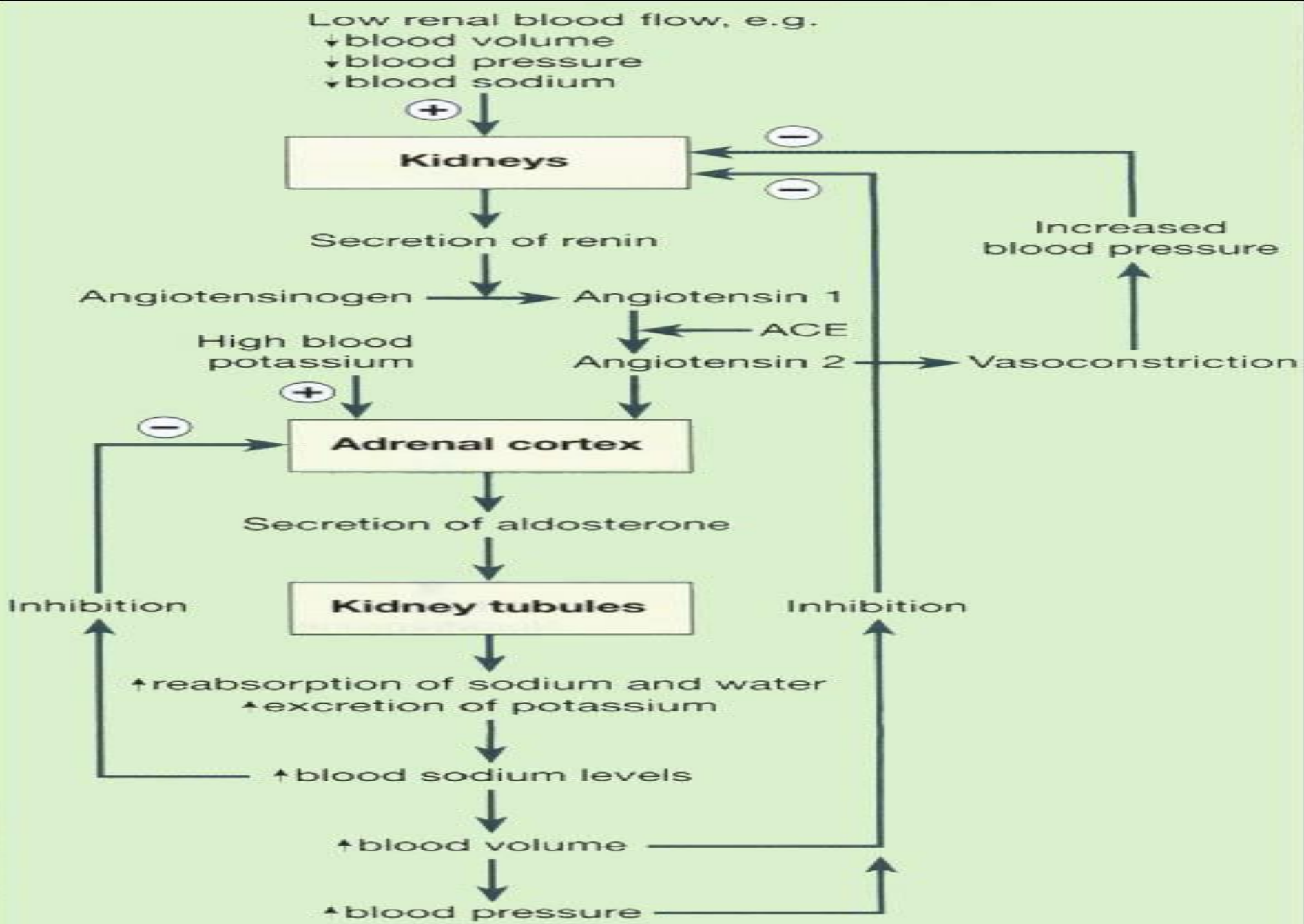
- In pathological and pharmacological quantities glucocorticoids:
 - have an anti-inflammatory action
 - suppress the immune response
 - suppress the response of tissues to injury
 - delay wound healing.

b) Mineralocorticoids e.g., aldosterone

- Angiotensin also stimulates the release of aldosterone.
- **Functions**
 - Maintenance of water and electrolyte balance in the body.
 - Stimulates the re-absorption of sodium (Na^+) by the renal tubules
 - Increases excretion of potassium (K^+) in the urine.
 - Regulation of blood volume and blood pressure

Renin-angiotensin-aldosterone system.

- When renal blood flow is reduced or blood sodium levels fall the enzyme renin is secreted by kidney cells.
- Renin converts the plasma protein angiotensinogen, produced by the liver, to angiotensin I.
- Angiotensin converting enzyme (ACE), formed in small quantities in the lungs, proximal kidney tubules and other tissues converts angiotensin I to angiotensin II, which stimulates secretion of aldosterone.
- It also causes vasoconstriction and increases blood pressure.



Regulation of aldosterone secretion

c) Sex hormones

- Secreted by the adrenal cortex
- Mainly androgens (male sex hormones).
- Contribute to the onset of puberty. An elevated level in females causes **masculinisation**.

Adrenal medulla

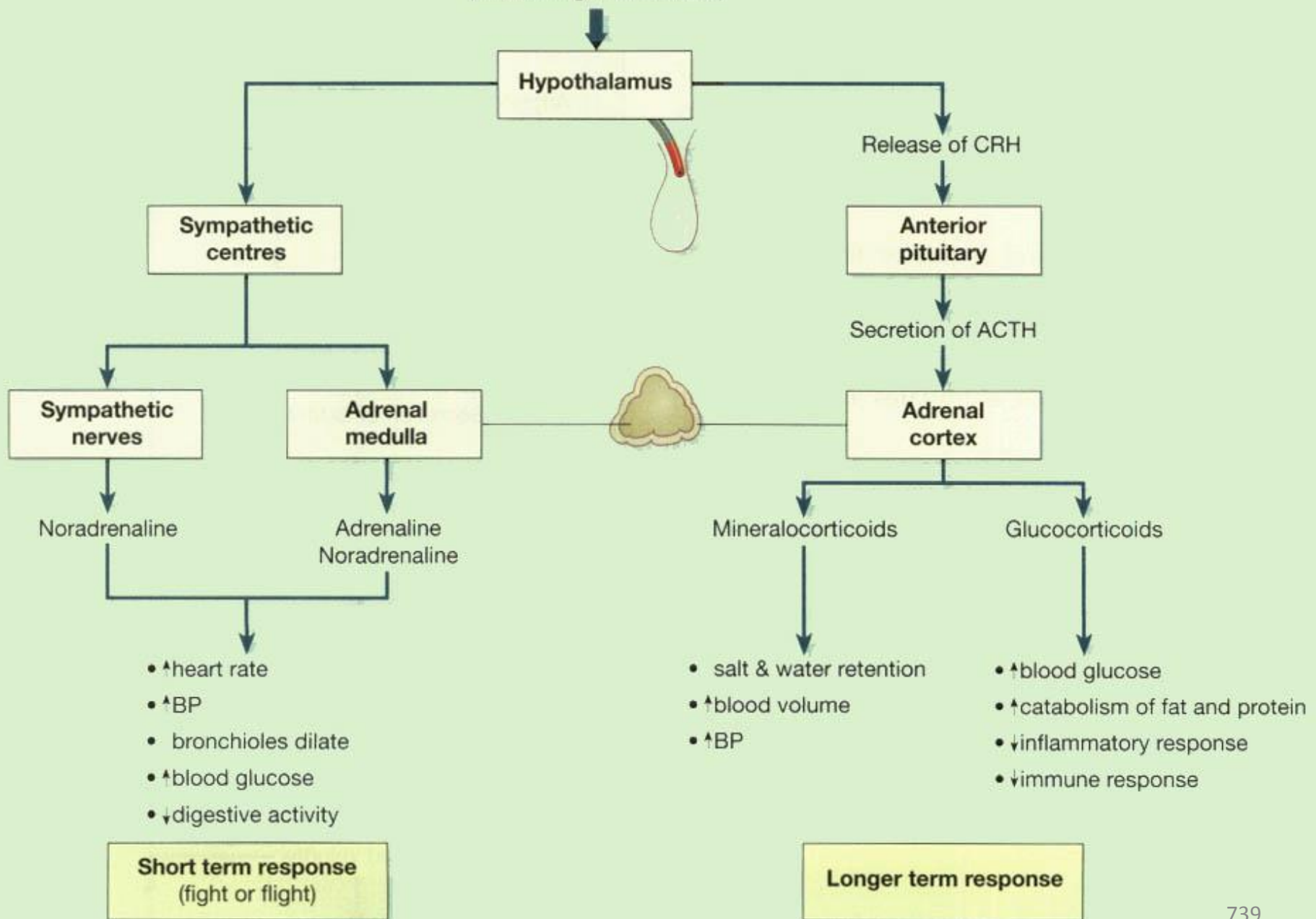
- Develops from nervous tissue in the embryo and is part of the sympathetic division of the autonomic nervous system.
- Stimulated by its extensive sympathetic nerve supply to produce the hormones **adrenaline and nor-adrenaline**.
- **Adrenaline and noradrenaline**
- Noradrenaline is the postganglionic neurotransmitter of the sympathetic division of the autonomic nervous system.
- Adrenaline and some noradrenaline are released into the blood from the adrenal medulla during stimulation of the sympathetic nervous system.

- They are structurally very similar with similar effects.
- Together they potentiate the fight or flight response after initial sympathetic stimulation by:
 - increasing heart rate
 - increasing blood pressure
 - diverting blood to essential organs including the heart, brain and skeletal muscles by dilating their vessels and constricting those of less essential organs, such as the skin
 - increasing metabolic rate
 - dilating the pupils.
- Adrenaline has a greater effect on the heart and metabolic processes whereas noradrenaline has more influence on blood vessels.

RESPONSE TO STRESS

- When the body is under stress homeostasis is disturbed. To restore it and, in some cases, to maintain life there are immediate and, if necessary, longer-term responses.
- Stressors include exercise, fasting, fright, temperature changes, infection, disease and emotional disturbances/ situations.
- The immediate response is described as preparing for 'fight or flight'. This is mediated by the sympathetic part of the autonomic nervous.
- In the longer term, ACTH from the anterior pituitary stimulates the release of glucocorticoids and mineralocorticoids from the adrenal cortex and a more prolonged response to stress occurs.

STRESSOR
(threatening homeostasis)



PANCREATIC ISLETS

- Found in clusters irregularly distributed throughout the substance of the pancreas.
- Pancreatic hormones are secreted directly into the bloodstream and circulate throughout the body.
- 3 main types of cells in the pancreatic islets:
 - α (alpha) cells that secrete glucagon
 - β (beta) cells that secrete insulin
 - δ (delta) cells that secrete somatostatin (GHRH).
- The normal blood glucose level is between 2.5 and 5.3 mmol/litre (45 to 95 mg/100 ml).
- Blood glucose levels are controlled mainly by the antagonistic actions of insulin and glucagon:
 - glucagon increases blood glucose levels
 - insulin reduces blood glucose levels.

a) Insulin

- Main function: Lowering blood levels of absorbed nutrients when they rise above normal.
- Insulin promotes storage by:
 - acting on cell membranes and stimulating uptake and use of glucose by muscle and connective tissue cells
 - increasing conversion of glucose to glycogen (glycogenesis), especially in the liver and skeletal muscles
 - accelerating uptake of amino acids by cells, and the synthesis of protein
 - promoting synthesis of fatty acids and storage of fat in adipose tissue (lipogenesis)
 - decreasing glycogenolysis
 - preventing the breakdown of protein and fat, and gluconeogenesis (formation of new sugar from, e.g. protein).

- Secretion of insulin is stimulated by increased blood glucose and amino acid levels, and gastrointestinal hormones, e.g. gastrin, secretin and cholecystokinin.
- Secretion is decreased by sympathetic stimulation, glucagon, adrenaline, cortisol and somatostatin (GHRH) secreted by cells of the pancreatic islets.
- Insulin is a polypeptide consisting of about 50 amino acids.

b) Glucagon

- Increases blood glucose levels by stimulating, e.g.:
 - conversion of glycogen to glucose in the liver and skeletal muscles (glycogenolysis)
 - gluconeogenesis.
- Secretion of glucagon is stimulated by a low blood glucose level and exercise and decreased by somatostatin and insulin.

c) Somatostatin (GHRH)

- Also produced by the hypothalamus; inhibits the secretion of both insulin and glucagon.

PINEAL GLAND/BODY

- Small body attached to the roof of the third ventricle and is connected to it by a short stalk containing nerves, many of which terminate in the hypothalamus.
- About 10 mm long; reddish brown in colour and is surrounded by a capsule.

Melatonin

- Hormone secreted by the pineal gland.
- Secretion is influenced by the amount of light entering the eye stimulating the optic pathways and levels fluctuate during each 24-hour period, being highest at night and lowest around midday.
- **Functions:**
 - coordination of the circadian and diurnal rhythms of many tissues, possibly by influencing the hypothalamus
 - inhibition of growth and development of the sex organs before puberty, possibly by preventing synthesis or release of gonadotrophins.
- Atrophies after puberty and may become calcified in later life.

THYMUS GLAND



Thymosin

- Hormone secreted by the thymus gland
- Required for the development of T-lymphocytes for cell mediated immunity.

LOCAL HORMONES

- a) **Histamine:** Synthesised by
- a) mast cells in the tissues
 - b) basophils in blood.
- Released as part of the inflammatory process, increasing capillary permeability and dilatation.
 - Causes contraction of smooth muscle of the bronchi and alimentary tract.
 - Stimulates the secretion of gastric juice.
- b) **Serotonin (5-hydroxytryptamine, 5-HT):** Present in
- platelets,
 - brain
 - the intestinal wall.
- Causes intestinal secretion and contraction of smooth muscle and its role in haemostasis (blood clotting)

- c) Prostaglandins (PGs):** Lipid substances that act as local hormones and have wide-ranging physiological effects in:
- the inflammatory response
 - potentiating pain
 - fever
 - regulating blood pressure
 - blood clotting
 - uterine contractions during labour.
- Chemically similar compounds include
 - leukotrienes
 - thromboxanes.

d) Erythropoietin:

- Synthesised by the kidneys
- **Function:** increases erythropoiesis

e) Gastrointestinal hormones

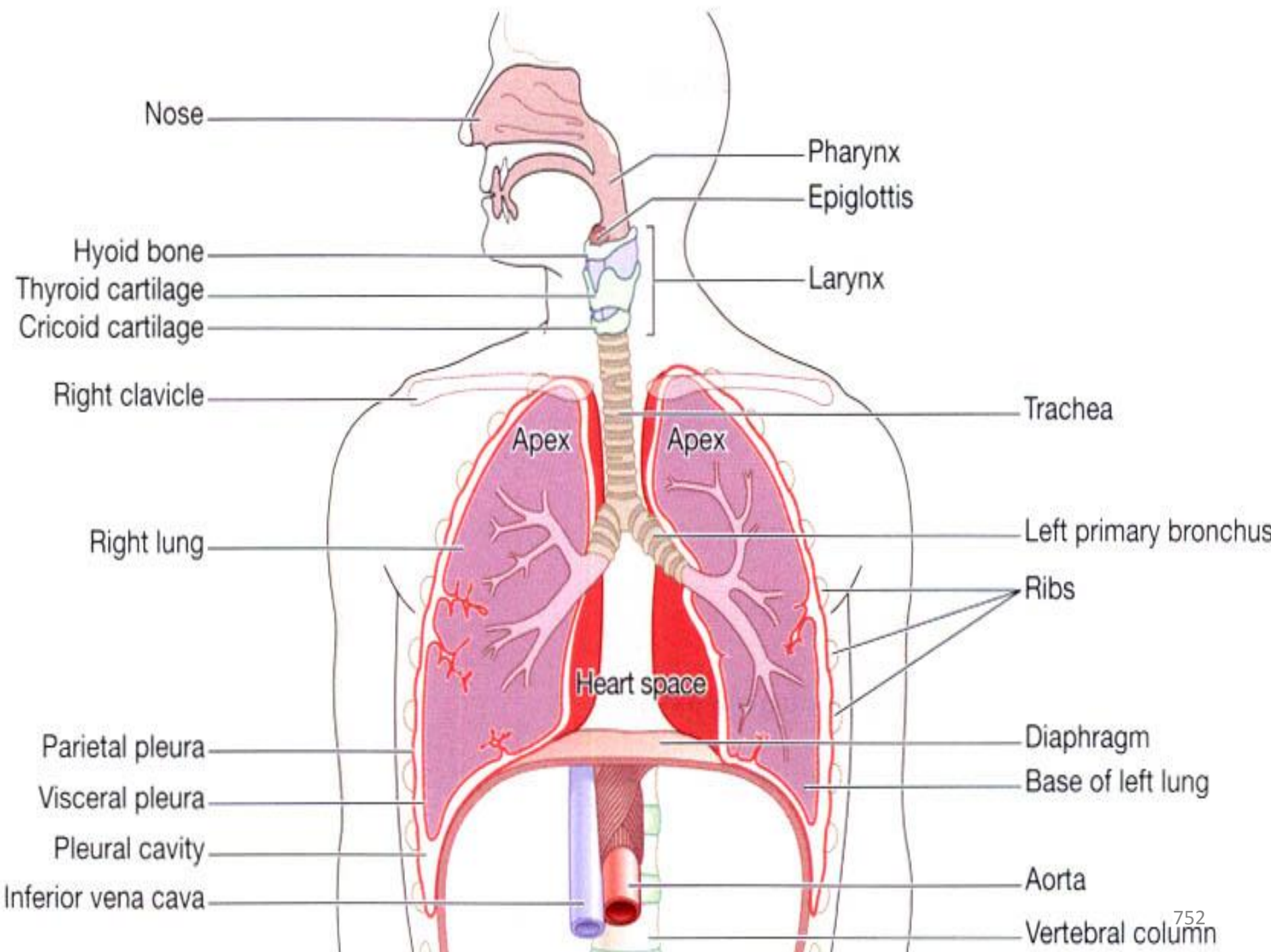
- Includes
 - Gastrin: Stimulates release of hydrochloric acid in stomach; produced by **G cells**
 - Ghrelin: stimulate appetite; produced by **P (Parvocellular cells) /D1 cells**
 - Neuropeptide Y: increased food intake & decreased physical activity.
 - Cholecystokinin (CCK), : Stimulates release of pancreatic secretions; produced by **I cells**
 - Secretin: Stimulates release of pancreatic enzymes, gallbladder contraction; produced by **S cells**

RESPIRATORY SYSTEM

Respiratory system

- Provides the route by which
 - supply of oxygen present in the atmospheric air gains entry to the body
 - excretion of carbon dioxide occurs.
- As the air breathed in moves through the air passages to reach the lungs, it is
 - warmed or cooled to body temperature,
 - moistened to become saturated with water vapour
 - 'cleaned' as particles of dust stick to the mucus which coats the lining membrane.

- Blood provides the transport system for these gases between the lungs and the cells of the body.
 - **External respiration:** exchange of gases between the blood and the lungs
 - **Internal respiration:** exchange of gases between the blood and the cells.
- Respiratory system organs are:
 - nose
 - pharynx
 - larynx
 - trachea
 - two bronchi (one bronchus to each lung)
 - bronchioles and smaller air passages
 - two lungs and their coverings, the pleura



Nose

Pharynx

Epiglottis

Hyoid bone

Larynx

Thyroid cartilage

Cricoid cartilage

Right clavicle

Trachea

Apex

Apex

Right lung

Left primary bronchus

Ribs

Heart space

Parietal pleura

Diaphragm

Visceral pleura

Base of left lung

Pleural cavity

Aorta

Inferior vena cava

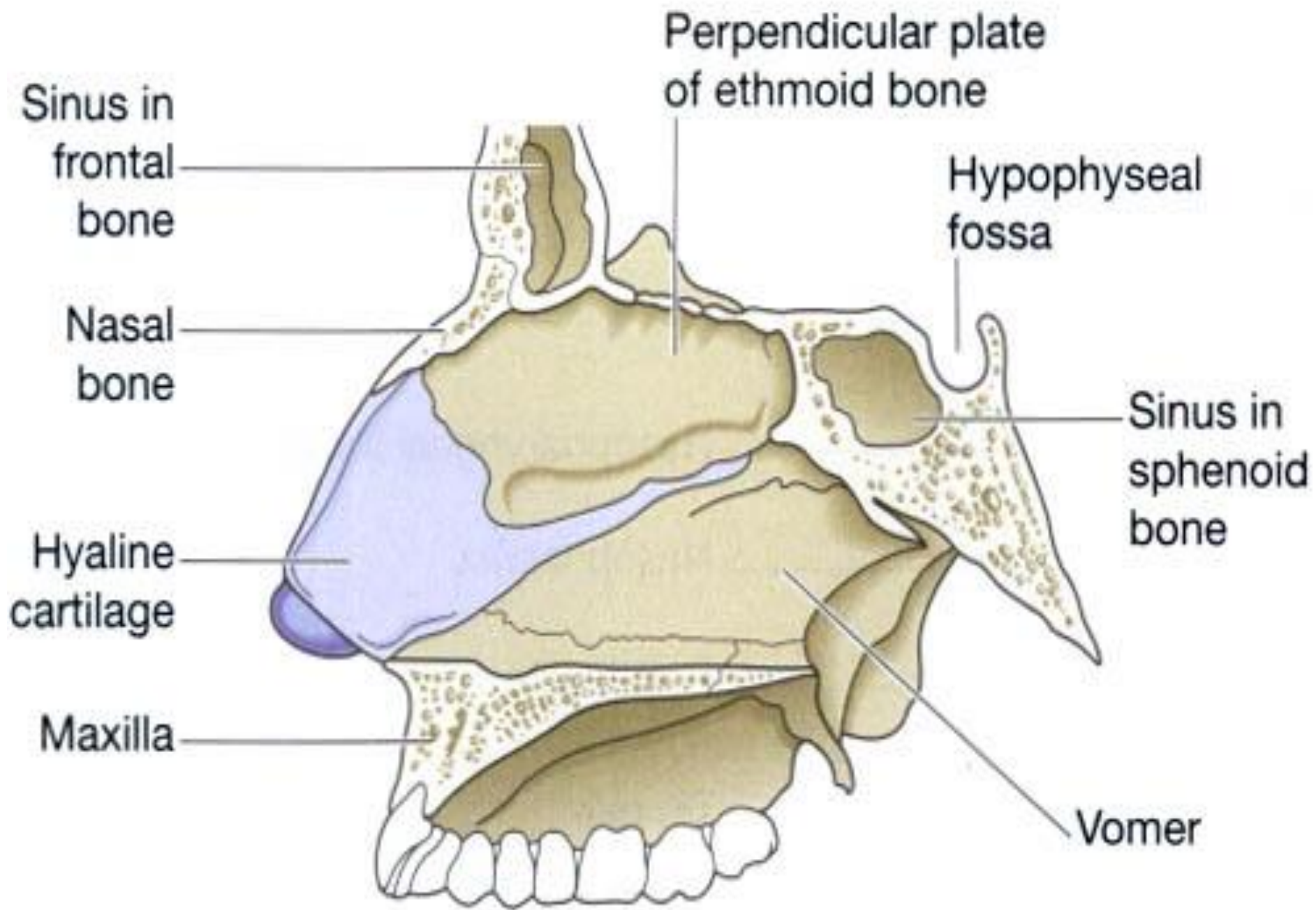
Vertebral column

- Assignment: draw the organs of respiration

NOSE AND NASAL CAVITY

Position and structure

- Nasal cavity; the 1st of the respiratory organs & consists of a large irregular cavity divided into 2 equal passages by a septum.
- **Posterior bony part** of the septum is formed by the perpendicular plate of the ethmoid bone and the vomer.
- **Anteriorly**; consists of hyaline cartilage.
- **Roof**; formed by the cribriform plate of the ethmoid bone, & the sphenoid bone, frontal bone and nasal bones.
- **Floor**; formed by the roof of the mouth & consists of the hard palate in front and the soft palate behind.
 - Hard palate; composed of the maxilla and palatine bones
 - Soft palate; consists of involuntary muscle.
- **Medial wall**; formed by the septum.
- **Lateral walls**; formed by the maxilla, the ethmoid bone and the inferior conchae.
- **Posterior wall**; formed by the posterior wall of the pharynx.



Structures forming the nasal septum

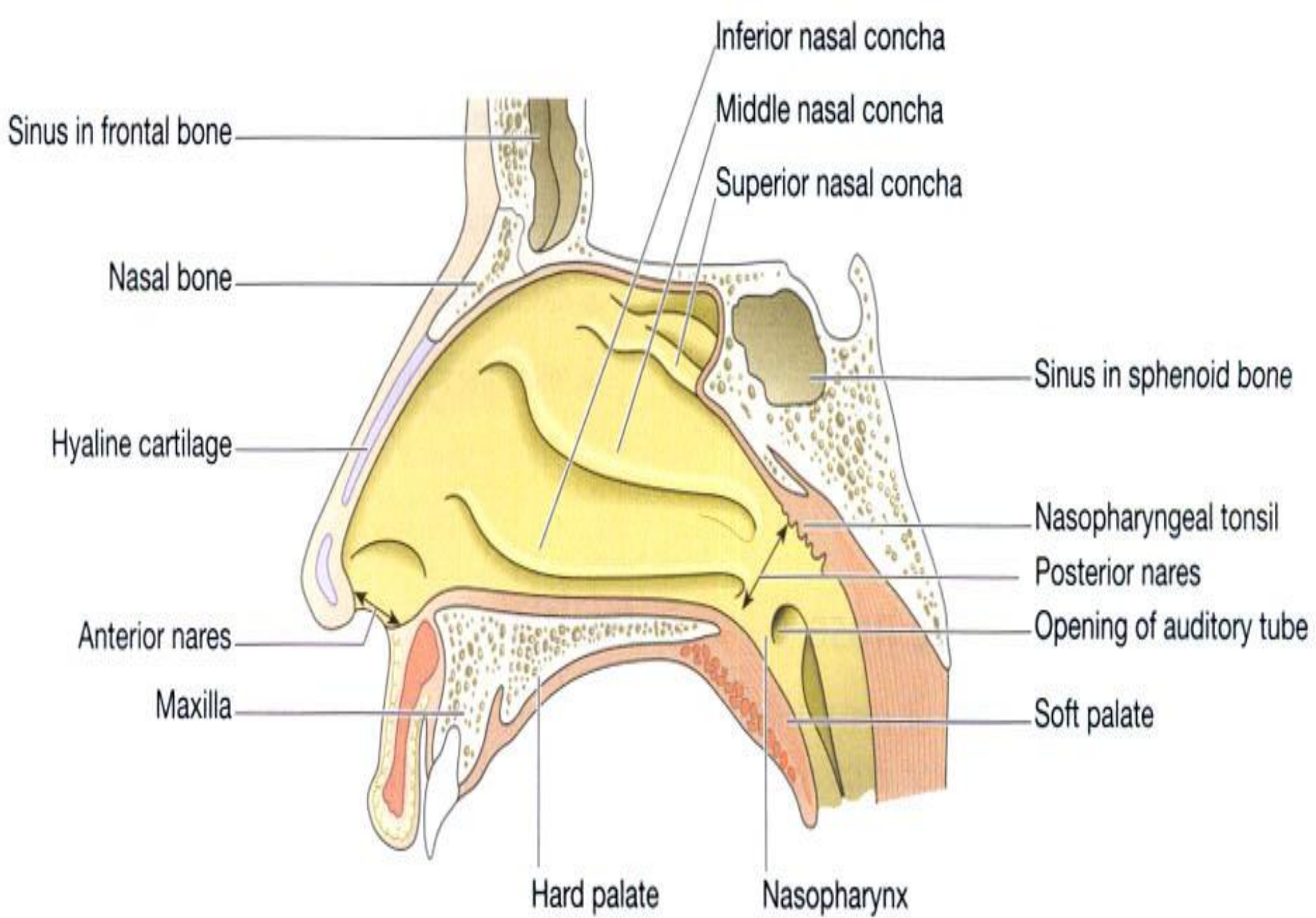
Lining of the nose

- By very vascular **ciliated columnar epithelium** (ciliated mucous membrane) containing mucus-secreting goblet cells.
- **Anteriorly**, it blends with the skin
- **Posteriorly**; it extends into the nasal part of the pharynx.

Openings into the nasal cavity

- **Anterior nares/nostrils**; openings from the exterior into the nasal cavity. Hairs are present in this area.
- **Posterior nares**: openings from the nasal cavity into the pharynx.

- **Paranasal sinuses:**
- **Def:** Cavities in the bones of the face and the cranium which contain air.
- Tiny openings lined with mucous membrane, continuous with that of the nasal cavity, exist between the paranasal sinuses and the nasal cavity.
- Main sinuses are:
 - **maxillary sinuses;** in the lateral walls
 - **frontal & sphenoidal** sinuses; in the roof
 - **ethmoidal sinuses;** in the upper part of the lateral walls .
- **Function**
 - Involved in speech
 - serve to lighten the skull.
- **Nasolacrimal ducts** extend from the lateral walls of the nose to the conjunctival sacs of the eye. They drain tears from the eyes.



Lateral wall of right nasal cavity.

Respiratory function of the nose

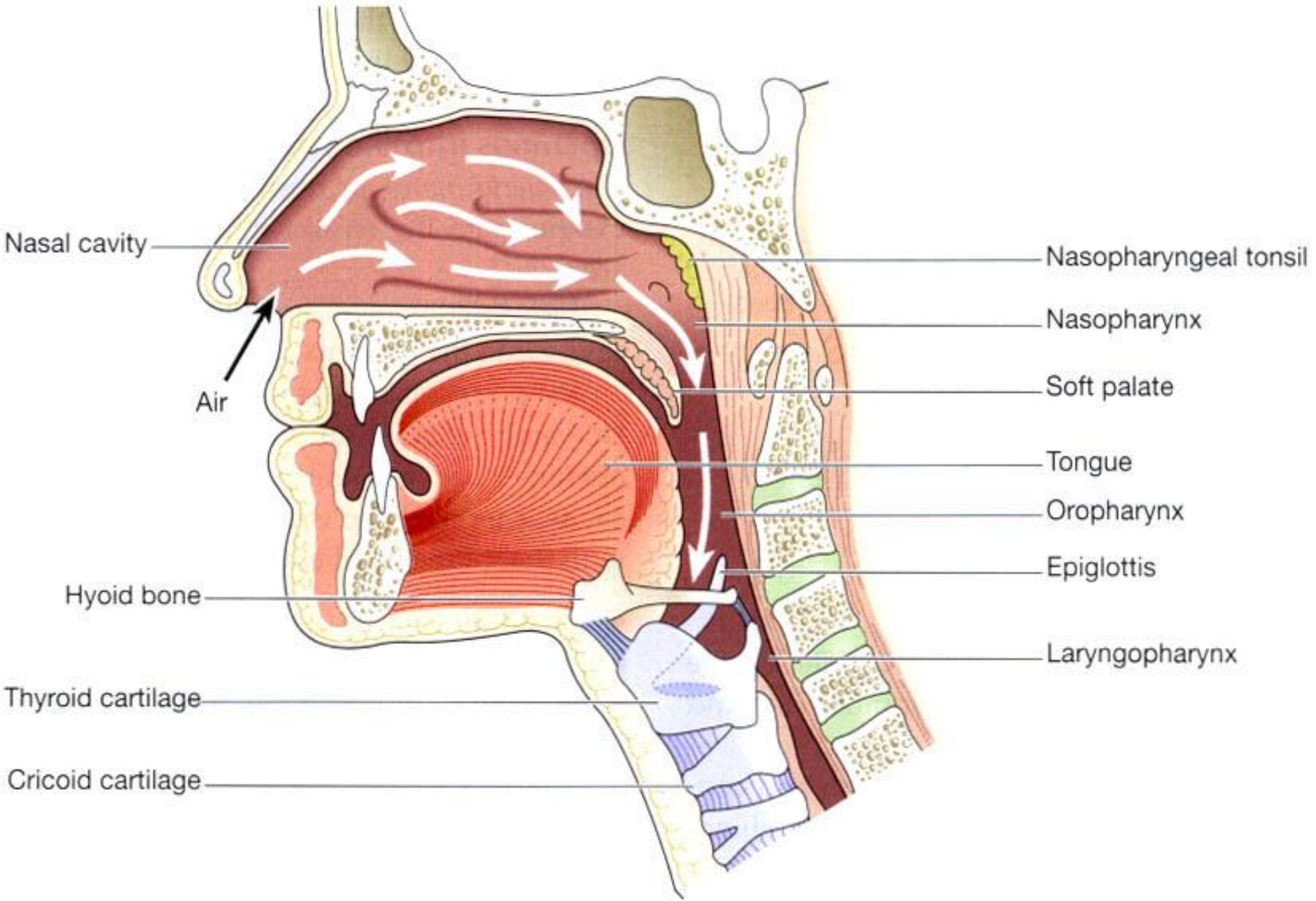
- Nose; the first part of the respiratory passages through which the inspired air passes.
 - **Function:** begins the process by which the air is **warmed, moistened and 'filtered'**.
 - Projecting **conchae** increase the surface area and cause turbulence, spreading inspired air over the whole nasal surface. The large surface area maximises warming, humidification and filtering.
- a) Warming.** Due to the immense vascularity of the mucosa. This explains the large blood loss when a nosebleed (epistaxis) occurs.

b) Filtering and cleaning of air. Occurs as hairs at the anterior nares trap larger particles. Smaller particles such as dust and microbes settle and adhere to the mucus.

- Mucus protects the underlying epithelium from irritation and prevents drying.
- Synchronous beating of the cilia wafts the mucus towards the throat where it is swallowed or expectorated.

c) Humidification. Occurs as air travels over the moist mucosa and becomes saturated with water vapour.

- Irritation of the nasal mucosa results in sneezing, a reflex action that forcibly expels an irritant.



pathway of air from the nose to the larynx

OLFACTORY FUNCTION OF THE NOSE

- Nose: the organ of the sense of smell.
- Nerve endings that detect smell, located in the roof of the nose in the area of the cribriform plate of the ethmoid bones and the superior conchae.
- Nerve endings are stimulated by chemical substances given off by odorous materials.
- Resultant nerve impulses are conveyed by the olfactory nerves to the brain where the sensation of smell is perceived.

PHARYNX

- **Position:** a tube 12 to 14 cm long that extends from the base of the skull to the level of the 6th cervical vertebra.
- Lies behind the nose, mouth & larynx
- Wider at its upper end.

Structures associated with the pharynx

- Superiorly — inferior surface of the base of the skull
- Inferiorly — continuous with the oesophagus
- Anteriorly — the wall is incomplete because of the openings into the nose, mouth and larynx
- Posteriorly — areolar tissue, involuntary muscle and the bodies of the first six cervical vertebrae
- Pharynx is divided into three parts: **nasopharynx, oropharynx & laryngopharynx**

a) **Nasopharynx:** nasal part of the pharynx

- Lies behind the nose above the level of the soft palate. On its lateral walls are the two openings of the auditory tubes, one leading to each middle ear.
- On the posterior wall there are the **pharyngeal tonsils** (adenoids), consisting of lymphoid tissue; most prominent in children up to approximately 7 years of age. Thereafter they gradually atrophy.

b) **Oropharynx:** oral part of the pharynx

- Lies behind the mouth, extending from below the level of the soft palate to the level of the upper part of the body of the 3rd cervical vertebra.
- Lateral walls of the pharynx blend with the soft palate to form two folds on each side.
- Between each pair of folds there is a collection of lymphoid tissue; the **palatine tonsil**.
- During swallowing, the nasal and oral parts are separated by the soft palate and the uvula

c) **Laryngopharynx:** laryngeal part of the pharynx

- Extends from the oropharynx above and continues as the oesophagus below, i.e. from the level of the 3rd to the 6th cervical vertebrae..

Structure

- Pharynx is composed of 3 layers of tissue:
 1. **Mucous membrane lining.** In the nasopharynx it is continuous with the lining of the nose and consists of **ciliated columnar epithelium**; in the oropharynx and laryngopharynx it is formed by tougher **stratified squamous epithelium** which is continuous with the lining of the mouth and oesophagus.
 2. **Fibrous tissue.** Forms the intermediate layer. Thicker in the nasopharynx, where there is little muscle and becomes thinner towards the lower end, where the muscle layer is thicker.
 3. **Muscle tissue.** Consists of several involuntary constrictor muscles that play part in the mechanism of swallowing (deglutition) which, in the pharynx, is not under voluntary control.

Blood and nerve supply

- **Arterial:** by several branches of the facial artery.
- **Venous return:** the facial and internal jugular veins.
- **Nerve supply:** from the **pharyngeal plexus**, formed by parasympathetic and sympathetic nerves.
 - Parasympathetic supply ; the vagus and glossopharyngeal nerves.
 - Sympathetic supply; by nerves from the superior cervical ganglia

Functions

- 1. Passageway for air and food;** Involved in both the respiratory and the digestive systems: air passes through the nasal and oral parts, and food through the oral and laryngeal parts.
- 2. Warming and humidifying;** air is further warmed and moistened as it passes through the pharynx.

- 3. Taste;** by olfactory nerve endings of the sense of taste in the epithelium of the oral and pharyngeal parts.
- 4. Hearing;** the auditory tube, extending from the nasal part to each middle ear, allows air to enter the middle ear. Satisfactory hearing depends on the presence of air at atmospheric pressure on each side of the tympanic membrane (ear drum).
- 5. Protection;** the lymphatic tissue of the pharyngeal and laryngeal tonsils produces antibodies in response to antigens.
- 6. Speech;** the pharynx acts as a resonating chamber for the sound ascending from the larynx, it helps (together with the sinuses) to give the voice its individual characteristics.

LARYNX (voice box)

Position: Extends from the root of the tongue & the hyoid bone to the trachea.

- Lies in front of the laryngopharynx at the level of the 3rd, 4th, 5th and 6th cervical vertebrae.
- After puberty, it grows larger in the male, which explains the prominence of the 'Adam's apple' and the generally deeper voice.

Structures associated with the larynx

- Superiorly — the hyoid bone & the root of the tongue
- Inferiorly — it is continuous with the trachea
- Anteriorly — the muscles attached to the hyoid bone and the muscles of the neck
- Posteriorly — the laryngopharynx and 3rd to 6th cervical vertebrae
- Laterally — the lobes of the thyroid gland

Structure

- **Cartilages:** Composed of several irregularly shaped cartilages attached to each other by ligaments and membranes.
- Main cartilages are:
 - 1 thyroid cartilage.....hyaline cartilage
 - 1 cricoid cartilage.....hyaline cartilage
 - 2 arytenoid cartilages.....hyaline cartilage
 - 1 epiglottis.....elastic fibrocartilage
- a) **Thyroid cartilage.** Most prominent and consists of 2 flat pieces of hyaline cartilage, or laminae, fused anteriorly, forming the laryngeal prominence (Adam's apple).
- Immediately above the laryngeal prominence the laminae are separated, forming a V-shaped notch known as the **thyroid notch**.
- Incomplete posteriorly & the posterior border of each lamina is extended to form 2 processes called the **superior & inferior cornu**.

- Upper part is lined with **stratified squamous epithelium** like the larynx, and the lower part with **ciliated columnar epithelium** like the trachea.

b) Cricoid cartilage

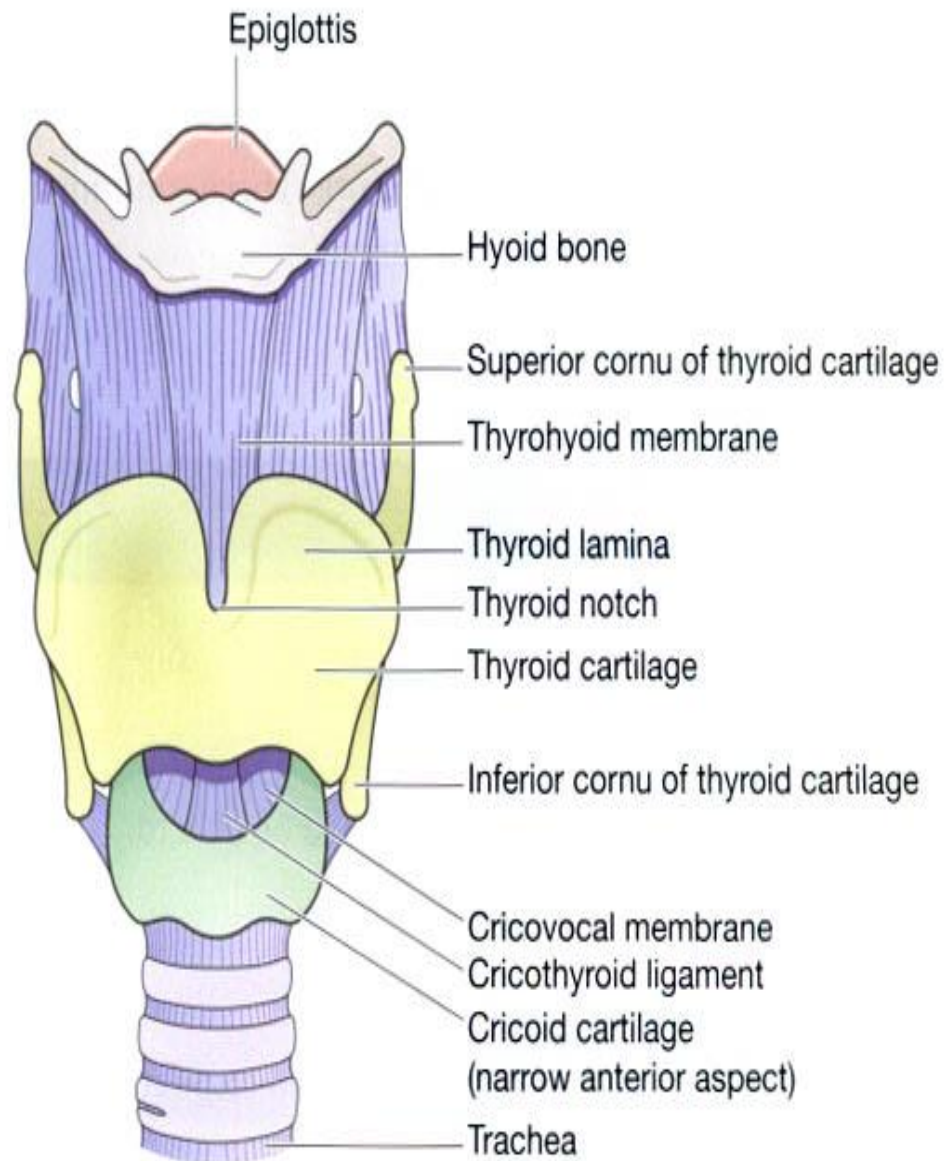
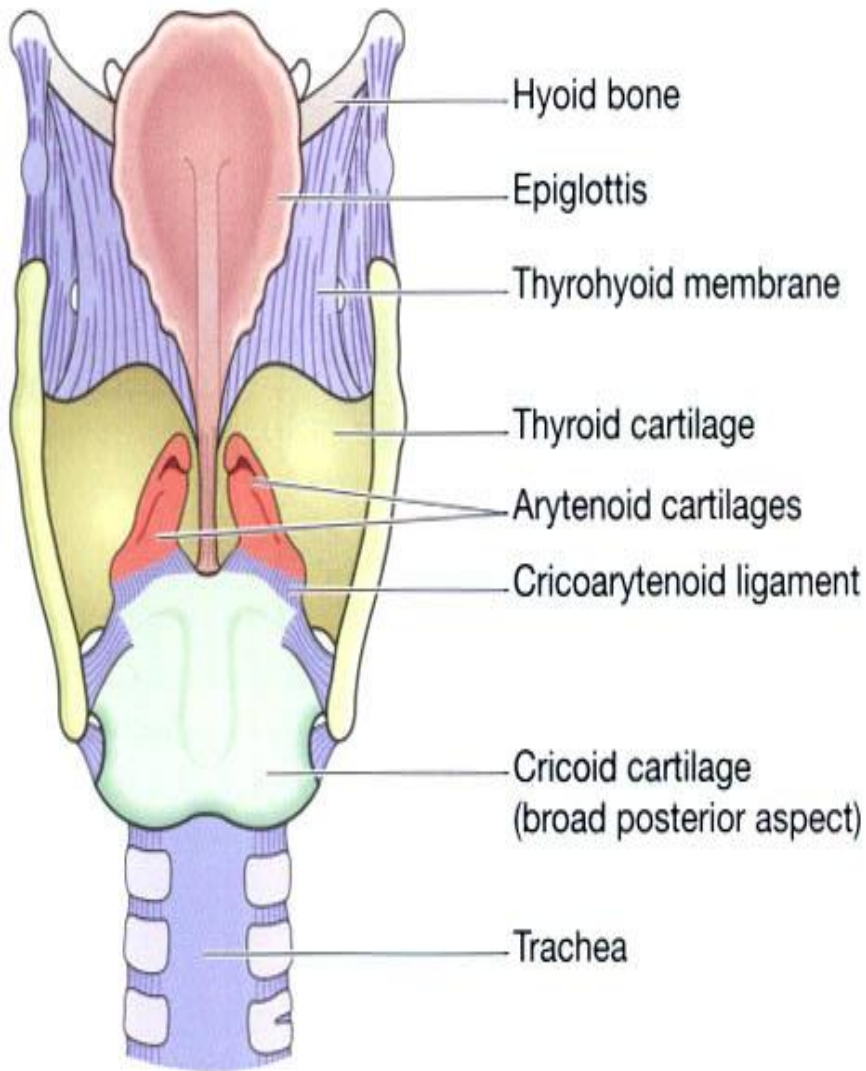
- Lies below the thyroid cartilage
- Composed of hyaline cartilage.
- Shaped like a signet ring, completely encircling the larynx with the narrow part anteriorly and the broad part posteriorly.
 - broad posterior part articulates with the arytenoid cartilages above and with the **inferior cornu** of the thyroid cartilage below.
- Lined with **ciliated columnar epithelium**
- Muscles & ligaments are attached to its outer surface.
- Its lower border marks the end of the upper respiratory tract.

c) **Arytenoid cartilages.**

- 2 roughly pyramid-shaped hyaline cartilages situated on top of the broad part of the cricoid cartilage forming part of the posterior wall of the larynx.
- Give attachment to the vocal cords & to muscles
- Lined with **ciliated columnar epithelium**.

d) **Epiglottis.**

- Leaf-shaped **fibroelastic cartilage** attached to the inner surface of the anterior wall of the thyroid cartilage immediately below the thyroid notch.
- Rises obliquely upwards behind the tongue and the body of the hyoid bone.
- Covered with **stratified squamous epithelium**.
- Acts as the lid; it closes off the larynx during swallowing, protecting the lungs from accidental inhalation of foreign objects.



Larynx; view from behind & front

Blood and nerve supply

- **Arterial blood:** by the superior & inferior laryngeal arteries
- **Venous drainage:** by the thyroid veins, which join the internal jugular vein.
- **Parasympathetic nerve supply:** from the superior laryngeal & recurrent laryngeal nerves; branches of the vagus nerves
- **Sympathetic nerves:** from the superior cervical ganglia, one on each side. They provide the motor nerve supply to the muscles of the larynx and sensory fibres to the lining membrane.

Interior of the larynx

- **Vocal cords:** 2 pale folds of mucous membrane with cord-like free edges which extend from the inner wall of the thyroid prominence anteriorly to the arytenoid cartilages posteriorly.
- When the muscles controlling the vocal cords are relaxed, the vocal cords open and the passageway for air coming up through the larynx is clear; the vocal cords are **abducted**. The pitch of the sound produced by vibrating the vocal cords in this position is **low**.
- When the muscles controlling the vocal cords contract, the vocal cords are stretched out tightly across the larynx—they are **adducted**. The sound produced is **high** pitched.
- Pitch of the voice; determined by the tension applied to the vocal cords by the appropriate sets of muscles.
- When not in use, the vocal cords are adducted.

Functions

1. **Production of sound;** Properties of pitch, volume and resonance.

- ✓ Pitch of the voice depends upon the length and tightness of the cords. At puberty, the male vocal cords begin to grow longer, hence the lower pitch of the adult male voice.
- ✓ Volume of the voice depends upon the force with which the cords vibrate. The greater the force of expired air the more the cords vibrate and the louder the sound emitted.
- ✓ Resonance, or tone, is dependent upon the shape of the mouth, the position of the tongue and the lips, the facial muscles and the air in the paranasal sinuses.

2. **Speech;** Occurs during expiration when the sounds produced by the vocal cords are manipulated by the tongue, cheeks and lips.

- 1. Protection of the lower respiratory tract;** During swallowing (deglutition) the larynx moves upwards, occluding the opening into it from the pharynx and the hinged epiglottis closes over the larynx. This ensures that food passes into the esophagus and not into the lower respiratory passages.
- 2. Passageway for air;** between the pharynx and trachea.
- 3. Humidifying, filtering and warming;** inspired air as it travels through the larynx.

TRACHEA(windpipe)

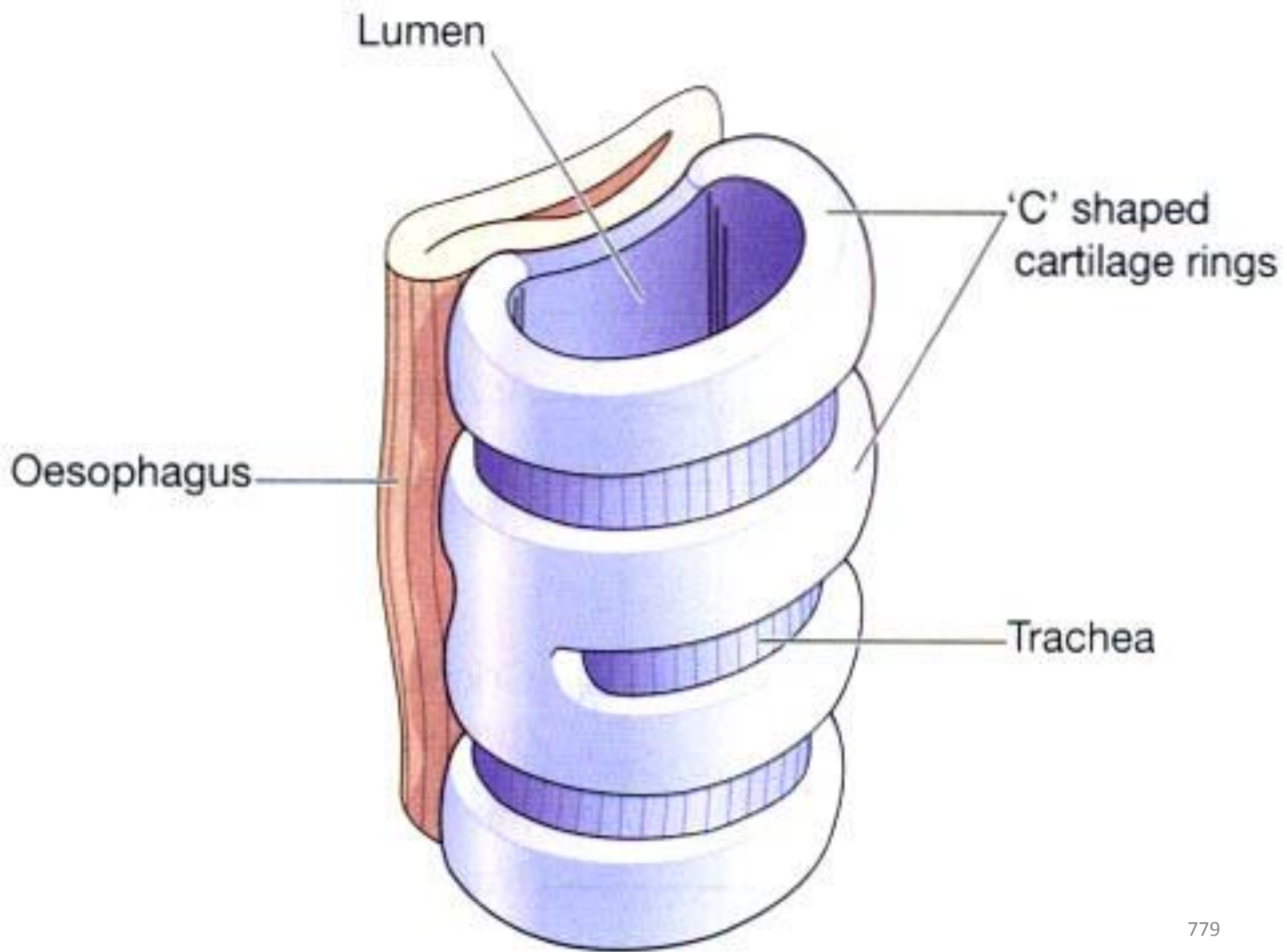
Position: a continuation of the larynx

- Extends downwards to about the level of the 5th thoracic vertebra where it divides (bifurcates) at the carina into the right and left bronchi, one bronchus going to each lung.
- Approximately 10 to 11 cm long
- Lies mainly in the median plane in front of the oesophagus.

Structures associated with the trachea

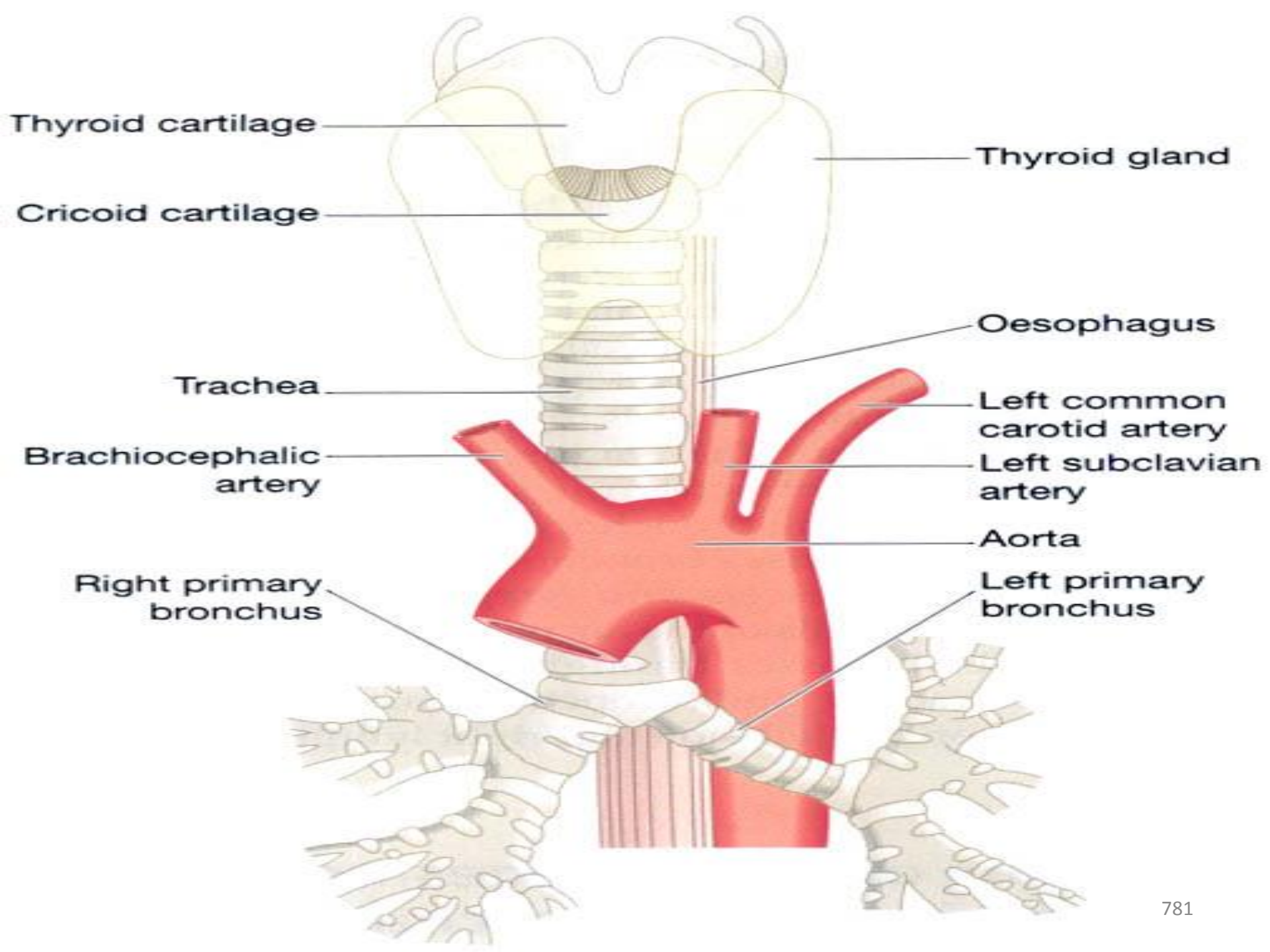
- Superiorly —larynx
- Inferiorly —right & left bronchi
- Anteriorly —**upper part:** isthmus of the thyroid gland
lower part: arch of the aorta & sternum
- Posteriorly —oesophagus separates the trachea from the vertebral column
- Laterally — lungs & the lobes of the thyroid gland

- **Structure**
- Composed of from 16 to 20 incomplete- posteriorly (C-shaped) rings of hyaline cartilages lying one above the other.
- Connective tissue & involuntary muscle join the cartilages and form the posterior wall where they are incomplete.
- Soft tissue posterior wall is in contact with the oesophagus.
- 3 layers of tissue 'clothe' the cartilages of the trachea.
 - **Outer layer:** Consists of fibrous & elastic tissue; encloses the cartilages.
 - **Middle layer:** Consists of cartilages & bands of smooth muscle that wind round the trachea in a helical arrangement. There is some areolar tissue, containing blood and lymph vessels and autonomic nerves.
 - **Inner lining:** Consists of ciliated columnar epithelium, containing mucus-secreting goblet cells.



Blood and nerve supply, lymph drainage

- **Arterial blood supply:** by the inferior thyroid & bronchial arteries
- **Venous return:** by the inferior thyroid veins into the brachiocephalic veins.
- **Nerve supply:**
 - **Parasympathetic supply:** by the recurrent laryngeal nerves and other branches of the vagus nerve .
 - **Sympathetic supply:** by nerves from the sympathetic ganglia.
- **Lymph:** Passes through lymph nodes situated round the trachea and in the carina, the area where it divides into 2 bronchi.



Functions

- 1. Support and patency:** Arrangement of cartilage and elastic tissue prevents kinking and obstruction of the airway as the head and neck move; prevents collapse of the tube when the internal pressure is less than intrathoracic pressure, i.e. at the end of forced expiration.
 - The absence of cartilage posteriorly allows the trachea to dilate and constrict in response to nerve stimulation, and for indentation as the oesophagus distends during swallowing.
- 2. Mucociliary escalator:** Synchronous and regular beating of the cilia of the mucous membrane lining that wafts mucus with adherent particles upwards towards the larynx where it is swallowed or expectorated.

- 3. Cough reflex:** Nerve endings in the larynx, trachea and bronchi are sensitive to irritation that generates nerve impulses which are conducted by the vagus nerves to the respiratory centre in the brain stem.
- The reflex motor response is deep inspiration followed by closure of the glottis. The abdominal and respiratory muscles then contract and suddenly the air is released under pressure expelling mucus and/or foreign material from the mouth.
- 4. Warming, humidifying and filtering of air.** These continue as in the nose, although air is normally saturated and at body temperature when it reaches the trachea.

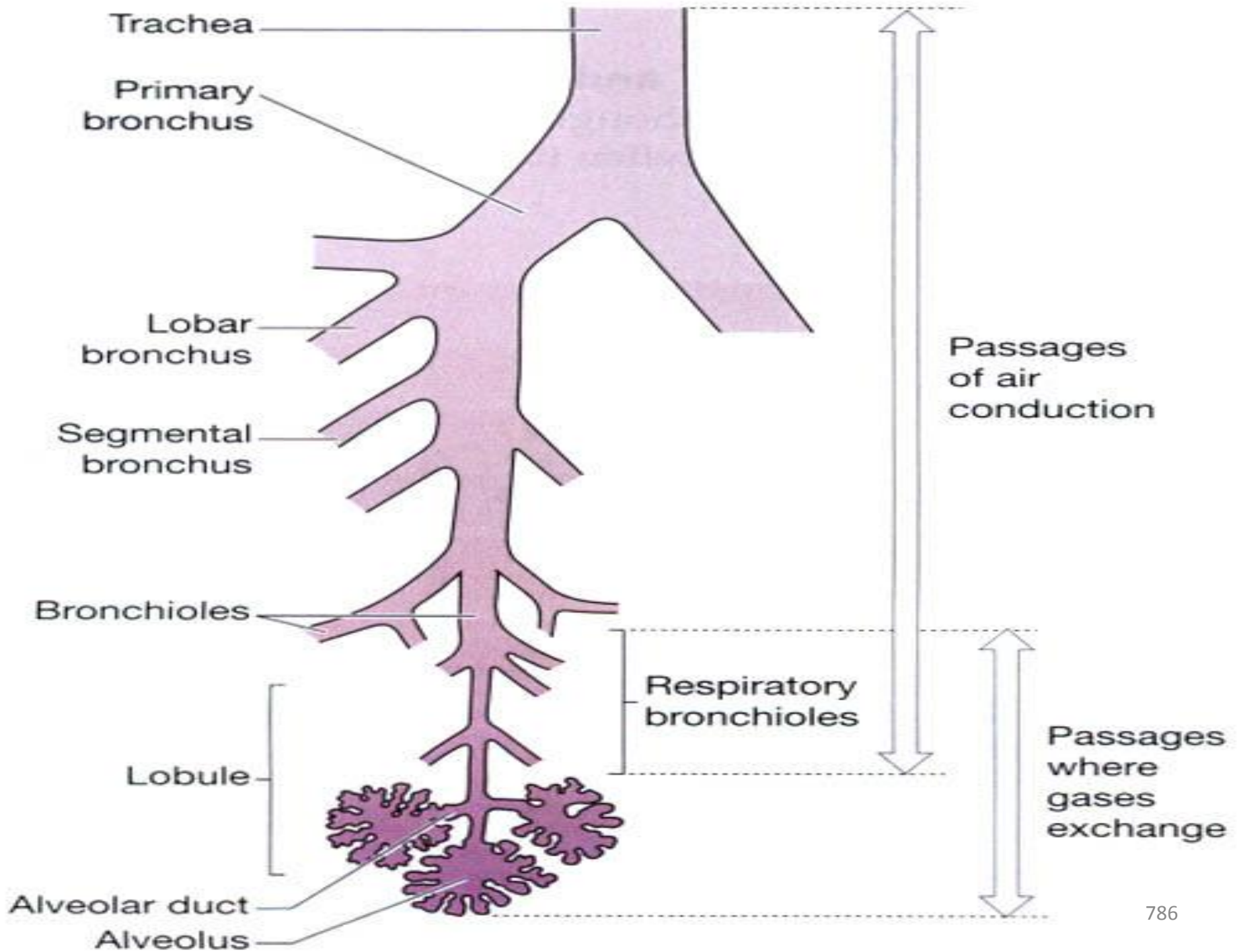
BRONCHI AND SMALLER AIR PASSAGES

- 2 primary bronchi; formed when the trachea divides
- a) The right bronchus.** Wider, shorter & more vertical than the left bronchus; more likely of the two to become obstructed by an inhaled foreign body.
- Approximately 2.5 cm long.
- After entering the right lung at the hilum it divides into 3 branches, one to each lobe.
- b) The left bronchus.** About 5 cm long & narrower than the right.
- After entering the lung at the hilum it divides into 2 branches, one to each lobe.
- Each branch then subdivides into progressively smaller tubes within the lung substance

BRONCHI AND BRONCHIOLES

Structure

- Composed of the same tissues as the trachea & lined with ciliated columnar epithelium.
- Bronchi progressively subdivide into bronchioles, terminal bronchioles, respiratory bronchioles, alveolar ducts and finally, alveoli.
- Towards the distal end of the bronchi the cartilages become irregular in shape and are absent at bronchiolar level.
- In the absence of cartilage, the smooth muscle in the walls of the bronchioles becomes thicker and is responsive to autonomic nerve stimulation & irritation.
- Ciliated columnar mucous membrane changes gradually to non-ciliated cuboidal shaped cells in the distal bronchioles.



Blood and nerve supply, lymph drainage

- **Arterial blood supply:** branches of the right & left bronchial arteries
- **Venous return:** by the bronchial veins. On the **right** side they empty into the **azygos vein** and on the **left** into the **superior intercostal vein**.
- **Nerve supply:**
 - **Vagus nerves** (parasympathetic) stimulate contraction of smooth muscle in the bronchial tree, causing bronchoconstriction.
 - Sympathetic stimulation causes bronchodilatation.
- **Lymphatic vessels and lymph nodes:** by a network of lymph vessels. It passes through lymph nodes situated around the trachea & bronchial tree then into the thoracic duct on the left side and right lymphatic duct on the other.

Functions of air passages not involved in gaseous exchange

1. Control of air entry thus regulating the volume of air entering the lungs; by autonomic nerve supply:
 - parasympathetic stimulation causes constriction
 - sympathetic stimulation causes dilatation .
2. warming and humidifying
3. support and patency
3. removal of particulate matter
4. cough reflex

RESPIRATORY BRONCHIOLES & ALVEOLI

Structure

- **Lobules:** blind ends of the respiratory tract distal to the terminal bronchioles, consisting of: respiratory bronchioles, alveolar ducts and alveoli (tiny air sacs).
- Process of gas exchange occurs here.
- The walls gradually become thinner until muscle & connective tissue fade out leaving a single layer of simple squamous epithelial cells in the alveolar ducts and alveoli.
- These distal respiratory passages are supported by a loose network of elastic connective tissue in which macrophages, fibroblasts, nerves and blood and lymph vessels are embedded.
- Alveoli are surrounded by a network of capillaries. Exchange of gases during respiration takes place across 2 membranes, the alveolar and capillary membranes.

- Interspersed between the squamous cells are other cells that secrete **surfactant**, a phospholipid fluid.
- Surfactant
 - prevents the alveoli from drying out.
 - reduces surface tension
 - prevents alveolar walls collapsing during expiration.
 - in newborn babies facilitates expansion of the lungs and the establishment of respiration
- Secretion of surfactant into the distal air passages and alveoli begins about the 35th week of fetal life.

Functions of respiratory bronchioles & alveoli

External respiration.

a) Defence against microbes;

- Protective cells (lymphocytes & plasma cells) produce antibodies in the presence of antigens,
- macrophages and polymorphonuclear lymphocytes, are phagocytic.

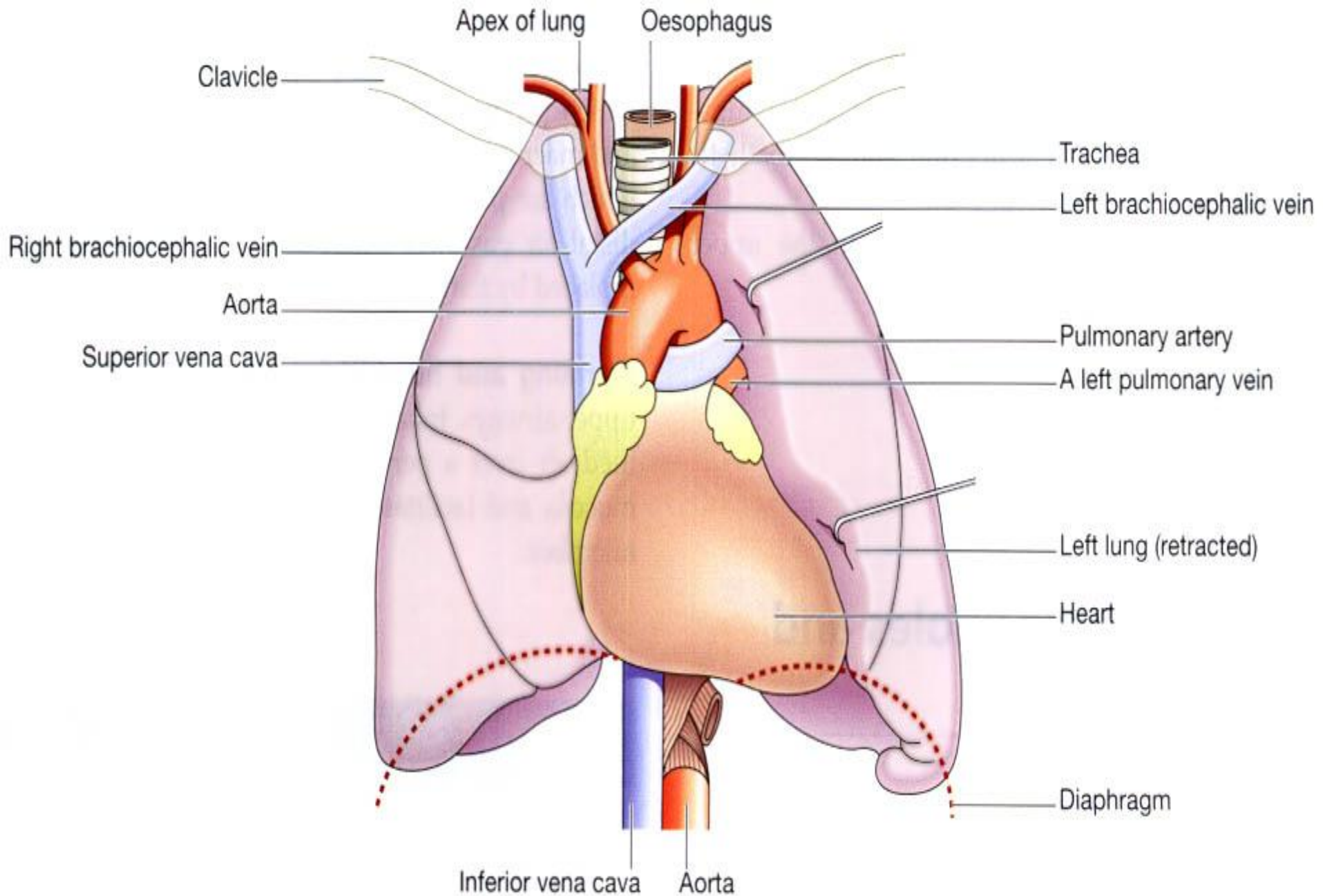
b) Warming and humidifying; continues as in the upper airways. Inhalation of dry or inadequately humidified air over a period of time causes irritation of the mucosa and facilitates the establishment of pathogenic microbes.

LUNGS

Position and associated structures

- 2 lungs, one lying on each side of the midline in the thoracic cavity.
- They are cone-shaped & have an apex, a base, costal surface and medial surface.
- a) The apex:** rounded & rises into the root of the neck, about 25 mm (1 inch) above the level of the middle third of the clavicle.
- Structures associated with it are the 1st rib, the blood vessels & nerves in the root of the neck.
- b) The base:** Concave & semilunar in shape & is closely associated with the thoracic surface of the diaphragm.

- c) The costal surface:** Convex & closely associated with the costal cartilages, the ribs & the intercostal muscles.
- d) The medial surface:** Concave & has a roughly triangular-shaped area, called the **hilum**, at the level of the 5th, 6th & 7th thoracic vertebrae.
- Structures which form the root of the lung enter & leave at the hilum. They are:
 - primary bronchus,
 - pulmonary artery supplying the lung
 - 2 pulmonary veins draining it,
 - bronchial artery & veins,
 - lymphatic and
 - nerve supply.
 - **Mediastinum** (area between the lungs) is occupied by the heart, great vessels, trachea, right and left bronchi, oesophagus, lymph nodes, lymph vessels and nerves.



Lungs and associated structures

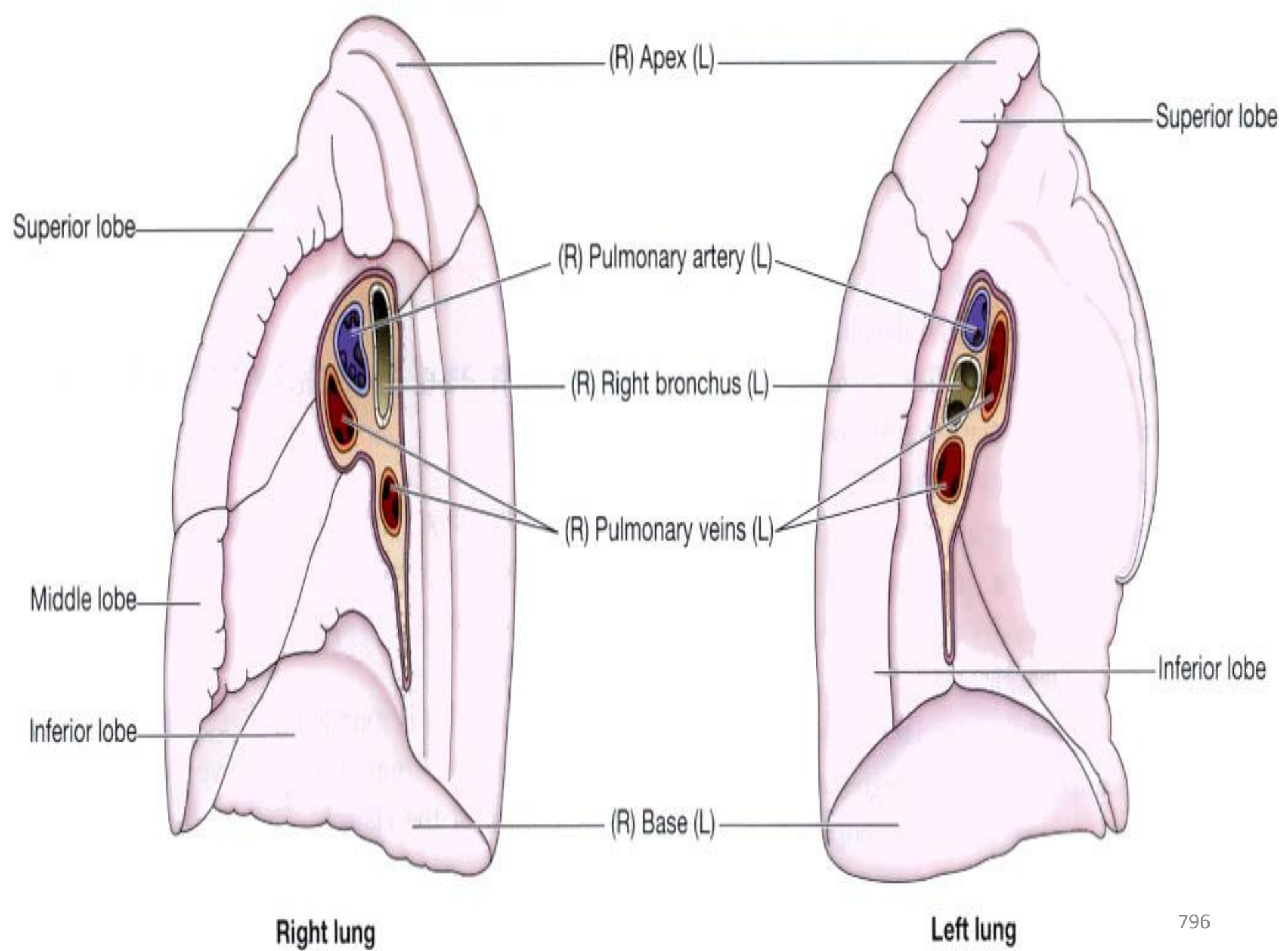
Organization of the lungs

a) The right lung

- Divided into 3 distinct lobes:
 - superior,
 - middle
 - inferior.

b) The left lung

- Smaller as the heart is situated left of the midline.
- Divided into only 2 lobes:
 - superior
 - inferior

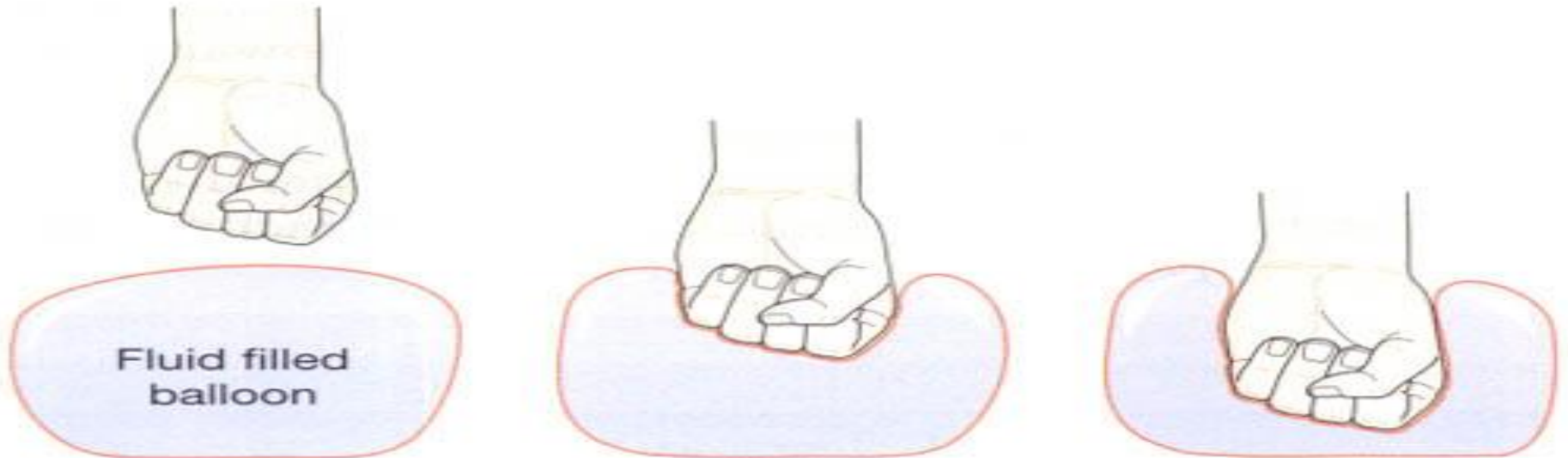


Pleura and pleural cavity

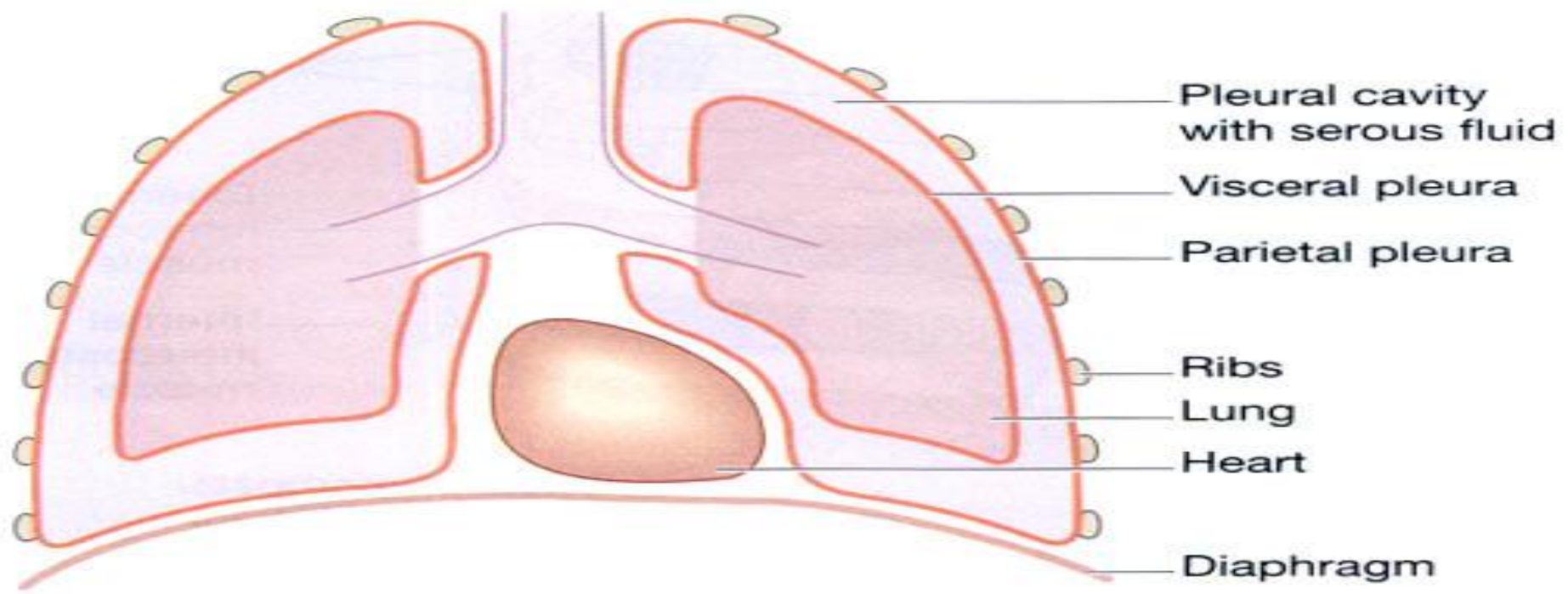
- **Pleura:** consists of a closed sac of serous membrane which contains a small amount of serous fluid.
- The lung is invaginated into this sac so that it forms two layers:
 - one adheres to the lung
 - the other to the wall of the thoracic cavity
- a) Visceral pleura:** Adherent to the lung, covering each lobe and passing into the fissures which separate them.
- b) Parietal pleura:** Adherent to the inside of the chest wall and the thoracic surface of the diaphragm.
 - Remains detached from the adjacent structures in the mediastinum
 - continuous with the visceral pleura round the edges of the hilum.

The pleural cavity; It's only a potential space.

- The 2 layers of pleura are separated by only a thin film of serous fluid which allows them to glide over each other, preventing friction between them during breathing.
- Serous fluid is secreted by the epithelial cells of the membrane.
- If either layer of pleura is punctured, the underlying lung collapses due to its inherent property of elastic recoil.



Fluid filled
balloon



Relationship between pleura and lungs

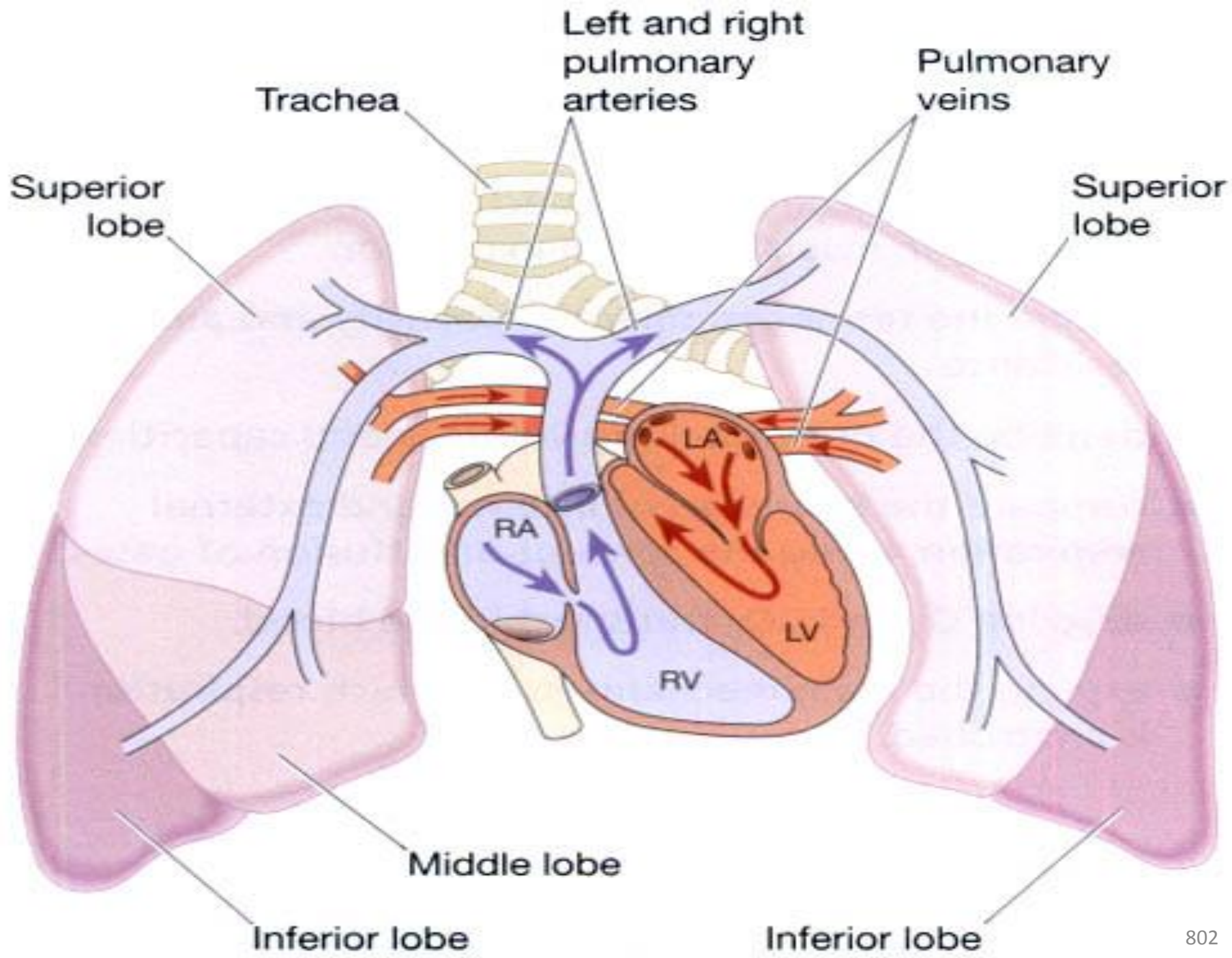
Interior of the lungs

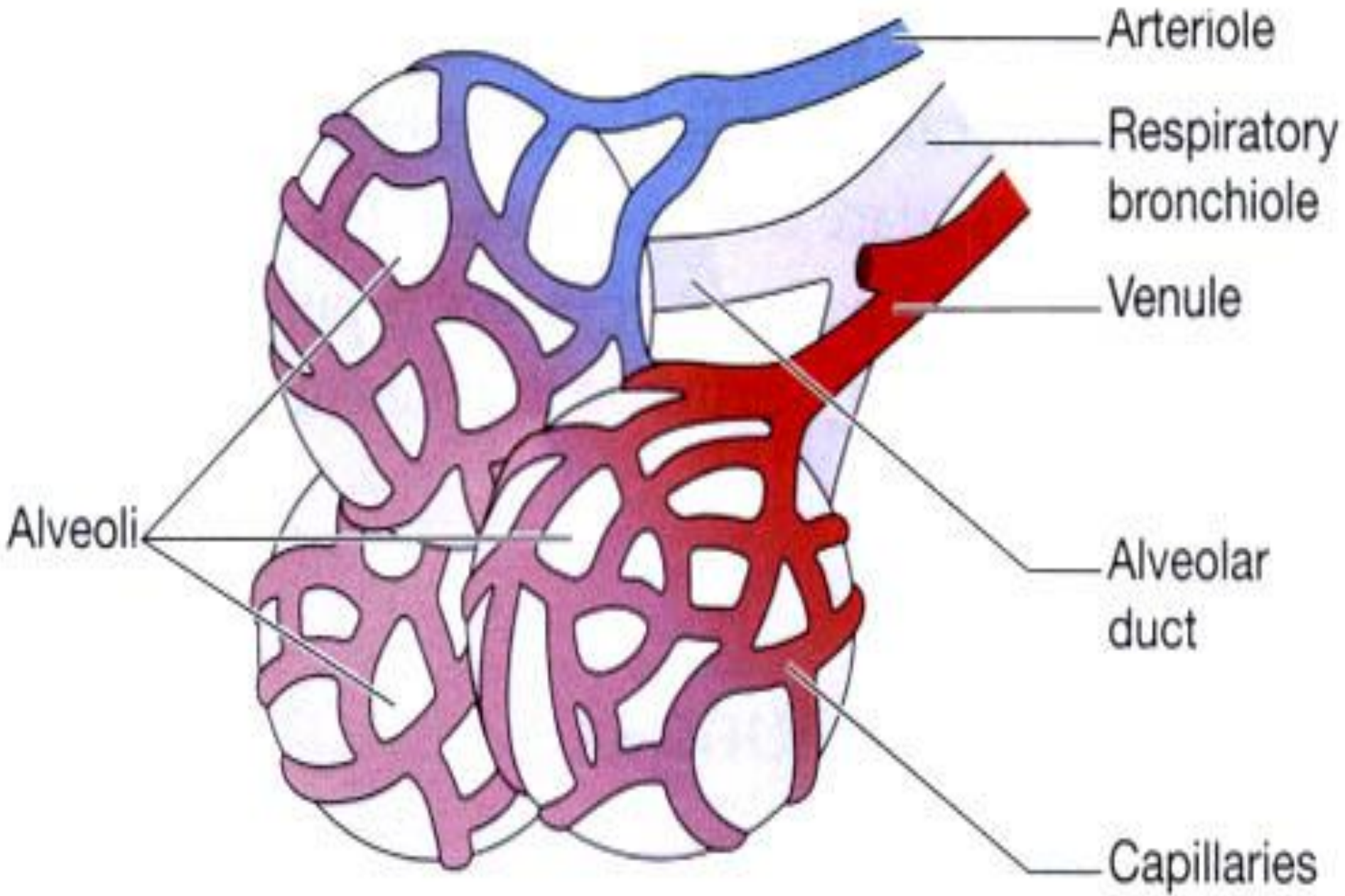
- Composed of the bronchi & smaller air passages, alveoli, connective tissue, blood vessels, lymph vessels and nerves.

Pulmonary blood supply

- Pulmonary artery divides into 2, one branch conveying deoxygenated blood to each lung.
- Within the lungs each pulmonary artery divides into many branches which eventually end in a dense capillary network around the walls of the alveoli.
- Walls of the alveoli & those of the capillaries each consist of only one layer of flattened epithelial cells.
- Exchange of gases between air in the alveoli & blood in the capillaries takes place across these two very fine membranes.

- Pulmonary capillaries join up, becoming 2 pulmonary veins in each lung.
- They leave the lungs at the hilum and convey oxygenated blood to the left atrium of the heart.





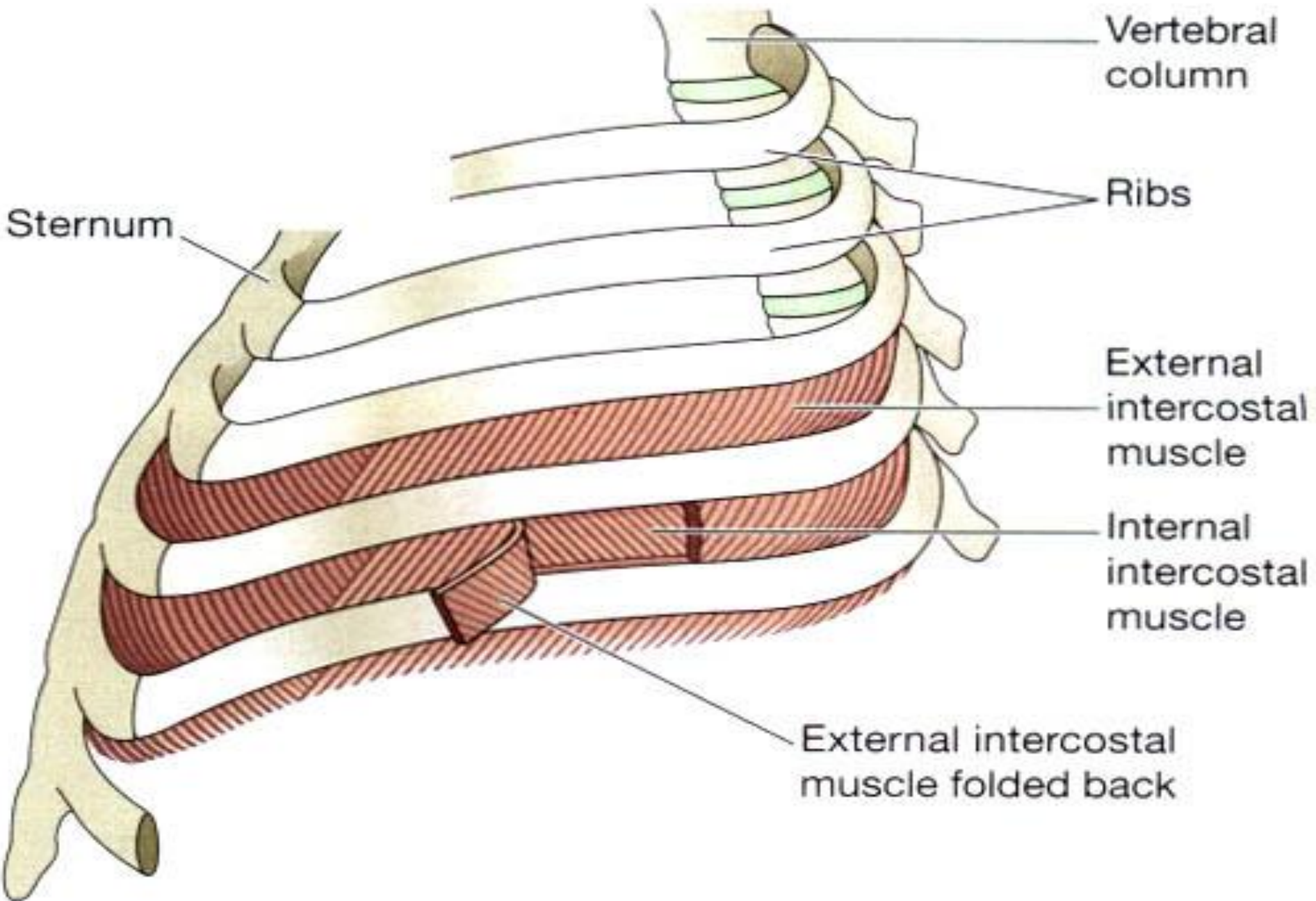
capillary network surrounding the alveoli.

Respiration

- **Muscles of respiration**
- Expansion of the chest during inspiration occurs partly voluntary and partly involuntary.
- Main muscles of respiration in normal quiet breathing are the:
 - **intercostal muscles**
 - **diaphragm.**
- During difficult or deep breathing they are assisted by the **muscles of the neck, shoulders and abdomen.**

a) Intercostal muscles

- 11 pairs that occupy the spaces between the 12 pairs of ribs.
- Arranged in 2 layers, **external & internal** intercostal muscles
 - **External intercostal muscle fibres:** Extend in a **downwards** and **forwards** direction from the lower border of the rib above to the upper border of the rib below.
 - **Internal intercostal muscle fibres:** Extend in a **downwards** and **backwards** direction from the lower border of the rib above to the upper border of the rib below, crossing the external intercostal muscle fibres at **right angles**.
- 1st rib is fixed. Therefore, when the intercostal muscles contract they pull all the other ribs towards the first rib.



The intercostal muscles and the bones of the thorax.

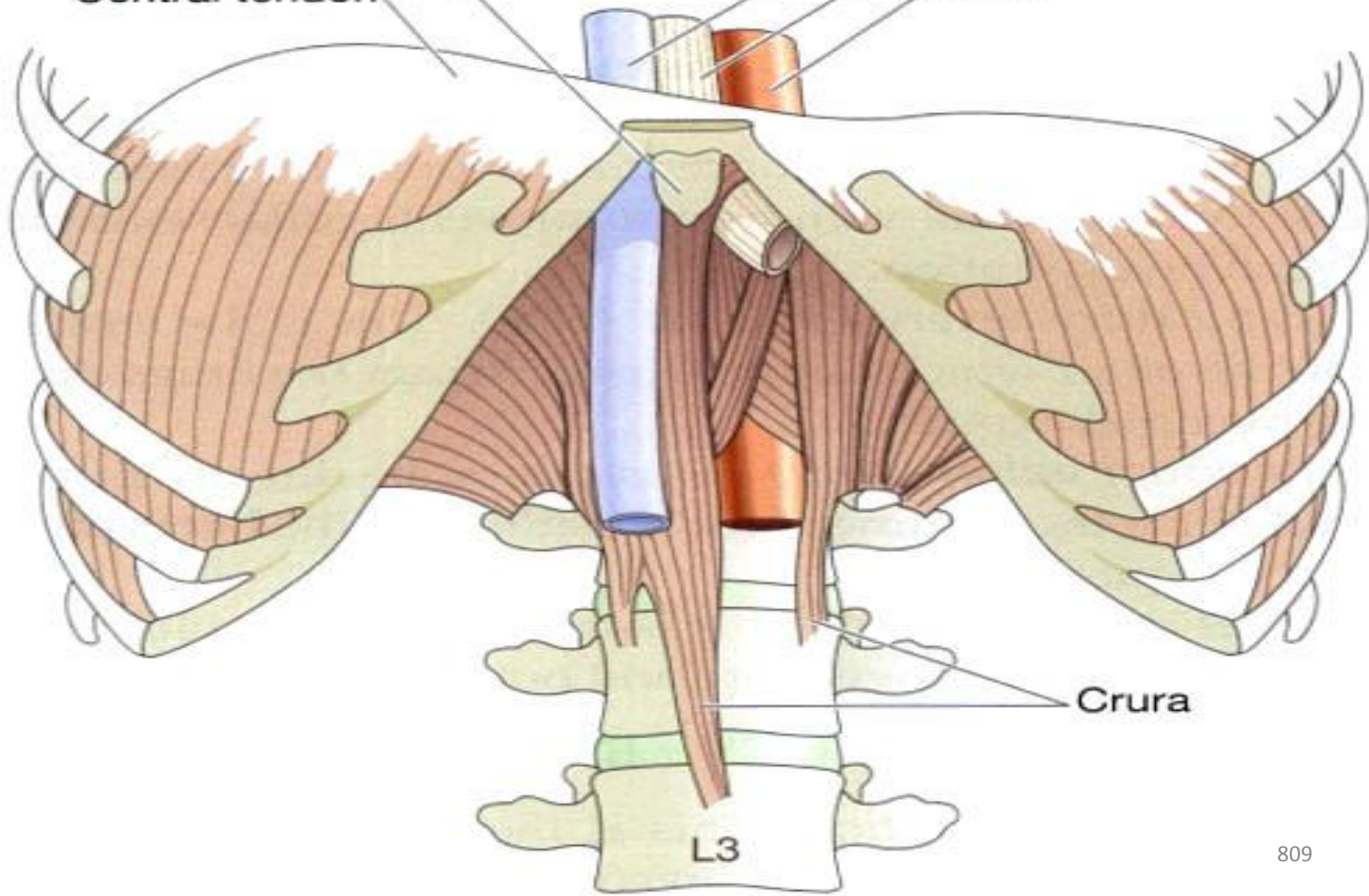
b) Diaphragm

- Dome-shaped structure separating the thoracic & abdominal cavities.
- Forms the floor of the thoracic cavity & the roof of the abdominal cavity
- Consists of a central tendon from which muscle fibres radiate to be attached to the lower ribs and sternum and to the vertebral column by **2 crura**.
- When the muscle of the diaphragm is **relaxed**, the central tendon is at the level of the **8th thoracic** vertebra.

- When it **contracts**, its muscle fibres shorten & the central tendon is pulled downwards to the level of the **9th thoracic** vertebra, enlarging the thoracic cavity in length. This decreases pressure in the thoracic cavity and increases it in the abdominal and pelvic cavities.
- Diaphragm is supplied by the **phrenic nerves**.
- Intercostal muscles & the diaphragm contract simultaneously ensuring the enlargement of the thoracic cavity in all directions, that is from back to front, side to side and top to bottom.

Xiphoid process
of sternum
Central tendon

Inferior vena cava
Oesophagus
Aorta



Crura

L3

CYCLE OF RESPIRATION

- Occurs 12 to 15 times per minute & consists of 3 phases:
 - inspiration
 - expiration
 - pause.

Inspiration

- During inspiration the space inside the chest cavity is increased by following two ways:
- The **muscles** of ribs **contract** and **elevate** the **ribs upwards** and **forwards**.
- The **muscles** of diaphragm **contract** and diaphragm become **less domelike**.

•

As the result of this **downward movement** of **diaphragm** and **outward** and **upward movement** of the **ribs**, the pressure from the lungs is released. When the pressure from the lungs is removed they expand. With the expansion of the lungs, **vacuum** (low pressure area) is created inside the lungs by which the air rushes into the lungs from the outside due to higher atmospheric pressure. This is **Inspiration**.

- Process of inspiration is **active**, as it requires expenditure of energy for muscle contraction.
- Negative pressure created in the thoracic cavity aids venous return to the heart and is known as the **respiratory pump**.

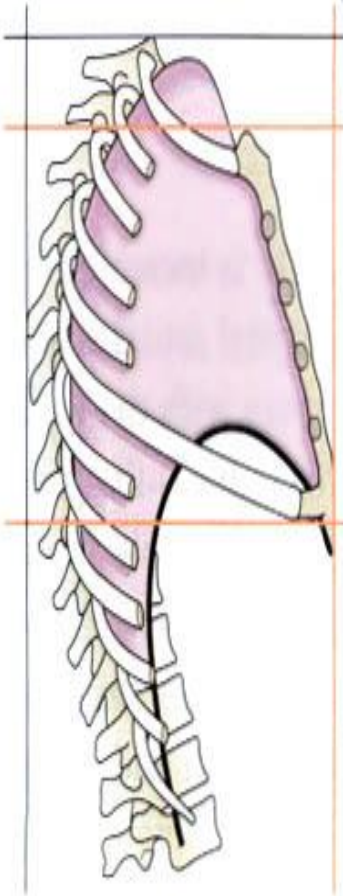
Expiration

- Relaxation of the intercostal muscles & the diaphragm results in downward & inward movement of the rib cage & elastic recoil of the lungs.
- As this occurs, pressure inside the lungs exceeds that in the atmosphere & therefore air is expelled from the respiratory tract.
- The lungs still contain some air & are prevented from complete collapse by the intact pleura.
- It's **passive** as it does not require the expenditure of energy. After expiration, there is a **pause** before the next cycle begins.

Expiration

Relaxed diaphragm
and intercostal muscles

a₁

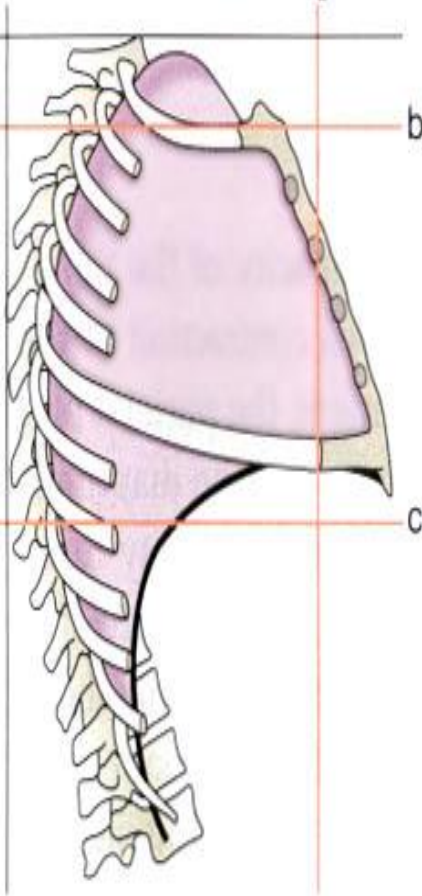


Side view

Inspiration

Contracted diaphragm
and intercostal muscles

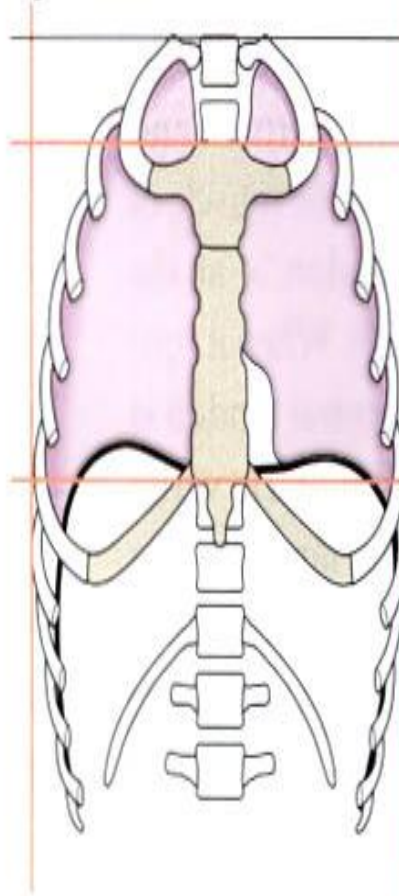
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Expiration

Relaxed diaphragm
and intercostal muscles

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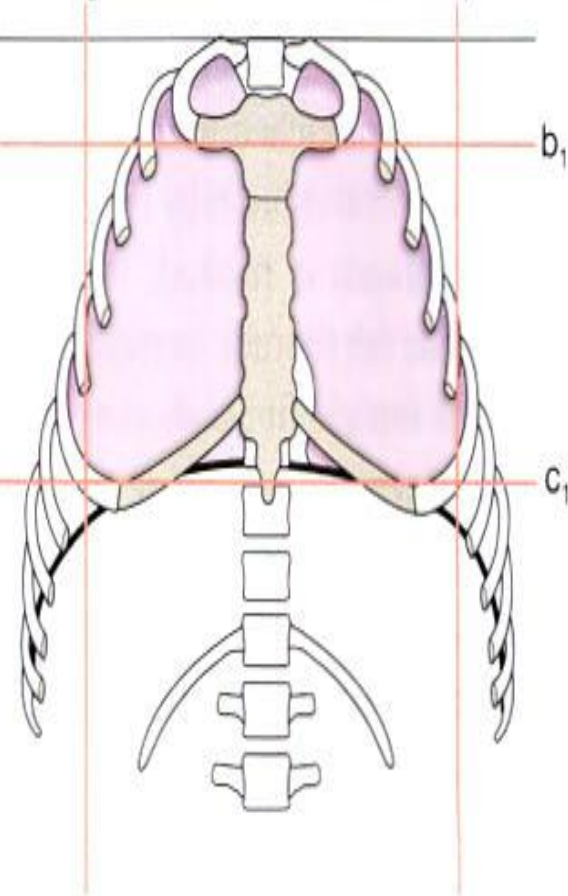


Anterior view

Inspiration

Contracted diaphragm
and intercostal muscles

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Physiological variables affecting respiration

- 1. Elasticity:** ability of the lung to return to its normal shape after each breath.
- 2. Compliance:** a measure of the distensibility of the lungs, i.e. the effort required to inflate the alveoli. When compliance is low the effort needed to inflate the lungs is greater than normal, e.g. in some diseases where elasticity is reduced or when insufficient surfactant is present.

NOTE: compliance & elasticity are **opposing** forces.

- 3. Airflow resistance.** When this is increased, e.g. in bronchoconstriction, more respiratory effort is required to inflate the lungs.

Lung volumes and capacities

- Normal quiet breathing; about 15 complete respiratory cycles per minute.
- Lungs & the air passages are never empty and, as the exchange of gases takes place only across the walls of the alveolar ducts and alveoli, the remaining capacity of the respiratory passages is called **the anatomical dead space** (about 150 ml).
- **Tidal volume (TV)**: Amount of air which passes into & out of the lungs during each cycle of quiet breathing (about 500 ml).
- **Inspiratory reserve volume (IRV)**: Extra volume of air that can be inhaled into the lungs during maximal inspiration.
- **Inspiratory capacity (IC)**: Amount of air that can be inspired with maximum effort; consists of the **TV & IRV**.

- **Functional residual capacity (FRC):** Amount of air remaining in the air passages & alveoli at the end of quiet expiration.
- As blood flows continuously through the pulmonary capillaries interchange of gases is not interrupted between breaths, preventing marked changes in the concentration of blood gases.
- FRC also prevents collapse of the alveoli on expiration.
- **Expiratory reserve volume (ERV):** Largest volume of air which can be expelled from the lungs during maximal expiration.

- **Residual volume (RV):** Volume of air remaining in the lungs after forced expiration. Cannot be directly measured
- **Forced expiratory volume (FEV):** Volume of air that can be forcibly exhaled within a specific time, normally 1-3 seconds.
- **Vital capacity (VC):** Maximum volume of air which can be moved into & out of the lungs:

$$\text{VC} = \text{Tidal volume} + \text{IRV} + \text{ERV}$$

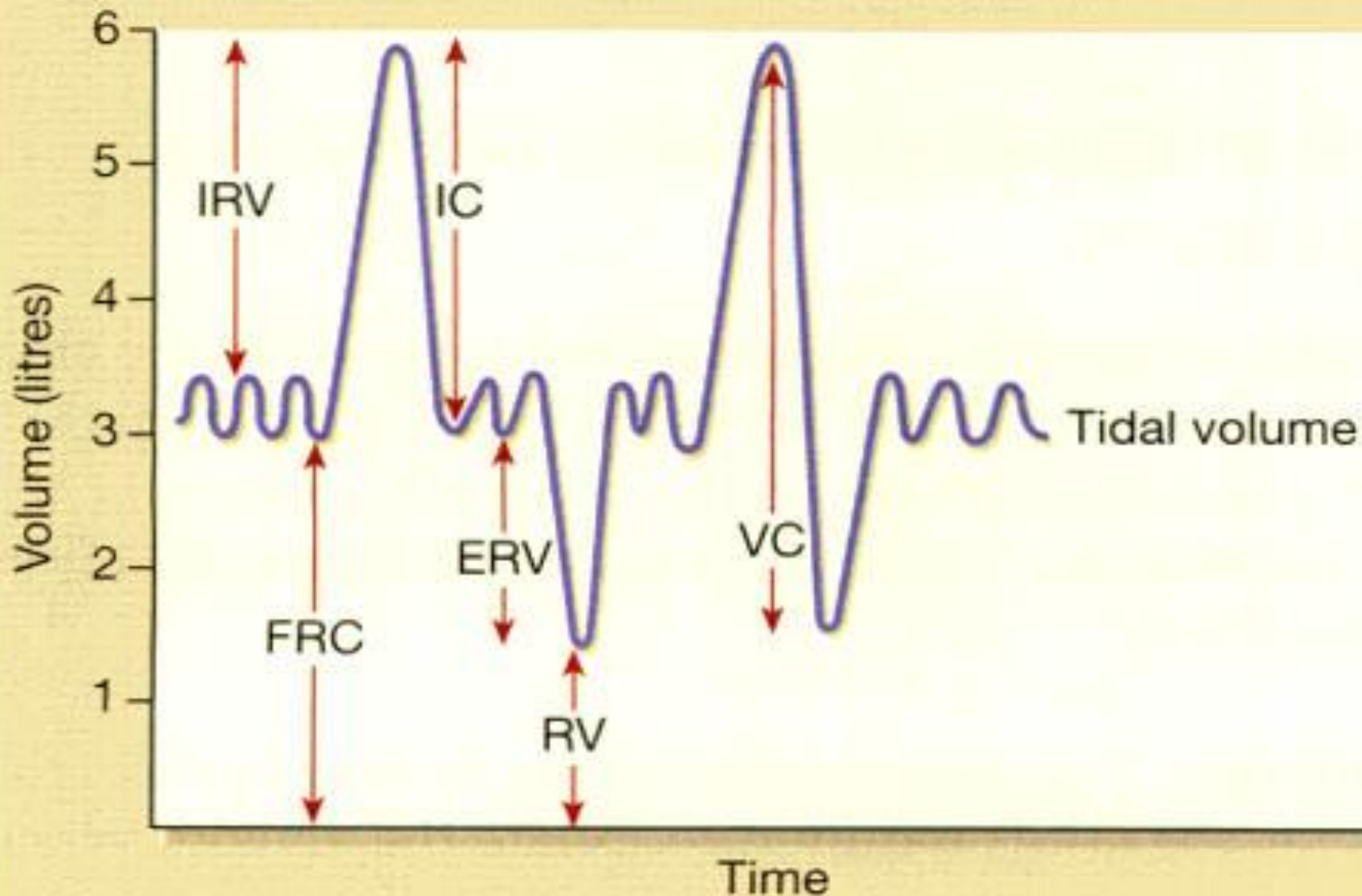
- **Alveolar ventilation:** Volume of air that moves into & out of the alveoli per minute. It is equal to the tidal volume minus the anatomical dead space, multiplied by the respiratory rate:

$$\text{Alveolar ventilation} = (\text{TV} - \text{anatomical dead space}) \times \text{respiratory rate}$$

$$= (500 - 150) \text{ ml} \times 15 \text{ per minute}$$

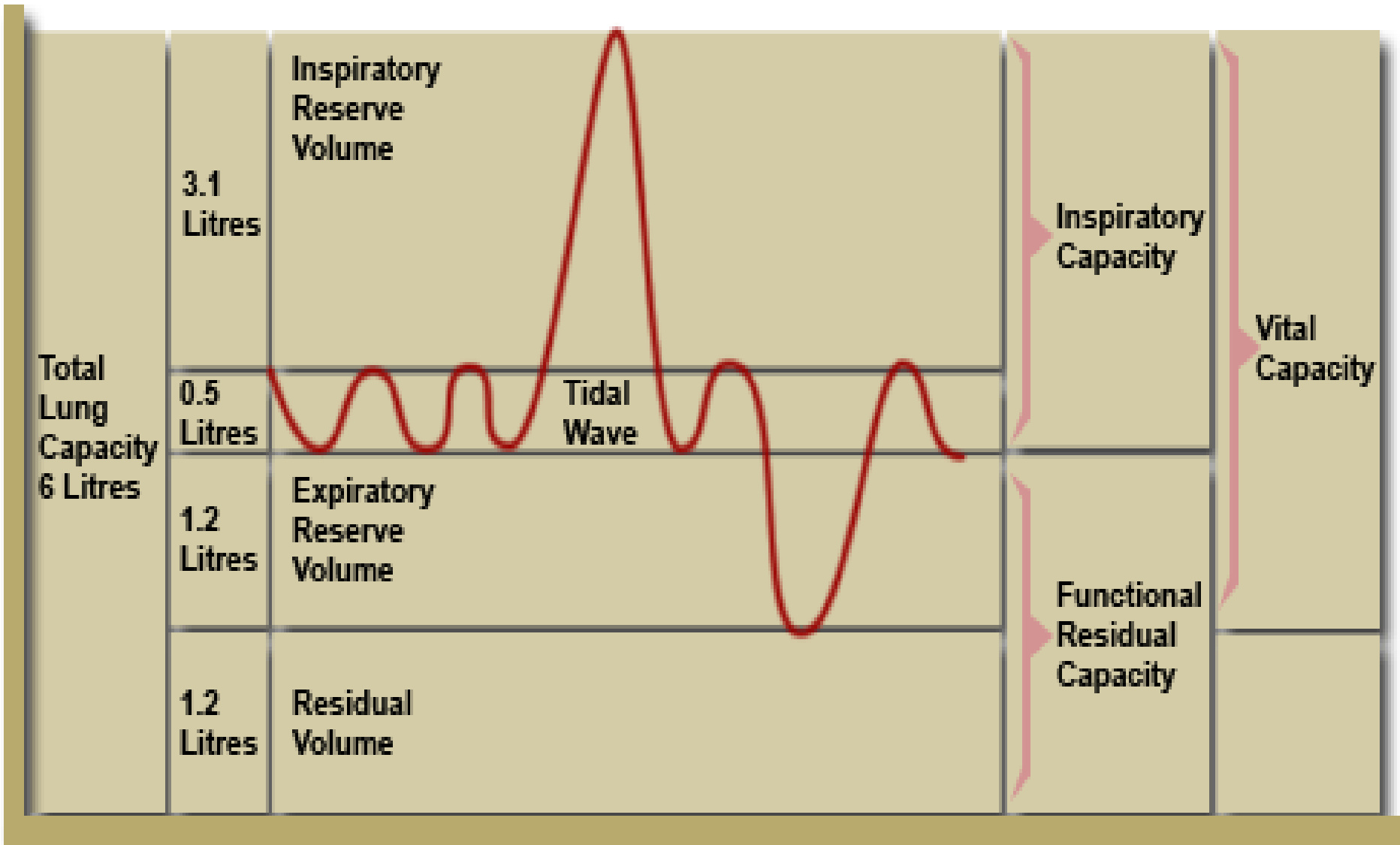
$$= 5.25 \text{ litres per minute}$$

- Lung function tests are carried out to determine respiratory function & are based on these parameters.



Lung volumes and capacities: IRV = inspiratory reserve volume; IC = inspiratory capacity; FRC = functional residual capacity; ERV = expiratory reserve volume; RV = residual volume; VC = vital capacity.

Lung Volumes and Capacities



Composition of air

- Air is a mixture of gases: nitrogen, oxygen, carbon dioxide, water vapour and small quantities of inert gases.
- Each gas in the mixture exerts a part of the total pressure proportional to its concentration, i.e. the partial pressure, e.g. P_{O_2} , P_{CO_2} .
- **Alveolar air**
- Its composition remains fairly constant & is different from atmospheric air.
- Saturated with water vapour
- Contains more CO_2 & less O_2 .

- Saturation with water vapour provides 6.3 kPa (47 mmHg) thus reducing the partial pressure of all the other gases present.
- During each inspiration only some of the alveolar gases are exchanged.
- **Expired air**
- A mixture of alveolar air & atmospheric air in the dead space.

Table 10.1 The composition of inspired and expired air

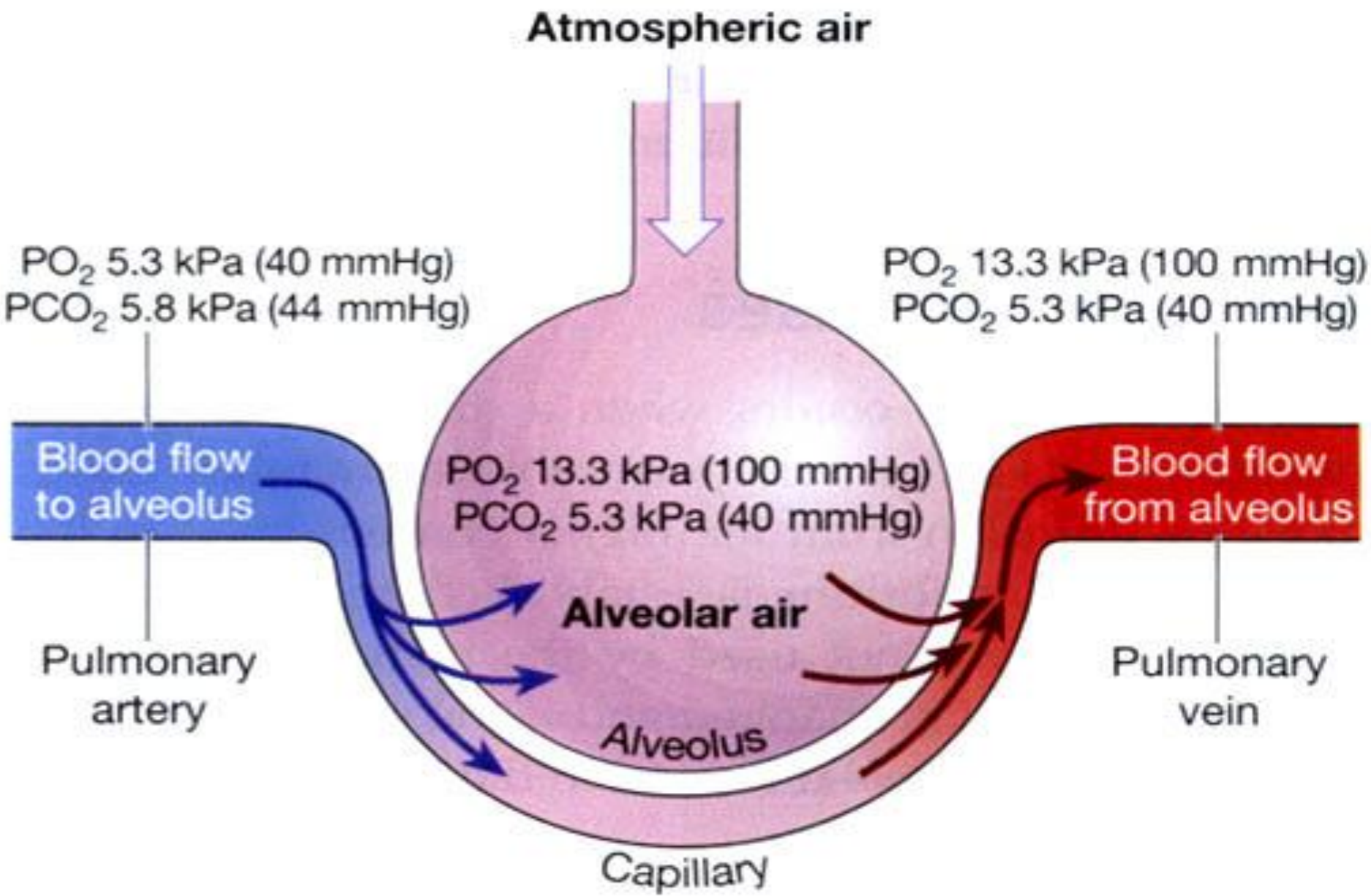
	Inspired air %	Expired air %
Oxygen	21	16
Carbon dioxide	0.04	4
Nitrogen and rare gases	78	78
Water vapour	Variable	Saturated

Diffusion of gases

- Exchange of gases occurs when a difference in partial pressure exists across semi-permeable membranes.
- Gases move by diffusion from the higher concentration to the lower until equilibrium is established
- Atmospheric nitrogen is not used by the body so its partial pressure remains unchanged and is the same in inspired and expired air, alveolar air and in the blood.

External respiration

- **Def:** Exchange of gases by diffusion between the alveoli and the blood.
- Total area for gas exchange in the lungs is 70 to 80 square metres.



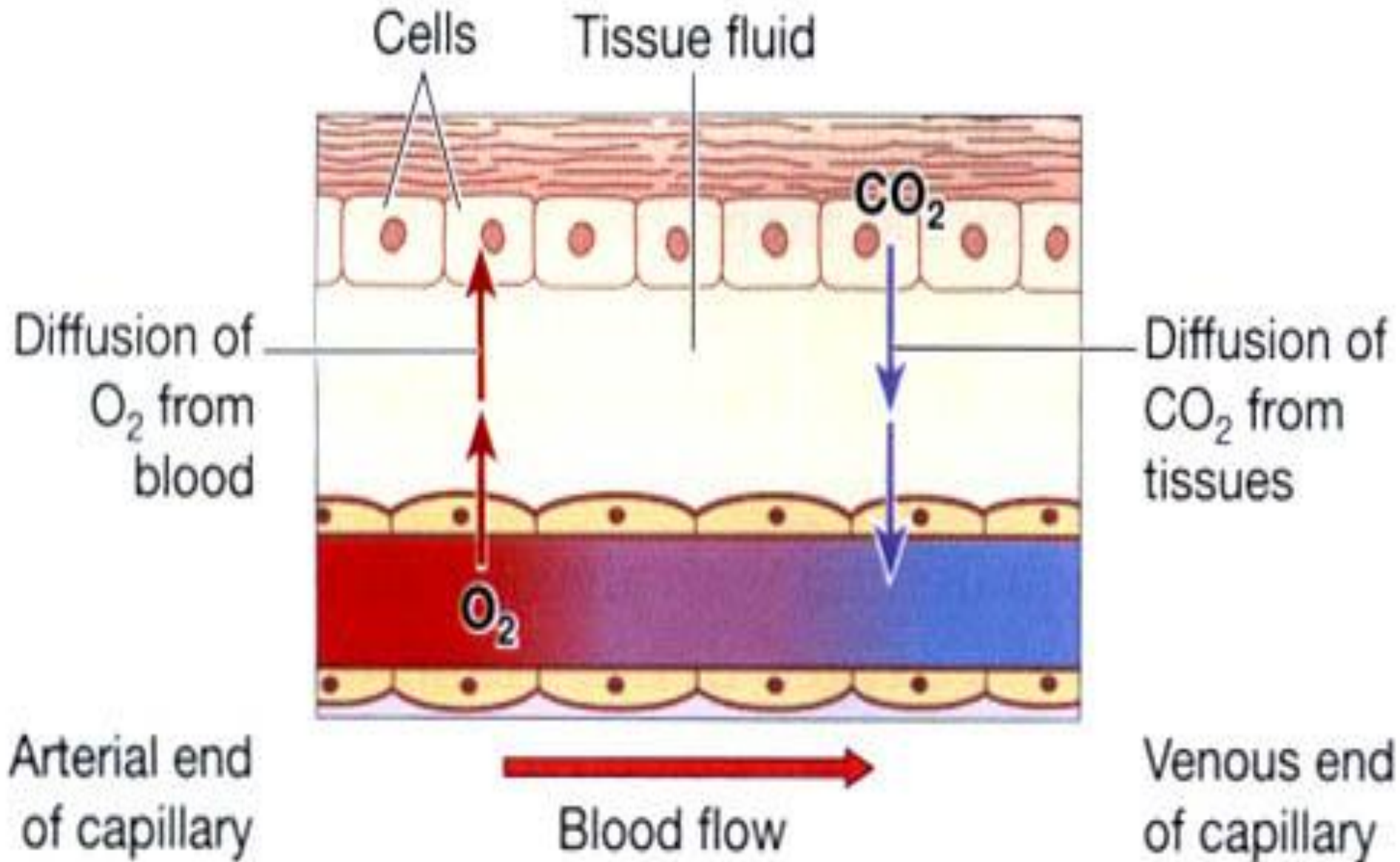
External respiration: exchange of gases btm alveolar air & capillary blood

- CO₂ diffuses from venous blood down its concentration gradient into the alveoli until equilibrium with alveolar air is reached while, O₂ diffuses from the alveoli into the blood.
- Slow flow of blood through the capillaries increases the time available for diffusion to occur.
- When blood leaves the alveolar capillaries, the O₂ & CO₂ concentrations are in equilibrium with those of alveolar air.

Internal respiration

- **Def:** Exchange of gases by diffusion between blood in the capillaries & the body cells.
- Gaseous exchange does not occur across the walls of the arteries carrying blood from the heart to the tissues, because their walls are too thick.

- PO_2 of blood arriving at the capillary bed is therefore the same as blood leaving the lungs.
- Blood arriving at the tissues has a higher PO_2 and a lower PCO_2 ; creating concentration gradients between the blood and the tissues, and gaseous exchange therefore occurs.
- O_2 diffuses from the bloodstream through the capillary wall into the tissues.
- CO_2 diffuses from the cells into the ECF then into the bloodstream towards the venous end of the capillary.



Internal respiration: exchange of gases between capillary blood and tissue cells.

Transport of gases in the blood stream

a) Oxygen

- Carried in the blood in:
 - chemical combination with haemoglobin as oxyhaemoglobin (98.5% of blood O₂)
 - solution in plasma water (1.5% of blood O₂).
- Oxyhaemoglobin is an unstable compound that under certain conditions readily dissociates releasing oxygen.
- Factors that increase dissociation include:
 - raised CO₂ content of tissue fluid,
 - raised temperature
 - 2,3-diphosphoglycerate (substance present in red blood cells).
- When oxygen leaves the erythrocyte, the deoxygenated haemoglobin turns **purplish** in colour.

b) Carbon dioxide

- Excreted by the lungs
- Transported by 3 mechanisms:
 - most of it is in the form of bicarbonate ions (HCO_3^-) in the plasma (70% of blood CO_2)
 - some is dissolved in the plasma (7% of blood CO_2)
 - some is carried in erythrocytes, loosely combined with haemoglobin as carbaminohaemoglobin (23% of blood CO_2).

CONTROL OF RESPIRATION

- Normally involuntary.
- Voluntary control is exerted during activities such as speaking and singing but is overridden if blood CO₂ rises (hypercapnia).

a) The respiratory centre

- Formed by groups of nerve cells that control the rate & depth of respiration. They are situated in the brain stem, in the medulla oblongata & the pons.
- In the medulla there are **inspiratory neurones & expiratory neurones**.
- Activity of the respiratory rhythmicity centre is adjusted by nerves in the pons i.e. the pneumotaxic centre (a neural center in the upper part of the pons that provides inhibitory impulses on inspiration and thereby prevents overdistension of the lungs and helps to maintain alternately recurrent inspiration and expiration) and the apneustic centre (It controls the intensity of breathing. The **apneustic center** is inhibited by pulmonary stretch receptors.) in response to input from other parts of the brain.
- Motor impulses leaving the respiratory centre pass in the phrenic and intercostal nerves to the diaphragm and intercostal muscles respectively.

b) Chemoreceptors

- **Def:** receptors that respond to changes in the partial pressures of O₂ & CO₂ in the blood & CSF.
- Located centrally & peripherally.
- **Central chemoreceptors:**
 - Are on the surface of the medulla oblongata & are bathed in CSF.
 - When the arterial PCO₂ rises (hypercapnia), they respond by stimulating the respiratory centre, increasing ventilation of the lungs & reducing arterial PCO₂.
 - Their sensitivity to raised arterial PCO₂ is the most important factor in maintaining homeostasis of blood gases in health.
 - A small reduction in PO₂ (hypoxaemia) has the same, but less pronounced effect, but a substantial reduction has a depressing effect.

- **Peripheral chemoreceptors:**

- Situated in the arch of the aorta & in the carotid bodies .
- More sensitive to small rises in arterial PCO_2 than to similarly low arterial PO_2 levels.
- Nerve impulses, generated in the peripheral chemoreceptors, are conveyed by the **glossopharyngeal** and **vagus** nerves to the medulla and stimulate the respiratory centre. The rate and depth of breathing are then increased.
- An increase in blood acidity stimulates them, resulting in increased ventilation, increased CO_2 excretion and increased blood pH.

c) Other factors that influence respiration

- ✓ Breathing may be modified by the higher centres in the brain by
 - speech, singing
 - emotional displays, e.g. crying, laughing, fear
 - drugs, e.g. sedatives, alcohol
 - sleep.
- ✓ Temperature influences breathing. In fever respiration is increased due to increased metabolic rate while in hypothermia it is depressed, as is metabolism.
- ✓ Temporary changes in respiration occur in swallowing, sneezing and coughing.
- ✓ **Hering-Breuer reflex;** prevents over-inflation of the lungs. Stretch receptors situated in the thoracic wall generate nerve inhibitory impulses when the lungs have inflated. They travel via the vagus nerves to the respiratory centre.

✓ **Strenuous exercise;** both the rate & depth of breathing increase, increasing O₂ uptake & CO₂ excretion in order to meet increased needs and so maintain homeostasis.

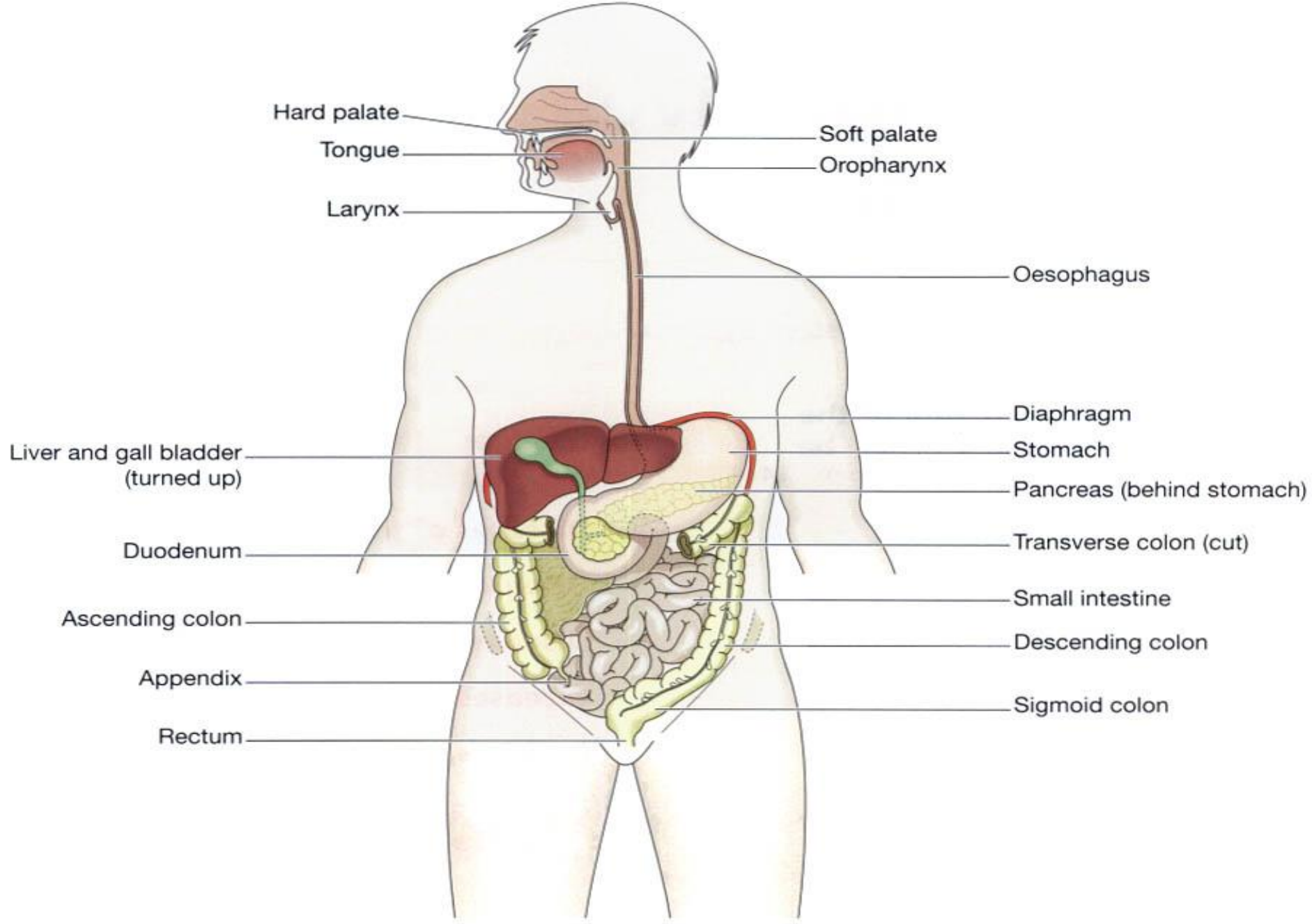
NOTE: When intense respiratory effort is required, the accessory muscles of respiration are used. The most important is the **sternodeidomastoid**.

THE DIGESTIVE SYSTEM

Digestive system

- Has a general structure which is modified at different levels to provide for the processes occurring at each level.
- Breaks down the foods eaten until they are in a form suitable for absorption: amino acids, mineral salts, fat and vitamins.
- Chemical substances which effect these changes are secreted into the canal by specialized glands, some
 - in the walls of the canal
 - outside the canal with ducts leading into it.

- Activities in the digestive system are:
 - 1. Ingestion:** process of taking food into the alimentary tract.
 - 2. Propulsion:** moves the contents along the alimentary tract.
 - 3. Digestion:** Consists of:
 - ✓ mechanical breakdown of food by, e.g. mastication (chewing)
 - ✓ chemical digestion of food by enzymes present in secretions produced by glands & accessory organs of the digestive system.
 - 4. Absorption:** process by which digested food substances pass through the walls of some organs of the alimentary canal into the blood and lymph capillaries for circulation round the body.
 - 5. Elimination:** Excretion of food substances which have been eaten but cannot be digested and absorbed.



Organs of the digestive system

Functions of digestive system

1. Movement of food along the digestive tract
2. Mechanical and chemical digestion of food
3. Absorption of digested food into circulatory and lymphatic system
4. Elimination of indigestible and waste products

ORGANS OF THE DIGESTIVE SYSTEM

Alimentary tract

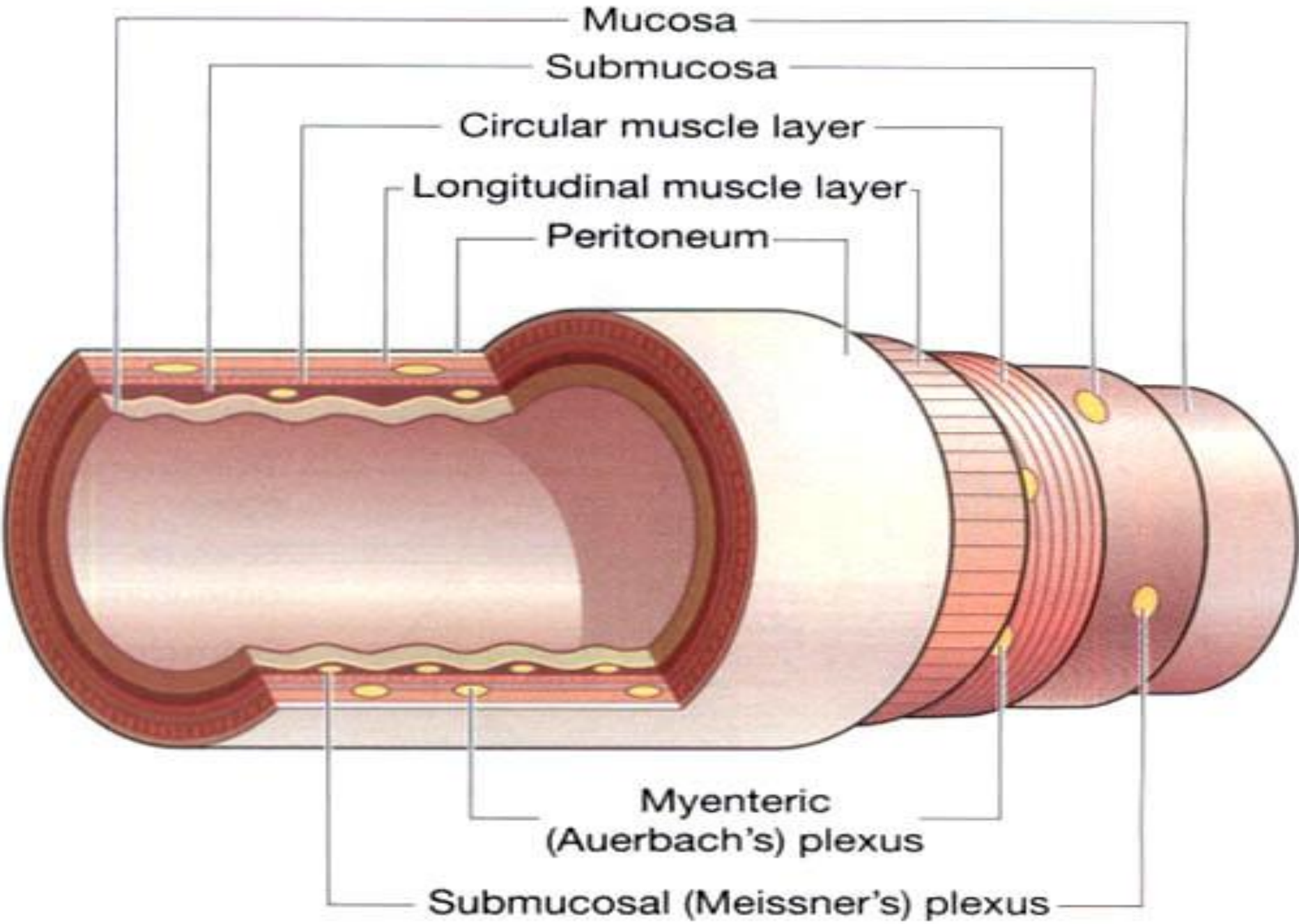
- **Def:** Long tube through which food passes.
- Commences at the mouth and terminates at the anus.
- The parts are:
 - mouth
 - pharynx
 - oesophagus
 - stomach
 - small intestine
 - large intestine
 - rectum
 - anal canal.

Accessory organs

- Includes glands in the lining membrane of the organs & glands situated outside the tract.
- Consist of:
 - 3 pairs of salivary glands
 - pancreas
 - liver & the biliary tract.
- The organs & glands are linked physiologically as well as anatomically in that digestion and absorption occur in stages, each stage being dependent upon the previous stage or stages.

BASIC STRUCTURE OF THE ALIMENTARY

- Layers of the walls of the alimentary canal follow a consistent pattern from the oesophagus onwards.
- Walls are formed by 4 layers of tissue:
 - adventitia or outer covering
 - muscle layer
 - submucosal layer
 - mucosa — lining.



General structure of alimentary canal ⁸⁴²

a) Adventitia (outer covering)

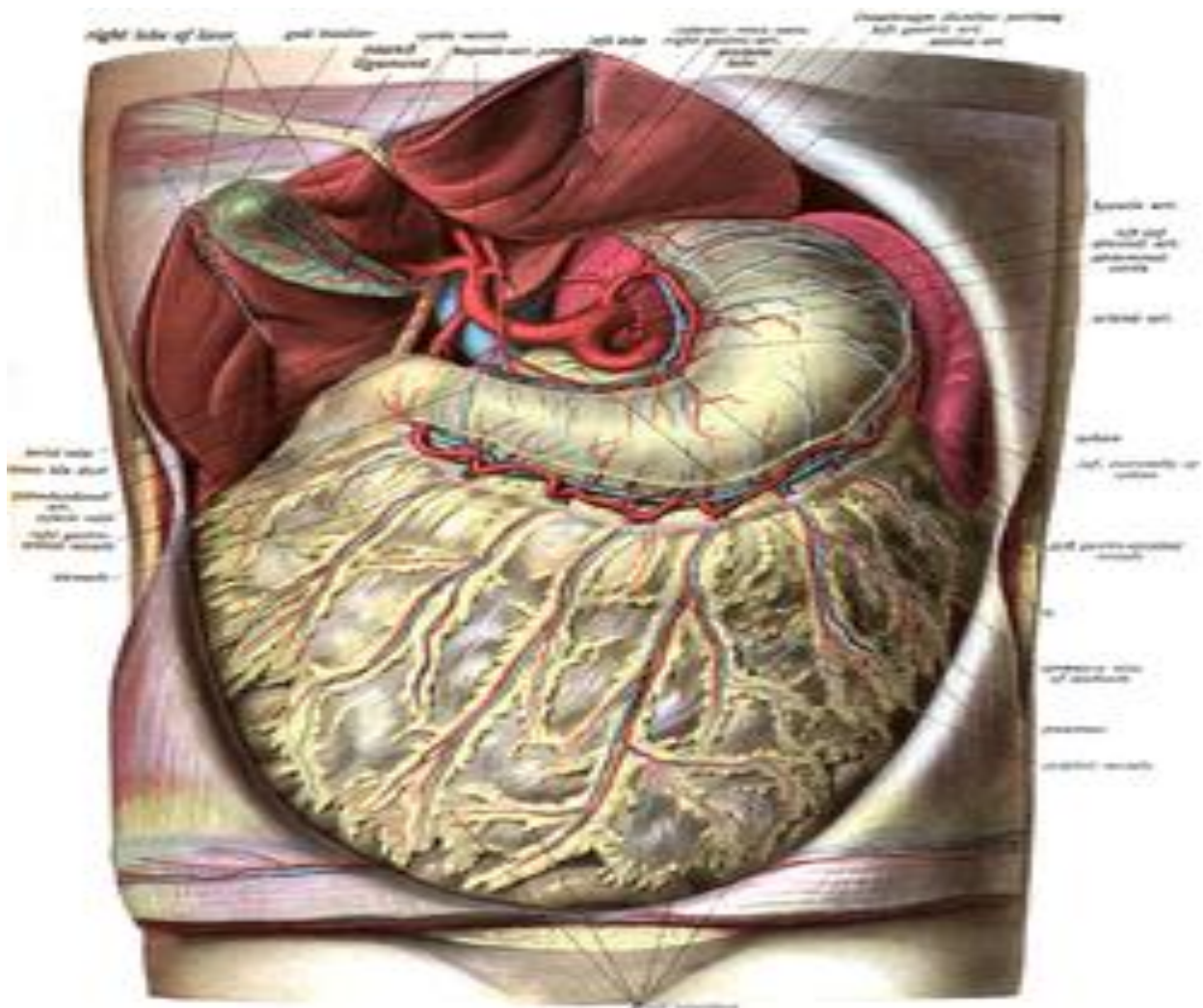
- Thorax; it consists of **loose fibrous tissue**
- Abdomen; organs are covered by a serous membrane called **peritoneum**.

Peritoneum

- Largest serous membrane of the body.
- Consists of a closed sac, containing a small amount of serous fluid, within the abdominal cavity; prevents friction.
- Richly supplied with blood and lymph vessels, and contains a considerable number of lymph nodes.
- Provides a physical barrier to local spread of infection, and can isolate an infective focus such as appendicitis, preventing involvement of other abdominal structures.
- Has 2 layers:
 - **parietal layer**; lines the abdominal wall
 - **visceral layer**; covers the organs (viscera) within the abdominal and pelvic cavities.

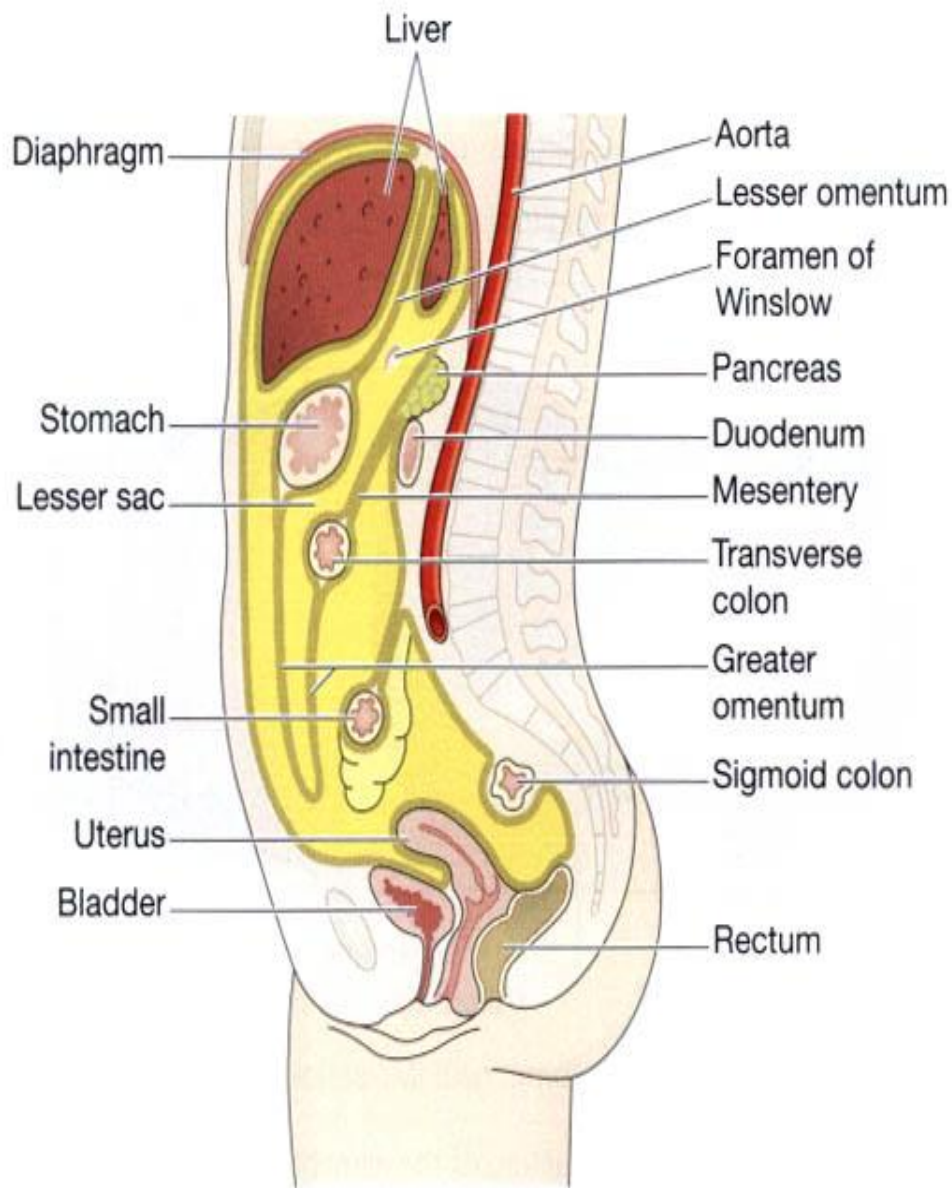
- Arrangement of the peritoneum is such that the organs are invaginated into the closed sac from below, behind and above so that they are at least partly covered by the visceral layer.
- This means that the:
 - pelvic organs are covered only on their superior surface
 - stomach & intestines, deeply invaginated from behind, are almost completely surrounded by peritoneum and have a double fold (**the mesentery**) that attaches them to the posterior abdominal wall.
 - fold of peritoneum enclosing the stomach extends beyond the greater curvature of the stomach, and hangs down in front of the abdominal organs like an apron (**greater omentum**). The greater omentum stores fat, which provides both insulation and a long-term energy store.

Greater omentum

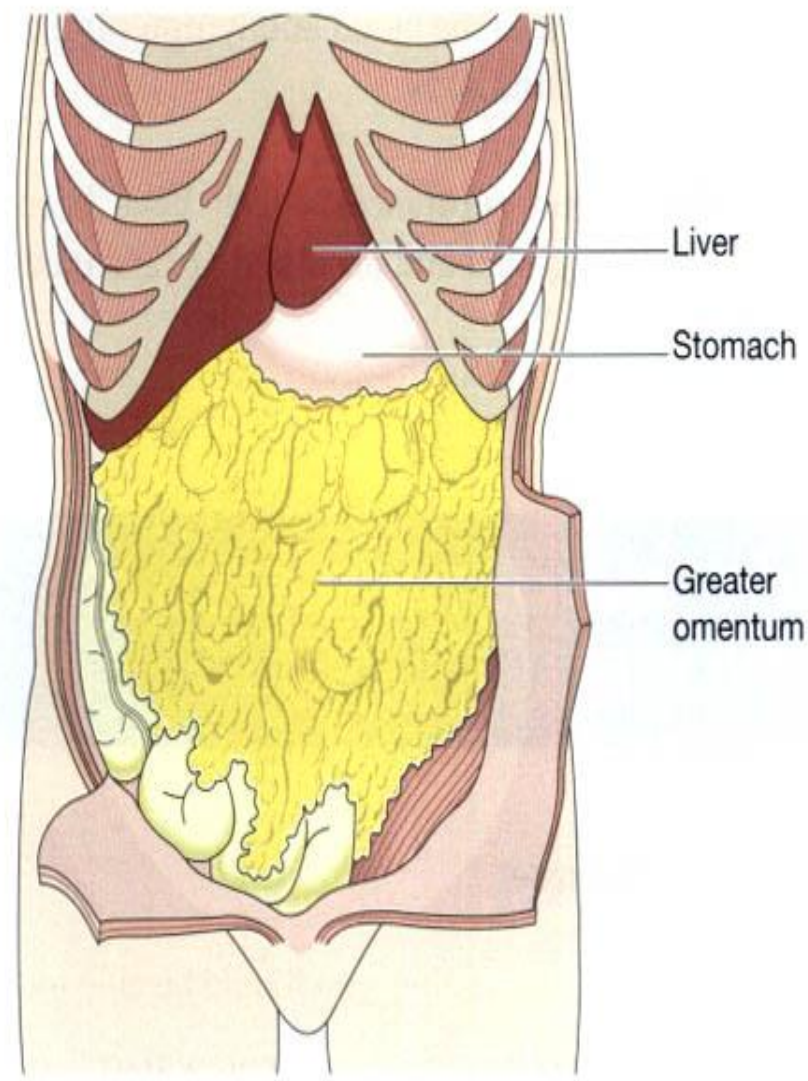


- pancreas, spleen, kidneys & adrenal glands are invaginated from behind but only their anterior surfaces are covered and are therefore retroperitoneal.
- liver is invaginated from above and is almost completely covered by peritoneum which attaches it to the inferior surface of the diaphragm
- main blood vessels & nerves pass close to the posterior abdominal wall & send branches to the organs between folds of peritoneum.

- **Parietal peritoneum** lines the anterior abdominal wall.
- In the male it is completely closed but in the female the uterine tubes open into it and the ovaries are the only structures inside



A



B

Peritoneal cavity (gold), the abdominal organs of the digestive system & pelvic organs.
 B. greater omentum

b) Muscle layer

- Consists of 2 layers of smooth muscle.
- Muscle fibres of the outer layer are arranged longitudinally, and those of the inner layer encircle the wall of the tube.
- Between these 2 muscle layers are blood vessels, lymph vessels and a plexus of sympathetic & parasympathetic nerves, called the **myenteric or Auerbach's plexus**; supply the adjacent smooth muscle & blood vessels.
- Contraction & relaxation of the muscle layers occurs in waves which push the contents of the tract onwards (**peristalsis**).
- Muscle contraction also mixes food with the digestive juices.
- Onward movement of the contents of the tract is controlled at various points by sphincters consisting of an increased number of circular muscle fibres. They also act as valves preventing backflow in the tract. The control allows time for digestion and absorption to take place.

c) Submucosa

- Consists of loose connective tissue with some elastic fibres.
- Within this layer are plexuses of blood vessels and nerves, lymph vessels and varying amounts of lymphoid tissues.
- Nerve plexus: **submucosal or Meissner's plexus**, consisting of sympathetic & parasympathetic nerves which supply the mucosal lining.

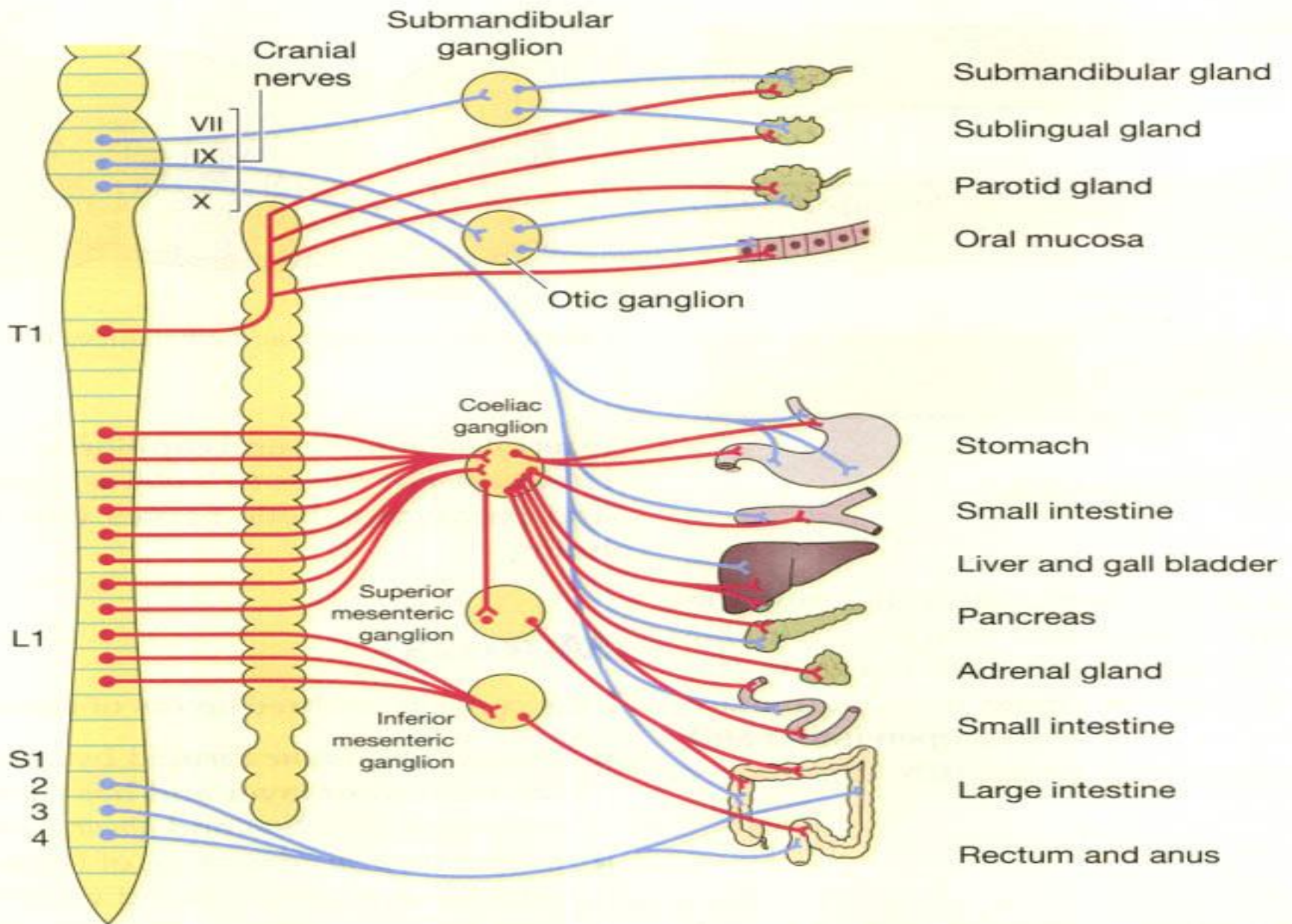
d) Mucosa: Consists of 3 layers of tissue:

- **mucous membrane**; formed by columnar epithelium; is the innermost layer & has 3 main functions: **protection, secretion & absorption**
- **lamina propria**; consisting of loose connective tissue, which supports the blood vessels that **nourish** the inner epithelial layer, and varying amounts of lymphoid tissue that has a **protective function**
- **muscularis mucosa**, a thin outer layer of smooth muscle that provides involutions of the mucosa layer, e.g. gastric glands, villi.

- **Mucous membrane**
- In parts of the tract which are subject to great wear and tear or mechanical injury this layer consists of **stratified squamous epithelium** with mucus-secreting glands just below the surface.
- In areas where the food is already soft and moist and where secretion of digestive juices and absorption occur, the mucous membrane consists of **columnar epithelial cells** interspersed with mucus-secreting goblet cells.
- Mucus lubricates the walls of the tract and protects them from digestive enzymes.

- The secretions include:
 - saliva from the salivary glands
 - gastric juice from the gastric glands
 - intestinal juice from the intestinal glands
 - pancreatic juice from the pancreas
 - bile from the liver.
- **Nerve supply**
- **Parasympathetic supply:** mostly provided by the **vagus nerves**. Stimulation causes **smooth muscle contraction** and **the secretion of digestive juices**. The most distal part of the tract is supplied by **sacral nerves**.

- **Sympathetic supply:** Nerves which emerge from the spinal cord in the thoracic and lumbar regions. These form plexuses in the thorax, abdomen and pelvis, from which nerves pass to the organs of the alimentary tract. Action: **reduce smooth muscle contraction** and **glandular secretion**.
- Within the walls of the canal are 2 nerve plexuses from which both sympathetic and parasympathetic fibres are distributed .
 - **Myenteric or Auerbach's plexus:** lies between the 2 layers of smooth muscle that it supplies, and influences peristalsis.
 - **Submucosal or Meissner's plexus:** lies in the submucosa & supplies the mucous membrane & secretory glands.

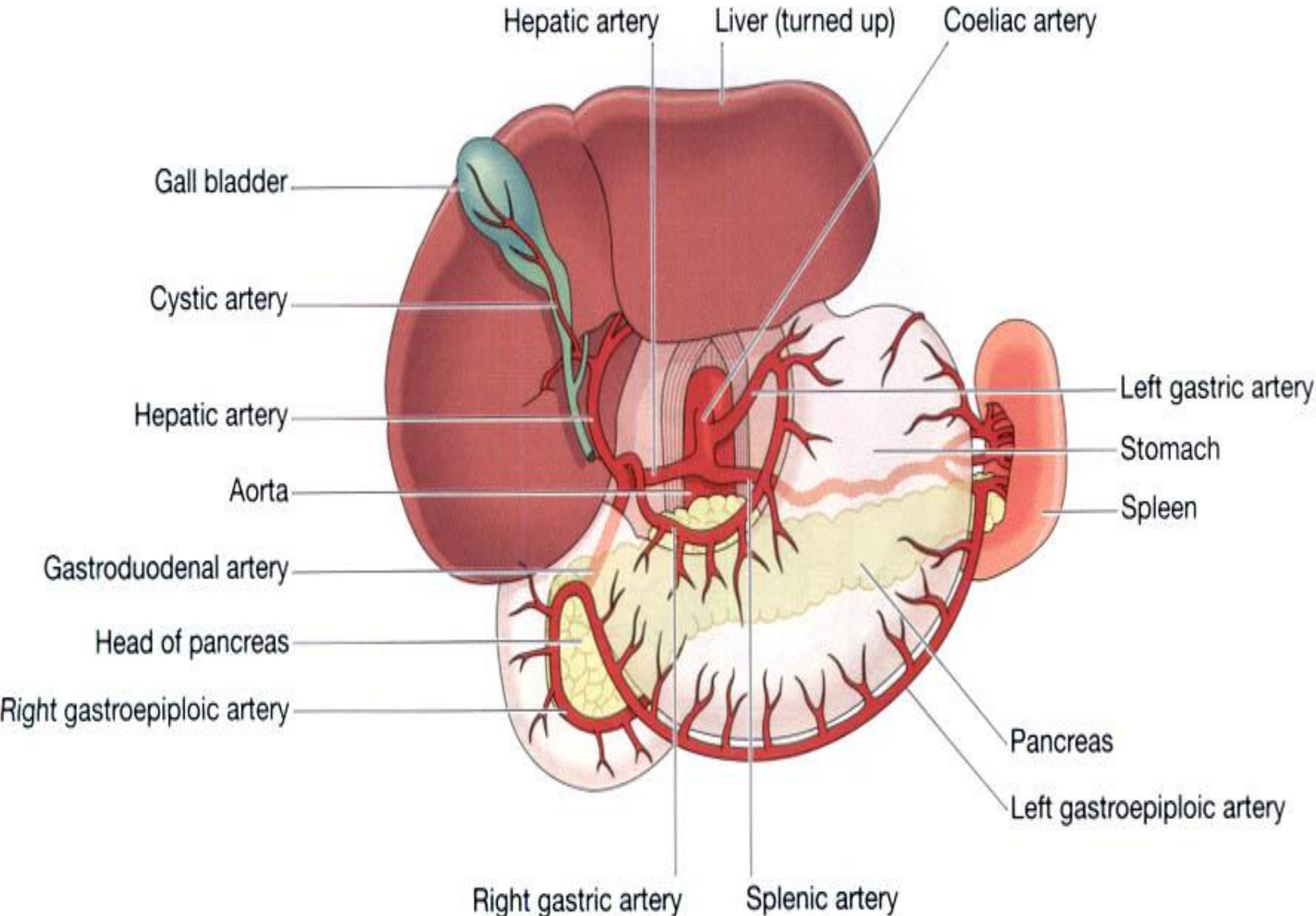


ANS supply to the digestive system; parasympathetic-blue, sympathetic-red

Blood supply

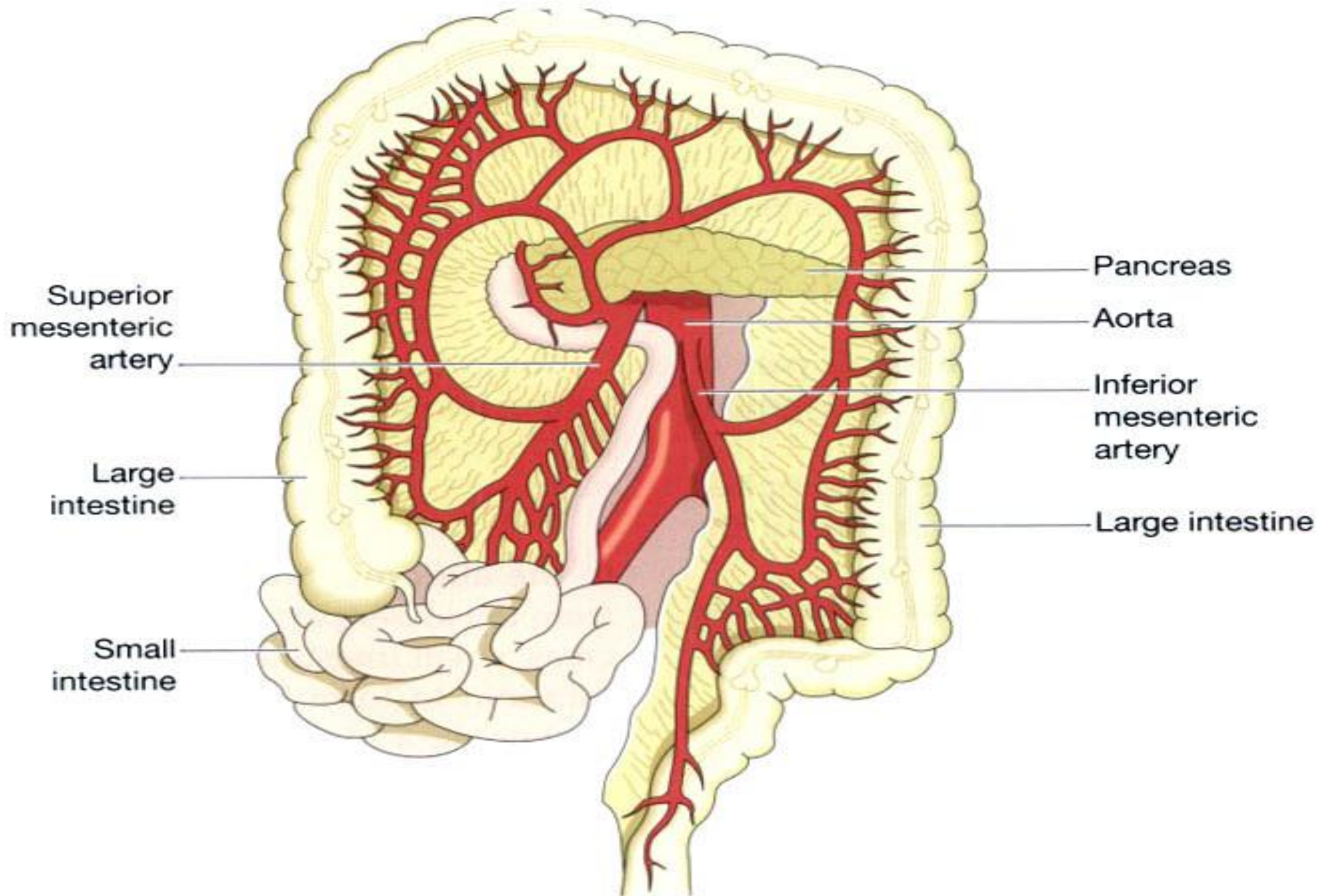
Arterial blood supply

- **In the thorax;** oesophagus is supplied by paired oesophageal arteries, branches from the thoracic aorta.
- **In the abdomen & pelvis;** alimentary tract, pancreas, liver & biliary tract are supplied by the unpaired branches from the aorta:
 - coeliac artery
 - superior & inferior mesenteric arteries.
- Coeliac artery divides into 3 branches which supply the stomach, duodenum, pancreas, spleen, liver, gall bladder & bile ducts. They are:
 - left gastric artery
 - splenic artery
 - hepatic artery.
- Superior mesenteric artery supplies the whole of the small intestine, the caecum, ascending colon and most of the transverse colon.



Branches of the coeliac artery and the organs they supply ⁸⁵⁵

- Inferior mesenteric artery supplies
 - a small part of the transverse colon,
 - the descending colon,
 - sigmoid colon and most of the rectum.
- Distal part of the rectum & the anus are supplied by the middle & inferior rectal arteries, branches of the internal iliac arteries.
- Arteries supplying the stomach & intestines pass between the layers of peritoneum from the posterior abdominal wall to the organs.



Blood supply to small and large intestines

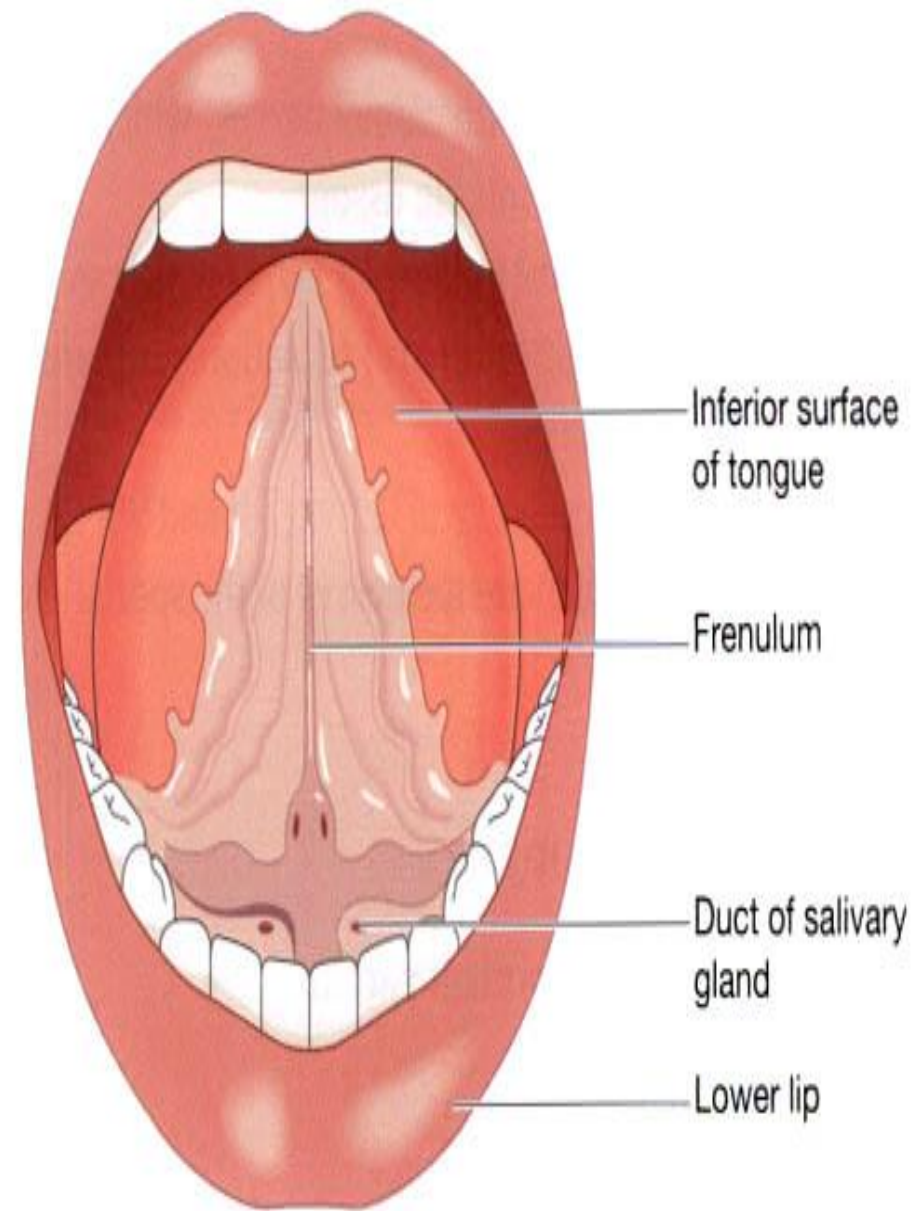
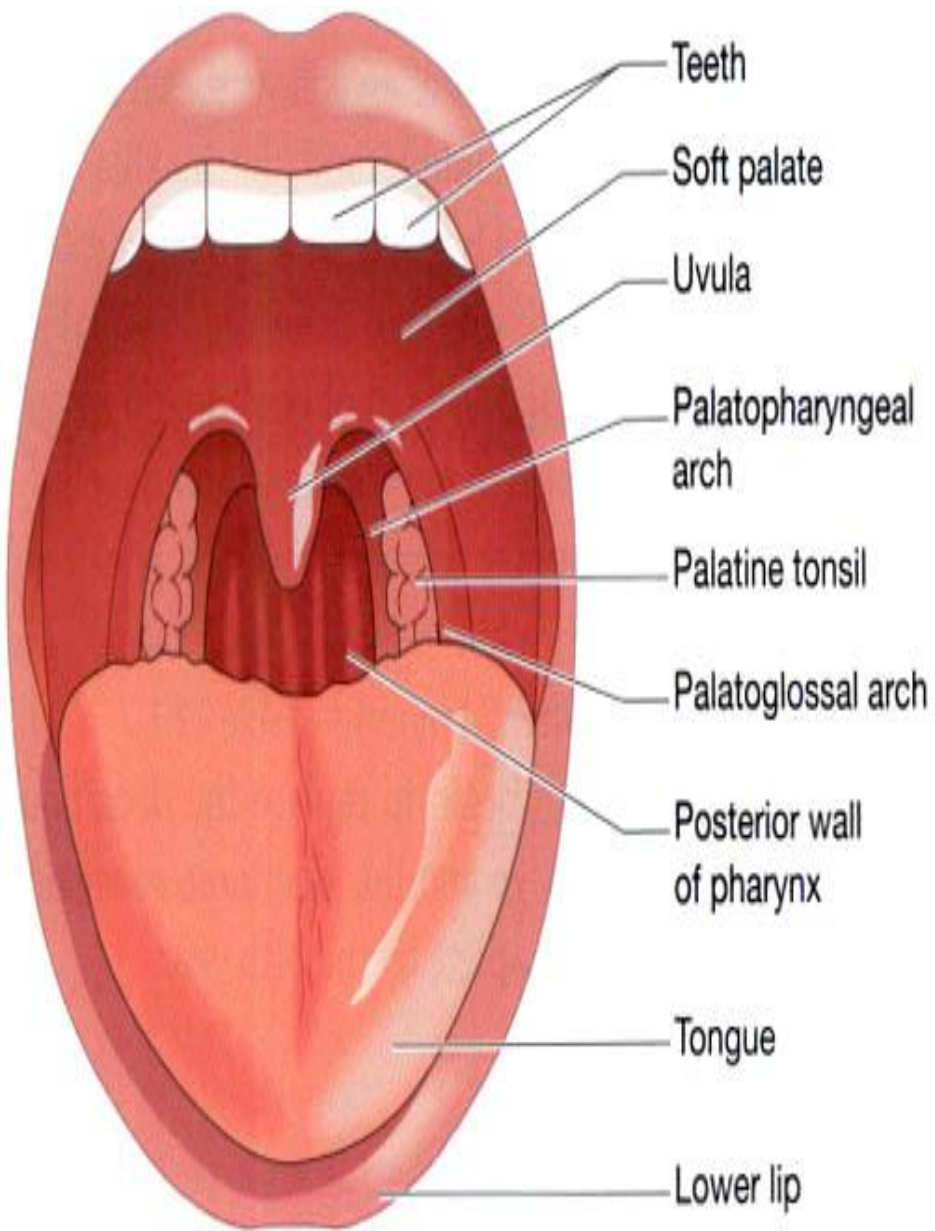
Venous drainage

- a) **In the thorax:** Venous blood from the **oesophagus** passes in the oesophageal veins to the **azygos & hemiazygos** veins.
- Azygos vein joins the superior vena cava near the heart, and the hemiazygos joins the left brachiocephalic vein.
- Some blood from the lower part of the oesophagus drains into the left gastric vein.
- b) **In the abdomen and pelvis:** Veins that drain blood from the lower part of the oesophagus, the stomach, pancreas, small intestine, large intestine and most of the rectum join to form the **portal vein**. The blood, containing a high concentration of absorbed nutritional materials, is conveyed first to the liver then to the inferior vena cava.
- Blood from the lower part of the rectum & anal canal drains into the **internal iliac veins**. This blood is delivered directly into the inferior vena cava.

THE MOUTH/ORAL CAVITY

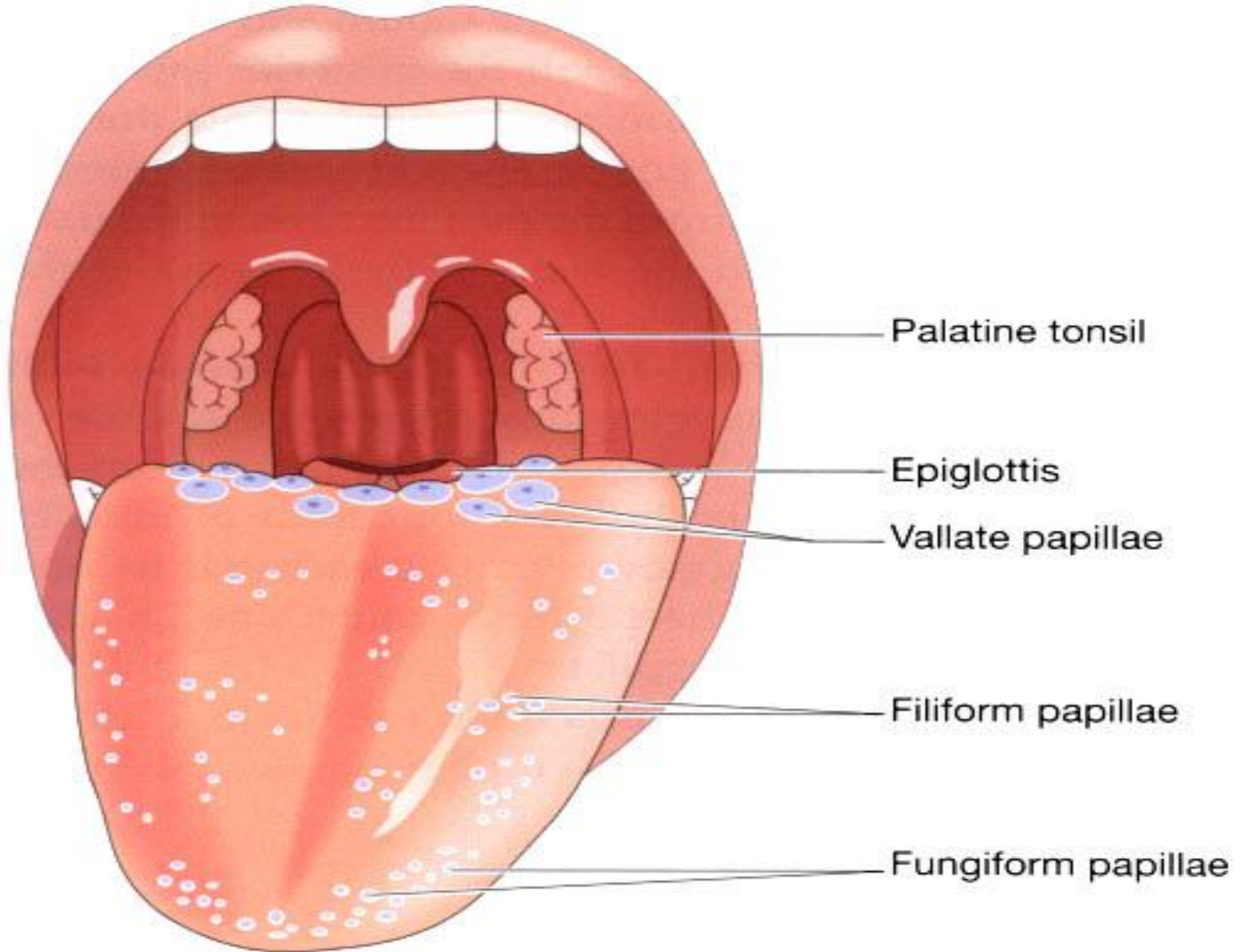
- Bounded by muscles & bones:
 - Anteriorly —lips
 - Posteriorly —continuous with the oropharynx
 - Laterally —muscles of the cheeks
 - Superiorly —bony hard palate & muscular soft palate
 - Inferiorly —muscular tongue & the soft tissues of the floor of the mouth.
- Lined throughout with mucous membrane, consisting of **stratified squamous epithelium** containing small mucus-secreting glands.
- Part of the mouth between the **gums (alveolar ridges)** & the cheeks is the **vestibule** and the remainder of the cavity is the **mouth proper**.
- Mucous membrane lining of the cheeks and the lips is reflected on to the gums or alveolar ridges and is continuous with the skin of the face.

- **Palate;** forms the roof of the mouth & is divided into the anterior hard palate and the posterior soft palate
 - Bones forming the **hard palate; maxilla & palatine bones.**
 - **Soft palate;** muscular, curves downwards from the posterior end of the hard palate & blends with the walls of the pharynx at the sides.
- **Uvula;** curved fold of muscle covered with mucous membrane, hanging down from the middle of the free border of the soft palate.
 - Originating from the upper end of the uvula are 4 folds of mucous membrane, 2 passing downwards at each side to form membranous arches.
 - The posterior folds, 1 on each side, are the **palatopharyngeal arches** and the 2 anterior folds are the **palatoglossal arches.** On each side, between the arches, is **palatine tonsil.**



structures in the mouth; inferior surface of the tongue.

- **Tongue**
- Voluntary muscular structure which occupies the floor of the mouth.
- Attached by its base to the hyoid bone & by a fold of its mucous membrane covering; the **frenulum**, to the floor of the mouth.
- Superior surface consists of **stratified squamous epithelium**, with numerous **papillae** (little projections), containing nerve endings of the sense of taste (**taste buds**).
- 3 varieties of papillae.
 - **Vallate papillae**, usually between 8 & 12 altogether; are arranged in an inverted V shape towards the base of the tongue. Are the largest of the papillae & are the most easily seen.
 - **Fungiform papillae**; situated mainly at the tip and the edges of the tongue & are more numerous than the vallate papillae.
 - **Filiform papillae**; smallest of the 3 types. Are most numerous on the surface of the anterior two-thirds of the tongue.



Locations of the papillae of the tongue and related structures.

- **Blood supply**
- Arterial blood supply: lingual branch of the external carotid artery.
- Venous drainage: lingual vein which joins the internal jugular vein.
- **Nerve supply:**
 - **Hypoglossal nerves;** supply the voluntary muscle tissue
 - **Lingual branch of the mandibular nerves;** nerves of somatic (ordinary) sensation, i.e. pain, temperature & touch
 - **Facial & glossopharyngeal nerves;** nerves of the special sensation of taste.

Functions of the tongue

- Plays an important part in:
 - mastication (chewing)
 - deglutition (swallowing)
 - speech

- **Teeth**
- Embedded in the alveoli or sockets of the alveolar ridges of the mandible & the maxilla.
- Each individual has 2 sets, or dentitions, the temporary or deciduous teeth and the permanent teeth.
- At birth the teeth of both dentitions are present in immature form in the mandible & maxilla.
- 20 temporary teeth, 10 in each jaw. They begin to erupt when the child is about 6 months old, and should all be present after 24 months.
- Permanent teeth begin to replace the deciduous teeth in the 6th year of age & this dentition, consisting of 32 teeth, is usually complete by the 24th year.

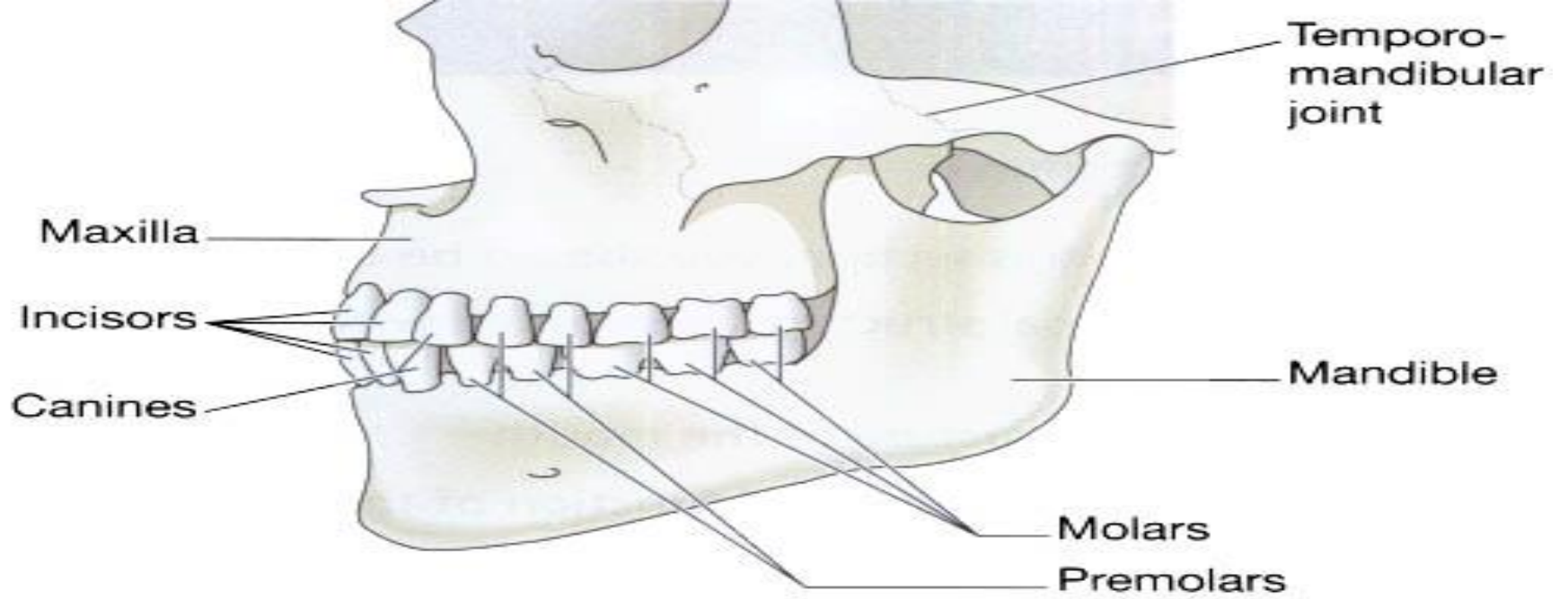
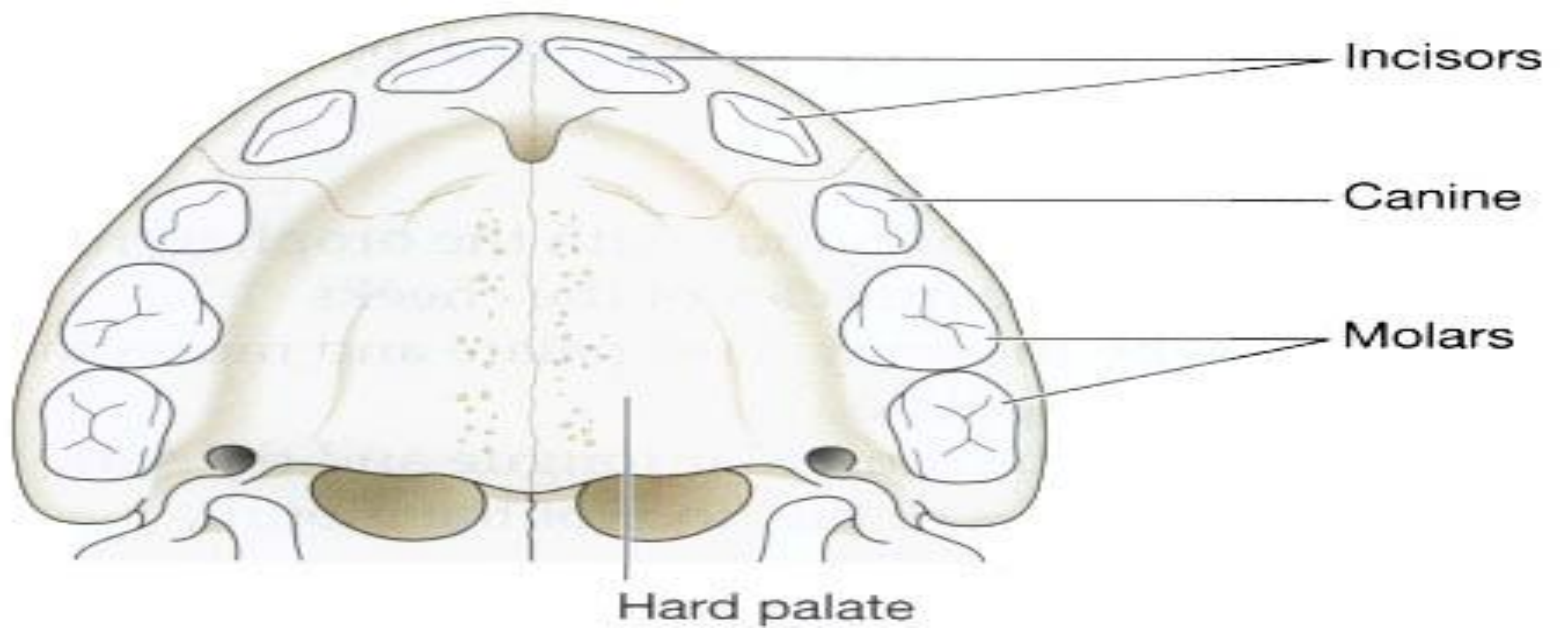


Figure 12.13 The permanent teeth and the jaw bones.



Functions of the teeth

1. Incisor & canine teeth; used for cutting & for biting off pieces of food,
2. Premolar & molar teeth, with broad, flat surfaces; for grinding or chewing food.

Structure of a tooth.

- Consists of:
 - the crown — part which protrudes from the gum
 - the root — part embedded in the bone
 - the neck — slightly narrowed region where the crown merges with the root.

- Centre of the tooth, is the **pulp cavity**; containing blood vessels, lymph vessels & nerves. Surrounding this is a hard ivory-like substance called **dentine**.
- Outside the dentine of the crown is a thin layer of very hard substance, the **enamel**.
- **Root** of the tooth is covered with a substance resembling bone; **cement**, which fixes the tooth in its socket.
- Blood vessels & nerves pass to the tooth through a small foramen at the apex of each root.

Nerve supply

- Upper teeth; branches of the maxillary nerves
- Lower teeth; branches of the mandibular nerves.
- Both branches of the trigeminal nerves



Molar



Premolar

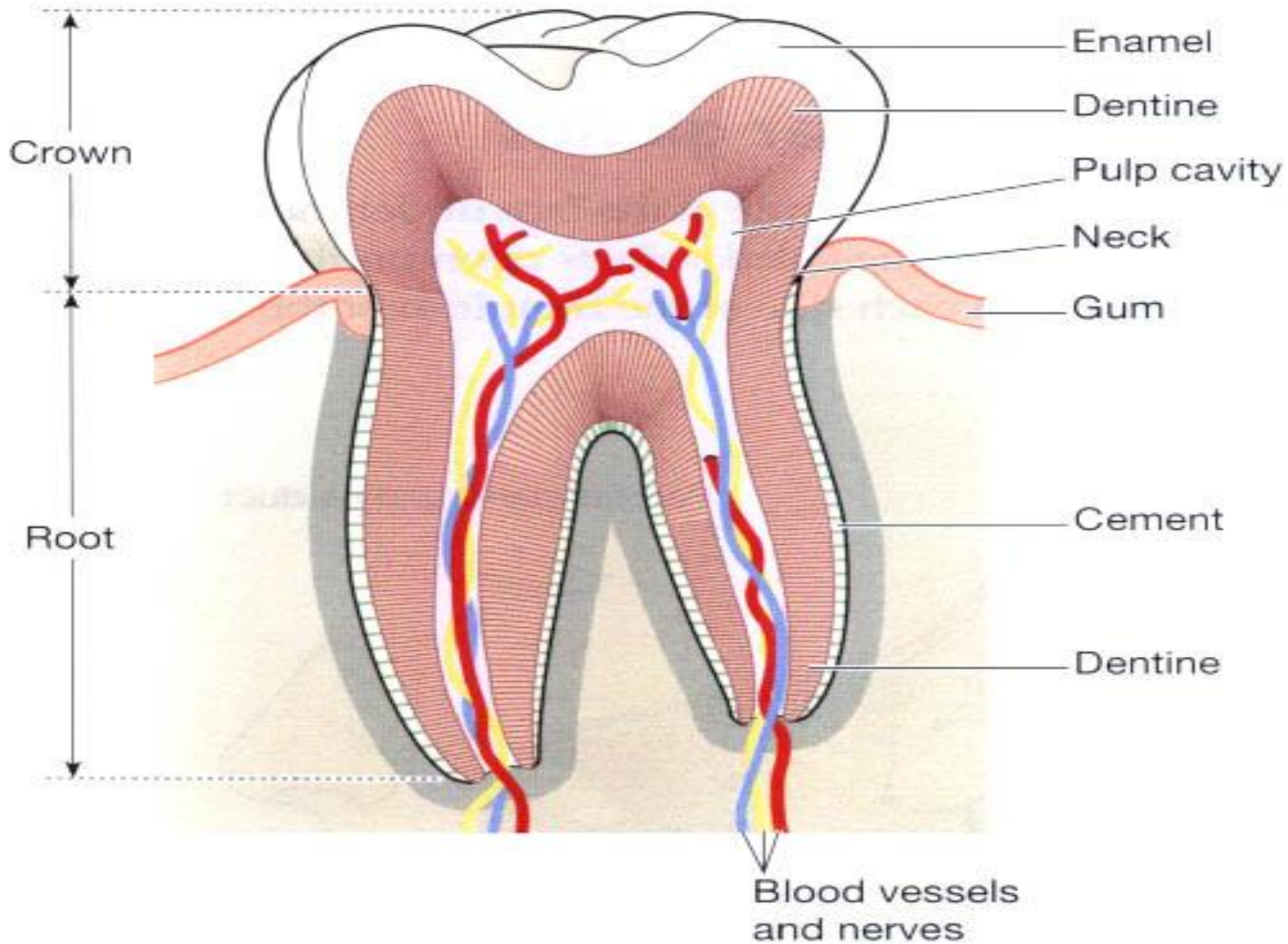


Canine



Incisor

shapes of the permanent teeth



Section of a tooth

SALIVARY GLANDS

- Pour their secretions into the mouth.
- 3 pairs: parotid, submandibular glands & sublingual glands.

a) Parotid glands

- Situated one on each side of the face just below the external acoustic meatus (is a canal within the [petrous part of the temporal bone](#) of the [skull](#) between the [posterior cranial fossa](#) and the [inner ear](#)). Each gland has a parotid duct opening into the mouth at the level of 2nd upper molar tooth.

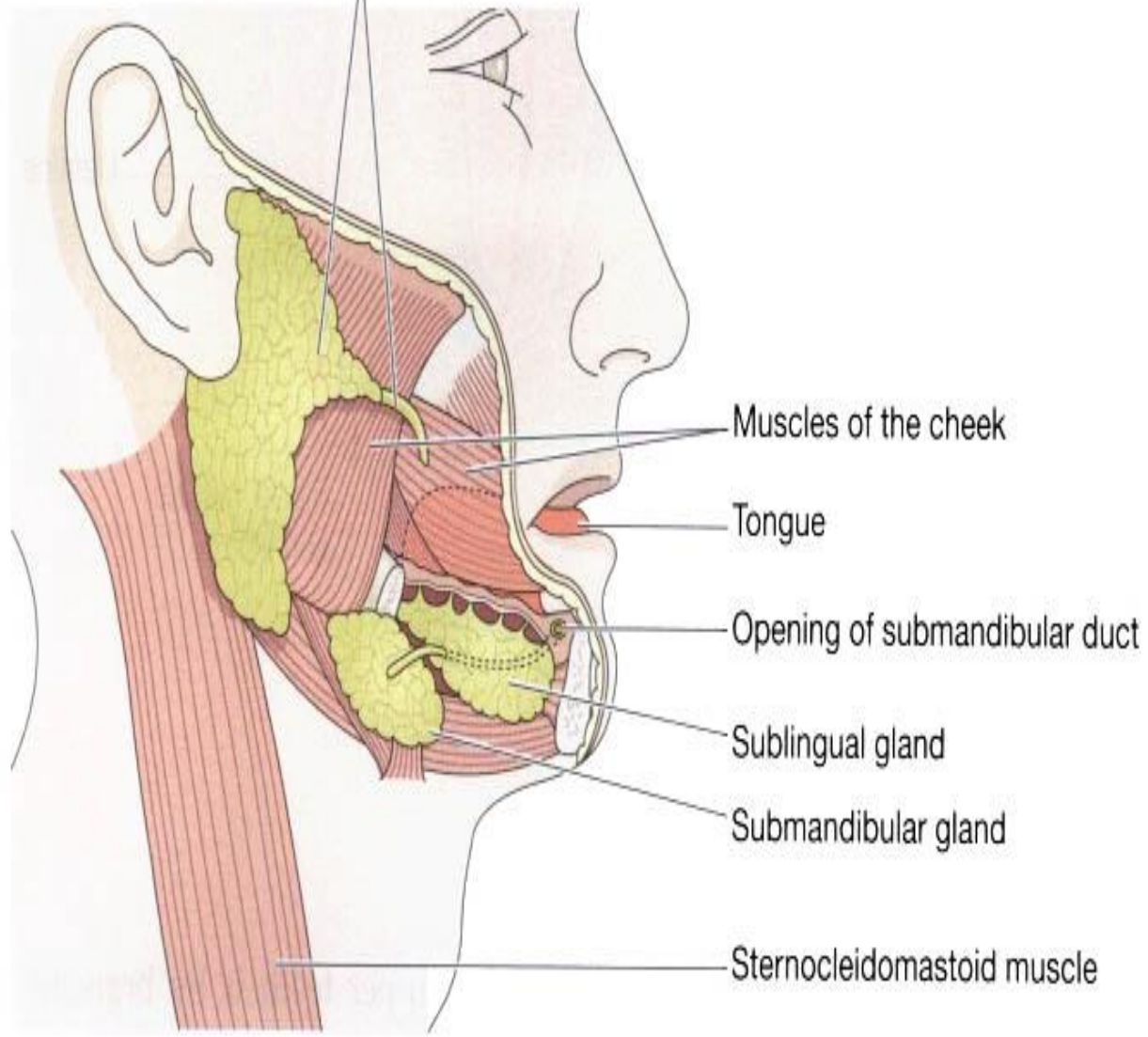
b) Submandibular glands

- Lie one on each side of the face under the angle of the jaw. 2 submandibular ducts open on the floor of the mouth, one on each side of the frenulum of the tongue.

c) Sublingual glands

- Lie under the mucous membrane of the floor of the mouth in front of the submandibular glands. Have numerous small ducts that open into the floor of the mouth.

Parotid gland and its duct



Muscles of the cheek

Tongue

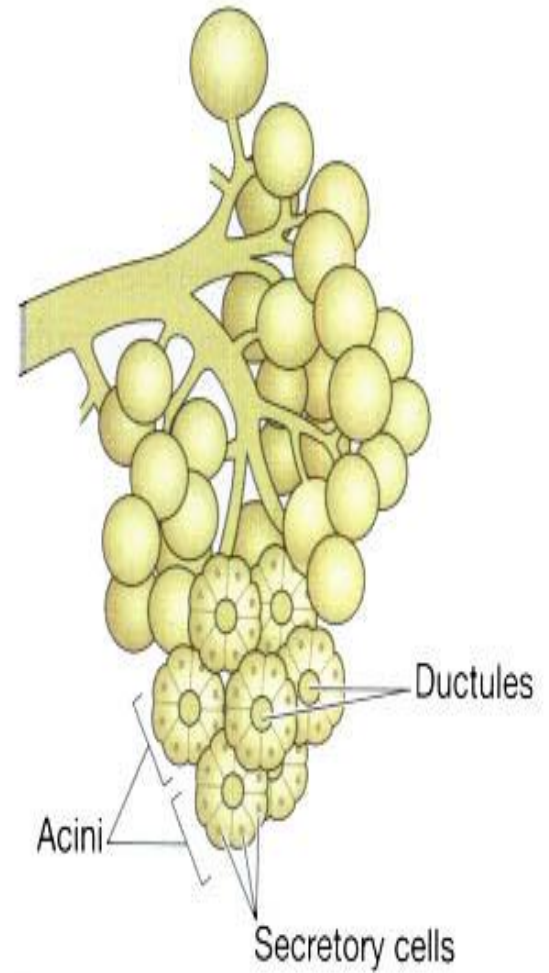
Opening of submandibular duct

Sublingual gland

Submandibular gland

Sternocleidomastoid muscle

A



Ductules

Acini

Secretory cells

B

Position of salivary glands

Structure of the salivary glands

- Surrounded by a fibrous capsule.
- Consist of a number of lobules made up of small acini lined with secretory cells.
- Secretions are poured into ductules which join up to form larger ducts leading into the mouth.

Nerve supply

- Parasympathetic stimulation; increases secretion
- sympathetic stimulation; decreases secretion.

Blood supply

- Arterial supply: branches from the external carotid arteries
- Venous drainage; into the external jugular veins.

Composition of saliva

- **Saliva:** combined secretions from the salivary glands & the small mucus-secreting glands of the lining of the oral cavity.
- About 1.5 litres of saliva is produced daily and it consists of:
 - water
 - mineral salts
 - enzyme: salivary amylase
 - mucus
 - lysozyme
 - immunoglobulins
 - blood-clotting factors.

Secretion of saliva

- Under autonomic nerve control.
- Parasympathetic stimulation causes vasodilatation and profuse secretion of watery saliva with a relatively low content of enzymes & other organic substances.
- Sympathetic stimulation causes vasoconstriction and secretion of small amounts of saliva rich in organic material, especially from the submandibular glands.
- Reflex secretion occurs when there is food in the mouth & the reflex can easily become conditioned so that the sight, smell and even the thought of food stimulates the flow of saliva.

Functions of saliva

- 1. Chemical digestion of polysaccharides:** Enzyme amylase begins the breakdown of complex sugars, reducing them to the disaccharide maltose.
 - Optimum pH for the action of salivary amylase is 6.8.
 - Salivary pH ranges from 5.8-7.4 depending on the rate of flow; the higher the flow rate, the higher is the pH.
- Enzyme action continues during swallowing until terminated by the strongly acidic pH (1.5 to 1.8) of the gastric juices, which degrades the amylase.
- 2. Lubrication of food.** Dry food entering the mouth is moistened & lubricated by saliva before it can be made into a bolus ready for swallowing.

- 3. Cleansing and lubricating.** An adequate flow of saliva is necessary to cleanse the mouth & keep its tissues soft, moist & pliable. Helps prevent damage to mucous membrane by rough/abrasive foodstuffs.
- 4. Non-specific defence.** Lysozyme, immunoglobulins & clotting factors combat invading microbes.
- 5. Taste.** Taste buds are stimulated only by chemical substances in solution. Dry foods stimulate the sense of taste only after thorough mixing with saliva.

PHARYNX

- Has 3 parts.
- **Nasopharynx**; important in respiration.
- **Oropharynx & laryngopharynx**; passages common to both the respiratory & digestive systems.
- Walls are built of 3 layers of tissue.
 - **Lining membrane (mucosa)**; stratified squamous epithelium, continuous with the lining of the mouth at one end & with the oesophagus at the other.
 - **Middle layer**; consists of fibrous tissue which becomes thinner towards the lower end & contains blood, lymph vessels & nerves.
 - **Outer layer**; consists of a number of involuntary constrictor muscles which are involved in swallowing. When food reaches the pharynx swallowing is no longer under voluntary control.

Blood supply

- Arterial: branches of the facial arteries.
- Venous drainage: into the facial veins & internal jugular veins.

Nerve supply

- From the pharyngeal plexus
- Parasympathetic & sympathetic nerves.
 - Parasympathetic supply: mainly by the glossopharyngeal & vagus nerves
 - sympathetic : from the cervical ganglia.

OESOPHAGUS

- About 25 cm long & about 2 cm in diameter
- Lies in the median plane in the thorax in front of the vertebral column behind the trachea and the heart.
- Continuous with the pharynx above & just below the diaphragm it joins the stomach.
- Passes between muscle fibres of the diaphragm behind the central tendon at the level of the 10th thoracic vertebra.
- Immediately the oesophagus has passed through the diaphragm it curves upwards before opening into the stomach. This sharp angle prevents the regurgitation of gastric contents into the oesophagus.
- Upper & lower ends of the oesophagus are closed by sphincter muscles.

- **Upper cricopharyngeal** sphincter; prevents air passing into the oesophagus during inspiration & aspiration of oesophageal contents.
- **Cardiac or lower oesophageal sphincter**; prevents reflux of acid gastric contents into the oesophagus.

Structure

- 4 layers of tissue.
- **Outer covering**; the adventitia, consists of elastic fibrous tissue.
- Proximal third; lined by stratified squamous epithelium
- Distal third; by columnar epithelium.
- Middle third; lined by a mixture of the two.

Blood supply

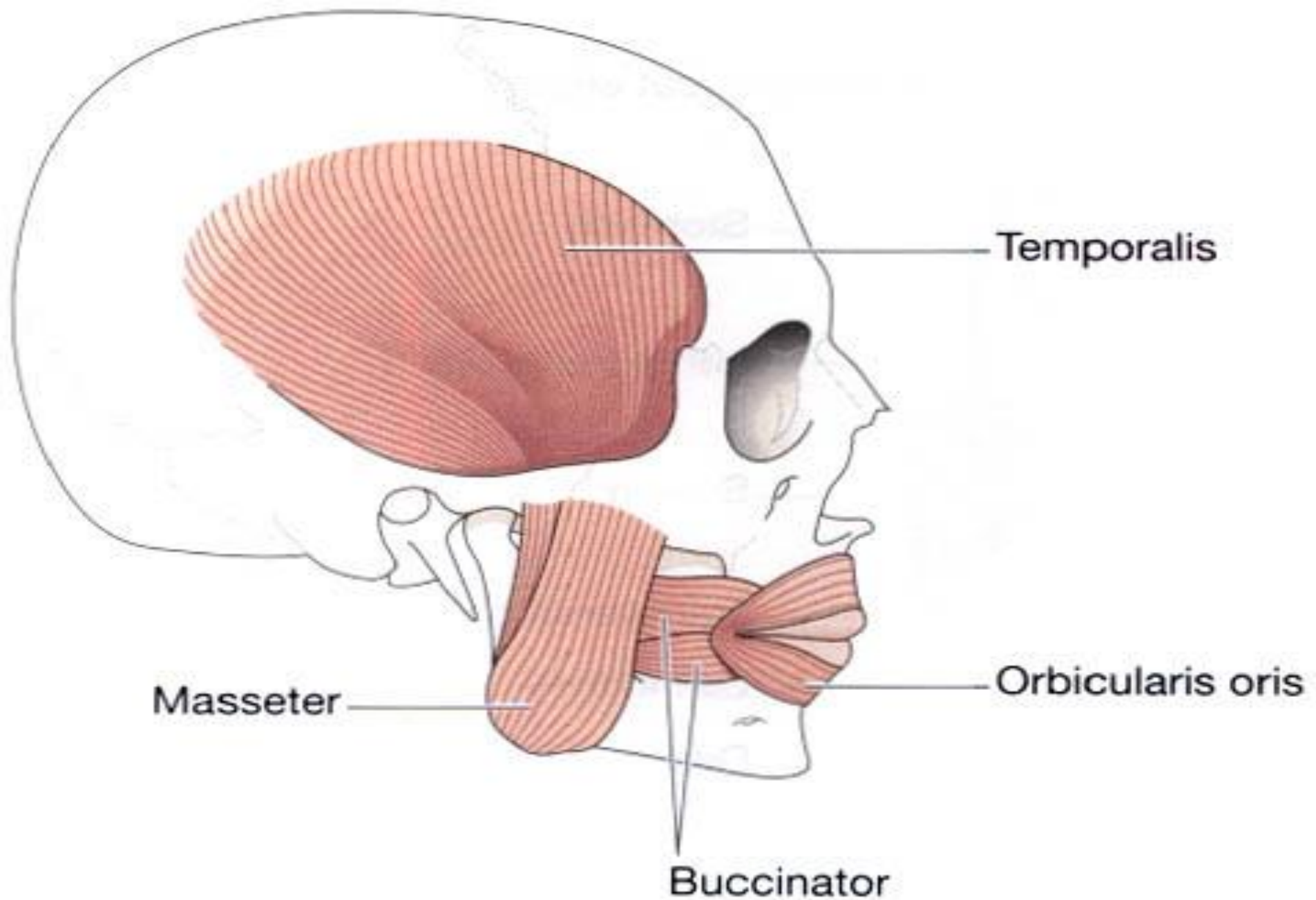
- **Arterial supply:**
 - thoracic region- mainly by the oesophageal arteries, branches from the aorta.
 - abdominal region - by branches from the inferior phrenic arteries and the left gastric branch of the coeliac artery.
- **Venous drainage.**
 - Thoracic region; into the azygos & hemiazygos veins.
 - Abdominal part drains into the left gastric vein. Venous plexus at the distal end links the upward & downward venous drainage, i.e. the general & portal circulations.

Nerve supply

- Sympathetic & parasympathetic nerves terminate in the myenteric & submucosal plexuses.
- Parasympathetic fibres are branches of the vagus nerves

Functions of the mouth, pharynx & oesophagus

- a) Formation of a bolus.** When food is taken into the mouth it is masticated or chewed by the teeth & moved round the mouth by the tongue & muscles of the cheeks.
- It is mixed with saliva & formed into a soft mass or bolus ready for deglutition or swallowing.
 - Length of time that food remains in the mouth depends, to a large extent, on the consistency of the food.
- b) Deglutition or swallowing.** Occurs in 3 stages after mastication is complete & the bolus has been formed. Initiated voluntarily but completed by a reflex (involuntary) action.

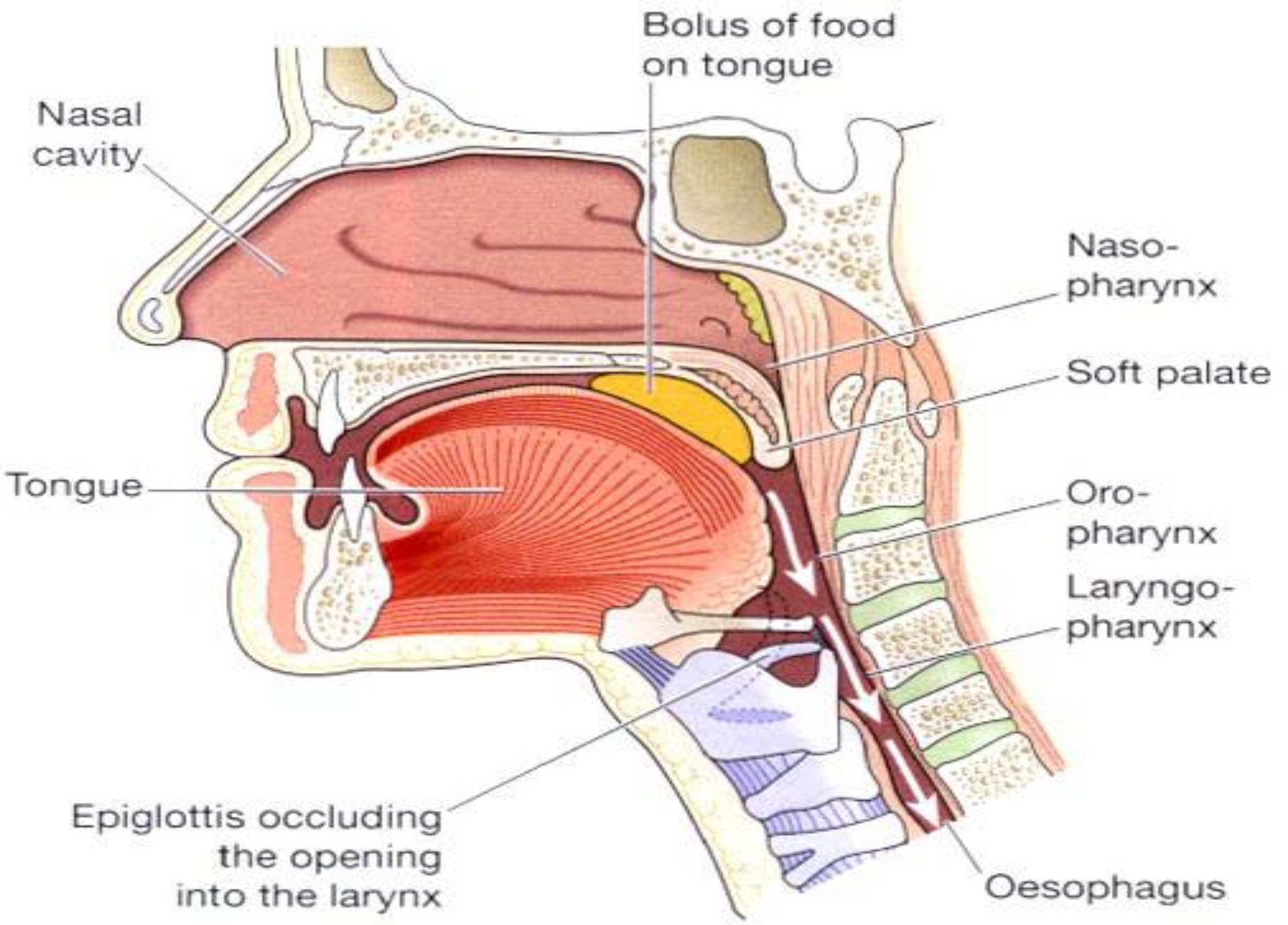


Muscles involved in mastication

Swallowing

1. Mouth is closed & voluntary muscles of the tongue & cheeks push the bolus backwards into the pharynx.
2. Muscles of the pharynx are stimulated by a reflex action initiated in the walls of the oropharynx & coordinated in the medulla & lower pons in the brain stem. Contraction of these muscles propels the bolus down into the oesophagus. Soft palate rises up & closes off the nasopharynx; the tongue & pharyngeal folds block the way back into the mouth; & larynx is lifted up & forward so that its opening is occluded by the overhanging epiglottis preventing entry into the airway.
3. Presence of the bolus in the pharynx stimulates a wave of peristalsis which propels the bolus through the oesophagus to the stomach.

- Peristaltic waves pass along the oesophagus only after swallowing.
- Ahead of a peristaltic wave, the cardiac sphincter guarding the entrance to the stomach relaxes to allow the descending bolus to pass into the stomach. Usually,
- Factors preventing gastric reflux include:
 - constriction of the cardiac sphincter.
 - Attachment of the stomach to the diaphragm by the peritoneum
 - Maintenance of an acute angle between the oesophagus & fundus of the stomach, i.e. an acute cardio-oesophageal angle
 - increased tone of the cardiac sphincter when intraabdominal pressure is increased & the pinching effect of diaphragm muscle fibres.
- Walls of the oesophagus are lubricated by mucus which assists the passage of the bolus during the peristaltic contraction of the muscular wall.



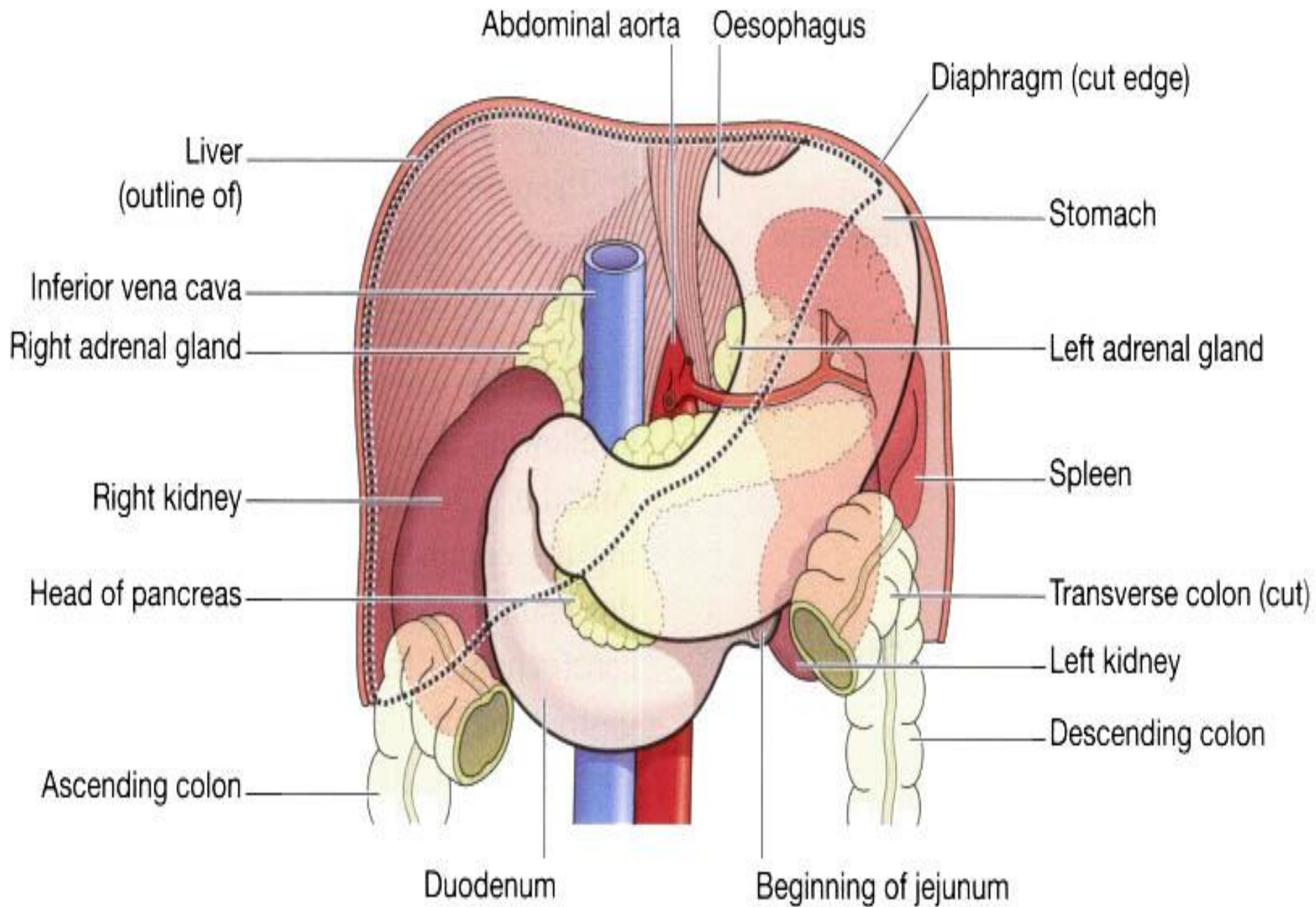
Positions of structures during swallowing.

STOMACH

- J-shaped dilated portion of the alimentary tract situated in the epigastric, umbilical & left hypochondriac regions of the abdominal cavity.

Organs associated with the stomach

- Anteriorly — left lobe of liver & anterior abdominal wall
- Posteriorly — abdominal aorta, pancreas, spleen, left kidney & adrenal gland
- Superiorly — diaphragm, oesophagus & left lobe of liver
- Inferiorly — transverse colon & small intestine
 - To the left — diaphragm & spleen
 - To the right — liver & duodenum

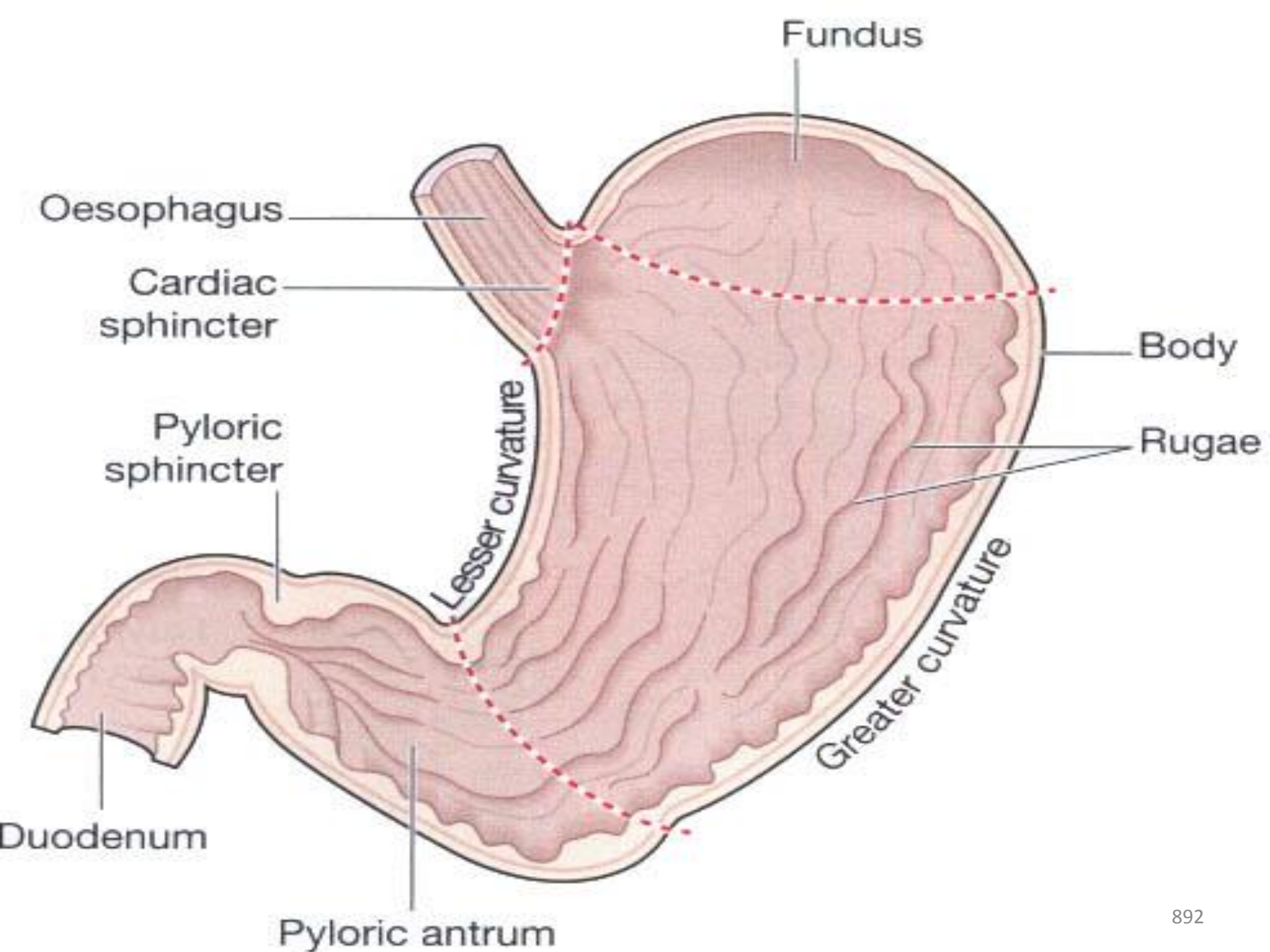


Stomach & associated structures

Structure of the stomach

- Continuous with the oesophagus at the **cardiac sphincter** & with the duodenum at the **pyloric sphincter**.
- Has 2 curvatures.
 - **Lesser curvature:** short, lies on the posterior surface of the stomach & is the downwards continuation of the posterior wall of the esophagus. Just before the pyloric sphincter it curves upwards to complete the J shape.
 - **Greater curvature:** formed where the oesophagus joins the stomach and the anterior region angles acutely upwards, curves downwards then slightly upwards towards the pyloric sphincter.

- stomach is divided into 3 regions:
 - **the fundus,**
 - **the body**
 - **the antrum.**
- When the stomach is inactive the pyloric sphincter is relaxed and open and when the stomach contains food the sphincter is closed.



Walls of the stomach

- a) **Muscle layer:** Consists of 3 layers of smooth muscle fibres:
- an outer layer of longitudinal fibres
 - a middle layer of circular fibres
 - an inner layer of oblique fibres.
- Has 3 layers of muscle instead of 2.
 - Arrangement allows for the churning motion characteristic of gastric activity, as well as peristaltic movement.
 - Circular muscle is strongest in the pyloric antrum & sphincter.

b) Mucosa.

- When the stomach is empty the mucous membrane lining is thrown into longitudinal folds or rugae, and when full the rugae are 'ironed out' and the surface has a smooth, velvety appearance.
- Numerous gastric glands are situated below the surface in the mucous membrane; that secrete gastric juice into the stomach.

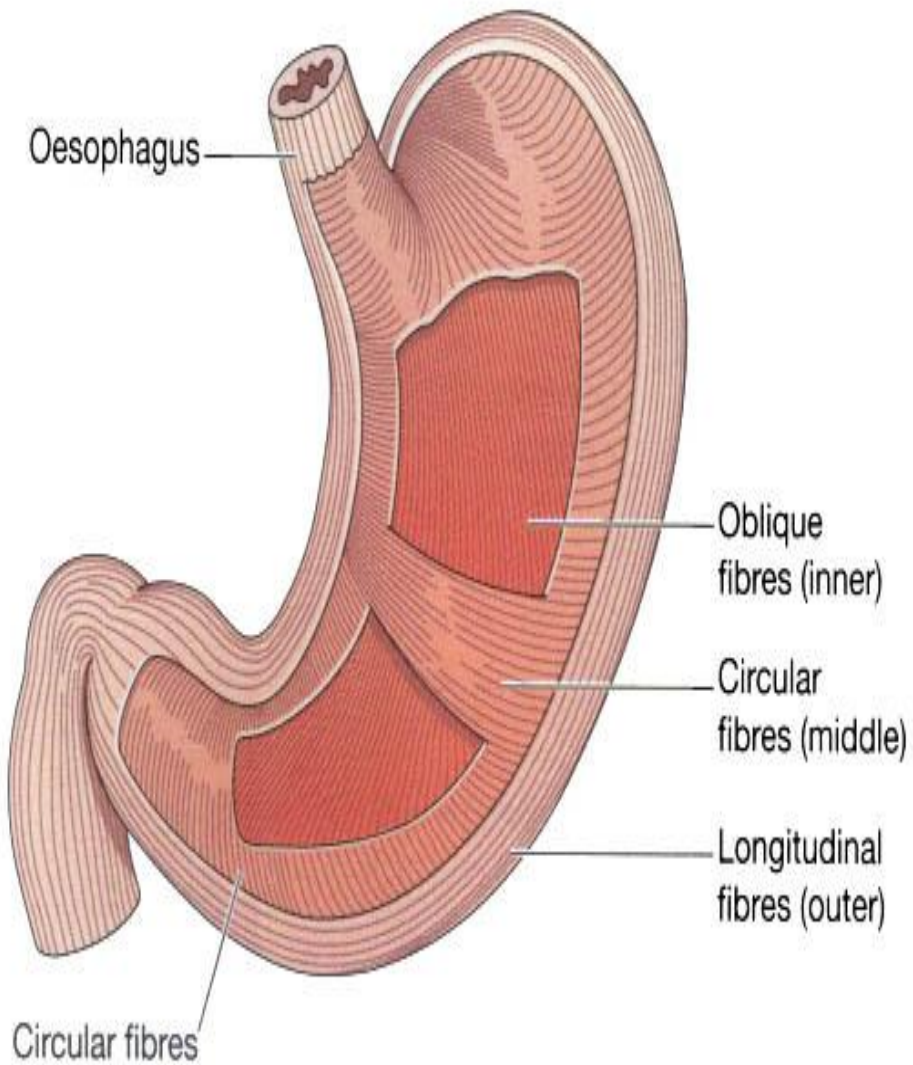


Figure 12.24 The muscle fibres of the stomach wall. Sections have been removed to show the three layers.

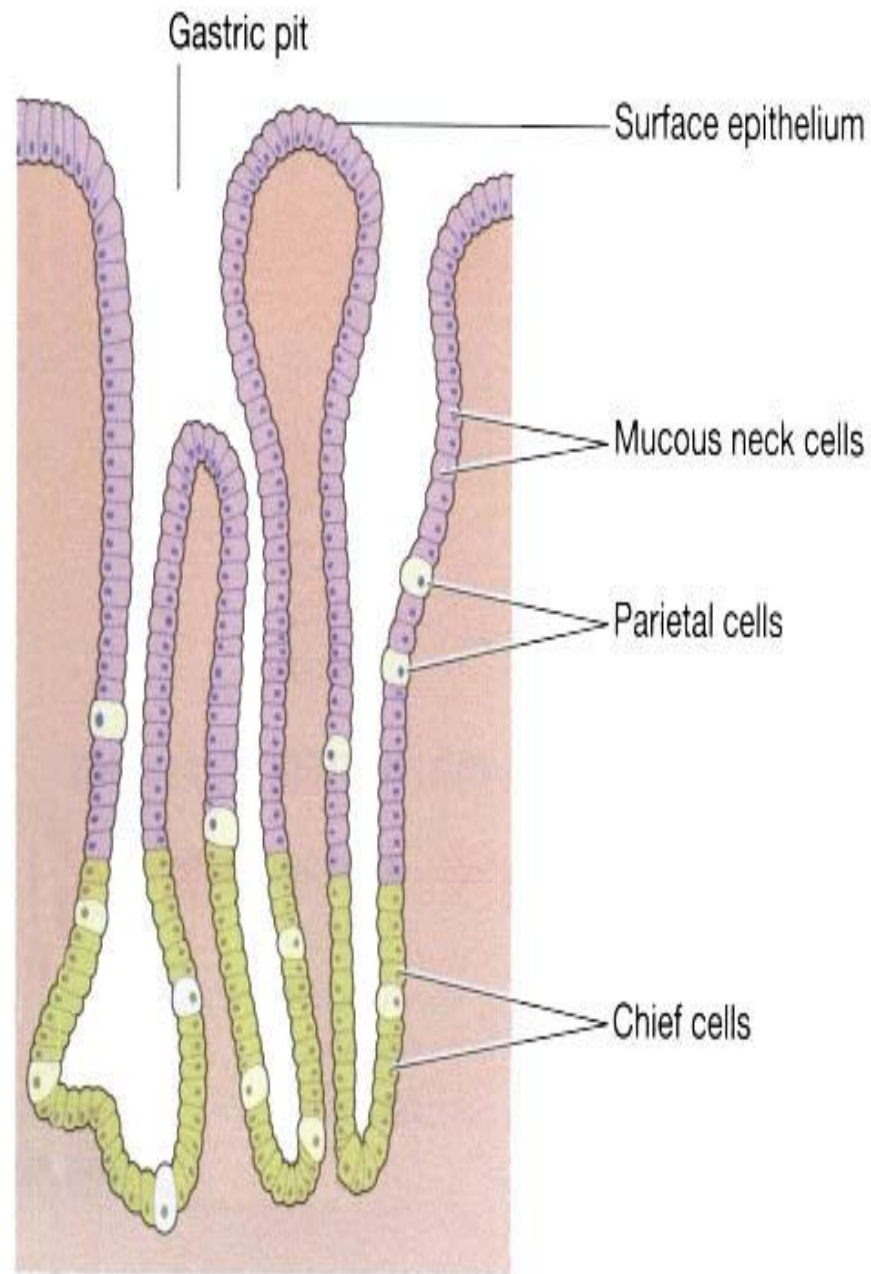


Figure 12.25 Structure of gastric glands.

- **Blood supply**
- Arterial blood: branches of the coeliac artery
- Venous drainage: into the portal vein.
- **Nerve supply**
 - Sympathetic supply: mainly from the coeliac plexus
 - Parasympathetic supply: from the vagus nerves.
- Sympathetic stimulation reduces
 - the motility of the stomach
 - The secretion of gastric juice
- Vagal stimulation has the opposite effect

Gastric juice and functions of the stomach

- Stomach size varies with the volume of food it contains, about 1.5 litres or more in an adult.
- When a meal has been eaten the food accumulates in the stomach in layers, the last part of the meal remaining in the fundus for some time.
- Mixing with the gastric juice takes place.
- Gastric muscle contraction consists of a churning movement that breaks down the bolus and mixes it with gastric juice, and peristaltic waves that propel the stomach contents towards the pylorus.
- When the stomach is active the pyloric sphincter closes. Strong peristaltic contraction of the pyloric antrum forces gastric contents, after they are sufficiently liquefied, through the pylorus into the duodenum in small spurts.

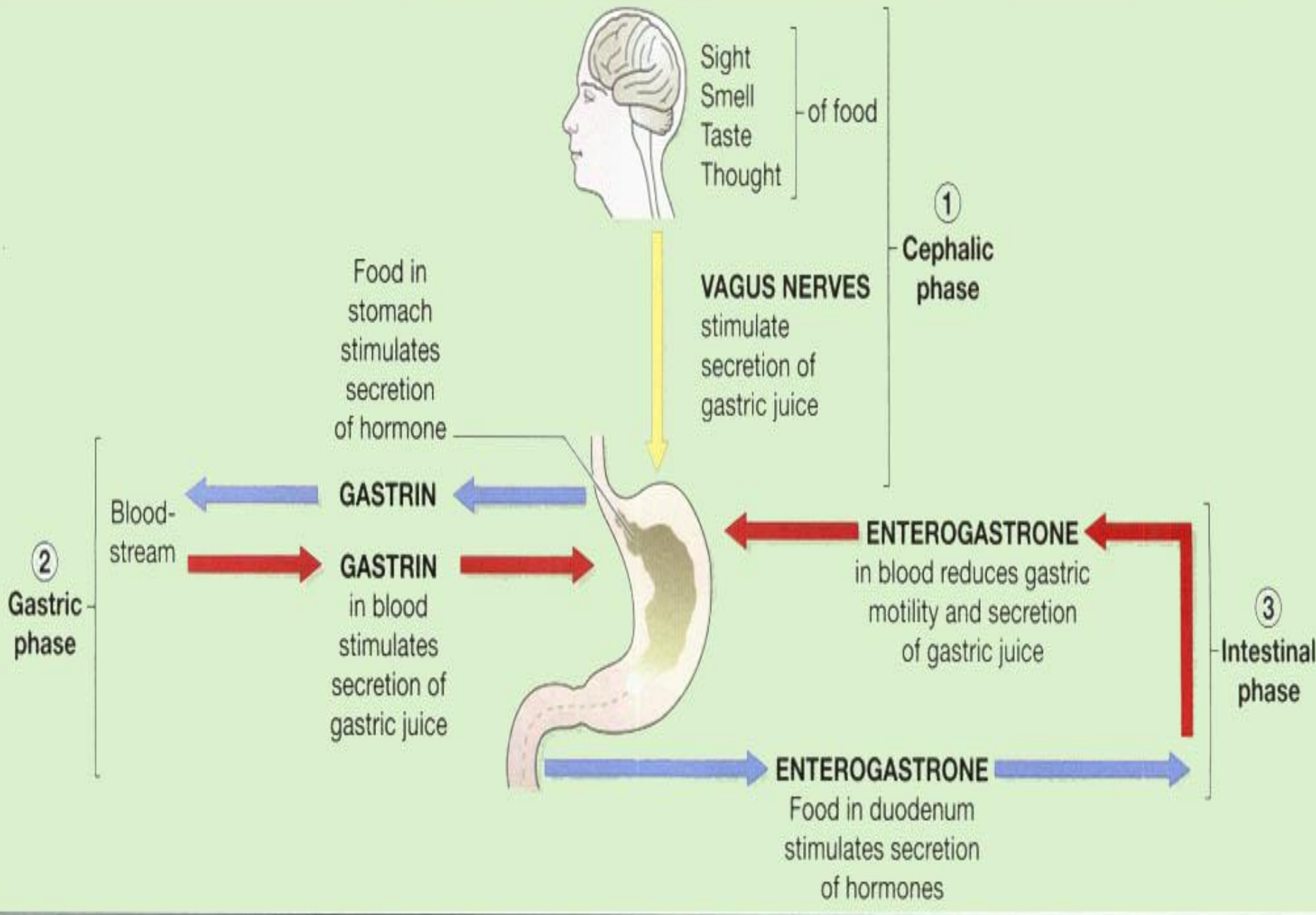
- **Gastric juice**
- About 2 litres are secreted daily.
- Consists of:
 - ✓ water.... secreted by gastric glands
 - ✓ mineral salts... secreted by gastric glands
 - ✓ Mucus..... secreted by goblet cells & on the stomach surface
 - ✓ hydrochloric acid ...secreted by parietal cells in the gastric glands
 - ✓ intrinsic factor 1.. secreted by parietal cells in the gastric glands
 - ✓ inactive enzyme precursors: pepsinogens secreted by chief cells in the glands.

Functions of gastric juice

- 1) Water further liquefies the food swallowed.
- 2) Hydrochloric acid:
 - acidifies the food and stops the action of salivary amylase
 - kills ingested microbes
 - provides the acid environment needed for effective digestion by pepsins.
- 3) Pepsinogens are activated to pepsins by hydrochloric acid and by pepsins already present in the stomach. They begin the digestion of proteins, breaking them into smaller molecules. Pepsins act most effectively at pH 1.5 to 3.5.
- 4) Intrinsic factor (a protein) is necessary for the absorption of vitamin B12 from the ileum.
- 5) Mucus prevents mechanical injury to the stomach wall by lubricating the contents. It prevents chemical injury by acting as a barrier between the stomach wall and the corrosive gastric juice.

- **Secretion of gastric juice**
- **Fasting juice:** small quantity of gastric juice always present in the stomach, even when it contains no food.
- Secretion reaches its maximum level about 1 hour after a meal then declines to the fasting level after about 4 hours.
- 3 phases of secretion of gastric juice
 1. **Cephalic phase.** Occurs before food reaches the stomach & is due to reflex stimulation of the vagus nerves initiated by the sight, smell or taste of food.
 2. **Gastric phase.** When stimulated by the presence of food, the entero-endocrine cells in the pyloric antrum & duodenum secrete **gastrin**.
 - Gastrin, circulating in the blood which supplies the stomach, stimulates the gastric glands to produce more gastric juice.
 - Gastrin secretion is suppressed when the pH in the pyloric antrum falls to about 1.5.

- 3. Intestinal phase.** When the partially digested contents of the stomach reach the small intestine, a hormone complex **enterogastrone** is produced by endocrine cells in the intestinal mucosa, which slows down the **secretion of gastric juice & reduces gastric motility.**
- 2 of the hormones forming this complex are **secretin & cholecystinin (CCK).**
 - By slowing the emptying rate of the stomach, the contents of the duodenum become more thoroughly mixed with bile & pancreatic juice. This phase is most marked when the meal has had a high fat content.
 - Rate at which the stomach empties depends to a large extent on the type of food eaten.
 - Carbohydrate meal leaves the stomach in 2 to 3 hours,
 - Protein meal remains longer
 - Fatty meal remains in the stomach longest.



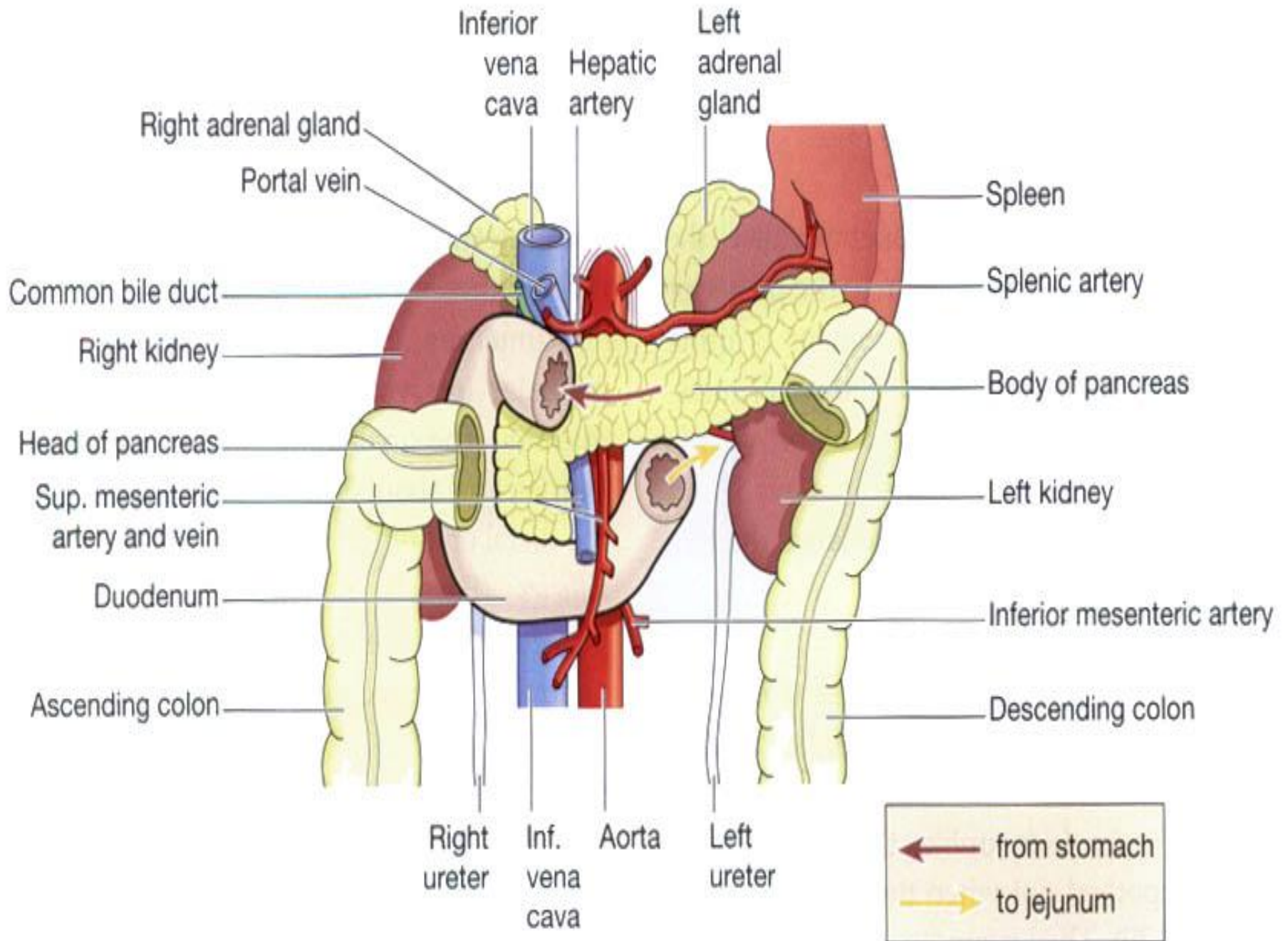
Phases of gastric juice secretion

Functions of the stomach

1. Temporary storage allowing time for the digestive enzymes, pepsins, to act.
2. chemical digestion — pepsins convert proteins to polypeptides
3. mechanical breakdown — 3 smooth muscle layers enable the stomach to act as a churn, gastric juice is added and the contents are liquefied to **chyme**
4. limited absorption of water, alcohol & some lipid soluble drugs
5. non-specific defence against microbes — provided by hydrochloric acid in gastric juice.
6. preparation of iron for absorption further along the tract — the acid environment of the stomach solubilises iron salts, which is required before iron can be absorbed
7. production of intrinsic factor needed for absorption of vitamin B12 in the terminal ileum.
8. regulation of the passage of gastric contents into the duodenum.

SMALL INTESTINE

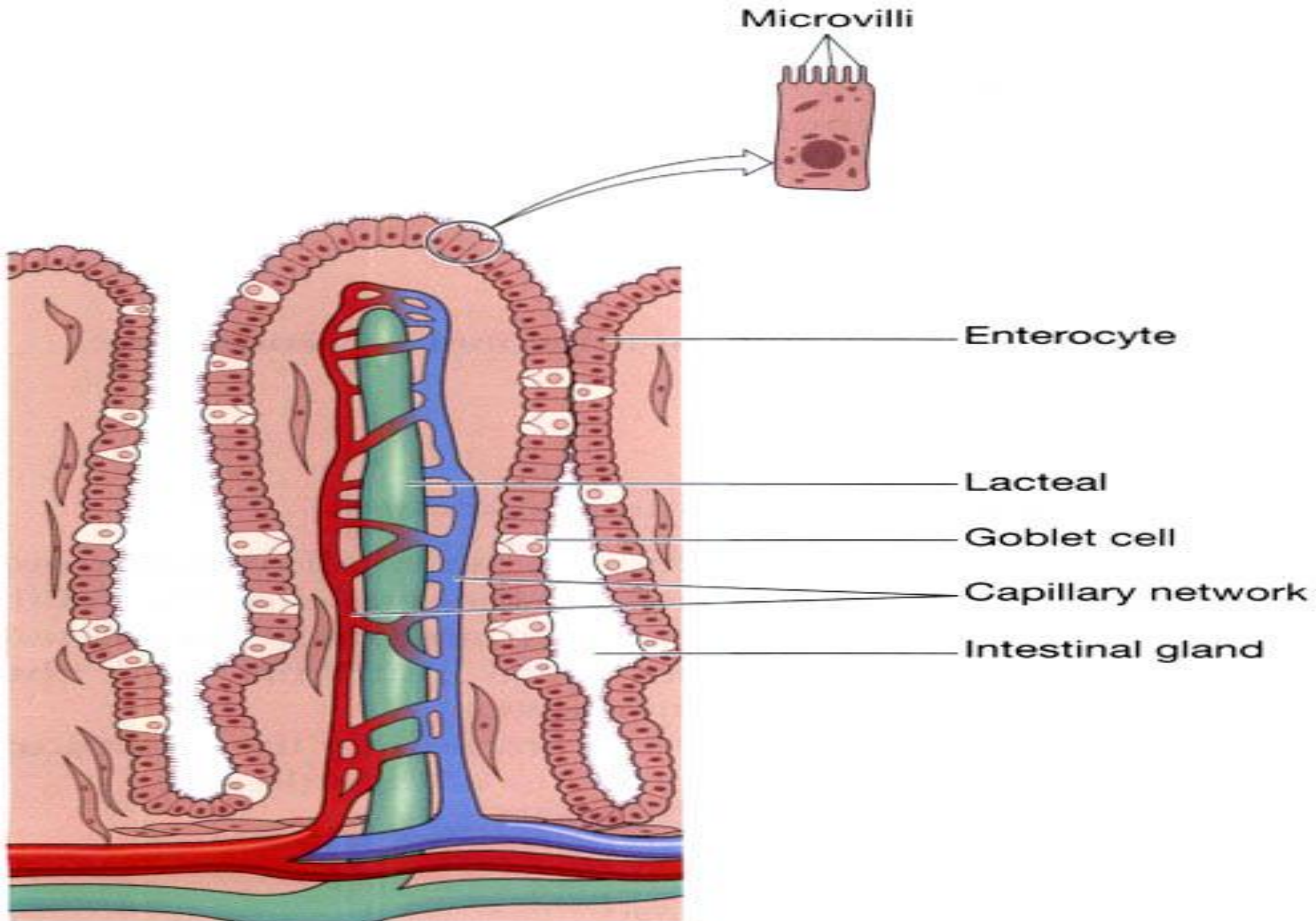
- Continuous with the stomach at the pyloric sphincter & leads into the large intestine at the ileocaecal valve.
- About 5 metres long & lies in the abdominal cavity surrounded by the large intestine.
- Chemical digestion of food is completed here & most of the absorption of nutrients takes place.
- Comprises 3 main sections continuous with each other.
 - **Duodenum**; about 25 cm long & curves around the head of the pancreas. Secretions from the gall bladder & pancreas are released into the duodenum through a common structure, the **hepatopancreatic ampulla**, & the opening into the duodenum is guarded by the **hepatopancreatic sphincter (of Oddi)**.
 - **Jejunum**; middle section, about 2 metres long.
 - **Ileum**; about 3 metres long & ends at the ileocaecal valve, which controls the flow of material from the ileum to the caecum, the first part of the large intestine, & prevents regurgitation.



Duodenum

Structure of the small intestine

- a) **Peritoneum.** **mesentery** attaches the jejunum & ileum to the posterior abdominal wall.
- Attachment is quite short in comparison with the length of the small intestine, therefore it is fan-shaped.
- b) **Mucosa.** Surface area is greatly increased by permanent circular folds, villi and microvilli.
- The **permanent circular folds**, unlike the rugae of the stomach, are not smoothed out when the small intestine is distended. They promote mixing of chyme as it passes along.



Villus in the small intestine

- **Villi:** tiny finger-like projections of the mucosal layer into the intestinal lumen, about 0.5 to 1 mm long .
 - Walls consist of columnar epithelial cells, or enterocytes, with tiny microvilli (1 μm long) on their free border. Goblet cells interspersed between the enterocytes.
- **Lymph capillaries/lacteals;** absorbed fat gives the lymph a milky appearance.
 - Absorption & some final stages of digestion of nutrients take place in the **enterocytes** before entering the blood and lymph capillaries.
- **Intestinal glands;** simple tubular glands situated below the surface between the villi.
 - Cells of the glands migrate upwards to form the walls of the villi replacing those at the tips as they are rubbed off by the intestinal contents. The entire epithelium is replaced every 3 to 5 days.

- During migration, the cells form digestive enzymes that lodge in the microvilli and, together with intestinal juice, complete the chemical digestion of carbohydrates, protein and fats.
- Numerous **lymph nodes** are found in the mucosa at irregular intervals throughout the length of the small intestine.
 - Smaller ones are called **solitary lymphatic follicles**
 - About 20 or 30 larger nodes situated towards the distal end of the ileum are called **aggregated lymphatic follicles (Peyer's patches)**.
 - **Function:** Strategically placed to neutralise ingested antigens.

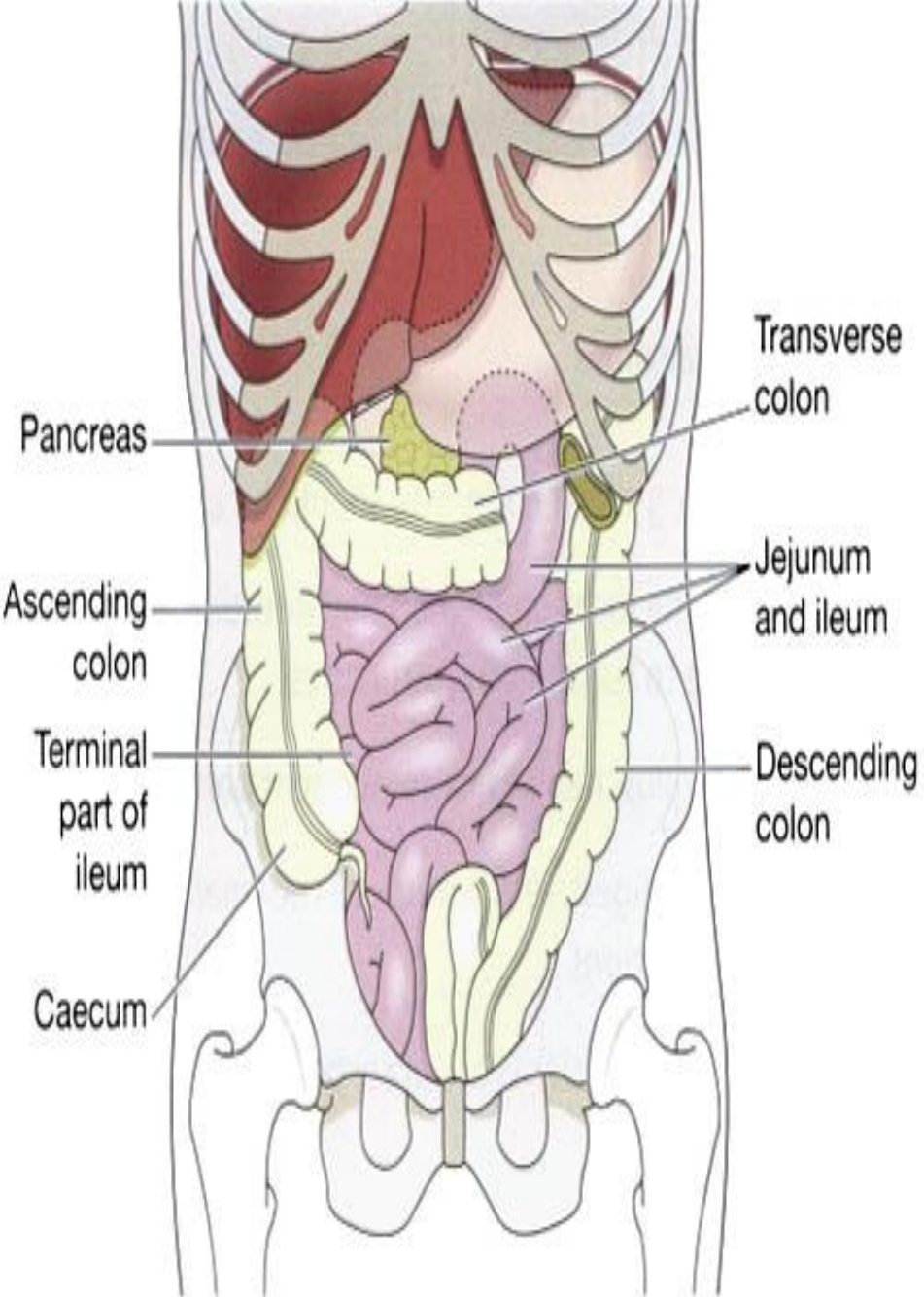


Figure 12.28 The jejunum and ileum and their related structures.

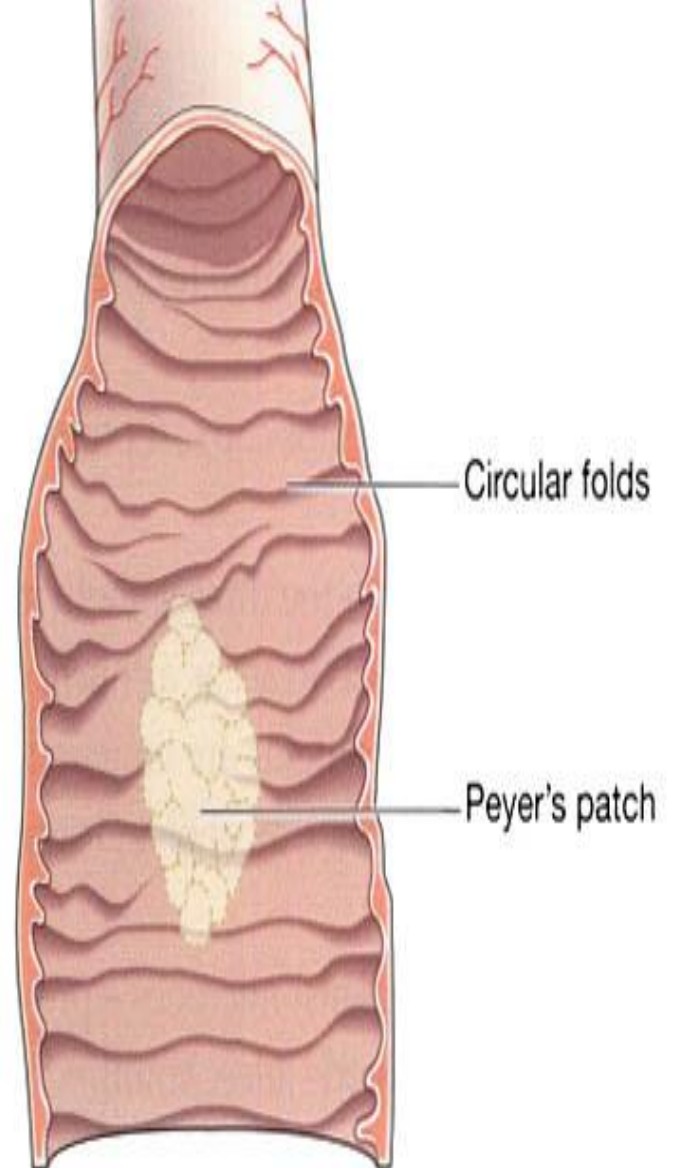


Figure 12.29 Section of a small piece of small intestine (opened out), showing the permanent circular folds.

- **Blood supply**
- Arterial blood: superior mesenteric artery
- Venous drainage: superior mesenteric vein which joins other veins to form the portal vein.
- **Nerve supply**
- Both sympathetic & parasympathetic .

Intestinal juice

- About 1500 ml secreted daily.
- Consists of:
 - Water
 - mucus
 - mineral salts
 - enzyme: enterokinase (enteropeptidases).
- pH of intestinal juice is usually between 7.8 & 8.0.

Functions of the small intestine

1. Onward movement of its contents; produced by peristalsis
2. Secretion of intestinal juice
3. Completion of chemical digestion of carbohydrates, protein and fats in the enterocytes of the villi
4. Protection against infection by microbes that have survived the antimicrobial action of the HCL in the stomach, by the solitary lymph follicles & aggregated lymph follicles
5. Secretion of the hormones cholecystokinin & secretin
6. absorption of nutrients.

Chemical digestion in the small intestine

- When acid chyme passes into the small intestine it is mixed with pancreatic juice, bile & intestinal juice, & is in contact with the enterocytes of the villi.
- Digestion of all the nutrients is completed:
 - Carbohydrates; broken down to monosaccharides
 - Proteins; broken down to amino acids
 - Fats; broken down to fatty acids & glycerol.

Pancreatic juice

- Enters the duodenum at the hepatopancreatic ampulla
- Consists of:
 - water
 - mineral salts
 - enzymes:
 - amylase
 - lipase
 - inactive enzyme precursors:
 - trypsinogen
 - chymotrypsinogen
 - procarboxypeptidase (pancreatic esterase).

- Alkaline (pH 8 to 8.3) because it contains significant quantities of bicarbonate ions, especially sodium & potassium which are alkaline in solution.
- Specific gravity is 1.010 to 1.030
- Total quantity is about 500 ml per meal & 1500 ml in 24 hrs.
- When acid stomach contents enter the duodenum, they are mixed with pancreatic juice & bile and the pH is raised to between 6 and 8; the pH at which the pancreatic enzymes, amylase and lipase, act most effectively.

- **Functions of pancreatic juice**

a) Digestion of proteins. Trypsinogen & chymotrypsinogen are inactive enzyme precursors activated by enterokinase (enteropeptidase), an enzyme in the microvilli, which converts them into the active proteolytic enzymes trypsin and chymotrypsin.

- These enzymes convert polypeptides to tripeptides, dipeptides & amino acids.
- They are produced as inactive precursors & are activated only upon arrival in the duodenum, otherwise they would digest the pancreas.

b) Digestion of carbohydrates. Pancreatic amylase converts all digestible polysaccharides (starches) not acted upon by salivary amylase to disaccharides.

c) Digestion of fats. Lipase converts fats to fatty acids and glycerol. To aid the action of lipase, bile salts emulsify fats, i.e. reduce the size of the globules, increasing their surface area.

Control of secretion

- Stimulated by **secretin & CCK**, produced by endocrine cells in the walls of the duodenum.
- Presence in the duodenum of acid material from the stomach stimulates the production of these hormones.

BILE

- Secreted & excreted by the liver
- Minute droplets of bile collect inside tiny vacuoles of liver cells & are discharged into bile capillaries.
- Liver bile is **alkaline** & contains bile salts & bile pigments
- In the gall bladder it's concentrated 5 to 10 times & its alkalinity is reduced.
- Total quantity is 500- 1000 ml daily; specific gravity 1.010- 1.011.
- Human bile is yellow green; taste is bitter & consistency viscid.
- Main bile pigments are **bilirubin & biliverdin**

- pH of 8; 500-1000 ml are secreted daily.
- Consists of:
 - water
 - mineral salts
 - mucus
 - bile salts
 - bile pigments, mainly bilirubin
 - cholesterol.
- **Bilirubin**; waste product of the breakdown of erythrocytes & is excreted in the bile rather than in the urine because of its low solubility in water.
 - Altered by microbes in the large intestine forming **urobilinogen** (highly water soluble) which is reabsorbed & then excreted in the urine, but most is converted to **stercobilin** & excreted in the faeces.

Functions of bile

1. Bile salts, **sodium taurocholate** & **sodium glycocholate**, emulsify fats in the small intestine.
2. Helps in absorption of fats, iron & fat soluble vitamins(e.g. vitamin K)
3. Excretion of cholesterol & lecithin
4. Stimulates peristalsis
5. Helps maintain suitable pH
6. Mucin of bile salts acts as a buffer & lubricant
7. Stercobilin colours & deodorises the faeces.

Release of bile from the gall bladder

- When a meal has been eaten, the hormone CCK is secreted by the duodenum during the intestinal phase of secretion of gastric juice.
- This stimulates contraction of the gall bladder & relaxation of the hepatopancreatic sphincter, enabling the bile & pancreatic juice to pass into the duodenum together.

INTESTINAL SECRETIONS

- Principal constituents are:
 - water
 - mucus
 - mineral salts
 - enzyme: enterokinase (enteropeptidase).
- Most of the digestive enzymes in the small intestine are contained in the enterocytes of the walls of the villi.
 - Digestion of carbohydrate, protein & fat is completed by direct contact between these nutrients & the microvilli & within the enterocytes.
- Enzymes involved in completing the chemical digestion of food in the enterocytes of the villi are:
 - peptidases
 - lipase
 - sucrase, maltase and lactase.

Chemical digestion associated with enterocytes

- Alkaline intestinal juice (pH 7.8 to 8.0) assists in raising the pH of the intestinal contents to between 6.5 & 7.5.
- **Enterokinase** activates pancreatic peptidases e.g trypsin which convert some polypeptides to amino acids and some to smaller peptides. Final stage of breakdown to amino acids of all peptides occurs inside the enterocytes.
- **Lipase** completes the digestion of emulsified fats to fatty acids & glycerol partly in the intestine & partly in the enterocytes.
- **Sucrase, maltase & lactase** complete the digestion of carbohydrates by converting disaccharides e.g sucrose, maltose & lactose to monosaccharides inside the enterocytes.

Control of secretion

- By the mechanical stimulation of the intestinal glands
- Hormone secretin may also be involved.

- **Absorption of nutrients**
- Occurs by 2 processes:
 - a) Diffusion.** Monosaccharides, amino acids, fatty acids & glycerol diffuse slowly down their concentration gradients into the enterocytes from the intestinal lumen.
 - b) Active transport.** Monosaccharides, amino acids, fatty acids & glycerol may be actively transported into the villi.
- Disaccharides, dipeptides & tripeptides are also actively transported into the enterocytes where their digestion is completed before transfer into the capillaries of the villi.
- Monosaccharides & amino acids pass into the capillaries in the villi; fatty acids & glycerol into the lacteals.
- Some proteins are absorbed unchanged, e.g. antibodies present in breast milk and oral vaccines, such as poliomyelitis vaccine.

- Vitamins, mineral salts & water are also absorbed from the small intestine into the blood capillaries.
- Fat-soluble vitamins are absorbed into the lacteals along with fatty acids & glycerol.
- Vitamin B12 combines with **intrinsic factor** in the stomach & is actively absorbed in the terminal ileum.
- Surface area through which absorption takes place in the small intestine is greatly increased by the
 - circular folds of mucous membrane
 - very large number of villi & microvilli present.
- Large amounts of fluid enter the alimentary tract each day. Of this, only about 500ml is not absorbed by the small intestine, & passes into the large intestine.

Lumen of intestine

Carbohydrate

Polypeptides

Fat molecules

Goblet cell

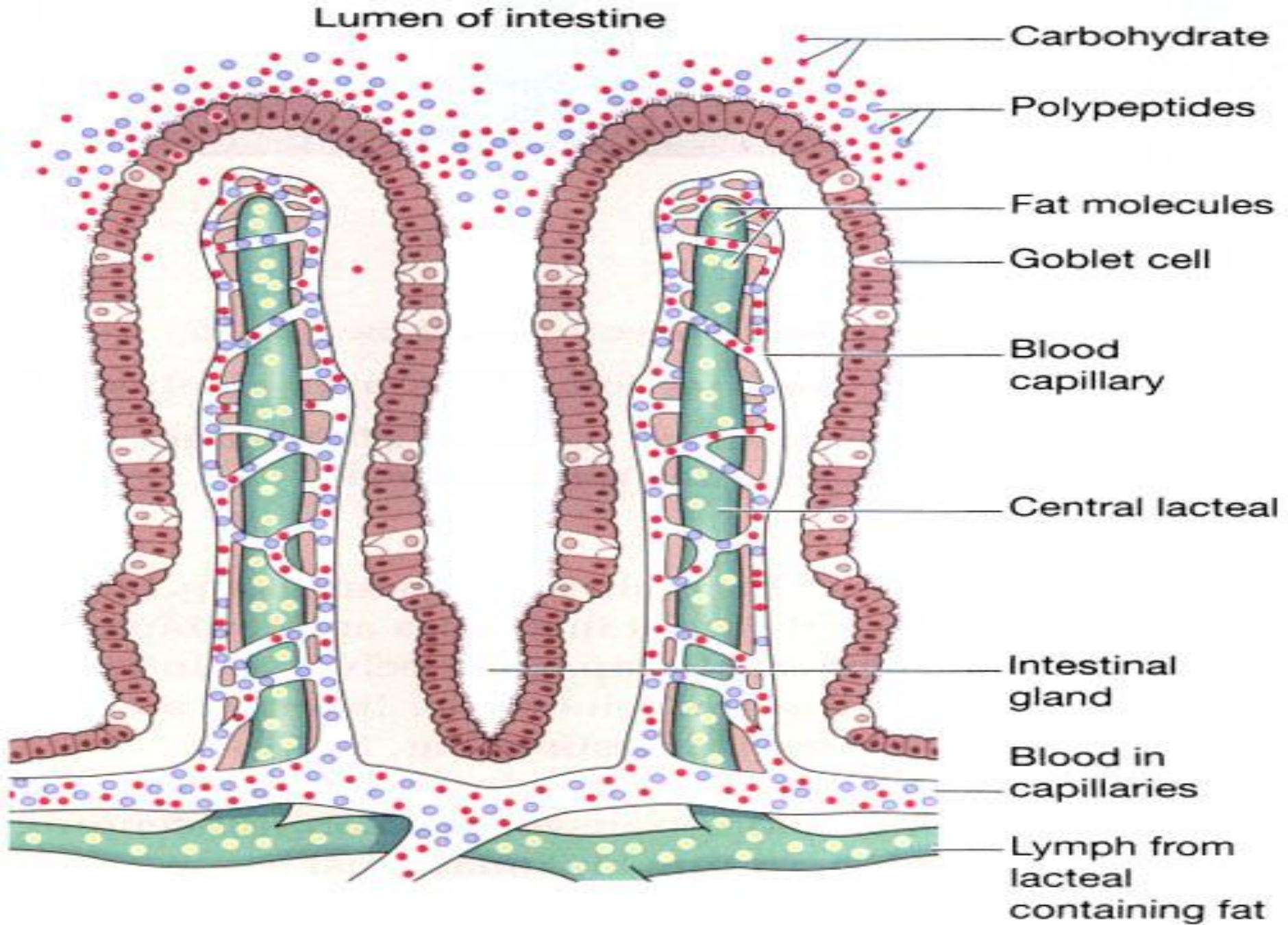
Blood capillary

Central lacteal

Intestinal gland

Blood in capillaries

Lymph from lacteal containing fat

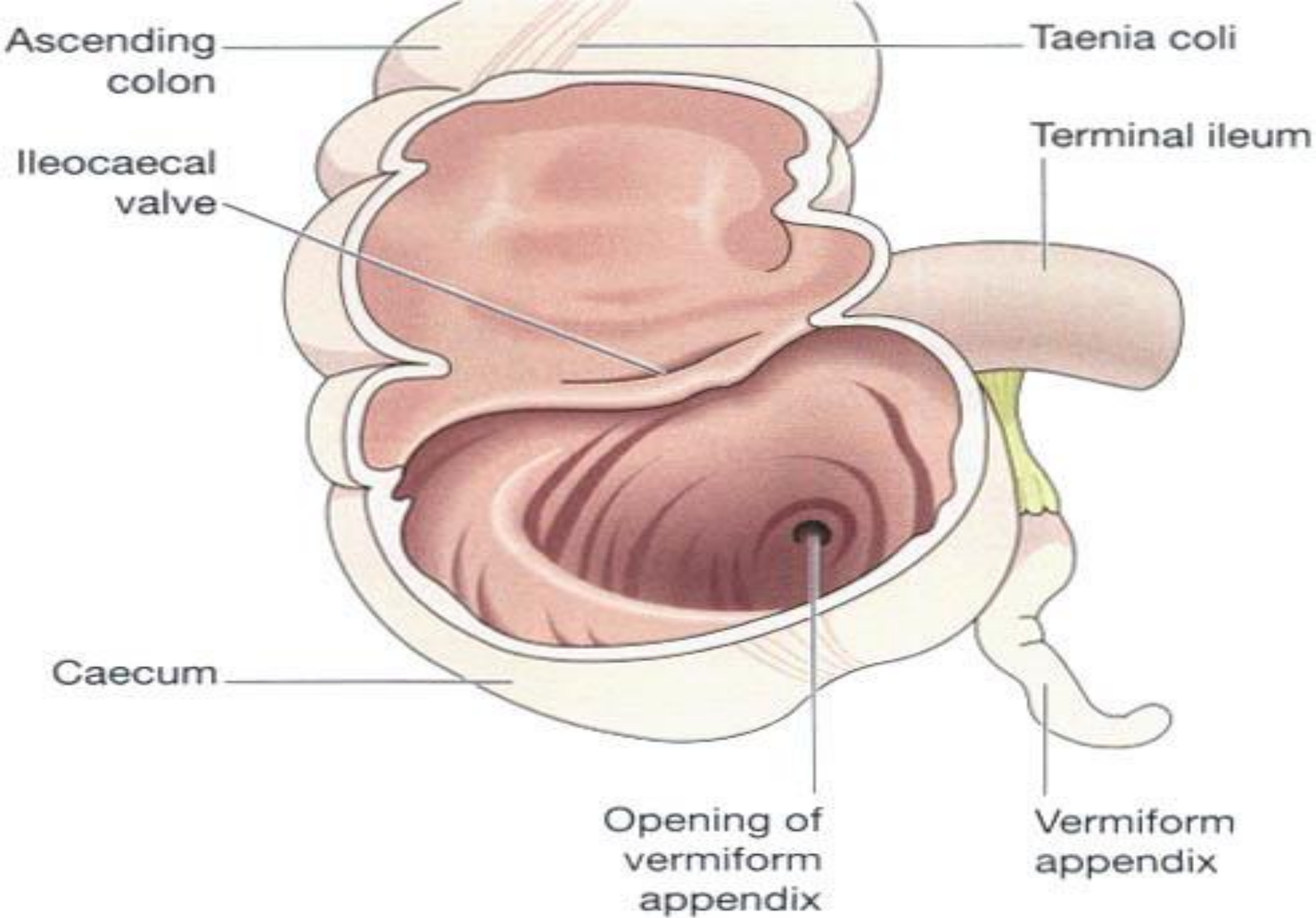


Absorption of nutrients

LARGE INTESTINE (COLON), RECTUM & ANAL CANAL

a) The large intestine.

- About 1.5 metres long, beginning at the caecum in the right iliac fossa & terminating at the rectum & anal canal deep in the pelvis.
- Has a larger lumen than that of the small intestine.
- Forms an arch round the coiled-up small intestine.
- Divided into the caecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum and anal canal.
- **Caecum.** First part of the colon.
 - Dilated region which has a blind end inferiorly
 - Continuous with the ascending colon superiorly.
 - Just below the junction of the 2 the ileocaecal valve opens from the ileum.



Interior of the caecum

- **Vermiform appendix;** a fine tube, closed at one end, which leads from the caecum.
 - About 13 cm long
 - Has the same structure as the walls of the colon but contains more lymphoid tissue.
- **Ascending colon.** Passes upwards from the caecum to the level of the liver where it curves acutely to the left at the hepatic flexure to become the transverse colon.
- **Transverse colon.** A loop of colon which extends across the abdominal cavity in front of the duodenum & the stomach to the area of the spleen where it forms the splenic flexure & curves acutely downwards to become the descending colon.
- **Descending colon.** Passes down the left side of the abdominal cavity then curves towards the midline.

– After it enters the true pelvis it is known as the sigmoid colon.

- **Sigmoid colon.** An S-shaped curve in the pelvis then continues downwards to become the rectum.

b) The rectum. Slightly dilated section of the colon about 13 cm long.

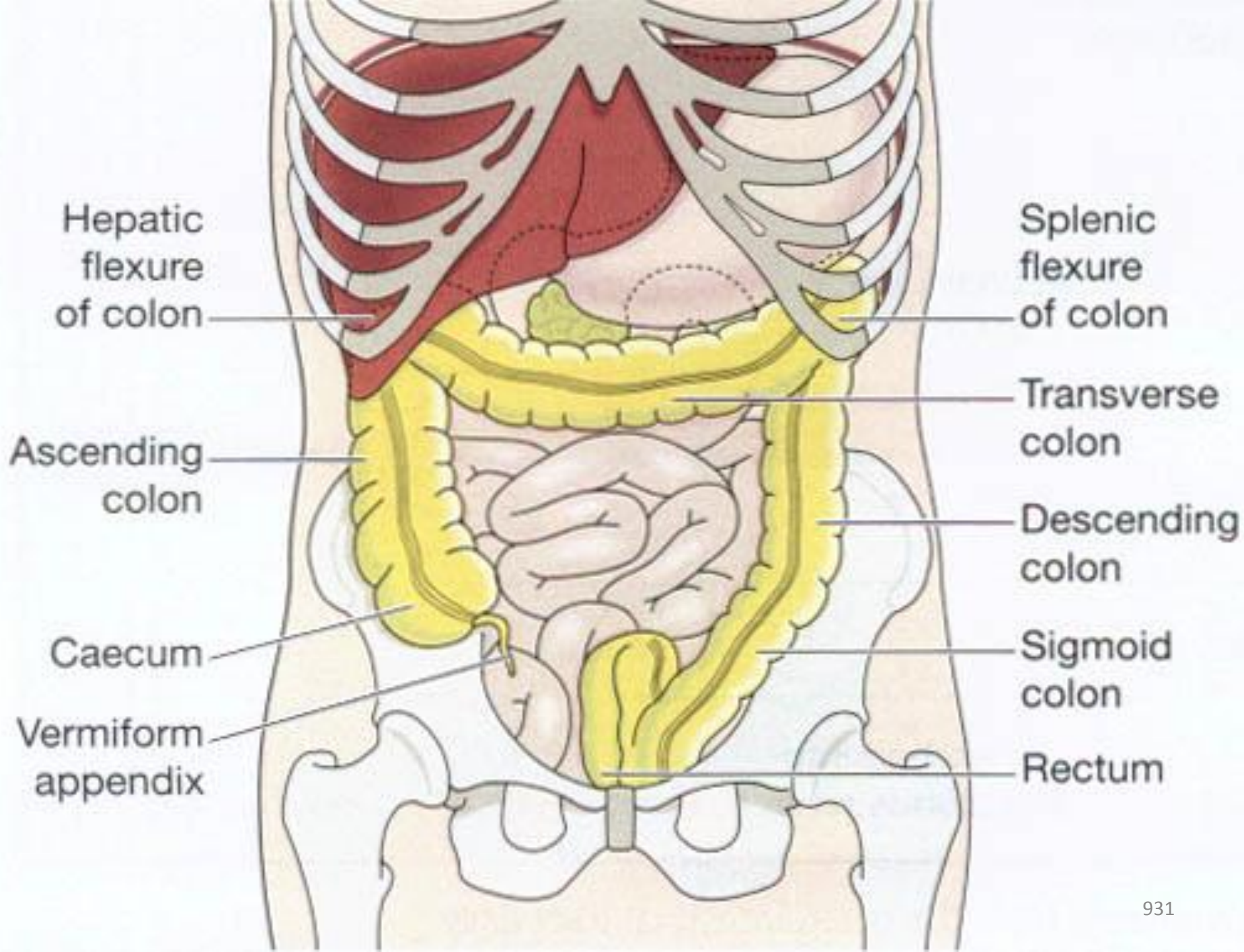
– Leads from the sigmoid colon & terminates in the anal canal.

c) The anal canal. A short passage about 3.8 cm long in the adult & leads from the rectum to the exterior.

- 2 sphincter muscles control the anus;

– **Internal sphincter**, consisting of smooth muscle fibres; is under the control of the ANS.

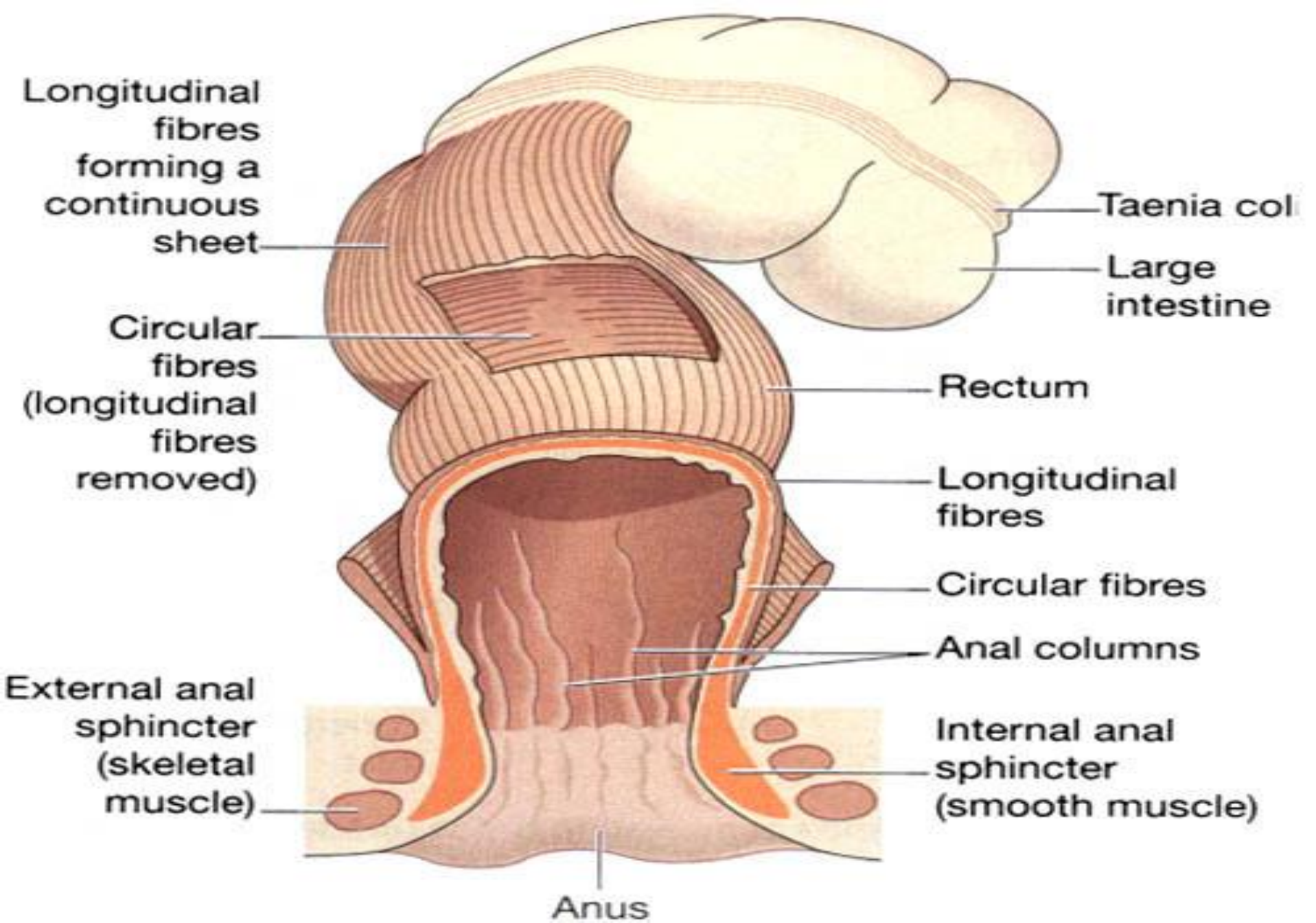
– **External sphincter**, formed by skeletal muscle, is under voluntary control.



Structure

- 4 layers of tissue of the basic structure of the GIT.
- Arrangement of the longitudinal muscle fibres is modified in the colon.
 - They don't form a smooth continuous layer of tissue but are collected into 3 bands, called **taeniae coli**, situated at regular intervals round the colon.
 - They stop at the junction of the sigmoid colon & the rectum.
- As these bands of muscle tissue are slightly shorter than the total length of the colon they give a sacculated or puckered appearance to the organ.
- The anal sphincters are formed by thickening of the circular muscle layer.

- **Submucosal** layer; there is more lymphoid tissue than in any other part of the alimentary tract, providing non-specific defence against invasion by resident & other microbes.
- **Mucosal lining** of the colon and the upper region of the rectum; large numbers of goblet cells which secrete mucus. They are not present beyond the junction between the rectum & the anus.
- Lining membrane of the anus consists of **stratified squamous epithelium**; continuous with the mucous membrane lining of the rectum above & merges with the skin beyond the external anal sphincter.
 - In the upper section of the anal canal the mucous membrane is arranged in 6 to 10 vertical folds, **the anal columns**.
 - Each column contains a terminal branch of the **superior rectal artery** and **vein**.



Arrangement of muscle fibres in the colon, rectum & anus ⁹³⁴

Blood supply

- **Arterial supply:** mainly by the superior & inferior mesenteric arteries.
 - Superior mesenteric artery supplies the caecum, ascending & most of the transverse colon.
 - Inferior mesenteric artery supplies the remainder of the colon & the proximal part of the rectum.
- Distal section of the rectum & the anus are supplied by branches from the internal iliac arteries.
- **Venous drainage:** mainly by the superior & inferior mesenteric veins.
 - They join the splenic & gastric veins to form the portal vein.
 - Veins draining the distal part of the rectum & the anus join the **internal iliac veins**.

Functions of the large intestine, rectum & anal canal

- 1. Absorption** of water, mineral salts, vitamins & some drugs are absorbed into the blood.
- 2. Microbial activity**
 - Large intestine is heavily colonised by *Escherichia coli*, *Enterobacter aerogenes*, *Streptococcus faecalis* and *Clostridium perfringens (welchii)*, which synthesise vitamin K & folic acid. These microbes are commensals in humans.
- 3. Mass movement**
 - Peristaltic movement occurs at fairly long intervals (about twice an hour) sweeping along the transverse colon forcing its contents into the descending & sigmoid colons (mass movement).
 - Precipitated by the entry of food into the stomach.
 - This combination of stimulus & response is called the **gastrocolic reflex**.

4. Defaecation

- In infants defecation occurs by reflex (involuntary) action.
- In the 2nd or 3rd year of life the ability to override the defecation reflex is developed; acquired voluntary control means that the brain can inhibit the reflex until such time as it is convenient to defecate.
- External anal sphincter is under conscious control through the **pudendal nerve**.
- Defecation involves involuntary contraction of the muscle of the rectum & relaxation of the internal anal sphincter.

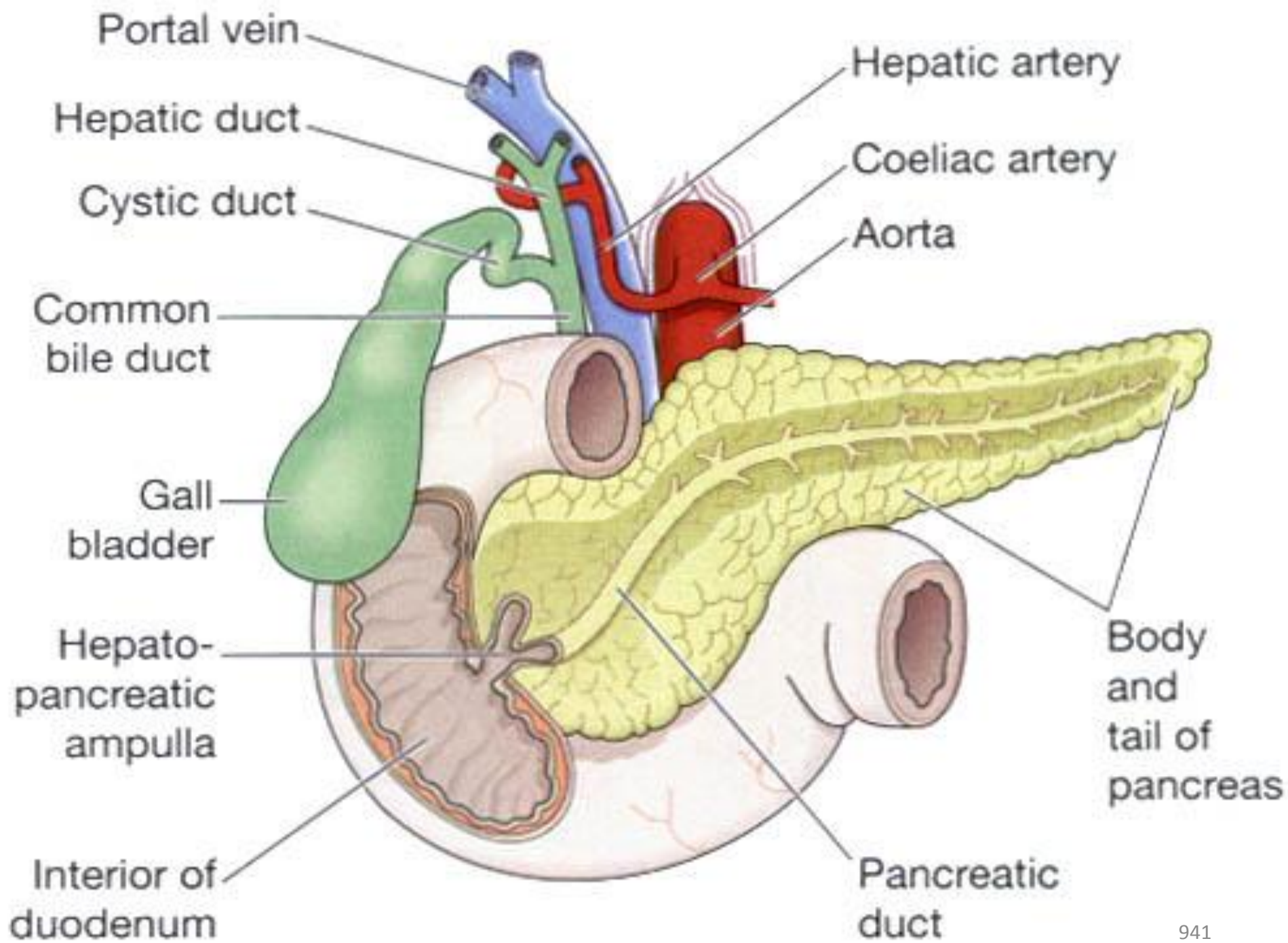
- Contraction of the abdominal muscles & lowering of the diaphragm increase the intra-abdominal pressure (**Valsalva's manoeuvre**) & so assist the process of defecation.
- When defecation is voluntarily postponed the feeling of fullness & need to defecate tends to fade until the next mass movement occurs & the reflex is initiated again.
- Repeated suppression of the reflex may lead to constipation.

Constituents of faeces.

- Semisolid brown mass.
- Brown colour is due to the presence of stercobilin.
- Even though absorption of water takes place in the large intestine, water still makes up about 60 to 70% of the weight of the faeces.
- Remainder consists of:
 - fibre (indigestible cellular plant and animal material)
 - dead and live microbes
 - epithelial cells from the walls of the tract
 - fatty acids
 - mucus secreted by the epithelial lining of the large intestine.
- Mucus helps to lubricate the faeces & an adequate amount of roughage in the diet ensures that the contents of the colon are sufficiently bulky to stimulate defecation.

PANCREAS

- Pale grey gland weighing about 60 grams.
- About 12 to 15 cm long & situated in the epigastric & left hypochondriac regions of the abdominal cavity.
- Consists of a broad head, a body & a narrow tail.
 - Head lies in the curve of the duodenum,
 - Body lies behind the stomach
 - Tail lies in front of the left kidney & just reaches the spleen.
- Abdominal aorta & the inferior vena cava lie behind the gland.
- Both an exocrine & endocrine gland.



The exocrine pancreas

- Consists of a large number of lobules made up of small alveoli, the walls of which consist of secretory cells.
- Each lobule is drained by a tiny duct & these unite eventually to form the pancreatic duct, which extends the whole length of the gland & opens into the duodenum.
- Just before entering the duodenum the pancreatic duct joins the common bile duct to form the hepatopancreatic ampulla.
- Duodenal opening of the ampulla is controlled by the hepatopancreatic sphincter (of Oddi).
- **Function:** to produce pancreatic juice containing enzymes that digest carbohydrates, proteins & fats .

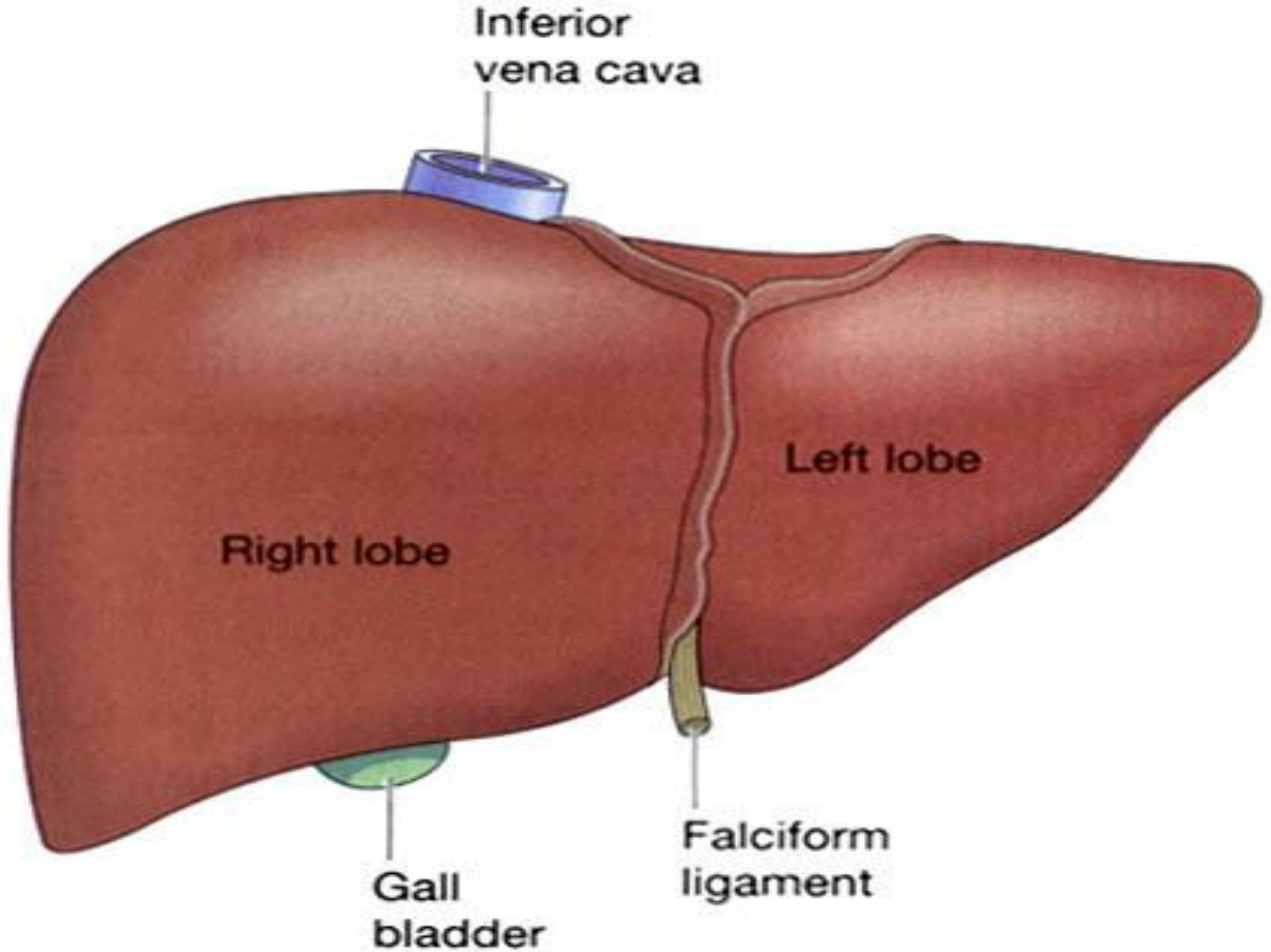
The endocrine pancreas

- Distributed throughout the gland are groups of specialized cells called the pancreatic islets (of Langerhans).
- The islets have no ducts so the hormones diffuse directly into the blood.
- **Function:** to secrete the hormones insulin & glucagon, which are principally concerned with control of blood glucose levels.

- **Blood supply**
- Arterial blood: splenic & mesenteric arteries
- Venous drainage: veins of the same names that join other veins to form the portal vein.
- **Nerve supply**
- Parasympathetic stimulation; increases the secretion of pancreatic juice
- Sympathetic stimulation depresses secretion of pancreatic juice.

LIVER

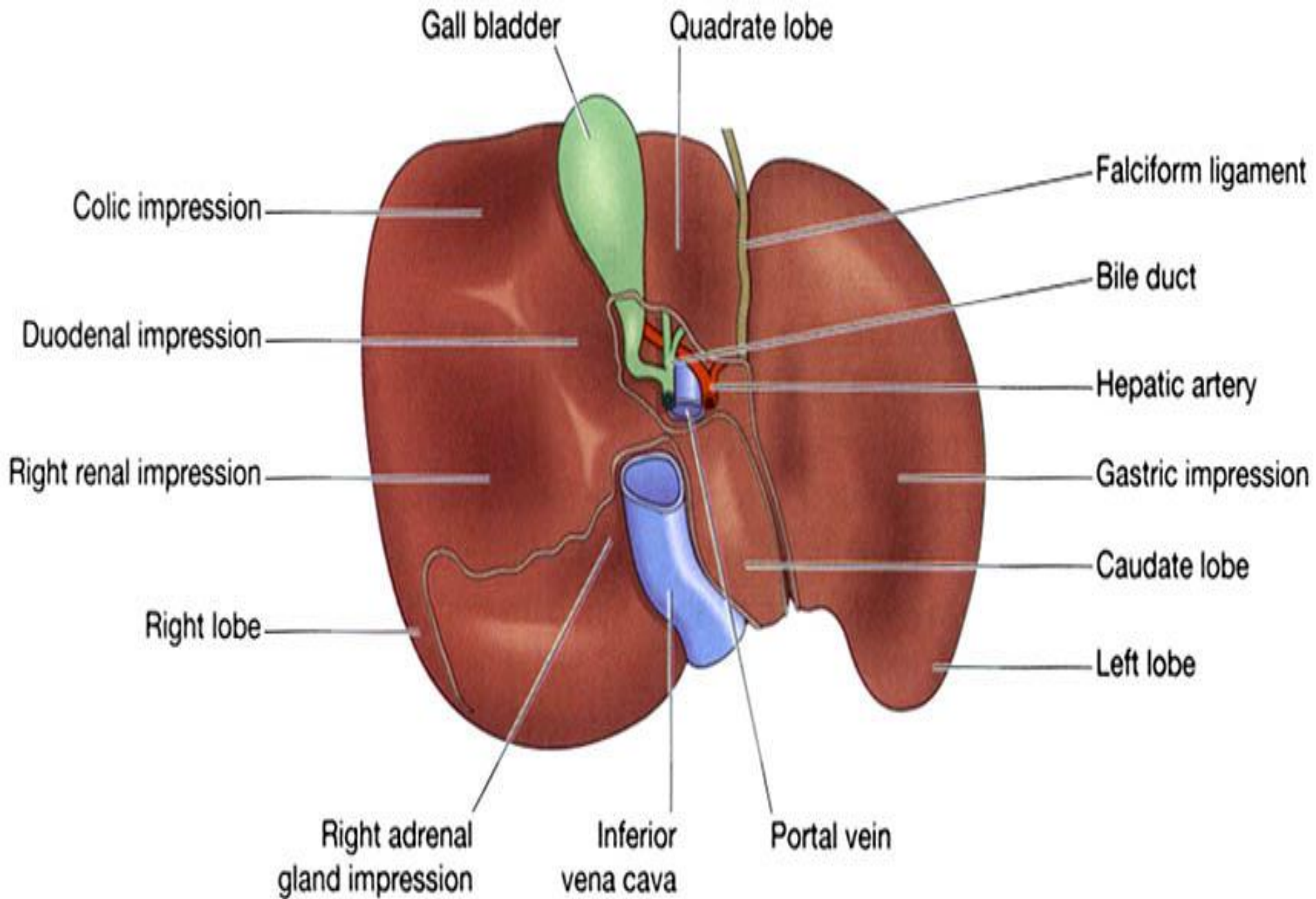
- Largest gland in the body, dark red in color, weighing 1 -2.3 kg; wedge shaped with its wider end to the right.
- About 28 cms long & 16 cms wide. It's greatest thickness is 9 cms.
- Situated in the upper part of the abdominal cavity occupying the greater part of the right hypochondriac region, part of the epigastric region & extending into the left hypochondriac region.
- Its upper & anterior surfaces are smooth & curved to fit the under surface of the diaphragm; its posterior surface is irregular in outline.



Anterior view

Organs associated with the liver

- Superiorly & anteriorly— diaphragm & anterior abdominal wall
- Inferiorly —stomach, bile ducts, duodenum, hepatic flexure of the colon, right kidney & adrenal gland
- Posteriorly —oesophagus, inferior vena cava, aorta, gall bladder, vertebral column & diaphragm
- Laterally — lower ribs & diaphragm

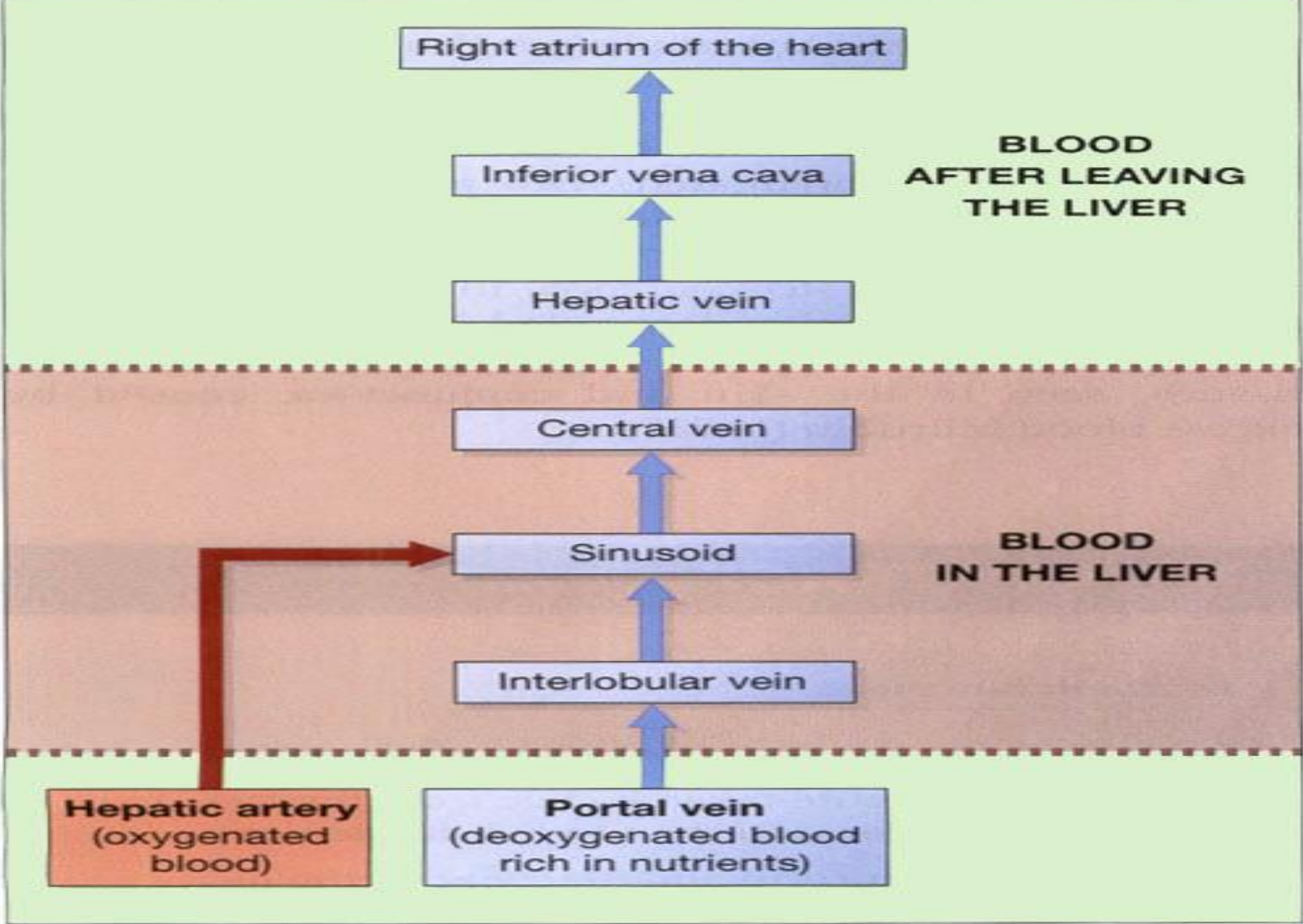


Posterior surface

- Enclosed in a thin inelastic capsule & incompletely covered by a layer of peritoneum.
- Folds of peritoneum form supporting ligaments attaching the liver to the inferior surface of the diaphragm.
 - Held in position partly by these ligaments & partly by the pressure of the organs in the abdominal cavity.
- Liver has 4 lobes,
 - Large right lobe
 - Left lobe; smaller, wedge-shaped
 - Caudate & quadrate lobes (are areas on the posterior surface)

The portal fissure

- **Def:** region on the posterior surface of the liver where various structures enter & leave the gland.
- **Portal vein** enters, carrying blood from the stomach, spleen, pancreas and the small and large intestines.
- **Hepatic artery** enters, carrying arterial blood.
- **Nerve fibres**, sympathetic & parasympathetic, enter here.
- **Right & left hepatic ducts** leave, carrying bile from the liver to the gall bladder.
- **Lymph vessels** leave the liver, draining some lymph to abdominal & some to thoracic nodes.
- **Blood supply**
- Arterial blood: hepatic artery & the portal vein
- Venous drainage: hepatic veins, varying in number, leave the posterior surface and immediately enter the inferior vena cava just below the diaphragm.

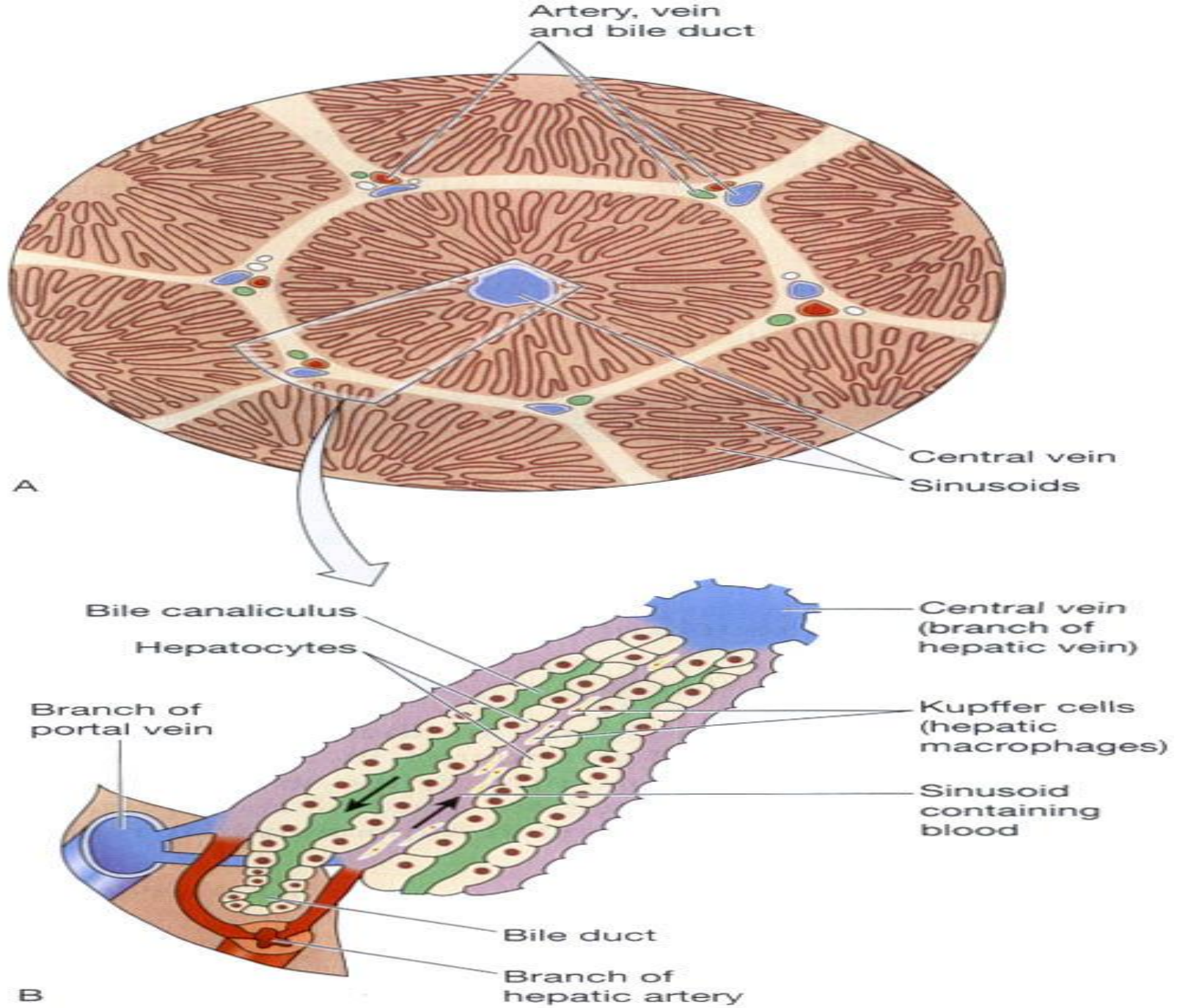


Blood flow through the liver

Structure of liver

- Lobes of the liver are made up of tiny lobules
- Lobules are hexagonal in outline & are formed by cubical-shaped cells; **hepatocytes**, arranged in pairs of columns radiating from a central vein.
- Between 2 pairs of columns of cells there are sinusoids containing a mixture of blood from the tiny branches of the portal vein & hepatic artery.
 - This arrangement allows the arterial blood & portal venous blood to mix & come into close contact with the liver cells.
- Amongst the cells lining the sinusoids are hepatic macrophages (Kupffer cells) whose function is to ingest and destroy any foreign particles present in the blood flowing through the liver.

- Blood drains from the sinusoids into central or centrilobular veins. These then join with veins from other lobules, forming larger veins, until eventually they become the hepatic veins which leave the liver & empty into the inferior vena cava just below the diaphragm.
- Bile canaliculi run between the columns of liver cells.
 - Each column of hepatocytes has a blood sinusoid on one side & a bile canaliculus on the other.
 - Canaliculi join up to form larger bile canals until eventually they form the right & left hepatic ducts which drain bile from the liver.
- Lymphoid tissue & a system of lymph vessels are present in each lobule.



Liver lobule

Functions of the liver

- 1. Carbohydrate metabolism.** Conversion of glucose to glycogen in the presence of insulin, & liver glycogen back to glucose in the presence of glucagon; to maintain the blood glucose level within relatively narrow limits.
- 2. Fat metabolism.** Desaturation of fat, i.e. converts stored fat to a form in which it can be used by the tissues to provide energy.
- 3. Protein metabolism.** Deamination of amino acids
 - removes the nitrogenous portion from the amino acids not required for the formation of new protein; urea is formed from this nitrogenous portion which is excreted in urine.
 - breaks down genetic material of worn-out cells of the body to form uric acid which is excreted in the urine.

- Transamination— removes the nitrogenous portion of amino acids & attaches it to other carbohydrate molecules forming new non-essential amino acids.
- Synthesis of plasma proteins & most of the blood clotting factors from the available amino acids occurs in the liver.

4. Breakdown of erythrocytes in adult life & defence against microbes. Carried out by phagocytic Kupffer cells in the sinusoids.

5. Detoxification of drugs & noxious substances e.g., ethanol & toxins produced by microbes.

6. Metabolism of ethanol; follows consumption of alcoholic drinks.

7. Inactivation of hormones. Include insulin, glucagon, cortisol, aldosterone, thyroid & sex hormones.

8. Synthesis of vitamin A from carotene. Carotene is the provitamin found in some plants, e.g. carrots

9. Production of heat. Has a high metabolic rate & is the main heat-producing organ of the body.

10. Secretion of bile. Hepatocytes synthesize the constituents of bile from the mixed arterial & venous blood in the sinusoids. These include bile salts, bile pigments and cholesterol.

11. Reduces the circulating adrenal-cortical & sex hormones by degradation & conjugation.

12. Storage. Substances include:

- fat-soluble vitamins: A, D, E, K
- iron, copper
- some water-soluble vitamins, e.g. riboflavine, niacin, pyridoxine, folic acid and vitamin B12.

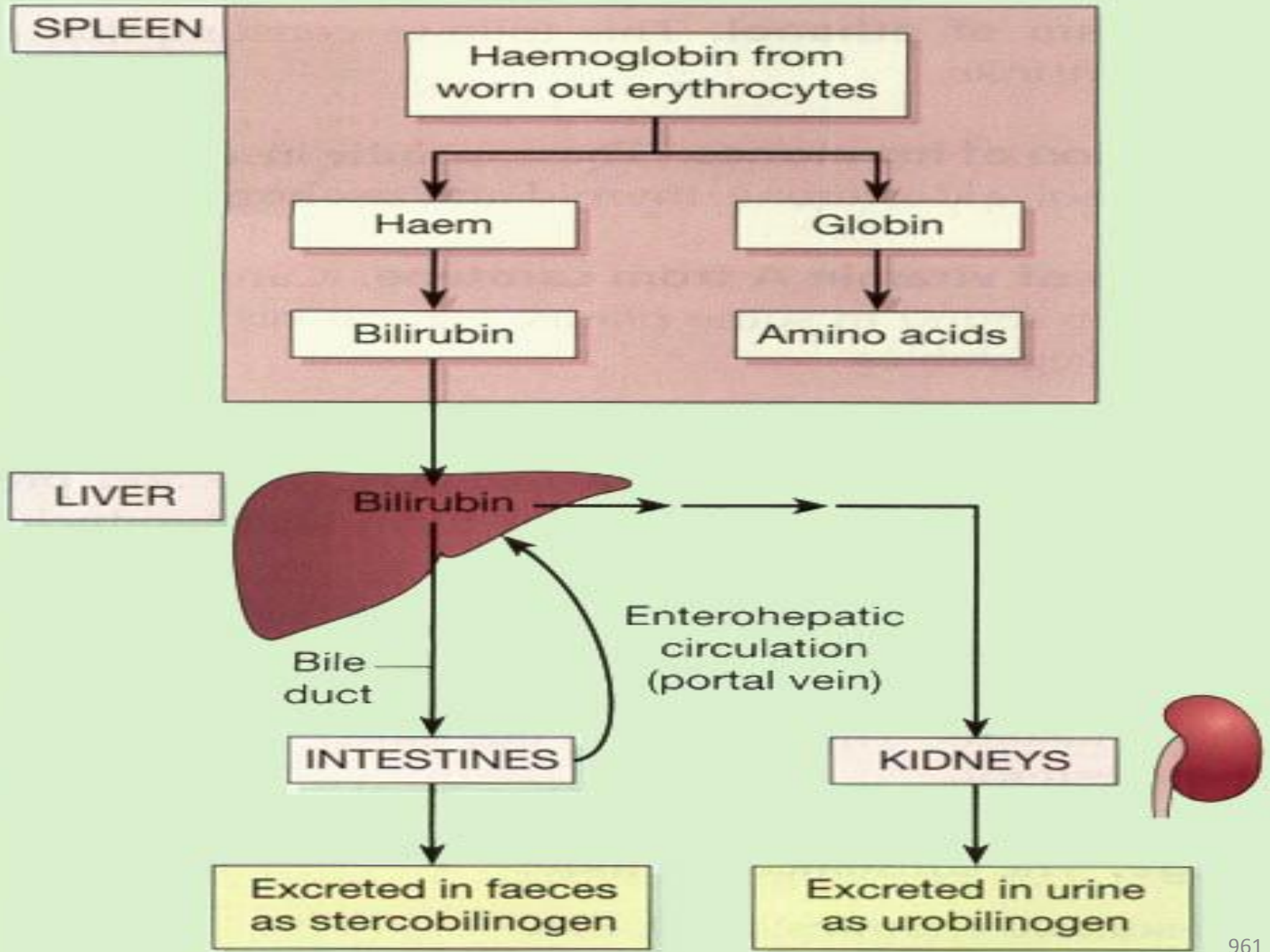
13. Acts as storehouse of blood & regulates blood volume
14. Forms RBCs in fetal life
15. Manufactures prothrombin & fibrinogen & prevents intravascular clotting.
16. It is the seat of ketone body formation
17. Major producer of thrombopoietin, a glycoprotein hormone that regulates the production of platelets by the bone marrow

Composition of bile

- About 500 ml of bile are secreted by the liver daily.
- Bile consists of:
 - water
 - mineral salts
 - mucus
 - bile pigments, mainly bilirubin
 - bile salts, which are derived from the primary bile acids, cholic acid and chenodeoxycholic acid
 - cholesterol.
- Bile acids, **cholic & chenodeoxycholic** acid, are synthesized by hepatocytes from cholesterol, conjugated (combined) with either **glycine** or **taurine**, then secreted into bile as sodium or potassium salts.

– In the terminal ileum most of the bile salts are reabsorbed & return to the liver in the portal vein; **enterohepatic circulation.**

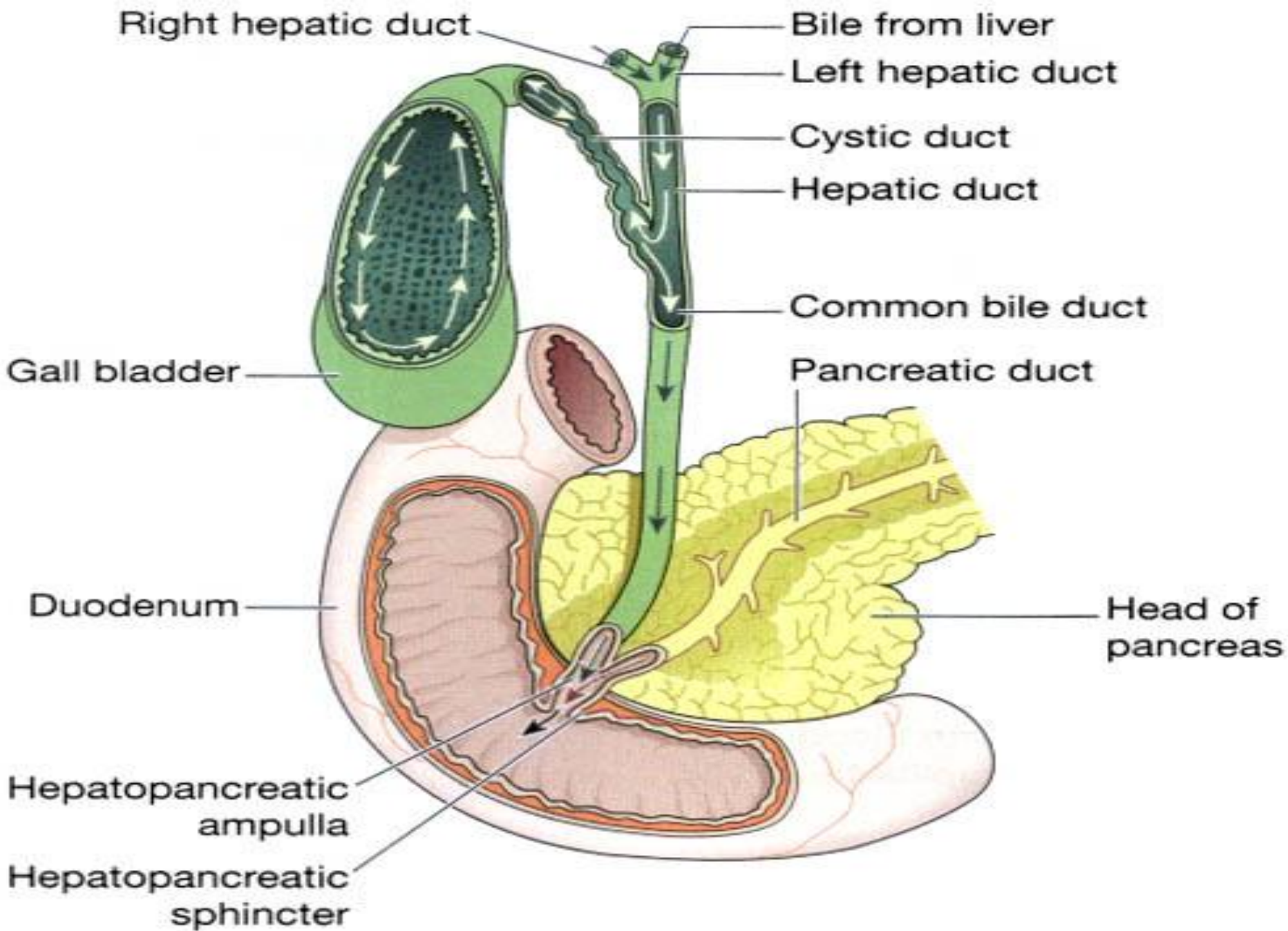
- Bilirubin is one of the products of haemolysis of erythrocytes by Kupffer cells in the liver & by other macrophages in the spleen & bone marrow.
 - It is insoluble in water & is carried in the blood bound to **albumin.**
 - In hepatocytes it is conjugated with **glucuronic acid** & becomes water soluble before being excreted in bile.
- Bacteria in the intestine change the form of bilirubin & most is excreted as **stercobilinogen** in the faeces.
 - A small amount is reabsorbed & excreted in urine as urobilinogen.
- Excess blood bilirubin causes jaundice.



BILIARY TRACT

Bile ducts

- Right & left hepatic ducts join to form the **common hepatic duct** just outside the portal fissure.
- **Hepatic duct** passes downwards for about 3 cm where it is joined at an acute angle by the **cystic duct** from the gall bladder.
- Cystic & hepatic ducts together form the **common bile duct** which passes downwards behind the head of the pancreas to be joined by the main pancreatic duct at the **hepatopancreatic ampulla**.
- Opening of the combined ducts into the duodenum is controlled by sphincter of Oddi.
- Common bile duct is about 7.5 cm long, diameter of about 6 mm.



Flow of bile from the liver to the duodenum

GALL BLADDER

- Pear-shaped sac attached to the posterior surface of the liver by connective tissue.
- Has a fundus, a body & a neck which is continuous with the cystic duct.

Structure

- Same layers of tissue as alimentary canal, with some modifications.
- Peritoneum covers only the inferior surface.
- In contact with the posterior surface of the right lobe of the liver & is held in place by the visceral peritoneum of the liver.
- Muscle layer; Has an additional layer of **oblique muscle fibres**.
- Mucous membrane displays **small rugae** when the gall bladder is empty that disappear when it is distended with bile.

- **Blood supply**
- Arterial blood: cystic artery; a branch of the hepatic artery.
- Venous drainage: cystic vein which joins the portal vein.
- **Nerve supply**
- By sympathetic & parasympathetic nerve fibres.

Functions of the gall bladder

1. reservoir for bile
2. concentration of the bile by up to 10- or 15-fold, by absorption of water through the walls of the gall bladder
3. release of stored bile.
 - Contraction is stimulated by:
 - a) Hormone **CCK**
 - b) Presence of fat & acid chyme in the duodenum.
 - Relaxation of the hepatopancreatic sphincter is caused by CCK

METABOLISM

- Constitutes all the chemical reactions that occur in the body, using absorbed nutrients to:
 - provide energy by chemical oxidation of nutrients
 - make new or replacement body substances.
- 2 types of processes are involved.

a) Catabolism.

- **Def:** Process of breaking down large molecules into smaller ones releasing chemical energy that is stored as ATP & heat.
- Heat is used to maintain core body temperature at the optimum level for chemical activity (36.8°C).
- Excess heat is lost through the skin & excreta

b) Anabolism.

- **Def:** Process of building up, or synthesis, of large molecules from smaller ones & requires a source of energy, usually ATP.
- Both involve a series of chemical reactions; **metabolic pathways** which permit controlled, efficient & gradual transfer of energy from ATP.
- Metabolic pathways are switched on & off by hormones, providing control of metabolism & meeting individual requirements.
- Both processes occur continually in all cells maintaining an energy balance.

Energy

- Measured and expressed in **units of work (joules)** or **units of heat (kilocalories)**.
- **A kilocalorie (kcal):** amount of heat required to raise the temperature of 1 litre of water by 1°C.
- On a daily basis, the body's collective metabolic processes generate a total of about 3 million kcal.
1 kcal = 4184 joules (J) = 4.184 kilojoules (kJ)
- Nutritional value of carbohydrates, protein & fats eaten in the diet may be expressed in **kilojoules per gram** or **kcal per gram**.
 - 1 gram of **carbohydrate** provides **17 kilojoules (4 kcal)**
 - 1 gram of **protein** provides **17 kilojoules (4 kcal)**
 - 1 gram of **fat** provides **38 kilojoules (9 kcal)**

Metabolic rate

- **Def:** Rate at which energy is released from the fuel molecules inside cells.
- Can be estimated by measuring O_2 or CO_2 excretion.
- **Basal metabolic rate (BMR):** Rate of metabolism when the individual is at rest in a warm environment & is in the post-absorptive state, i.e. has not had a meal for at least 12 hours.
 - release of energy is sufficient to meet only the essential needs of vital organs, e.g heart, lungs, nervous system & kidneys.

- Post-absorptive state is important because the intake of food, especially protein, stimulates an increase in metabolic rate, due to increased energy utilization by the liver; **specific dynamic action (SDA)** of food.
- In measuring the BMR, surface area of the body is taken into account because energy in the form of heat is lost through the skin.
- Surface area in square meters is calculated from the height and weight of the individual.
- Carbohydrates, proteins & fats are the sources of energy & they are obtained from the variety of food, usually in the following proportions:
 - protein 10-15%
 - fat 15-30%
 - carbohydrate 55-75%

Table 12.3 Factors affecting metabolic rate

Factor	Effect on metabolic rate
Age	Gradually reduced with age
Gender	Higher in men than women
Height, weight	Relatively higher in small people
Pregnancy, menstruation, lactation	Increased
Ingestion of food	Increased
Muscular activity	Increased
Elevated body temperature	Increased
Excess thyroid hormones	Increased
Starvation	Decreased

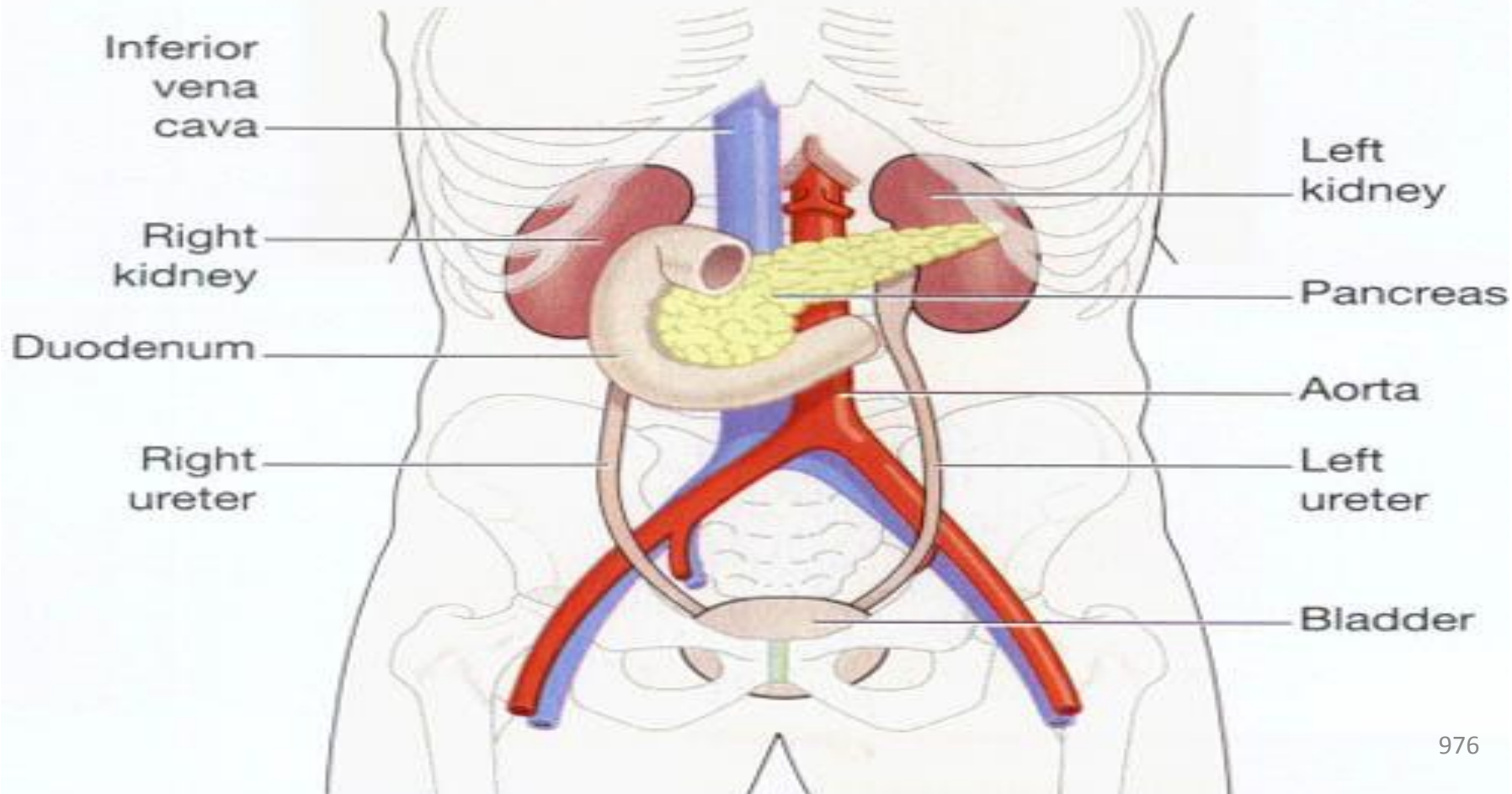
Assignment Take away

- Central metabolic pathways
 - Glycolysis
 - The citric acid or Krebs cycle
 - Oxidative phosphorylation
- Metabolism of
 - Carbohydrates
 - Proteins
 - Fats

THE URINARY SYSTEM

Urinary system

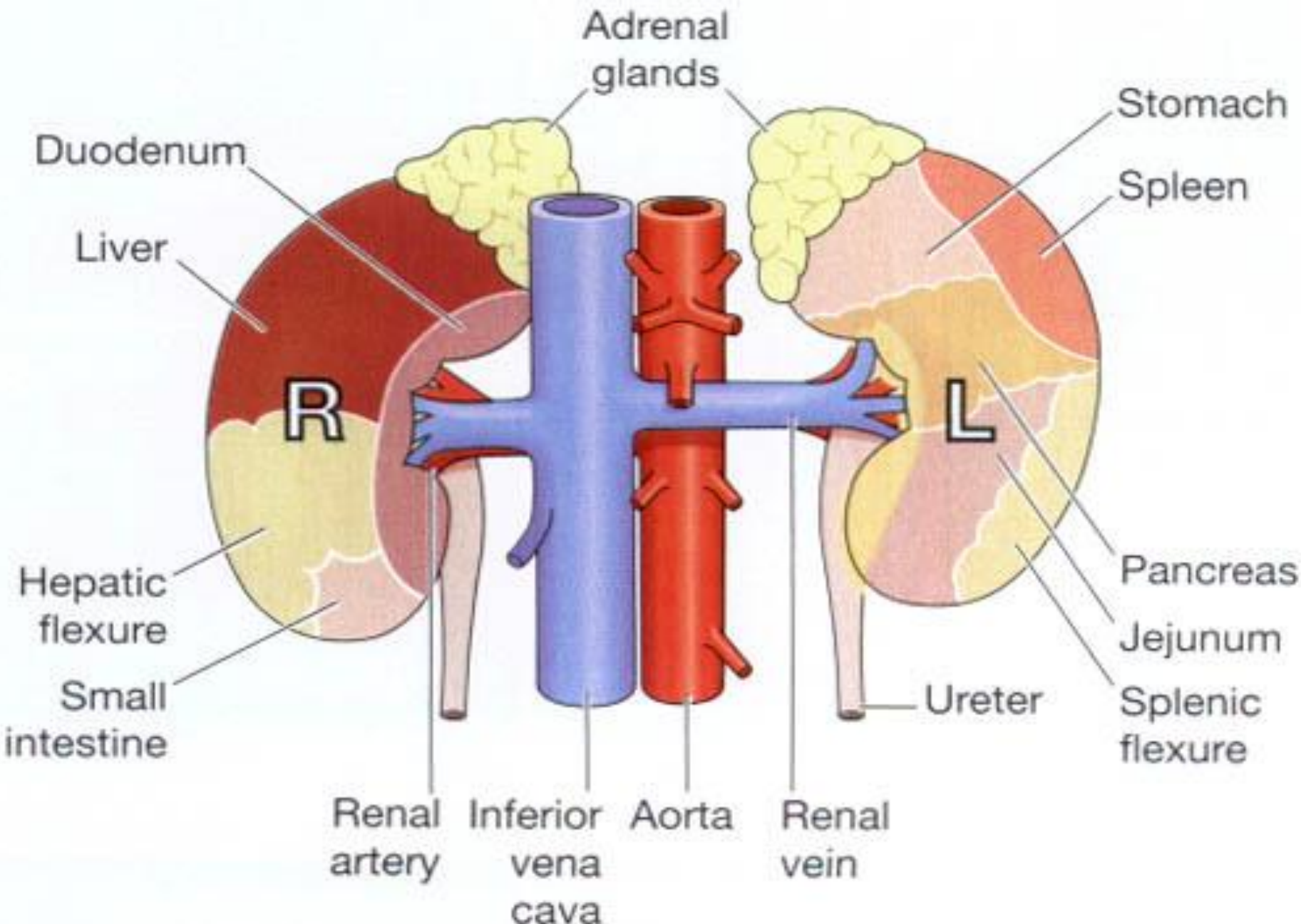
- One of the excretory systems of the body.
- Consists of:
 - a. 2 kidneys, which secrete urine
 - b. 2 ureters, which convey the urine from the kidneys to the urinary bladder
 - c. 1 urinary bladder where urine collects & is temporarily stored
 - d. 1 urethra through which the urine is discharged from the urinary bladder to the exterior.



- Plays a vital part in maintaining homeostasis of water and electrolyte concentrations within the body.
- Kidneys produce urine that contains metabolic waste products, including the nitrogenous compounds urea & uric acid, excess ions & some drugs.
- **Main functions of the kidneys:**
 1. formation & secretion of urine
 2. production & secretion of erythropoietin
 3. production & secretion of renin, an important enzyme in the control of blood pressure.
- Urine is stored in the bladder & excreted by the process of **micturition**.

KIDNEYS

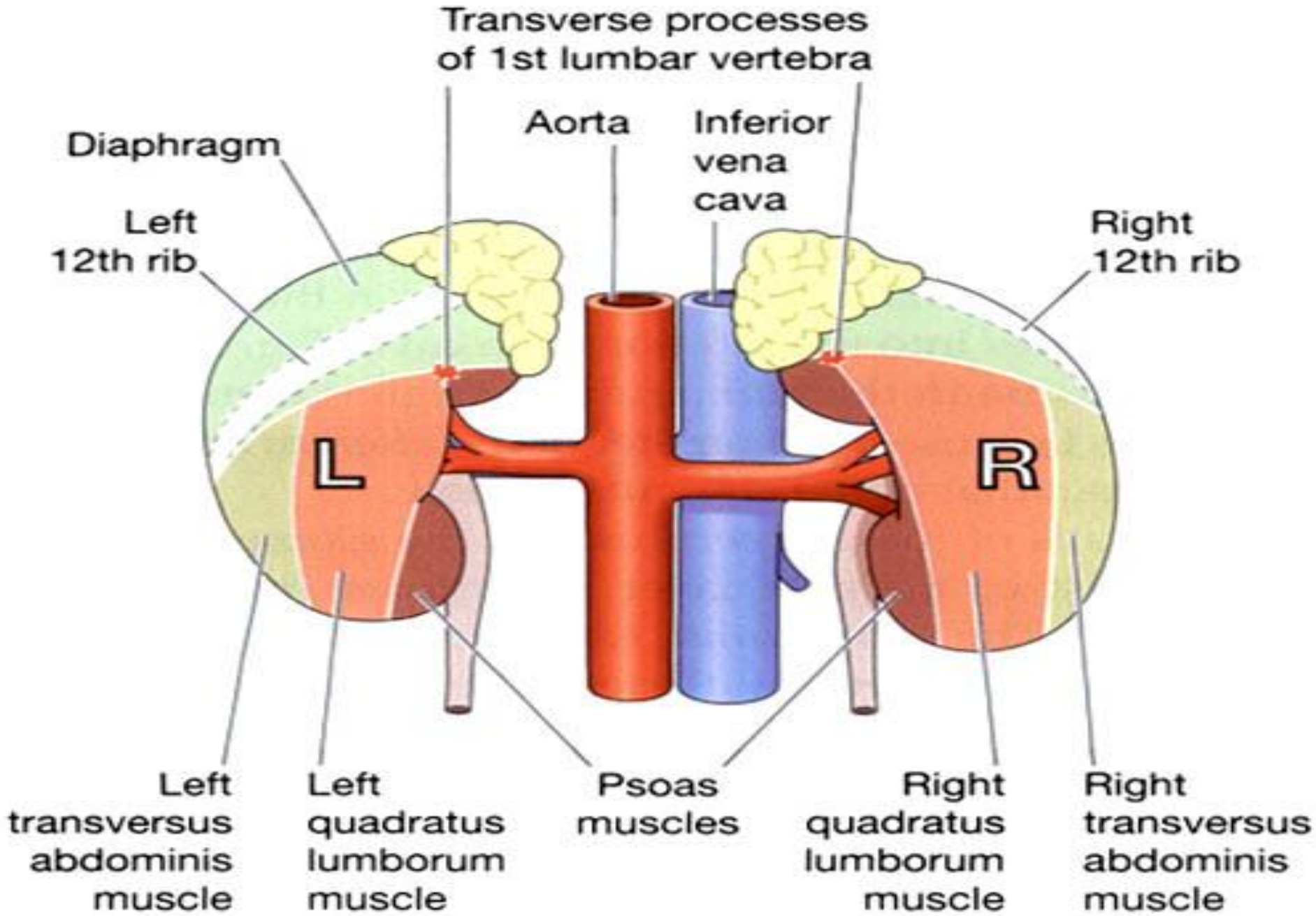
- Lie on the posterior abdominal wall, one on each side of the vertebral column, behind the peritoneum & below the diaphragm.
- Extend from the level of the 12th thoracic vertebra to the 3rd lumbar vertebra, receiving some protection from the lower rib cage.
- Right kidney is usually slightly lower than the left, because of the considerable space occupied by the liver.
- Bean-shaped organs, about 11 cm long, 6 cm wide, 3 cm thick & weigh 150 g.
- Embedded in, & held in position by a mass of fat.
- A sheath of fibroelastic renal fascia encloses the kidney and the renal fat.



Anterior view

Organs associated with the kidneys

- **Right kidney**
- Superiorly — right adrenal gland
- Anteriorly — right lobe of the liver, duodenum & hepatic flexure of the colon
- Posteriorly — diaphragm & muscles of the posterior abdominal wall
- **Left kidney**
- Superiorly — left adrenal gland
- Anteriorly — spleen, stomach, pancreas, jejunum & splenic flexure of the colon
- Posteriorly — diaphragm & muscles of the posterior abdominal wall

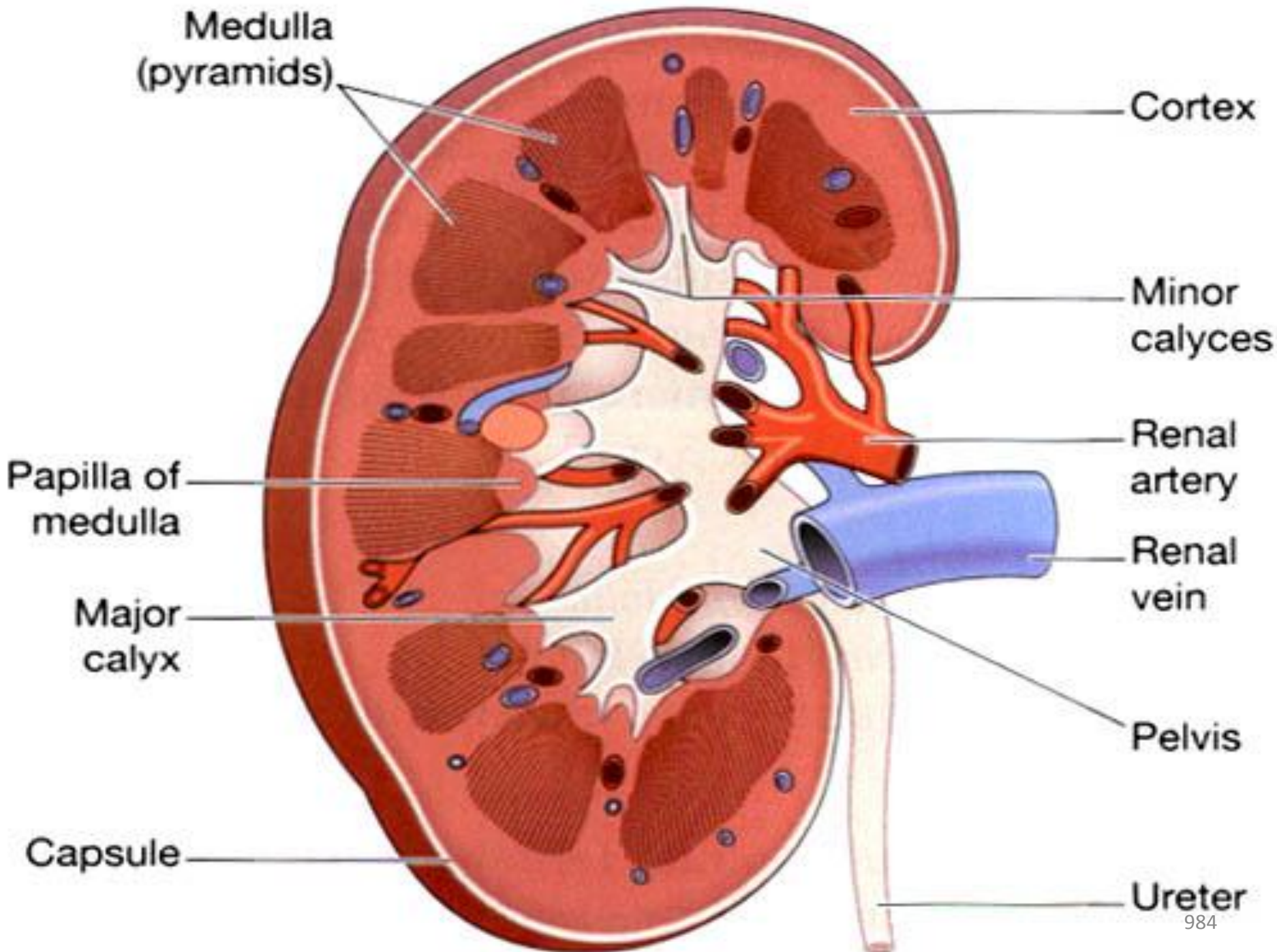


Posterior view

Gross structure of the kidney

- 3 areas of tissue:
 - a **fibrous capsule**, surrounding the kidney
 - **cortex**, a reddish-brown layer of tissue immediately below the capsule & outside the Pyramids
 - **medulla**, the innermost layer, consisting of pale conical-shaped striations; renal pyramids.
- **Hilum**; concave medial border of the kidney where the renal blood & lymph vessels, ureter & nerves enter.
- **Renal pelvis**; funnel-shaped structure which acts as a receptacle for the urine formed by the kidney.
 - Has a number of distal branches called **calyces**, each of which surrounds the apex of a renal pyramid.

- Urine formed in the kidney passes through a **papilla** at the apex of a pyramid into a **minor calyx**, then into a **major calyx** before passing through the **pelvis** into the **ureter**.
- Walls of the pelvis contain smooth muscle & are lined with transitional epithelium.
- Peristalsis of the smooth muscle originating in pacemaker cells in the walls of the calyces propels urine through the pelvis & ureters to the bladder.
 - This is an intrinsic property of the smooth muscle, & is not under nerve control.



Microscopic structure of the kidney

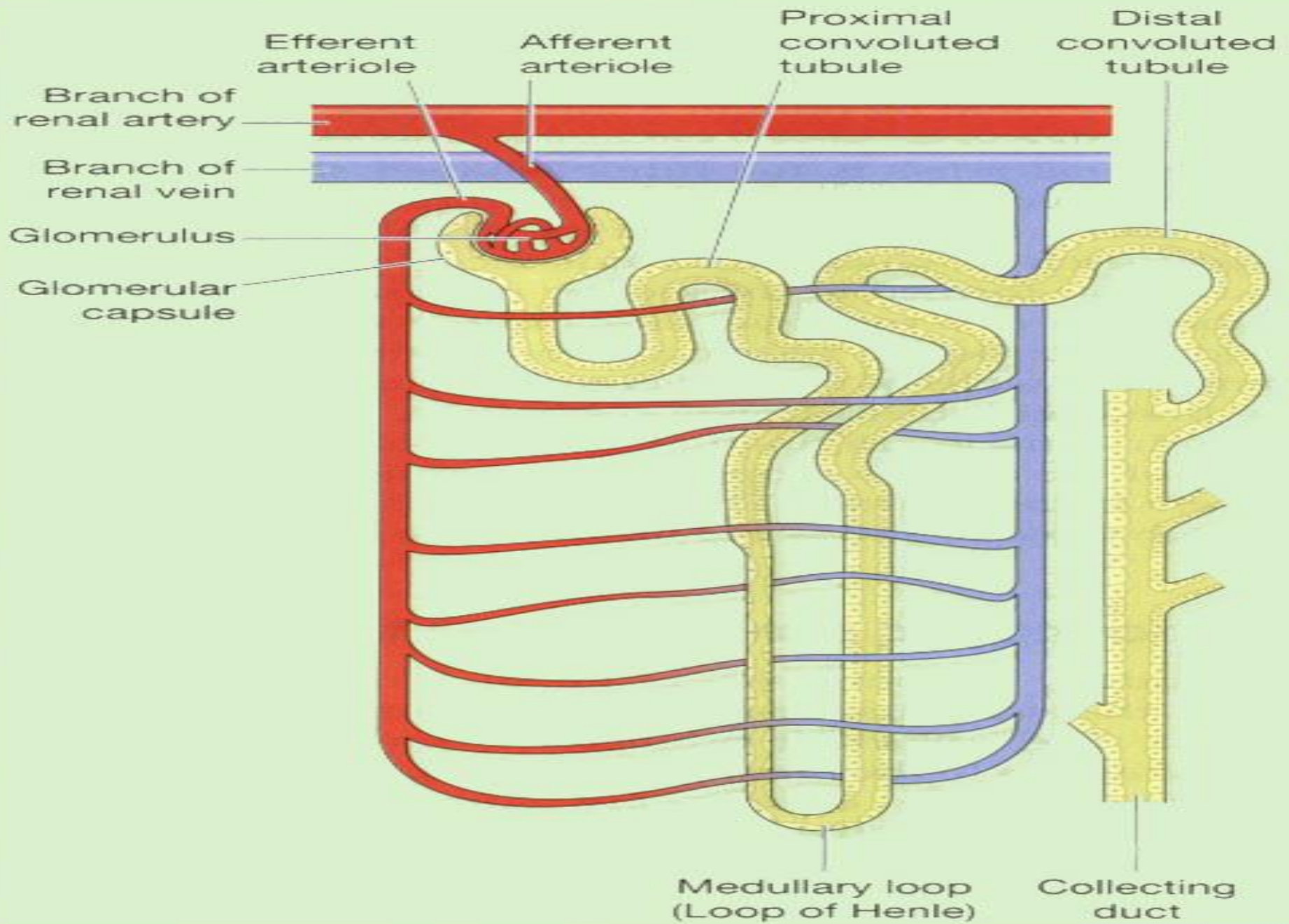
- Composed of about 1 million functional units, the **nephrons**, & a smaller number of collecting **tubules**.
- Collecting tubules transport urine through the pyramids to the renal pelvis giving them their striped appearance.
- Tubules are supported by a small amount of connective tissue, containing blood vessels, nerves & lymph vessels.

The Nephron

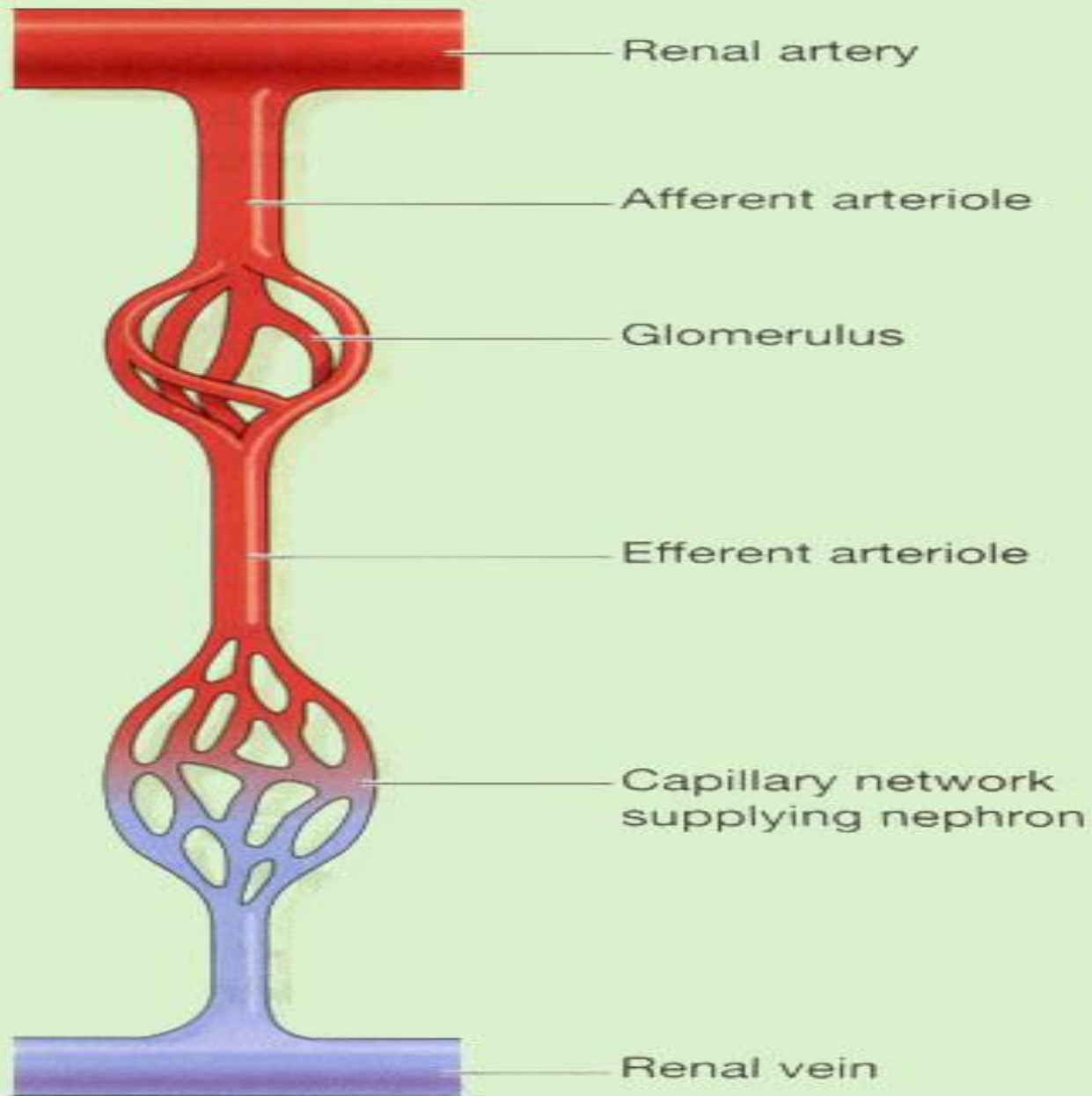
- Tubule closed at one end, the other end opening into a collecting tubule.
- Closed/blind end is indented to form **Bowman's capsule** which almost completely encloses a network of arterial capillaries, the **glomerulus**.
- Continuing from the glomerular capsule, remainder of the nephron is about 3 cm long & has 3 parts:
 - proximal convoluted tubule
 - medullary loop (loop of Henle)
 - distal convoluted tubule, leading into a collecting duct.
- Collecting ducts unite, forming larger ducts that empty into the minor calyces.

- After entering the kidney at the hilum, **renal artery** divides into smaller arteries & arterioles.
- In the cortex an **afferent arteriole**, enters each glomerular capsule then subdivides into a cluster of capillaries, forming the glomerulus.
- Between the capillary loops there are connective tissue phagocytic mesangial cells; part of the **reticuloendothelial system**.
- Blood vessel leading away from the glomerulus; **efferent arteriole**, breaks up into a 2nd capillary network to supply oxygen & nutrients to the remainder of the nephron.

- Bp in the glomerulus is higher than in other capillaries because the diameter of the afferent arteriole is greater than that of the efferent arteriole.
- Walls of the glomerulus & glomerular capsule consist of a single layer of flattened epithelial cells.
- Nerve supply to the blood vessels of the kidney consists of sympathetic & parasympathetic nerves thus permits control of renal blood vessel diameter & renal blood flow independently of autoregulation.



Nephron & associated vessels



Blood vessels series

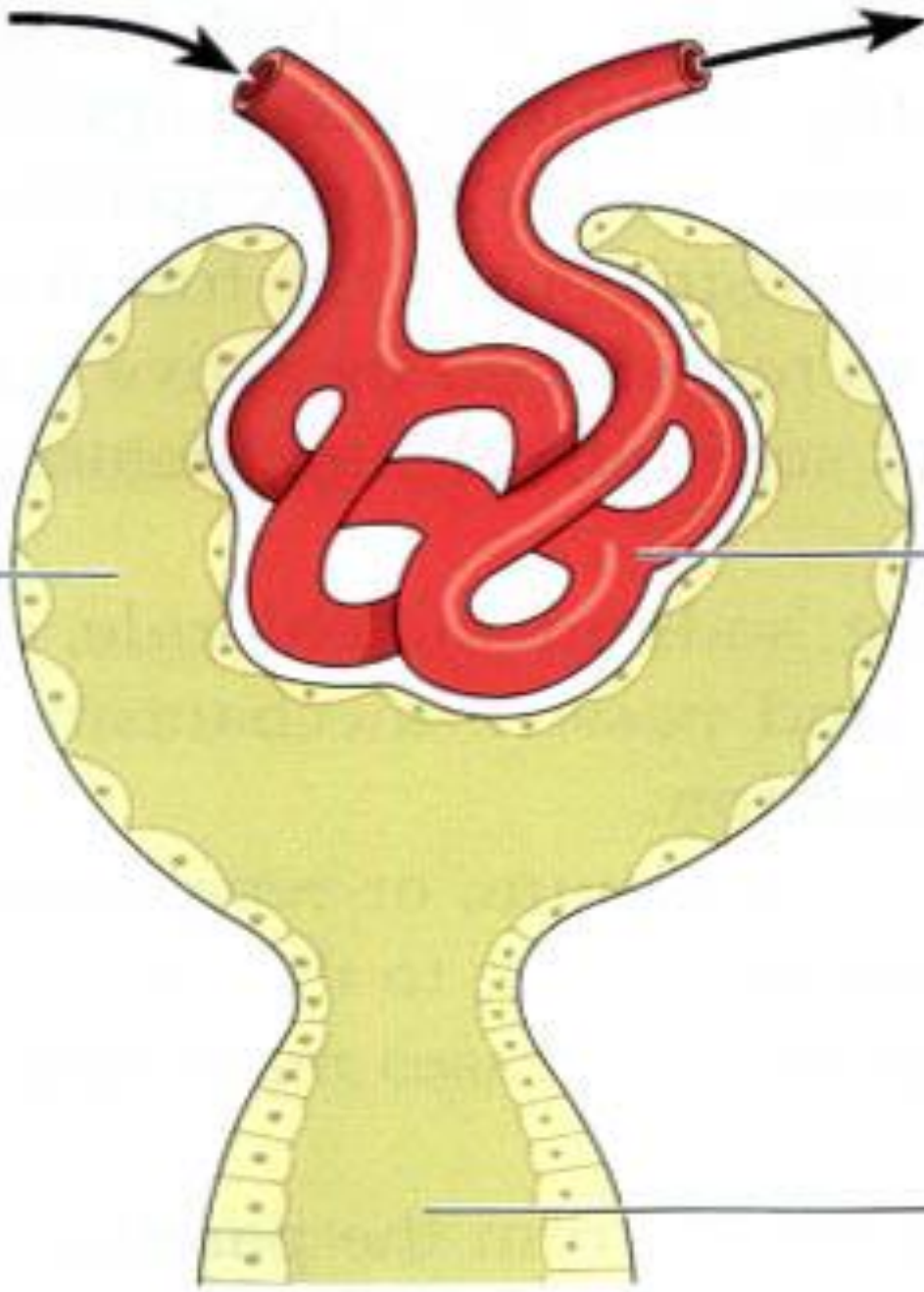
Afferent arteriole

Efferent arteriole

Glomerular capsule

Glomerulus

Proximal convoluted tubule



Functions of the kidney

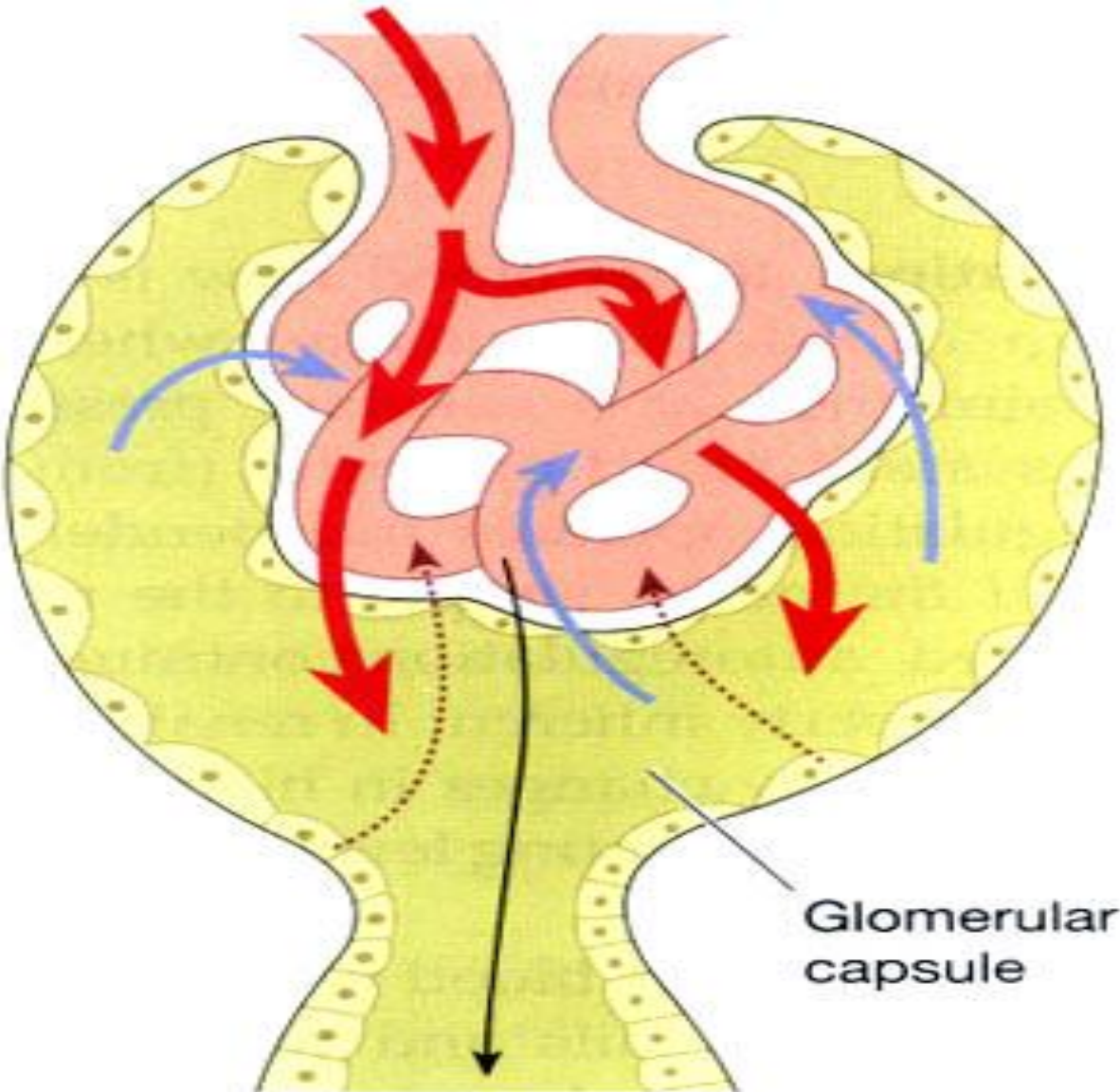
a) Formation of urine

- Waste products of protein metabolism are excreted, electrolyte balance is maintained and the pH is maintained by the excretion of hydrogen ions.
- 3 processes are involved:
 - simple filtration
 - selective re-absorption
 - secretion

i) Simple filtration

- Takes place through the semi-permeable walls of the glomerulus & glomerular capsule.

- Water & a large number of small molecules pass through.
 - Blood cells, plasma proteins & other large molecules are unable to filter through & remain in the capillaries.
- **Filtration** is assisted by the difference between the blood pressure in the glomerulus & the pressure of the filtrate in the glomerular capsule.
 - Because the diameter of the efferent arteriole is less than that of the afferent arteriole, a capillary hydrostatic pressure of about 7.3 kPa (55 mmHg) builds up in the glomerulus.
 - This pressure is opposed by the osmotic pressure of the blood, about 4 kPa (30 mmHg), and by filtrate hydrostatic pressure of about 2 kPa (15 mmHg) in the glomerular capsule.



- ↓ Glomerular (blood) hydrostatic pressure (55 mmHg)
- ↑ Blood colloid osmotic pressure (30 mmHg)
- ↑ Capsular hydrostatic pressure (15 mmHg)

Glomerular capsule

Net outward pressure (10 mmHg)

Filtration in the nephron

- Net filtration pressure is, therefore:
 $7.3 - (4 + 2) = 1.3 \text{ kPa}$, or
 $55 - (30 + 15) = 10 \text{ mmHg}$.
- **Glomerular filtration rate (GFR):** Volume of filtrate formed by both kidneys each minute.
- Healthy adult; GFR is about 125 ml/min; i.e. 180 litres of dilute filtrate are formed each day by the 2 kidneys.
- Most of the filtrate is reabsorbed with less than 1%, i.e. 1 to 1.5 litres, excreted as urine.

Autoregulation of filtration.

- **Autoregulation:** protective mechanism whereby renal blood flow is maintained at a constant pressure across a wide range of systolic blood pressures (from 80 to 200 mmHg).

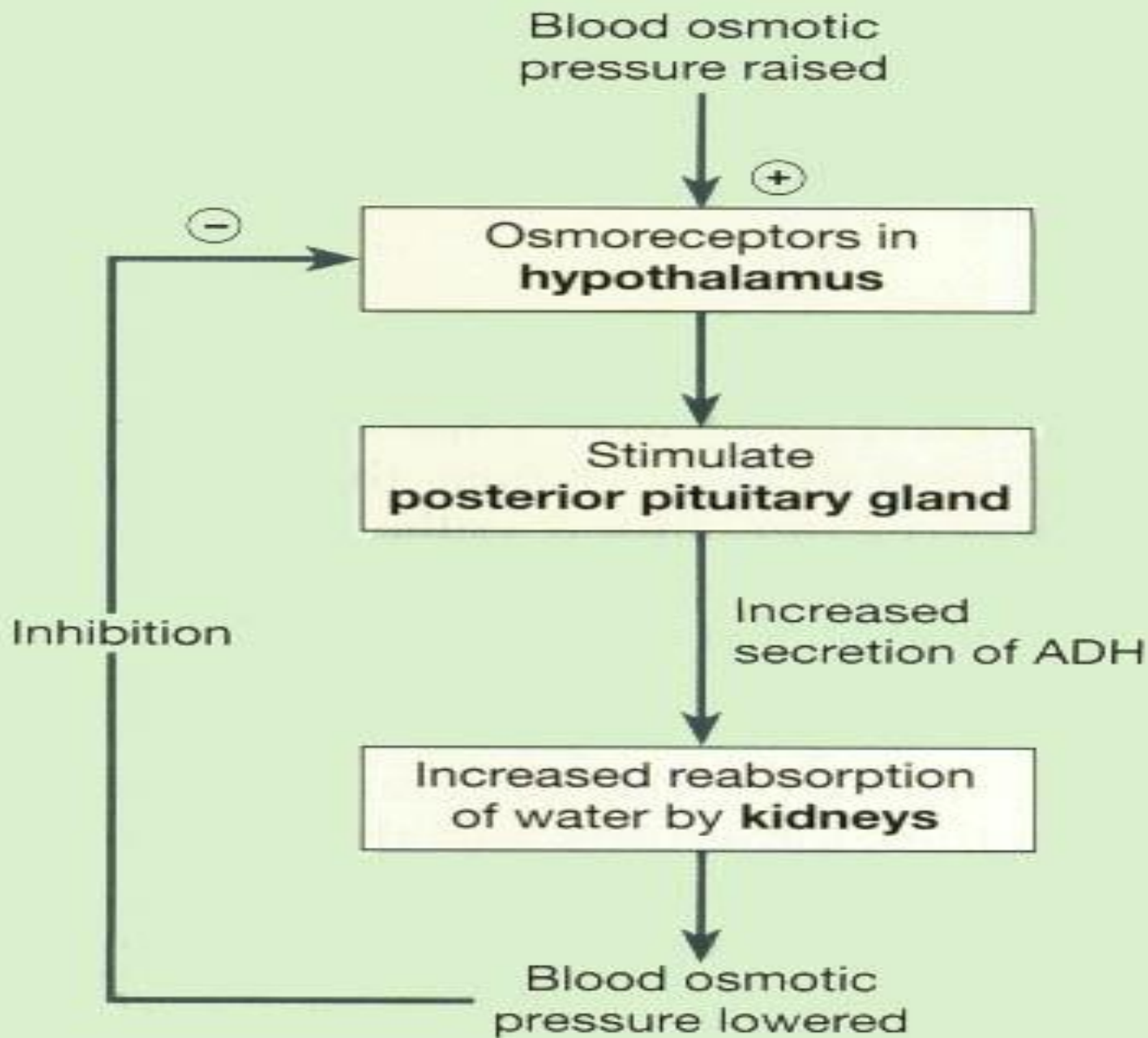
- Operates independently of nervous control.
 - An inherent property in renal blood vessels; it may be stimulated by changes in blood pressure in the renal arteries or by fluctuating levels of certain metabolites, e.g. prostaglandins.

ii) Selective re-absorption

- **Def:** Process by which the composition & volume of the glomerular filtrate are altered during its passage through the convoluted tubules, the medullary loop and collecting tubule.
- **General purpose:** To reabsorb into the blood those filtrate constituents needed by the body to maintain fluid & electrolyte balance & the pH of the blood.

- Active transport is carried out at carrier sites in the epithelial membrane.
- Some constituents of glomerular filtrate (e.g. glucose, amino acids) do not normally appear in urine because they are completely reabsorbed unless they are present in blood in excessive quantities.
- Kidneys' maximum capacity for re-absorption of a substance is the **transport maximum**, or renal threshold, e.g. normal blood glucose level is 2.5 to 5.3 mmol/l (45 to 95 mg/100 ml).
 - If the level rises above the transport maximum of about 9 mmol/l (160 mg/100 ml) glucose appears in the urine because all the carrier sites are occupied & the mechanism for active transfer out of the tubules is overloaded.

- Other substances reabsorbed by active transport include amino acids & sodium, calcium, potassium, phosphate & chloride.
- In some cases re-absorption is regulated by hormones.
 - **Parathyroid hormone & calcitonin**; together regulate re-absorption of calcium & phosphate.
 - **ADH**; increases the permeability of the distal convoluted tubules & collecting tubules, increasing water re-absorption.
 - **Aldosterone**; increases the re-absorption of sodium & excretion of potassium
- Nitrogenous waste products, e.g. urea & uric acid, are reabsorbed only to a slight extent.



Negative feedback regulation of secretion of ADH

iii) Secretion

- Involves removal of substances not required & foreign materials not be cleared from the blood by filtration because of the short time they remain in the glomerulus.
 - Such substances are excreted from the body in the urine.
- Tubular secretion of hydrogen (H^+) ions is important in maintaining homeostasis of blood pH.

• **Composition of urine**

• Water 96%

• Urea 2%

• Uric acid

• Creatinine

• Ammonia

• Sodium

• Potassium 2%

• Chlorides

• Phosphates

• Sulphates

• Oxalates



- Urine is clear & amber in colour due to the presence of urobilin.
- Specific gravity is between 1.020 & 1.030 & pH is around 6 (normal range of 4.5 to 8).
- A healthy adult passes 1000 to 1500 ml per day.
- Amount of urine produced & the specific gravity vary according to the fluid intake & the amount of solute excreted.
- During sleep & muscular exercise urine production is decreased.

Water and urine output

- Water is excreted
 - in saturated expired air,
 - as a constituent of the faeces,
 - through the skin as sweat
 - as the main constituent of urine.
- Amount lost in expired air & in the faeces is fairly constant.
- Amount of sweat produced is associated with the maintenance of normal body temperature.
- Balance between fluid intake & output is thus controlled by the kidneys.
- Minimum urinary output is about 500 ml per day.
 - Amount produced in excess of this is controlled mainly by ADH.

Water and urine output ct.

- Osmoreceptors detect changes in the osmotic pressure of the blood.
- Nerve impulses from the osmoreceptors stimulate the posterior lobe of the pituitary gland to release ADH.
- When the osmotic pressure is raised, ADH output is increased & as a result, water re-absorption by the cells in distal convoluted tubules and collecting ducts is increased, reducing the blood osmotic pressure & ADH output.
 - Feedback mechanism may be opposed when there is an excessive amount of a dissolved substance in the blood. E.g., DM, excess water is excreted with the excess glucose. Polyuria may lead to dehydration in spite of increased production of ADH but it is usually accompanied by acute thirst & increased water intake.

Electrolyte balance

- Changes in the concentration of electrolytes in the body fluids may be due to changes in:
 - body water content, or
 - electrolyte levels.

Sodium & potassium concentration

- Sodium is excreted mainly in urine & sweat.
- Sodium is a normal constituent of urine & amount excreted is regulated by the hormone aldosterone.
- Cells in the afferent arteriole of the nephron are stimulated to produce the enzyme renin by sympathetic stimulation, low blood volume or by low arterial blood pressure.
- Renin converts the plasma protein angiotensinogen, produced by the liver, to angiotensin I.
- ACE converts angiotensin I into angiotensin II; a very potent vasoconstrictor & increases Bp.

- Water is reabsorbed with sodium & together they increase blood volume, leading to reduced renin secretion.
- When sodium re-absorption is increased, potassium excretion is increased, indirectly reducing intracellular potassium.
- Amount of sodium excreted in sweat is insignificant except when sweating is excessive.
 - When excessive sweating is sustained, acclimatization occurs in about 7 to 10 days & amount of electrolytes lost in sweat is reduced.
- Sodium & potassium occur in high concentrations in digestive juices — sodium in gastric juice & potassium in pancreatic & intestinal juice.

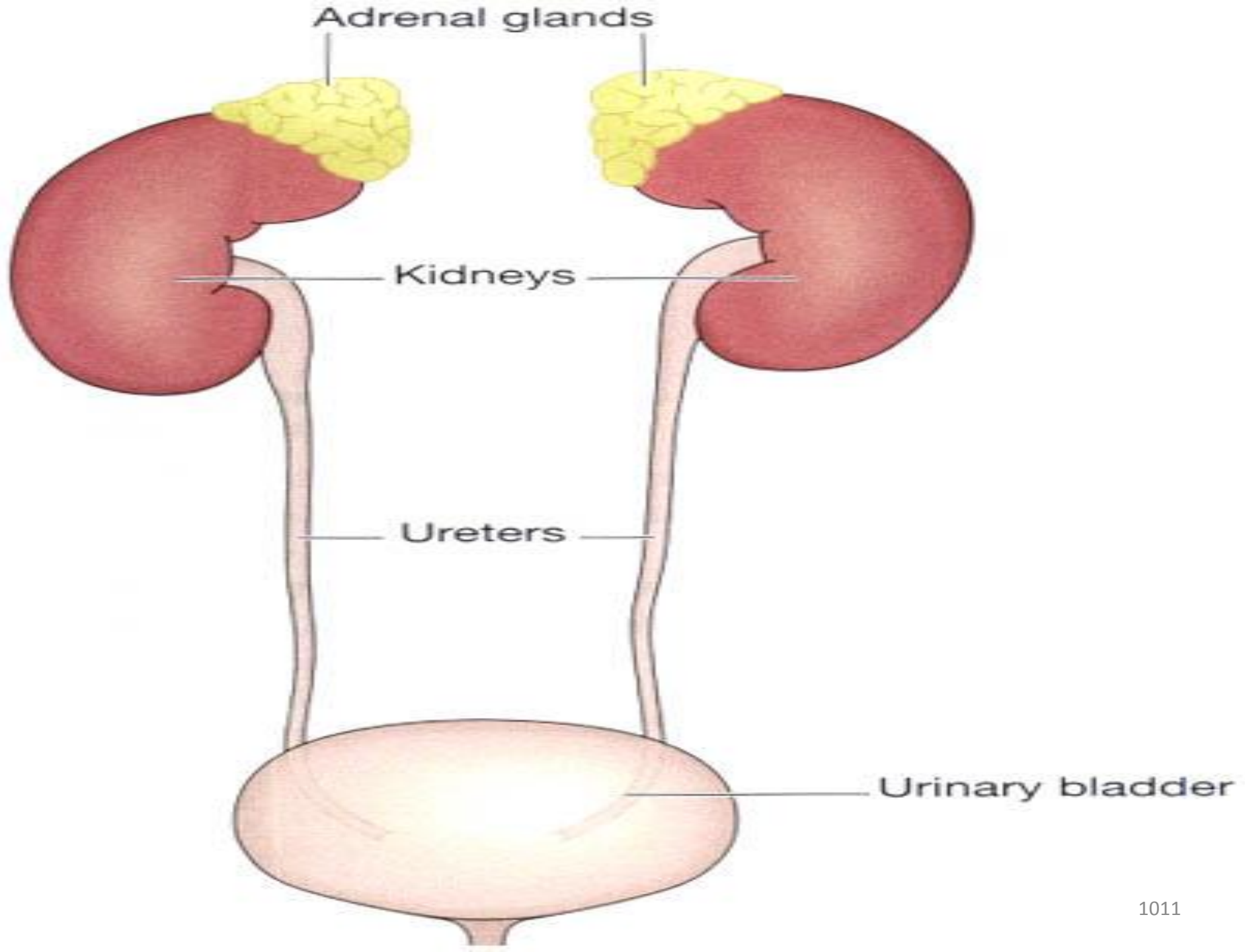
- Normally these ions are reabsorbed by the colon but following acute & prolonged diarrhoea they may be excreted in large quantities with resultant electrolyte imbalance.
- To maintain the normal pH of the blood, the cells of the proximal convoluted tubules secrete H^+ ions.
- In the filtrate they combine with buffers:
 - bicarbonate, forming carbonic acid
 $(H^+ + HCO^- \rightarrow H_2CO_3)$
 - ammonia, forming ammonium ions
 $(H^+ + NH_3 \rightarrow NH_4^+)$
 - hydrogen phosphate, forming dihydrogen phosphate
 $(H^+ + HPO_4^{2-} \rightarrow H_2PO_4^-)$.

- Carbonic acid is converted to CO_2 & H_2O), & the CO_2 is reabsorbed maintaining the buffering capacity of the blood.
- H^+ ions are excreted in the urine as ammonium salts & hydrogen phosphate.
- Normal pH of urine varies from 4.5 to 7.8 depending on
 - diet, large amount of animal proteins tend to produce more acidic urine than vegetarians.
 - time of day etc.

- Urinary system consists of two kidneys, two ureters, the urinary bladder, and the urethra.
- The kidneys form urine,rest of the system eliminates urine.
- The purpose of urine formation is the removal of potentially toxic waste products from the blood;
- Other kidney functions :
 - Regulation of the blood volume, composition, and pressure by the excretion or conservation of water
 - Regulation of the electrolyte balance of the blood by the excretion or conservation of minerals
 - Regulation of the acid-base balance of the blood by the excretion or conservation of ions such as hydrogen or bicarbonate
 - Production of erythropoietin, which then stimulates eryth ocyte production in the bone marrow.

URETERS

- **Def:** Tubes that convey urine from the kidneys to the urinary bladder.
- About 25 to 30 cm long with a diameter of about 3 mm.
- Continuous with the funnel-shaped renal pelvis.
- Passes downwards through the abdominal cavity, behind the peritoneum in front of the psoas muscle into the pelvic cavity & passes obliquely through the posterior wall of the bladder.
- When urine accumulates & the pressure in the bladder rises, the ureters are compressed & the openings occluded.
 - Prevents reflux of urine into the ureters as the bladder fills & during micturition, when pressure increases as the muscular bladder wall contracts.

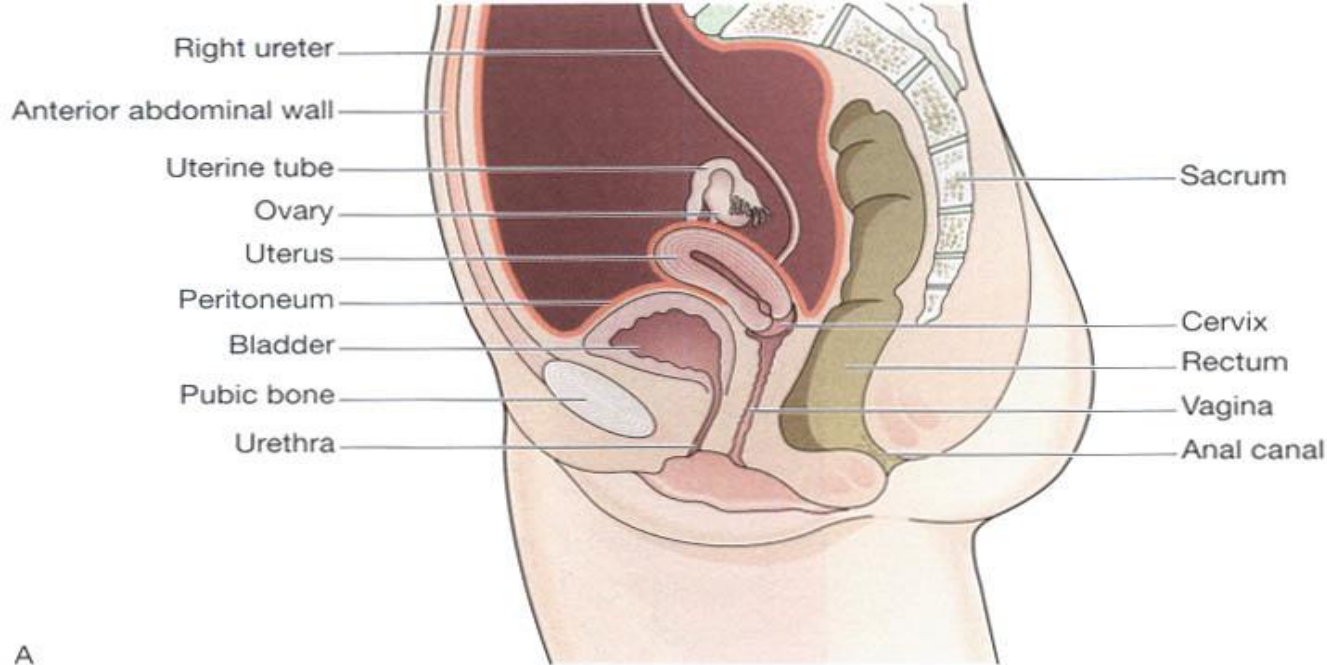


Structure

- 3 layers of tissue:
 - an outer **covering of fibrous tissue**, continuous with the fibrous capsule of the kidney
 - a **middle muscular layer** consisting of interlacing smooth muscle fibres that form a syncytium spiralling round the ureter, some in clockwise and some in anticlockwise directions and an additional outer longitudinal layer in the lower third
 - an **inner layer**, the mucosa, lined with transitional epithelium.
- **Function**
- Propel urine from the kidneys into the bladder by peristaltic contraction of the smooth muscle layer.
 - An intrinsic property of the smooth muscle. Waves of contraction originate in a pacemaker in the minor calyces,

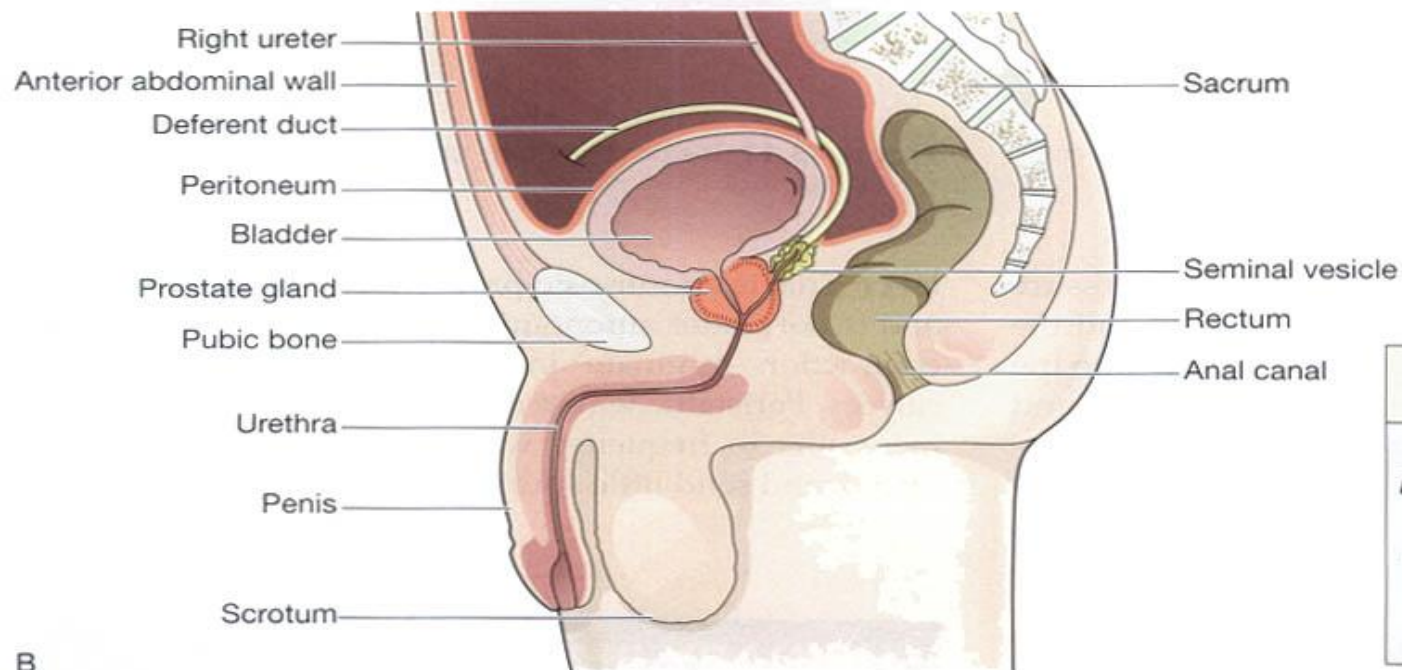
URINARY BLADDER

- A reservoir for urine.
- Lies in the pelvic cavity & its size & position vary, depending on the amount of urine it contains. When distended, the bladder rises into the abdominal cavity.
- **Structure**
- Roughly pear-shaped, but becomes more oval as it fills with urine.
- Has anterior, superior & posterior surfaces.
 - posterior surface is the base.
- Opens into the urethra at its lowest point, the neck.
- Peritoneum covers only the superior surface before it turns upwards as the **parietal peritoneum**, lining the anterior abdominal wall.



Organs associated with the bladder in the female	
Anteriorly	— the symphysis pubis
Posteriorly	— the uterus and upper part of the vagina
Superiorly	— the small intestine
Inferiorly	— the urethra and the muscles forming the pelvic floor

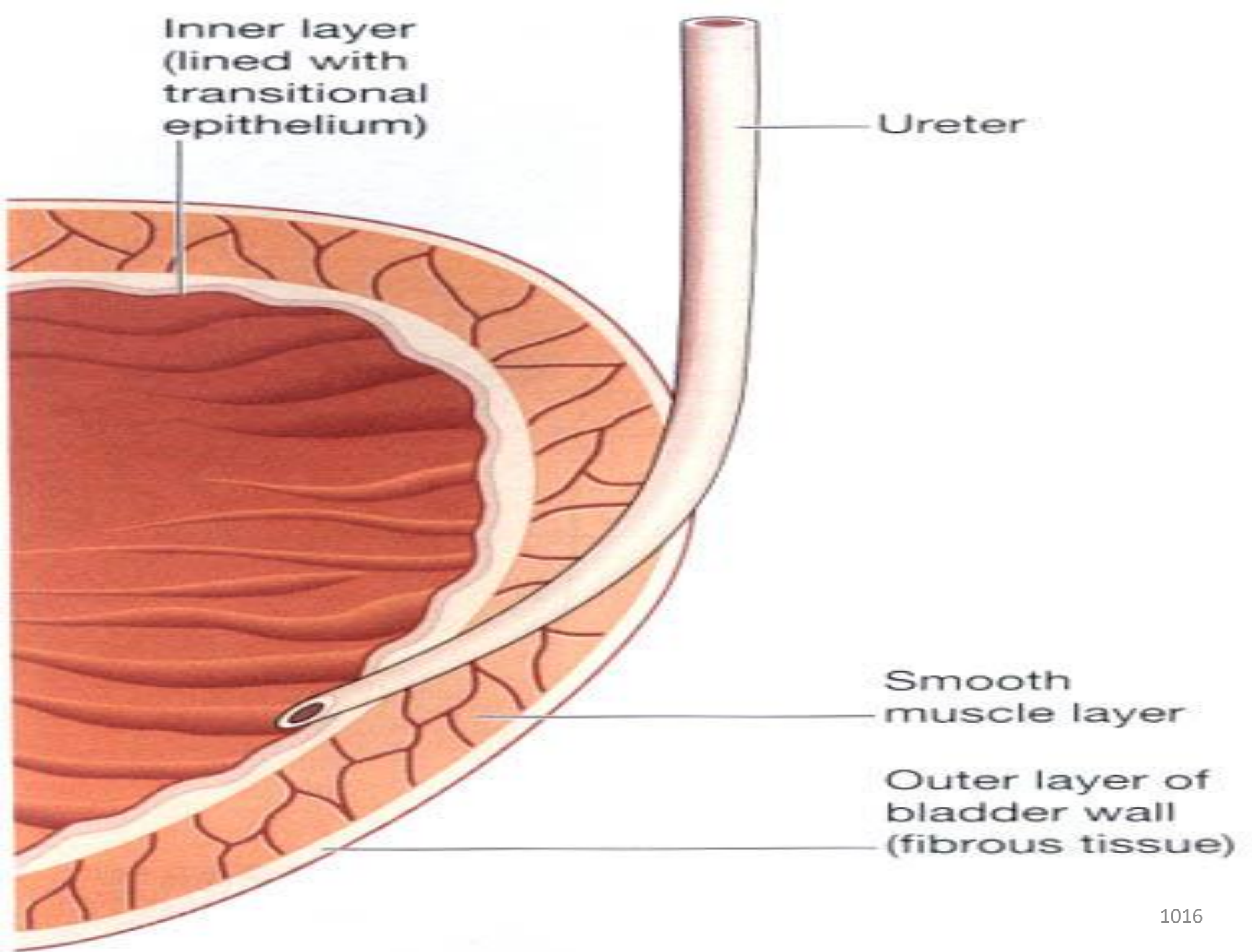
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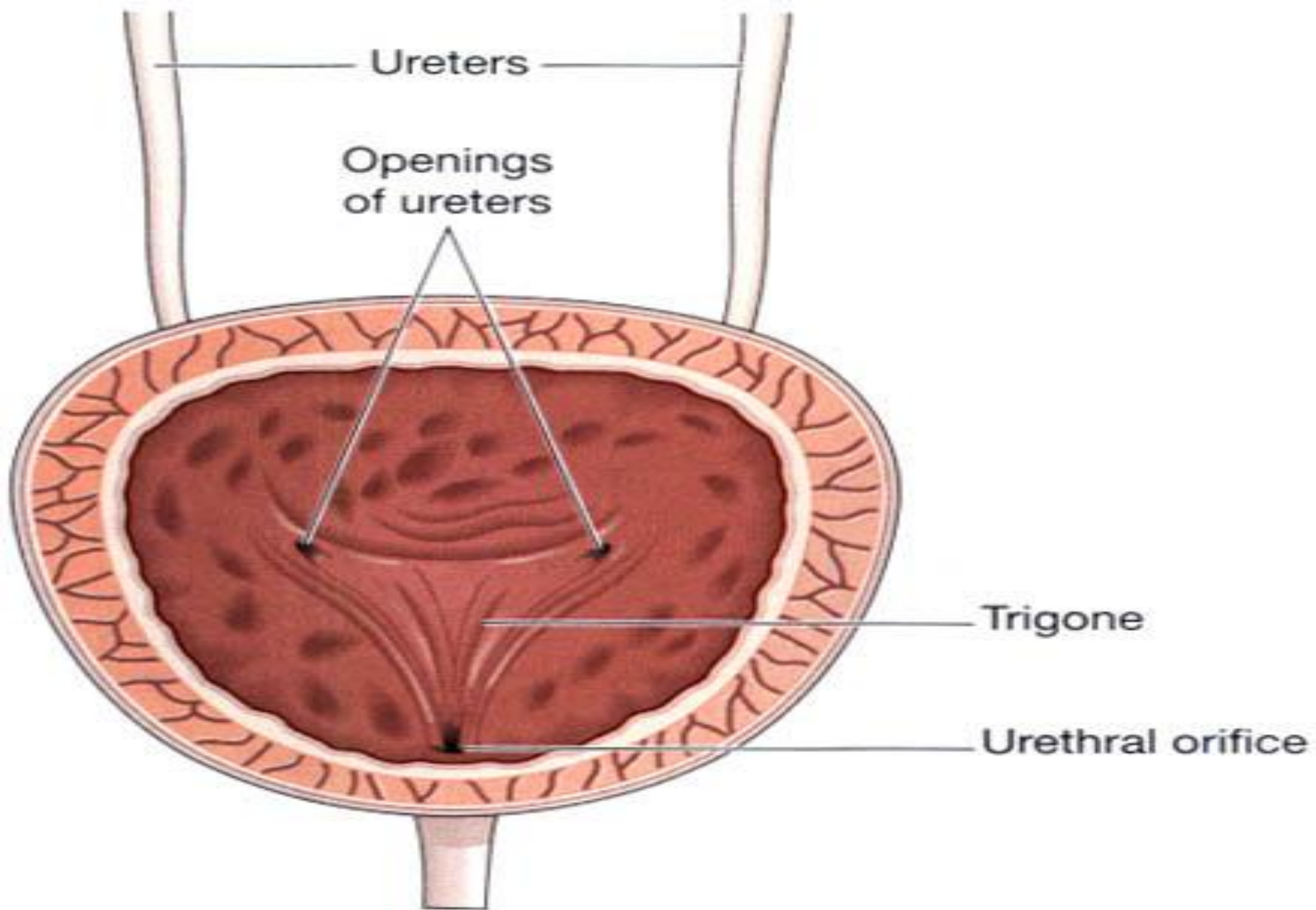
Organs associated with the bladder in the male	
Anteriorly	— the symphysis pubis
Posteriorly	— the rectum and seminal vesicles
Superiorly	— the small intestine
Inferiorly	— the urethra and prostate gland

B

- Bladder wall is composed of 3 layers:
 - **Outer layer** of loose connective tissue, containing blood & lymphatic vessels and nerves, covered on the upper surface by the peritoneum
 - Middle layer, consisting of a mass of interlacing smooth muscle fibres and elastic tissue loosely arranged in three layers.; the detrusor muscle and it empties the bladder when it contracts.
 - Mucosa, lined with transitional epithelium.



- When the bladder is empty the inner lining is arranged in folds/rugae, & these gradually disappear as the bladder fills.
- Bladder is distensible but when it contains 300 to 400 ml, the awareness of the desire to urinate is initiated.
 - Total capacity is about 600 ml.
- 3 orifices in the bladder wall form a triangle/**trigone**
 - Upper 2 orifices on the posterior wall are the openings of the ureters.
 - Lower orifice is the point of origin of the urethra.
- Where the urethra commences is a thickening of the smooth muscle layer forming the internal urethral sphincter; not under voluntary control.



The trigone

URETHRA

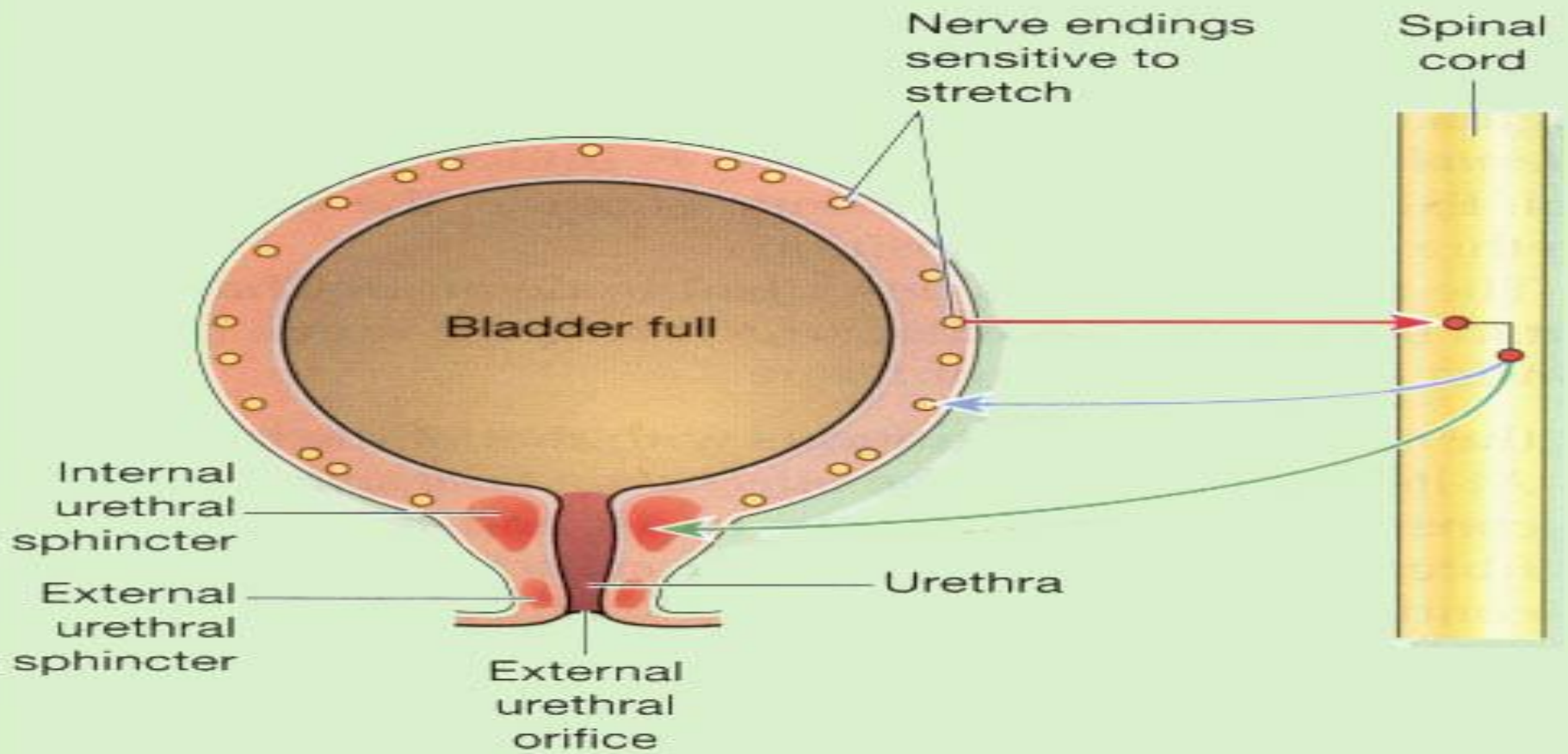
- **Def:** canal extending from the neck of the bladder to the exterior, at the external urethral orifice.
- Female urethra is approximately 4 cm long.
 - It runs downwards & forwards behind the symphysis pubis & opens at the external urethral orifice just in front of the vagina.
- External urethral orifice is guarded by the external urethral sphincter; under voluntary control.
- Walls consist of 3 layers of tissue.
 - **Muscle layer**, continuous with that of the bladder. At its origin there is the internal urethral sphincter, consisting mainly of elastic tissue & smooth muscle fibres, under **autonomic nerve control**.

- Slow and continuous contraction of this sphincter keeps the urethra closed. In the **middle third** there is **skeletal muscle** surrounding the urethra, under **voluntary nerve control**, that forms the **external urethral sphincter**.
- **Submucosa**, a spongy layer containing blood vessels & nerves
- **Mucosa**, continuous with that of the bladder in the upper part.
 - In the lower part, it consists of **stratified squamous epithelium**, continuous externally with the skin of the vulva.

MICTURITION

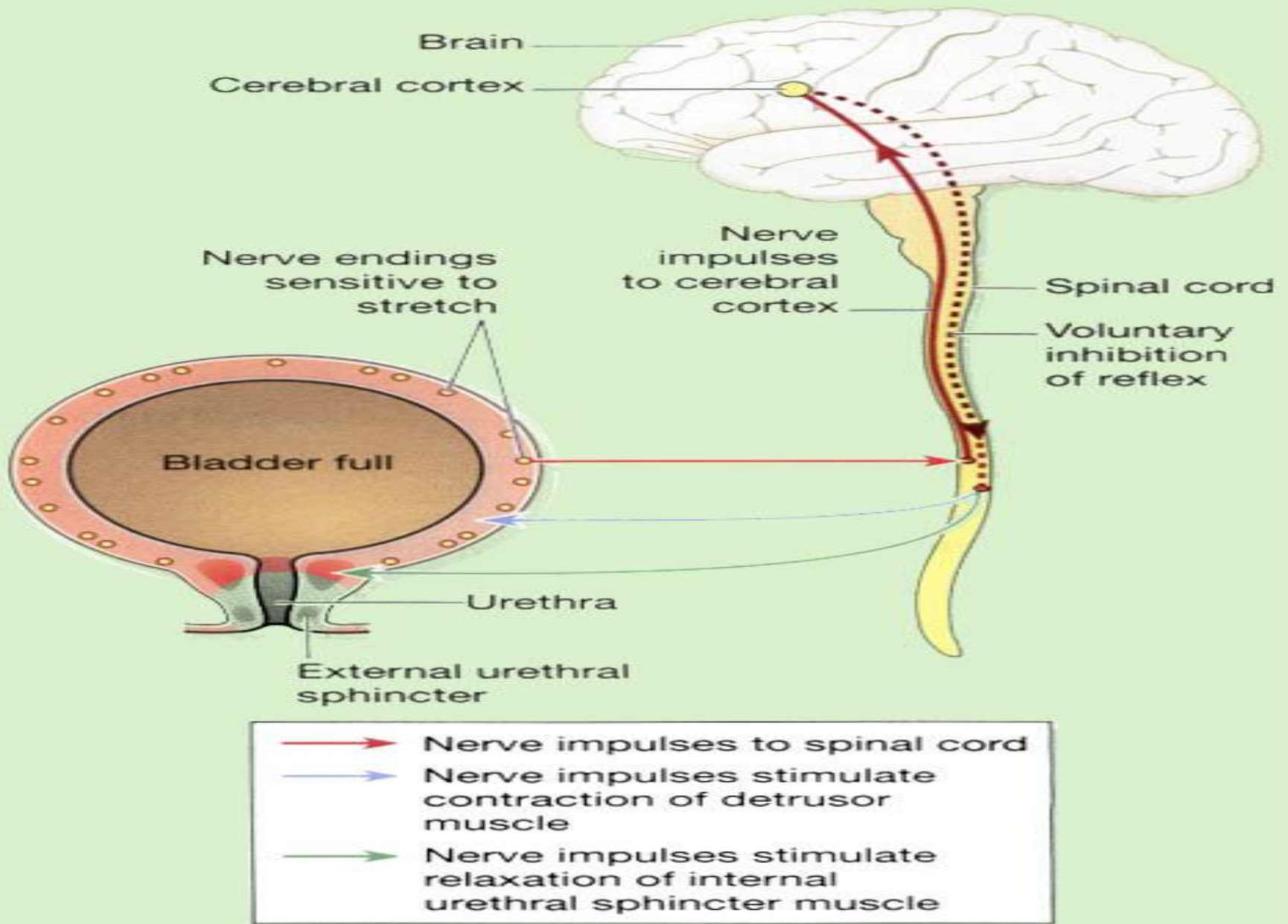
- When 300 to 400 ml of urine have accumulated, afferent autonomic nerve fibres in the bladder wall sensitive to stretch are stimulated.
- In the infant this initiates a spinal reflex action & micturition occurs.
- Micturition occurs when autonomic efferent fibres convey impulses to the bladder causing contraction of the detrusor muscle & relaxation of the **internal urethral sphincter**.
- When the nervous system is fully developed the micturition reflex is stimulated but sensory impulses pass upwards to the brain & there is an awareness of the desire to pass urine.
 - By conscious effort, reflex contraction of the bladder wall and relaxation of the internal sphincter can be inhibited for a limited period of time.

- In adults, micturition occurs when the detrusor muscle contracts, & there is **reflex relaxation of the internal sphincter & voluntary relaxation of the external sphincter.**
- It can be assisted by increasing the pressure within the pelvic cavity, **Valsalva's manoeuvre.**



- Nerve impulses to spinal cord
- Nerve impulses stimulate contraction of detrusor muscle
- Nerve impulses stimulate relaxation of internal urethral sphincter

Simple reflex control of micturition where conscious effort can't override reflex action



Control of micturition where conscious effort overrides reflex action

THE SKIN

The skin

- Completely covers the body
- Continuous with the membranes lining the body orifices.
- It:
 - protects the underlying structures from injury & from invasion by microbes
 - contains sensory (somatic) nerve endings of pain, temperature & touch
 - is involved in the regulation of body temperature.

The skin

- Surface area of about 1.5 to 2 m² in adults
- Contains glands, hair & nails.
- 2 main layers:
 - epidermis
 - dermis.
- Between the skin & underlying structures; is a layer of subcutaneous fat.

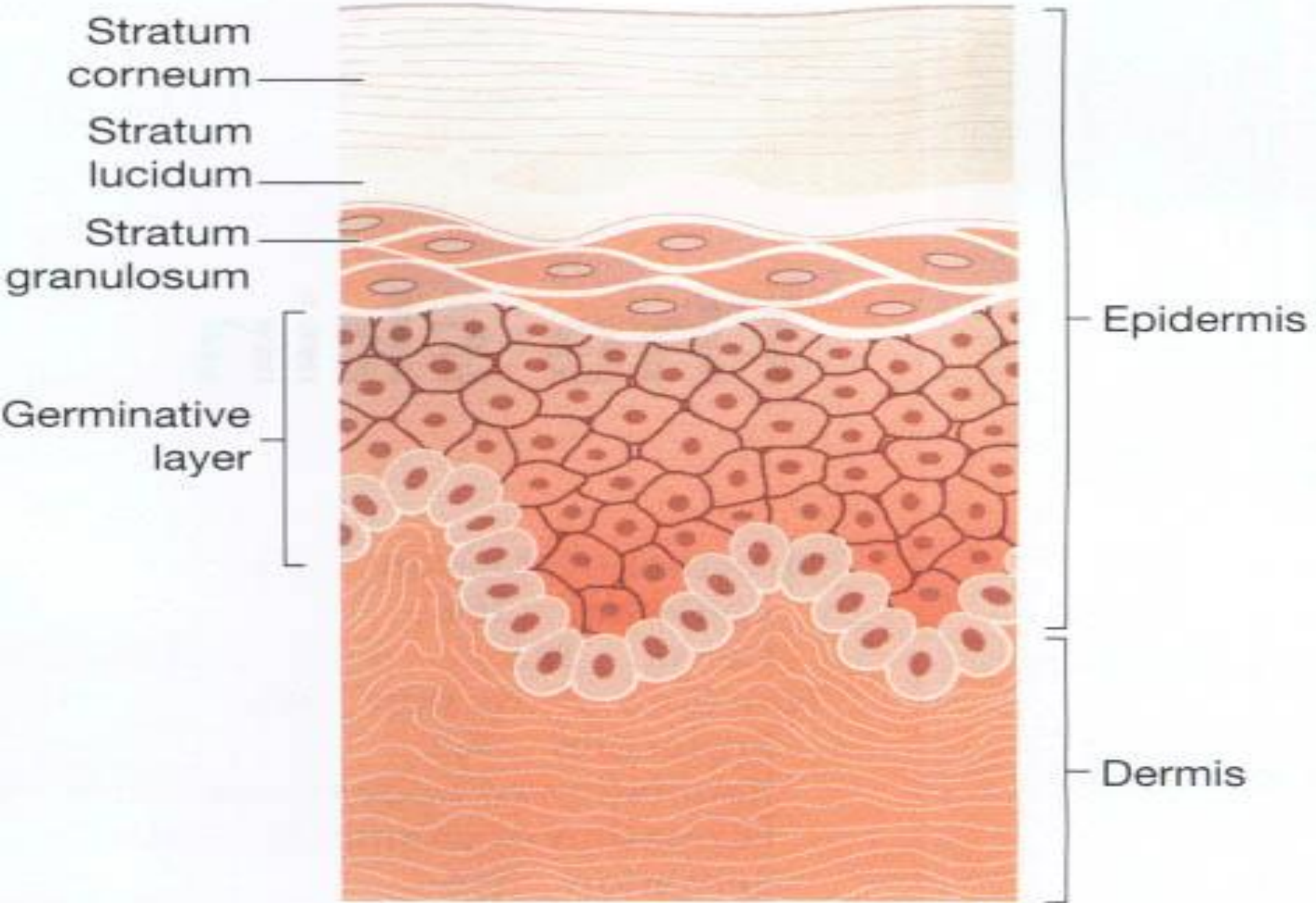
A) Epidermis

- Most superficial layer of the skin
- Composed of **stratified keratinised squamous epithelium** which varies in thickness in different parts of the body.
 - Thickest on the palms of the hands & soles of the feet.

- No blood vessels or nerve endings in the epidermis, but its deeper layers are bathed in interstitial fluid from the dermis, which provides oxygen and nutrients, and is drained away as lymph.
- Has several layers (strata) of cells which extend from the deepest germinative layer to the surface **stratum corneum** (a thick horny layer).
- Cells on the surface are flat, thin, non-nucleated, dead cells, or **squames**, in which the cytoplasm has been replaced by the fibrous protein keratin.
 - Constantly being rubbed off & replaced by cells which originated in the germinative layer & have undergone gradual change as they progressed towards the surface.

- Complete replacement of the epidermis takes about 40 days.
- Maintenance of healthy epidermis depends upon 3 processes being synchronised:
 - desquamation (shedding) of the keratinised cells from the surface
 - effective keratinisation of the cells approaching the surface
 - continual cell division in the deeper layers with newly formed cells being pushed to the surface.
- Hairs, secretions from sebaceous glands & ducts of sweat glands pass through the epidermis to reach the surface.

- Surface of epidermis is ridged by projections of cells in the dermis; **papillae**.
- Downward projections of the germinative layer between the papillae aid nutrition of epidermal cells & stabilise the 2 layers, preventing damage due to shearing forces.
- Blisters develop when acute trauma causes separation of the dermis & epidermis & serous fluid collects between the 2 layers.



Main layers of the epidermis

- **Colour of the skin is affected by 3 main factors.**
 - a) Melanin**, a dark pigment derived from the amino acid tyrosine & secreted by melanocytes in the deep germinative layer, is absorbed by surrounding epithelial cells.
 - No. of melanocytes is fairly constant; colour differences depend on the amount of melanin secreted. It protects the skin from the harmful effects of sunlight.
 - Exposure to sunlight promotes synthesis of increased amounts of melanin.
 - b) Level of oxygenation** of Hb & amount of blood circulating in the dermis give the skin its pink colour.
 - c) Bile pigments** in blood & carotenes in subcutaneous fat give the skin a yellowish colour.

B) Dermis

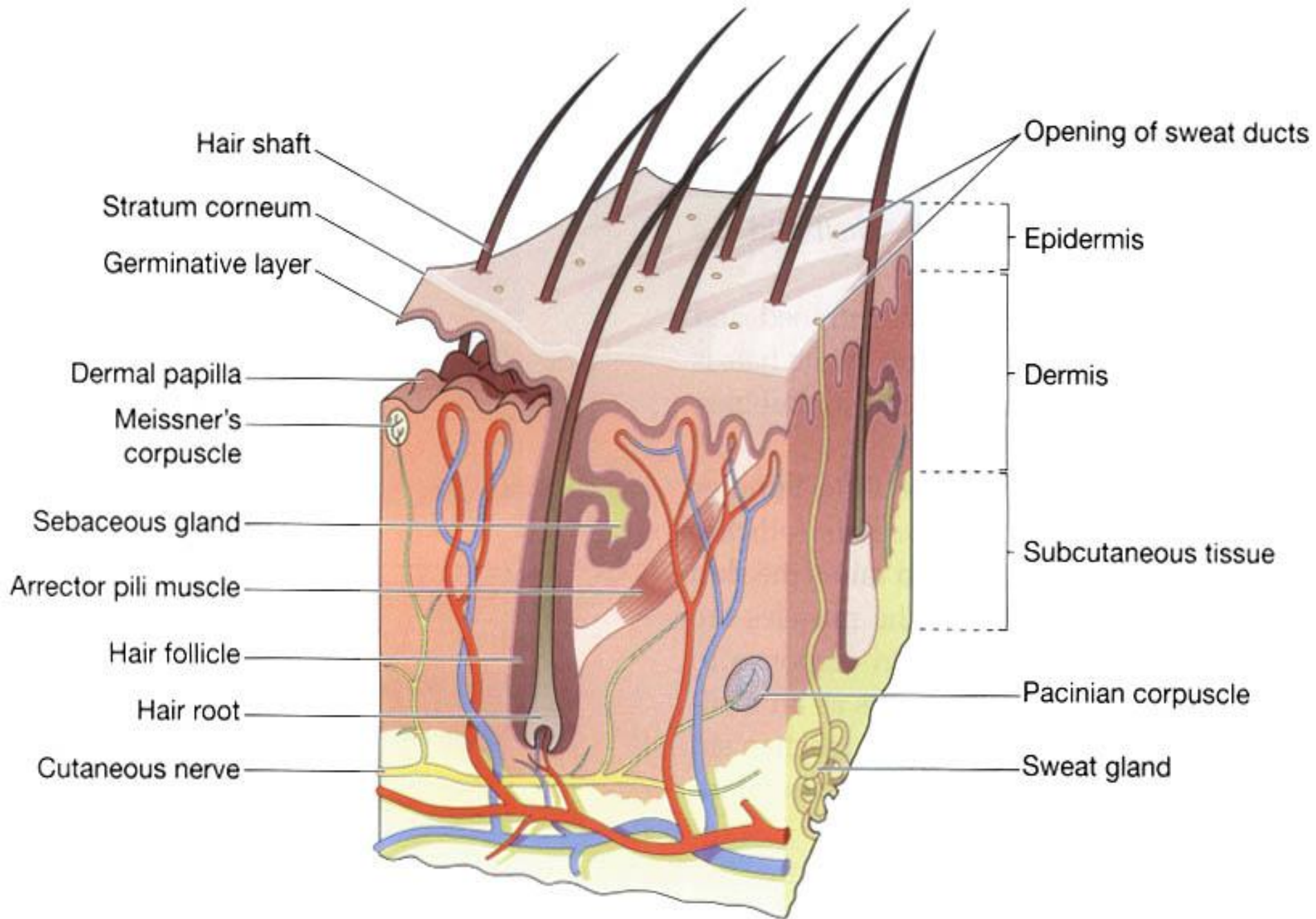
- Tough & elastic.
- Formed from connective tissue
- Matrix contains collagen fibres interlaced with elastic fibres.
- Rupture of elastic fibres occurs when the skin is overstretched, resulting in permanent striae, or stretch marks, that may be found in pregnancy & obesity. Collagen fibres bind water & give the skin its tensile strength, but as this ability declines with age, wrinkles develop.
- Main cells found in the dermis; Fibroblasts, macrophages & mast cells

Two layers of dermis

- Papillary – areolar connective tissue; includes dermal papillae

- Reticular – “reticulum” (network) of collagen and reticular fibers

- Underlying its deepest layer is areolar tissue & varying amounts of adipose tissue (fat).
- Structures in the dermis are:
 - blood vessels
 - lymph vessels
 - Sensory nerve endings
 - sweat glands and their ducts
 - hairs, arrector pili muscles
 - sebaceous glands



Main structures in the dermis

- **Blood vessels.** Arterioles form a fine network with capillary branches supplying sweat glands, sebaceous glands, hair follicles & the dermis.
 - Epidermis has no blood supply; obtains nutrients and oxygen from interstitial fluid derived from blood vessels in the papillae of the dermis.
- **Lymph vessels.** Form a network throughout the dermis.
- **Sensory nerve endings.** Receptors sensitive to touch, change in temperature, pressure & pain are widely distributed in the dermis.

Box 14.1. Sensory receptors in the skin

Sensory receptor

Meissner's corpuscle

Pacinian corpuscle

Free nerve ending

Stimulus

Light pressure

Deep pressure

Pain

- **Sweat glands**
- Found widely distributed throughout the skin & are most numerous in the palms of the hands, soles of the feet, axillae & groins.
- Composed of epithelial cells.
- Their bodies lie coiled in the subcutaneous tissue.
- Some ducts open onto the skin surface at tiny depressions, or pores, & others open into hair follicles.
 - **Glands opening into hair follicles don't become active until puberty.**
 - In the axilla, they secrete an odourless milky fluid which, if decomposed by surface microbes, causes an unpleasant odour.
- Stimulated by sympathetic nerves in response to raised body temperature & fear.

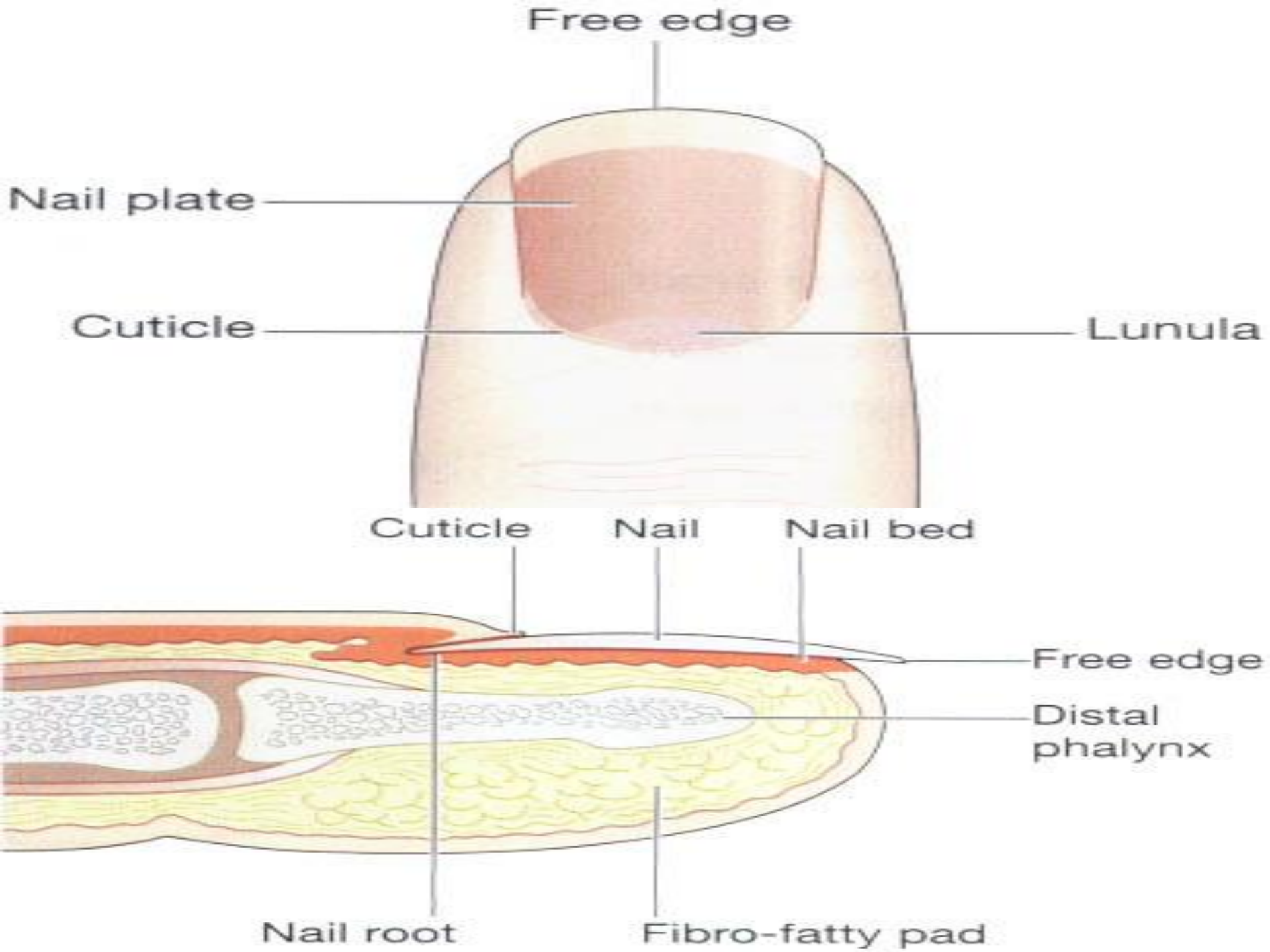
- **Function:** Regulation of body temperature.
 - Evaporation of sweat from body surfaces takes heat from the body
 - Amount of sweat produced is governed by the temperature-regulating centre in the hypothalamus.
- **Hairs**
- Formed by a down-growth of epidermal cells into the dermis or subcutaneous tissue, called **hair follicles**.
- At the base of the follicle is a cluster of cells; **bulb**.
- Formed by multiplication of cells of the bulb & as they are pushed upwards, away from their source of nutrition, the cells die & become keratinised.

- Part of the hair above the skin is the **shaft** & the remainder, **the root**.
- Hair colour is genetically determined & depends on the amount of melanin present.
 - White hair is the result of the replacement of melanin by tiny air bubbles.
- **The arrector pili.**
- Little bundles of smooth muscle fibres attached to the hair follicles.
- Contraction makes the hair stand erect & raises the skin around the hair, causing '**goose flesh**'.
 - The muscles are stimulated by sympathetic nerve fibres in response to fear & cold.
- Erect hairs trap air, which acts as an insulating layer; an efficient warming mechanism especially when accompanied by shivering.

- **The sebaceous glands.**
- Consist of secretory epithelial cells derived from the same tissue as the hair follicles.
- Secrete an oily substance, **sebum**, into the hair follicles.
- Present in the skin of all parts of the body except the palms of the hands & the soles of the feet.
- Most numerous in the skin of the scalp, face, axillae & groins.
- In regions of transition from one type of superficial epithelium to another, e.g, lips, eyelids, nipple, labia minora & glans penis, they are independent of hair follicles, secreting sebum directly on to the surface.

- Sebum
 - keeps the hair soft & pliable
 - gives the hair a shiny appearance.
 - provides some waterproofing on the skin
 - acts as a bactericidal & fungicidal agent on the skin, preventing the successful invasion of microbes.
 - prevents drying & cracking of skin, especially on exposure to heat & sunshine.
- Activity of these glands increases at puberty & is less at the extremes of age, rendering infants & elderly prone to the effects of excessive moisture, e.g. nappy rash in infants.

- **Nails**
- Derived from the same cells as epidermis & hair.
- Consist of a hard, horny keratin plate.
- Protect the tips of the fingers & toes.
- It's root is embedded in the skin, is covered by the cuticle & forms the hemispherical pale area called the **lunula**.
- **Nail plate**: exposed part that has grown out from the germinative zone of the epidermis called the **nail bed**.
- Finger nails grow more quickly than toe nails & growth is quicker when the environmental temperature is high.



Functions of the skin

1. Protection

- Forms a relatively waterproof layer that protects the deeper & more delicate structures. It acts as a barrier against:
 - invasion by microbes
 - chemicals
 - physical agents, e.g. mild trauma, ultraviolet light
 - dehydration.
- Epidermis contains **Langerhans cells** which phagocytose intruding antigens & travel to lymphoid tissue, where they present antigen to T-lymphocytes, thus stimulating an immune response.

The pigment melanin affords some protection against harmful ultraviolet rays in sunlight

Due to the presence of the sensory nerve endings in the skin the body reacts by reflex action to unpleasant or painful stimuli, protecting it from further injury.

2. Regulation of body temperature

- **Heat production**
- Principal organs involved are:.
- **Muscles.** Contraction of skeletal muscles produces a large amount of heat & the more strenuous the muscular exercise the greater the heat produced. Shivering involves muscle contraction & produces heat when there is the risk of the body temperature falling below normal.
- **Liver;** very chemically active & heat is produced as a by-product. Metabolic rate and heat production are increased after eating.

- **Digestive organs;** produce heat during peristalsis & by the chemical reactions involved in digestion.
- **Heat loss** through the skin is affected by the
 - difference between body & environmental temperatures,
 - amount of the body surface exposed to the air
 - type of clothes worn.
- Air is a poor conductor of heat and when layers of air are trapped in clothing & between the skin & clothing they act as effective insulators against excessive heat loss.
- Control is achieved mainly by thermoreceptors in the hypothalamus.

- **Mechanisms of heat loss.**
- In evaporation, the body is cooled when heat is used to convert the water in sweat to water vapour.
- In radiation, exposed parts of the body radiate heat away from the body.
- In conduction, clothes and other objects in contact with the skin take up heat.
- In convection, air passing over the exposed parts of the body is heated and rises, cool air replaces it and convection currents are set up. Heat is also lost from the clothes by convection.

Control of body temperature

a) Nervous control.

_By temperature regulating centre in the hypothalamus; responsive to the temperature of circulating blood.

- **Vasomotor centre** in the medulla oblongata controls the diameter of the small arteries and arterioles; thus the amount of blood which circulates in the capillaries in the dermis.
- Nerve impulses sent to skeletal muscles stimulate shivering

b) Activity of the sweat glands. When the temperature of the body is increased by 0.25 to 0.5°C the sweat glands are stimulated to secrete sweat, which is conveyed to the surface of the body by ducts.

- c) Effects of vasodilatation.** As heat production increases, the arterioles become dilated & more blood pours into the capillary network in the skin.
- amount of sweat produced is increased
 - temperature of the skin is raised and there is an increase in the amount of heat lost by radiation, conduction and convection.
- If the environmental temperature is low, vasoconstriction is stimulated by sympathetic nerves; decreasing blood flow near the body surface, conserving heat.

d) Fever. Caused by release of chemicals (pyrogens) from damaged tissue and the cells involved in inflammation.

- Pyrogens act on the hypothalamus, which releases prostaglandins that reset the hypothalamic thermostat to a higher temperature.
 - The body responds by activating heat-promoting mechanisms until the new higher temperature is reached.
 - When the thermostat is reset to the normal level, heat-loss mechanisms are activated. There is profuse sweating and vasodilatation accompanied by warm, pink (flushed) skin until body temperature falls to the normal range again.

- e) Hypothermia.** Present when core temperature, e.g. the rectal temperature, is below 35°C (95°F).
- At a rectal temperature below 32°C (89.6°F), compensatory mechanisms to restore body temperature usually fail, e.g.
 - shivering is replaced by muscle rigidity and cramps
 - vasoconstriction fails to occur
 - there is lowered blood pressure, pulse and respiration rates.
 - Mental confusion and disorientation occur. Death usually occurs when the temperature falls below 25°C (77°F).

3. Formation of vitamin D

- 7-dehydrocholesterol is a lipid-based substance in the skin and ultraviolet light from the sun converts it to vitamin D.
- This circulates in the blood & is used, with calcium and phosphate, in the formation & maintenance of bone.
- Excess vitamin D is stored in the liver.

4. Cutaneous sensation

- Sensory receptors in the dermis are sensitive to touch, pressure, temperature or pain.
- Stimulation generates nerve impulses in sensory nerves that are transmitted to the cerebral cortex.

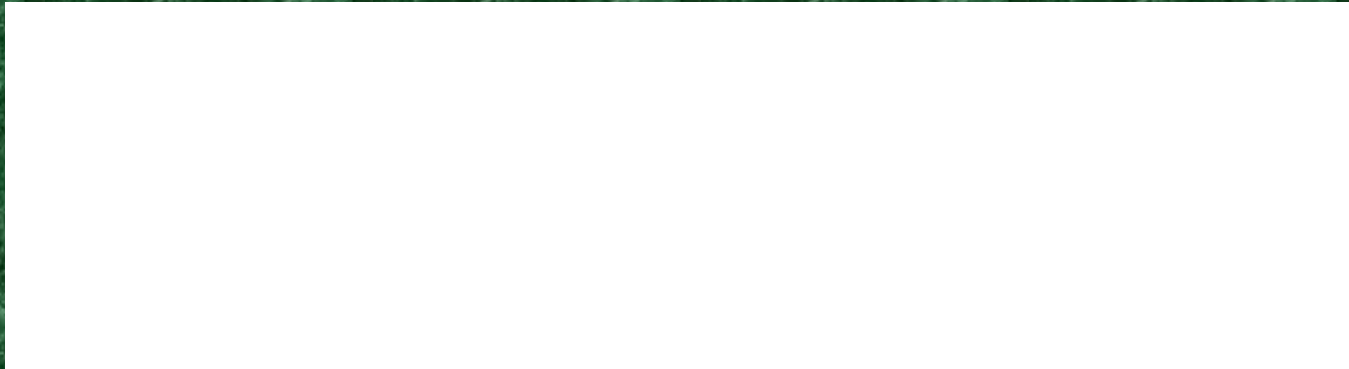
5. Absorption

- Of:
 - some drugs, in transdermal patches, e.g. hormones used as replacement therapy in postmenopausal women, nicotine as an aid to stopping smoking
 - some toxic chemicals, e.g. mercury.

6. Excretion

- Of:
 - sodium chloride in sweat and excess sweating may lead to abnormally low blood sodium levels
 - urea, especially when kidney function is impaired
 - aromatic substances, e.g. garlic and other spices.

THE SKELETON



BONE

- A strong and durable type of connective tissue.
- Consists of:
 - water (25%)
 - organic constituents including osteoid (the carbon containing part of the matrix) and bone cells (25%)
 - inorganic constituents, mainly calcium phosphate (50%).

Functions of bones

1. provide the framework of the body
2. give attachment to muscles and tendons
3. permit movement of the body as a whole and of parts of the body, by forming joints that are moved by muscles
4. form the boundaries of the cranial, thoracic and pelvic cavities, protecting the organs they contain
5. contain red bone marrow in which blood cells develop; haematopoiesis
6. provide a reservoir of minerals, especially calcium phosphate.

Types of bones

- Bones are classified as long, short, irregular, flat and sesamoid
- Long bones consist of a shaft and two extremities. Examples include the femur, tibia and fibula
- Short, irregular, flat and sesamoid bones have no shafts or extremities and are diverse in shape and size e.g short bones-carpals(wrist), irregular bones-vertebrae and some skull bones, flat bones-sternum, ribs and most skull bones, sesamoid bones-patella(knee cap)

TYPES OF BONES

1. Long Bones

- Tubular shell with cavity in the middle.
- Found in: Arms, legs, hands, etc. E.g. humerus & femur
- Has the following layers
 - Periosteal layer for oppositional growth
 - Compact layer for rigidity
 - Cancellous/spongy layer for inner support
 - Marrow support for blood forming cells
- Growth takes place at the epiphyseal disc
- Blood supply is from
 - nutritional arteries,
 - periosteal arteries supplying periosteum,
 - epiphyseal arteries supplying epiphyses and around

2. Short Bones

- No marrow cavity; don't contain epiphysis
- Are cuboidal than tubular in shape
- Found in: Wrist & ankle E.g. carpals and tarsals

3. Flat Bones

- Flat and thin, (protection, broad surface for muscle attachment)
- Found in: Cranium, pectoral & pelvic girdles E.g. parietal, scapula, ilium, sternum

4. Irregular Bones

- Specialized shape & function (support weight, dissipate loads, protect spinal cord)
- Found in: Spinal column E.g. vertebral bodies

5. Sesamoid Bones

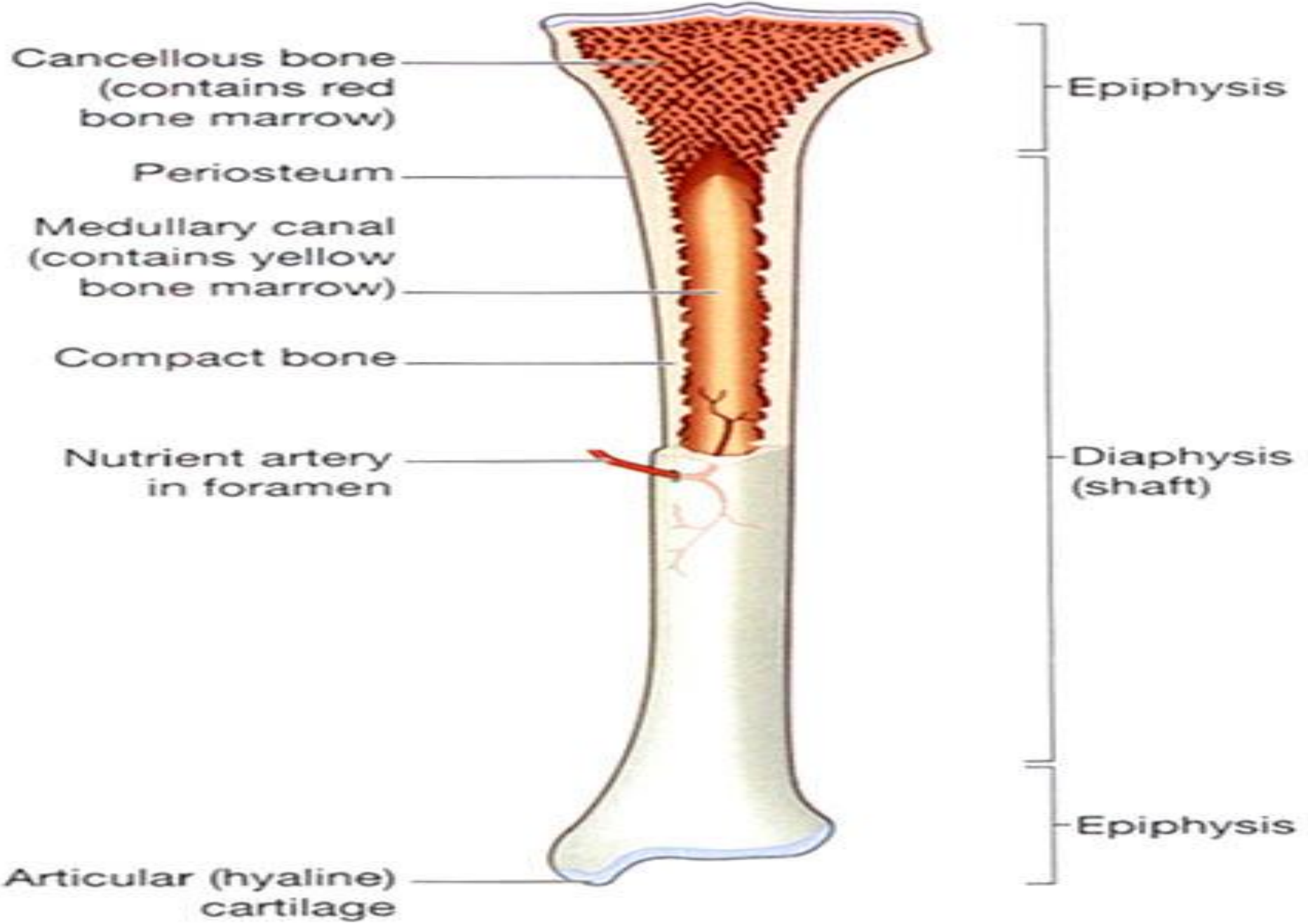
- Small bones embedded within a tendon or joint capsule (alters angle of insertion, reduces friction)
- Found in: Knee, hand, thumb & big toe E.g. patella & Pisiform

BONE STRUCTURE

General structure of a long bone

- Have a diaphysis or shaft & two epiphyses or extremities.
- **Diaphysis**; composed of compact bone with a central medullary canal, containing fatty yellow bone marrow.
- **Epiphyses**; Consist of an outer covering of compact bone with cancellous bone inside.
- Diaphysis & epiphyses are separated by **epiphyseal cartilages**, which ossify when growth is complete.
- Thickening of a bone occurs by the deposition of new bone tissue under the periosteum.

- Long bones are almost completely by, the periosteum.
- Periosteum:
 - Has an outer layer, **fibrous** & the inner layer, **osteogenic**, containing osteoblasts & osteoclasts which are involved in maintenance & remodelling of bones;
 - gives attachment to muscles & tendons
 - protects bones from injury.
- **Hyaline cartilage** replaces periosteum on the articular surfaces of bones forming synovial joints.



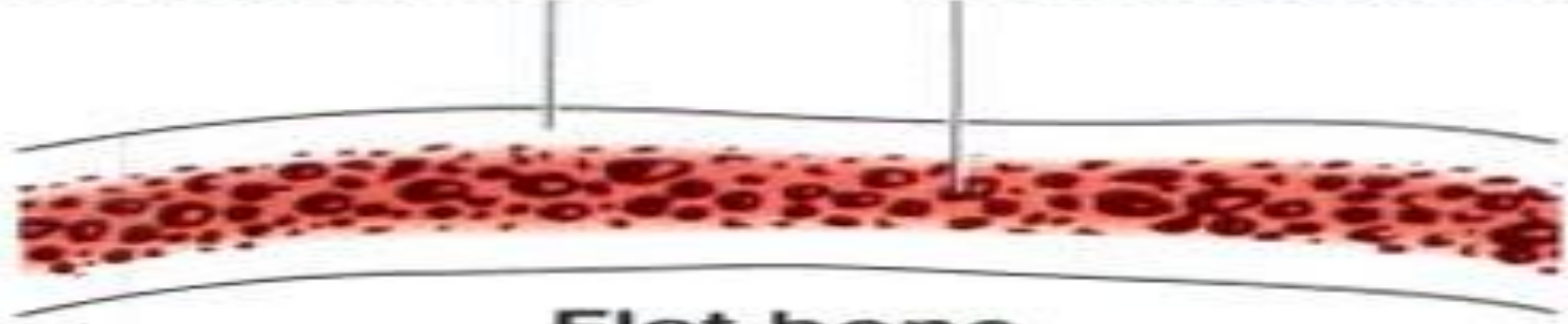
Structure of a mature long bone

Structure of short, irregular, flat & sesamoid bones

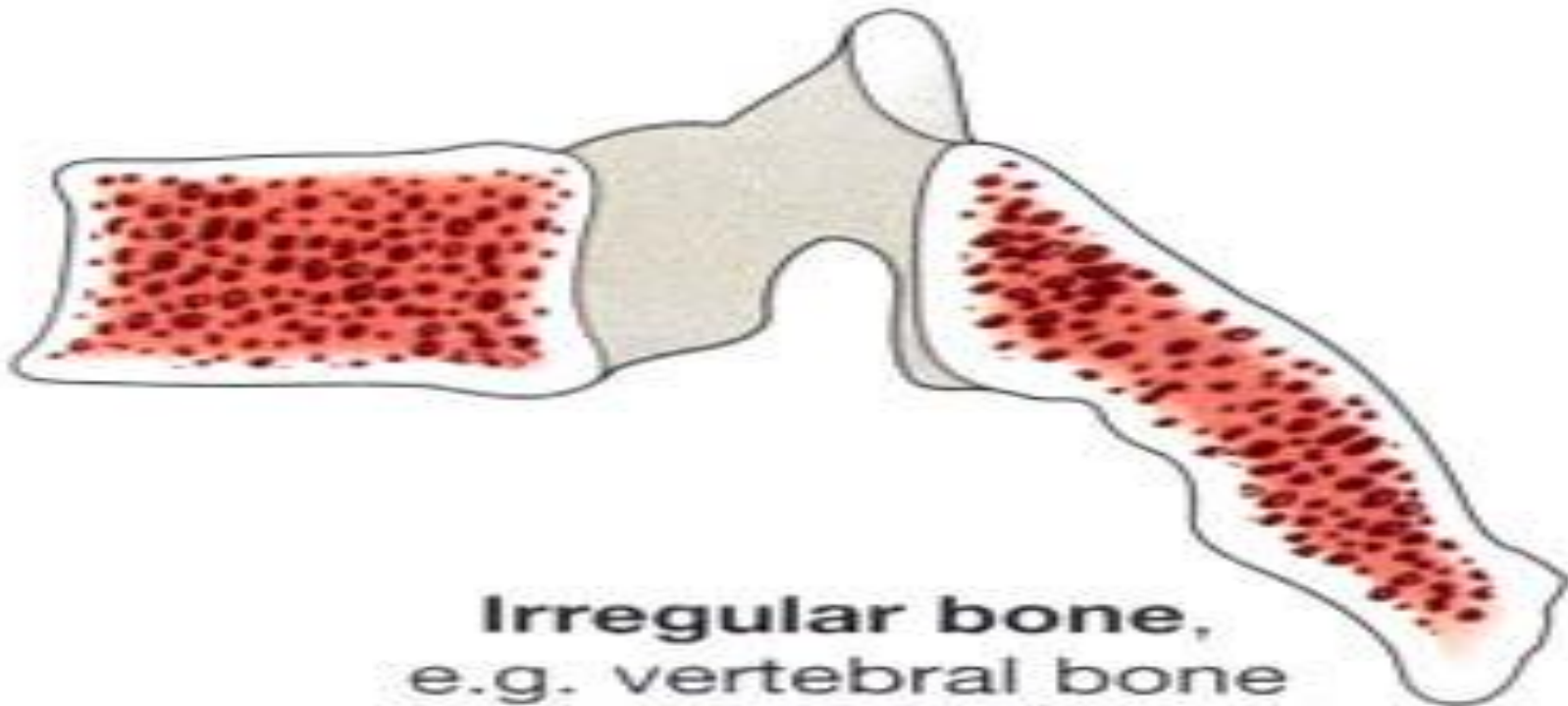
- Relatively **thin outer layer of compact** bone with **cancellous** bone inside containing red bone marrow.
- Enclosed by periosteum except the inner layer of the cranial bones where it is replaced by dura mater.

Compact bone

Cancellous bone



Flat bone,
e.g. skull



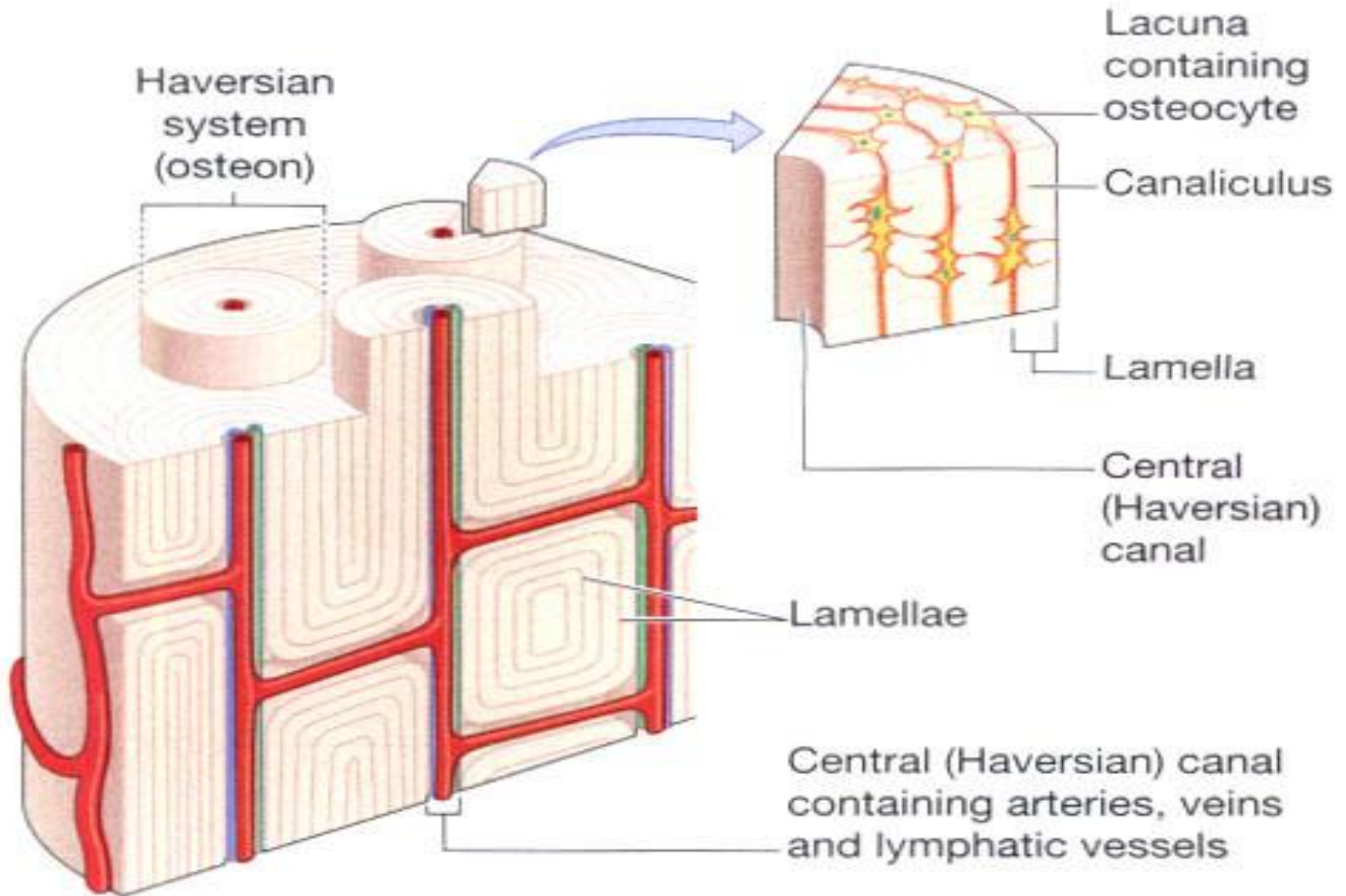
Irregular bone,
e.g. vertebral bone

Flat & irregular bones

Microscopic structure of bone

a) Compact (cortical) bone

- Large numbers of Haversian systems or osteons.
- Consist of a central Haversian canal, containing blood & lymph vessels & nerves, surrounded by concentric rings or plates of bone (lamellae).
 - Between these are **lacunae**, tiny spaces, containing tissue fluid & spider-shaped osteocytes.
- **Canaliculi** link the lacunae with each other and with the central Haversian canal.
- Tissue fluid nourishes the bone cells.
- Areas between Haversian systems contain **interstitial lamellae**, remains of older systems partially broken down during remodelling or growth of bone.
- The 'tubular' arrangement of lamellae gives bone greater strength than a solid structure of the same size.



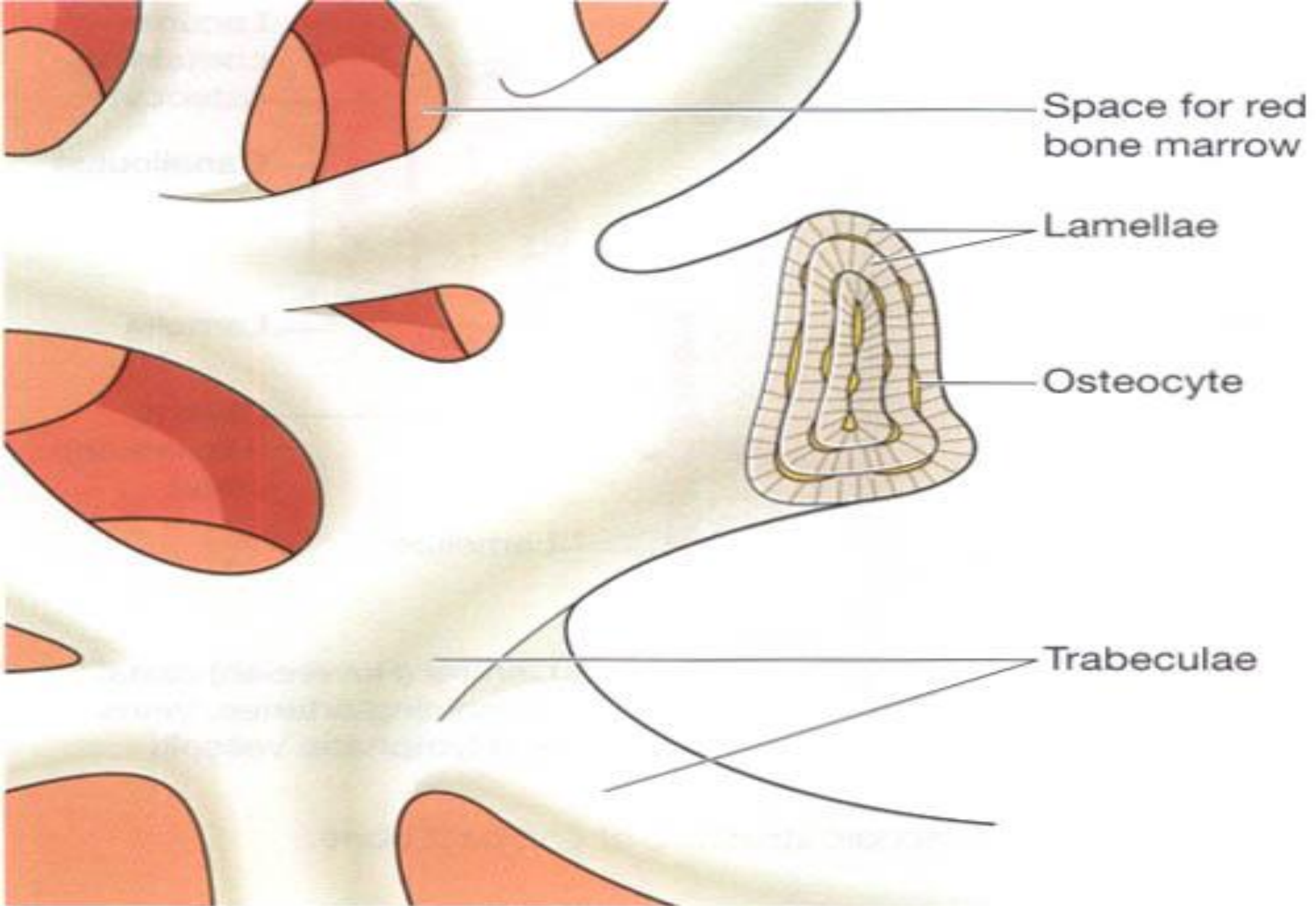
Microscopic structure of compact bone¹⁰⁶⁹

b) Cancellous (trabecular, spongy) bone

- Has a framework formed from trabeculae which consist of a few lamellae & osteocytes interconnected by canaliculi.
- Spaces between the trabeculae contain red bone marrow that nourishes the osteocytes.

Bone cells

- **Osteoblasts:** cells responsible for bone formation (later mature into osteocytes).
- Osteoblasts & chondrocytes (cartilage-forming cells) develop from the same parent fibrous tissue cells.
- Differentiation into osteogenic cells, rather than chondroblasts, depends upon an adequate oxygen supply.



Microscopic structure of cancellous bone

- **Osteoblasts**
- Bone-forming cells that secrete collagen & other constituents of bone tissue.
- Present:
 - in the deeper layers of periosteum
 - in the centres of of immature bone
 - at the ends of the diaphysis adjacent to the epiphyseal cartilages of long bones
 - at the site of a fracture.
- **Osteocytes**
- As bone develops, osteoblasts become trapped and remain isolated in lacunae. They stop forming new bone at this stage and are called **osteocytes**.
- Osteocytes are nourished by tissue fluid in the canaliculi that radiate from the Haversian canals.

- **Osteoclasts**
- **Function:** resorption of bone to maintain the optimum shape.
- Takes place at bone surfaces:
 - under the periosteum, to maintain the shape of bones during growth and to remove excess callus formed during healing of fractures
 - round the walls of the medullary canal during growth and to canalise callus during healing.
- A fine balance of osteoblast & osteoclast activity maintains normal bone structure and functions.

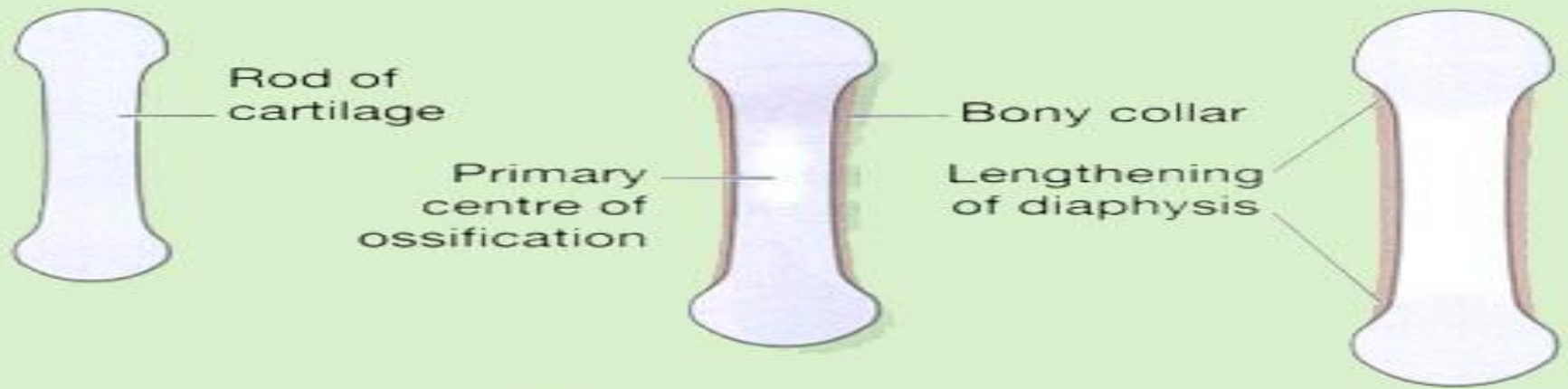
Development of bone tissue (osteogenesis or ossification)

- Begins before birth & is not complete until about the 21st year of life.
- Long, short & irregular bones develop from rods of cartilage, **cartilage models**.
- **Flat bones** develop from **membrane models** and **sesamoid bones** from **tendon models**.
- Bone development consists of 2 processes:
 - secretion by osteoblasts of osteoid, i.e. collagen fibres in a mucopolysaccharide matrix which gradually replaces the original cartilage and membrane models
 - calcification of osteoid immediately after its deposition.

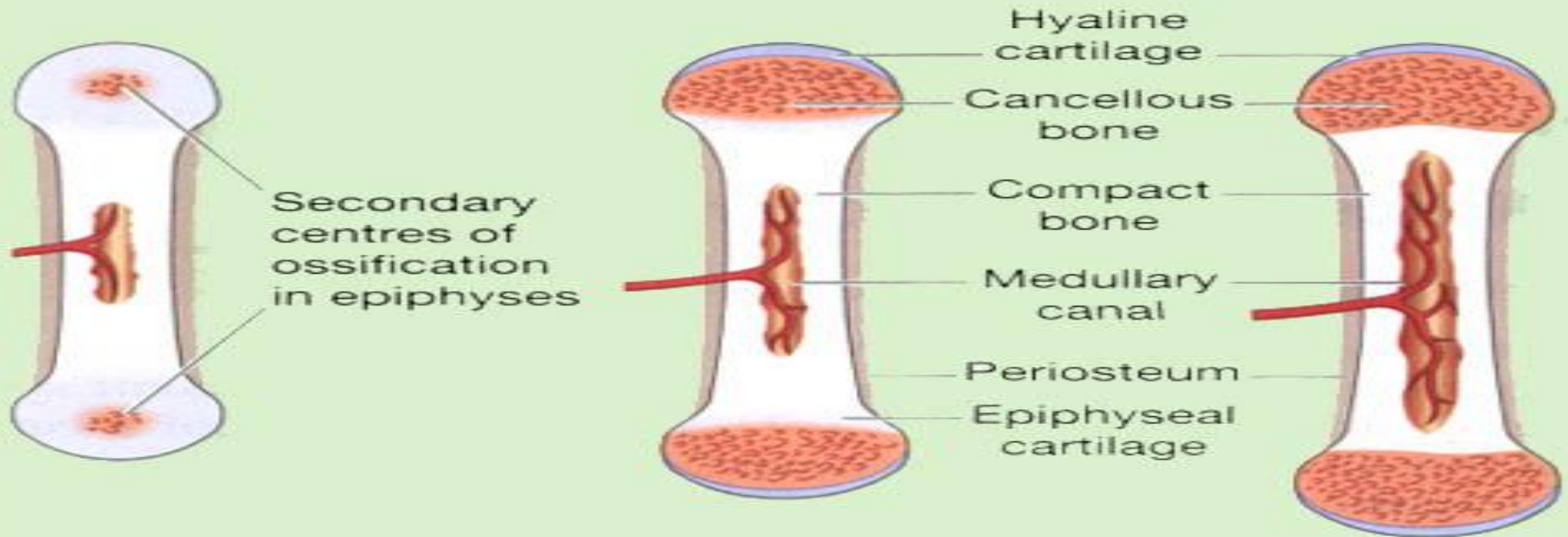
- 2 types of arrangement of collagen in osteoid.
- 1. Woven (non-lamellar) bone.** Collagen fibres are deposited in irregular bundles, then ossified.
 - Occurs during ossification of bones that originate as membrane models, e.g. skull bones.
 - In adults it is also present in bone tumours & healing fractures.
- 2. Lamellar bone.** Collagen fibres are deposited as in woven bone, organised into characteristic lamellae found in compact and cancellous bone then ossified.
 - Occurs when cartilage models are replaced by bone and in healing of fractures.

Development of long bones

- Ossification begins in small areas of osteogenic cells, or centres of ossification in the cartilage model.
 - This is accompanied by development of a bone collar at about 8 weeks of gestation.
- Later blood supply develops & bone tissue replaces cartilage as osteoblasts secrete osteoid components in the shaft.
- Bone lengthens as ossification continues & spreads to the epiphyses.
- Around birth, secondary centres of ossification develop in the epiphyses & the medullary canal forms when osteoclasts break down the central bone tissue in the middle of the shaft.
- After birth, the bone grows in length by ossification of the diaphyseal surface of the epiphyseal cartilages and growth is complete when the cartilages become completely ossified.



Fetal development



Birth

Childhood and adolescence

Adult

Stages in long bone development

Hormonal regulation of bone growth

1. Growth hormone & thyroid hormones, are especially important during infancy & childhood.
2. Testosterone & oestrogens influence the physical changes that occur at puberty.
3. Calcitonin & PTH; homeostasis of blood & bone calcium levels required for bone development.

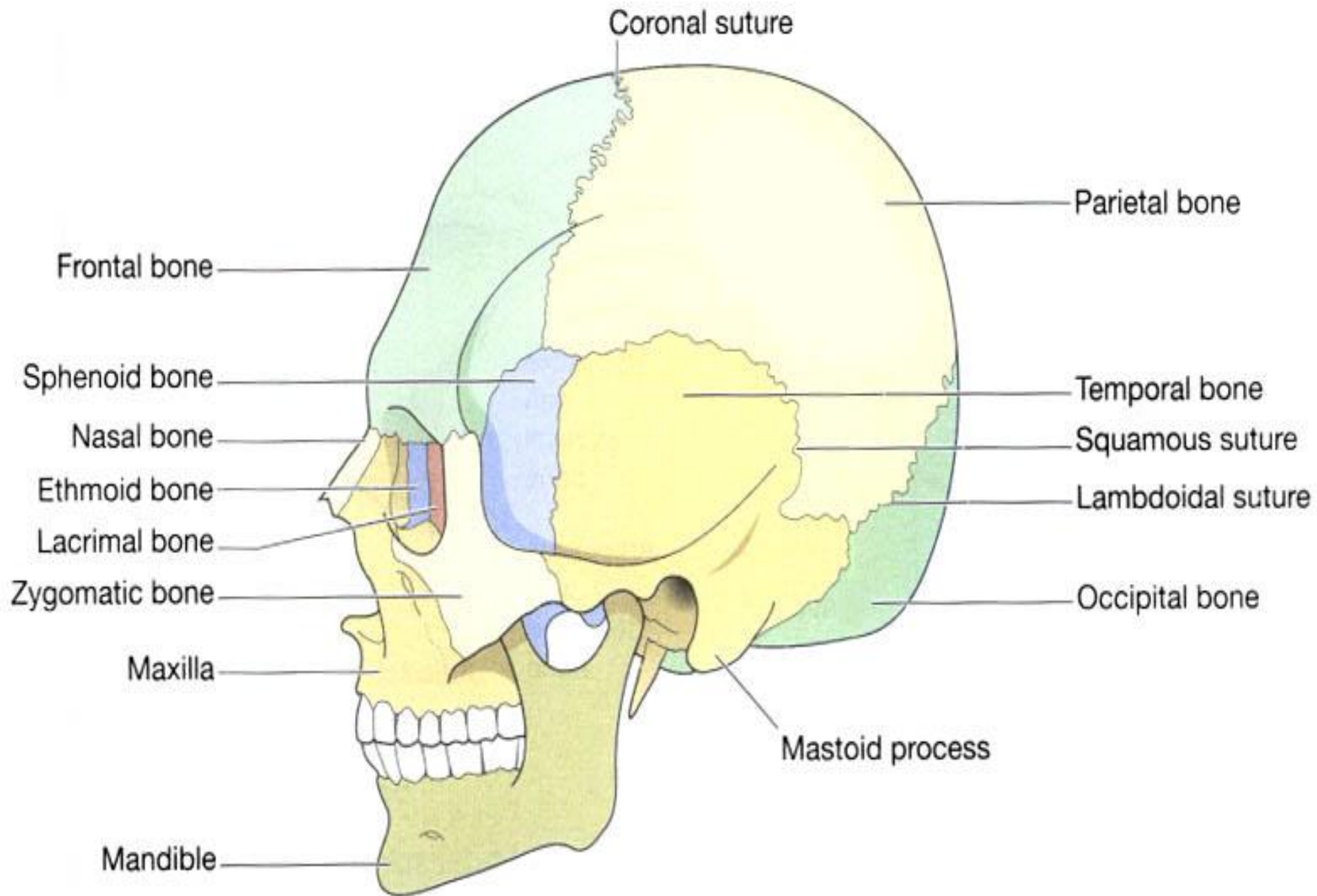
AXIAL SKELETON

- Skull, vertebral column, ribs & sternum.

a) Skull

- Rests on the upper end of the vertebral column
- Its bony structure is divided into 2 parts: cranium & face.
- **Cranium**
- Formed by a number of flat & irregular bones that provide a bony protection for the brain.
- Has a **base** upon which the brain rests & a **vault** that surrounds & covers it.
- Periosteum inside the skull bones consists of the **outer layer of dura mater**. In the mature skull the joints (sutures) between the bones are immovable (**fibrous**).

- Bones have numerous perforations through which nerves, blood & lymph vessels pass.
- Bones of the cranium:
 - 1 frontal bone
 - 2 parietal bones
 - 2 temporal bones
 - 1 occipital bone
 - 1 sphenoid bone
 - 1 ethmoid bone



Bones of the skull and sutures

i) Frontal bone

- Bone of the forehead.
- Forms part of the orbital cavities & supraorbital margins.
- Originates in 2 parts joined in the midline by frontal suture

ii) Parietal bones

- Form sides & roof of skull.
- Articulate with each other at the sagittal suture, with the frontal bone at the coronal suture, with the occipital bone at the lambdoidal suture and with the temporal bones at the squamous sutures.
- Inner surface is concave & is grooved by the brain & blood vessels

iii) Temporal bones

- Lie one on each side of the head & form immovable joints with the parietal, occipital, sphenoid & zygomatic bones.

iv) Occipital bone

- Forms the back of the head & part of the base of the skull.
- Has immovable joints with the parietal, temporal & sphenoid bones.
- Occiput has 2 articular condyles that form hinge joints with the first bone of the vertebral column, **the atlas**.
- Between the condyles there is the **foramen magnum** through which the spinal cord passes into the cranial cavity.

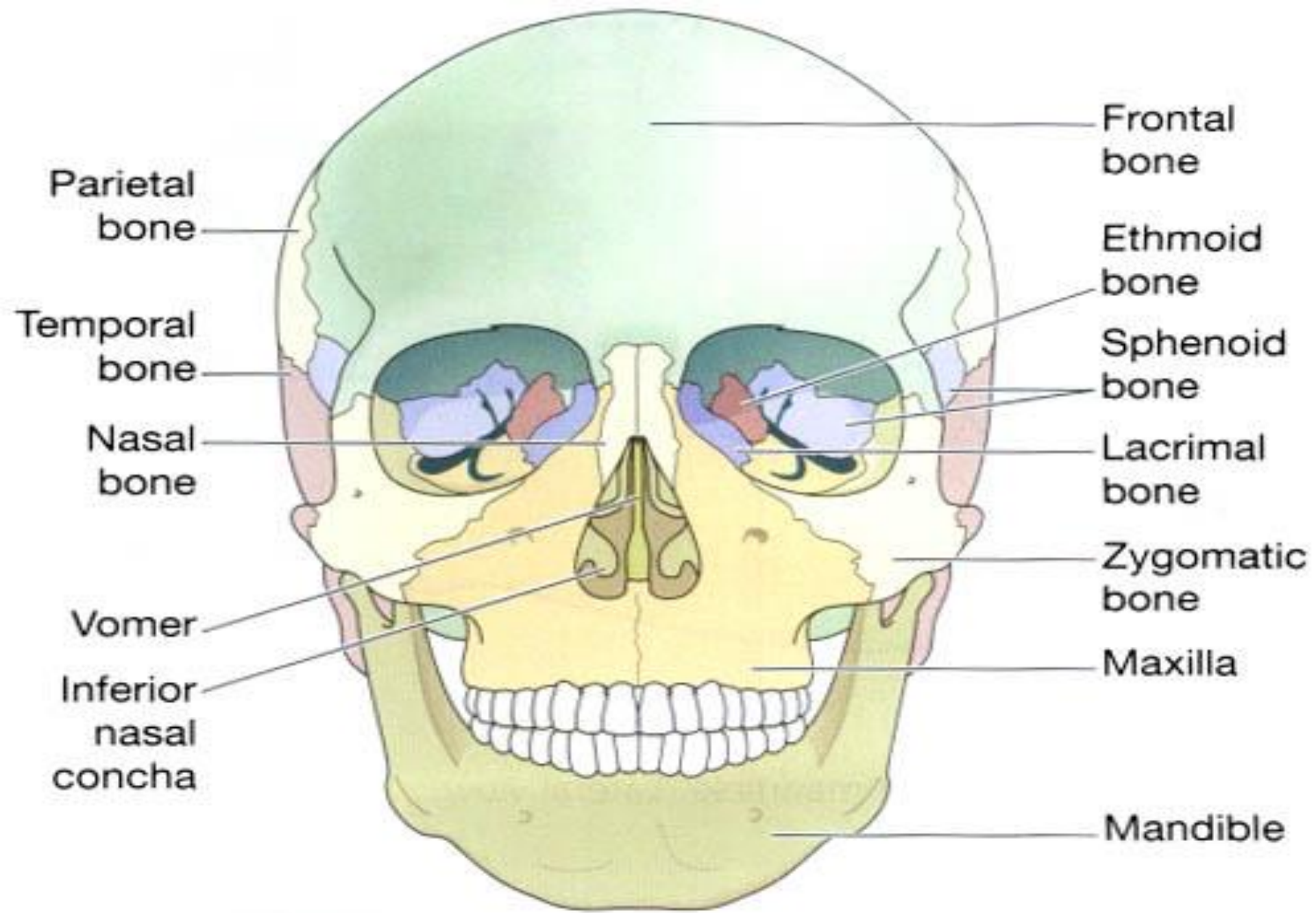
v) Sphenoid bone

- Occupies middle portion of the base of skull & it articulates with the **occipital**, temporal, parietal & frontal bones.
- Superior surface in the middle of the bone is **hypophyseal fossa (sella turcica)**; pituitary gland rests.

vi) Ethmoid bone

- Occupies the anterior part of the base of the skull & helps to form the orbital cavity, the nasal septum & the lateral walls of the nasal cavity.
- On each side are 2 projections into the nasal cavity, the **upper & middle conchae** or turbinated processes.
- Horizontal flattened part, the **cribriform plate**, forms the roof of the nasal cavity & has numerous small foramina through which nerve fibres of the olfactory nerve pass upwards from the nasal cavity to the brain.

- **Face**
- 13 bones in addition to the frontal bone:
 - 2 zygomatic or cheek bones
 - 1 maxilla (originated as 2)
 - 2 nasal bones
 - 2 lacrimal bones
 - 1 vomer
 - 2 palatine bones
 - 2 inferior conchae
 - 1 mandible (originated as 2).



Parietal bone

Temporal bone

Nasal bone

Vomer

Inferior nasal concha

Frontal bone

Ethmoid bone

Sphenoid bone

Lacrimal bone

Zygomatic bone

Maxilla

Mandible

Bones of the face

i) Zygomatic/cheek bones

- Form the prominences of the cheeks & part of the floor & lateral walls of the orbital cavities.

ii) Maxilla/upper jaw bone

- Originates as 2 bones; fusion takes place before birth.
- Forms upper jaw, anterior part of the roof of the mouth, lateral walls of the nasal cavity & part of the floor of the orbital cavities.
- Alveolar ridge/process, projects downwards & carries the upper teeth. On each side is the maxillary sinus, lined with ciliated mucous membrane & with openings into the nasal cavity.

iii) Nasal bones

- 2 small flat bones which form the greater part of the lateral & superior surfaces of the bridge of the nose.

iv) Lacrimal bones

- 2 small bones; posterior & lateral to the nasal bones & form part of the medial walls of the orbital cavities. Each is pierced by a foramen for the passage of the nasolacrimal duct which carries the tears from the medial canthus of the eye to the nasal cavity.

v) Vomer

- Thin flat bone which extends upwards from the middle of the hard palate to form the main part of the nasal septum.
- Superiorly; articulates with the perpendicular plate of the ethmoid bone.

vi) Palatine bones

- 2 L-shaped bones.
- Horizontal parts unite to form the **posterior part of the hard palate**
- Perpendicular parts project upwards to form **part of the lateral walls of the nasal cavity**. At their upper extremities they form part of the orbital cavities.

vii) Inferior conchae

- Each concha is a scroll-shaped bone which forms part of the lateral wall of the nasal cavity & projects into it below the middle concha. Superior & middle conchae are parts of the ethmoid bone.

viii) Mandible

- Only movable bone of the skull.
- Originates as 2 parts which unite at the midline. Each half consists of 2 main parts:
 - a curved body with the **alveolar ridge** containing the lower teeth
 - a **ramus** which projects upwards almost at right angles to the posterior end of the body. At the upper end the ramus divides into the **condylar process** which articulates with the temporal bone to form the temporomandibular joint and the **coronoid process** that gives attachment to muscles and ligaments. The point where the ramus joins the body is the **angle of the jaw**.

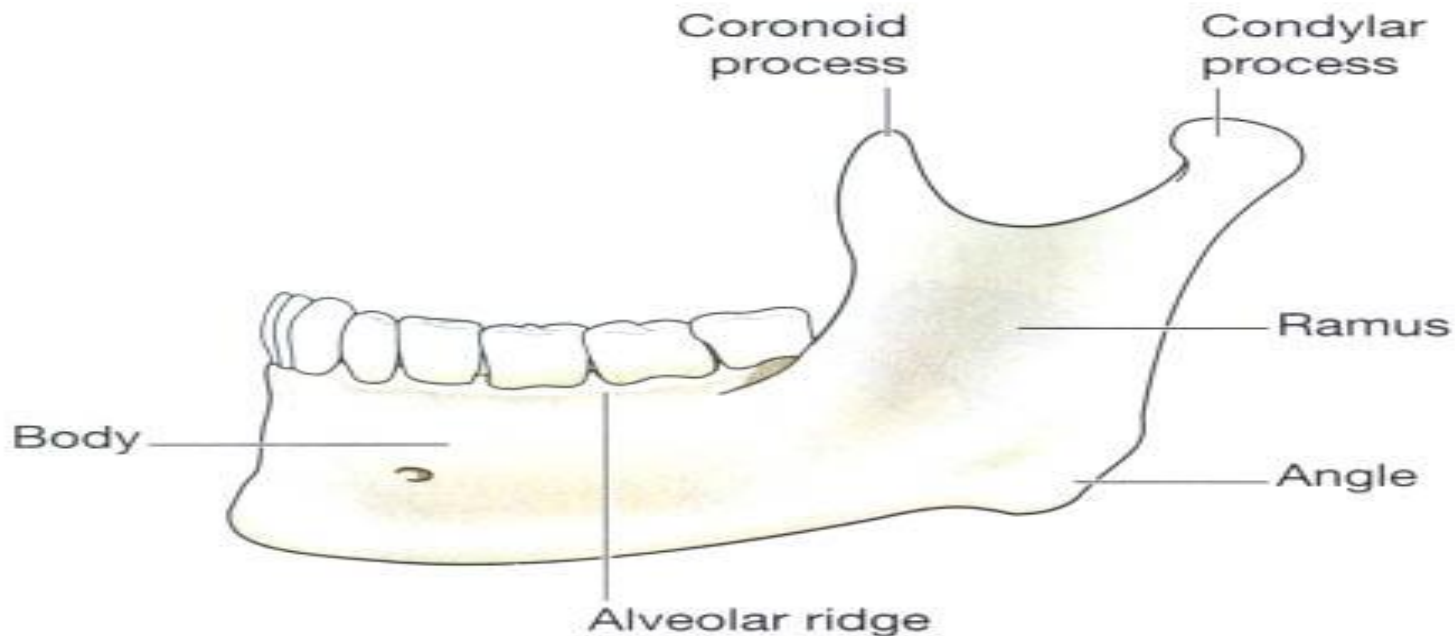
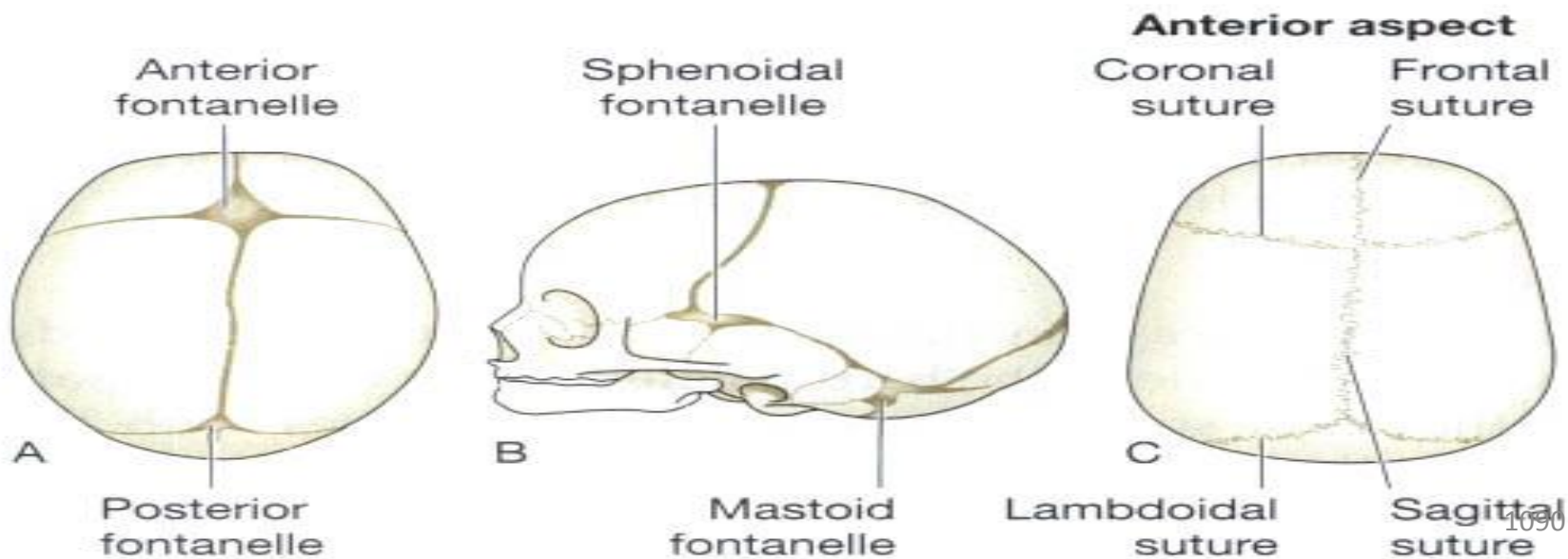


Figure 16.14 The left mandible. Lateral view.



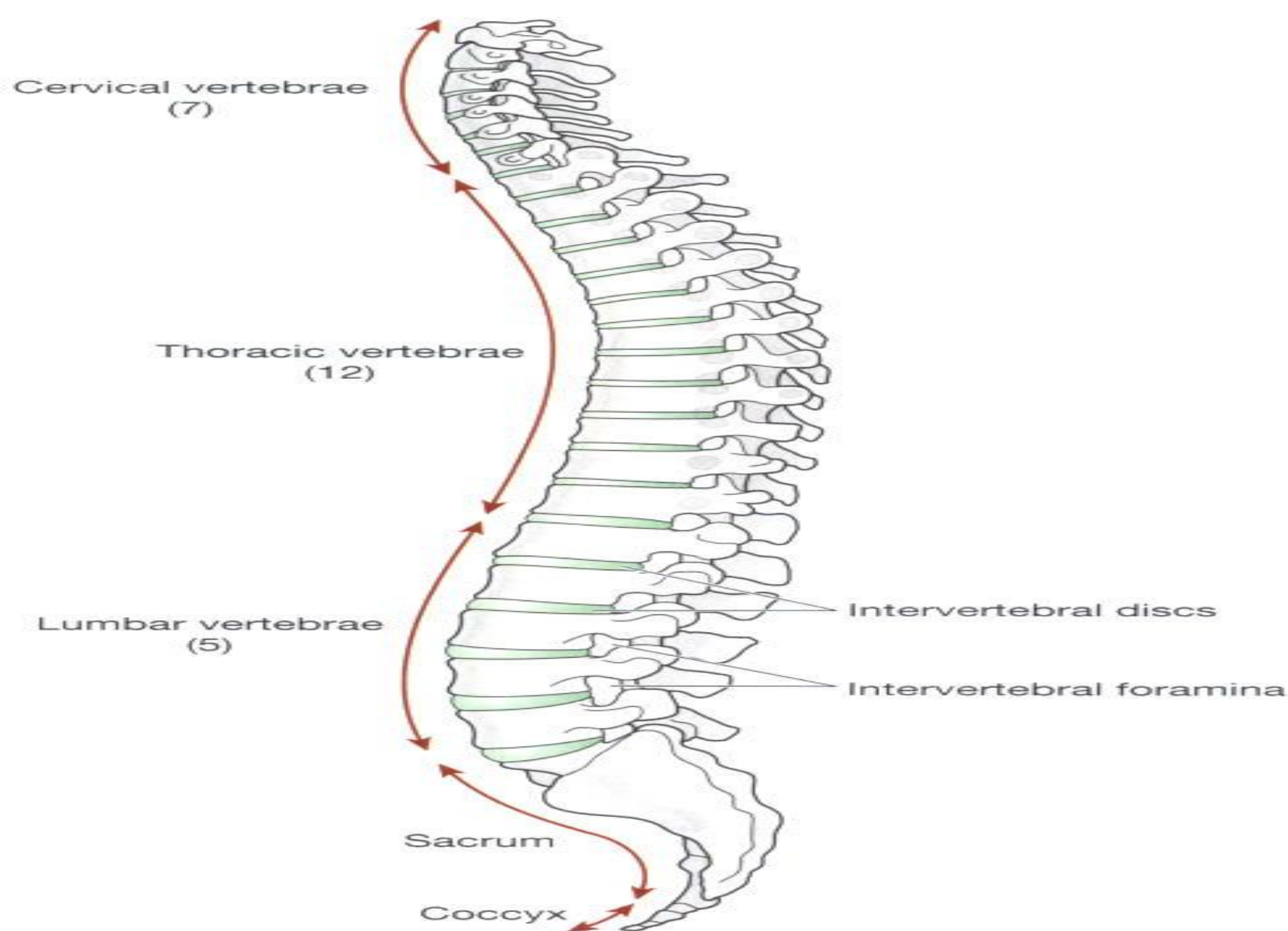
- **Sinuses**
- Containing air are present in sphenoid, ethmoid, maxillary & frontal bones.
- All communicate with the nasal cavity & are lined with ciliated mucous membrane.
- **Functions :**
 - to give resonance to the voice
 - to lighten the bones of the face & cranium, making it easier for the head to balance on top of the vertebral column.

Fontanelles of the skull

- Where 3 or more bones meet; **fontanelles**.
- 2 largest
 - anterior fontanelle, not fully ossified until the child is 12 to 18 months old,
 - posterior fontanelle, usually ossified 2 to 3 months after birth.
- Skull bones don't fuse before birth to allow for moulding of the baby's head during its passage through the birth canal.

b) Vertebral column

- 24 separate movable, irregular bones, sacrum (five fused bones) & coccyx (four fused bones).
- 24 separate bones, in 3 groups:
 - 7 cervical,
 - 12 thoracic
 - 5 lumbar.

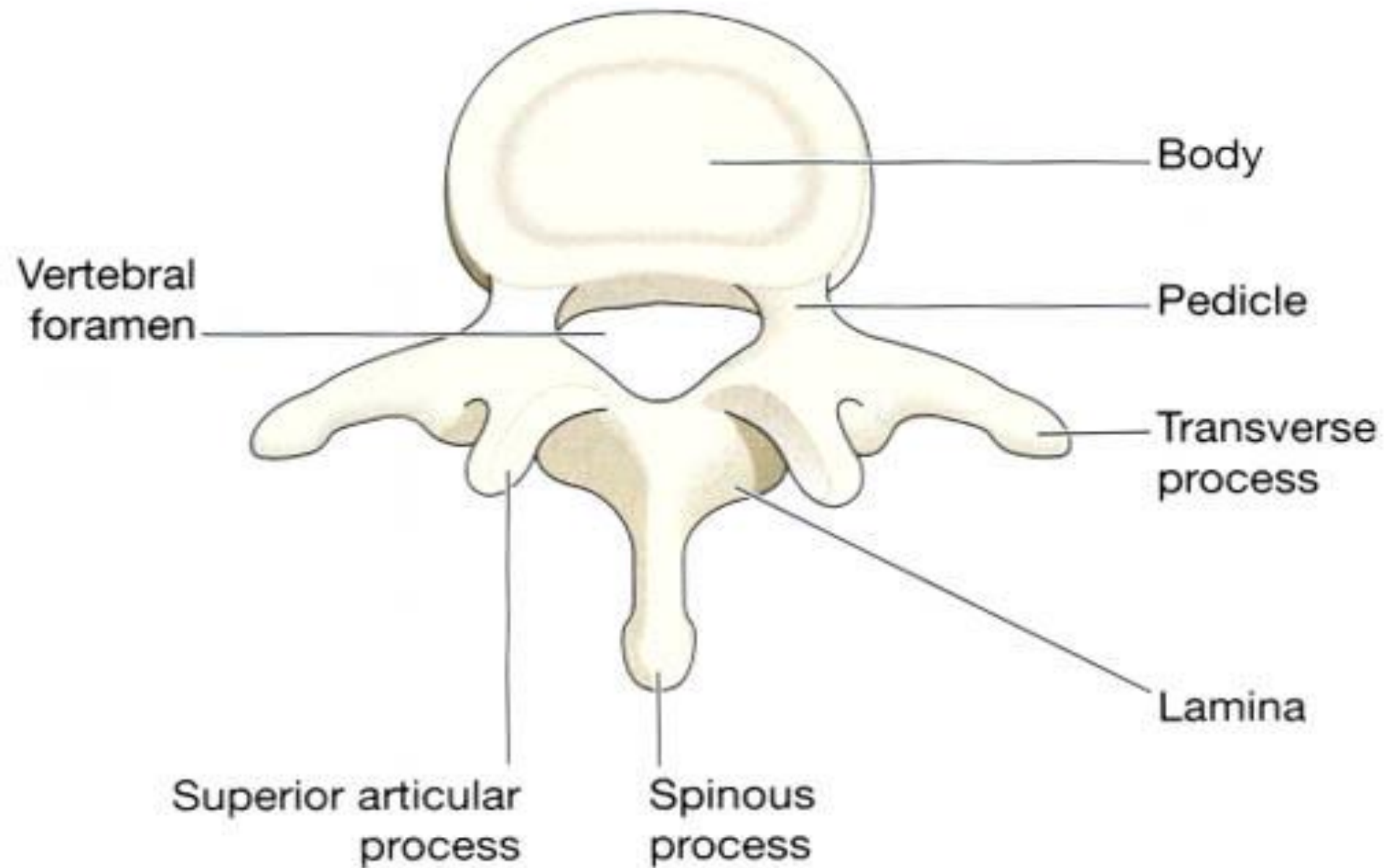


Vertebral column

Characteristics of a typical vertebra

- a) **The body.** situated anteriorly & size varies with the site; Smallest in the cervical region & become larger towards the lumbar region.
- b) **The vertebral (neural) arch** encloses a large vertebral foramen.
- Ring of bone consists of 2 pedicles that project backwards from the body & 2 laminae.
 - Where the **pedicles** & **laminae** unite, **transverse processes** project laterally
 - Where the 2 **laminae** meet in the midline posteriorly they form a **spinous process**.
- **Neural arch** has 4 articular surfaces:
 - 2 articulate with the vertebra above & 2 with the one below.
- **Vertebral foramina** form the vertebral (neural) canal that contains the spinal cord.

Anterior aspect



A typical vertebra

Special features of vertebrae in different parts of the vertebral column

1. Cervical vertebrae

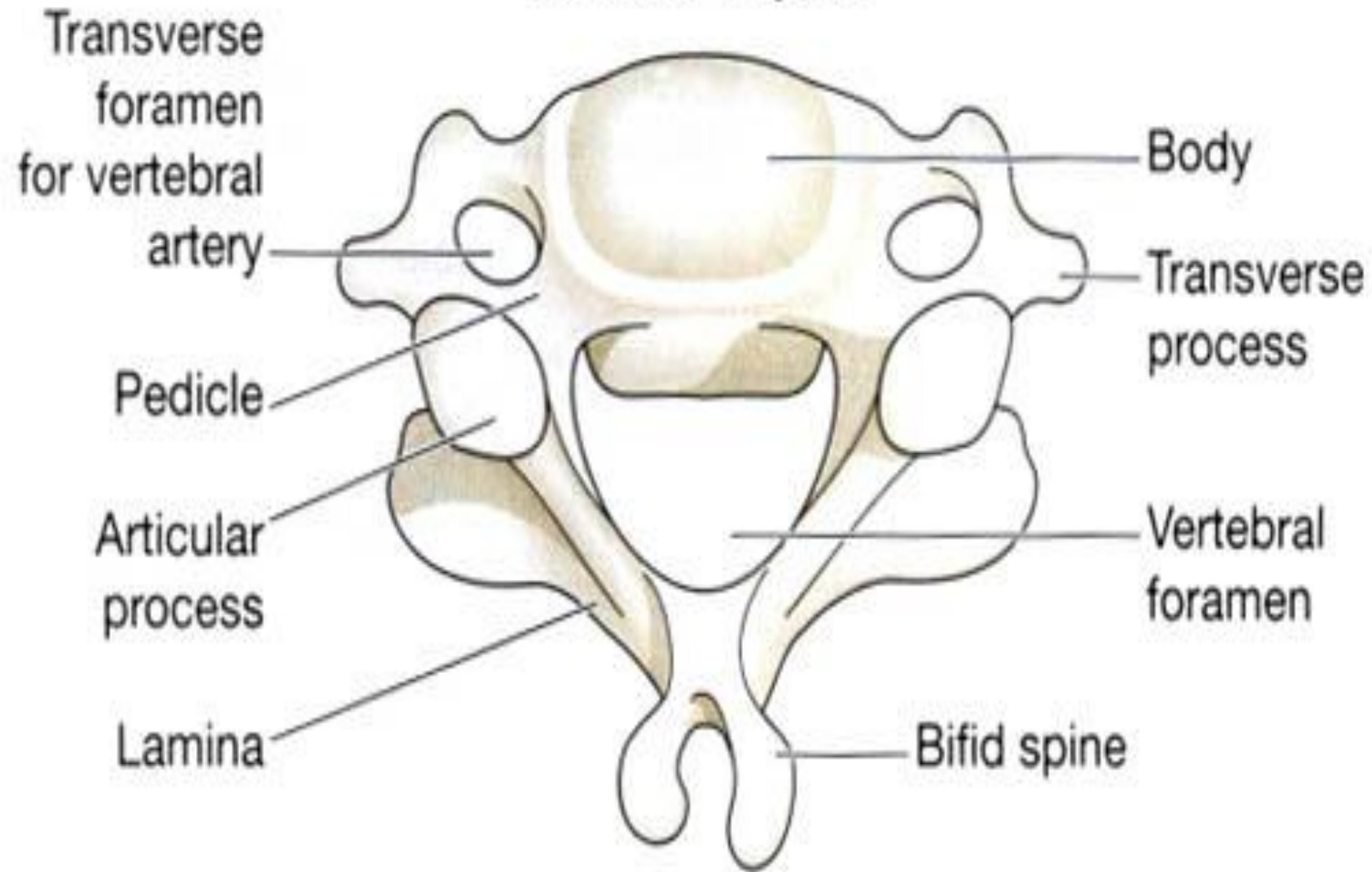
- Transverse processes have a foramen through which a vertebral artery passes upwards to the brain.
- First 2 cervical vertebrae are atypical.
- **The atlas; 1st cervical vertebra & consists simply of a ring of bone with 2 short transverse processes.**
 - Anterior part of the large vertebral foramen is occupied by the odontoid process of the axis, which is held in position by a transverse ligament.
 - Thus, the **odontoid process** forms the body of the atlas.

- Posterior part is the true vertebral foramen & is occupied by the spinal cord.
- Superior surface; has 2 articular facets which form joints with the condyles of the occipital bone of the skull. Nodding movement of the head takes place at these joints.

- **The axis; 2nd cervical vertebra.**

- Body is small
- Has the upward projecting odontoid process or dens that articulates with the atlas.
- Movement at this joint is turning the head from side to side.

Anterior aspect



Cervical vertebra

2. Thoracic vertebrae: Bodies & transverse processes have facets for articulation with the ribs.

3. Lumbar vertebrae: Have no special features.

4. Sacrum

- 5 rudimentary vertebrae fused to form a triangular or wedge-shaped bone with a concave anterior surface.
- Upper part/base, articulates with the 5th lumbar vertebra.
- On each side it articulates with the ilium to form a **sacroiliac joint**, & at its inferior tip it articulates with the coccyx.
- Anterior edge of the base, the **promontory**, protrudes into the pelvic cavity.
- Vertebral foramina are present, & on each side of the bone there is a series of foramina for the passage of nerves.

5. Coccyx : 4 terminal vertebrae fused to form a very small triangular bone, the broad base of which articulates with the tip of the sacrum.

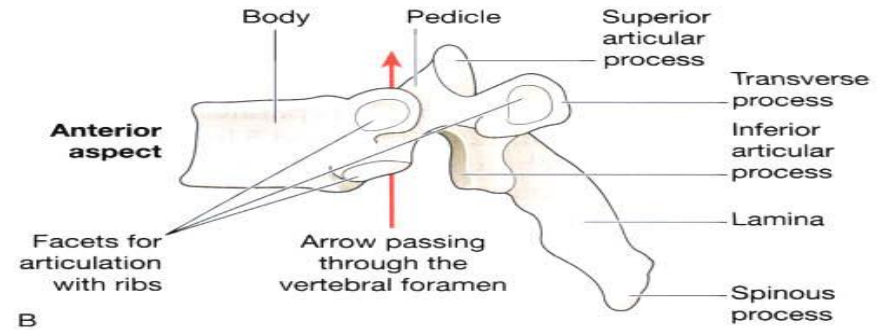
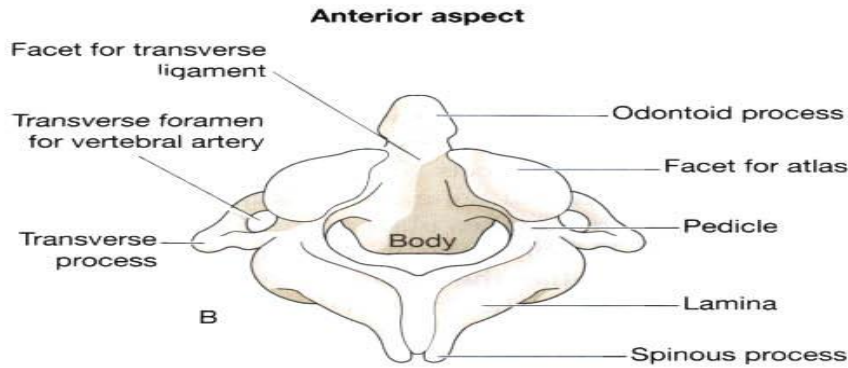
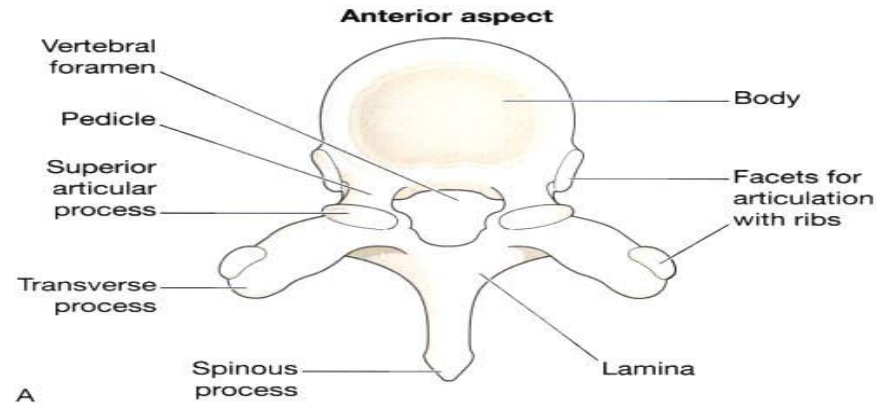
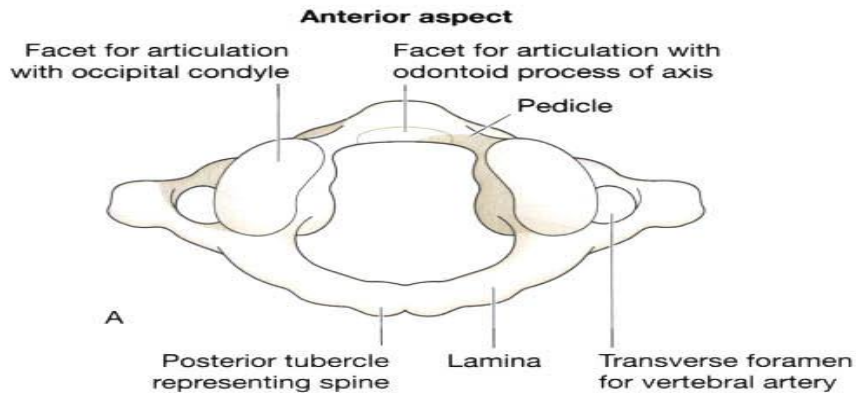


Figure 16.20 A thoracic vertebra: A. Viewed from above. B. Viewed from the side.

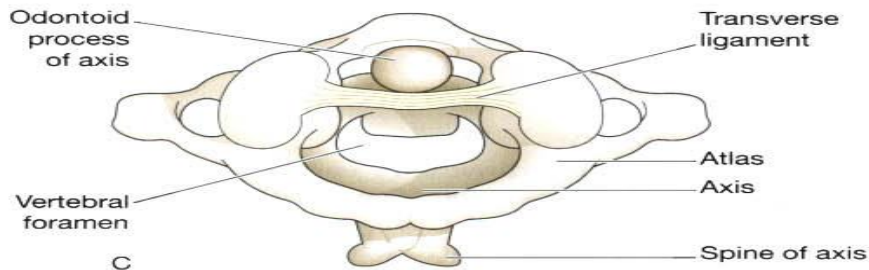


Figure 16.19 The upper cervical vertebrae viewed from above: A. The atlas. B. The axis. C. The atlas and axis in position showing the transverse ligament.

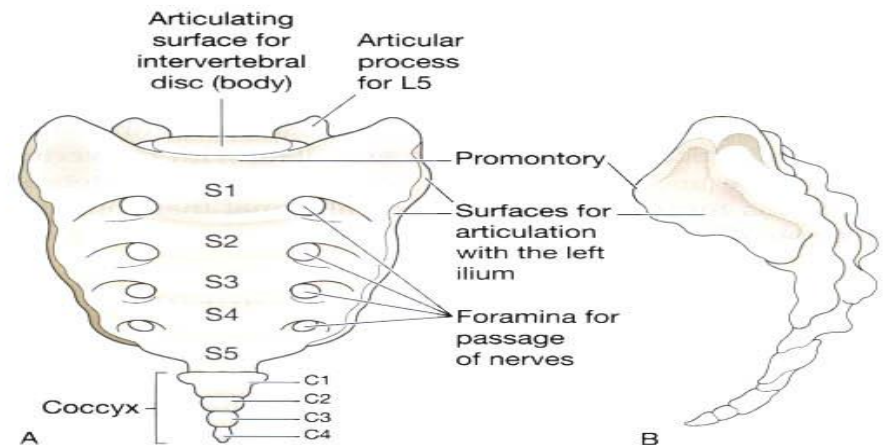


Figure 16.21 The sacrum and coccyx: A. Anterior view. B. Lateral view.

Features of vertebral column

1. Intervertebral discs

- Bodies of adjacent vertebrae are separated by intervertebral discs, consisting of an **outer rim** of **fibrocartilage** (annulus fibrosus) and a **central core** of soft gelatinous material (nucleus pulposus).
- Thinnest in the cervical region & become progressively thicker towards the lumbar region.
- Posterior longitudinal ligament in the vertebral canal helps to keep them in place.
- Have a shock-absorbing function
- Cartilaginous joints they form contribute to the flexibility of the vertebral column as a whole.

2. Intervertebral foramina

- Throughout the length of the column, on each side between every pair of vertebrae, through which the spinal nerves, blood vessels & lymph vessels pass.

3. Ligaments of the vertebral column

- Hold the vertebrae together & help to maintain the intervertebral discs in position.
- **Transverse ligament** maintains the odontoid process of the axis in the correct position in relation to the atlas
- **Anterior longitudinal ligament** extends the whole length of the column & lies in front of the vertebral bodies.

- **Posterior longitudinal ligament** lies inside the vertebral canal & extends the whole length of the vertebral column in close contact with the posterior surface of the bodies of the bones. **Ligamenta flava** connect the laminae of adjacent vertebrae.
- **Ligamentum nuchae & supraspinous ligament** connect the spinous processes, extending from the occiput to the sacrum.

4. Curves of the vertebral column

- 4 curves, 2 primary & 2 secondary.
- **Primary curvature:** position shown by the fetus in the uterus; lies curled up so that the head & the knees are more or less touching.

- **Secondary cervical curve;** develops when the child can hold up his head (after about 3 months) & the **secondary lumbar curve** develops when he stands upright (after 12 to 15 months).
- Thoracic & sacral primary curves are retained.

5. Movements of the vertebral column

- Movts. Between individual bones of the vertebral column are very limited.
- Movts. of the column as a whole are quite extensive & include flexion (bending forward), extension (bending backward), lateral flexion (bending to the side) and rotation.

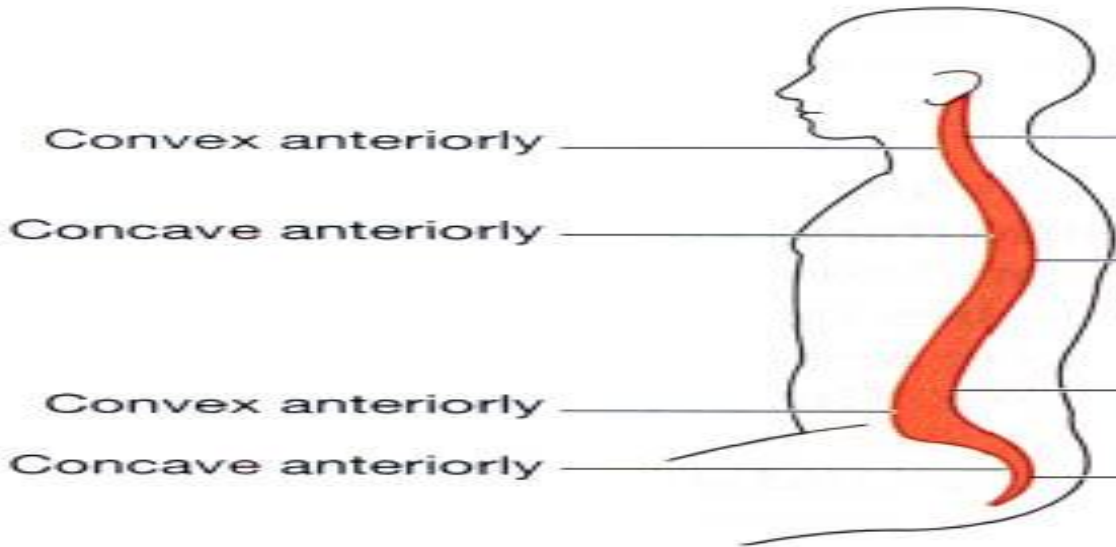


Primary curve



1st secondary curve
(cervical)

Primary curve



Convex anteriorly

Concave anteriorly

Convex anteriorly

Concave anteriorly

1st secondary curve
(cervical)

Primary curve
(thoracic)

2nd secondary curve
(lumbar)

Primary curve
(sacral)

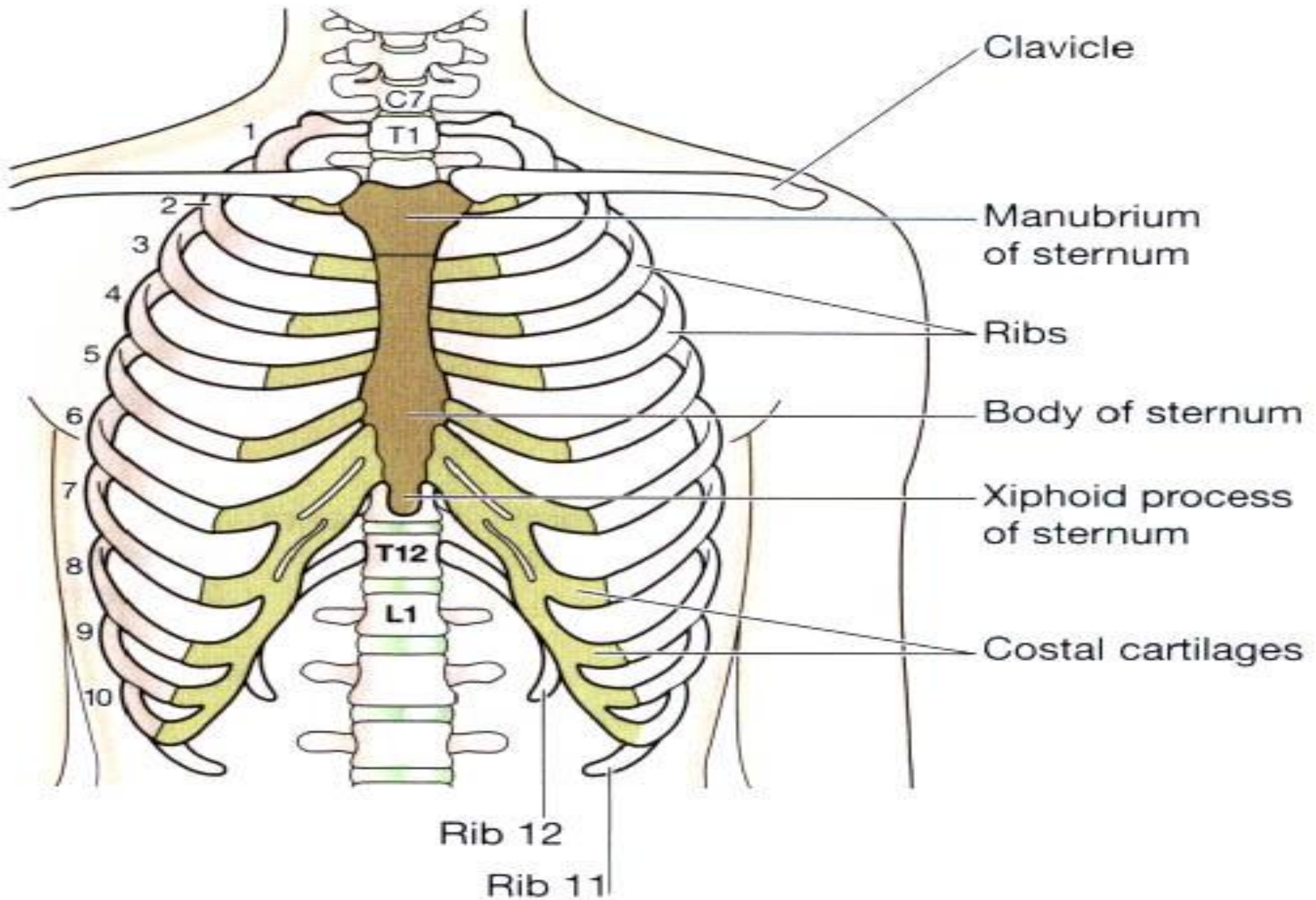
Development of spinal curves

Functions of the vertebral column

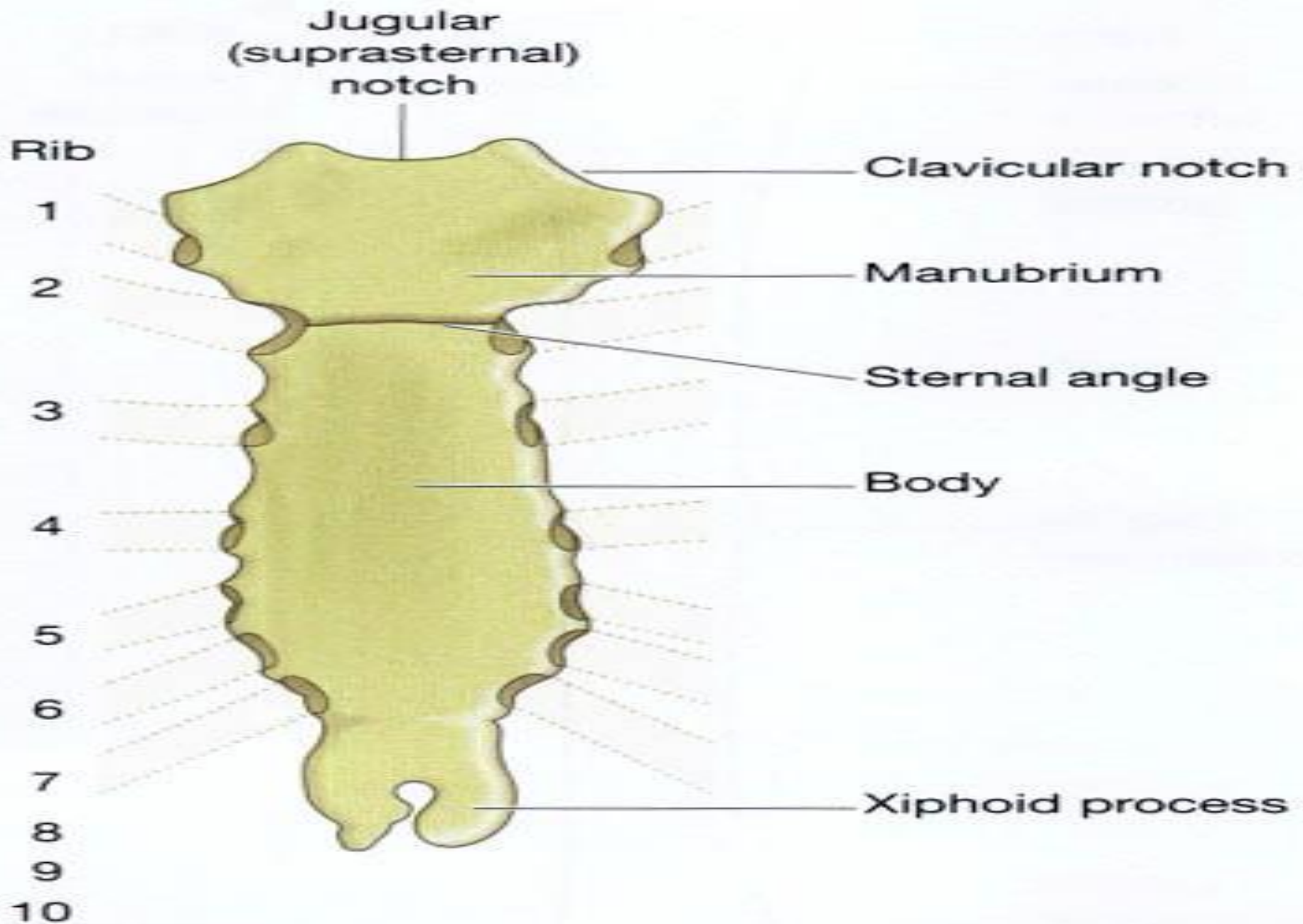
1. Collectively the vertebral foramina form the vertebral canal which provides a strong bony protection for the delicate spinal cord lying within it.
2. Pedicles of adjacent vertebrae form intervertebral foramina, one on each side, providing access to the spinal cord for spinal nerves, blood vessels & lymph vessels.
3. Numerous individual bones enable a certain amount of movement.
4. Supports the skull.
5. Intervertebral discs act as shock absorbers, protecting the brain.
6. Forms the axis of the trunk, giving attachment to the ribs, shoulder girdle and upper limbs, and the pelvic girdle and lower limbs.

THORACIC CAGE

- Bones are:
 - 1 sternum
 - 2 pairs of ribs
 - 12 thoracic vertebrae
- **Sternum or breast bone**
- Flat bone felt just under the skin in the middle of the front of the chest.
- **Manubrium**; uppermost section & articulates with the clavicles at the **sternoclavicular** joints & with the first 2 pairs of ribs.
- **Body/middle** portion gives attachment to the ribs.
- **Xiphoid process**; tip of the bone.
 - Gives attachment to the diaphragm, muscles of the anterior abdominal wall & the linea alba.



Thoracic cage



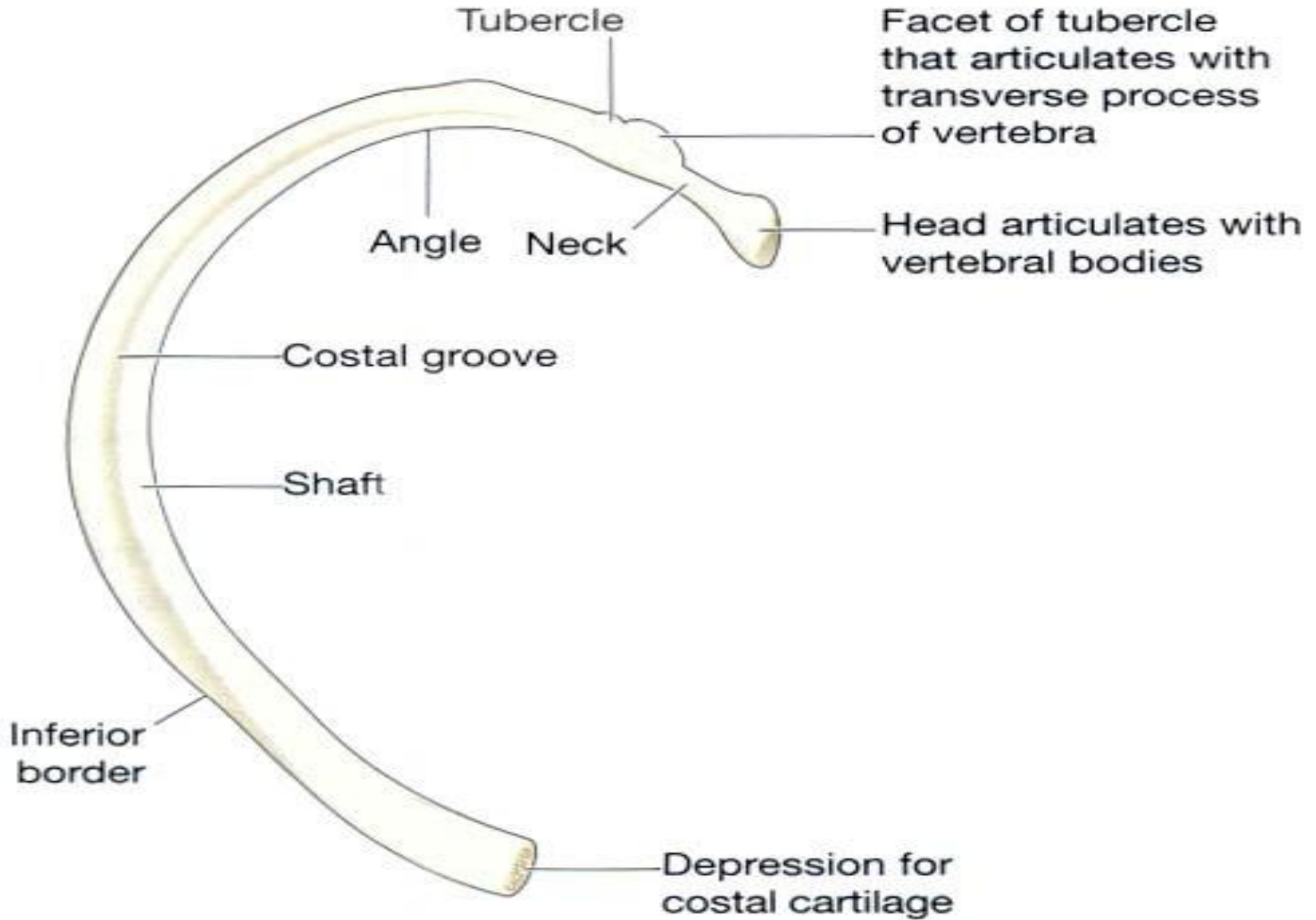
The sternum

- **Ribs**

- 12 pairs which form the bony lateral walls of the thoracic cage & articulate posteriorly with the thoracic vertebrae.
- First 10 pairs are attached anteriorly to the sternum by costal cartilages, some directly & some indirectly.
- Last 2 pairs (floating ribs) have no anterior attachment.

- **Characteristics of a rib**

1. Head articulates posteriorly with the bodies of 2 adjacent thoracic vertebrae
2. On the tubercle there is a facet that articulates with the transverse process of one.
3. Sternal end is attached to the sternum by a costal cartilage.
4. Superior border is rounded & smooth while the inferior border has a marked groove occupied by the intercostal blood vessels and nerves.



A typical rib

APPENDICULAR SKELETON

- Shoulder girdle with upper limbs & pelvic girdle with lower limbs.

Shoulder girdle & upper limb

- Each shoulder girdle consists of:
 - 1 clavicle
 - 1 scapula.
- Each upper limb consists of:
 - 1 humerus
 - 1 radius
 - 1 ulna
 - 8 carpal bones
 - 5 metacarpal bones
 - 14 phalanges.

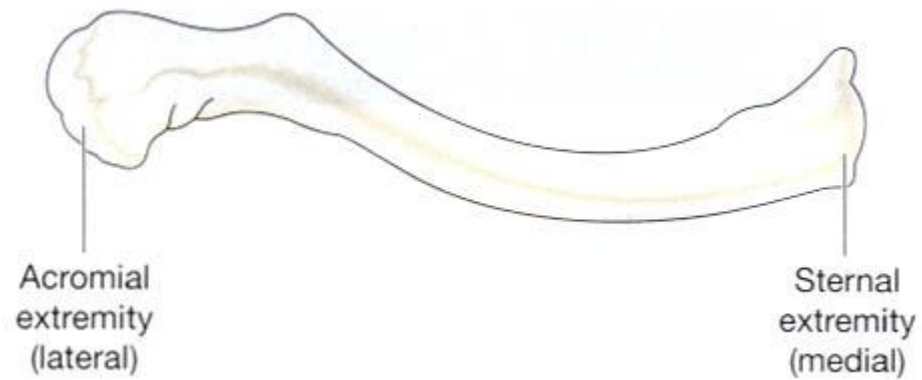
1. Clavicle/collar bone

- Long bone which has a double curve.
- Articulates with manubrium of sternum at sternoclavicular joint and forms acromioclavicular joint with the acromion process of scapula.
- Provides the only bony link between upper limb & axial skeleton.

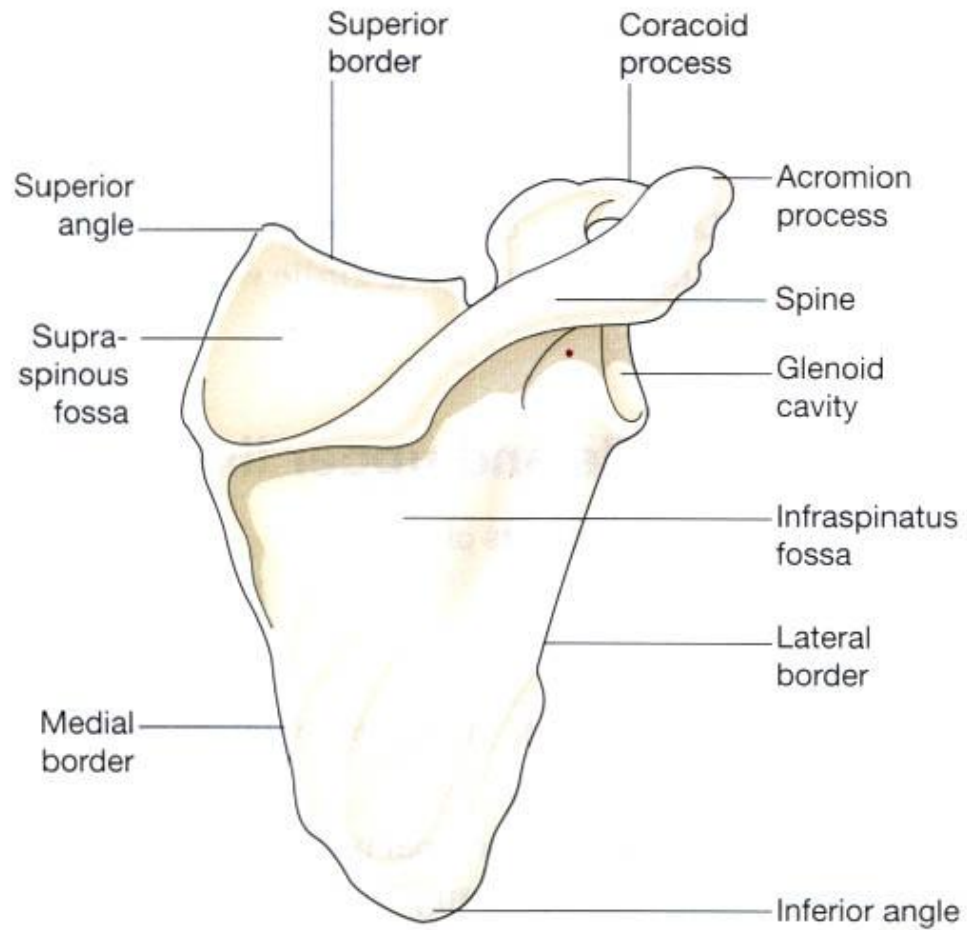
2. Scapula/shoulder blade

- Flat triangular-shaped bone, lying on the posterior chest wall superficial to the ribs & separated from them by muscles.
- Lateral angle; is a shallow articular surface, glenoid cavity which, with the head of the humerus, forms the shoulder joint.
- Posterior surface; spinous process that projects beyond lateral angle of bone that overhangs the shoulder joint; acromion process.
- Articulates with clavicle at acromioclavicular joint.
- Coracoid process, a projection from the upper border of the bone, gives attachment to muscles that move the shoulder joint.

Collar bone

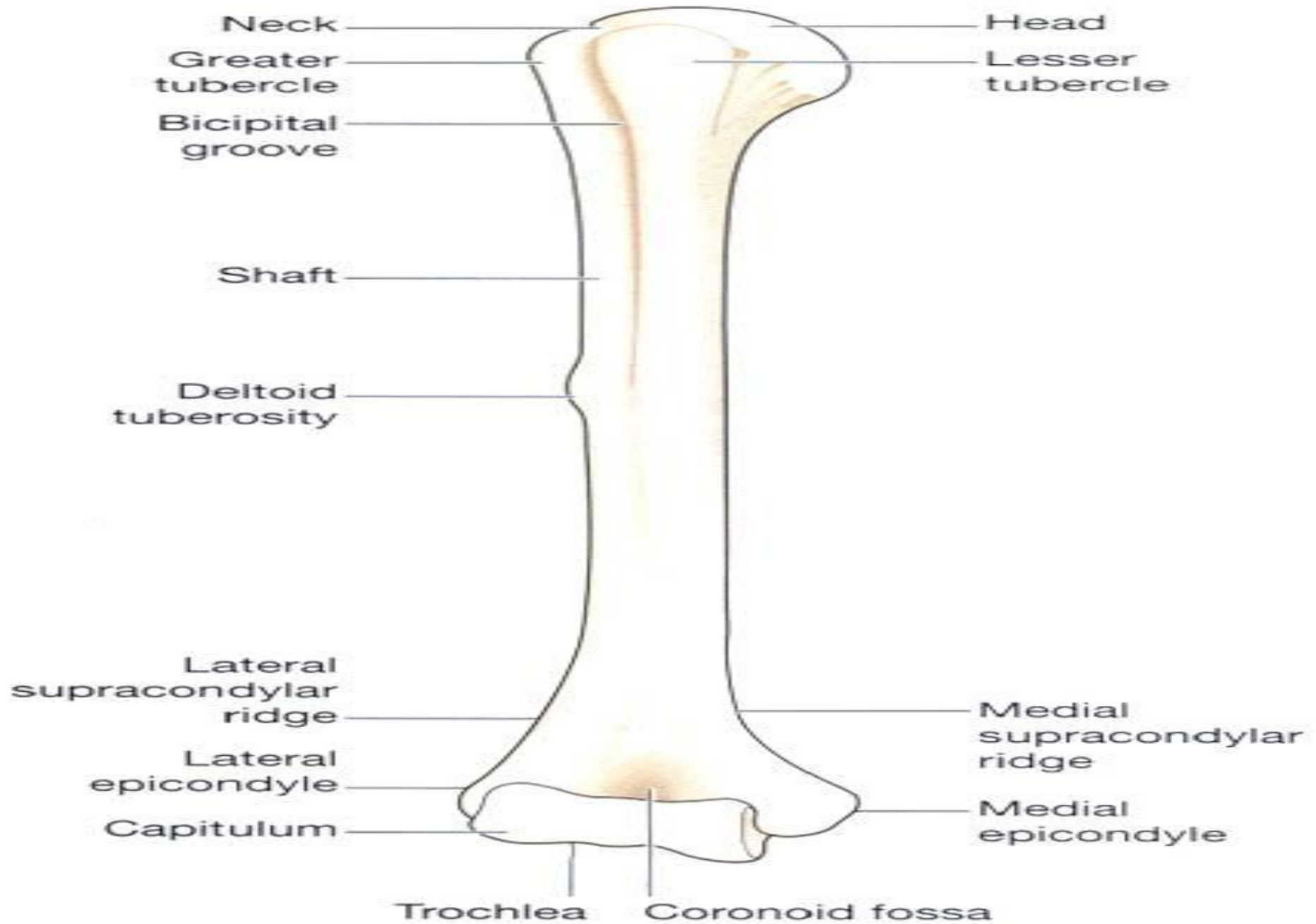


Right scapula



3. Humerus

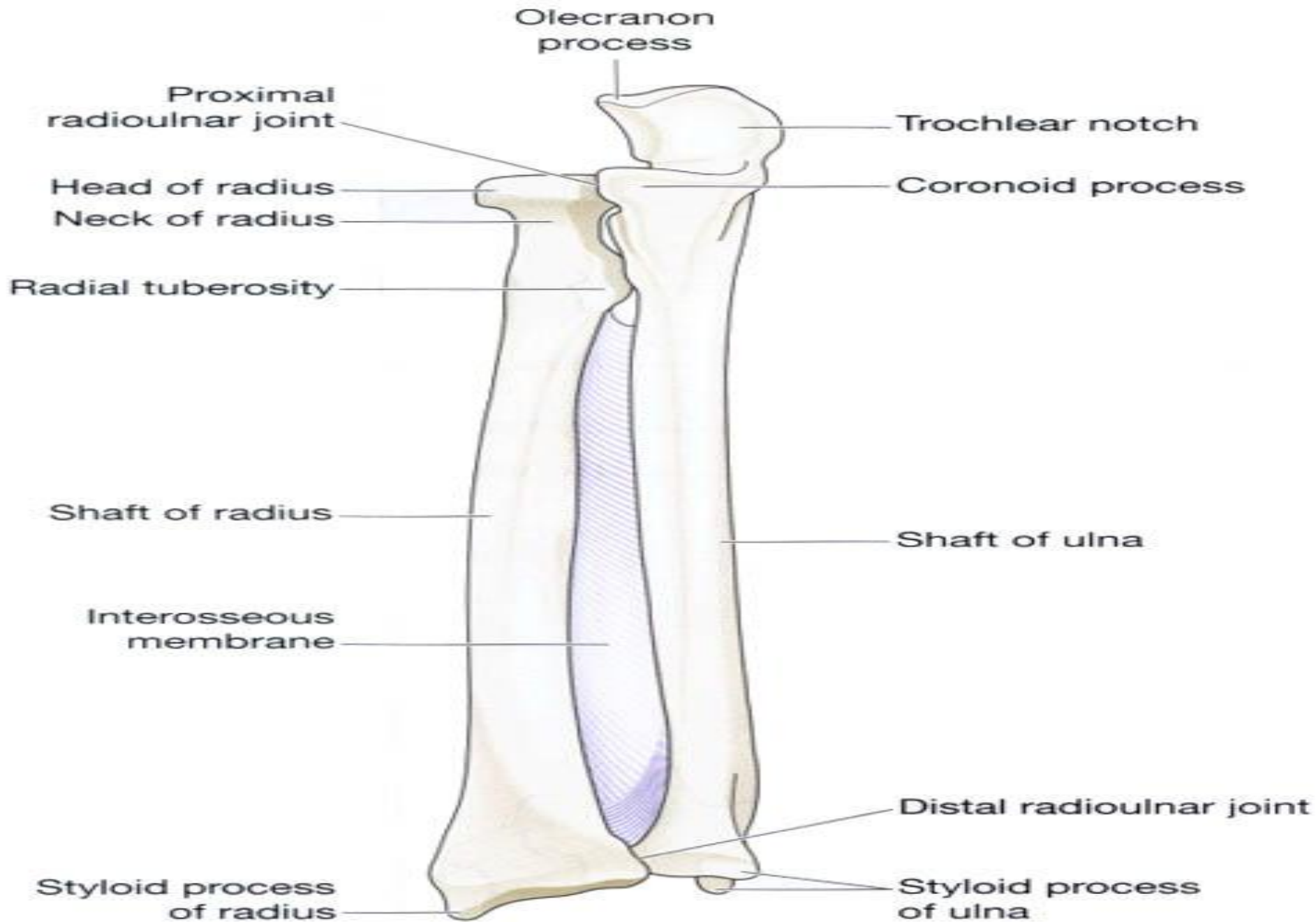
- Bone of upper arm.
- Head articulates with glenoid cavity of scapula, forming shoulder joint.
- Distal to the head are 2 roughened projections of bone, **greater & lesser tubercles**, & between them is a deep groove, **bicipital groove or intertubercular sulcus**, occupied by one of the tendons of biceps muscle.
- Distal end presents 2 surfaces that articulate with radius & ulna to form elbow joint.



Right humerus

4. Ulna & radius

- 2 bones of forearm.
- Ulna is **longer** than & **medial** to the radius & when the arm is in anatomical position, the 2 bones are parallel.
- Articulate with humerus at elbow joint, carpal bones at wrist joint & with each other at the proximal & distal radioulnar joints.



Radius and ulna

5. Carpal or wrist bones

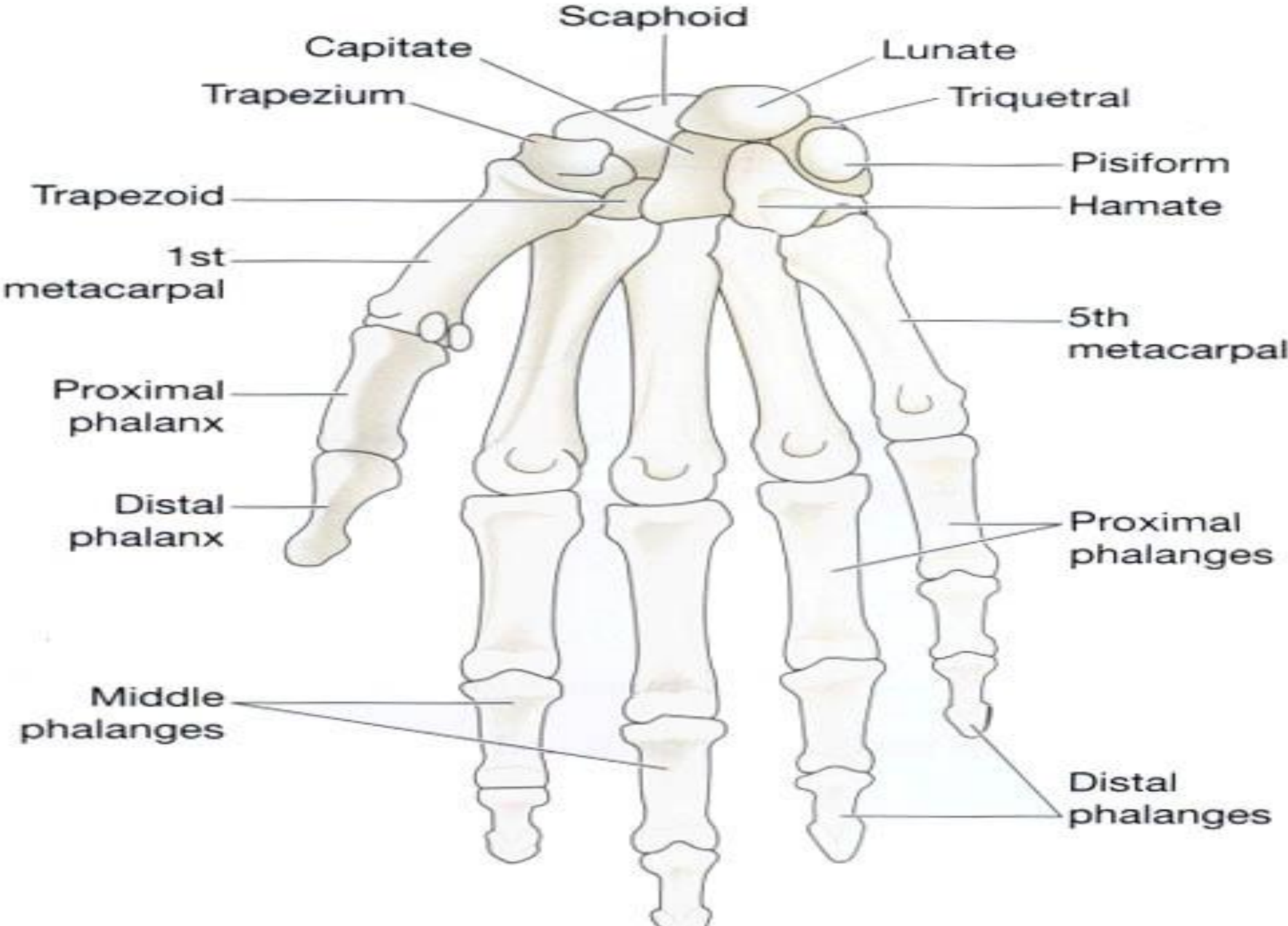
- 8 carpal bones arranged in 2 rows of 4.
- From outside inwards:
 - proximal row: **scaphoid, lunate, triquetral, pisiform**
 - distal row: **trapezium, trapezoid, capitate, hamate.**
- Closely fitted together & held in position by ligaments.
- Bones of proximal row are associated with **wrist joint** & those of distal row form joints with **metacarpal bones**.
- Tendons of muscles lying in the forearm cross the wrist & are held close to the bones by strong fibrous bands, called **retinacula**.

6. Metacarpal bones/bones of the hand

- 5 bones.
- Numbered from thumb side inwards.
- Proximal ends articulate with carpal bones & distal ends with phalanges.

7. Phalanges/finger bones

- 14 phalanges, 3 in each finger & 2 in the thumb.
- Articulate with metacarpal bones & with each other.



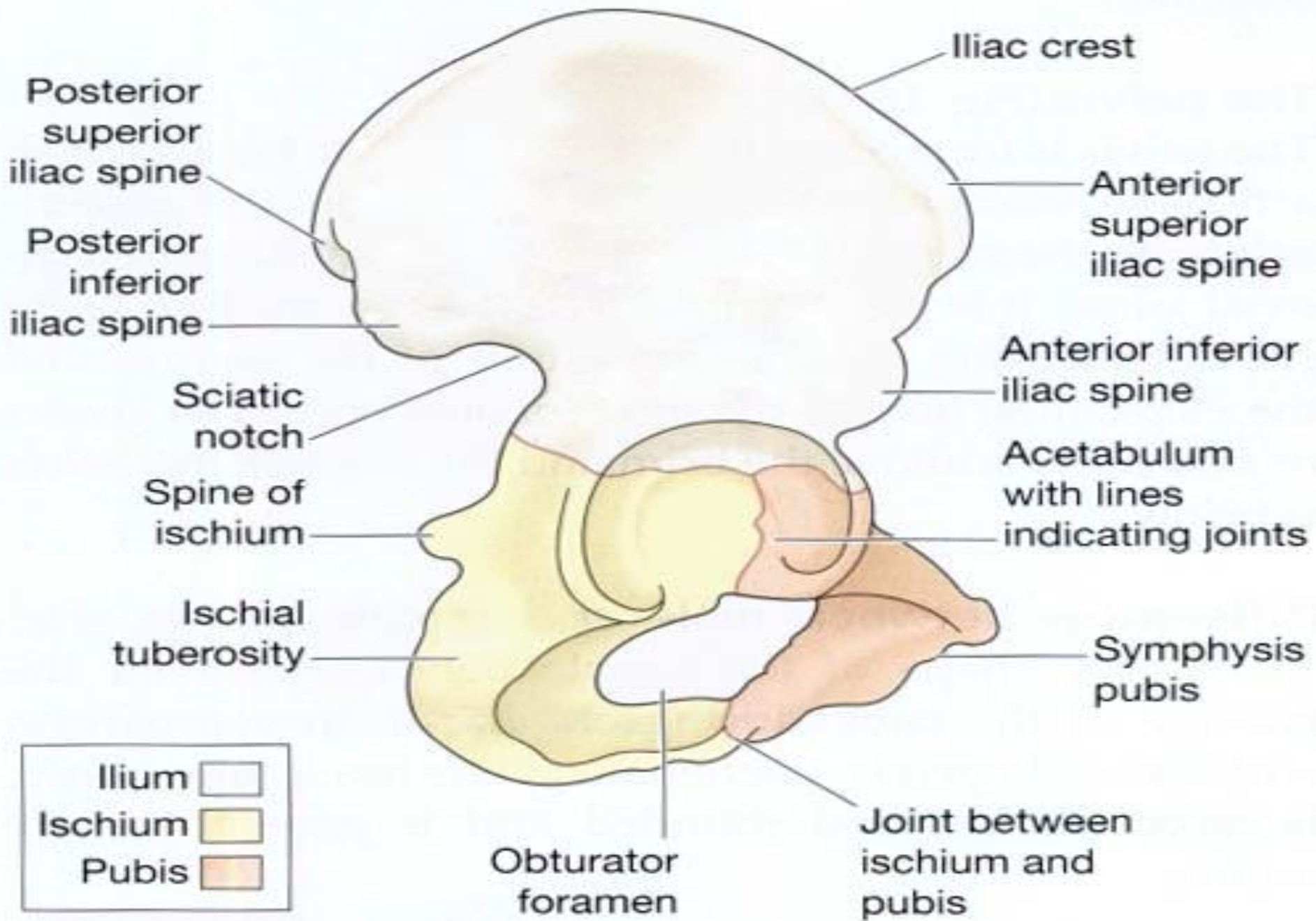
Bones of the wrist, hand and fingers ¹¹²⁴

Pelvic girdle & lower limb

- Pelvic girdle bones:
 - 2 innominate bones
 - 1 sacrum.
- Lower limb bones:
 - 1 femur
 - 1 tibia
 - 1 fibula
 - 1 patella
 - 7 tarsal bones
 - 5 metatarsal bones
 - 14 phalanges

1. Innominate/hip bones

- Each, 3 fused bones, ilium, ischium & pubis.
- On its outer surface is a deep depression, **acetabulum**, which forms the hip joint with head of femur.
- **The ilium**; upper flattened part of the bone, presents the iliac crest, anterior point of which is called **anterior superior iliac spine**.
- **The pubis**; anterior part of the bone, articulates with pubis of the other hip bone at a cartilaginous joint, **symphysis pubis**.
- **The ischium**; inferior & posterior part.
- Union of the 3 parts takes place in the acetabulum.



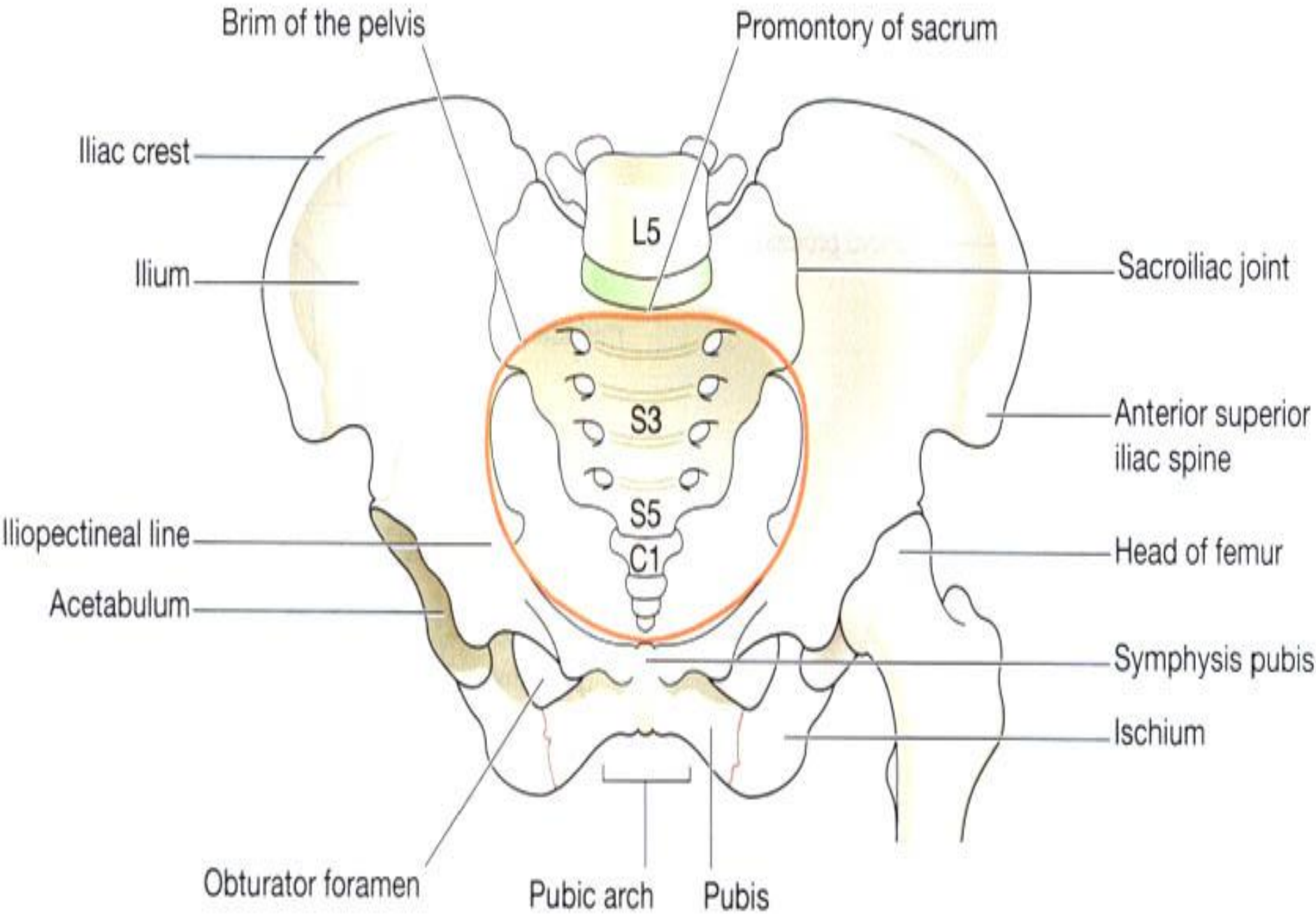
Right innominate bone

2. The pelvis

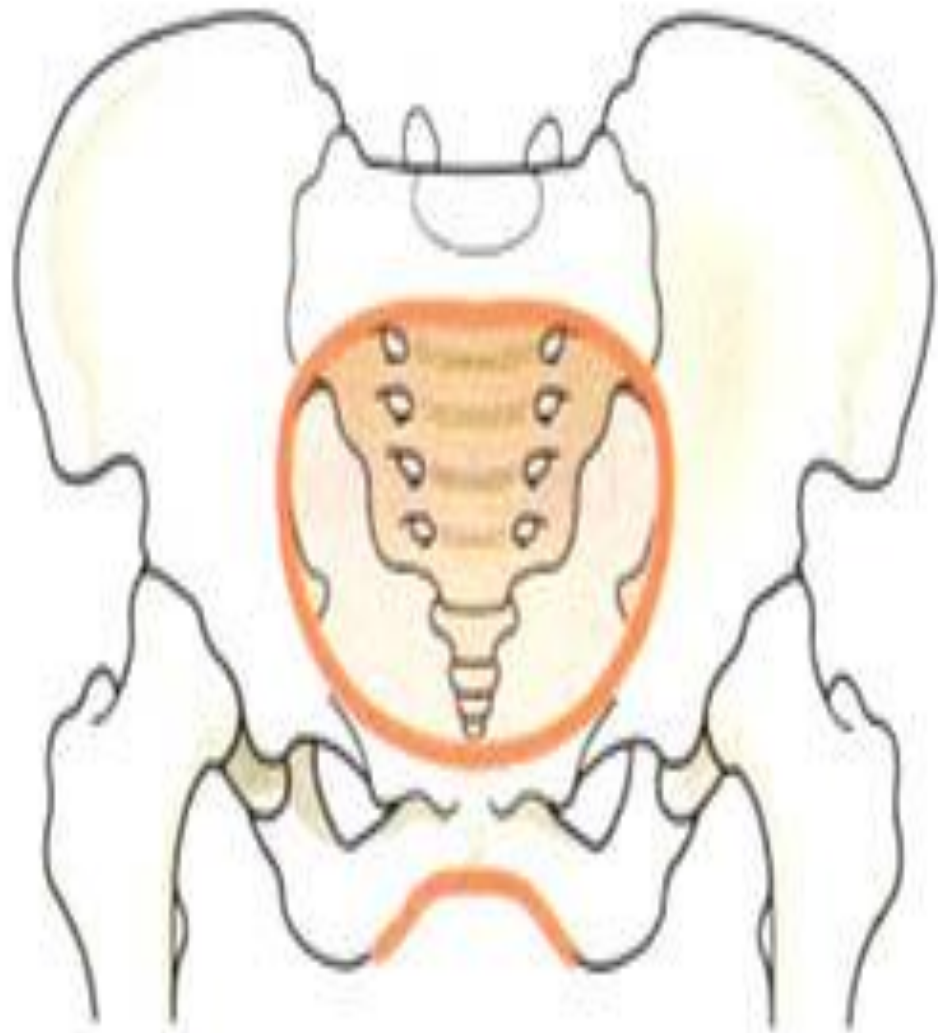
- Formed by 2 innominate bones which articulate anteriorly at **symphysis pubis** & posteriorly with sacrum at **sacroiliac joints**.
- Divided into 2 parts by brim of the pelvis, consisting of **promontory of the sacrum & iliopectineal lines of innominate bones**.
- Greater/false pelvis: above the brim; lesser/true pelvis; below.

Differences between male & female pelves

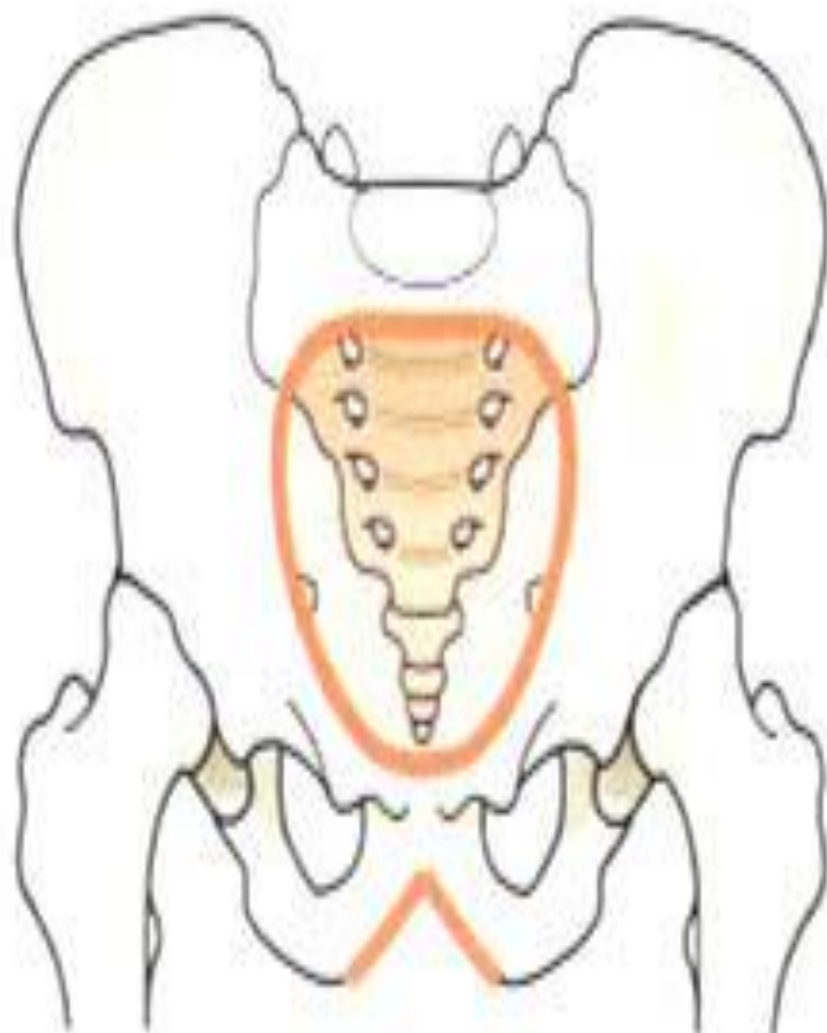
- Female pelvis has lighter bones, is more shallow and rounded and is generally more roomy.



Bones of the pelvis



Female

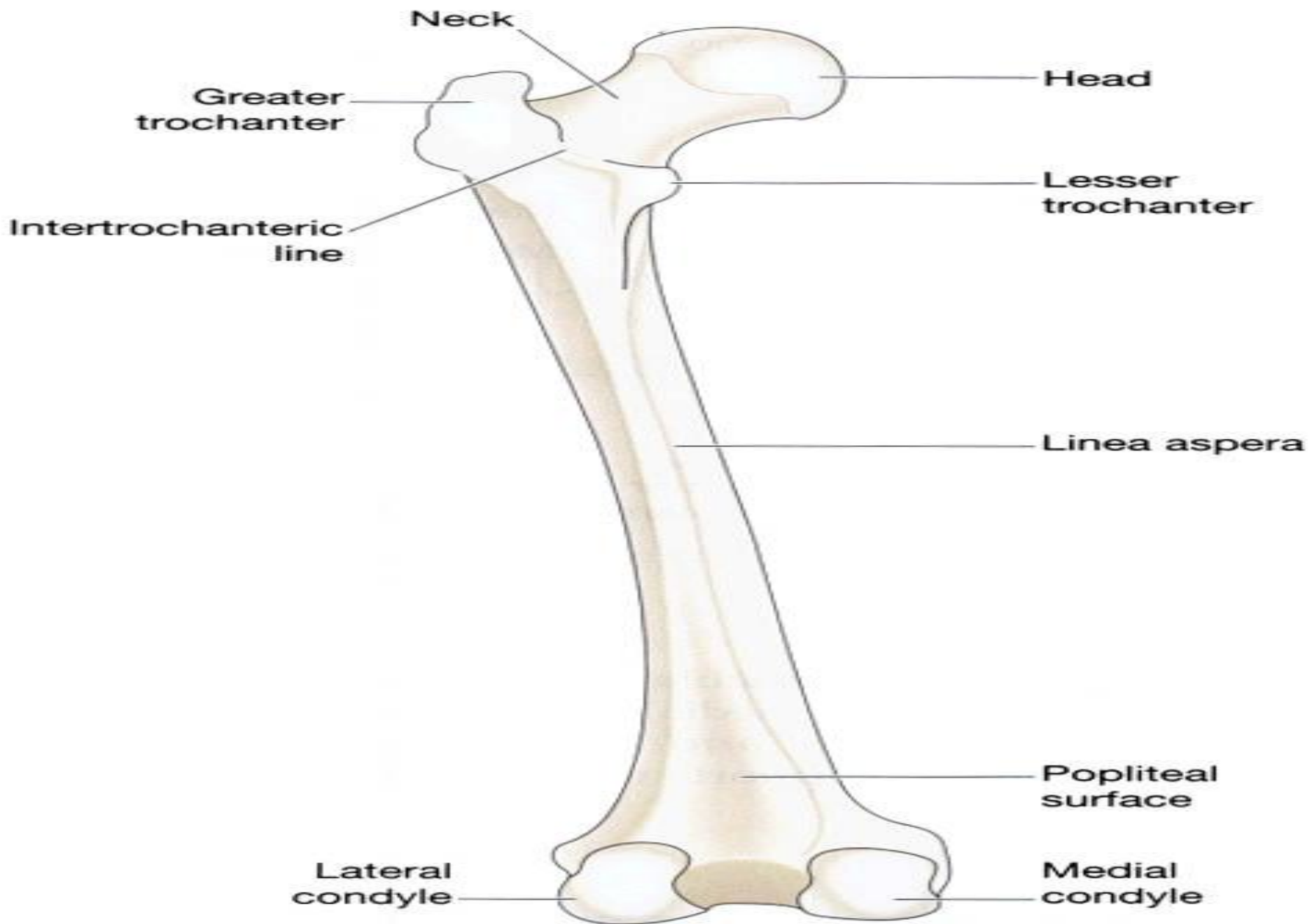


Male

Male and female pelves

3. Femur/thigh bone

- Longest & strongest bone of the body.
- Head is almost spherical & fits into the acetabulum of hip bone; hip joint.
- Centre of the head is a small depression for attachment of **ligament of the head** of femur.
- Neck extends outwards & slightly downwards from the head to the shaft
 - Most of it is within the capsule of the hip joint.
- Posterior surface of the lower third forms a flat triangular area; **popliteal surface**.
- Distal extremity has 2 articular condyles which, with tibia & patella, form **knee joint**.



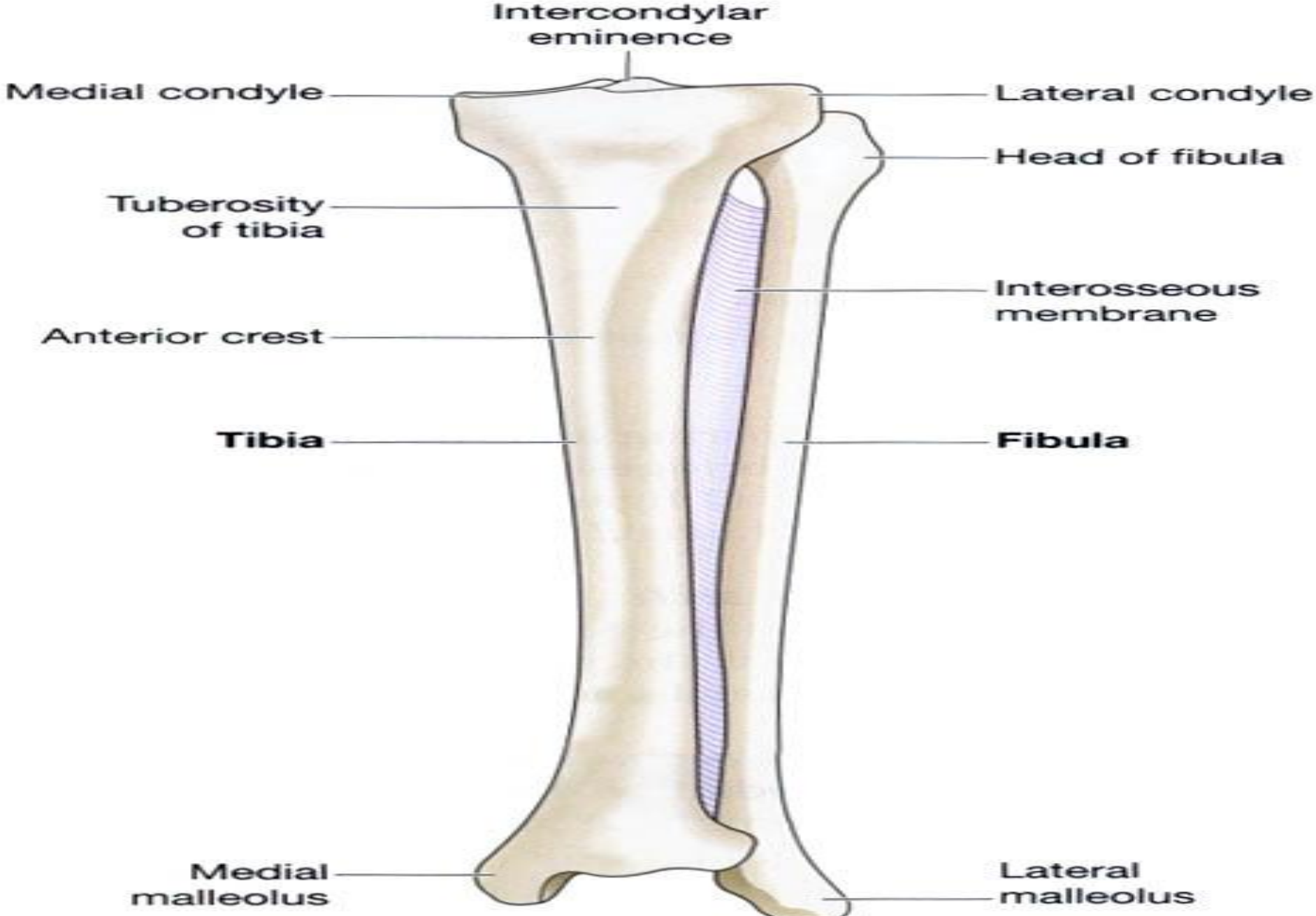
Left femur

4. Tibia or shin bone

- Medial of the 2 bones of the lower leg.
- Proximal extremity is broad & flat and presents 2 condyles for articulation with the femur at the knee joint.
 - Head of the fibula articulates with the inferior aspect of the lateral condyle, forming the proximal tibiofibular joint.
- Distal extremity of the tibia forms the ankle joint; with the talus & the fibula.
- Medial malleolus; a downward projection of bone medial to the ankle joint.

5. Fibula

- Long slender lateral bone in the leg.
- Head/upper extremity articulates with the lateral condyle of the tibia forming the proximal tibiofibular joint and the lower extremity articulates with the tibia then projects beyond it to form the lateral malleolus



Left tibia and fibula

6. Patella or knee cap

- Roughly triangular-shaped sesamoid bone.
- Posterior surface articulates with the patellar surface of the femur in the knee joint & its anterior surface is in the patellar tendon.

7. Tarsal or ankle bones

- 7; form posterior part of the foot.
 - 1 talus
 - 1 calcaneus
 - 1 navicular
 - 3 cuneiform
 - 1 cuboid.
- Talus articulates with tibia & fibula at ankle joint.
- Calcaneus forms heel of the foot.

8. Metatarsal bones of the foot

- 5 bones, numbered from within outwards.
- Proximal ends; they articulate with the tarsal bones & at their distal ends, with the phalanges.
- Enlarged distal head of the 1st metatarsal bone forms the **'ball' of the foot.**

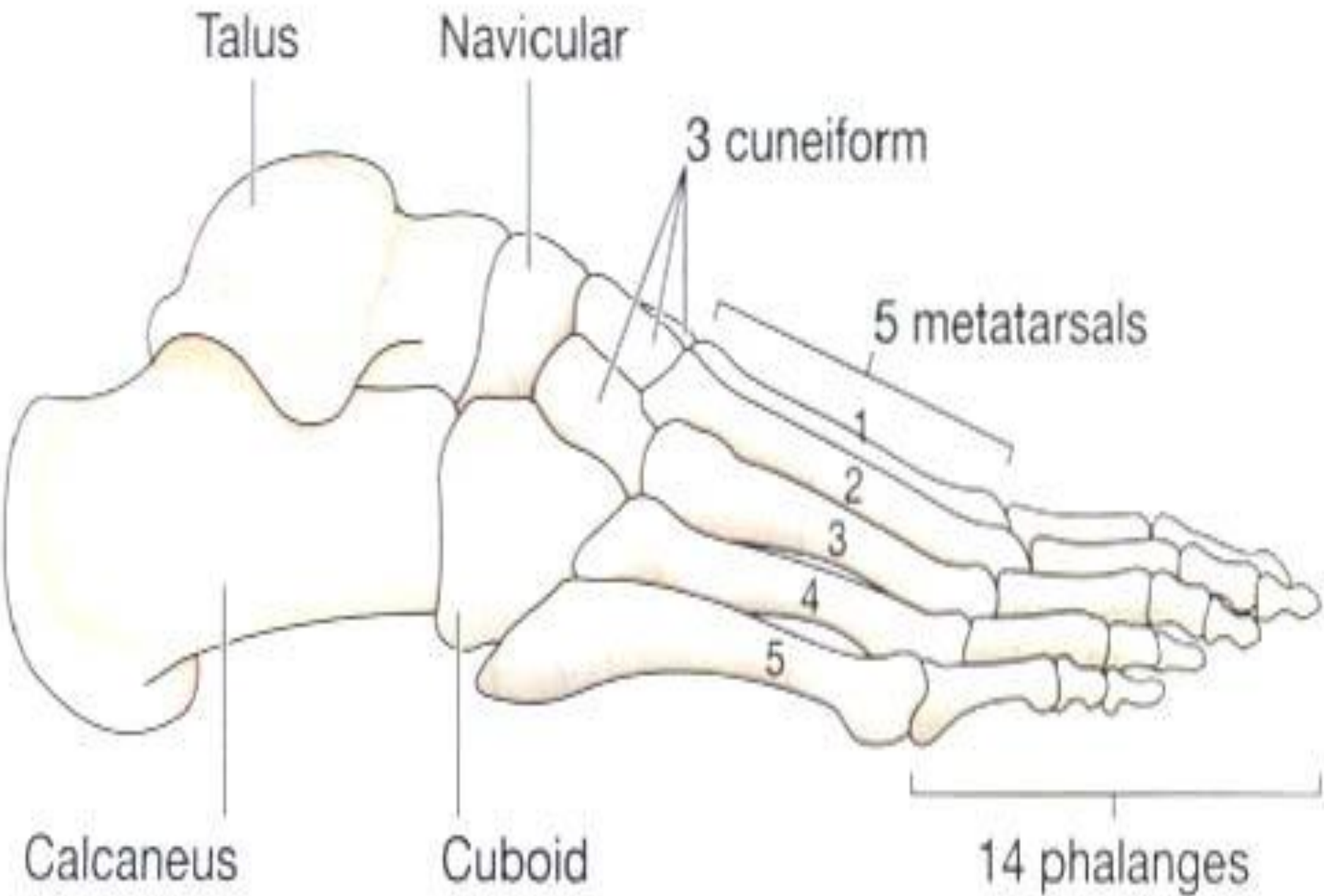
9. Phalanges of the toes

- 14; arranged in a similar manner to those in the fingers.

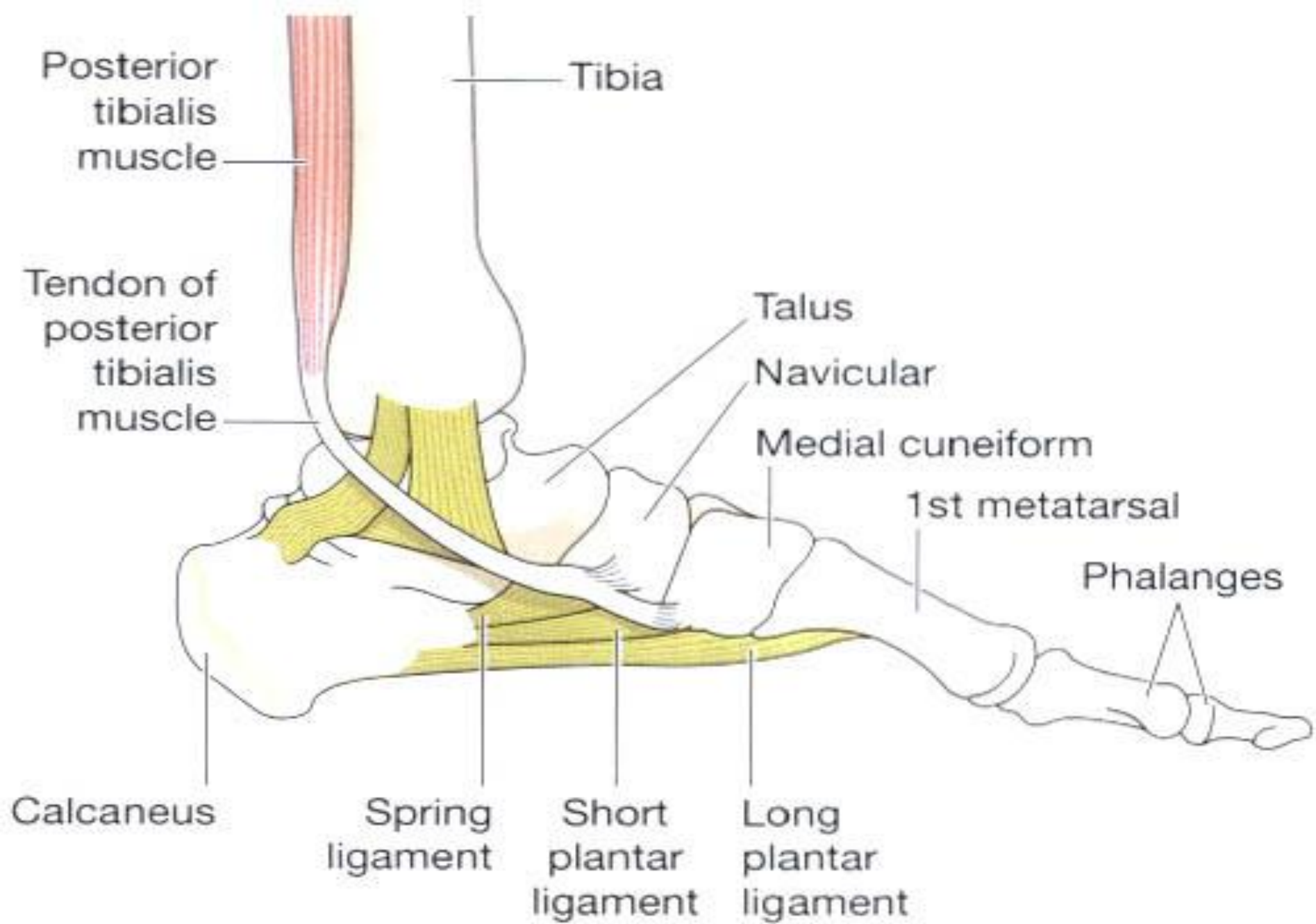
10. Arches of the foot.

- Bones have a bridge-like arrangement & are supported by muscles and ligaments so that 4 arches are formed,
 - a medial
 - lateral longitudinal arch and
 - 2 transverse arches.
- **Medial longitudinal arch.** Highest; formed by calcaneus, talus, navicular, 3 cuneiform & first 3 metatarsal bones.
 - Only calcaneus & distal end of metatarsal bones should touch the ground.

- **Lateral longitudinal arch.** Much less marked than its medial counterpart.
 - Bony components; calcaneus, cuboid, 2 lateral metatarsal bones.
 - Again only calcaneus & metatarsal bones should touch ground.
- **Transverse arches.** Run across the foot.
 - Most marked at the level of the 3 cuneiform & cuboid bones.



Bones of the foot



Tendons and ligaments supporting arches of the left foot

THE JOINTS

Joints

- **Def:** Site at which any 2 or more bones articulate.
- Some joints:
 - Have no movement (fibrous),
 - Have some only slight movement (cartilaginous)
 - are freely movable (synovial).

TYPES OF JOINTS

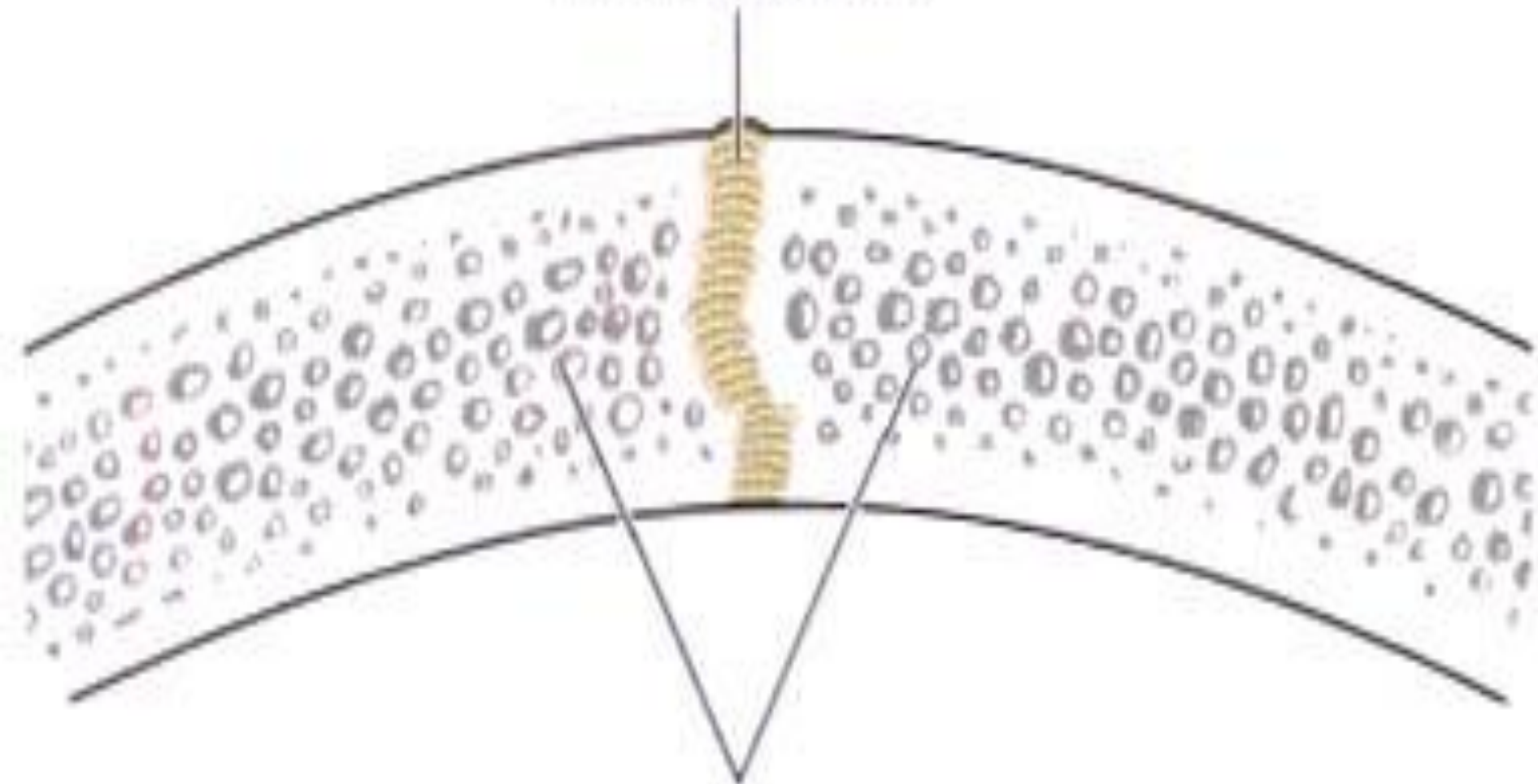
a) Fibrous or fixed joints

- Immovable joints having fibrous tissue between the bones, e.g.
 - between bones of skull (sutures)
 - between teeth & maxilla & mandible.

b) Cartilaginous or slightly movable joints

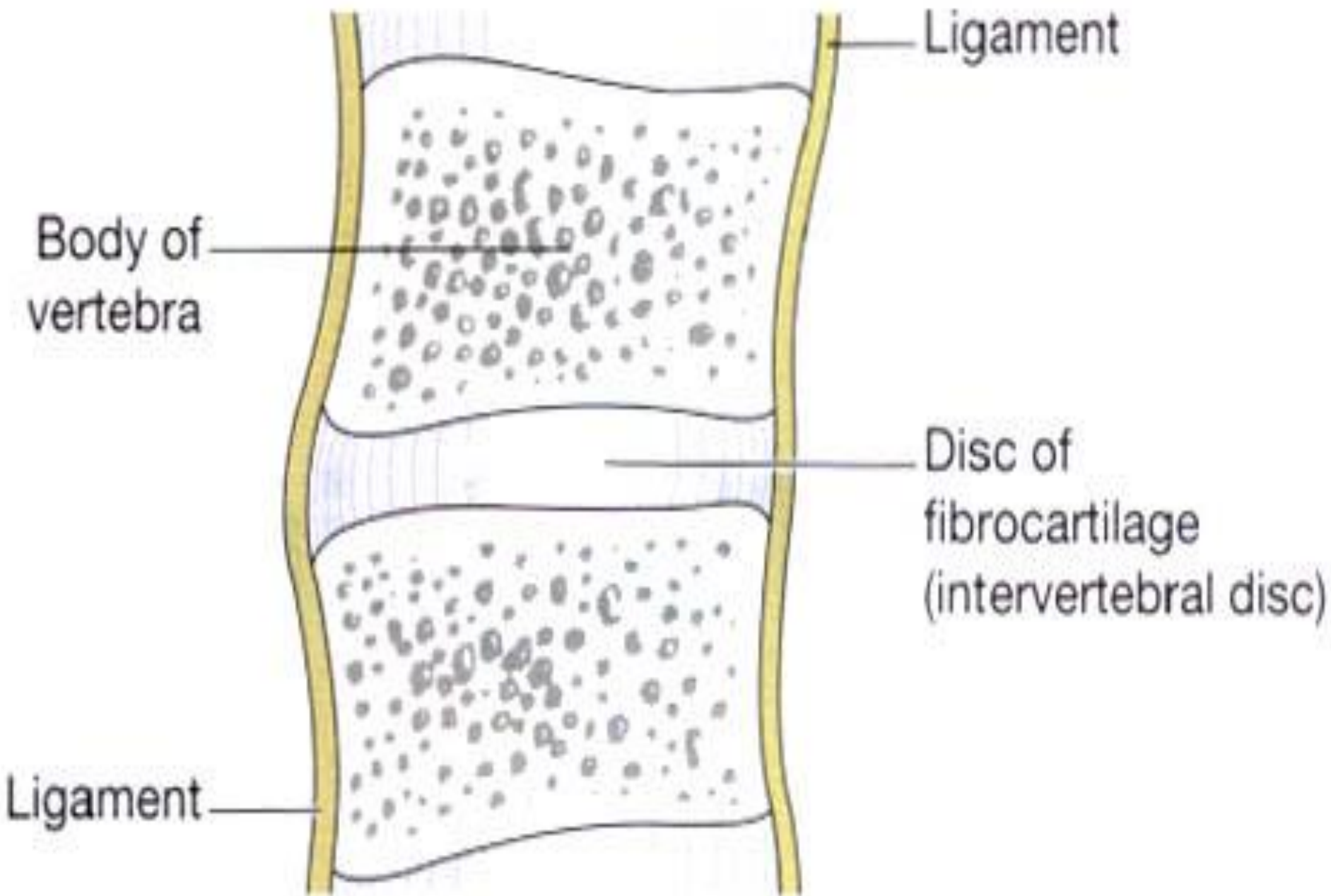
- Pad of fibro-cartilage between ends of bones that form the joint allows for very slight movement. E.g., the
 - symphysis pubis
 - joints between vertebral bodies.

Fibrous joint



Bones

Fibrous or fixed joint e.g., sutures of the skull



Cartilaginous or slightly movable joint

c) Synovial or freely movable joints

- Allow a wide range of movements.
- Classified according to
 - range of movement possible
 - shape of articulating parts of the bones involved.

i) Ball and socket joint.

- Head or ball of one bone articulates with a socket of another & shape of the bones allows for a wide range of movement.
- Movements possible; flexion, extension, adduction, abduction, rotation & circumduction.
- E.g., shoulder & hip.

ii) Hinge joints. Allow movements of flexion & extension only.

E.g.,

- elbow, knee, ankle,
- joints between atlas & occipital bone
- interphalangeal joints of fingers & toes.

iii) Gliding joints. Articular surfaces glide over each other, e.g.

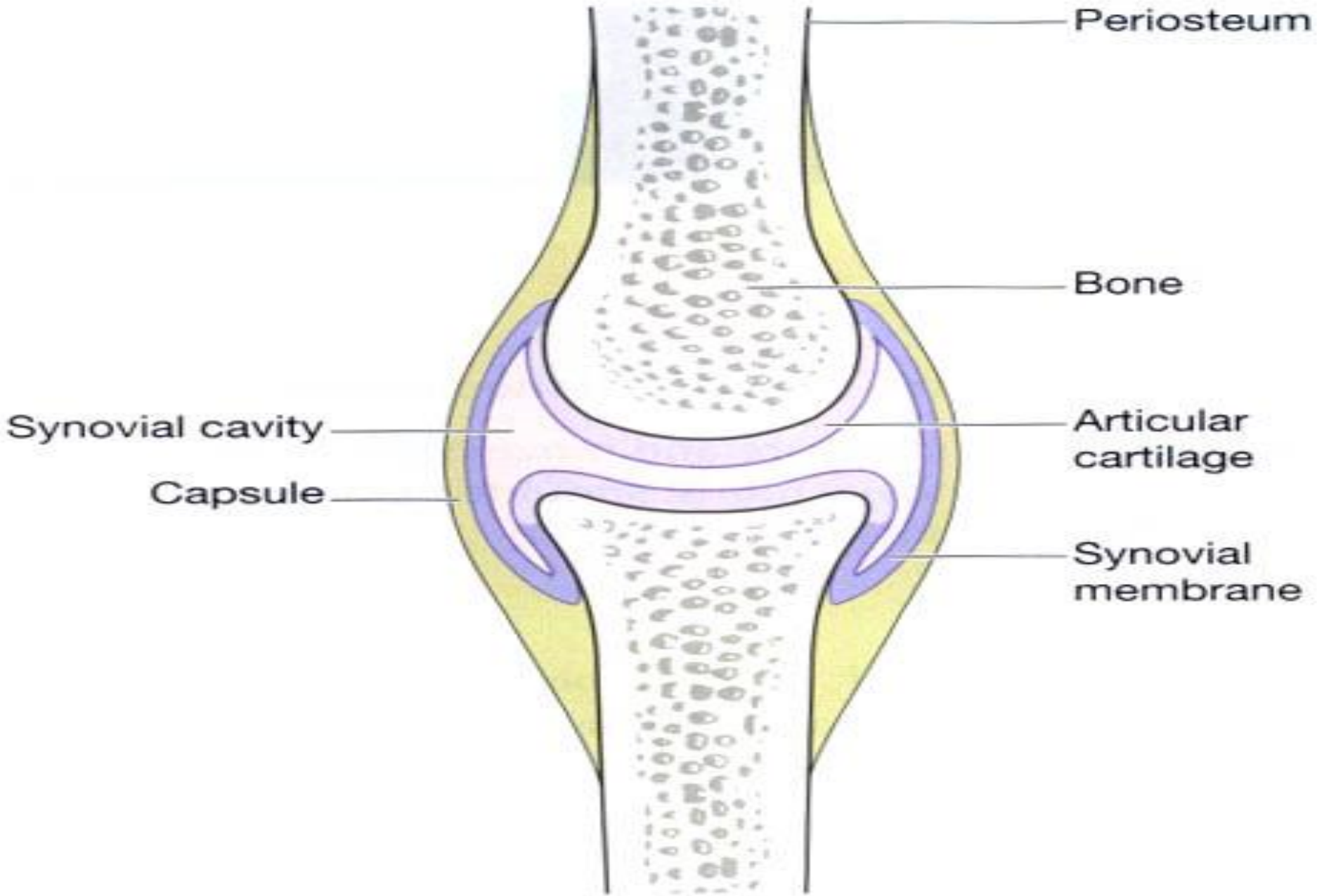
- sternoclavicular joints,
- acromioclavicular joints
- joints between carpal bones
- Joints between tarsal bones.

iv) Pivot joints. Movement is round one axis (rotation), e.g. the

- proximal & distal radioulnar joints
- joint between atlas & odontoid process of the axis.

v) saddle joints. Movements take place round 2 axes, permitting flexion, extension, abduction, adduction & circumduction, e.g. the

- wrist, temporomandibular, metacarpophalangeal & metatarsophalangeal joints.



Synovial joint

Table 17.1 Movements possible at synovial joints

Movement	Definition
Flexion	Bending, usually forward but occasionally backward, e.g. knee joint
Extension	Straightening or bending backward
Abduction	Movement away from the midline of the body
Adduction	Movement towards the midline of the body
Circumduction	Combination of flexion, extension, abduction and adduction
Rotation	Movement round the long axis of a bone
Pronation	Turning the palm of the hand down
Supination	Turning the palm of the hand up
Inversion	Turning the sole of the foot inwards
Eversion	Turning the sole of the foot outwards

Characteristic of synovial joint

1. Articular or hyaline cartilage

- Covers parts of bones which are in contact.
- Provides a smooth articular surface
- Strong enough to absorb compression forces & bear the weight of the body.
- Cartilage lining, which is up to 7mm thick in young people, becomes thinner & less compressible with age.
- Has no blood supply
 - receives its nourishment from synovial fluid.

2. Capsule or capsular ligament

- Sleeve of fibrous tissue surrounding & enclosing the joint; hold bones together.
- Sufficiently loose to allow freedom of movement but strong enough to protect it from injury.

3. Synovial membrane

- Composed of epithelial cells
- Found:
 - lining the capsule
 - covering those parts of the bones within the joint not covered by articular cartilage
 - covering all intracapsular structures that do not bear weight.

4. Synovial fluid.

- Thick sticky fluid, of egg-white consistency, secreted by synovial membranes into the synovial cavity,
- **Functions:**
 - provides nutrients for structures within joint cavity
 - contains phagocytes; remove microbes & cellular debris
 - acts as a lubricant
 - maintains joint stability
 - prevents the ends of the bones from being separated, as does a little water between two glass surfaces.
- Little sacs of synovial fluid or bursae are present in some joints, e.g. knee.
 - Act as cushions to prevent friction between a bone & a ligament or tendon, or skin where a bone in a joint is near the surface.

5. Other intracapsular structures

- Structures within the capsule, but outside the synovial membrane, which assist in maintenance of stability, e.g. fat pads & menisci in the knee joint.

6. Extracapsular structures

- **Ligaments** that blend with capsule provide additional stability at most joints.
- **Muscles** or their tendons also provide stability and stretch across the joints they move.

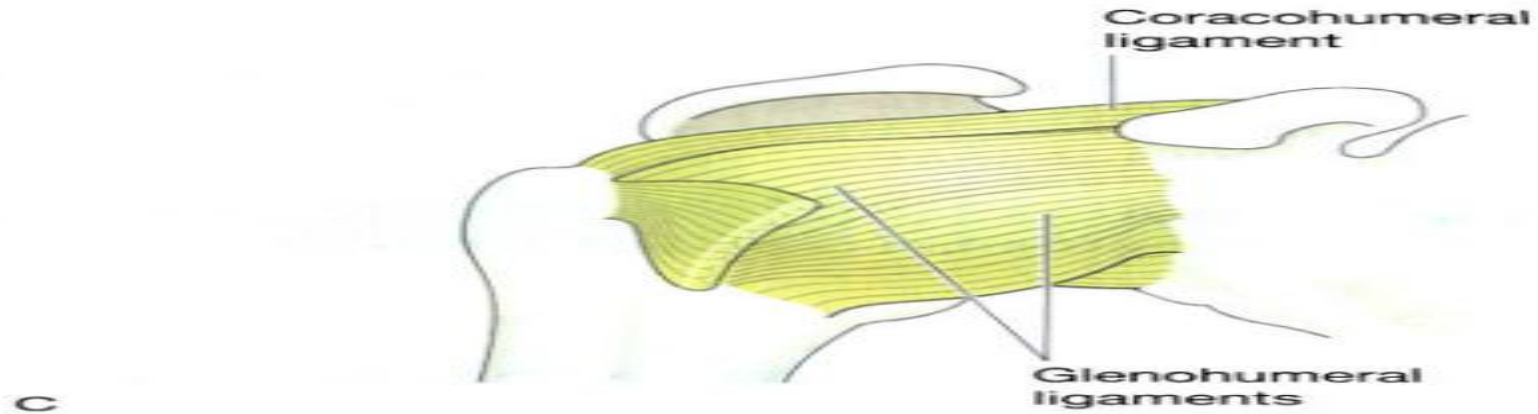
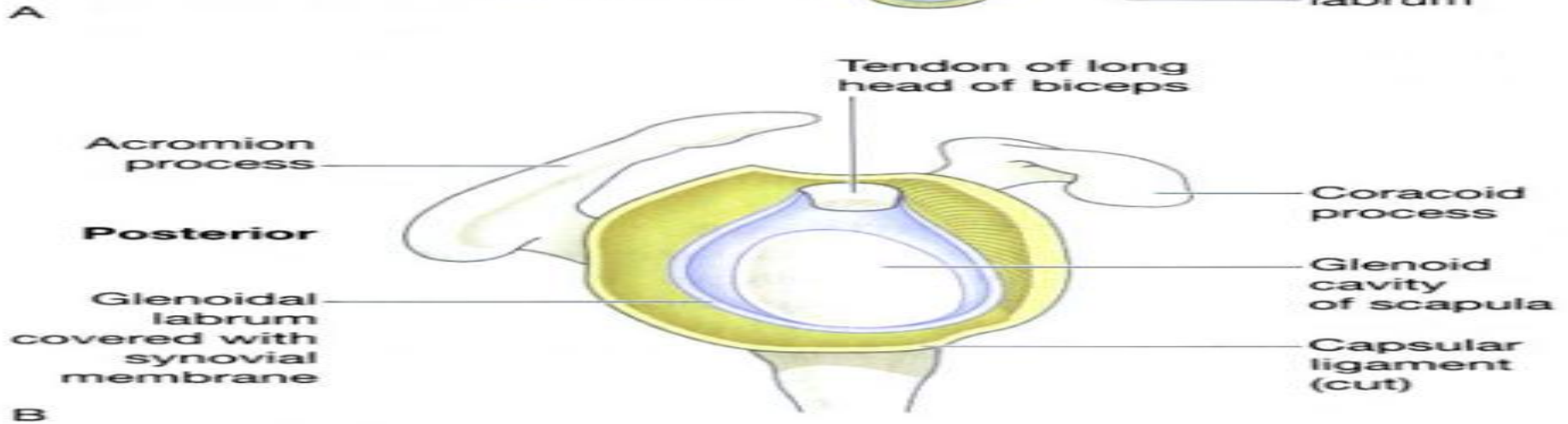
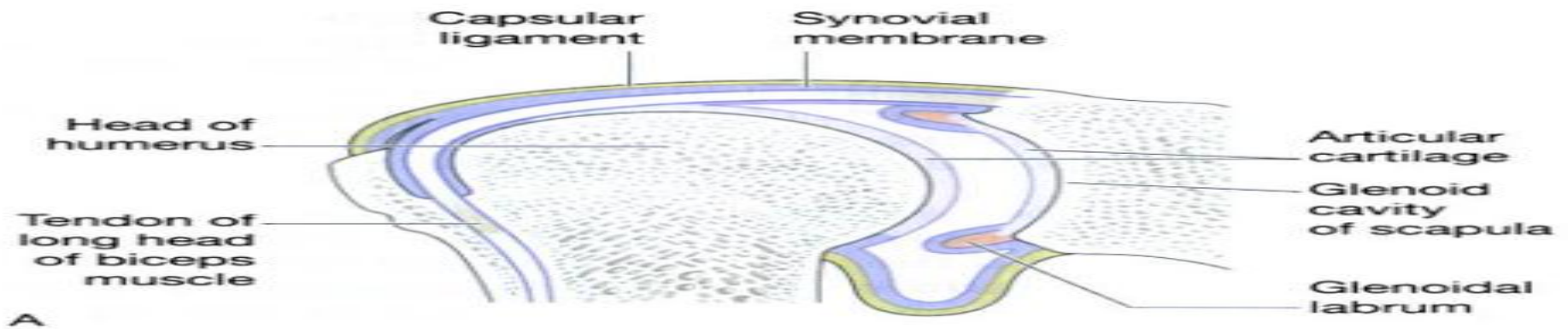
7. Nerve & blood supply

- Crossing a joint usually supply the capsule & muscles that move it.

a) Shoulder joint

- Ball & socket
- Capsular ligament is very loose inferiorly to allow for the free movement of the joint.
- Glenoid cavity is deepened by a rim of fibrocartilage, the **glenoid labrum**, which provides additional stability without limiting movement.
- Tendon of the long head of the biceps muscle extends through the joint cavity & is attached to the upper rim of the glenoid cavity.
 - important in stabilising the joint.

- Extracapsular structures consist of:
 - coracohumeral ligament, extending from coracoid process of the scapula to the humerus
 - glenohumeral ligaments, which blend with & strengthen the capsule
 - transverse humeral ligament, retaining biceps tendon in the intertubercular groove.



Shoulder joint

Muscles and movements

- **MUSCLES**

1. **Coracobrachialis muscle.** Lies on the upper medial aspect of the arm. Arises from coracoid process of scapula, stretches across in front of shoulder joint; inserted into middle third of humerus.
 - flexes shoulder joint.

2. **Deltoid muscle.** Origin: from clavicle, acromion process & spine of scapula & radiate over the shoulder joint; inserted into deltoid tuberosity of humerus.

- Forms fleshy & rounded contour of shoulder.

- Anterior fibres cause flexion, middle/main part, abduction; posterior fibres extend shoulder joint.

3. Pectoralis major. Lies on anterior thoracic wall.

- Fibres originate from middle third of clavicle & from sternum; inserted into lip of the intertubercular groove of humerus.
- Flexes & adducts the arm.

4. Latissimus dorsi. Origin: posterior part of iliac crest & spinous processes of lumbar & lower thoracic vertebrae.

- Passes upwards across the back then under the arm; inserted into the bicipital groove of humerus.
- Adducts, medially rotates & extends the arm.

5. Teres major. Origin: inferior angle of scapula; inserted into the humerus just below shoulder joint.

- Extends, adducts & medially rotates the arm.

Movements

- Flexion: coracobrachialis, anterior fibres of deltoid & pectoralis major.
- Extension: teres major, latissimus dorsi & posterior fibres of deltoid.
- Abduction: deltoid.
- Adduction: combined action of flexors & extensors.
- Circumduction: flexors, extensors, abductors & adductors acting in series.
- Medial rotation: pectoralis major, latissimus dorsi, teres major & anterior fibres of deltoid.
- Lateral rotation: posterior fibres of deltoid.

b) Elbow joint

- Formed by trochlea & capitulum of humerus & trochlear notch of ulna & head of radius.
- Extracapsular structures; anterior, posterior, medial & lateral strengthening ligaments.

Muscles

i) Biceps muscle.

- Lies on anterior aspect of upper arm.
- Proximal end; divided into 2 parts (heads).
 - Short head rises from coracoid process of scapula & passes in front of shoulder joint to the arm.
 - Long head originates from rim of glenoid cavity & its tendon passes through joint cavity & bicipital groove of humerus to the arm.

- Retained in the bicipital groove by a transverse ligament which stretches across the groove.
- Helps stabilise & flex shoulder joint
- Assists with flexion & supination at elbow joint

ii) **Brachialis muscle.**

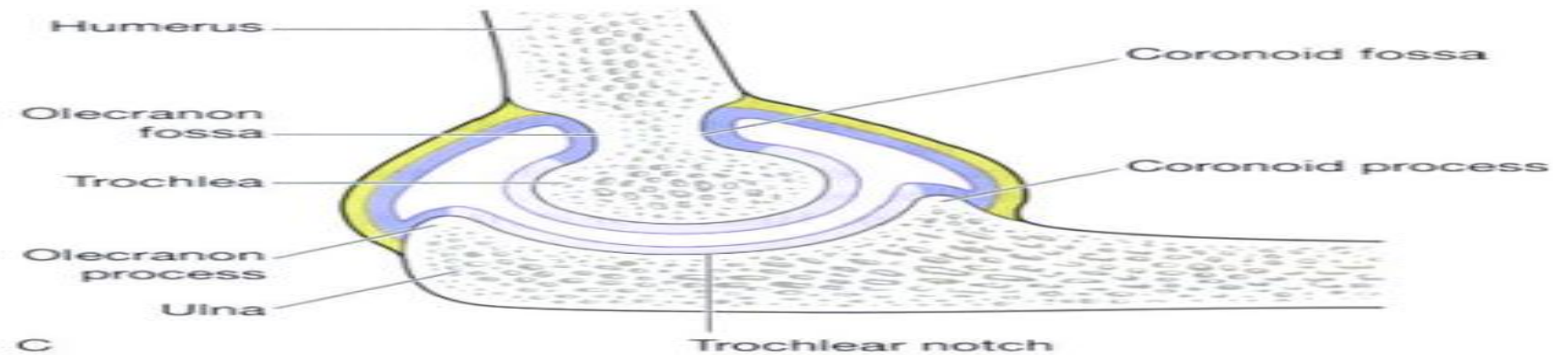
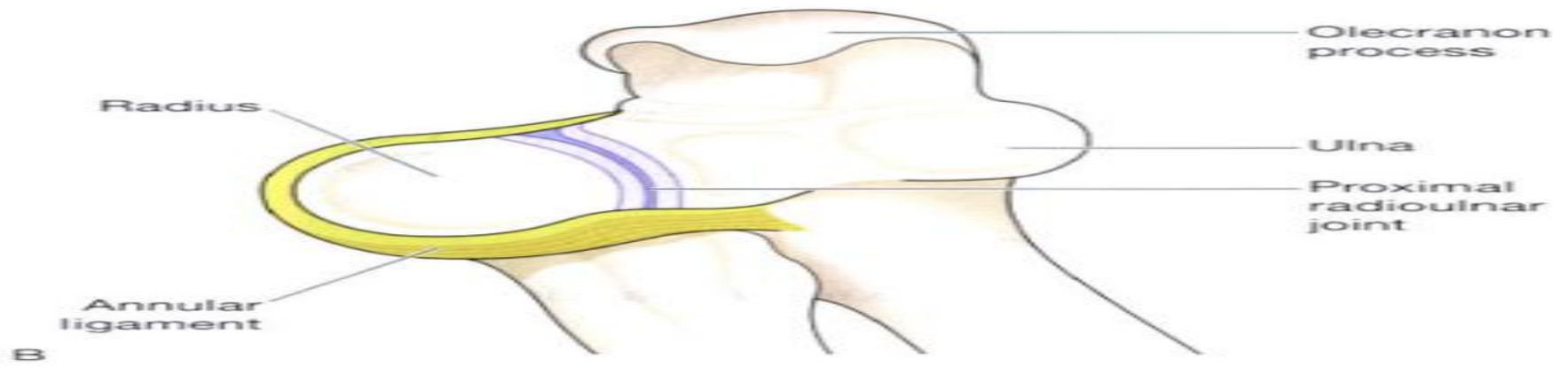
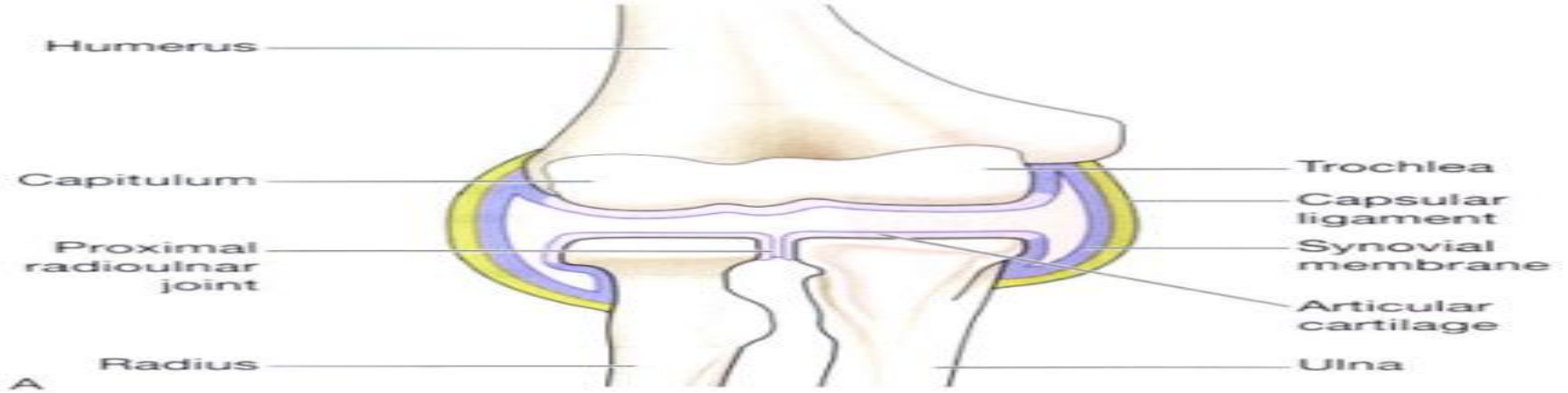
- Lies on anterior aspect of upper arm deep to biceps.
- Origin: shaft of humerus, extends across elbow joint; inserted into the ulna just distal to the joint capsule.
- Main flexor of elbow joint.

iii) **Triceps muscle.** Lies on posterior aspect of humerus.

- Arises from 3 heads, one from scapula, 2 from posterior surface of humerus. Insertion: by a common tendon to the olecranon process of ulna.
- Helps stabilise shoulder joint, assists in adduction of the arm and extends the elbow joint.

Movements

- Flexion: biceps & brachialis.
- Extension: triceps.



The elbow and proximal radio-ulnar joint

c) Proximal and distal radioulnar joints

- Proximal; formed by rim of head of radius rotating in the radial notch of ulna, is in the same capsule as elbow joint.
- Annular ligament encircles the head of radius & keeps it in contact with radial notch of ulna.
- Distal; pivot joint between distal end of radius & head of ulna.

Muscles

1. **Pronator teres.** Lies obliquely across upper third of the front of forearm.
 - Origin: medial epicondyle of humerus & coronoid process of ulna; passes obliquely across the forearm; inserted into lateral surface of shaft of radius.
 - Rotates radioulnar joints, changing the hand from the anatomical to writing position, i.e. pronation

2. Supinator muscle. Lies obliquely across posterior & lateral aspects of forearm.

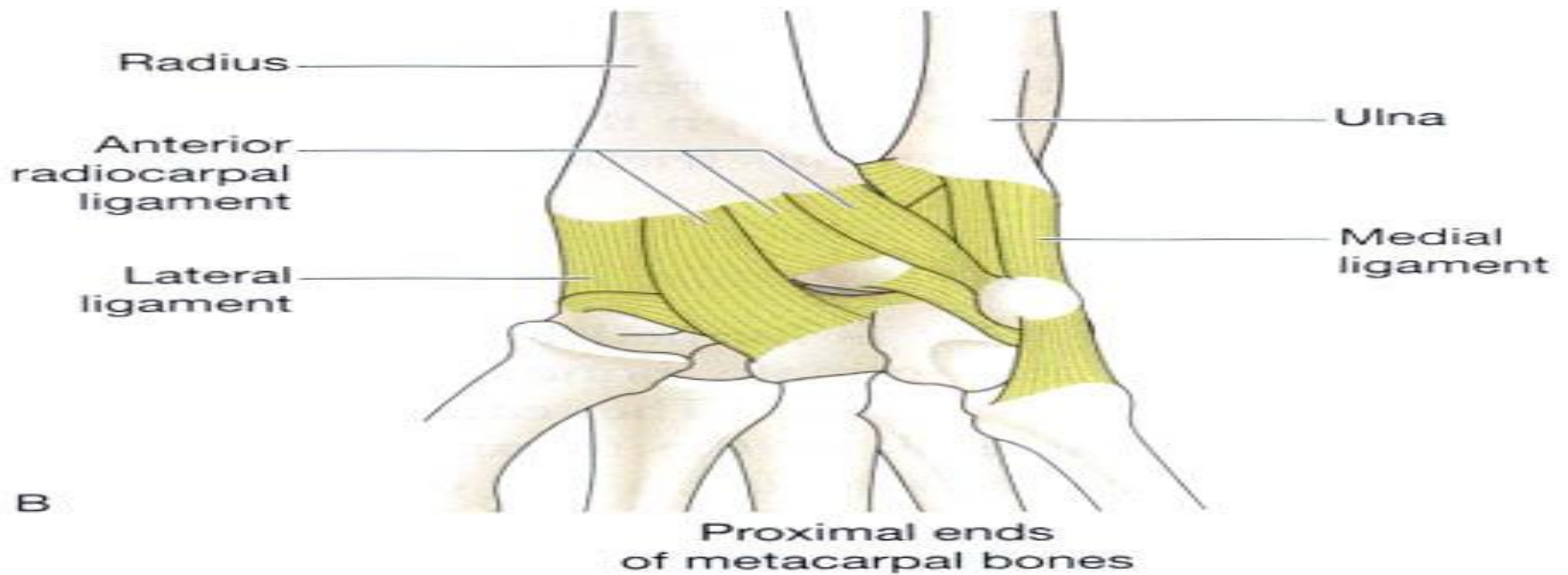
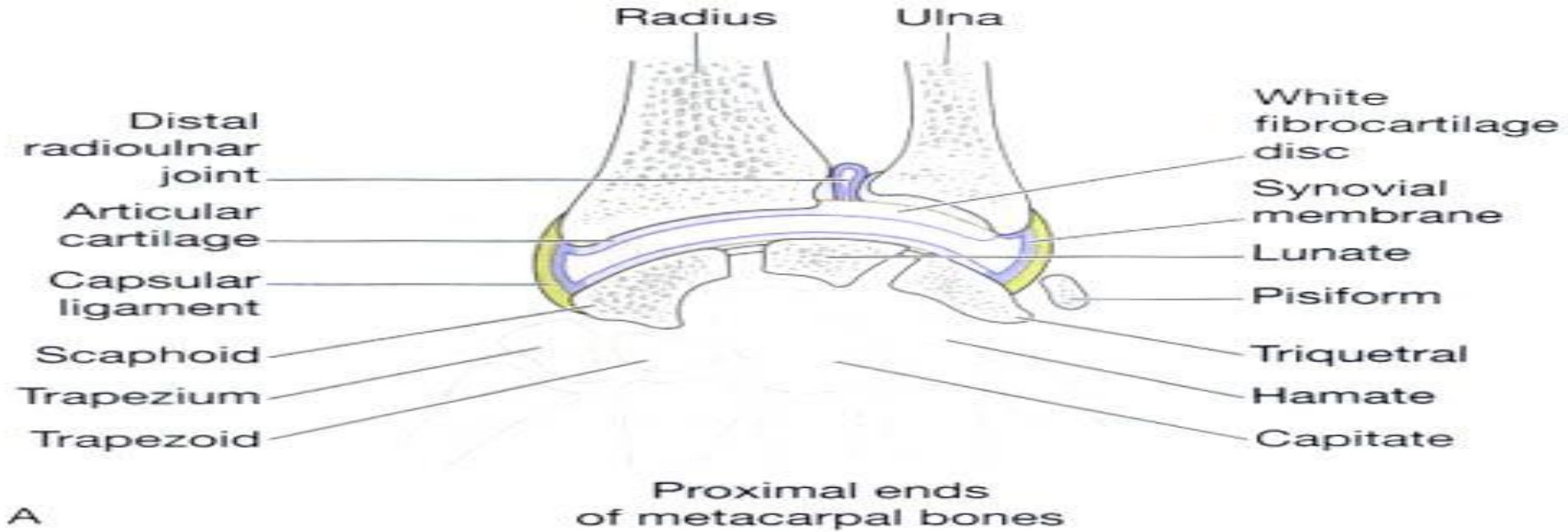
- Origin: lateral epicondyle of humerus & upper part of ulna; inserted into the lateral surface of upper third of radius.
- Rotates radioulnar joints, changing hand from the writing to anatomical position, i.e. supination.
- **Movements**
- Pronation: pronator teres.
- Supination: supinator and biceps.

d) Wrist joint

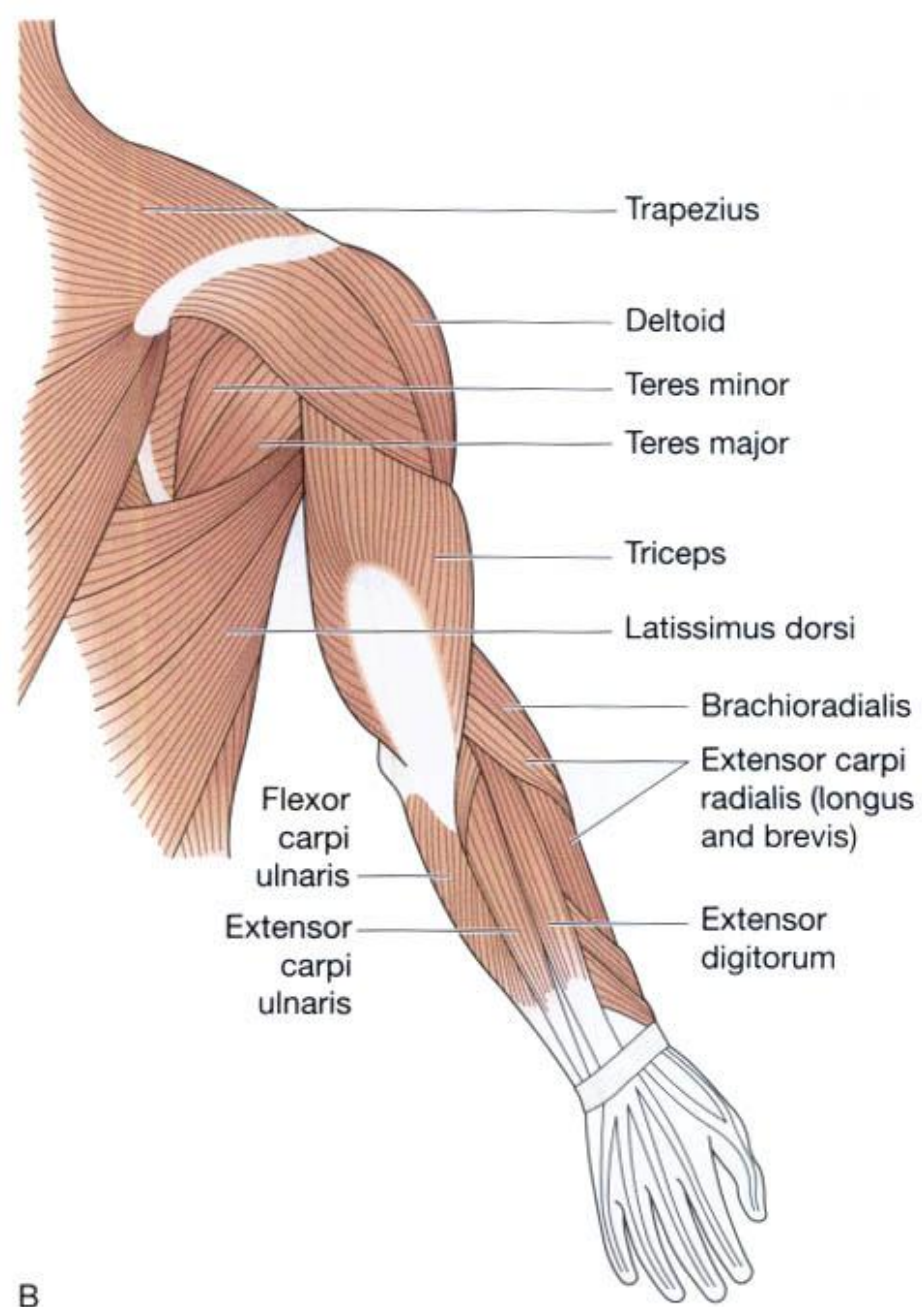
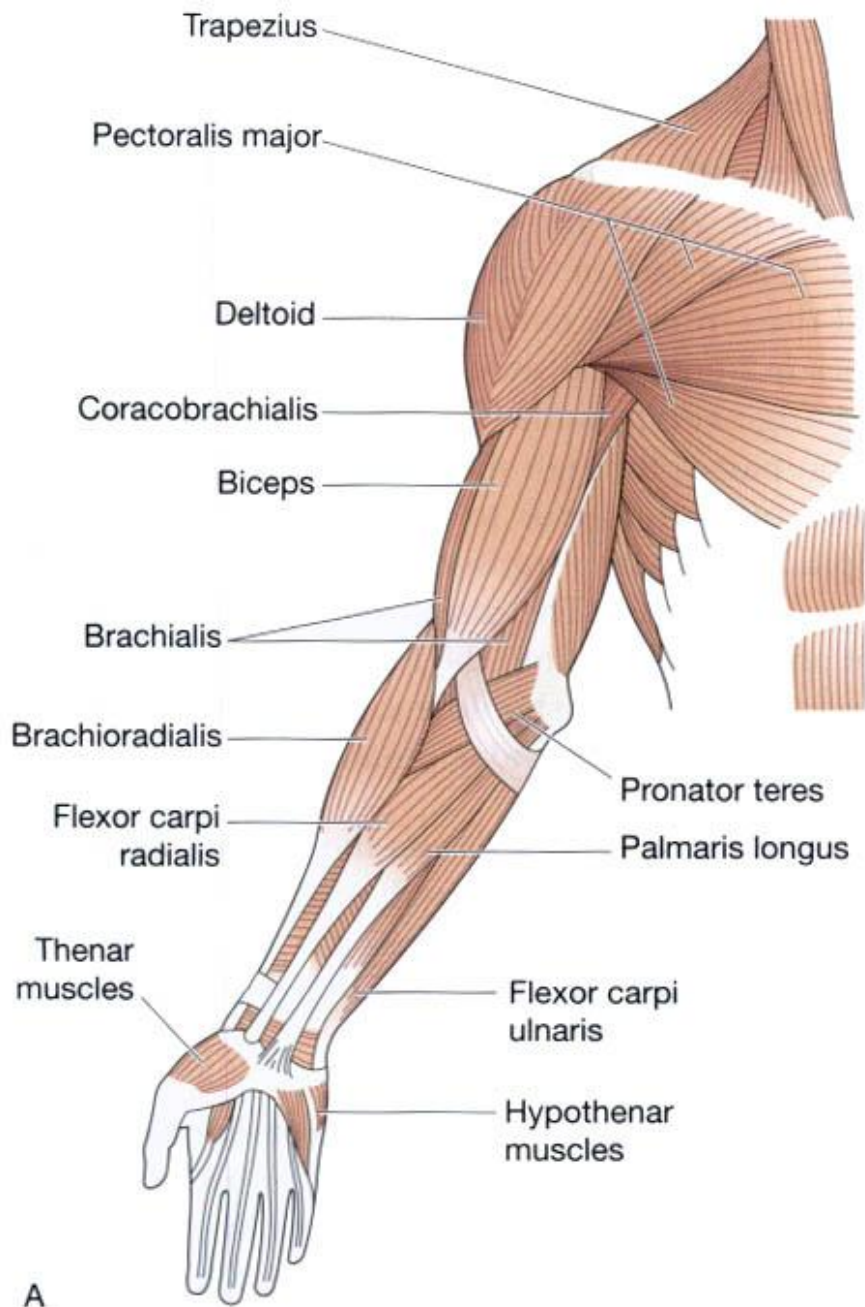
- A condyloid joint between the distal end of the radius and the proximal ends of the scaphoid, lunate and triquetral.
- A disc of white fibrocartilage separates the ulna from the joint cavity and articulates with the carpal bones. It also separates the inferior radioulnar joint from the wrist joint.
- Extracapsular structures consist of medial and lateral ligaments and anterior and posterior radiocarpal ligaments.
- **Muscles and movements**
- **Muscles**
 1. **Flexor carpi radialis.** Lies on the anterior surface of the forearm.
 - Originates from the medial epicondyle of the humerus and is inserted into the second and third metacarpal bones.
 - Flexes the wrist joint, and when acting with the extensor carpi radialis, abducts the joint.

- 2. Flexor carpi ulnaris.** Lies on the medial aspect of the forearm. It originates from the medial epicondyle of the humerus and the upper parts of the ulna and is inserted into the pisiform, the hamate and the fifth metacarpal bones. It flexes the wrist, and when acting with the extensor carpi ulnaris, adducts the joint.
- 3. Extensor carpi radialis longus and brevis.** These lie on the posterior aspect of the forearm. The fibres originate from the lateral epicondyle of the humerus and are inserted by a long tendon into the second and third metacarpal bones. They extend and abduct the wrist.
- 4. Extensor carpi ulnaris.** Lies on the posterior surface of the forearm. It originates from the lateral epicondyle of the humerus and is inserted into the fifth metacarpal bone. It extends and adducts the wrist.

- **Movements**
- Flexion: flexor carpi radialis and the flexor carpi ulnaris.
- Extension: extensors carpi radialis (longus and brevis)
- and the extensor carpi ulnaris.
- Abduction: flexor and extensors carpi radialis.
- Adduction: flexor and extensor carpi ulnaris.



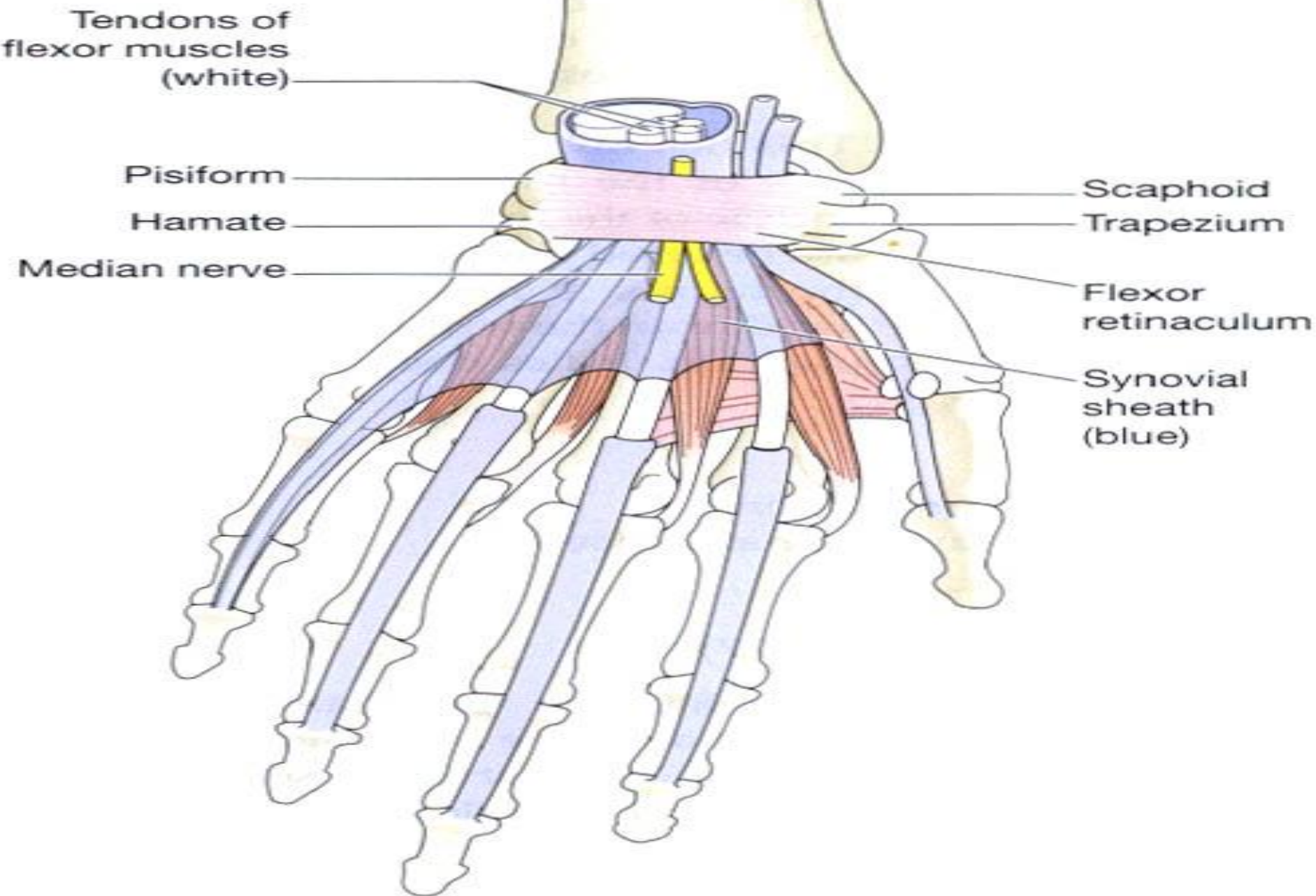
The wrist and distal radio-ulnar joint



Muscles of the upper limb

- **Joints of the hands and fingers**
- There are synovial joints between the carpal bones, between the carpal and metacarpal bones, between the metacarpal bones and proximal phalanges and between the phalanges.
- The powerful movements that occur at these joints are produced by muscles in the forearm which have tendons extending into the hand.
- The **flexor retinaculum**; a strong fibrous band that stretches across the front of the carpal bones, enclosing their concavity and forming the carpal tunnel.

- The tendons of flexor muscles of the wrist joint and the fingers and the median nerve pass through the carpal tunnel, the retinaculum holding them close to the bones.
- Synovial membrane forms sleeves around these tendons in the carpal tunnel and extends some way into the palm of the hand.
- Synovial sheaths also enclose the tendons on the flexor surfaces of the fingers. Synovial fluid prevents friction that might damage the tendons as they move over the bones.
- The **extensor retinaculum**; a strong fibrous band that extends across the back of the wrist.
- Tendons of muscles that extend the wrist and finger joints are encased in synovial membrane under the retinaculum.
- The synovial sheaths are less extensive than on the flexor aspect.
- The synovial fluid secreted prevents friction.



The carpal tunnel & synovial sheaths

Hip joint

- Ball and socket joint formed by the cup-shaped acetabulum of the innominate bone and the almost spherical head of the femur.
- The capsular ligament includes most of the neck of the femur. The cavity is deepened by the acetabular labrum, a ring of fibrocartilage attached to the rim of the acetabulum. This adds stability to the joint without limiting its range of movement.
- The ligament of the head of the femur extends from the shallow depression in the middle of the head of the femur to the acetabulum. It conveys a blood vessel to the head of the femur.
- Synovial membrane covers both sides of the acetabular labrum and forms a sleeve around the ligament of the head of the femur.
- 3 important ligaments surround and strengthen the capsule.
- They are the iliofemoral, ischiofemoral and pubofemoral ligaments.

Muscles and movements

• **Muscles**

- 1. Psoas muscle.** Arises from the transverse processes and bodies of the lumbar vertebrae.
 - Passes across the flat part of the ilium and behind the inguinal ligament to be inserted into the femur.
 - Together with the iliacus it flexes the hip joint.
- 2. Iliacus muscle.** Lies in the iliac fossa of the innominate bone.
 - Originates from the iliac crest, passes over the iliac fossa and joins the tendon of the psoas muscle to be inserted into the lesser trochanter of the femur.
 - Iliacus and psoas flexes the hip joint.

- 3. Quadriceps femoris.** Group of 4 muscles lying on the front and sides of the thigh; the rectus femoris and three vasti.
- The rectus femoris originates from the ilium and the three vasti from the upper end of the femur. Together they pass over the front of the knee joint to be inserted into the tibia by the patellar tendon.
 - Only the rectus femoris flexes the hip joint.
 - Together the group acts as a very strong extensor of the knee joint.
- 4. Gluteal muscles.** Consist of the gluteus maximus, medius and minimus which together form the fleshy part of the buttock.
- They originate from the ilium and sacrum and are inserted into the femur.
 - They cause extension, abduction and medial rotation at the hip joint.

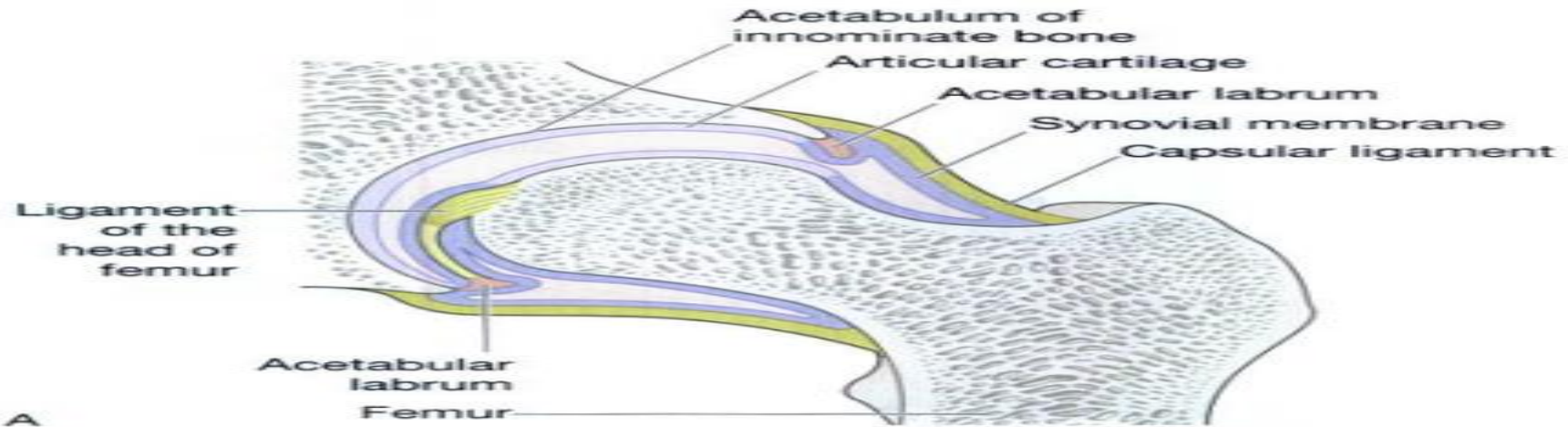
5. Sartorius. Longest muscle in the body and crosses both the hip and knee joints.

- Originates from the anterior superior iliac spine and passes obliquely across the hip joint, thigh and knee joint to be inserted into the medial surface of the upper part of the tibia.
- Associated with flexion and abduction at the hip joint and flexion at the knee.

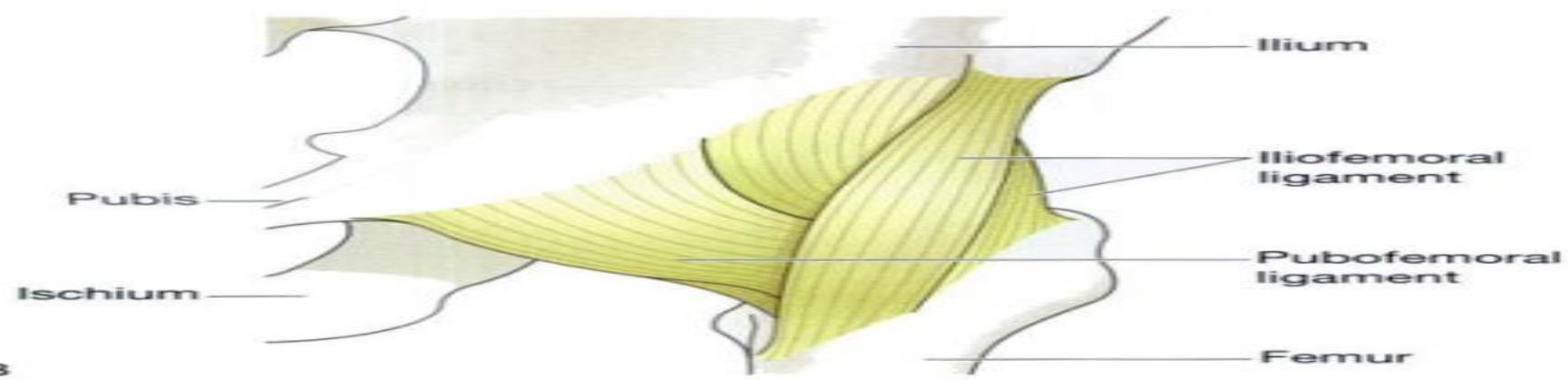
6. Adductor group. Lies on the medial aspect of the thigh.

- They originate from the pubic bone and are inserted into the linea aspera of the femur.
- They adduct and medially rotate the thigh.

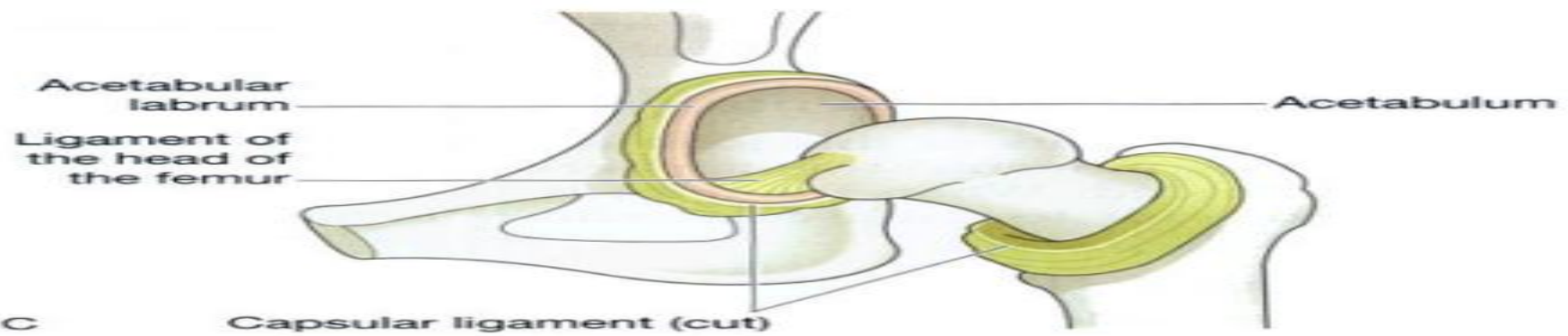
- **Movements**
- Flexion: psoas, iliacus, rectus femoris and sartorius.
- Extension: gluteus maximus and the hamstrings.
- Abduction: gluteus medius and minimus, sartorius and others.
- Adduction: adductor group.
- Lateral rotation: mainly gluteal muscles and adductor group.
- Medial rotation: gluteus medius and minimus and others.



A

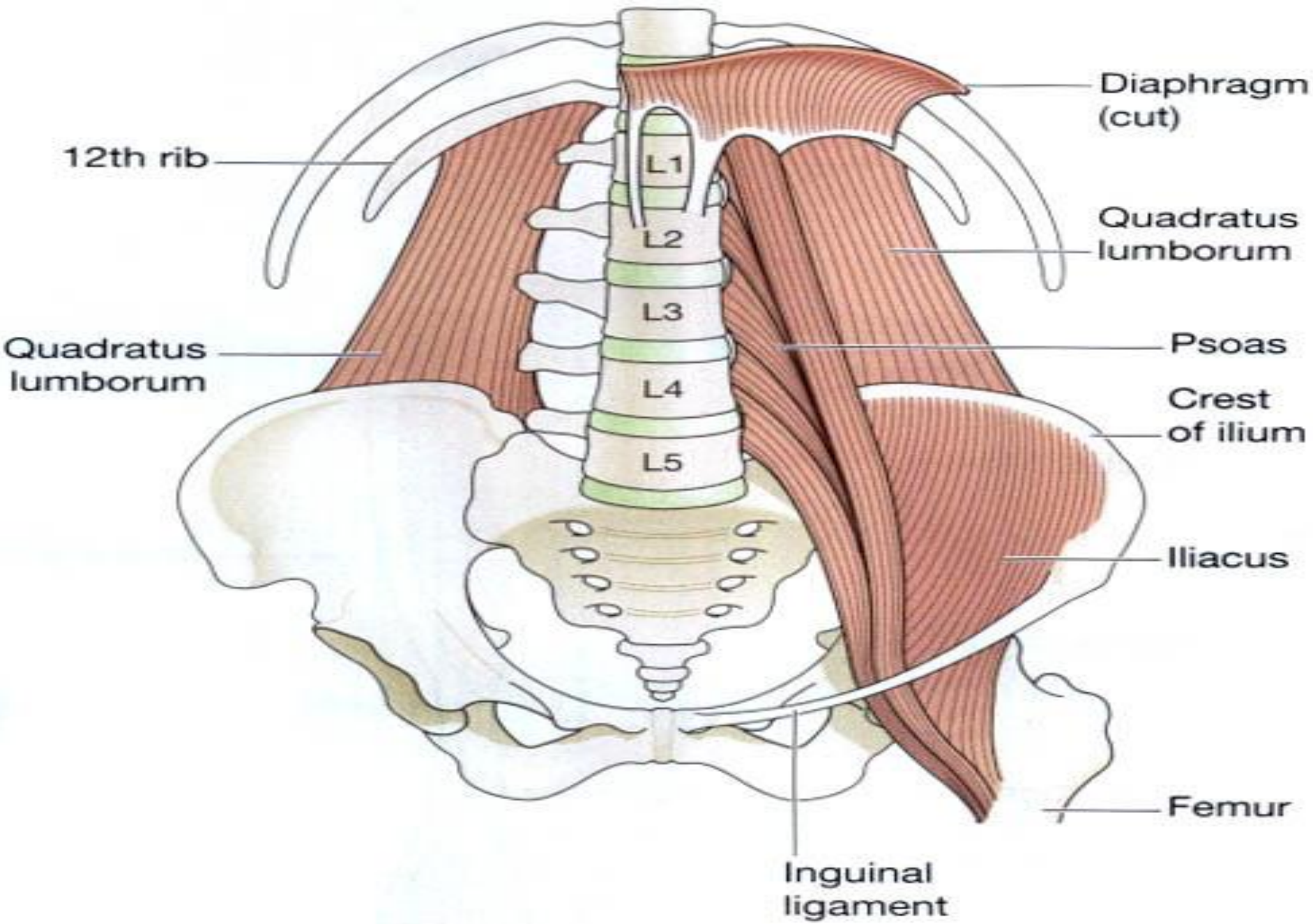


B



C

Hip joint

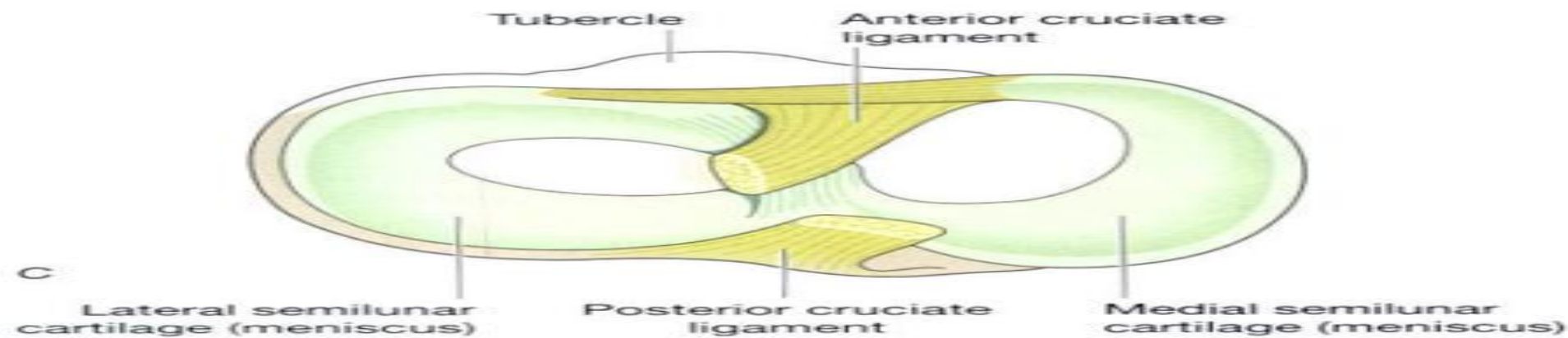
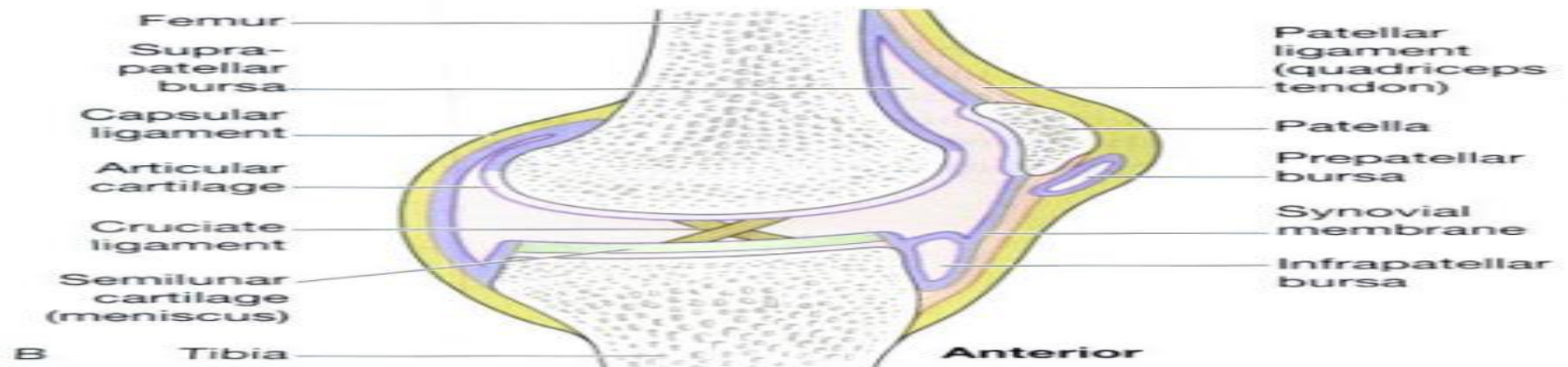
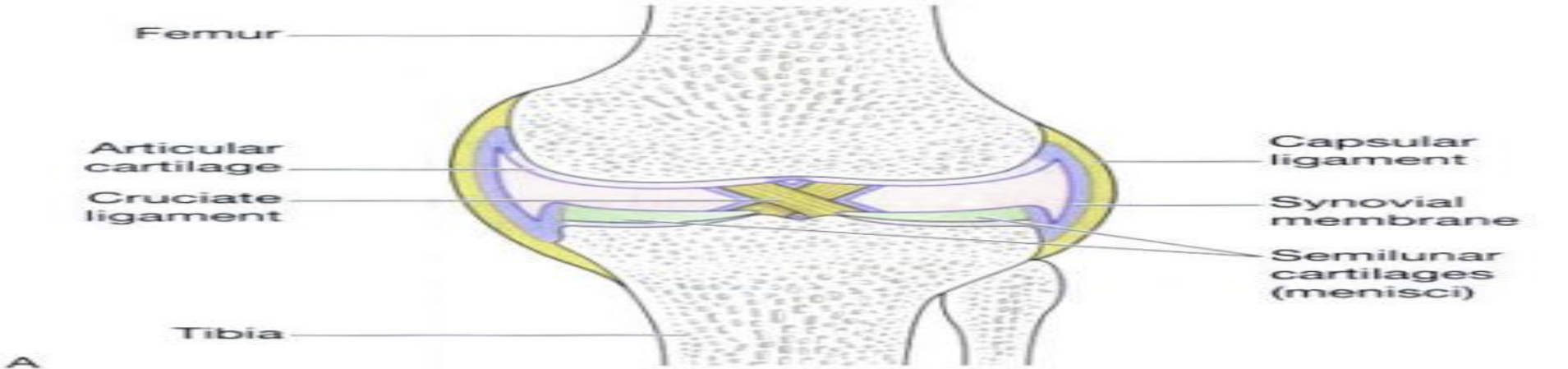


Muscles of posterior abdominal wall & pelvis which flex the hip joint

Knee joint

- Largest and most complex joint.
- It is a hinge joint formed by the condyles of the femur, the condyles of the tibia and the posterior surface of the patella.
- The anterior part of the capsule consists of the tendon of the quadriceps femoris muscle which also supports the patella.
- Intracapsular structures include **two cruciate ligaments** that cross each other, extending from the intercondylar notch of the femur to the intercondylar eminence of the tibia. They help to stabilise the joint.
- Semilunar cartilages or menisci are incomplete discs of white fibrocartilage lying on top of the articular condyles of the tibia. They are wedge-shaped, being thicker at their outer edges. They help to stabilise the joint by preventing lateral displacement of the bones.

- **Bursae and pads** of fat are numerous. They prevent friction between a bone and a ligament or tendon and between the skin and the patella.
- **Synovial membrane** covers the cruciate ligaments and the pads of fat. The menisci are not covered with synovial membrane because they are weight bearing.
- The most important strengthening ligaments are the medial and lateral ligaments.
- **Muscles and movements**
- Possible movements at this joint are flexion, extension and a rotatory movement which 'locks' the joint when it is fully extended.
- When the joint is locked, balance is maintained with less muscular effort than when it is flexed.



Knee joint

- **Muscles**

1. **Hamstring muscles.** Lie on the posterior aspect of the thigh.

- They originate from the ischium and are inserted into the upper end of the tibia.
- They are biceps **femoris, semi-membranosus and semi-tendinosus muscles.**
- They flex the knee joint.

2. **Gastrocnemius.** Forms the bulk of the calf of the leg.

- Arises by two heads, one from each condyle of the femur, and passes down behind the tibia to be inserted into the calcaneus by the calcanean tendon (Achilles tendon).
- It crosses both knee and ankle joints, causing flexion at the knee and plantarflexion at the ankle.

Hamstring Muscles

Biceps Femoris

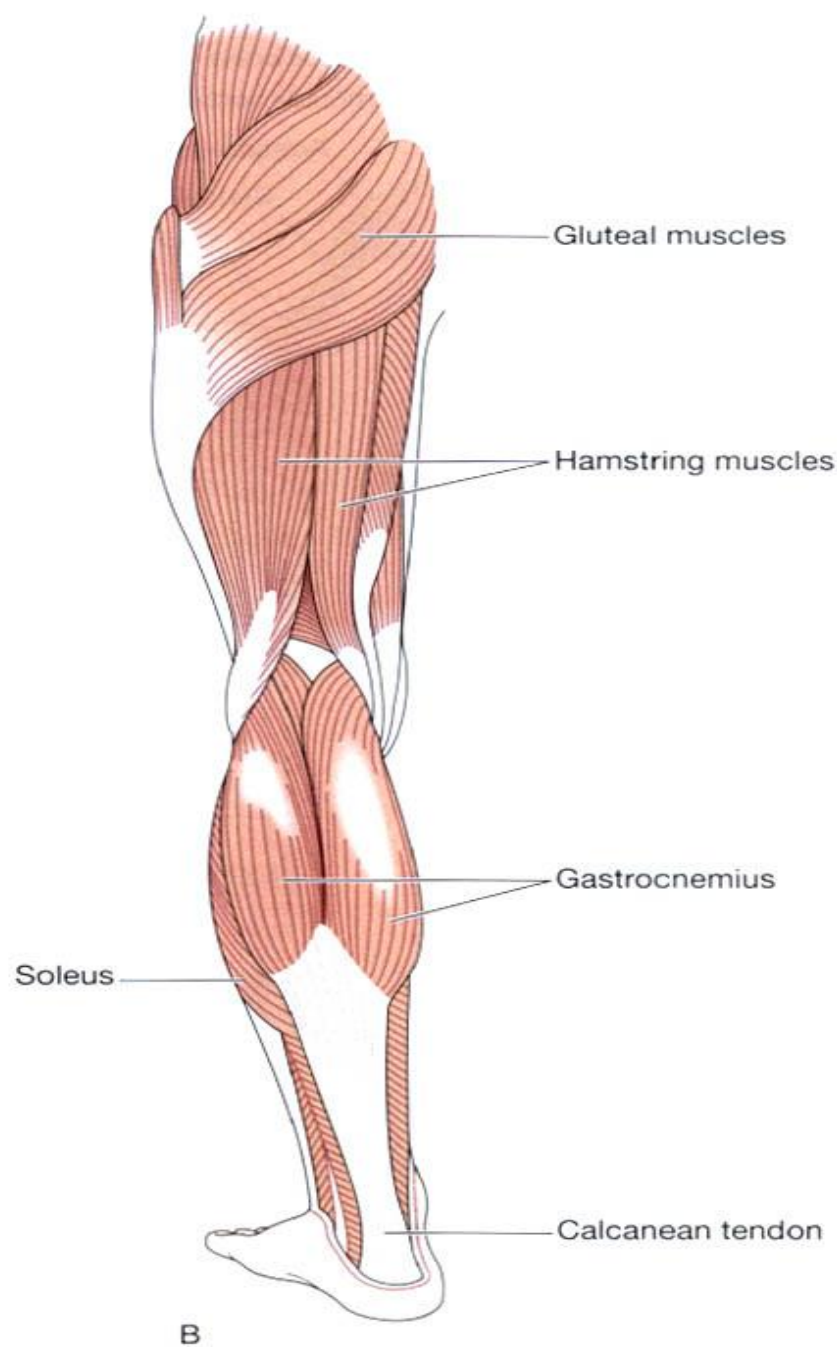
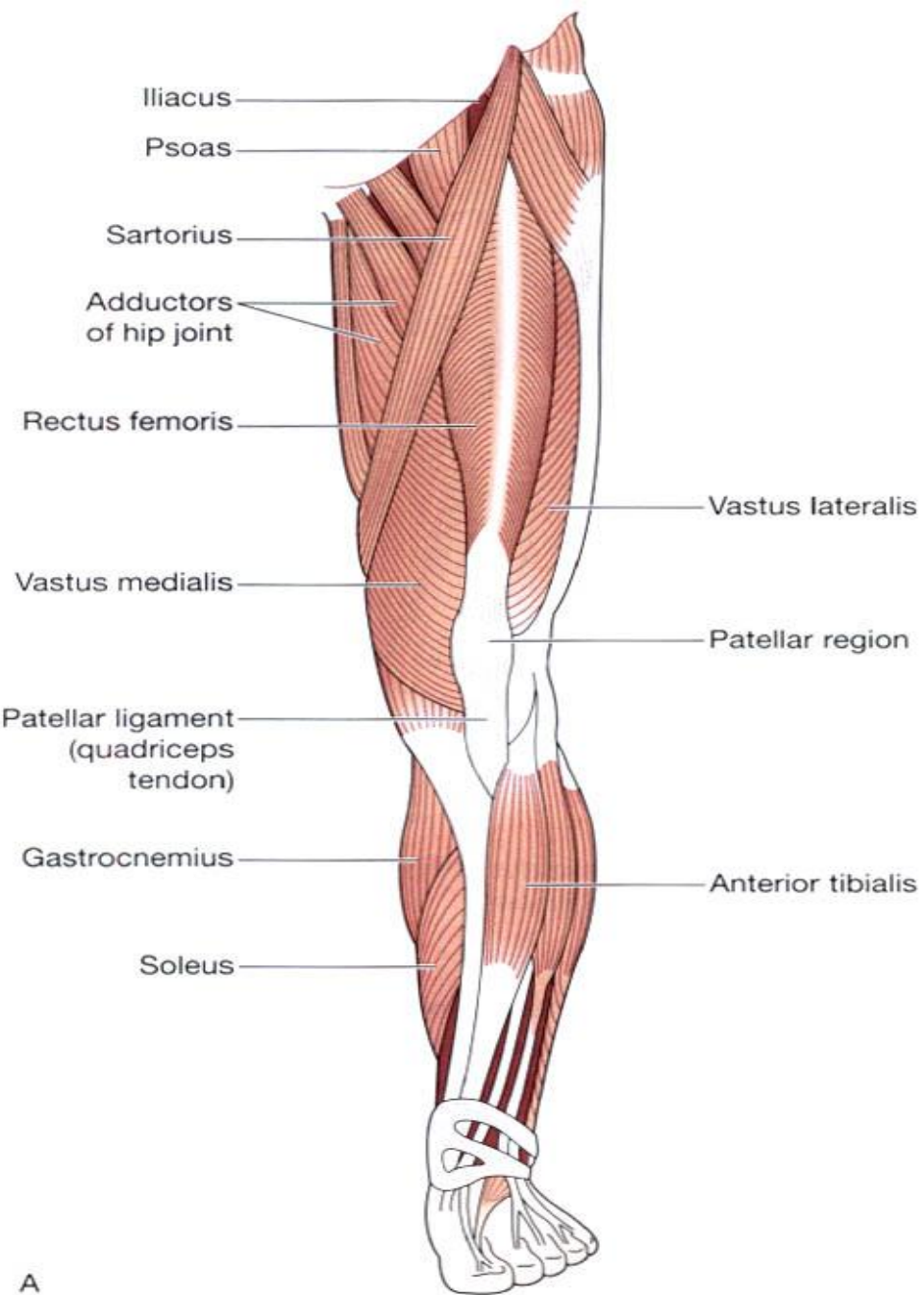
Semitendinosus

Semimembranosus



3. **Quadriceps femoris** . Extends the knee joint.

- **Movements**
- Flexion (bending backwards): gastrocnemius and hamstrings.
- Extension (straightening): quadriceps femoris muscle.



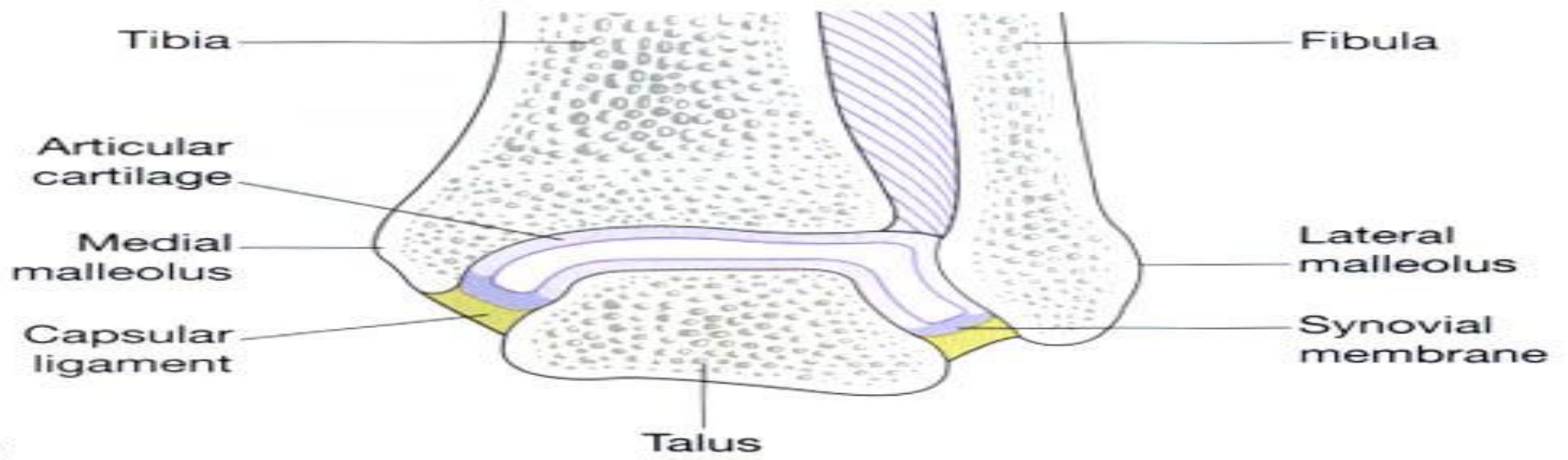
A

B

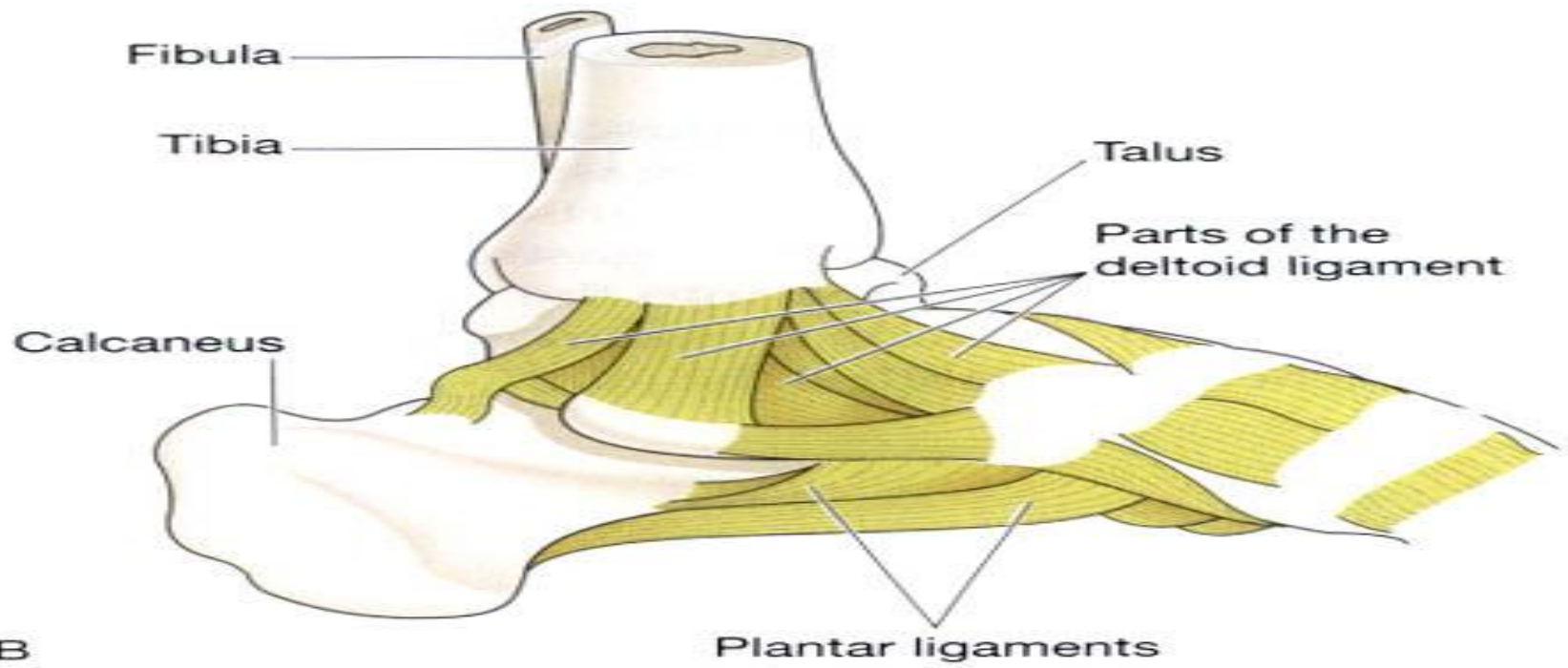
Main muscles of the lower limb; anterior, posterior ¹¹⁸⁶

- **Ankle joint**
- Hinge joint formed by the distal end of the tibia and its malleolus (medial malleolus), the distal end of the fibula (lateral malleolus) and the talus.
- 4 important ligaments strengthen this joint. They are the **deltoid and anterior, posterior, medial and lateral** ligaments.
- **Muscles and movements**
- **Muscles**
- 1. **Anterior tibialis muscle.** Originates from the upper end of the tibia, lies on the anterior surface of the leg and is inserted into the middle cuneiform bone by a long tendon. It is associated with dorsiflexion of the foot.

- 2. Soleus.** One of the main muscles of the calf of the leg, lying immediately deep to the gastrocnemius.
- Originates from the heads and upper parts of the fibula and the tibia.
 - Its tendon joins that of the gastrocnemius so that they have a common insertion into the calcaneus by the calcanean (Achilles) tendon.
 - It causes plantar-flexion at the ankle and helps to stabilise the joint when standing



A



B

Left ankle joint

3. Gastrocnemius. a powerful plantarflexor.

- **Movements**
- Flexion (dorsiflexion): anterior tibialis assisted by the muscles which extend the toes.
- Extension (plantarflexion): gastrocnemius and soleus assisted by the muscles which flex the toes.
- The movements of inversion and eversion occur between the tarsal bones and not at the ankle joint.

- **Joints of the foot and toes**
- Synovial joints are between the tarsal bones, between the tarsal and metatarsal bones, between the metatarsals and proximal phalanges and between the phalanges.
- Movements are produced by muscles in the leg with long tendons which cross the ankle joint, and by muscles of the foot.
- The tendons crossing the ankle joint are encased in synovial sheaths and are held close to the bones by strong transverse ligaments. They move smoothly within their sheaths as the joints move.
- In addition to moving the joints of the foot these muscles support the arches of the foot and help to maintain body balance.

THE MUSCULAR SYSTEM

MUSCLES OF THE FACE

- 1. Occipitofrontalis (unpaired).** Consists of a posterior muscular part over the occipital bone (**occipitalis**), an anterior part over the frontal bone (**frontalis**) & an extensive flat tendon or **aponeurosis** that stretches over the dome of the skull and joins the 2 muscular parts.
 - **Function:** Raises the eyebrows.
- 2. Levator palpebrae superioris.** Extends from the posterior part of the orbital cavity to the upper eyelid.
 - **Function:** It raises the eyelid.
- 3. Orbicularis oculi.** Surrounds the eye, eyelid & orbital cavity.
 - **Function:** Closes the eye & when strongly contracted 'screws up' the eyes.
- 4. Buccinator.** Flat muscle of the cheek. Draws the cheeks in towards the teeth in chewing & in forcible expulsion of air from the mouth ('the trumpeter's muscle').

5. **Orbicularis oris (unpaired).** Surrounds the mouth & blends with the muscles of the cheeks.
 - **Function:** Closes the lips & when strongly contracted, shapes the mouth for whistling.
6. **Masseter.** Broad muscle, extending from the zygomatic arch to the angle of the jaw.
 - **Function:** In chewing it draws the mandible up to the maxilla, closing the jaw & exerts considerable pressure on the food.
7. **Temporalis.** Covers the squamous part of the temporal bone. It passes behind the zygomatic arch to be inserted into the coronoid process of the mandible.
 - **Function:** Closes the mouth & assists with chewing.
8. **Pterygoid.** Extends from the sphenoid bone to the mandible.
 - **Function:** Closes the mouth & pulls the lower jaw forward.

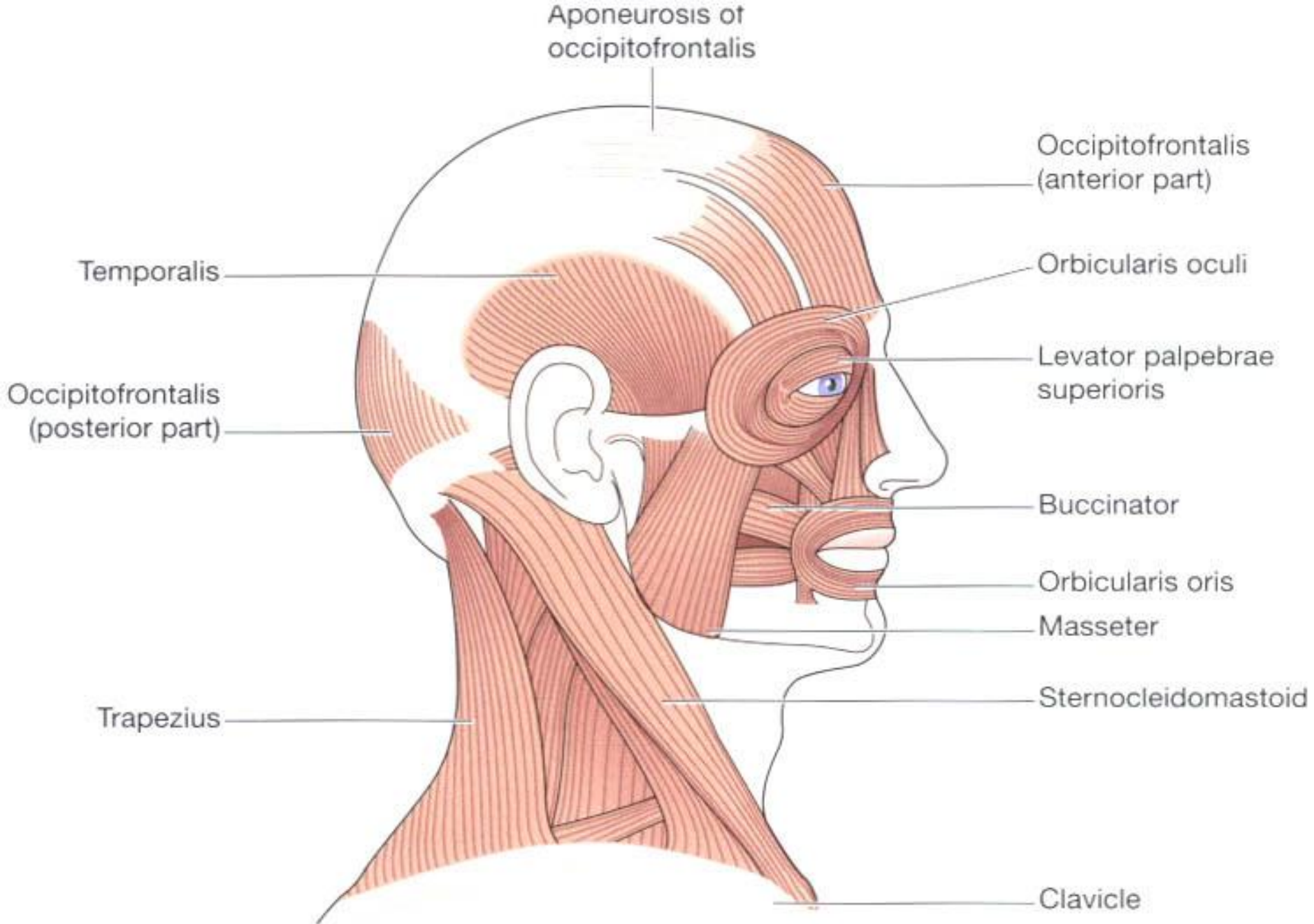
MUSCLES OF THE NECK

1. Sternocleidomastoid.

- Arises from the manubrium of the sternum & the clavicle & extends upwards to the mastoid process of the temporal bone.
- **Function:**
 - Assists in turning the head from side to side.
 - When the muscle on one side contracts it draws the head towards the shoulder.
 - When both contract at the same time they flex the cervical vertebrae or draw the sternum & clavicles upwards when the head is maintained in a fixed position, e.g. in forced respiration.

2. Trapezius.

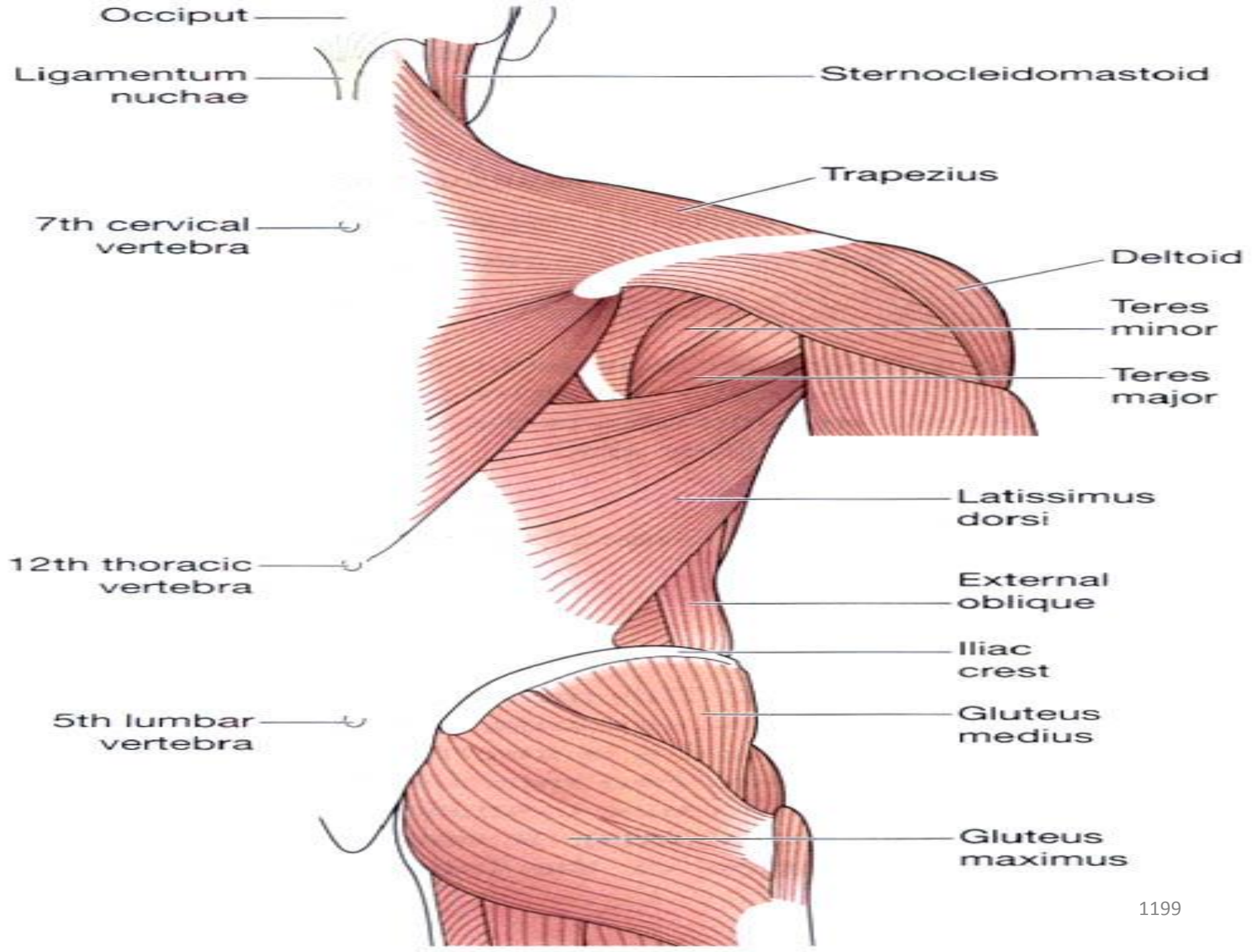
- Covers the shoulder & the back of the neck.
 - Upper attachment: to the **occipital protuberance**
 - Medial attachment: to the **transverse processes** of the cervical and thoracic vertebrae
 - Lateral attachment: to the **clavicle** & to the **spinous & acromion** processes of the **scapula**.
- **Function:**
 - pulls the head backwards,
 - squares the shoulders
 - controls the movements of the scapula when the shoulder joint is in use.



Muscles of the face, head and neck

MUSCLES OF THE BACK

- 6 pairs of large muscles
- Arrangement of these muscles is the same on each side of the vertebral column.
- They are:
 - trapezius
 - teres major
 - psoas
 - latissimus dorsi
 - quadratus lumborum
 - sacrospinalis.



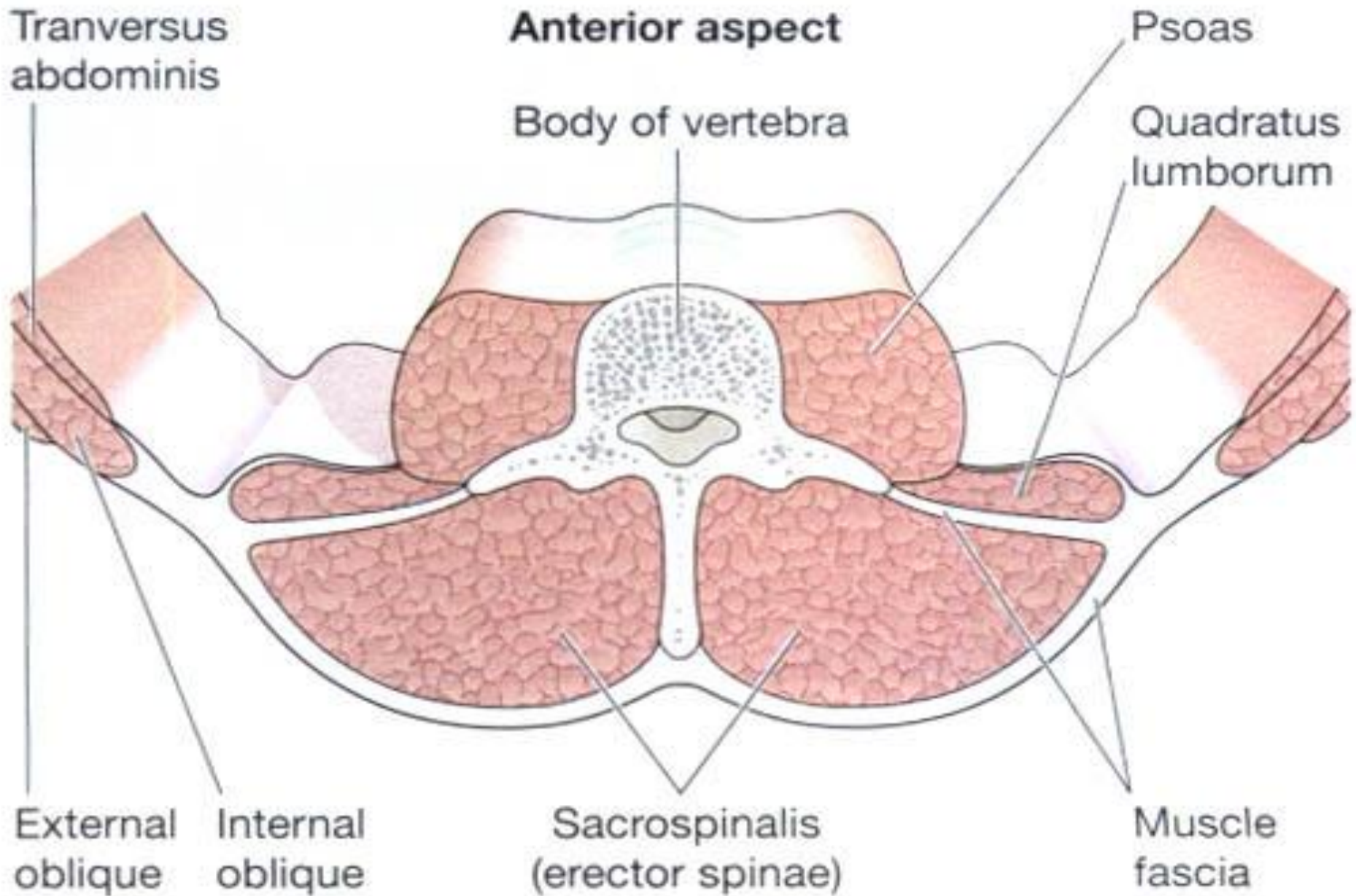
1. Quadratus lumborum. Originates from the iliac crest then it passes upwards, parallel & close to the vertebral column & is inserted into the 12th rib.

- **Function:**

- the 2 muscles fix the lower rib during respiration & cause extension of the vertebral column (bending backwards).
- If one muscle contracts it causes lateral flexion of the lumbar region of the vertebral column.

2. Sacrospinalis (erector spinae). Group of muscles lying between the spinous & transverse processes of the vertebrae. Originate from the sacrum & inserted into the occipital bone.

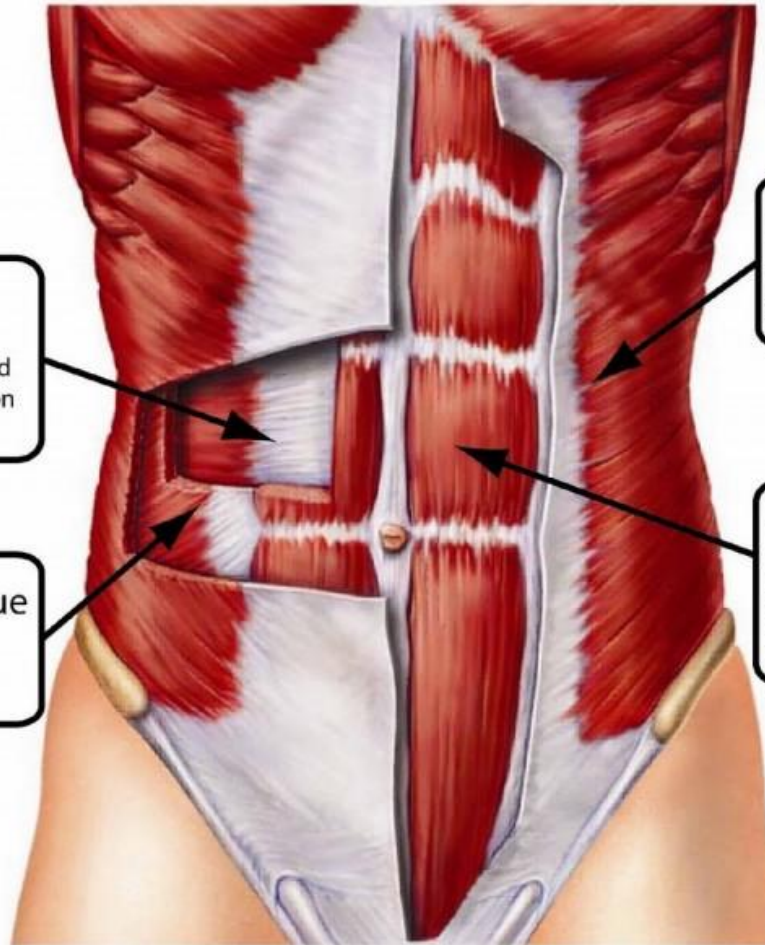
- **Function:** Their contraction causes extension of the vertebral column.



Transverse section of posterior abdominal wall ¹²⁰¹

MUSCLES OF THE ABDOMINAL WALL

- 6 pairs of muscles.
- From the surface inwards they are:
 - rectus abdominis
 - external oblique
 - internal oblique
 - transversus abdominis
 - quadratus lumborum
 - Psoas



Transverse abdominis

Located under the obliques, it is the deepest of the abdominal muscles and wraps around your spine for protection and stability.

Internal abdominal oblique

Located under the external obliques, running in the opposite direction.

External abdominal oblique

Located on the side and front of the abdomen.

Rectus abdominis

Located along the front of the abdomen, this is the most well-known abdominal. Often referred to as the "six pack."

- Anterior abdominal wall is divided longitudinally by the **linea alba** which extends from the xiphoid process of the sternum to the symphysis pubis.

1. Rectus abdominis. Most superficial muscle.

- Broad & flat, originating from the transverse part of the pubic bone then passing upwards to be inserted into the lower ribs & the xiphoid process of the sternum.
- Medially the 2 muscles are attached to the linea alba.

2. External oblique. Extends from the lower ribs downwards & forward to be inserted into the iliac crest & by an aponeurosis, to the linea alba.

3. Internal oblique. Lies deep to the external oblique.

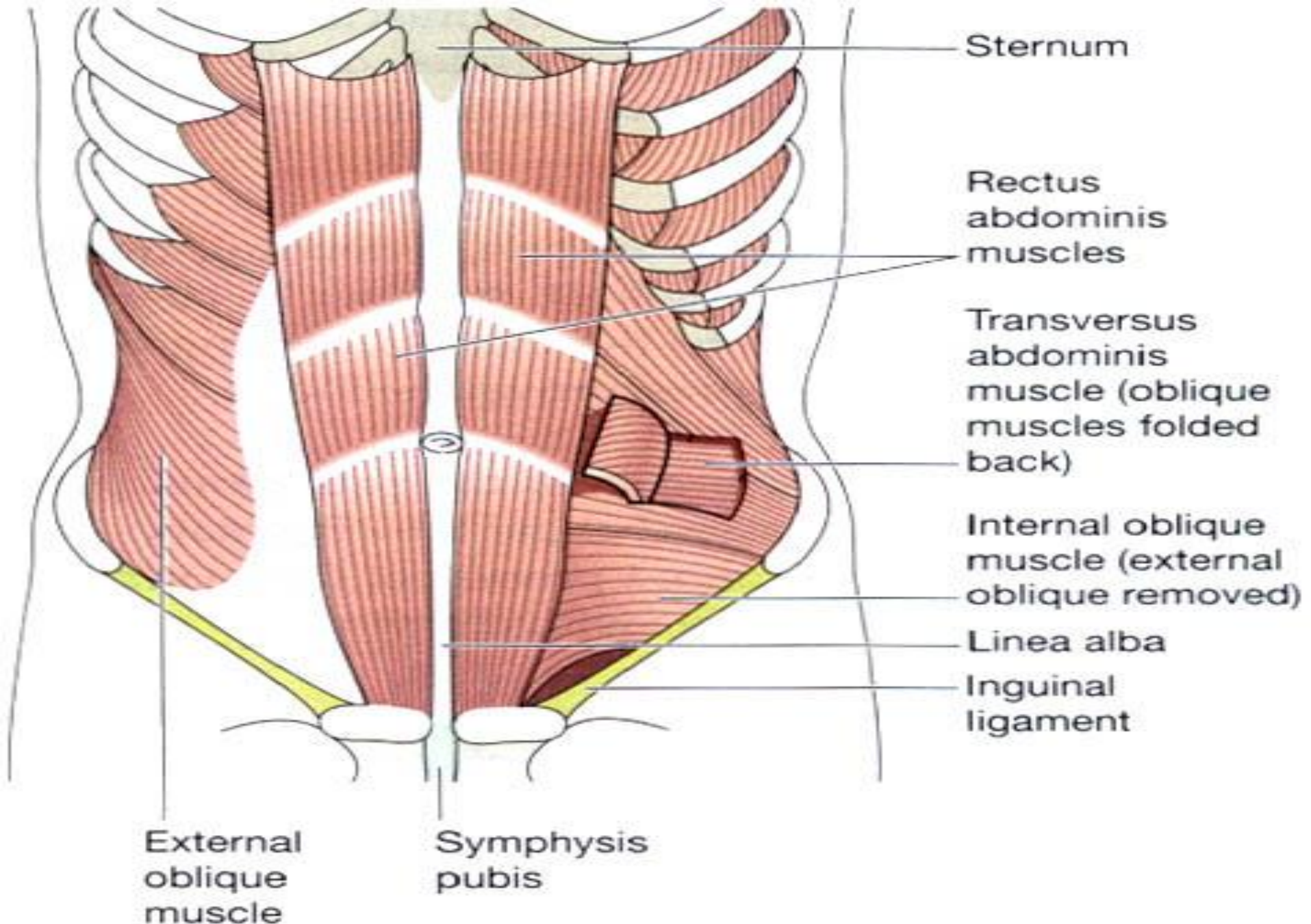
- Arises from the iliac crest & by a broad band of fascia from the spinous processes of the lumbar vertebrae.
- Fibres pass upwards towards the midline to be inserted into the lower ribs & by an **aponeurosis**, into the linea alba.
- Fibres are at right angles to those of the external oblique.

4. Transversus abdominis. Deepest muscle of the abdominal wall.

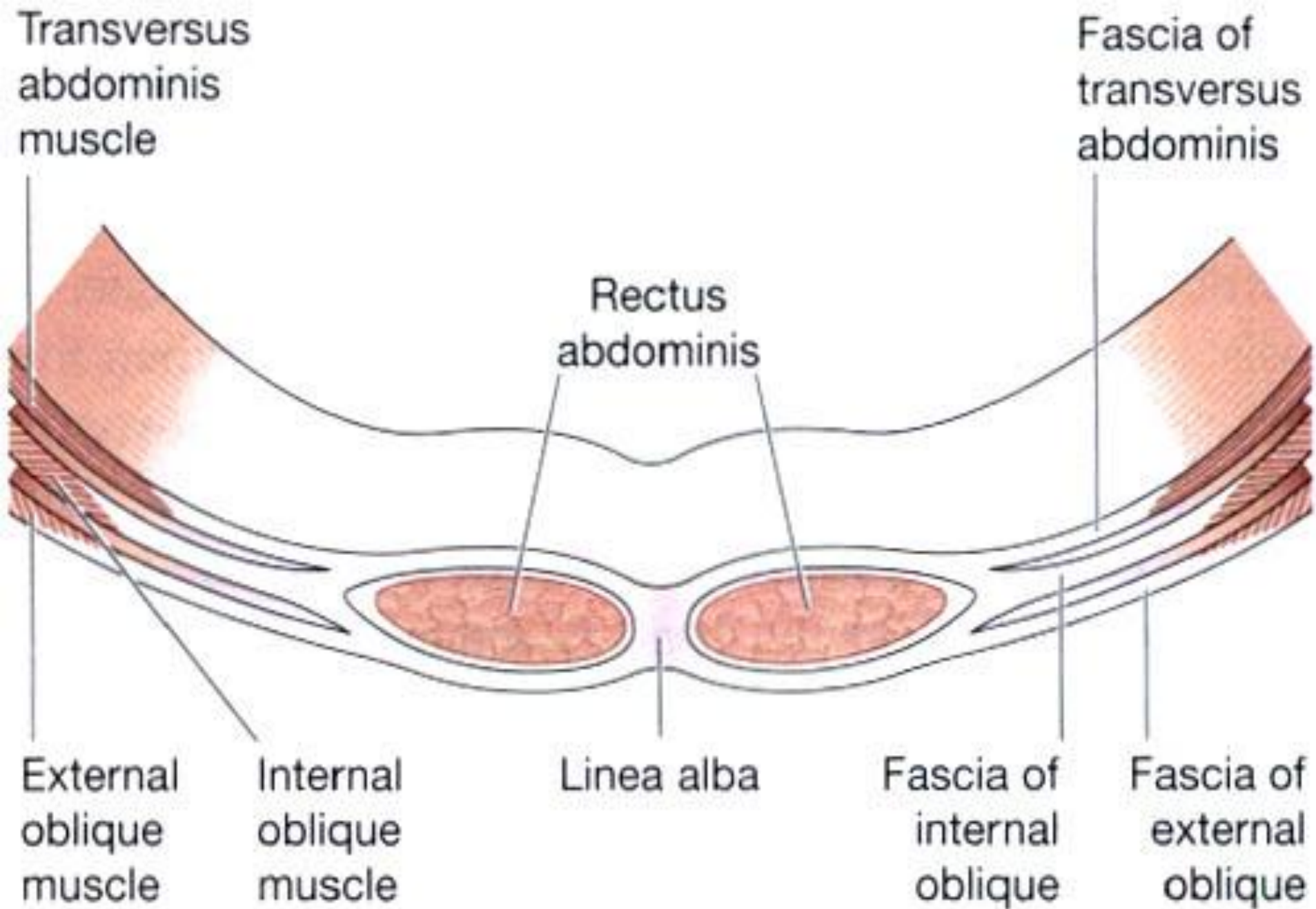
- Fibres arise from the iliac crest & the lumbar vertebrae & pass across the abdominal wall to be inserted into the linea alba by an **aponeurosis**.
- Fibres are at right angles to those of the rectus abdominis.

Functions

- Main function of the 4 pairs of muscles is to form the strong muscular anterior wall of the abdominal cavity. When the muscles contract together they:
 - compress the abdominal organs
 - flex the vertebral column in the lumbar region
- Contraction of the muscles on one side only bends the trunk towards that side.
- Contraction of the oblique muscles on one side rotates the trunk.



Anterior abdominal wall muscles



Transverse section of muscles and fascia of anterior abdominal wall

Inguinal canal

- Canal, 2.5 to 4 cm long & passes obliquely through the abdominal wall.
- Runs parallel to and immediately in front of the transversalis fascia & part of the inguinal ligament.
- In the male it contains the spermatic cord
- In the female, the round ligament.
- Constitutes a weak point through which herniation may occur.

MUSCLES OF THE PELVIC FLOOR

- Pelvic floor is divided into 2 identical halves that unite along the midline.
- Each half consists of fascia & muscle.
- Muscles are:
 - levator ani
 - coccygeus.
- 1. Levator ani.** Broad flat muscle, forming the anterior part of the pelvic floor.
- Originate from the inner surface of the true pelvis & unite in the midline.
- Together they form a sling which supports the pelvic organs.

- 2. Coccygeus.** Triangular sheet of muscle & tendinous fibres situated behind the levator ani.
- Originate from the medial surface of the ischium & are inserted into the sacrum & coccyx.
 - Complete the formation of the pelvic floor which is perforated in the male by the urethra & anus; in the female by the urethra, vagina & anus.

Functions

- Pelvic floor supports the organs of the pelvis & maintains continence, i.e. resists raised intrapelvic pressure during micturition & defaecation.

THE REPRODUCTIVE SYSTEMS

Reproductive system

- Both males & females produce specialised reproductive germ cells; **gametes**.
 - **Male gametes; spermatozoa**
 - **Female gametes; ova.**
 - Contain the genetic material/genes, on chromosomes, which pass inherited characteristics on to the next generation.
- In other body cells there are 46 chromosomes arranged in 23 pairs but in the gametes there are only 23, one from each pair.
- Gametes are formed by **meiosis**

Functions of reproductive system

Female

1. formation of female gametes, ova
2. reception of male gametes, spermatozoa
3. provision of suitable environments for fertilisation of the ovum by spermatozoa and development of the resultant fetus
4. Parturition
5. Lactation.

Male

1. production of male gametes, spermatozoa
2. transmission of spermatozoa to the female.

FEMALE REPRODUCTIVE SYSTEM

- Divided into external & internal organs.

A) External genitalia (vulva)

- Consist of labia majora & labia minora, clitoris, vaginal orifice, vestibule, hymen & the vestibular glands (Bartholin's glands).

a) Labia majora

- 2 large folds which form the boundary of the vulva.
- Composed of skin, fibrous tissue & fat and contain large numbers of sebaceous glands.
- Anteriorly, the folds join in front of the symphysis pubis, & posteriorly they merge with the skin of the perineum.
- At puberty hair grows on the mons pubis & on the lateral surfaces of the labia majora.

b) Labia minora

- 2 smaller folds of skin between the labia majora, containing numerous sebaceous glands.
- Cleft between the labia minora is the **vestibule**.
- Vagina, urethra & ducts of the greater vestibular glands open into the vestibule.

c) Clitoris

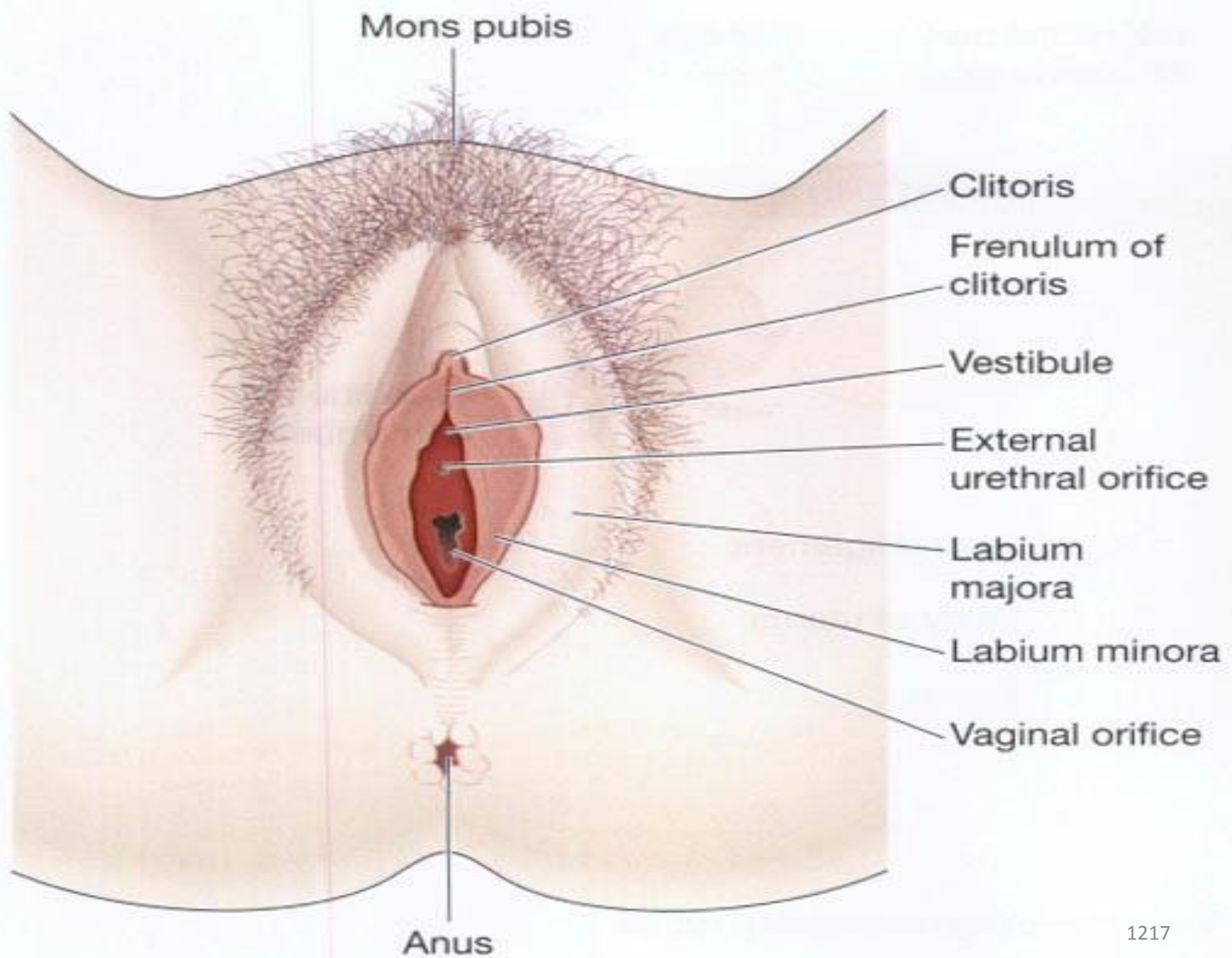
- Corresponds to the penis in the male & contains sensory nerve endings & erectile tissue.

d) Hymen

- Thin layer of mucous membrane which partially occludes the opening of the vagina. Normally incomplete to allow for passage of menstrual flow.

e) Vestibular glands (Bartholin's glands)

- Situated one on each side near the vaginal opening.
- About the size of a small pea & have ducts, opening into the vestibule immediately lateral to the attachment of the hymen. They secrete mucus that keeps the vulva moist.



Blood supply, lymph drainage & nerve supply

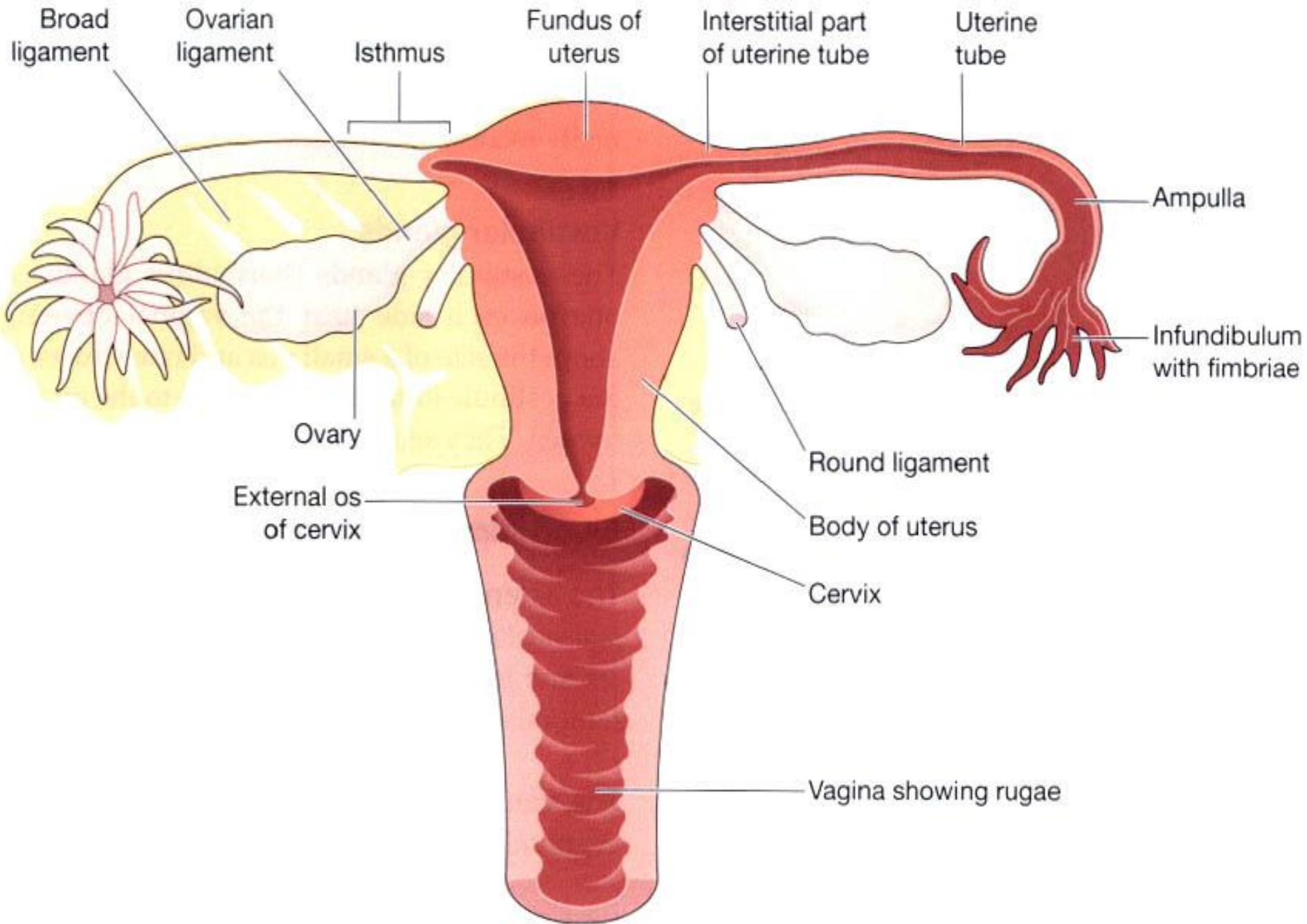
- **Arterial supply:** by branches from the **internal pudendal arteries** that branch from the internal iliac arteries and by **external pudendal arteries** that branch from the femoral arteries.
- **Venous drainage:** Forms a large plexus which eventually drains into the internal iliac veins.
- **Lymph drainage:** Through the superficial inguinal nodes.
- **Nerve supply:** by branches from pudendal nerves.
- **Perineum**
- Area extending from the base of the labia minora to the anal canal.
- Roughly triangular & consists of connective tissue, muscle and fat.
- Gives attachment to the muscles of the pelvic floor

INTERNAL GENITALIA

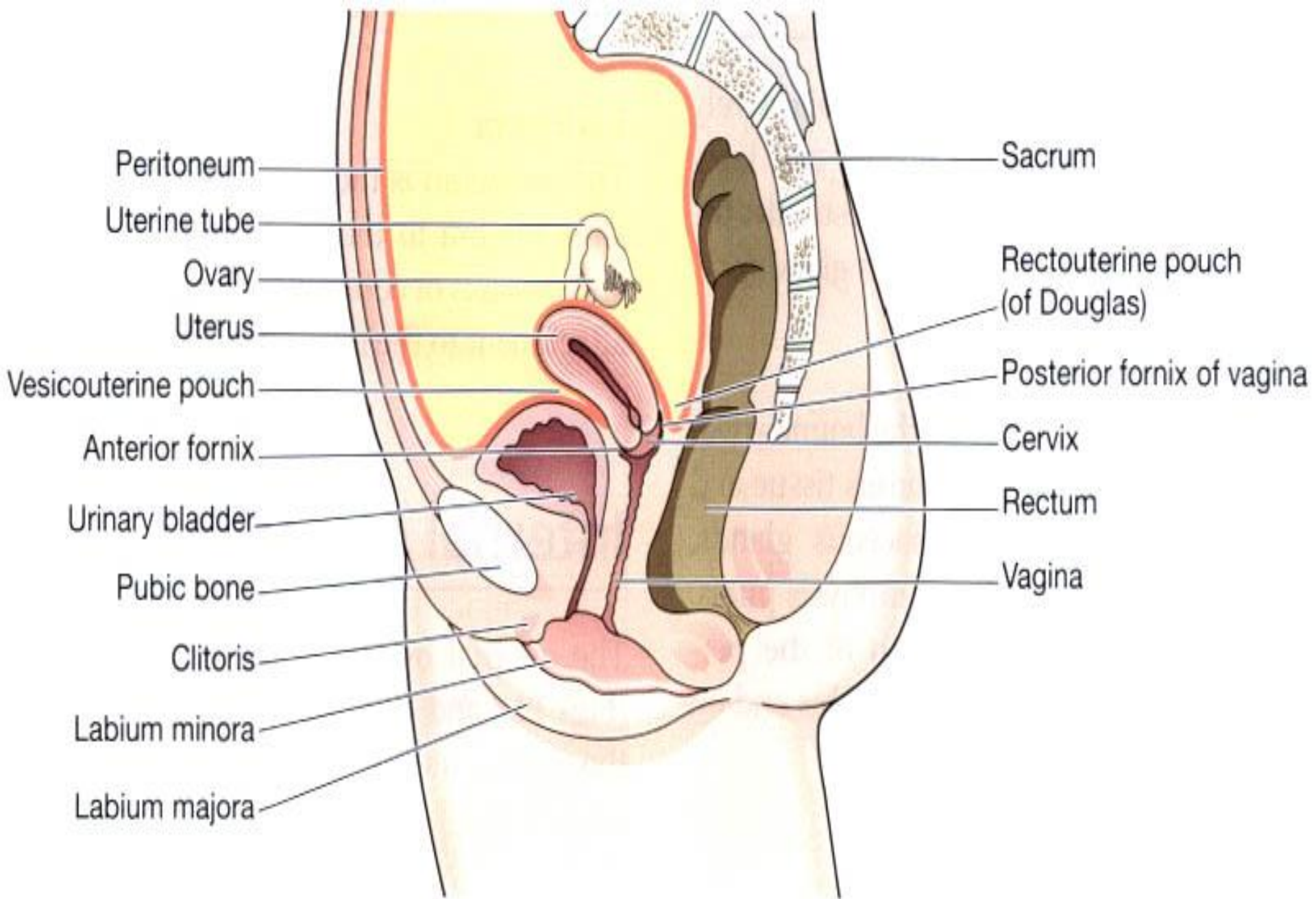
- Lie in the pelvic cavity
- Consist of vagina, uterus, 2 uterine tubes & 2 ovaries.

a) Vagina

- Fibromuscular tube lined with **stratified squamous epithelium**, connecting the external & internal organs of reproduction.
- Runs obliquely upwards & backwards at an angle of about 45° between the bladder in front & rectum & anus behind.
- Adult; anterior wall is about 7.5 cm (3 inches) long & the posterior wall about 9 cm long.
- Difference is due to the angle of insertion of the cervix through the anterior wall.



Female reproductive organs in the pelvis 1220



Female reproductive organs in the pelvis and associated structures 1224

- **Structure of the vagina**
- 3 layers:
 - an outer covering of areolar tissue,
 - a middle layer of smooth muscle
 - an inner lining of stratified squamous epithelium that forms ridges or **rugae**.
- Has no secretory glands but the surface is kept moist by cervical secretions.
- Between puberty & menopause, **Lactobacillus acidophilus** bacteria are normally present which secrete lactic acid, maintaining the pH between 4.9 and 3.5.
- Acidity inhibits the growth of most microbes that may enter the vagina from the perineum.

Blood supply, lymph drainage & nerve supply

- **Arterial supply:** by an arterial plexus formed round the vagina, derived from the uterine & vaginal arteries which are branches of the internal iliac arteries.
- **Venous drainage:** by a venous plexus, situated in the muscular wall, drains into the internal iliac veins.
- **Lymph drainage.** Through the deep & superficial iliac glands.
- **Nerve supply:** Parasympathetic fibres from the sacral outflow, sympathetic fibres from the lumbar & somatic sensory fibres from the pudendal nerves.
- **Functions of the vagina**
 - Acts as the receptacle for the penis during coitus
 - provides an elastic passageway through which the baby passes during childbirth.

b) Uterus

- Hollow muscular pear-shaped organ, flattened antero-posteriorly.
- Lies in the pelvic cavity between the urinary bladder & the rectum.
- Leans forward (anteversion), & is bent forward (anteflexion) almost at right angles to the vagina, so that its anterior wall rests partly against the bladder below, & forming the **vesicouterine** pouch between the two organs.
- When the body is in the upright position the uterus lies in an almost horizontal position.
- About 7.5 cm long, 5 cm wide & its walls are about 2.5 cm thick.

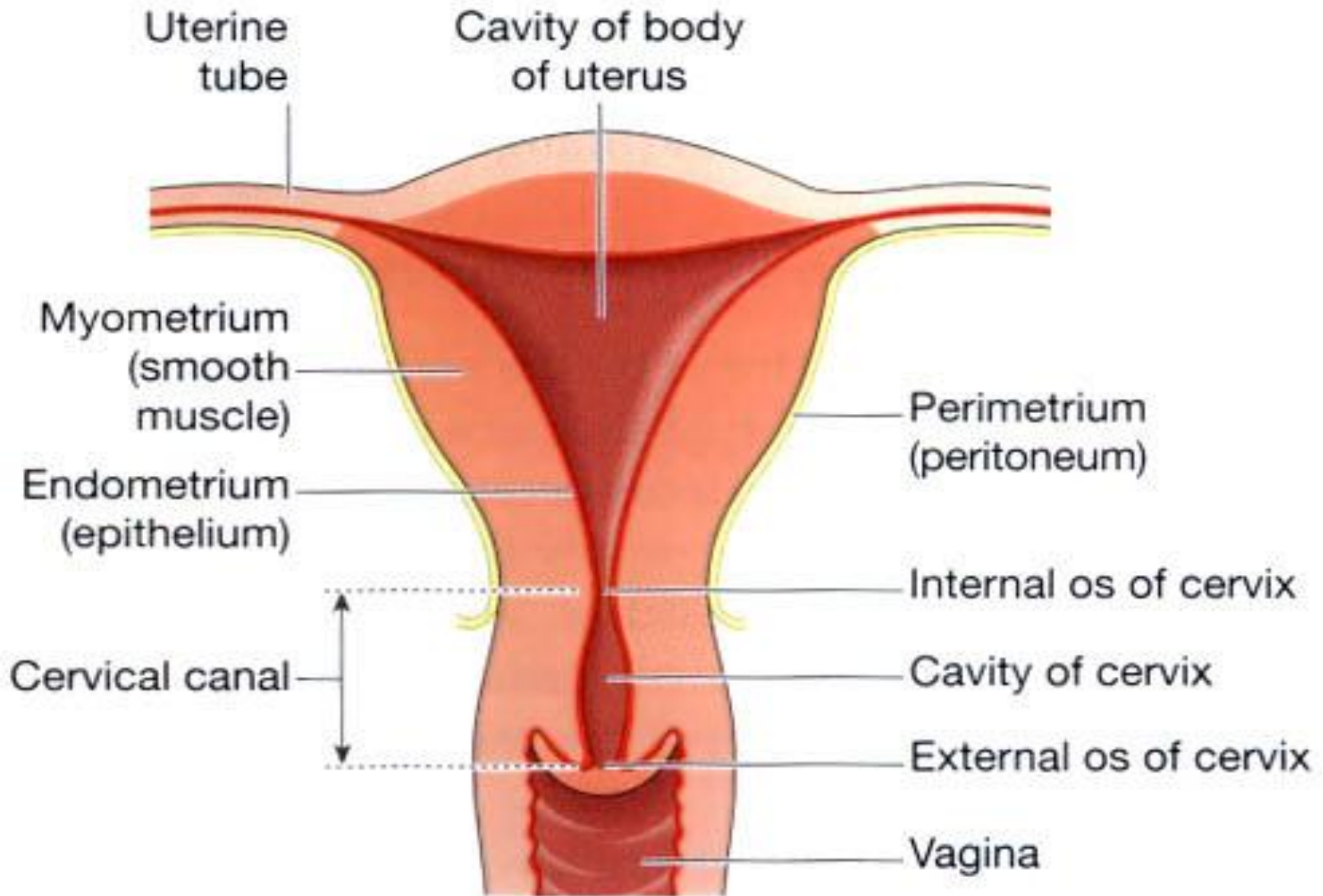
- Weighs from 30 to 40 grams.
- Its parts are the fundus, body & cervix
- **The fundus:** Dome-shaped part of the uterus above the openings of the uterine tubes.
- **The body:** main part.
 - Narrowest inferiorly at the internal os where it is continuous with the cervix.
- **The cervix ('neck' of the uterus):** Protrudes through the anterior wall of the vagina, opening into it at the external os.

Structure of the uterus

- Walls are composed of 3 layers of tissue: perimetrium, myometrium & endometrium
- **Perimetrium**
- Peritoneum, which is distributed differently on the various surfaces of the uterus.

- Anteriorly, it extends over the fundus & the body where it is folded on to the upper surface of the urinary bladder forming the **vesicouterine pouch**.
- Posteriorly, the peritoneum extends over the fundus, the body and the cervix, then it continues on to the rectum to form the **rectouterine pouch (of Douglas)**.
- Laterally, only the fundus is covered because the peritoneum forms a double fold with the uterine tubes in the upper free border.
 - This double fold is the **broad ligament** which, at its **lateral ends, attaches the uterus to the sides of the pelvis**.

- **Myometrium**
- Thickest layer of tissue in the uterine wall.
- Mass of smooth muscle fibres interlaced with areolar tissue, blood vessels & nerves.
- **Endometrium**
- Consists of columnar epithelium containing a large number of mucus-secreting tubular glands.
- Divided functionally into 2 layers.
- a) **The functional layer:** upper layer & it thickens & becomes rich in blood vessels in the first half of the menstrual cycle. If the ovum is not fertilised & does not implant, it's shed during menstruation.
- b) **The basal layer:** lies next to the myometrium, and is not lost during menstruation. Layer from which the fresh functional layer is regenerated during each cycle.
- Upper two-thirds of the cervical canal is lined with this mucous membrane.



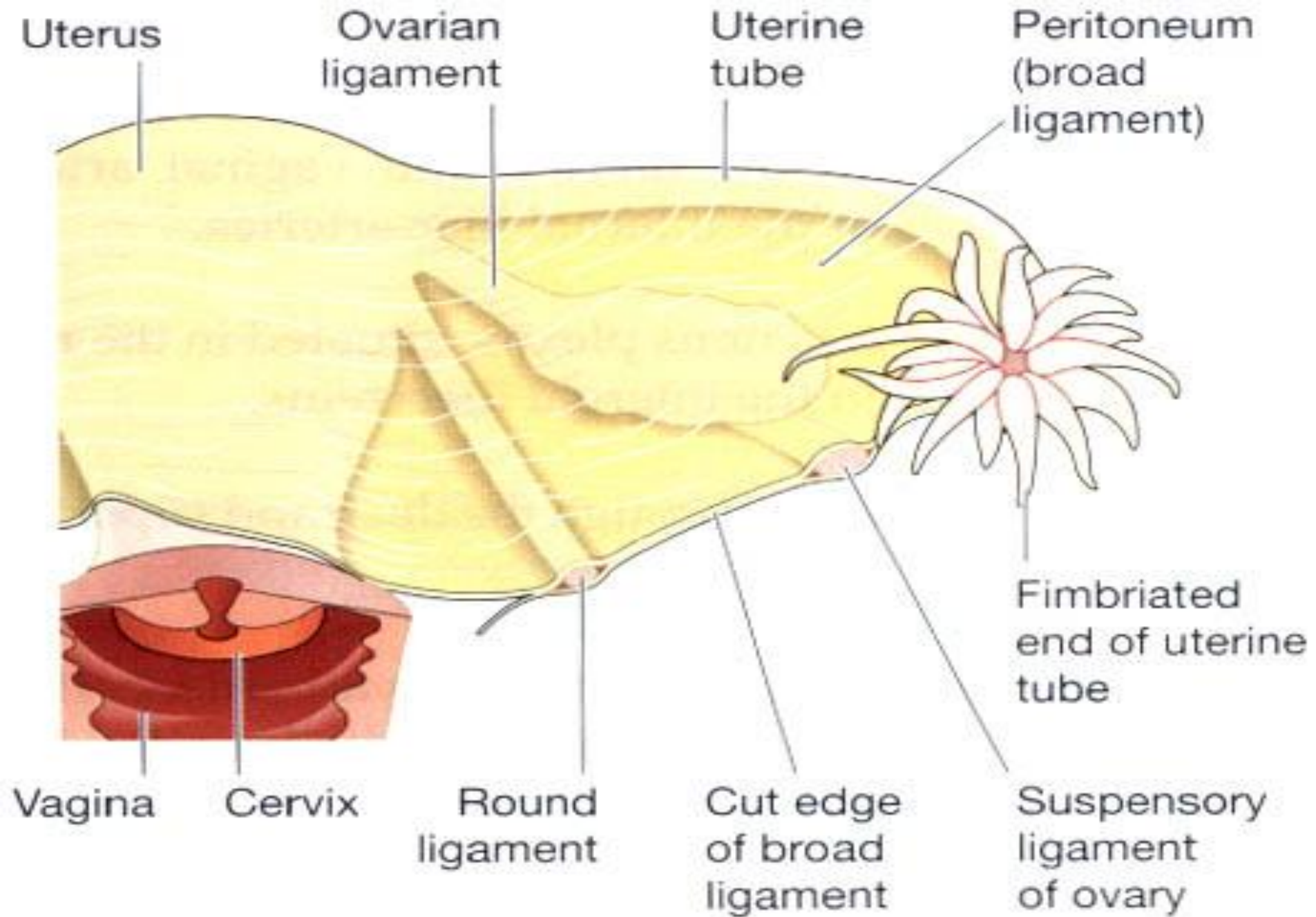
Section of the uterus

Blood supply, lymph drainage & nerve supply

- **Arterial supply:** by the uterine arteries; branches of the internal iliac arteries.
 - Supply the uterus & uterine tubes & join with the **ovarian arteries** to supply the ovaries.
 - Branches pass downwards to anastomose with the vaginal arteries to supply the vagina.
- **Venous drainage:** Veins follow the same route as the arteries & drain into the internal iliac veins.
- **Lymph drainage:** by deep & superficial lymph vessels which drain lymph from uterus & uterine tubes to the aortic lymph nodes & groups of nodes associated with the iliac blood vessels.
- **Nerve supply:** Parasympathetic fibres from the sacral outflow & sympathetic fibres from the lumbar outflow.

- **Supports of the uterus**
- By surrounding organs, muscles of the pelvic floor & ligaments that suspend it from the walls of the pelvis.
- **Supporting structures**
- a) **Broad ligaments.** Formed by a double fold of peritoneum, one on each side of the uterus.
- Hang down from the uterine tubes as though draped over them & at their lateral ends they are attached to the sides of the pelvis.
- Uterine tubes are enclosed in the upper free border
- Near the lateral ends they penetrate the posterior wall of the broad ligament & open into the peritoneal cavity.
- Ovaries are attached to the posterior wall, one on each side.
- Blood, lymph vessels & nerves pass to the uterus & uterine tubes between the layers of the broad ligaments.

- b) Round ligaments:** Bands of fibrous tissue between the 2 layers of broad ligament, one on each side of the uterus.
- Pass to the sides of the pelvis then through the inguinal canal to end by fusing with the labia majora.
- c) Uterosacral ligaments.** Originate from the posterior walls of the cervix & vagina & extend backwards, one on each side of the rectum, to the sacrum.
- d) Transverse cervical ligaments (cardinal ligaments).**
- Extend one from each side of the cervix & vagina to the side walls of the pelvis.
- e) Pubocervical fascia.** Extends forward from the transverse cervical ligaments on each side of the bladder & is attached to the posterior surface of the pubic bones.



Main ligaments supporting the uterus

Functions of the uterus

1. After puberty, the endometrium of the uterus goes through a regular monthly cycle of changes, the menstrual cycle; to prepare the uterus to receive, nourish & protect a fertilised ovum. If the ovum is not fertilised a new cycle begins with a short period of bleeding (menstruation).
2. If the ovum is fertilised the zygote embeds itself in the uterine wall. The uterine muscle grows to accommodate the embryo during its first 8 weeks, and a fetus for the remainder of the pregnancy.
3. Uterine secretions nourish the ovum before it implants in the endometrium, & after implantation the rapidly expanding ball of cells is nourished by the endometrial cells themselves.
4. Provides attachment to the placenta, which provides the means by which the growing baby receives oxygen & nutrients & gets rid of its wastes.

5. During labour, the uterus forcefully expels the baby by means of powerful rhythmical contractions.

c) Uterine tubes (Fallopian tubes)

- About 10 cm long & extend from the sides of the uterus between the body & the fundus.
- Lie in the upper free border of the broad ligament
- Their trumpet-shaped lateral ends penetrate the posterior wall, opening into the peritoneal cavity close to the ovaries.
- End of each tube has fingerlike projections; **fimbriae**. Longest is the **ovarian fimbria** which is in close association with the ovary.

Structure of the uterine tubes

- Have an outer covering of peritoneum (broad ligament), a middle layer of smooth muscle & are lined with ciliated epithelium.

Blood supply, lymph drainage & nerve supply

- Same as for the uterus.

Function of the uterine tubes

- Convey the ovum from the ovary to the uterus by peristalsis & ciliary movement.
- Mucus secreted by the lining membrane provides ideal conditions for movement of ova & spermatozoa.
- Fertilisation of the ovum usually takes place in the uterine tube

d) Ovaries

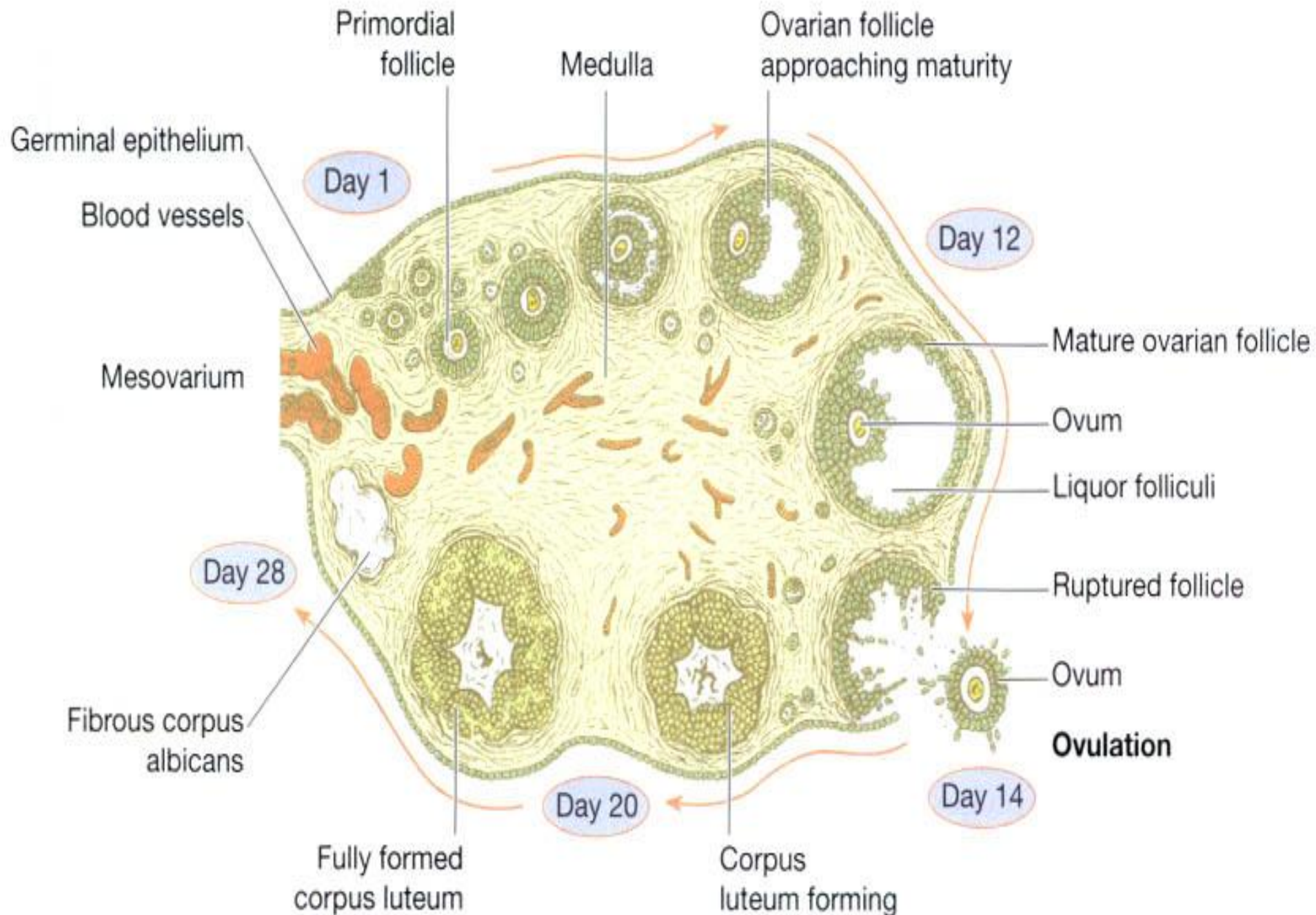
- Female gonads/glands
- Lie in a shallow fossa on the lateral walls of the pelvis.
- 2.5 to 3.5 cm long, 2 cm wide & 1 cm thick.
- Each is attached to the upper part of the uterus by the ovarian ligament & to the back of the broad ligament by a broad band of tissue, **the mesovarium**.
 - Blood vessels and nerves pass to the ovary through the mesovarium.

Structure of the ovaries

- 2 layers of tissue.
- i) **The medulla.** Lies in the centre & consists of fibrous tissue, blood vessels & nerves.

ii) **The cortex.** Surrounds the medulla.

- Has a framework of connective tissue, or stroma, covered by germinal epithelium.
- Contains ovarian follicles in various stages of maturity, each of which contains an ovum.
- Before puberty the ovaries are inactive but the stroma already contains immature (**primordial follicles**), which the female has from birth.
- During the childbearing years, about every 28 days, one ovarian follicle (**Graafian follicle**) matures, ruptures & releases its ovum into the peritoneal cavity (**ovulation**).



Development of the ovarian follicle

Blood supply, lymph drainage & nerve supply

- **Arterial supply:** by the ovarian arteries, which branch from the abdominal aorta just below the renal arteries.
- **Venous drainage:** a plexus of veins behind the uterus from which the ovarian veins arise. Right ovarian vein opens into the inferior vena cava & the left into the left renal vein.
- **Lymph drainage:** to the lateral aortic & pre-aortic lymph nodes. Lymph vessels follow the same route as the arteries.
- **Nerve supply:** by parasympathetic nerves from the sacral outflow & sympathetic nerves from the lumbar outflow.

- **Functions of the ovaries**
- Maturation of the follicle is stimulated by FSH from the anterior pituitary, and **oestrogen** secreted by the follicle lining cells.
- **Ovulation** is triggered by a surge of LH from the anterior pituitary, which occurs a few hours before ovulation.
- After ovulation, the follicle lining cells develop into the **corpus luteum** (yellow body), under the influence of LH.
- Corpus luteum produces **progesterone** & some **oestrogen**.
- If the ovum is fertilised it embeds itself in the wall of the uterus where it grows & develops & produces the hormone **human chorionic gonadotrophin (hCG)**, which stimulates the corpus luteum to continue secreting progesterone & oestrogen for the first 3 months of the pregnancy after which time this function is continued by the placenta.

- If the ovum is not fertilised the corpus luteum degenerates & a new cycle begins with menstruation.
- At the site of the degenerate corpus luteum an inactive mass of fibrous tissue forms; **corpus albicans**.
- Sometimes more than one follicle matures at a time, releasing 2 or more ova in the same cycle.
 - When this happens & the ova are fertilised; result is a multiple pregnancy.

Puberty in the female

- **Puberty:** age at which internal reproductive organs reach maturity. Called the **menarche**; marks the beginning of the childbearing period.
- Age of puberty varies between 10 & 14 years & a number of physical and psychological changes take place at this time:
 - ✓ uterus, uterine tubes & ovaries reach maturity
 - ✓ menstrual cycle & ovulation begin (menarche)
 - ✓ breasts develop & enlarge
 - ✓ pubic & axillary hair begins to grow
 - ✓ there is an increase in the rate of growth in height & widening of the pelvis
 - ✓ there is an increase in the amount of fat deposited in the subcutaneous tissue, especially at the hips & breasts.

The menstrual cycle

- **Def:** a series of events, occurring regularly in females every 26 to 30 days throughout the childbearing period of about 36 years.
- Consists of a series of changes that take place concurrently in the ovaries & uterine walls, stimulated by changes in the blood concentrations of hormones.
- Hormones secreted in the cycle are regulated by negative feedback mechanisms.
- Hypothalamus secretes LHRH which stimulates the anterior pituitary to secrete:
 - **FSH**, which promotes the maturation of ovarian follicles & the secretion of oestrogen, leading to ovulation
 - **LH**, which triggers ovulation, stimulates the development of the corpus luteum & the secretion of progesterone.

- Average length of the menstrual cycle is about 28 days.
- Days of the cycle are numbered from the beginning of the menstrual phase of the menstrual cycle which usually lasts about 4 days.
- Followed by the proliferative phase (about 10 days), then by the secretory phase (about 14 days).

a) Menstrual phase

- When the ovum is not fertilised, the corpus luteum starts to degenerate. Progesterone & oestrogen levels fall, & the functional layer of the endometrium, which is dependent on high levels of these ovarian hormones, is shed in menstruation.
- Menstrual flow consists of the secretions from endometrial glands, endometrial cells, blood from the broken down capillaries & unfertilised ovum.
- Falling levels of oestrogen & progesterone lead to resumed anterior pituitary activity, rising FSH levels & the initiation of the next cycle.

b) Proliferative phase

- Ovarian follicle, stimulated by FSH, grows towards maturity & produces oestrogen.
- Oestrogen stimulates the proliferation of the functional layer of the endometrium in preparation for the reception of a fertilised ovum.
- Endometrium becomes thicker by rapid cell multiplication accompanied by an increase in the numbers of mucus-secreting glands & blood capillaries.
- Ends when ovulation occurs & oestrogen production declines.

c) Secretory phase

- Immediately after ovulation, the lining cells of the ovarian follicle are stimulated by LH to develop the corpus luteum, which produces progesterone & some oestrogen.
- Under the influence of progesterone, the endometrium becomes oedematous & the secretory glands produce increased amounts of watery mucus, which assists the passage of the spermatozoa through the uterus to the uterine tubes where the ovum is usually fertilised.
- Similar increase in the secretion of watery mucus by the glands of the uterine tubes & by cervical glands which lubricate the vagina also occurs.

- The ovum may survive in a fertilisable form for a very short time after ovulation; about 8 hours.
- Spermatozoa, deposited in the vagina during coitus, may be capable of fertilising the ovum for only about 24 hours although they may survive for several days.
 - This means that the period in each cycle during which fertilisation can occur is relatively short.
- Time of ovulation can be determined by observing certain changes in the woman's body around this period.
- Changes in cervical mucus, from thick & dry in consistency to thin, elastic & watery, are detected &, in addition, body temperature rises by a small but measurable amount immediately following ovulation.

- If the ovum is not fertilised menstruation occurs & a new cycle begins.
- If the ovum is fertilised there is no breakdown of the endometrium & no menstrual flow.
- Fertilised ovum (zygote) travels through the uterine tube to the uterus where it becomes embedded in the wall and produces hCG.
- hCG keeps the corpus luteum intact, enabling it to continue secreting progesterone & oestrogen for the first 3 to 4 months of the pregnancy, inhibiting the maturation of further ovarian follicles.
 - During that time the placenta develops & produces oestrogen, progesterone & gonadotrophins.

MENOPAUSE (CLIMACTERIC)

- Occurs between the ages of 45 & 55 years, marking the end of the childbearing period.
- May occur suddenly or over a period of years, sometimes as long as 10 years
- Caused by changes in sex hormone levels.
- Ovaries gradually become less responsive to FSH and LH, & ovulation and the menstrual cycle become irregular, eventually ceasing.

- Several other phenomena may occur at the same time including:
 - short-term unpredictable vasodilatation with flushing, sweating & palpitations, causing discomfort & disturbance of the normal sleep pattern
 - shrinkage of the breasts
 - Axillary & pubic hair become sparse
 - atrophy of the sex organs
 - episodes of uncharacteristic behaviour sometimes occur, e.g. irritability, mood changes
 - gradual thinning of the skin
 - loss of bone mass that predisposes to osteoporosis
 - slow increase in blood cholesterol levels that predisposes postmenopausal women to cardiovascular disorders.
- Similar changes occur after bilateral irradiation or surgical removal of the ovaries.

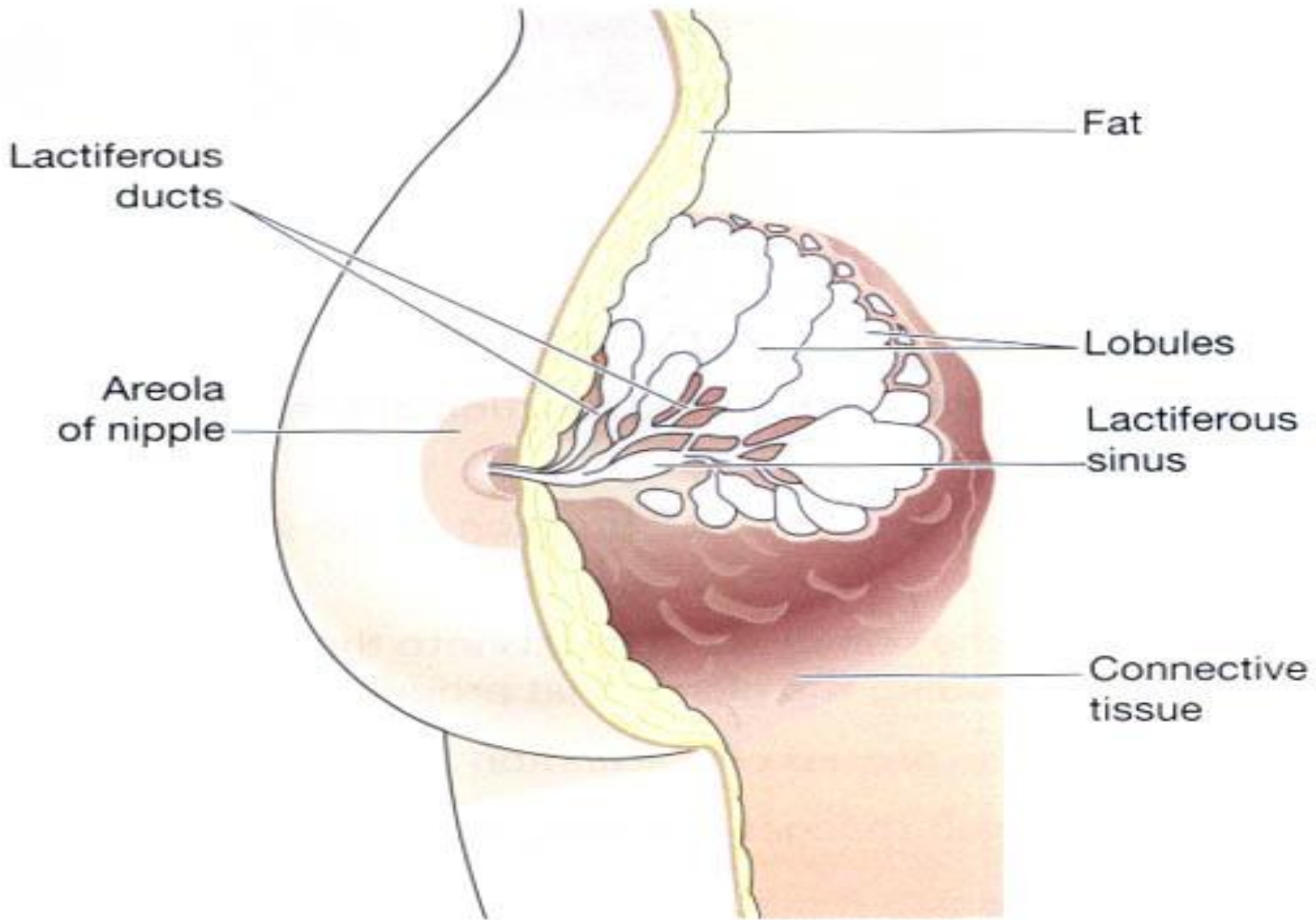
BREASTS (MAMMARY GLANDS)

- Accessory glands of the female reproductive system.
- Also in the male but in only a rudimentary form.
- In the female the breasts are small & immature until puberty. Thereafter they grow and develop to their mature size under the influence of oestrogen and progesterone. During pregnancy these hormones stimulate further growth.
- After the baby is born the hormone prolactin from the anterior pituitary stimulates the production of milk, and oxytocin from the posterior pituitary stimulates the release of milk in response to the stimulation of the nipple by the sucking baby, by a positive feedback mechanism.

Structure of the breast

- Consists of glandular tissue, fibrous tissue and fatty tissue.
- Each breast consists of about 20 lobes of glandular tissue, each lobe being made up of a number of lobules that radiate around the nipple.
- The lobules consist of a cluster of alveoli which open into small ducts and these unite to form large excretory ducts, called **lactiferous ducts**.
- The lactiferous ducts converge towards the centre of the breast where they form dilatations or reservoirs for milk.
- Leading from each dilatation, or **lactiferous sinus**, is a narrow duct which opens on to the surface at the nipple.

- Fibrous tissue supports the glandular tissue and ducts, and fat covers the surface of the gland and is found between the lobes.
- **The nipple.**
- A small conical eminence at the centre of the breast surrounded by a pigmented area, the **areola**.
- On the surface of the areola are numerous sebaceous glands (**Montgomery's tubercles**) which lubricate the nipple during lactation.



Structure of the breast

Blood supply, lymph drainage and nerve supply

- **Arterial blood supply:** by blood from the thoracic branches of the axillary arteries and from the internal mammary and intercostal arteries.
- **Venous drainage:** by an anastomotic circle round the base of the nipple from which branches carry the venous blood to the circumference and end in the axillary and mammary veins.
- **Lymph drainage:** Mainly into the axillary lymph vessels and nodes. Lymph may drain through the internal mammary nodes if the superficial route is obstructed.

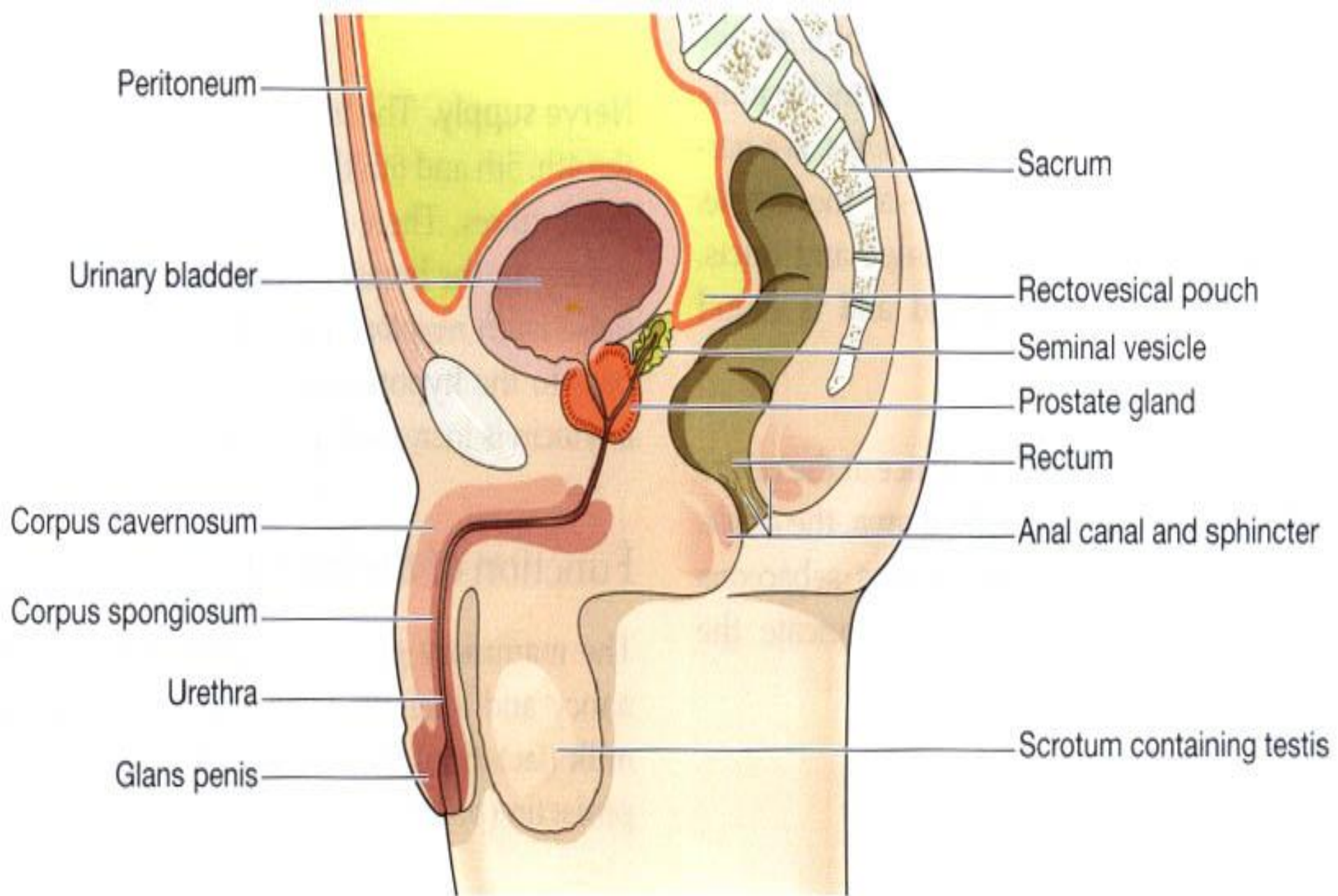
- **Nerve supply:** by branches from the 4th, 5th and 6th thoracic nerves which contain sympathetic fibres.
- There are numerous somatic sensory nerve endings in the breast especially around the nipple. When these touch receptors are stimulated by sucking, impulses pass to the hypothalamus and the flow of the hormone oxytocin is increased, promoting the release of milk.

Function of the breast

- Production of milk (lactation).

MALE REPRODUCTIVE SYSTEM

- Consists of the following organs:
 - 2 testes
 - 2 epididymides
 - 2 deferent ducts (vas deferens)
 - 2 spermatic cords
 - 2 seminal vesicles
 - 2 ejaculatory ducts
 - 1 prostate gland
 - 1 penis



Male reproductive organs and associated structures 1259

a) Scrotum

- A pouch of deeply pigmented skin, fibrous and connective tissue and smooth muscle.
- Divided into 2 compartments each of which contains one testis, one epididymis and the testicular end of a spermatic cord.
- Lies below the symphysis pubis, in front of the upper parts of the thighs and behind the penis.

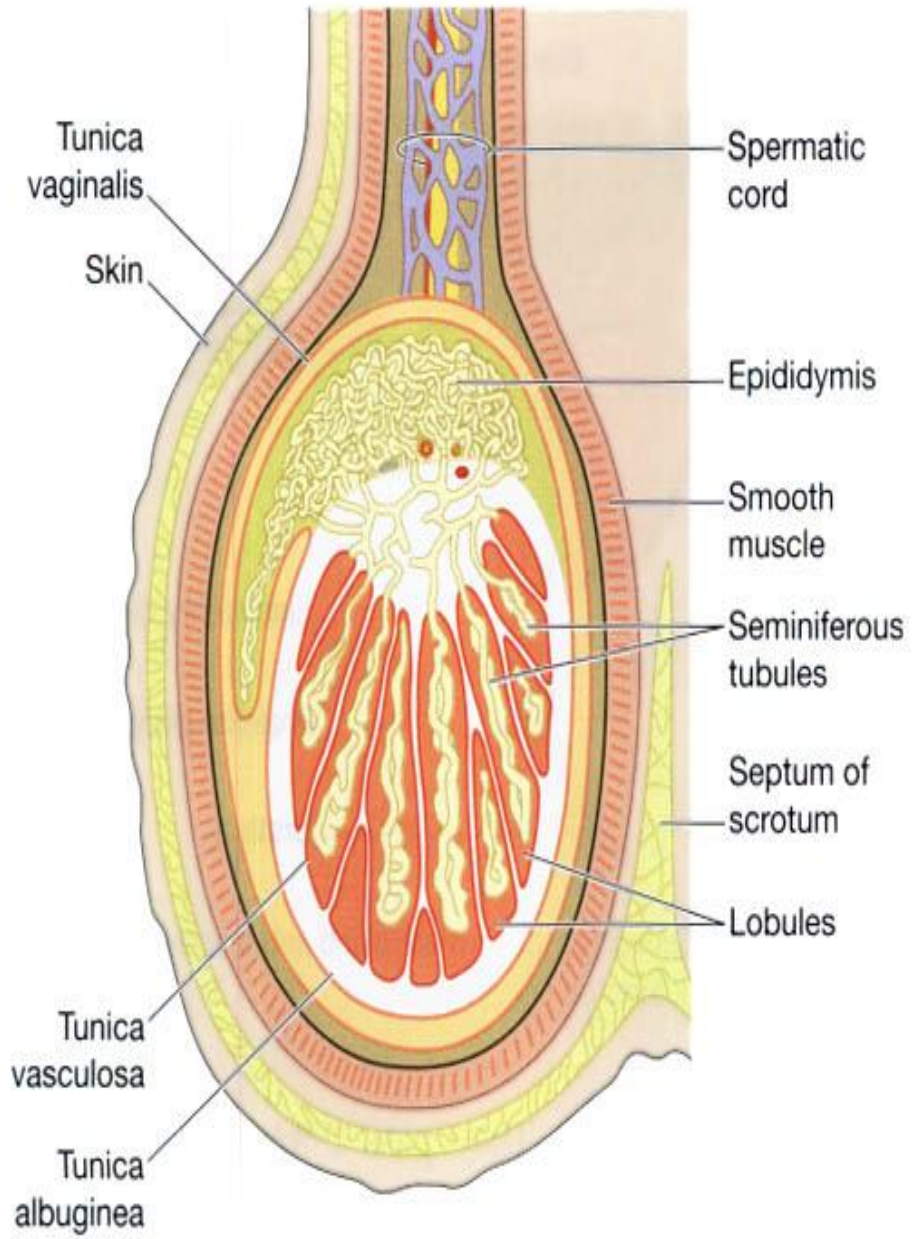
b) Testes

- The reproductive glands of the male and are the equivalent of the ovaries in the female.
- Are about 4.5 cm long, 2.5 cm wide and 3 cm thick
- Suspended in the scrotum by the spermatic cords.
- Are surrounded by three layers of tissue.

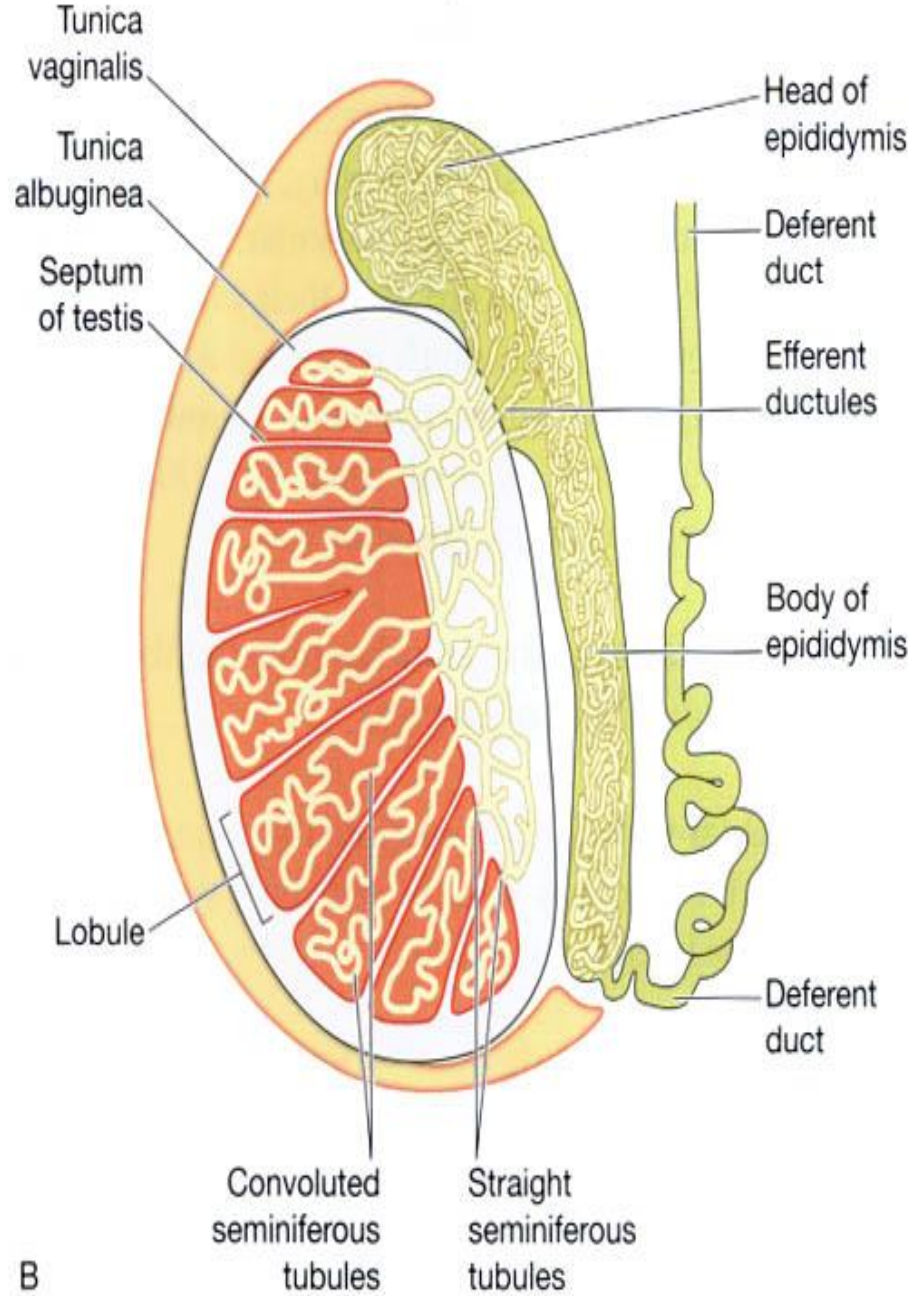
- i) The tunica vaginalis:** A double membrane, forming the outer covering of the testes, and is a downgrowth of the abdominal and pelvic peritoneum.
- During early fetal life the testes develop in the lumbar region of the abdominal cavity just below the kidneys.
 - They then descend into the scrotum taking with them coverings of peritoneum, blood and lymph vessels, nerves and the deferent duct.
 - The peritoneum eventually surrounds the testes in the scrotum, and becomes detached from the abdominal peritoneum.

- Descent of the testes into the scrotum should be complete by the 8th month of fetal life.
- ii) The tunica albuginea:** a fibrous covering beneath the tunica vaginalis that surrounds the testes. Ingrowths form septa dividing the glandular structure of the testes into **lobules**.
- iii) The tunica vasculosa:** Consists of a network of capillaries supported by delicate connective tissue.

- **Structure of the testes**
- In each testis are 200 to 300 lobules and within each lobule are 1 to 4 convoluted loops composed of germinal epithelial cells, called **seminiferous tubules**.
- Between the tubules there are groups of **interstitial cells (of Leydig)** that secrete the hormone **testosterone** after puberty.
- At the upper pole of the testis the tubules combine to form a single tubule. This tubule, about 6 m in its full length, is repeatedly folded and tightly packed into a mass called the **epididymis**. It leaves the scrotum as the deferent duct (vas deferens) in the spermatic cord.
- Blood and lymph vessels pass to the testes in the spermatic cords.



A



B

Testis and its coverings

Functions of the testes

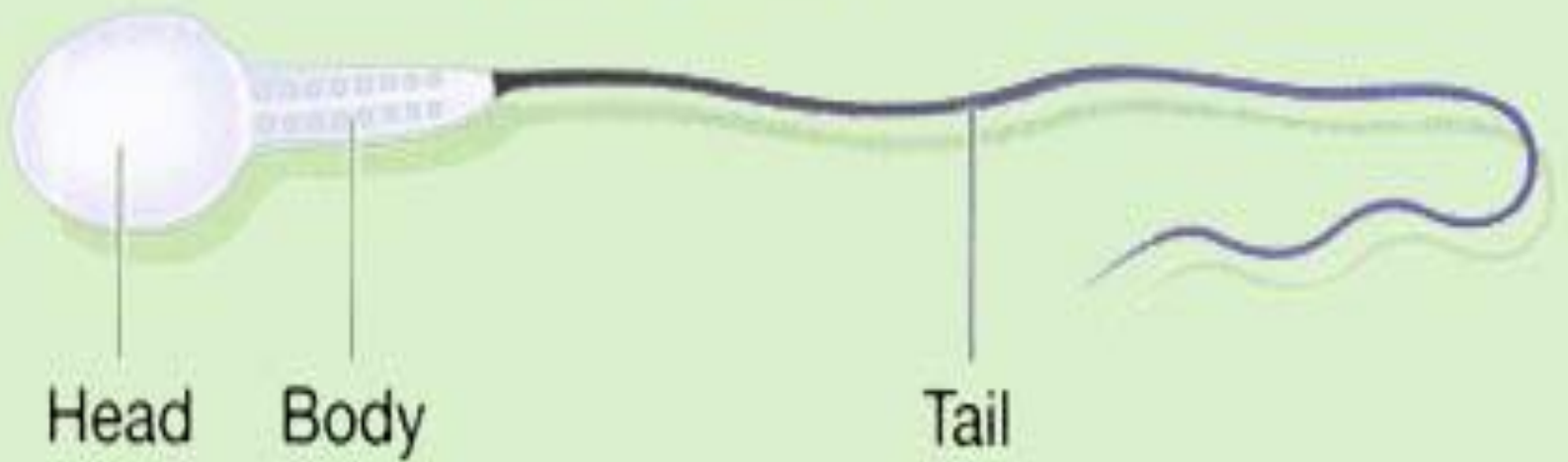
- Spermatozoa (sperm) are produced in the seminiferous tubules of the testes, and mature as they pass through the long and convoluted epididymis, where they are stored.
- Sperm production is controlled by hormone FSH from the anterior pituitary.

Spermatozoa

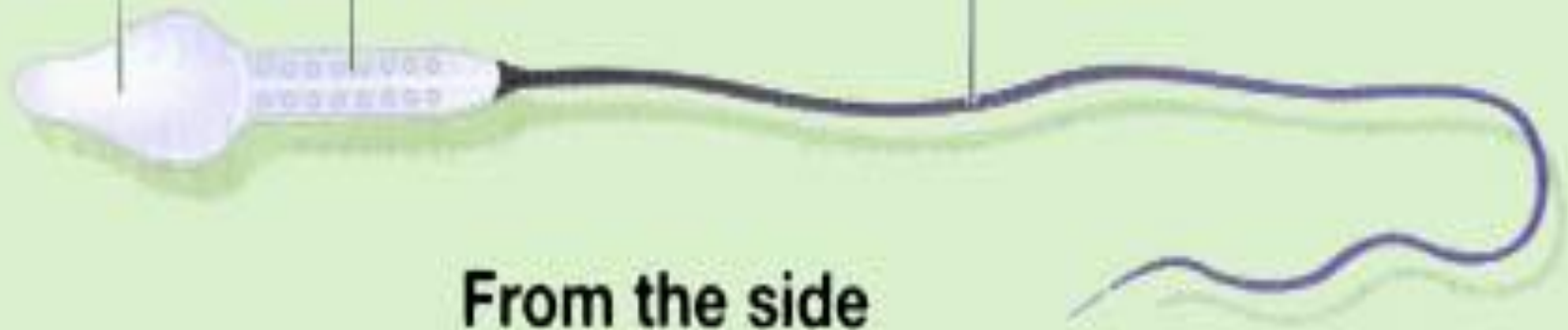
- A mature sperm has a head, a body, and a long whip-like tail that is used for motility.
- The head is almost completely filled by the nucleus, containing its DNA. It also contains the enzymes required to penetrate the outer layers of the ovum to reach, and fuse with, its nucleus.

- The body of the sperm is packed with mitochondria, which fuel the propelling action of the tail that powers the sperm on its journey into the female reproductive tract.
- Successful spermatogenesis takes place at a temperature about 3°C below normal body temperature.
- The testes are cooled by their position outside the abdominal cavity, and the thin outer covering of the scrotum has very little insulating fat.

From above



From the side



A spermatozoon

c) The spermatic cords

- Suspend the testes in the scrotum.
- Each cord contains a testicular artery, testicular veins, lymphatics, a deferent duct and testicular nerves, which come together to form the cord from their various origins in the abdomen.
- The cord, which is covered in a sheath of smooth muscle and connective and fibrous tissues, extends through the inguinal canal and is attached to the testis on the posterior wall.
- **The testicular artery.** branches from the abdominal aorta, just below the renal arteries.

- **The testicular vein:** passes into the abdominal cavity. The left vein opens into the left renal vein and the right into the inferior vena cava.
- **Lymph drainage.** Through lymph nodes around the aorta.
- **The deferent duct.** About 45 cm long. It passes upwards from the testis through the inguinal canal and ascends medially towards the posterior wall of the bladder where it is joined by the duct from the **seminal vesicle** to form the **ejaculatory duct**.
- **The nerve supply:** by branches from the 10th and 11th thoracic nerves.

d) Seminal vesicles

- 2 small fibromuscular pouches lined with columnar epithelium, lying on the posterior aspect of the bladder.
- At its lower end each seminal vesicle opens into a short duct which joins with the corresponding deferent duct to form an ejaculatory duct.

Functions of the seminal vesicles

- They contract and expel, seminal fluid, during ejaculation.
- Seminal fluid, which forms 60% of the bulk of the fluid ejaculated at male orgasm, contains nutrients to support the sperm during their journey through the female reproductive tract.

e) Ejaculatory ducts

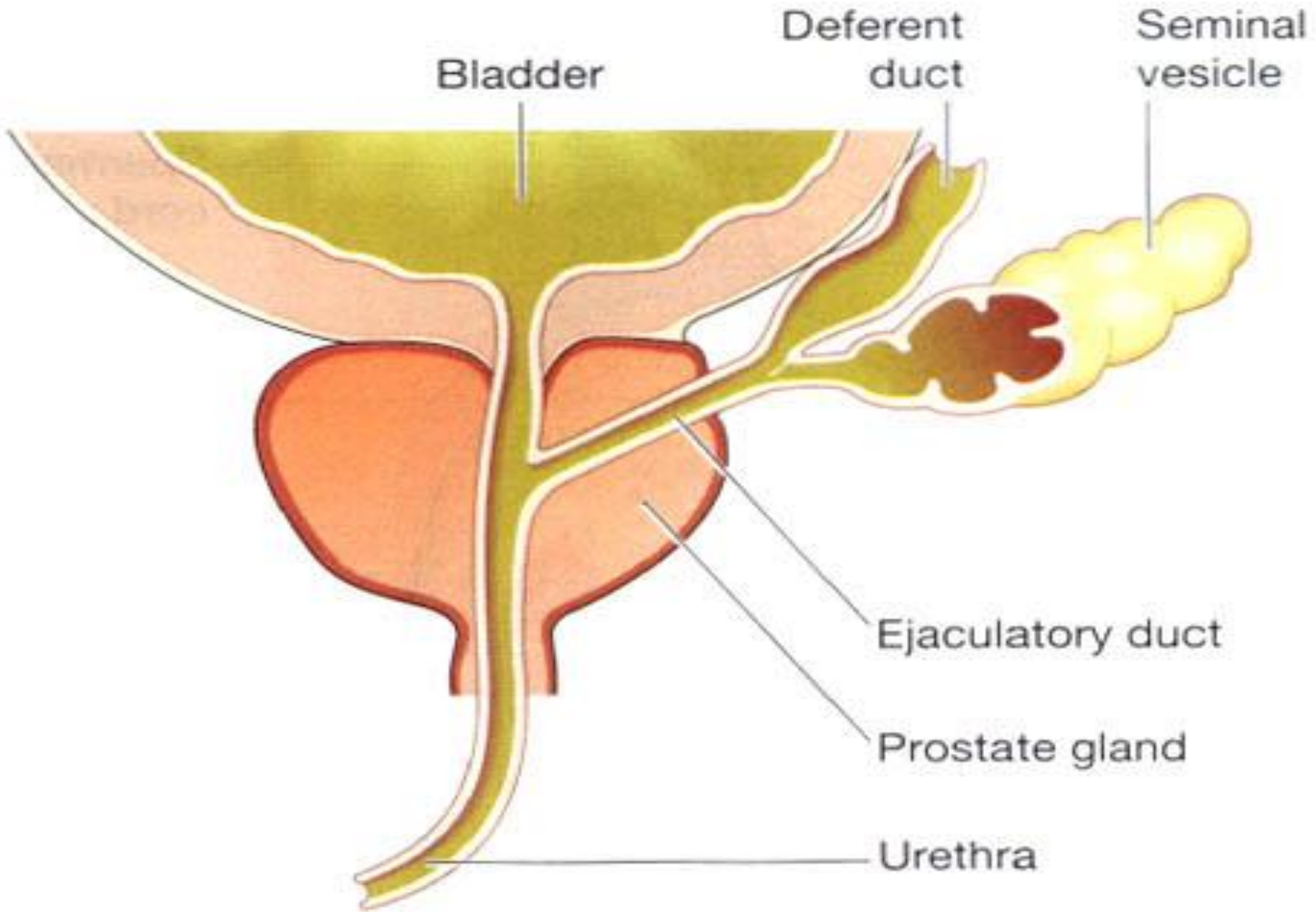
- 2 tubes about 2 cm long, each formed by the union of the duct from a seminal vesicle and a deferent duct.
- They pass through the prostate gland and join the prostatic urethra, carrying seminal fluid and spermatozoa to the urethra.
- Are composed of the same layers of tissue as the seminal vesicles.

f) Prostate gland

- Lies in the pelvic cavity in front of the rectum and behind the symphysis pubis, surrounding the first part of the urethra.
- Consists of an outer fibrous covering, a layer of smooth muscle and glandular substance composed of columnar epithelial cells.

Functions of the prostate gland

- Secretes a thin, milky fluid that makes up about 30% of semen, and gives it its milky appearance.
- It is slightly alkaline, which provides a protective local environment for sperm arriving in the acidic vagina.
- It also contains a clotting enzyme, which thickens the semen in the vagina, increasing the likelihood of semen being retained in the vicinity of the cervix.



A section of the prostate and associated structures ¹²⁷³

g) Urethra

- Provides a common pathway for the flow of urine and semen.
- About 19 to 20 cm long
- Consists of 3 parts:
 - **The prostatic urethra** originates at the urethral orifice of the bladder and passes through the prostate gland.
 - The **membranous urethra** is the shortest and narrowest part and extends from the prostate gland to the bulb of the penis, after passing through the perineal membrane.
 - The **spongiose or penile urethra** lies within the corpus spongiosum of the penis and terminates at the external urethral orifice in the glans penis.

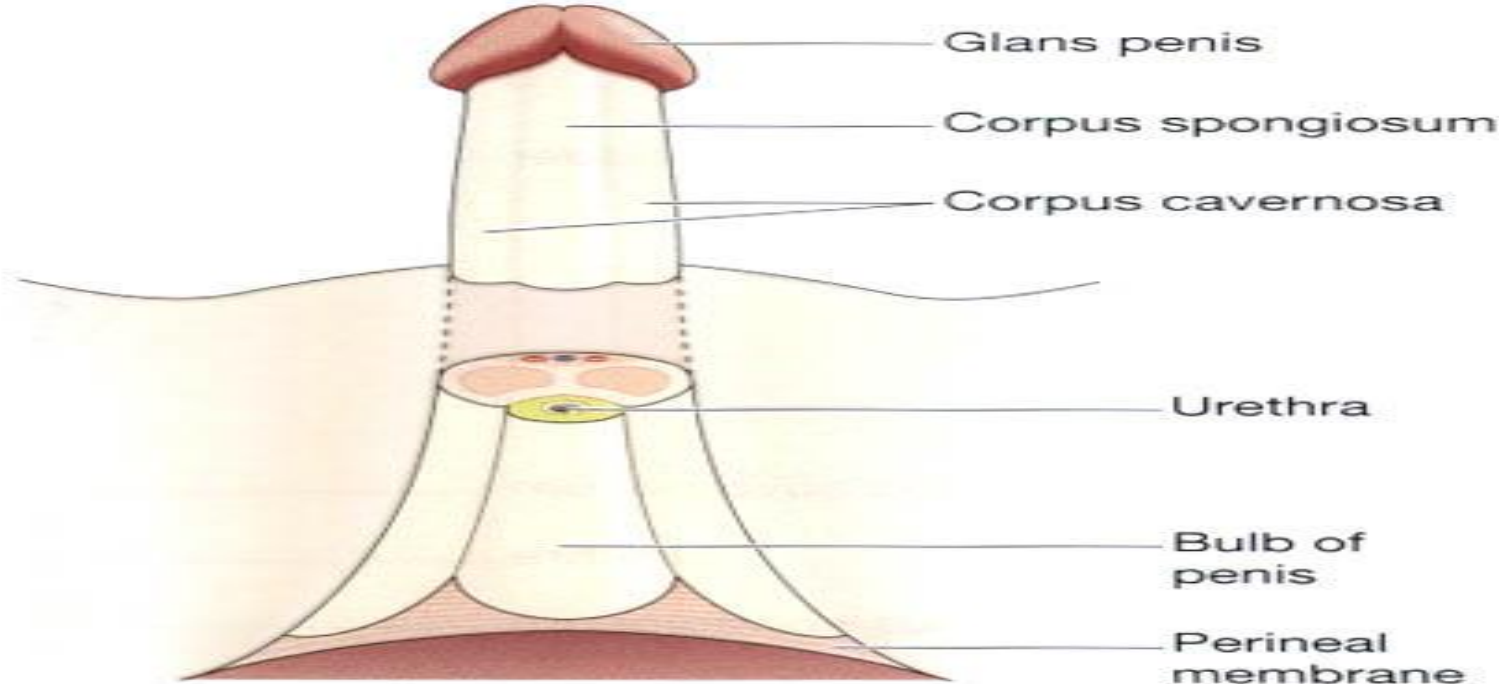
- There are two urethral sphincters. The internal sphincter consists of **smooth muscle** fibres at the neck of the bladder above the prostate gland.
- The external sphincter consists of **skeletal muscle fibres** surrounding the membranous part.

h) Penis

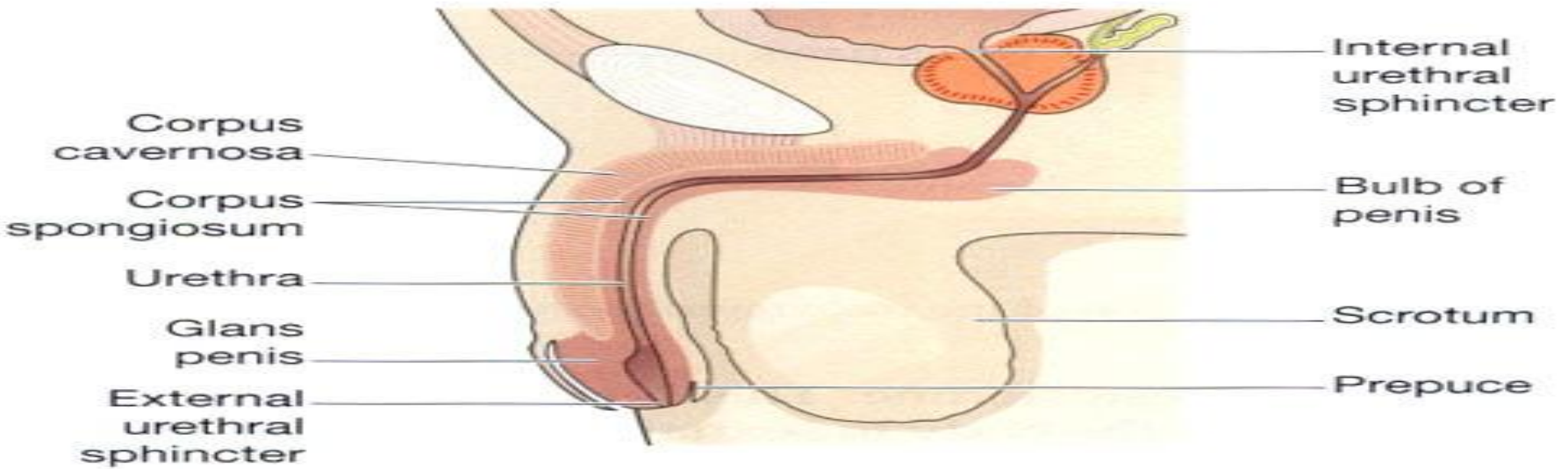
- Has a root and a body.
- The root lies in the perineum and the body surrounds the urethra.
- Formed by three cylindrical masses of erectile tissue and involuntary muscle.
- The erectile tissue is supported by fibrous tissue and covered with skin and has a rich blood supply.

- The **two lateral** columns are called the **corpora cavernosa** and the column between them, containing the urethra, is the **corpus spongiosum**.
- At its tip it is expanded into a triangular structure known as the **glans penis**.
- Just above the glans the skin is folded upon itself and forms a movable double layer, **the foreskin or prepuce**.
- **Arterial blood**: supplied by deep, dorsal and bulbar arteries of the penis which are branches from the internal pudendal arteries.

- **Venous drainage:** A series of veins drain blood to the internal pudendal and internal iliac veins.
- **Nerve supply:** by autonomic and somatic nerves.
 - Parasympathetic stimulation leads to filling of the spongy erectile tissue with blood, caused by arteriolar dilatation and venoconstriction, which increases blood flow into the penis and obstructs outflow.
 - The penis therefore becomes engorged and erect, an essential prerequisite for coitus to occur.



A

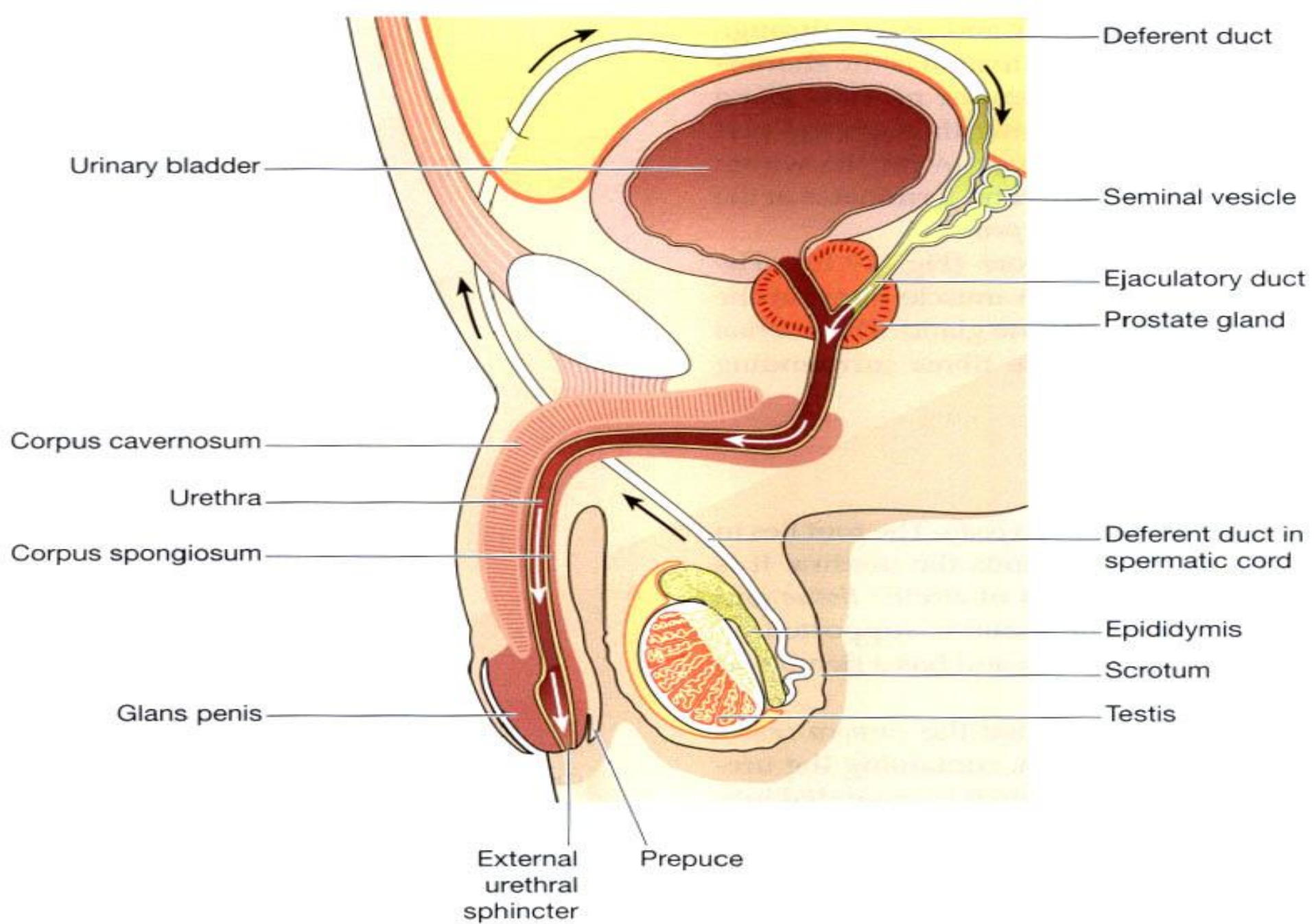


B

The penis

Ejaculation

- Occurs at the point of male orgasm.
- Spermatozoa are expelled from the epididymis and pass through the deferent duct, the ejaculatory duct and the urethra.
- The semen is propelled by powerful rhythmical contraction of the smooth muscle in the walls of the deferent duct; the muscular contractions are sympathetically mediated.
- Muscle in the walls of the seminal vesicles and prostate gland also contracts, adding their contents to the fluid passing through the genital ducts.
- The force generated by these combined processes leads to emission of the semen through the external urethral sphincter.



Route taken by spermatozoa during ejaculation

- Sperm comprise only 10% of the final ejaculate, the remainder being made up of seminal and prostatic fluids, which are added to the sperm during male orgasm, as well as mucus produced in the urethra.
- Between 2 and 5 ml of semen are produced in a normal ejaculate, and contain between 40 and 100 million spermatozoa per ml.
- If not ejaculated, sperm gradually lose their fertility after several months and are reabsorbed by the epididymis.

Puberty in the male

- Occurs between the ages of 10 and 14.
- Luteinising hormone from the anterior lobe of the pituitary gland stimulates the interstitial cells of the testes to increase the production of testosterone.
- Testosterone influences the development of the body to sexual maturity.
- In the male, fertility and sexual ability tend to decline gradually with ageing.
- The secretion of testosterone gradually declines, usually beginning at about 50 years of age.

- The changes which occur at puberty are:
 - ✓ growth of muscle and bone and a marked increase in height and weight
 - ✓ enlargement of the larynx and deepening of the voice — it 'breaks'
 - ✓ growth of hair on the face, axillae, chest, abdomen and pubis
 - ✓ enlargement of the penis, scrotum and prostate gland
 - ✓ maturation of the seminiferous tubules and production of spermatozoa
 - ✓ the skin thickens and becomes more oily.

THE END! Questions

