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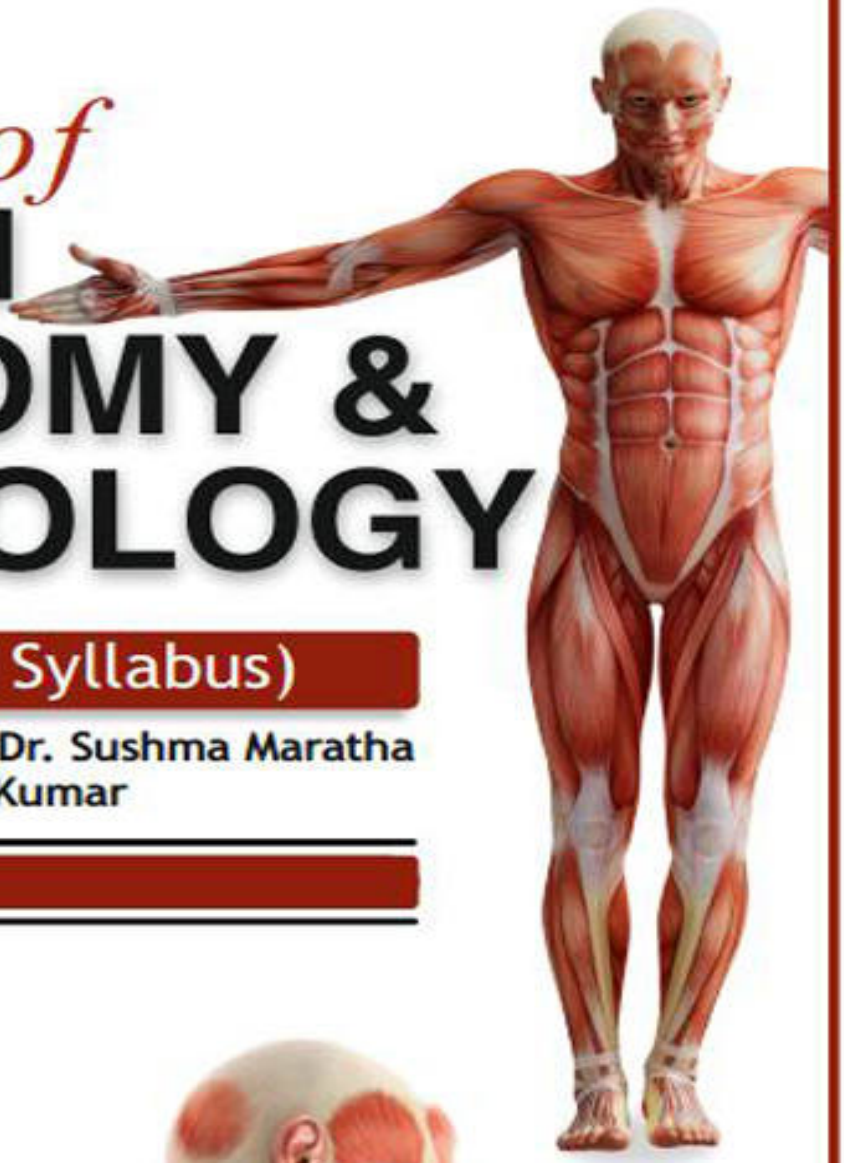

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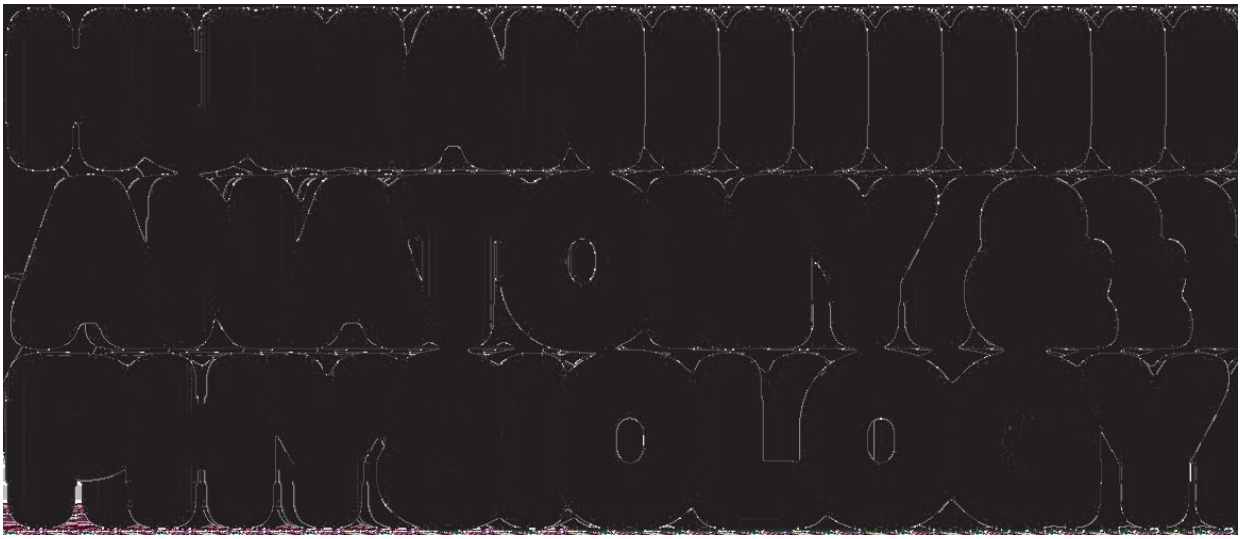

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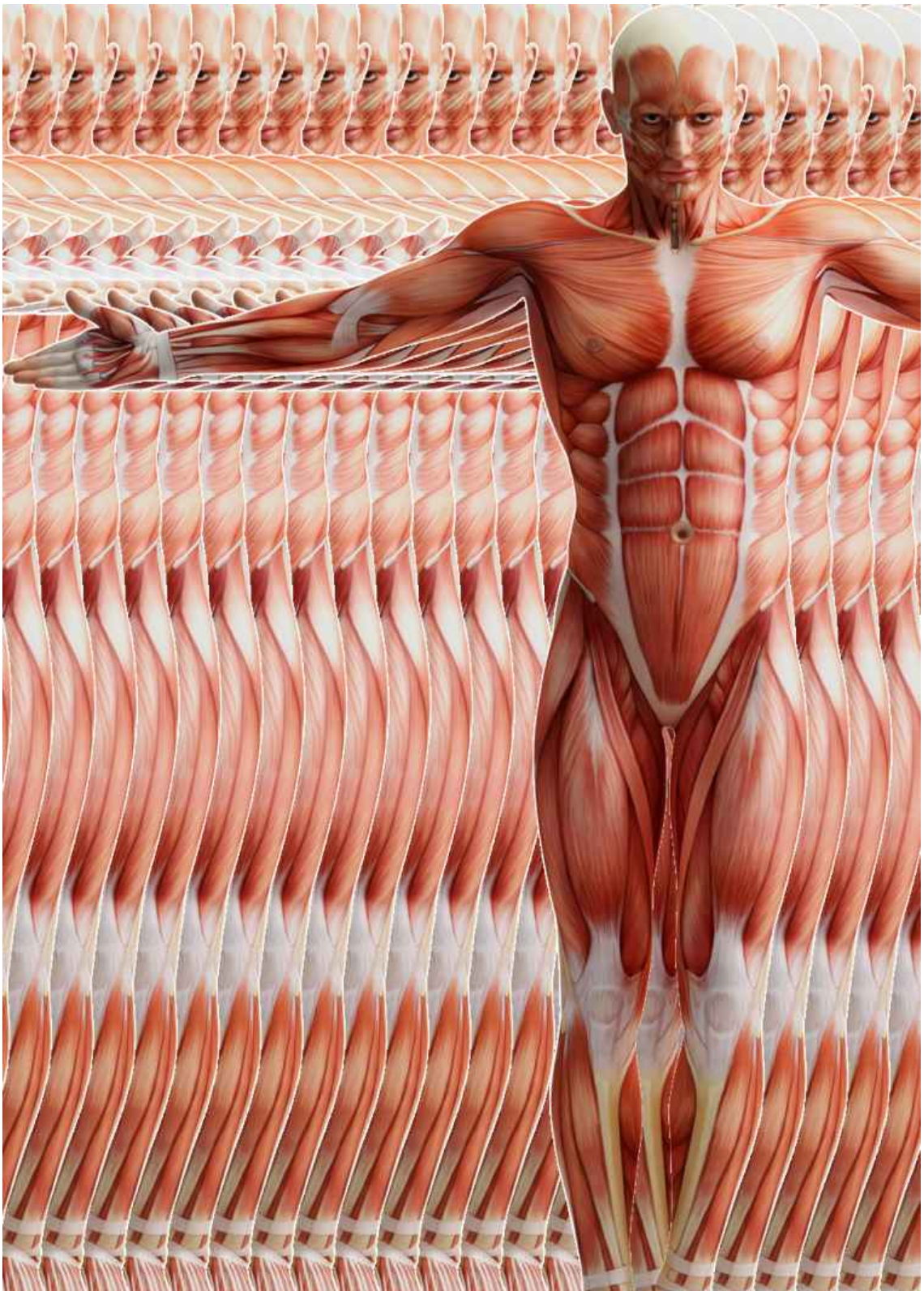

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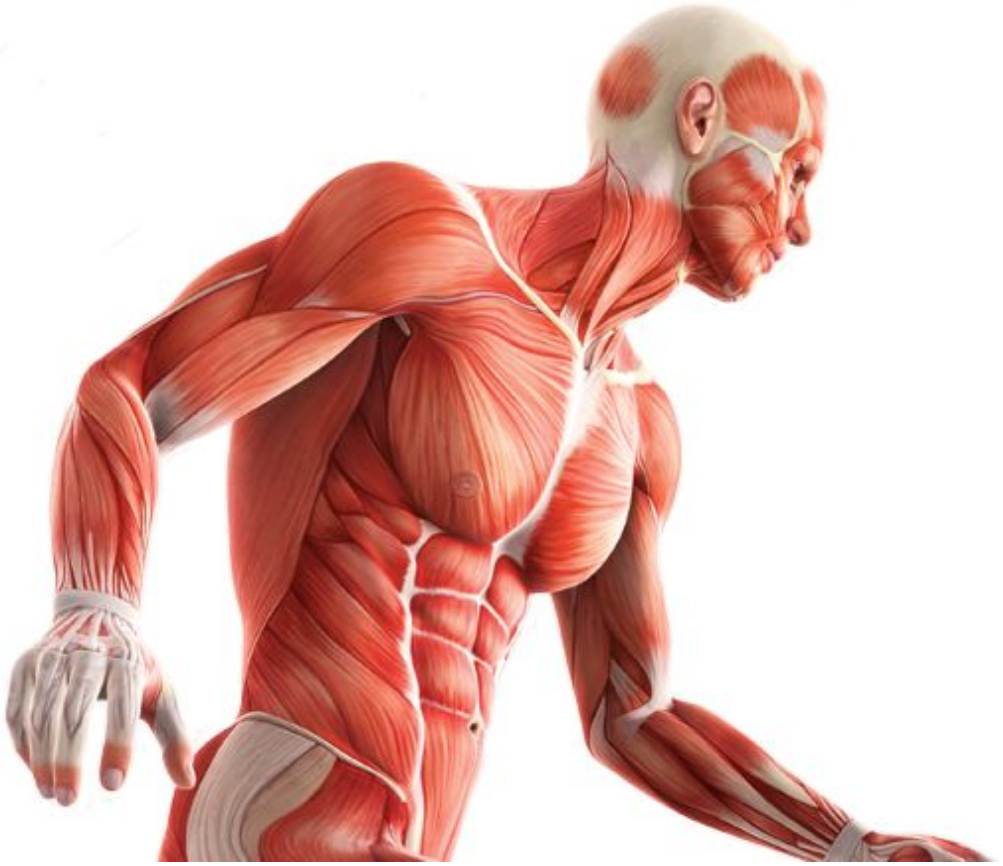

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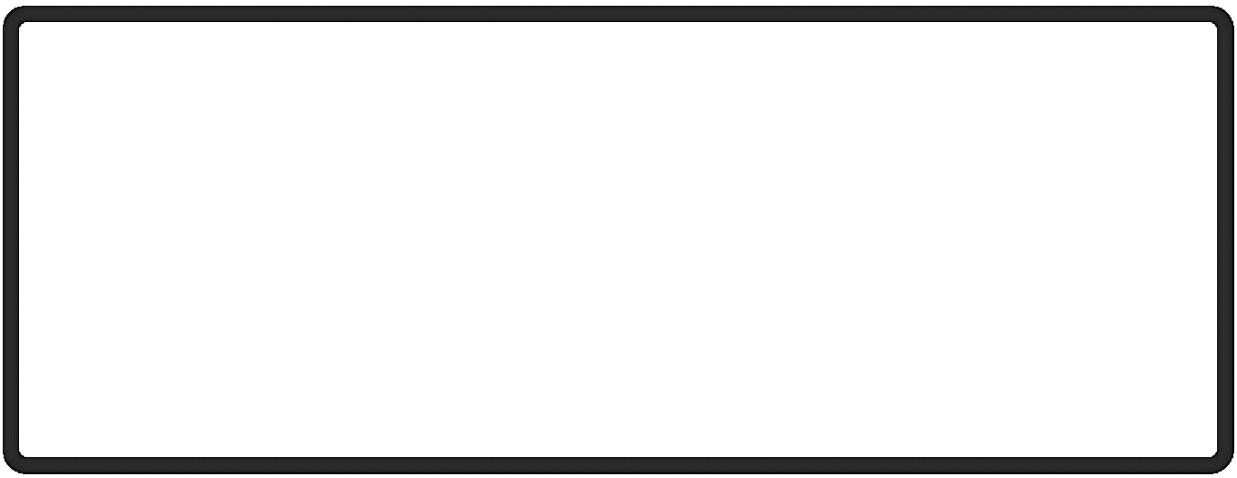

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Preface

This book has been written to help the graduate students of pharmacy (D.Pharm, B.Pharm) to meet the requirements of the revised syllabus of prescribed by the Pharmacy Council of India.

The book is designed as a small and humble effort to compile the necessary information which covers the subject Pharmaceutics including all the basic

concepts, questions asked in various competitive examinations, simple and effective way to learn and revise.

The book has been written in lucid and easy language so that it is easy for the students to understand the concepts. At the end of each chapter questions have been given so that there is clear understanding to the chapter.

I hope that the readers will find the book useful. Their comments and suggestions for the improvement of this textbook will be appreciated.

Our special thanks to Mr. Gaurav Singh and Neeraj Sharma V.M. BOOKS (Publishers & Distributers) India for untiring efforts in the direction of bringing out this book in time.

Authors v

Syllabus

1. Scope of Anatomy and Physiology. Definition of various terminologies.
2. Structure of Cell: Components and its functions.
3. Tissues of the Human Body: Epithelial, Connective, Muscular and Nervous tissues–Their sub-types and characteristics.

4. Osseous System: Structure and functions of bones of axial and appendicular skeleton. 3 Classification, types and movements of joints, disorders of joints.

5. Haemopoetic System
• Composition and functions of blood
• Process of Haemopoesis

• Characteristics and functions of RBC’s, WBC’s and platelets
• Mechanism of blood clotting
• importance of blood groups

6. Lymphatic System

• Lymph and lymphatic system, composition, function and its formation.
• Structure and functions of spleen and lymph node.

7. Cardiovascular System
• Anatomy and Physiology of heart
• Blood vessels and circulation (Pulmonary, coronary

and systemic circulation)

• Cardiac cycle and Heart sounds, Basic knowledge of ECG
• Blood pressure and its regulation
8. Respiratory System
• Anatomy of respiratory organs and their functions.
• Regulation and mechanism of respiration.
• Respiratory volumes and capacities (Definitions)
9. Digestive System
• Anatomy and Physiology of GIT.
• Anatomy and functions of accessory glands.
• Physiology of digestion and absorption

10. Skeletal Muscles
• Histology
• Physiology of muscle contraction

• Disorder of skeletal muscles

11. Nervous System
• Classification of nervous system
• Anatomy and physiology of cerebrum, cerebellum,

mid brain
• Function of hypothalamus, medulla oblongata and
basal ganglia
• Spinal cord - Structure and reflexes
• Names and functions of cranial nerves.

• Anatomy and physiology of sympathetic and parasympathetic nervous system (ANS)

12. Sense Organs

Anatomy and physiology of

• Eye,
• Ear,
• Skin
• Tongue
• Nose

13. Urinary System

• Anatomy and physiology of urinary system

• Physiology of urine formation
• Renin - angiotensin system
• Clearance tests and micturition.

14. Endocrine System (Hormones and their Functions)

• Pituitary gland

• Adrenal gland
• Thyroid and parathyroid gland
• Pancreas and gonads

15. Reproductive System

• Anatomy of male and female reproductive system
• Physiology of menstruation
• Spermatogenesis and Oogenesis
• Pregnancy and parturition

Contents

1

Scope of Anatomy and Physiology

Anatomy is the study of structure, and physiology is the study of function. These approaches are complementary and never entirely separable. In some of its facets anatomy is closely related to embryology, comparative anatomy and comparative embryology, through common roots in evolution. Anatomy is subdivided into gross anatomy (or macroscopic anatomy) and microscopic anatomy.

Gross anatomy (also called topographical anatomy, regional anatomy, or anthropotomy) is the study of anatomical structures that can be seen by unaided vision. Microscopic anatomy is the study of minute anatomical structures assisted with microscopes, which includes histology (the study of the organisation of tissues), and cytology (the study of cells).

The history of anatomy has been characterized, over time, by a continually developing understanding of the functions of organs and structures in the body. Methods have also advanced dramatically, advancing from examination of animals through dissection of cadavers (dead human bodies) to technologically complex techniques developed in the 20th century.

Anatomy should not be confused with anatomical pathology (also called morbid anatomy or histopathology), which is the study of the gross and microscopic appearances of diseased organs.

Physiology has traditionally been divided between plant physiology and animal physiology but the principles of physiology are universal, no matter what particular organism

is being studied. For example, what is learned about the physiology of yeast cells may also apply to human cells.

The field of animal physiology extends the tools and methods of human physiology to non-human animal species. Plant physiology also borrows techniques from both fields. Its scope of subjects is at least as diverse as the tree of life itself.

SCOPE OF ANATOMY AND PHYSIOLOGY

1. Anatomy: Anatomy is the Science of body structures and relationships among the structures.
2. Physiology: Physiology is the Science of body functions, that is, how the body parts work.
3. To inquire into fascinating complexity of human body.
4.As gateway to careers in health related fields. Mass therapy and Athletics training.

5.As a foundation to advanced scientific studies.
6. To know the structure and function of human body.
7. For understanding pathology, of disease and pathological changes.
8. For determining techniques of surgeries.
9. To know parameters of normal health.
10. Factors affecting various physiological processes and its effects.
11. Overall effective maintenance of individual and community health.
12. The Principles of Anatomy and Physiology to meet the existing requirements of introductory anatomy and Physiology courses.
13. It also gives values, simplicity, direction and sort of power to the learners.
14. Human Anatomy and Physiology is formidable body of knowledge to present in an introductory course and mastering subject.
15. It also highlights the practical application of anatomical and physiological concepts to students.
16. The dynamic physiological constancy known as Homeostasis is the cardinal theme in principles of Anatomy and Physiology.
17. By studying concepts of Physiology, we know, how the various feedback mechanisms work to maintain physiological processes within a narrow range that is compatible with life.
18. It is needed to understand how individual structures are related to the composition of entire body.
Therefore anatomical nomenclature such as regional names, directional terms and planes to sections that enable the learners to precisely describe the relationship of one body structure to another.

DEFINITION OF VARIOUS TERMINOLOGY

Anatomists and health care providers use terminology that can be bewildering to the uninitiated. However, the purpose of this language is not to confuse, but rather to increase precision and reduce medical errors. For example, is a scar “above the wrist” located on the forearm two or three inches away from the hand? Or is it at the base of the hand? Is it on the palm-side or backside? By using precise anatomical terminology, we eliminate ambiguity. Anatomical terms derive from ancient Greek and Latin words. Because these languages are no longer used in everyday conversation, the meaning of their words does not change.

Anatomical terms are made up of roots, prefixes, and suffixes. The root of a term often refers to an organ, tissue, or condition, whereas the prefix or suffix often describes the root. For example, in the disorder hypertension, the prefix “hyper-” means “high” or “over,” and the root word “tension” refers to pressure, so the word “hypertension” refers to abnormally high blood pressure.

Anatomical Position

To further increase precision, anatomists standardize the way

in which they view the body. Just as maps are normally oriented with north at the top, the standard body “map,” or anatomical position, is that of the body standing upright, with the feet at shoulder width and parallel, toes forward. The upper limbs are held out to each side, and the palms of the hands face forward as illustrated in Figure 1. Using this standard position reduces confusion. It does not matter how the body being described is oriented, the terms are used as if it is in anatomical position. For example, a scar in the “anterior (front) carpal (wrist) region” would be present on the palm side of the wrist. The term “anterior” would be used even if the hand were palm down on a table.

A body that is lying down is described as either prone or supine. Prone describes a face-down orientation, and supine describes a face up orientation. These terms are sometimes used in describing the position of the body during specific physical examinations or surgical procedures.

Regional Terms

The human body’s numerous regions have specific terms to

help increase precision. Notice that the term “brachium” or “arm” is reserved for the “upper arm” and “antebrachium” or “forearm” is used rather than “lower arm.” Similarly, “femur” or “thigh” is correct, and “leg” or “crus” is reserved for the portion of the lower limb between the knee and the ankle. You will be able to describe the body’s regions using the terms from the figure.

Directional Terms

Certain directional anatomical terms appear throughout this

and any other anatomy textbook (Figure 1.2). These terms are essential for describing the relative locations of different body structures. For instance, an anatomist might describe one band of tissue as “inferior to” another or a physician might describe a tumour as “superficial to” a deeper body structure.

Commit these terms to memory to avoid confusion when you are studying or describing the locations of particular body parts.

• Anterior (or ventral) Describes the front or direction toward the front of the body. The toes are anterior to the foot.
• Posterior (or dorsal) Describes the back or direction toward the back of the body. The popliteus is posterior to the patella.
• Superior (or cranial) describes a position above or higher than another part of the body proper. The orbits are superior to the oris.
• Inferior (or caudal) describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column). The pelvis is inferior to the abdomen.

Frons or forehead (frontal)
Oris or mouth (oral) Mentis or chin
(mental)
Axilla or armpit (axillary)
Brach um or
arm (brachial)

Antecubitis
or front of elbow (antecubital)

Antebrachium
or forearm
(antebrachial)

Carpus
or wrist
(carpal)

Pollex
or thumb
Palma or
palm (palmar)

Digits (phalanges) or fingers (digital or pha angeal) Cranium or skull (cranial)

Facies
or face (facial)

Patella or kneecap (patellar) Oculus or eye (orbital or ocular)

Bucca or cheek (buccal) Auris or ear (otic)
Nasus or nose (nasal)
Cervicis or neck (cervical)

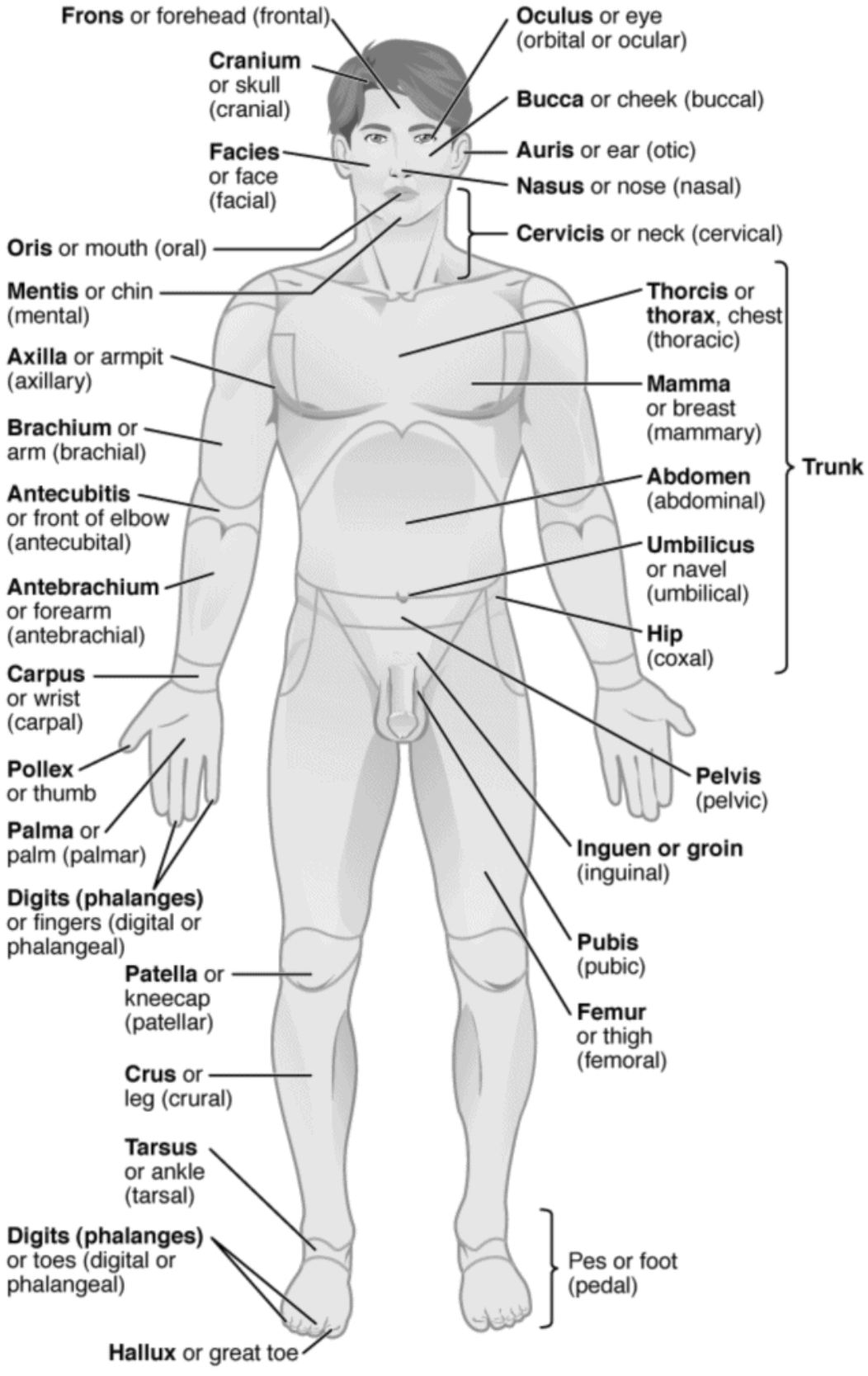
Thorcis or
thorax, chest
(thoracic)

Mamma
or breast
(mammary)

Abdomen Trunk (abdominal)

Umbilicus
or navel
(umbilical)

Hip
(coxal)
Pelvis (pelvic) Inguen or groin (inguinal)
Pubis
(pubic) Femur or thigh Crus or


Frons or forehead (frontal)
Oculus or eye (orbital or ocular)
Cranium or skull (cranial)
Bucca or cheek (buccal)
Facies or face (facial)
Auris or ear (otic)
Nasus or nose (nasal)
Cervicis or neck (cervical)
Oris or mouth (oral)
Mentis or chin (mental)
Thorcis or **thorax**, chest (thoracic)
Axilla or armpit (axillary)
Mamma or breast (mammary)
Brachium or arm (brachial)
Abdomen (abdominal)
Trunk
Antecubitis or front of elbow (antecubital)
Umbilicus or navel (umbilical)
Antebrachium or forearm (antebrachial)
Hip (coxal)
Carpus or wrist (carpal)
Pollex or thumb
Pelvis (pelvic)
Palma or palm (palmar)
Inguen or groin (inguinal)
Digits (phalanges) or fingers (digital or phalangeal)
Pubis (pubic)
Patella or kneecap (patellar)
Femur or thigh (femoral)
Crus or leg (crural)
Tarsus or ankle (tarsal)
Digits (phalanges) or toes (digital or phalangeal)
Pes or foot (pedal)
Hallux or great toe

(a) Anterior view

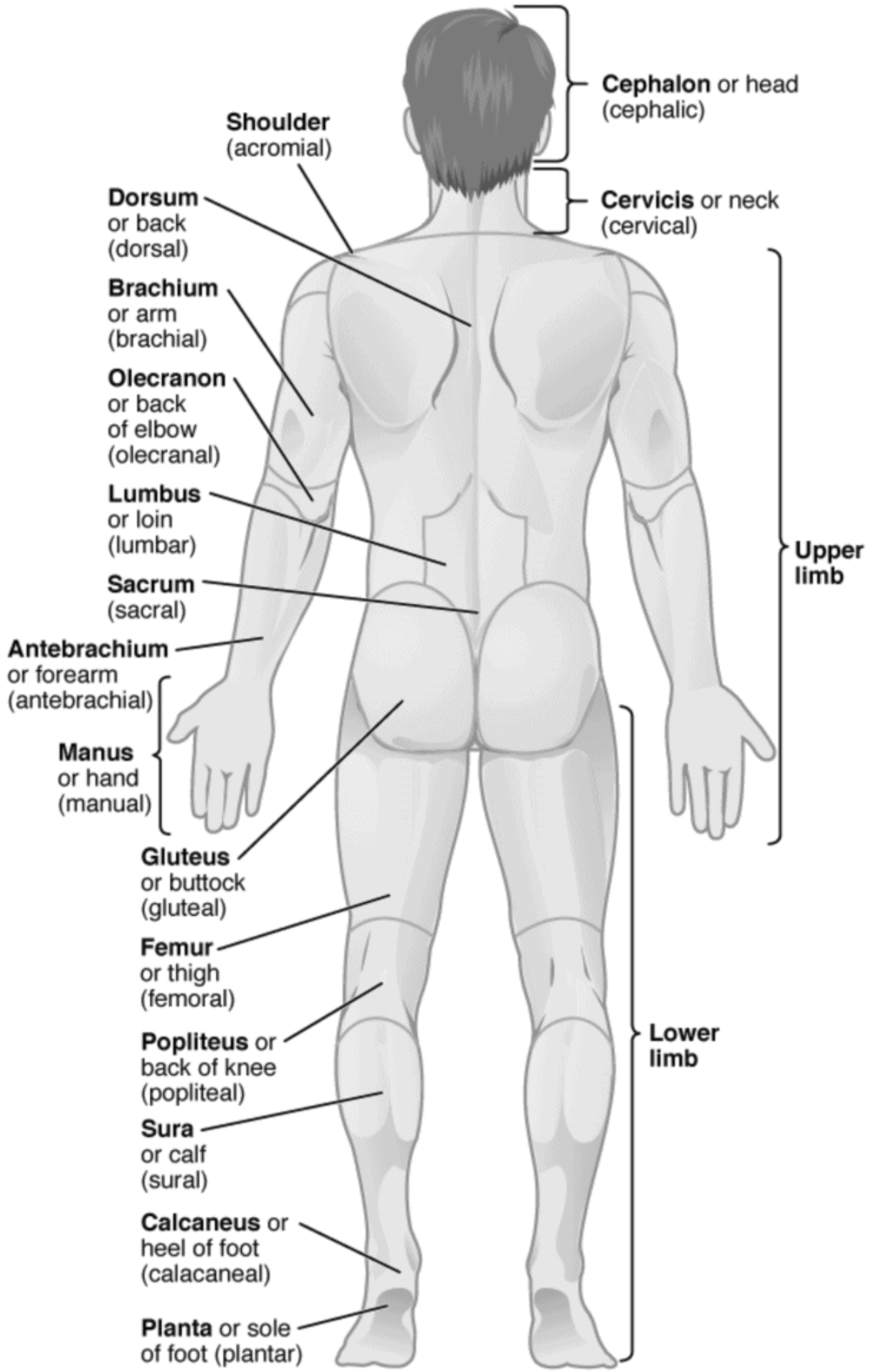
(femoral) leg (crural)

Tarsus
or ankle
(tarsal)

Digits (phalanges)
or toes (digital or Pes or foot phalangeal) (pedal)

Hallux or great toe

(a) Anterior view



(b) Posterior view

(b) Posterior view

Figure 1.1: Regions of the Human Body. The human body is shown in anatomical position in an (a) anterior view and a (b) posterior view. The regions of the body are labelled in boldface.

• Lateral describes the side or direction toward the side of the body. The thumb (pollex) is lateral to the digits.
• Medial describes the middle or direction toward the middle of the body. The hallux is the medial toe.
• Proximal describes a position in a limb that is nearer to the point of attachment or the trunk of the body. The brachium is proximal to the antebrachium.
• Distal describes a position in a limb that is farther from the point of attachment or the trunk of the body. The crus is distal to the femur.
• Superficial describes a position closer to the surface of the body. The skin is superficial to the bones.
• Deep describes a position farther from the surface of the body. The brain is deep to the skull.

Body Planes
A section is a two-dimensional surface of a three-dimensional

structure that has been cut. Modern medical imaging devices enable clinicians to obtain “virtual sections” of living bodies. We call these scans. Body sections and scans can be correctly interpreted, however, only if the viewer understands the plane along which the section was made.

A plane is an imaginary two-dimensional surface that passes through the body. There are three planes commonly referred to in anatomy and medicine, as illustrated in Figure 1.3.

• The **sagittal plane** is the plane that divides the body or an organ vertically into right and left sides. If this vertical plane runs directly down the middle of the body, it is called the midsagittal or median plane. If it divides the body into unequal right and left sides, it is called a parasagittal plane or less commonly a longitudinal section.
• The **frontal plane** is the plane that divides the body or an organ into an

anterior (front) portion and a posterior (rear) portion. The frontal plane is often referred to as a coronal plane. (“Corona” is Latin for “crown.”)
• The **transverse plane** is the plane that divides the body or organ horizontally into upper and lower portions. Transverse planes produce images referred to as cross sections.

Superior

Cranial Right Left

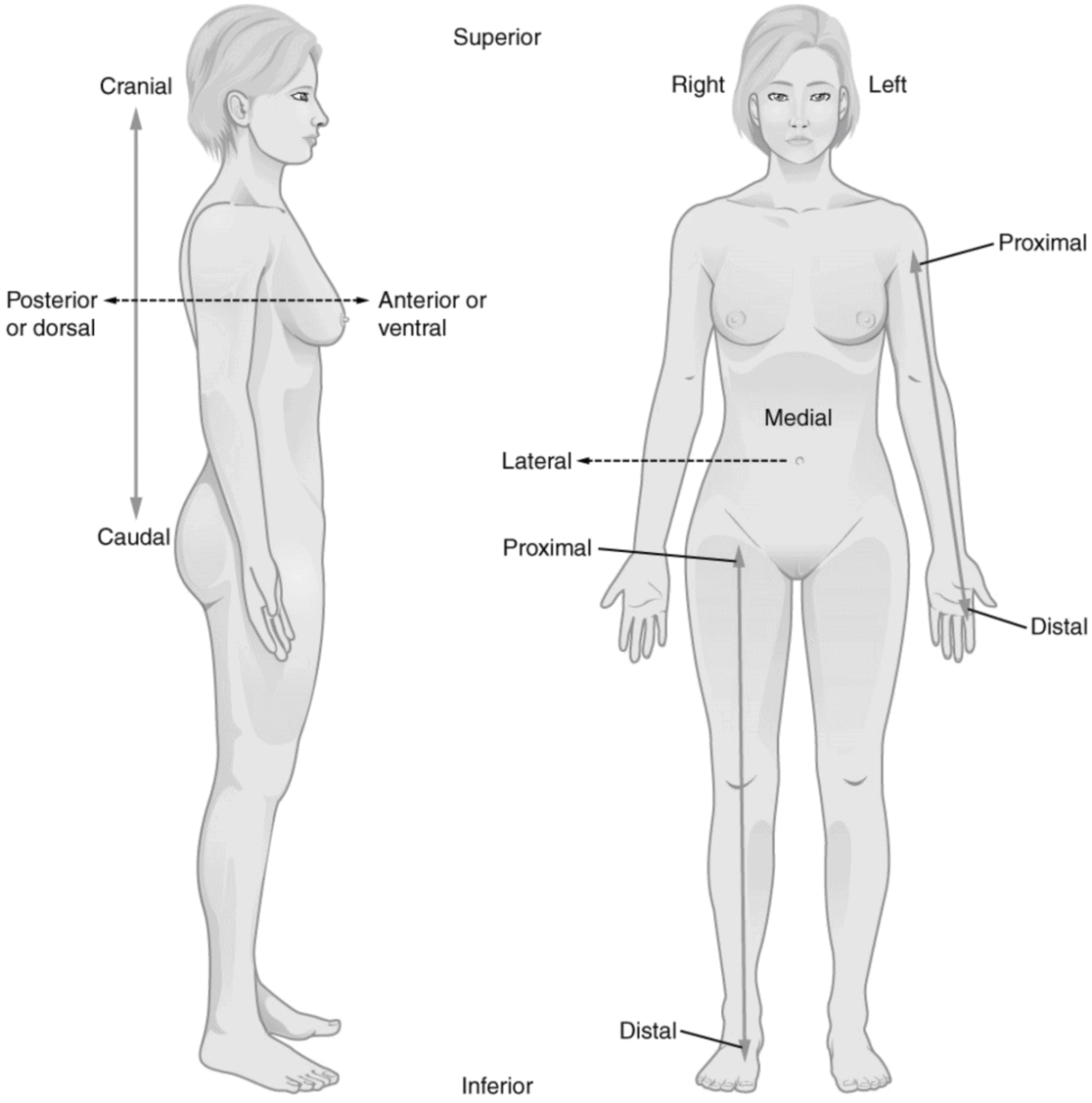
Posterior
or dorsal

Proximal Anterior or

ventral

Lateral

Caudal Proximal



Distal

Distal

Inferior

Figure 1.2: Directional Terms Applied to the Human Body.

Paired directional terms are shown as applied to the human body

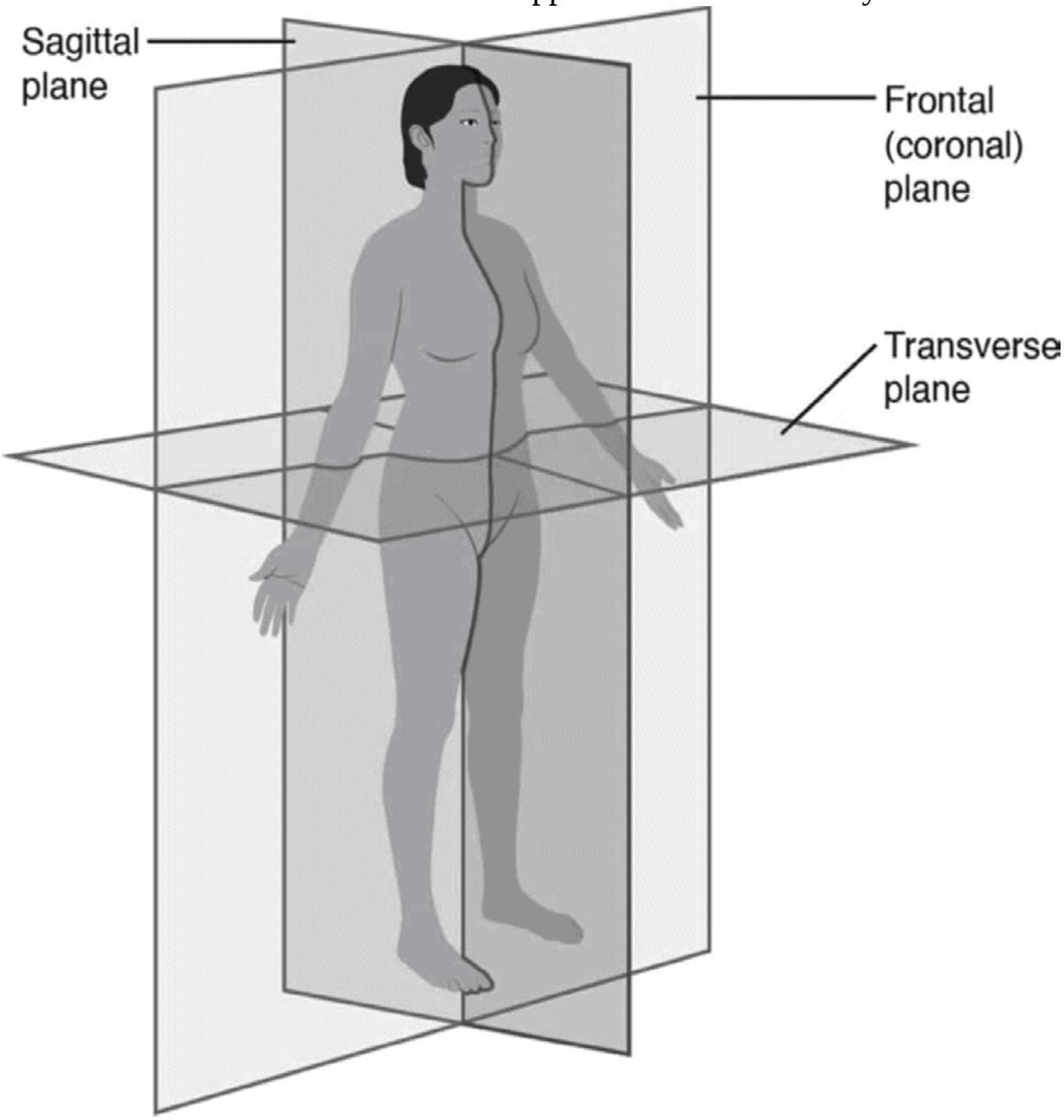


Figure 1.3: Planes of the Body. The three planes most commonly used in anatomical and medical imaging are the sagittal, frontal (or coronal), and transverse plane

Body Cavities and Serous Membranes

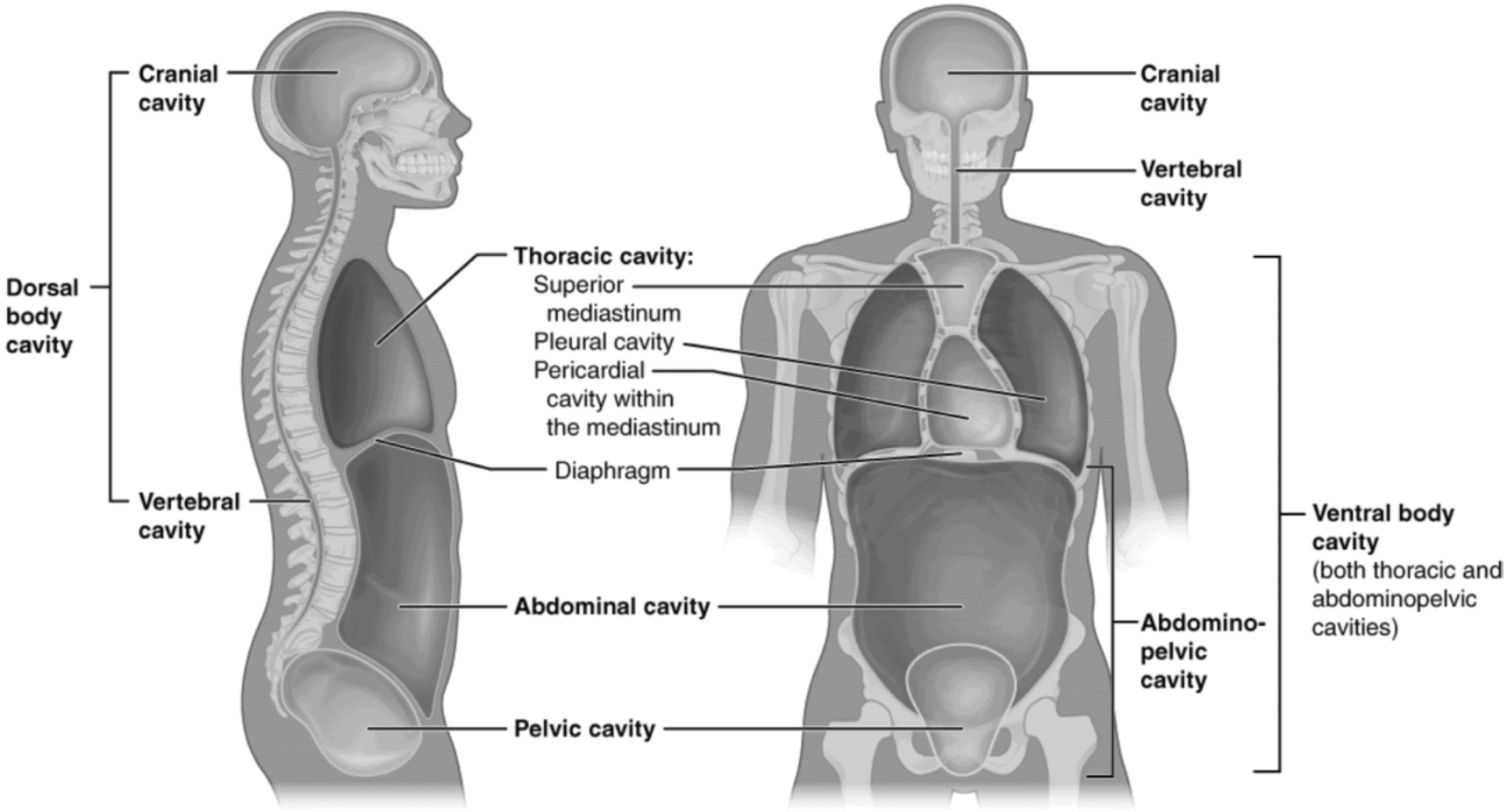
The body maintains its internal organization by means of membranes, sheaths, and other structures that separate compartments. The dorsal (posterior) cavity and the ventral (anterior) cavity are the largest body compartments. These cavities contain and protect delicate internal organs, and the ventral cavity allows for significant changes in the size and shape of the organs as they perform their functions. The lungs, heart, stomach, and intestines, for example, can expand and contract without distorting other tissues or disrupting the activity of nearby organs.

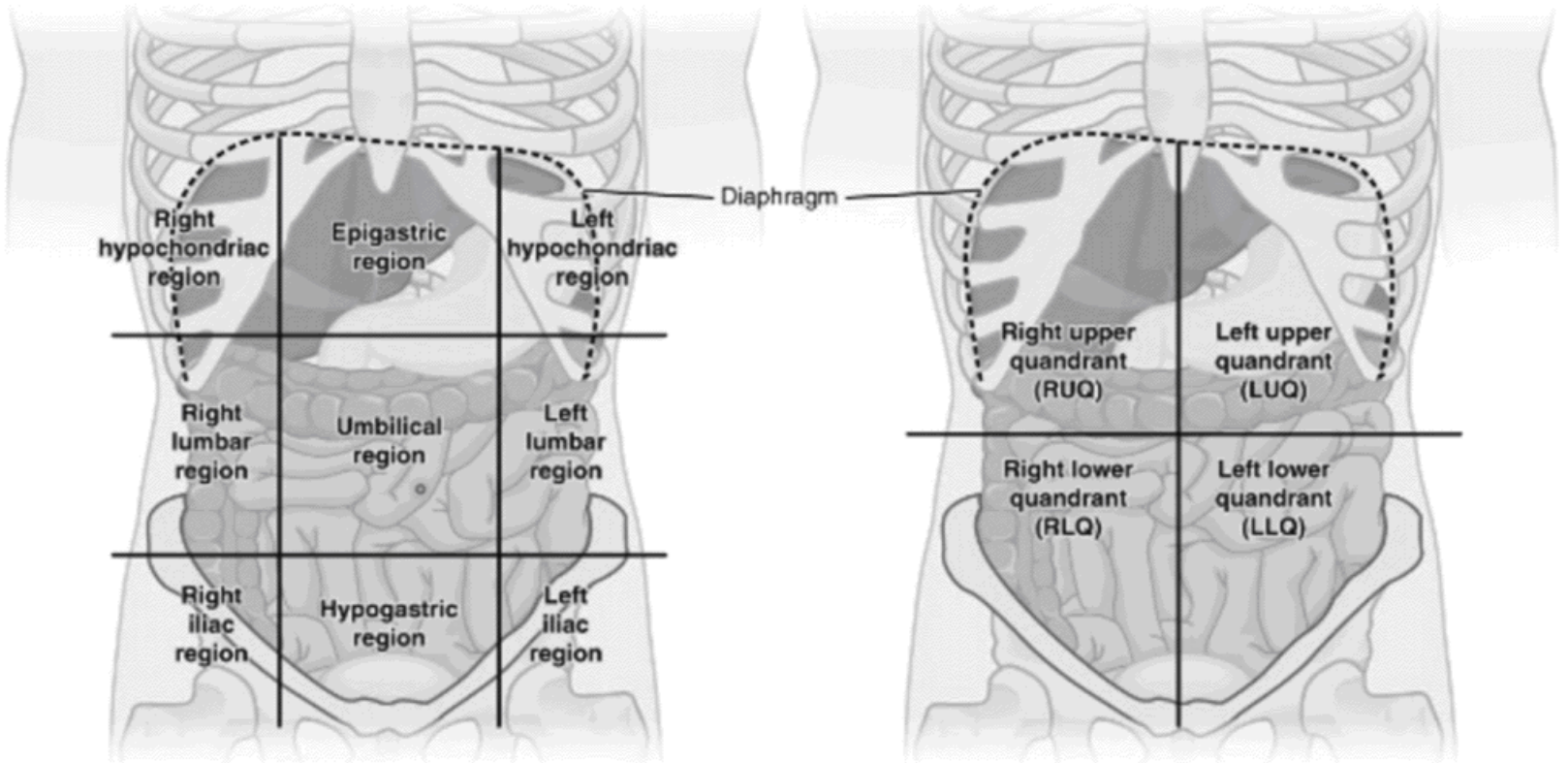
Subdivisions of the Posterior (Dorsal) and Anterior (Ventral) Cavities The posterior (dorsal) and anterior (ventral) cavities are each subdivided into smaller cavities. In the posterior (dorsal) cavity, the cranial cavity houses the brain, and the spinal cavity (or vertebral cavity) encloses the spinal cord. Just as the brain and spinal cord make up a continuous, uninterrupted structure, the cranial and spinal cavities that house them are also continuous. The brain and spinal cord are protected by the bones of the skull and vertebral column and by cerebrospinal fluid, a colourless fluid produced by the brain, which cushions the brain and spinal cord within the posterior (dorsal) cavity.

The anterior (ventral) cavity has two main subdivisions: the thoracic cavity and the abdominopelvic cavity. The thoracic cavity is the more superior subdivision of the anterior cavity, and it is enclosed by the rib cage. The thoracic cavity contains the lungs and the heart, which is located in the mediastinum. The diaphragm forms the floor of the thoracic cavity and separates it from the more inferior abdominopelvic cavity. The abdominopelvic cavity is the largest cavity in the body. Although no membrane physically divides the abdominopelvic cavity, it can be useful to distinguish between the abdominal cavity, the division that houses the digestive organs, and the pelvic cavity, the division that houses the organs of reproduction.

Abdominal Regions and Quadrants

To promote clear communication, for instance about the location of a patient’s abdominal pain or a suspicious mass, health care providers typically divide up the cavity into either nine regions or four quadrants.


Cranial cavity
Dorsal body cavity
Vertebral cavity
Thoracic cavity:
Superior mediastinum
Pleural cavity
Pericardial cavity within the mediastinum
Diaphragm
Abdominal cavity
Pelvic cavity
Lateral view
Cranial cavity
Vertebral cavity
Abdomino-pelvic cavity
Ventral body cavity (both thoracic and abdominopelvic cavities)
Anterior view

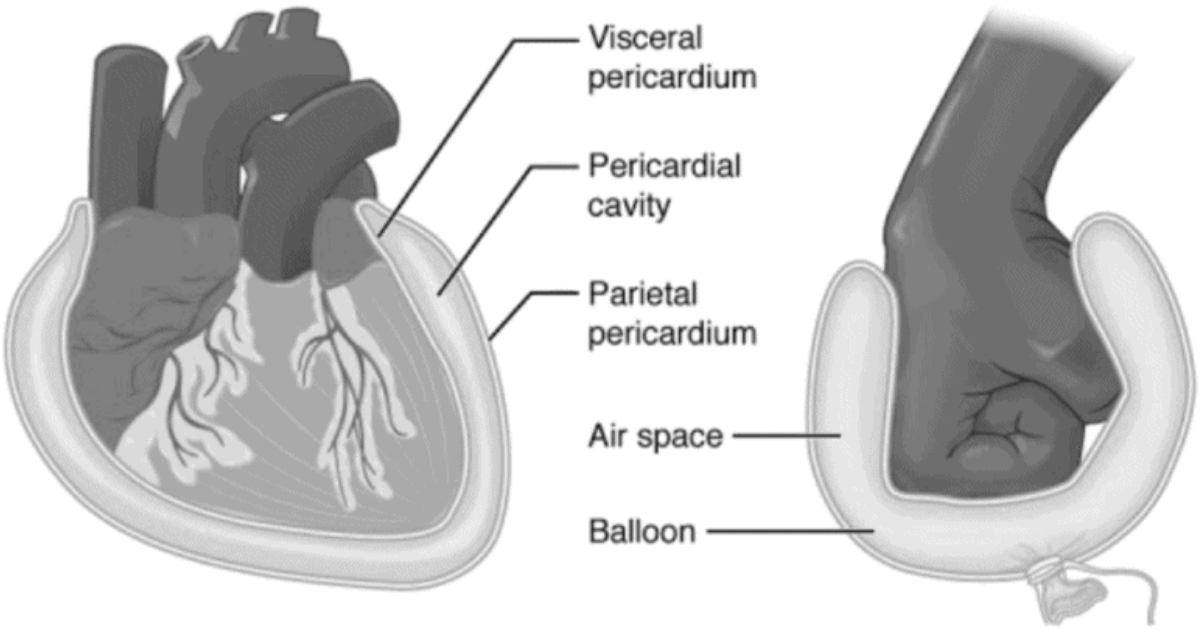

Diaphragm
Right hypochondriac region
Epigastric region
Left hypochondriac region
Right lumbar region
Umbilical region
Left lumbar region
Right iliac region
Hypogastric region
Left iliac region
Right upper quandrant (RUQ)
Left upper quandrant (LUQ)
Right lower quandrant (RLQ)
Left lower quandrant (LLQ)

The more detailed regional approach subdivides the cavity with one horizontal line immediately inferior to the ribs and one immediately superior to the pelvis, and two vertical lines drawn as if dropped from the midpoint of each clavicle (collarbone). There are nine resulting regions. The simpler quadrants approach, which is more commonly used in medicine, subdivides the cavity with one horizontal and one vertical line that intersect at the patient's umbilicus (navel).

Membranes of the Anterior (Ventral) Body Cavity
A serous membrane (also referred to a serosa) is one of the thin

membranes that cover the walls and organs in the thoracic and abdominopelvic cavities. The parietal layers of the membranes line the walls of the body cavity (pariet- refers to a cavity wall). The visceral layer of the membrane covers the organs (the viscera). Between the parietal and visceral layers is a very thin, fluid-filled serous space, or cavity.

Visceral
pericardium
Pericardial cavity
Visceral
pericardium
Air space



Balloon

Figure 1.6: Serous Membrane. Serous membrane lines the pericardial cavity and reflects back to cover the heart—much the same way that an underinflated balloon would form two layers surrounding a fist.

There are three serous cavities and their associated membranes. The pleura is the serous membrane that surrounds the lungs in the pleural cavity; the pericardium is the serous membrane that surrounds the heart in the pericardial cavity; and the peritoneum is the serous membrane that surrounds several organs in the abdominopelvic cavity. The serous membranes form fluid-filled sacs, or cavities, that are meant to cushion and reduce friction on internal organs when they move, such as when the lungs inflate or the heart beats. Both the parietal and visceral serosa secrete the thin, slippery serous fluid located within the serous cavities. The pleural cavity reduces friction between the lungs and the body wall. Likewise, the pericardial cavity reduces friction between the heart and the wall of the pericardium. The peritoneal cavity reduces friction between the abdominal and pelvic organs and the body wall. Therefore, serous membranes provide additional protection to the viscera they enclose by reducing friction that could lead to inflammation of the organs.

GLOSSARY

Abdominopelvic cavity: division of the anterior (ventral) cavity that houses the abdominal and pelvic viscera.
Anatomical position: standard reference position used for describing locations and directions on the human body.
Anterior: describes the front or direction toward the front of the body; also referred to as ventral.
Anterior cavity: larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membranelined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as ventral cavity.
Caudal: describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as inferior.
Cranial: describes a position above or higher than another part of the body proper; also referred to as superior.
Cranial cavity: division of the posterior (dorsal) cavity that houses the

brain.
Deep: describes a position farther from the surface of the body.
Distal: describes a position farther from the point of attachment or the trunk of the body.
Dorsal: describes the back or direction toward the back of the body; also referred to as posterior.
Dorsal cavity: posterior body cavity that houses the brain and spinal cord; also referred to the posterior body cavity.
Frontal plane: two-dimensional, vertical plane that divides the body or organ into anterior and posterior portions.
Inferior: describes a position below or lower than another part of the body proper: near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as caudal.
Lateral: describes the side or direction toward the side of the body.
Medial: describes the middle or direction toward the middle of the body.
Pericardium: Sac that encloses the heart.
Peritoneum: serous membrane that lines the abdominopelvic cavity and covers the organs found there.
Plane: imaginary two-dimensional surface that passes through the body.
Pleura: serous membrane that lines the pleural cavity and covers the lungs.
Posterior: describes the back or direction toward the back of the body; also referred to as dorsal.
Posterior cavity: posterior body cavity that houses the brain and spinal cord; also referred to as dorsal cavity.
Prone: face down.
Proximal: describes a position nearer to the point of attachment or the trunk of the body.
Sagittal plane: two-dimensional, vertical plane that divides the body or organ into right and left sides.
Section: in anatomy, a single flat surface of a threedimensional structure that has been cut through.
Serous membrane: membrane that covers organs and reduces friction; also referred to as serosa.
Serosa: membrane that covers organs and reduces friction; also referred to as serous membrane.
Spinal cavity: division of the dorsal cavity that houses the spinal cord; also referred to as vertebral cavity.

Superficial: describes a position nearer to the surface of the body.
Superior: describes a position above or higher than another part of the body proper; also referred to as cranial.
Supine: face up.
Thoracic cavity: division of the anterior (ventral) cavity that houses the heart, lungs, esophagus, and trachea.
Transverse plane: two-dimensional, horizontal plane that divides the body or organ into superior and inferior portions.
Ventral: describes the front or direction toward the front of the body; also referred to as anterior.
Ventral cavity: larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membranelined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as anterior body cavity.

2

Structure of Cell

THE CELL AND CELLULAR LEVEL OF ORAGMISATION

The **cell membrane** is an extremely pliable structure composed primarily of back-to-back phospholipids (a “bilayer”). Cholesterol is also present, which contributes to the fluidity of the membrane, and there are various proteins embedded within the membrane that have a variety of functions.

A single phospholipid molecule has a phosphate group on one end, called the “head,” and two side-by-side chains of fatty acids that make up the lipid tails (Fig. 2.1). The phosphate group is negatively charged, making the head polar and hydrophilic—or “water loving.” A **hydrophilic** molecule (or region of a molecule) is one that is attracted to water. The phosphate heads are thus attracted to the water molecules of both the extracellular and intracellular environments. The lipid tails, on the other hand, are uncharged, or nonpolar, and are hydrophobic—or “water fearing.” A **hydrophobic** molecule (or region of a molecule) repels and is repelled by water.ome lipid tails consist of saturated fatty acids and some contain unsaturated fatty acids.

This combination adds to the fluidity of the tails that are constantly in motion. Phospholipids are thus amphipathic molecules. An **amphipathic** molecule is one that contains both a hydrophilic and a hydrophobic region. In fact, soap works to remove oil and grease stains because it has amphipathic properties. The hydrophilic portion can dissolve in water while the hydrophobic portion can trap grease in micelles that then can be washed away.

17

The cell membrane consists of two adjacent layers of phospholipids. The lipid tails of one layer face the lipid tails of the other layer, meeting at the interface of the two layers. The phospholipid heads face outward, one layer exposed to the interior of the cell and one layer exposed to the exterior (Fig. 2.2). Because the phosphate groups are polar and hydrophilic, they are attracted to water in the intracellular fluid. **Intracellular fluid (ICF)** is the fluid interior of the cell. The phosphate groups are also attracted to the extracellular fluid. **Extracellular fluid (ECF)** is the fluid environment outside the enclosure of the cell membrane. **Interstitial fluid (IF)** is the term given to extracellular fluid not contained within blood vessels. Because the lipid tails are hydrophobic, they meet in the inner region of the membrane, excluding watery intracellular and extracellular fluid from this space. The cell membrane has many proteins, as well as other lipids (such as cholesterol), that are associated with the phospholipid bilayer. An important feature of the membrane is that it remains fluid; the lipids and proteins in the cell membrane are not rigidly locked in place.

Figure 2.1: Phospholipid Molecule

MEMBRANE PROTEINS

The lipid bilayer forms the basis of the cell membrane, but it is peppered throughout with various proteins. Two different types of proteins that are commonly associated with the cell membrane are the integral proteins and peripheral protein (Fig. 2.3. Cell Membrane). As its name suggests, **an integral protein** is a protein that is embedded in the membrane. A **channel protein** is an example of an integral protein that selectively allows particular materials, such as certain ions, to pass into or out of the cell.

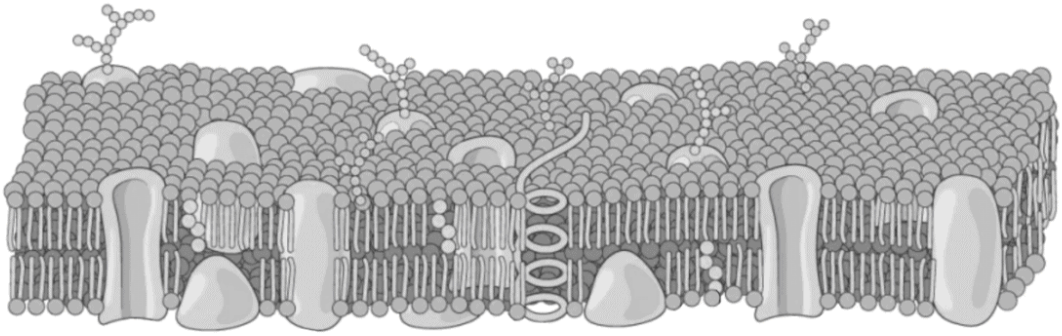


Figure 2.2: Phospholipid Biloger

Another important group of integral proteins are cell recognition proteins, which serve to mark a cell's identity so that it can be recognized by other cells. A **receptor** is a type of recognition protein that can selectively bind a specific molecule outside the cell, and this binding induces a chemical reaction within the cell. A **ligand** is the specific molecule that binds to and activates a receptor. Some integral proteins serve dual roles as both a receptor and an ion channel. One example of a receptor-ligand interaction is the receptors on nerve cells that bind neurotransmitters, such as dopamine. When a dopamine molecule binds to a dopamine receptor protein, a channel within the transmembrane protein opens to allow certain ions to flow into the cell.

Transport across the Cell Membrane
One of the great wonders of the cell membrane is its ability to

regulate the concentration of substances inside the cell. These substances include ions such as Ca^{++}, Na^{+}, K^{+}, and Cl nutrients including sugars, fatty acids, and amino acids; and waste products, particularly carbon dioxide (CO^{2}), which must leave the cell.

The membrane's lipid bilayer structure provides the first level of control. The phospholipids are tightly packed together, and the membrane has a hydrophobic interior. This structure causes the membrane to be **selectively permeable.** A membrane that has selective permeability allows only substances meeting certain criteria to pass through it unaided. In the case of

the cell membrane, only relatively small, nonpolar materials can move through the lipid bilayer (remember, the lipid tails of the membrane are nonpolar). Some examples of these are other lipids, oxygen and carbon dioxide gases, and alcohol. However, water-soluble materials—like glucose, amino acids, and electrolytes—need some assistance to cross the membrane because they are repelled by the hydrophobic tails of the phospholipid bilayer. All substances that move through the membrane do so by one of two general methods, which are categorized based on whether or not energy is required. **Passive transport** is the movement of substances across the membrane without the expenditure of cellular energy. In contrast, **active transport** is the movement of substances across the membrane using energy from adenosine triphosphate (ATP).

Passive Transport
In order to understand *how* substances move passively across

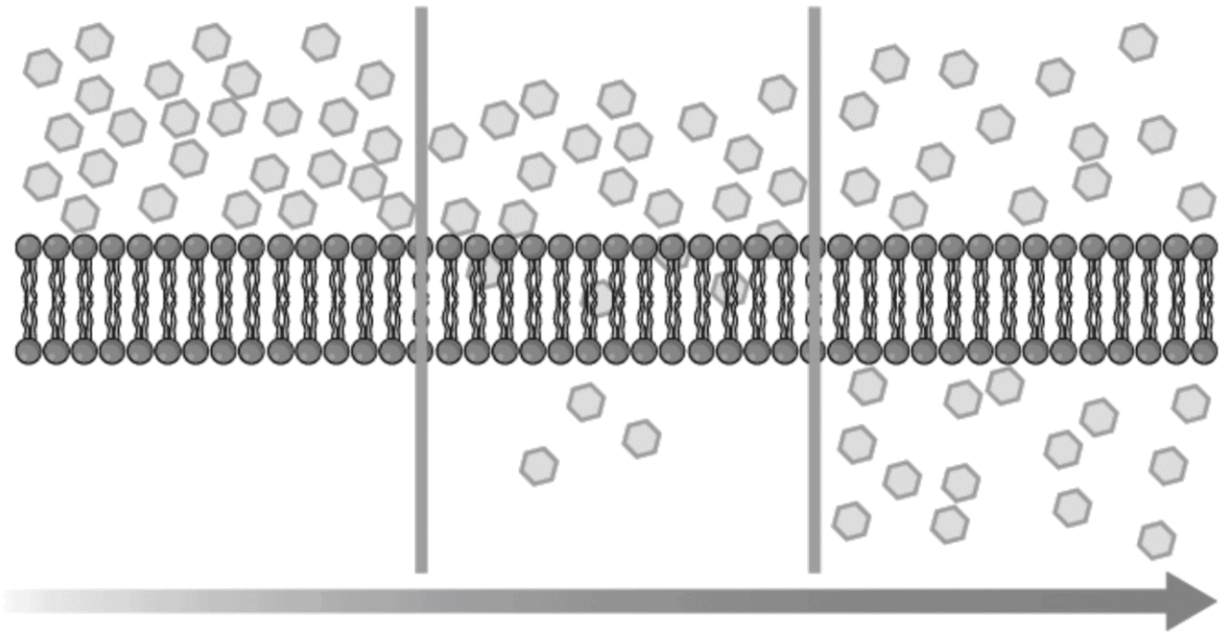
a cell membrane, it is necessary to understand concentration gradients and diffusion. A **concentration gradient** is the difference in concentration of a substance across a space. Molecules (or ions) will spread/diffuse from where they are more concentrated to where they are less concentrated until they are equally distributed in that space. (When molecules move in this way, they are said to move *down* their concentration gradient.) **Diffusion** is the movement of particles from an area of higher concentration to an area of lower concentration. A couple of common examples will help to illustrate this concept. Imagine being inside a closed bathroom. If a bottle of perfume were sprayed, the scent molecules would naturally diffuse from the spot where they left the bottle to all corners of the bathroom, and this diffusion would go on until no more concentration gradient remains. Another example is a spoonful of sugar placed in a cup of tea. Eventually, the sugar will diffuse throughout the tea until no concentration gradient remains. In both cases, if the room is warmer or the tea hotter, diffusion occurs even faster as the molecules are bumping into each other and spreading out faster than at cooler temperatures. Having an internal body temperature around 98.6°F thus also aids in diffusion of particles within the body.

Whenever a substance exists in greater concentration on one side of a semipermeable membrane, such as the cell membranes, any substance that can move down its concentration gradient across the membrane will do so.

Consider substances that can easily diffuse through the lipid bilayer of the cell membrane, such as the gases oxygen (O_2) and CO_2. O_2 generally diffuses into cells because it is more concentrated outside of them, and CO_2 typically diffuses out of cells because it is more concentrated inside of them. Neither of these examples requires any energy on the part of the cell, and therefore they use passive transport to move across the membrane.

Before moving on, you need to review the gases that can diffuse across a cell membrane. Because cells rapidly use up oxygen during metabolism, there is typically a lower concentration of O_2 inside the cell than outside. As a result, oxygen will diffuse from the interstitial fluid directly through the lipid bilayer of the membrane and into the cytoplasm within the cell. On the other hand, because cells produce CO_2 as a byproduct of metabolism, CO_2 concentrations rise within the cytoplasm; therefore, CO_2 will move from the cell through the lipid bilayer and into the interstitial fluid, where its concentration is lower. This mechanism of molecules moving across a cell membrane from the side where they are more concentrated to the side where they are less concentrated is a form of passive transport called simple diffusion.

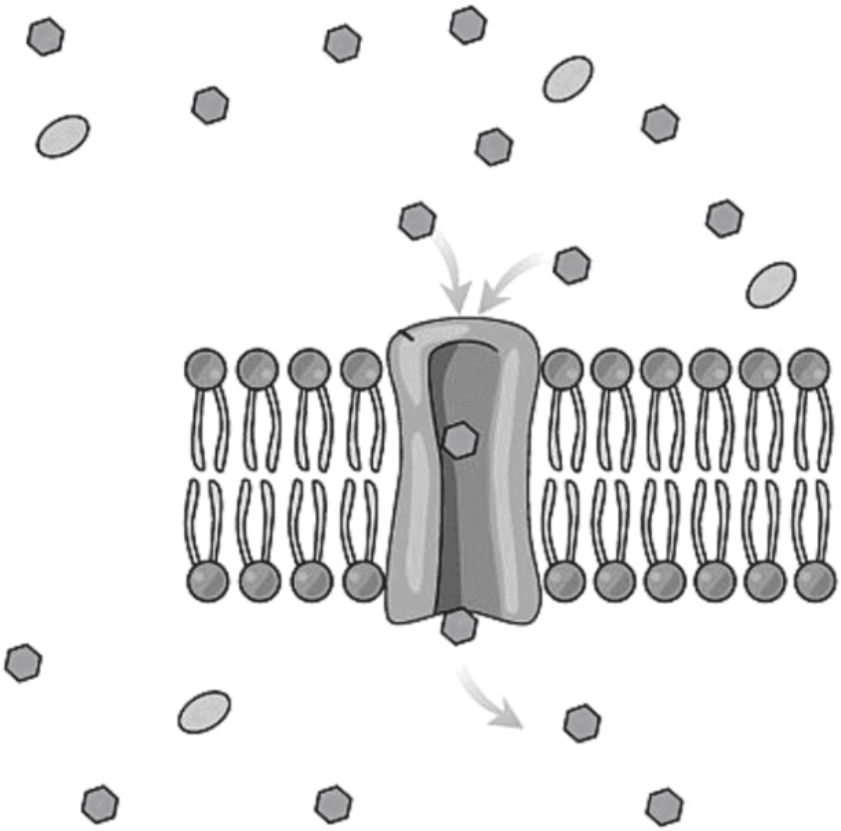
Simple Diffusion across the Cell (Plasma) Membrane



Large polar or ionic molecules, which are hydrophilic, cannot easily cross the phospholipid bilayer. Very small polar molecules, such as water, can cross via simple diffusion due to their small size. Charged atoms or molecules of any size cannot cross the cell membrane via simple diffusion as the charges are repelled by the hydrophobic tails in the interior of the phospholipid bilayer. Solutes dissolved in water on either side of the cell membrane will tend to diffuse down their concentration gradients, but because most substances cannot pass freely through the lipid bilayer of the cell membrane, their movement is restricted to protein channels and specialized transport mechanisms in the membrane. **Facilitated diffusion** is the diffusion process used for those substances that cannot cross the lipid bilayer due to their size, charge, and/or polarity (Fig. 2.4. Facilitated Diffusion). A common example of facilitated diffusion is the movement of glucose into the cell, where it is used to make ATP. Although glucose can be more concentrated outside of a cell, it cannot cross the lipid bilayer via simple diffusion because it is both large and polar. To resolve this, a specialized carrier protein called the glucose transporter will transfer glucose molecules into the cell to facilitate its inward diffusion.

Facilitated Diffusion
As an example, even though sodium ions (Na^+) are highly

concentrated outside of cells, these electrolytes are charged and cannot pass through the nonpolar lipid bilayer of the membrane. Their diffusion is facilitated by membrane proteins that form sodium channels (or “pores”), so that Na^+ ions can move down their concentration gradient from outside the cells to inside the cells. There are many other solutes that must undergo facilitated diffusion to move into a cell, such as amino acids, or to move out of a cell, such as wastes. Because facilitated diffusion is a passive process, it does not require energy expenditure by the cell.



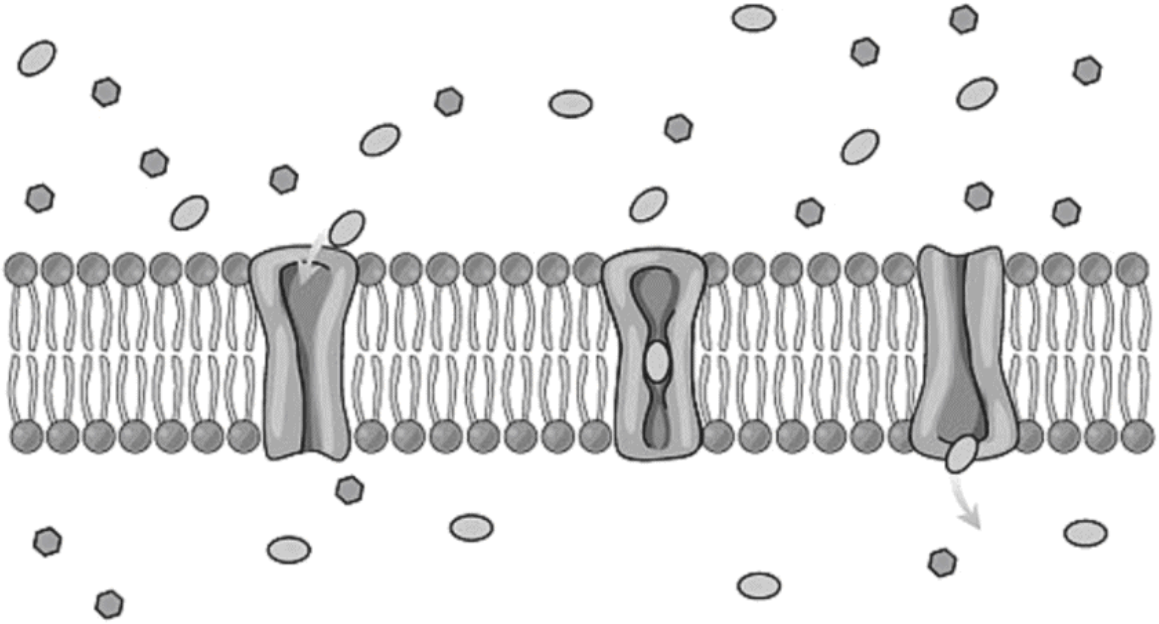
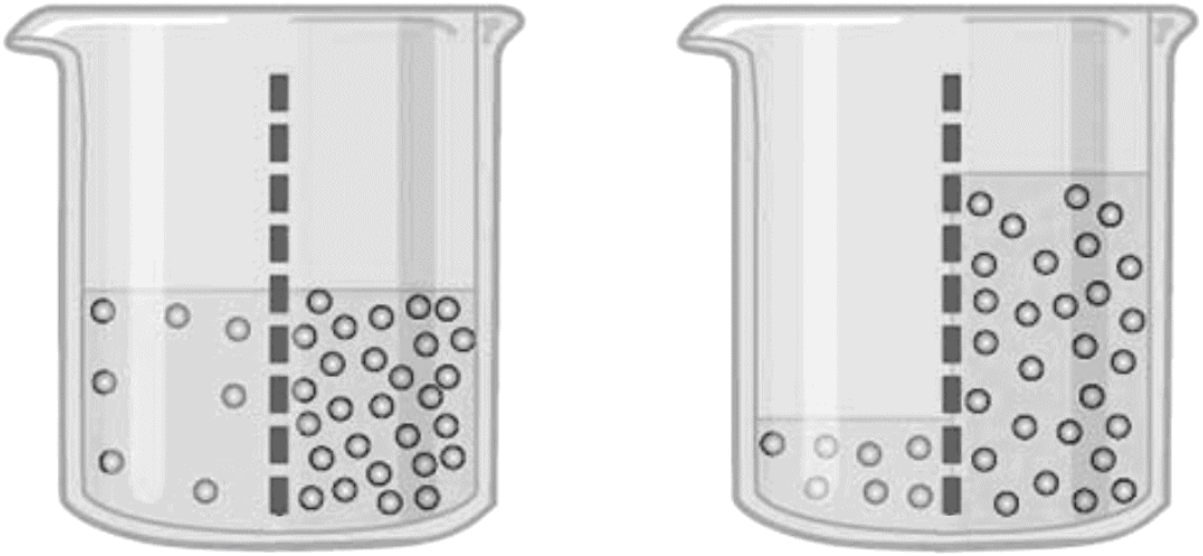


Figure 2.4

Water also can move freely across the cell membrane of all cells, either through protein channels or by slipping between the lipid tails of the membrane itself. **Osmosis** is the diffusion of water through a semipermeable membrane.

Osmosis

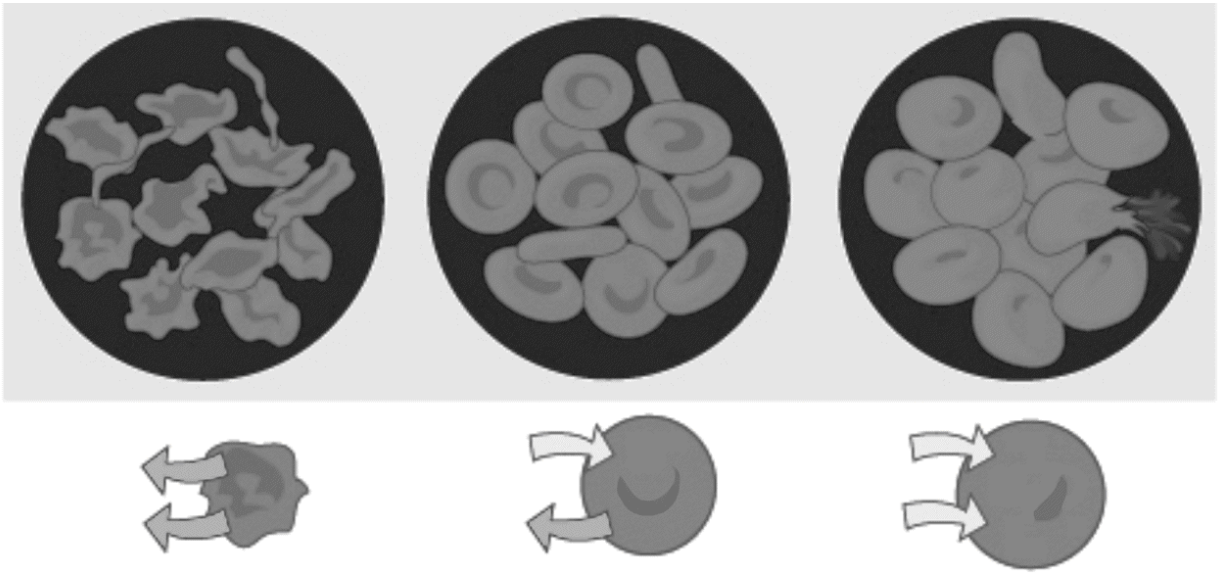


The movement of water molecules is not itself regulated by cells, so it is important that cells are exposed to an environment in which the concentration of solutes outside of the cells (in the extracellular fluid) is equal to the concentration of solutes inside the cells (in the cytoplasm). Two solutions that have the same concentration of solutes are said to be **isotonic** (equal tension). When cells and their extracellular environments are isotonic, the concentration of water molecules is the same outside and inside the cells, and the cells maintain their normal shape (and function).

Osmosis occurs when there is an imbalance of solutes outside of a cell versus inside the cell. A solution that has a higher concentration of solutes than another solution is said to be **hypertonic,** and water molecules tend to diffuse into a hypertonic solution (Fig. 2.6). Concentration of Solutions). Cells in a hypertonic solution will shrivel as water leaves the cell via

osmosis. In contrast, a solution that has a lower concentration of solutes than another solution is said to be **hypotonic,** and water molecules tend to diffuse out of a hypotonic solution. Cells in a hypotonic solution will take on too much water and swell, with the risk of eventually bursting. A critical aspect of homeostasis in living things is to create an internal environment in which all of the body's cells are in an isotonic solution. Various organ systems, particularly the kidneys, work to maintain this homeostasis.

CONCENTRATION OF SOLUTIONS



Another mechanism besides diffusion to passively transport materials between compartments is filtration. Unlike diffusion of a substance from where it is more concentrated to less concentrated, filtration uses a hydrostatic pressure gradient that pushes the fluid—and the solutes within it — from a higher pressure area to a lower pressure area. Filtration is an extremely important process in the body. For example, the circulatory system uses filtration to move plasma and substances across the endothelial lining of capillaries and into surrounding tissues, supplying cells with the nutrients. Filtration pressure in the kidneys provides the mechanism to remove wastes from the bloodstream.

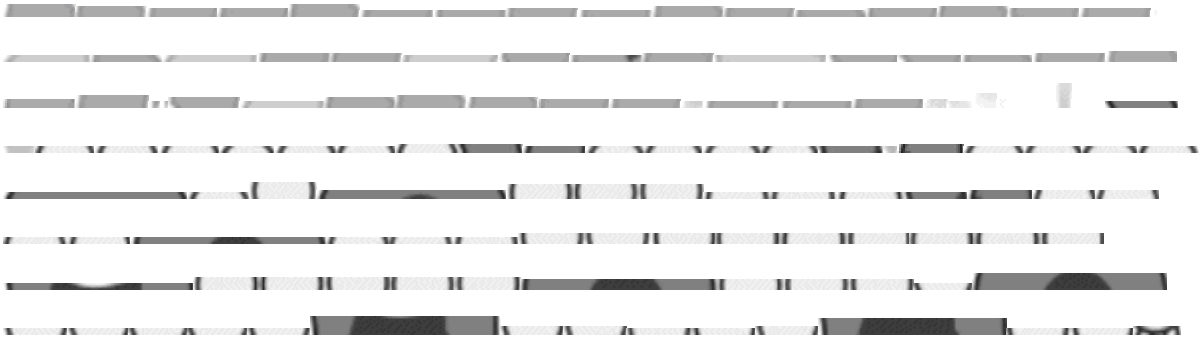
Active Transport
For all of the transport methods described above, the cell

expends no energy. Membrane proteins that aid in the passive transport of substances do so without the use of ATP. During active transport, ATP is required to move a substance across a membrane, often with the help of protein carriers, and usually *against* its concentration gradient.

One of the most common types of active transport involves proteins that serve as pumps. The word “pump” probably conjures up thoughts of using energy to pump up the tire of a bicycle or a basketball. Similarly, energy from ATP is required for these membrane proteins to transport substances—molecules or ions—across the membrane, usually against their concentration gradients (from an area of low concentration to an area of high concentration).

The **sodium-potassium pump,** which is also called Na^+/K^+ ATPase, transports sodium out of a cell while moving potassium into the cell. The Na^+/K^+ pump is an important ion pump found in the membranes of many types of cells. These pumps are particularly abundant in nerve cells, which are constantly pumping out sodium ions and pulling in potassium ions to maintain an electrical gradient across their cell membranes. An **electrical gradient** is a difference in electrical charge across a space. In the case of nerve cells, for example, the electrical gradient exists between the inside and outside of the cell, with the inside being negatively-charged (at around 70 mV) relative to the outside. The negative electrical gradient is maintained because each Na^+/K^+ pump moves three Na^+ ions out of the cell and two K^+ ions into the cell for each ATP molecule that is used (Fig. 2.7. Sodium-Potassium Pump). This process is so important for nerve cells that it accounts for the majority of their ATP usage.

Sodium-Potassium Pump



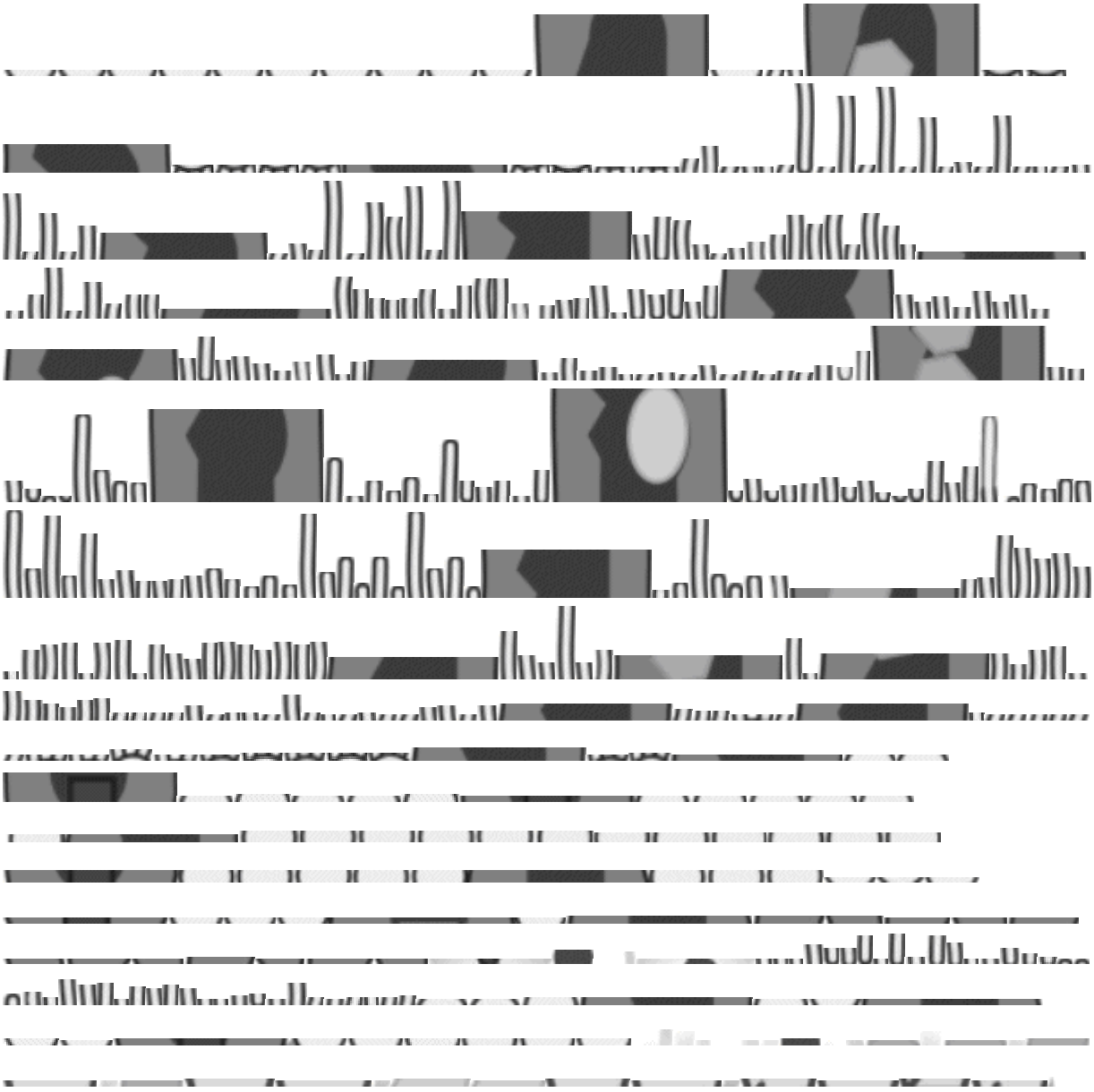


Figure 2.7: Sodium Potassium Pump

Active transport pumps can also work together with other active or passive transport systems to move substances across the membrane. For example, the sodium-potassium pump maintains a high concentration of sodium ions outside of the cell. Therefore, if the cell needs sodium ions, all it has to do is open a passive sodium channel, as the concentration gradient of the sodium ions will drive them to diffuse into the cell. In this way, the action of an active transport pump (the sodiumpotassium pump) powers the passive transport of sodium ions by creating a concentration gradient. When active transport powers the transport of another substance in this way, it is called secondary active transport.

Symporters are secondary active transporters that move two substances in the same direction. For example, the sodiumglucose symporter uses sodium ions to “pull” glucose molecules into the cell. Because cells store glucose for energy, glucose is typically at a higher concentration inside of the cell than outside. However, due to the action of the sodium-potassium pump, sodium ions will easily diffuse into the cell when the symporter is opened. The flood of sodium ions through the symporter provides the energy that allows glucose to move through the symporter and into the cell, against its concentration gradient.

Conversely, antiporters are secondary active transport systems that transport substances in opposite directions. For example, the sodium-hydrogen ion antiporter uses the energy from the inward flood of sodium ions to move hydrogen ions (H^+) out of the cell. The sodium-hydrogen antiporter is used to maintain the pH of the cell’s interior.

Other forms of active transport do not involve membrane carriers. **Endocytosis** (bringing “into the cell”) is the process of a cell ingesting material by enveloping it in a portion of its cell membrane, and then pinching off that portion of membrane (Fig. 2.8). Once pinched off, the portion of membrane and its contents becomes an independent, intracellular vesicle. A **vesicle** is a membranous sac—a spherical and hollow organelle bounded by a lipid bilayer membrane. Endocytosis often brings materials into the cell that must to be broken down or digested. **Phagocytosis** (“cell eating”) is the endocytosis of large particles. Many immune cells engage in phagocytosis of invading pathogens. Like little Pac-men, their job is to patrol body tissues for unwanted matter, such as invading bacterial cells, phagocytize them, and digest them. In contrast to phagocytosis, **pinocytosis** (“cell drinking”) brings fluid containing dissolved substances into a cell through membrane vesicles.

Three Forms of Endocytosis
Phagocytosis and pinocytosis take in large portions of

extracellular material, and they are typically not highly selective in the substances they bring in. Cells regulate the endocytosis of specific substances via receptor-mediated endocytosis. **Receptor-mediated endocytosis** is endocytosis by a portion of the cell membrane that contains

many receptors that are specific for a certain substance. Once the surface receptors have bound sufficient amounts of the specific substance (the receptor's ligand), the cell will endocytose the part of the cell membrane containing the receptor-ligand complexes. Iron, a required component of hemoglobin, is endocytosed by red blood cells in this way. Iron is bound to a protein called transferrin in the blood. Specific transferrin receptors on red blood cell surfaces bind the iron-transferrin molecules, and the cell endocytoses the receptor-ligand complexes.

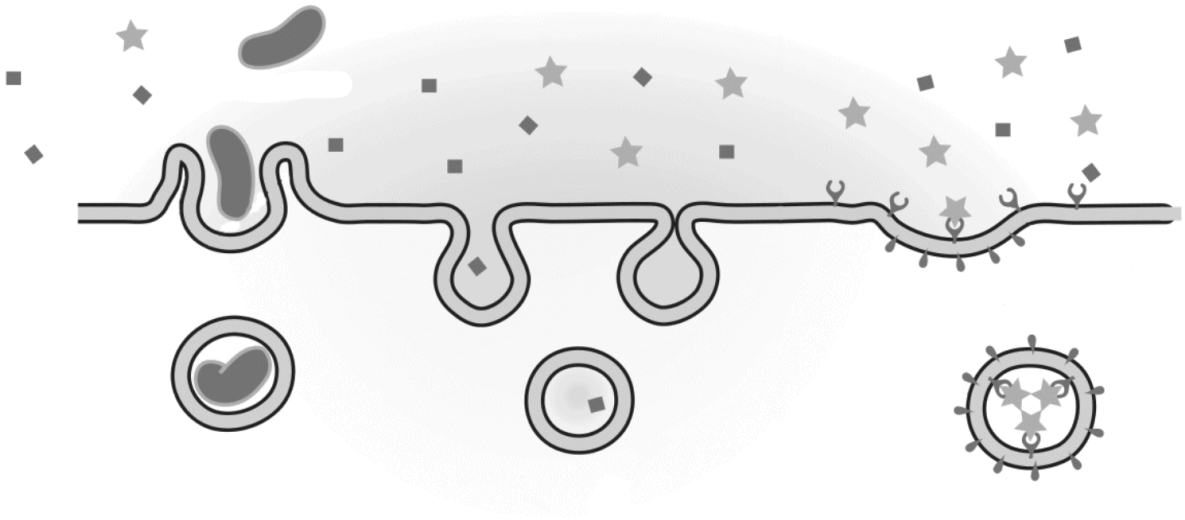


Figure 2.8: Three Forms of Endocytosis

In contrast with endocytosis, **exocytosis** (taking "out of the cell") is the process of a cell exporting material using vesicular transport (Fig. 2.9). Many cells manufacture substances that must be secreted, like a factory manufacturing a product for export. These substances are typically packaged into membrane-bound vesicles within the cell. When the vesicle membrane fuses with the cell membrane, the vesicle releases it contents into the interstitial fluid. The vesicle membrane then becomes part of the cell membrane. Cells of the stomach and pancreas produce and secrete digestive enzymes through exocytosis (Fig. 2.9). Pancreatic Cells' Enzyme Products). Endocrine cells produce and secrete hormones that are sent throughout the body, and certain immune cells produce and secrete large amounts of histamine, a chemical important for immune responses.

Exocytosis

Figure 2.9: Exocytosis

Organelle

An organelle is a subcellular structure that has one or more specific jobs to perform in the cell, much like an organ does in the body. Among the more important cell organelles are the nuclei, which store genetic information; mitochondria, which produce chemical energy; and ribosomes, which assemble proteins (Fig. 2.10).

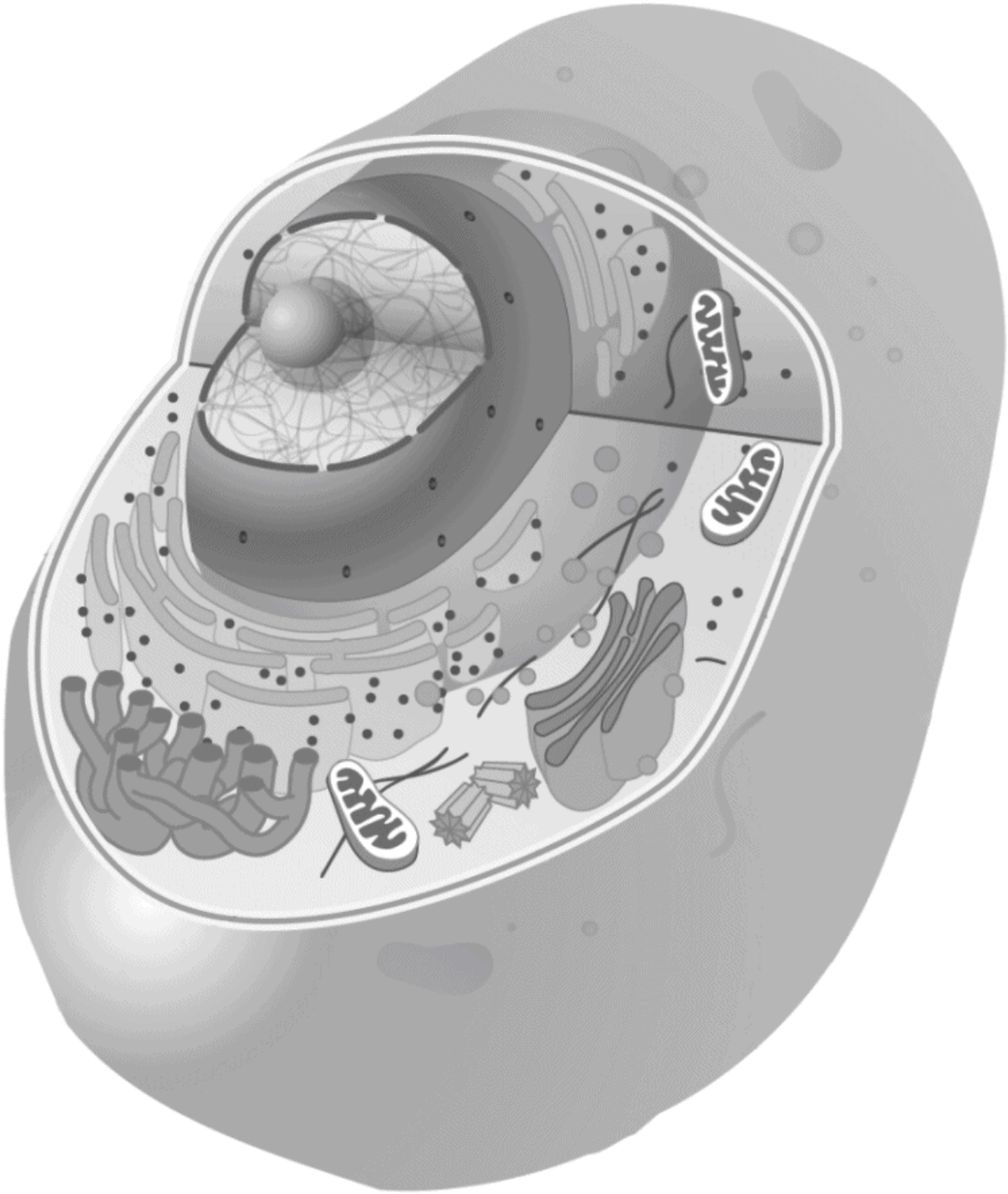


Figure 2.10: Organelle

An organelle is a specific structure within a cell, and there are many different types of organelles. Organelles are also called vesicles within a cell. And they really have a function that’s important, because we need to compartmentalize all the functions within the cell. So there needs to be a

membrane around the mechanisms for making a different product within a cell. So really, organelles are all membrane-bound. And they separate one function from another function. So for example, the mitochondrion has the function to produce energy, and the lysosome has the function of producing small molecules from large molecules, from breaking those things down. They need to be compartmentalized because the mitochondrion all of its pathways, all of its proteins and enzymes in it, to convert one chemical to another, and the lysosome needs an acid pH. And if those things were to mix, none of the functions would be produced at all. So that really is the heart and soul of an organelle: To be compartmentalized and allow a high concentration of proteins or acid, or whatever to create that environment so that a particular function can be performed.

Ribosome

A ribosome is a complex molecular machine found inside the living cells that produce proteins from amino acids during a process called protein synthesis or translation. The process of protein synthesis is a primary function, which is performed by all living cells.

Ribosomes are specialized cell organelles and are found in both prokaryotic and eukaryotic cells. Every living cell requires ribosomes for the production of proteins.

This cell organelle also functions by binding to a messenger ribonucleic acid (mRNA) and decoding the information carried by the nucleotide sequence of the mRNA. They transfer RNAs (tRNAs) comprising amino acids, and enter into the ribosome at the acceptor site. Once it gets bind up, it adds amino acid to the growing protein chain on tRNA.

A ribosome is a complex of RNA and protein and is, therefore, known as a ribonucleoprotein. It is composed of two subunits - smaller and larger.

The smaller subunit, where the mRNA binds and is decoded, and in the larger subunit, the amino acids get added. Both of the subunits contain both protein and ribonucleic acid components.

The two subunits are joined to each other by interactions between the rRNAs in one subunit and proteins in the other subunit.

Ribosomes are located inside the cytosol found in the plant cell and animal cell.

The ribosome structure includes the following

• It is located in two areas of cytoplasm.

• Scattered in the cytoplasm.
• Prokaryotes have 70S ribosomes while eukaryotes have 80S ribosomes.
• Around 62% of ribosomes are comprised of RNA, while the rest is proteins.
• The structure of free and bound ribosomes is similar and is associated with **protein** synthesis.

RIBOSOMES FUNCTION

The important ribosome function includes

1. It assembles amino acid to form proteins that are essential to carry out cellular functions.
2. The DNA produces mRNA by the process of DNA transcription.
3. The mRNA is synthesized in the nucleus and transported to the cytoplasm for the process of protein synthesis.
4. The ribosomal subunits in the cytoplasm are bound around mRNA polymers. The tRNA then synthesizes proteins.
5. The proteins synthesized in the cytoplasm are utilized in the cytoplasm itself, the proteins synthesized by bound ribosomes are transported outside the cell.

ENDOPLASMIC RETICULUM

The endoplasmic reticulum transpires in two forms: a type with a ribosome-studded surface and another with a smooth surface. The latter is called the **smooth endoplasmic reticulum,** and the former is called the **rough endoplasmic reticulum.** These membranes form continuous folds, eventually joining the outer layer of the nuclear membrane. Except for sperm cells and red blood cells, the endoplasmic reticulum is observed in every other type of eukaryotic cell.

Endoplasmic Reticulum Diagram
The below diagram shows the variants of the endoplasmic reticulum:

• Rough ER
• Smooth ER
Rough endoplasmic reticulum has ribosomes embedded

within its structure, giving a “rough” appearance. The smooth endoplasmic reticulum does not have these ribosomes, hence appearing “smooth.”

Structure of Endoplasmic Reticulum
The structure of the endoplasmic reticulum is shaped like a

sac. Since ER is of two types, each has its own distinguishing features:
rough endoplasmic reticulum Structure

• The rough endoplasmic reticulum is named so because of its appearance.
• It is a series of connected flattened sacs having several ribosomes on its outer surface, hence the name.
• It synthesizes and secretes proteins in the liver, hormones and other substances in the glands.
• Rough ER is prominent in cells where protein synthesis happens (such as hepatocytes)

Smooth endoplasmic reticulum Structure

• The smooth endoplasmic reticulum, on the other hand, does not have ribosomes.
• The smooth endoplasmic reticulum has a tubular form.
• It participates in the production of phospholipids, the chief lipids in cell membranes and are essential in the process of metabolism.
• Smooth ER transports the products of the rough ER to other cellular organelles, especially the Golgi apparatus.

Functions of Endoplasmic Reticulum

As stated above, the endoplasmic reticulum is categorised into two types, and both these types of ER perform specific functions:

Smooth Endoplasmic Reticulum Function

• Smooth ER is responsible for the synthesis of essential lipids such as phospholipids and cholesterol.
• Smooth ER is also responsible for the production and secretion of steroid hormones.
• It is also responsible for the metabolism of carbohydrates.
• The smooth ER store and releases calcium ions. These are quite important for the nervous system and muscular systems.

Rough Endoplasmic Reticulum Function

• The majority of the functions of rough ER is associated with protein synthesis.
• The rough endoplasmic reticulum also plays a vital role in protein folding.
• Also ensures quality control (regarding correct protein folding).
• The second most important function after protein synthesis and protein folding is protein sorting.

GOLGI APPARATUS

The Golgi apparatus has multiple names such as Golgi complex or Golgi body. The name is given on the name of the scientist, who discovered the organelle, i.e. Camillo Golgi. It is found in all the eukaryotic cells, plants as well as animals. They are membrane-bound organelle present in the cytosol of the cell. Let us explore more about Golgi complex.

Golgi Bodies Functions

Its main function is the packaging and secretion of proteins. It

receives proteins from Endoplasmic Reticulum. It packages it into membrane-bound vesicles, which are then transported to various destinations, such as lysosomes, plasma membrane or secretion. They also take part in the transport of lipids and the formation of lysosomes.

Lysosomes

Lysosomes are membrane-bound organelles and the area

within the membrane is called the lumen, which contains the hydrolytic enzymes and other cellular debris.

The pH level of the lumen lies between 4.5 and 5.0, which makes it quite acidic. It is almost comparable to the function of acids found in the stomach.

Besides breaking down biological polymers, lysosomes are also involved in various other cell processes such as counting discharged materials, energy metabolism, cell signalling, and restoration of the plasma membrane.

The sizes of lysosomes vary, with the largest ones measuring in more at than 1.2 mm. But they typically range from 0.1 pm to 0.6 mm.

Lysosome function

The key function of lysosomes is digestion and removal of waste. Cellular debris or foreign particles are pulled in to the cell through the process of endocytosis. The process of endocytosis happens when the cell membrane falls in on itself (invagination), creating a vacuole or a pouch around the external contents and then bringing those contents into the cell.

Mitochondria

Mitochondria are membrane-bound organelles present in the cytoplasm of all eukaryotic cells, that produces adinosine triphosphate (ATP), the main energy molecule used by the cell." Popularly known as the "Powerhouse of the cell," mitochondria (singular: mitochondrion) are a double membrane-bound organelle found in most eukaryotic organisms. They are found inside the cytoplasm and essentially function as the cell's "digestive system."

They play a major role in breaking down nutrients and generating energy-rich molecules for the cell. Many of the biochemical reactions involved in cellular respiration take place within the mitochondria.

Functions of Mitochondria

The most important function of mitochondria is to produce energy through the process of oxidative phosphorylation. It is also involved in the following

process:

1. Regulates the metabolic activity of the cell.
2. Promotes the growth of new cells and cell multiplication.
3. Helps in detoxifying ammonia in the liver cells.
4. Plays an important role in apoptosis or programmed cell death.
5. Responsible for building certain parts of the blood and various hormones like testosterone and oestrogen.
6.Helps in maintaining an adequate concentration of calcium ions within the compartments of the cell.
7. It is also involved in various cellular activities like cellular differentiation, cell signalling, cell senescence, controlling the cell cycle and also in cell growth.

MICROTUBULES

Microtubules, the third principal component of the cytoskeleton, are rigid hollow rods approximately 25 nm in diameter. Like actin filaments, microtubules are dynamic structures that undergo continual assembly and disassembly within the cell. They function both to determine cell shape and in a variety of cell movements, including some forms of cell locomotion, the intracellular transport of organelles, and the separation of chromosomes during mitosis.

Flagella
• Eukaryotic flagella are usually found singly or in pairs.

• Waves of bending propagate from one end of a flagellum to the other in a snake-like undulation.
• Forces exerted by these waves on the surrounding fluid medium move the cell.

Cilia

• Cilia (singular cilium) are usually present in great numbers.
• They beat stiffly in one direction and recover flexibly in the other direction (like a swimmer’s arm), so that the recovery stroke does not undo the work of the power stroke.

• The power or effective stroke propels the cilium through the surrounding fluid, which allows the movement of the organism inside the water.
• The cilium next bends along its length, while it is pulled forward during the recovery stroke in preparation for another effective stroke.

MITOSIS

Cell division is the driving process of reproduction at the cellular level. Most eukaryotic cells divide in a manner where the ploidy or the number of chromosomes remains the same, except in the case of germ cells where the number of chromosomes is halved.

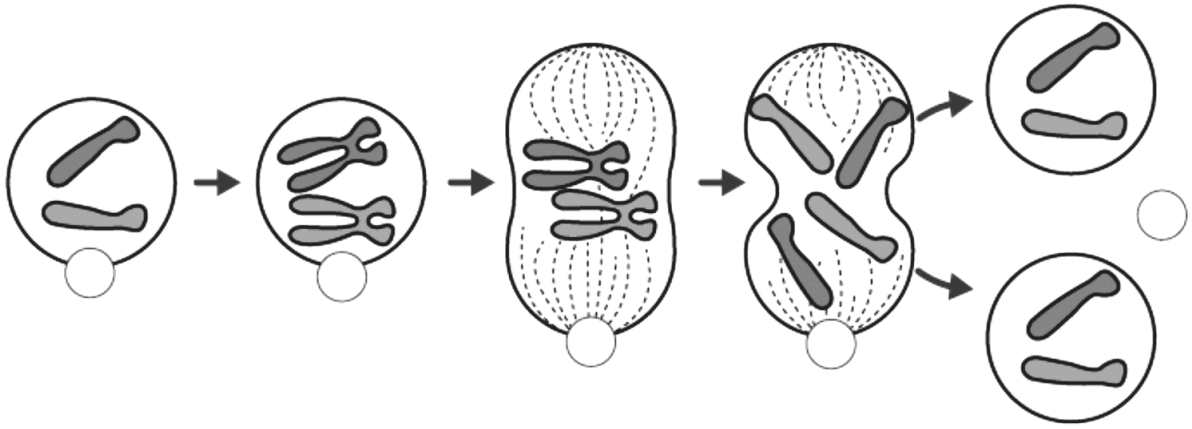


Figure 2.11

Stages of Mitosis

Right before prophase, the cell spends most of its life in the interphase, where preparations are made before the beginning of mitosis (the DNA is copied). However, since the actual process involves the division of the nucleus, prophase is technically the first stage of this process.

The different stages of mitosis occurring during cell division are given as follows:

Interphase

Before entering mitosis, a cell spends a period of its growth under interphase. It undergoes the following phases when in interphase:

• **G1 Phase:** This is the period before the synthesis of DNA.
• **S Phase:** This is the phase during which DNA synthesis takes place.
• **G2 Phase:** This is the phase between the end of DNA synthesis and the beginning of prophase.

Prophase

Prophase immediately follows S and G2 phase of the cycle and is marked by condensation of the genetic material to form compact mitotic chromosomes composed of two chromatids attached at the centromere.

The completion of prophase is characterised by the initiation of the assembly of the mitotic spindle, the microtubules and the proteinaceous components of cytoplasm that help in the process.

The nuclear envelope starts disintegrating:

Prometaphase

In the prometaphase, the nuclear envelop disintegrates. Now the microtubules are allowed to extend from the centromere to the chromosome. The microtubules attach to the kinetochores which allow the cell to move the chromosome around.

Metaphase

At this stage, the microtubules start pulling the chromosomes with equal force and the chromosome ends up in the middle of the cell. This region is known as the metaphase plate. Thus, each cell gets an entire functioning genome.

Anaphase

The splitting of the sister chromatids marks the onset of anaphase. These sister chromatids become the chromosome of the daughter nuclei. The chromosomes are then pulled towards the pole by the fibres attached to the kinetochores of each chromosome. The centromere of each chromosome leads at the edge while the arms trail behind it.

Telophase

The chromosomes that cluster at the two poles start coalescing into an undifferentiated mass, as the nuclear envelope starts forming around it. The nucleolus, Golgi bodies and ER complex, which had disappeared after prophase, start to reappear.

Functions of Mitosis
Following are the two important functions of mitosis:

1. Mitosis helps in the development of an organism. In single-celled organisms, mitosis is the process of asexual reproduction.

2. Mitosis helps in the replacement of damaged tissues. The cells near the damaged cells begin mitosis when they do not sense the neighbouring cells. The dividing cells reach each other and cover the damaged cells.

Significance of Mitosis:

1. Mitosis is responsible for the development of the zygote into an adult.
2. Equal distribution of chromosomes to each daughter cell. **3.** It is responsible for the growth and development of an individual.
4. It maintains the constant number of chromosomes in all body cells of an organism.
5. Mitosis is required for asexual reproduction, vegetative propagation in plants and also responsible for repair and regeneration of damaged tissues.
6. Mitosis helps in maintaining purity of genome as no recombination or crossing over takes place.
7. It is responsible for repair and regeneration of old and damaged cells in animals e.g. gut epithelium, blood cells, etc.

HOMEOSTATIC

• **Homeostasis** is the tendency to resist change in order to maintain a stable, relatively constant internal environment.
• Homeostasis typically involves **negative feedback loops** that counteract changes of various properties from their target values, known as **set points.**
• In contrast to negative feedback loops, **positive feedback loops** amplify their initiating stimuli, in other words, they move the system *away* from its starting state.

The tendency to maintain a stable, relatively constant internal environment is called **homeostasis.** The body maintains homeostasis for many factors in addition to temperature. For instance, the concentration of various ions in your blood must be kept steady, along with pH and the concentration of glucose. If these values get too high or low, you can end up getting very sick.

Homeostasis is maintained at many levels, not just the level of the whole body as it is for temperature. For instance, the stomach maintains a pH that's different from that of surrounding organs, and each individual cell maintains ion concentrations different from those of the surrounding fluid. Maintaining homeostasis at each level is key to maintaining the body's overall function.

So, how is homeostasis maintained? Let's answer this question by looking at some examples.
Maintaining homeostasis

Biological systems like those of your body are constantly being pushed away from their balance points. For instance, when you exercise, your muscles increase heat production, nudging your body temperature upward. Similarly, when you drink a glass of fruit juice, your blood glucose goes up. Homeostasis depends on the ability of your body to detect and oppose these changes.

Maintenance of homeostasis usually involves **negative feedback loops.** These loops act to oppose the **stimulus,** or cue, that triggers them. For example, if your body temperature is too high, a negative feedback loop will act to bring it back down towards the **set point,** or target value. How does this work? First, high temperature will be detected by sensors primarily nerve cells with endings in your skin and brain—and relayed to a temperature- regulatory **control center** in your brain. The control center will process the information and activate effectors such as the sweat glandwhose job is to oppose the stimulus by bringing body temperature down.

(a) A negative feedback loop has four basic parts: A stimulus, sensor, control, and effector.
(b) Body temperature is regulated by negative feedback. The stimulus is when the body temperature exceeds 37 degrees Celsius, the sensors are the nerve cells with endings in the skin and brain, the control is the temperature

regulatory center in the brain, and the effector is the sweat glands throughout the body.

Figure 2.12

Of course, body temperature doesn’t just swing above its target value—it can also drop below this value. In general, homeostatic circuits usually involve at least two negative feedback loops:

• One is activated when a parameter—like body temperature—is *above* the set point and is designed to bring it back down.
• One is activated when the parameter is *below* the set point and is designed to bring it back up.

To make this idea more concrete, let’s take a closer look at the opposing feedback loops that control body temperature. Homeostatic Responses in Temperature Regulation

If you get either too hot or too cold, sensors in the periphery and the brain tell the temperature regulation center of your brain— in a region called the hypothalamus—that your temperature has strayed from its set point.

For instance, if you been exercising hard, your body temperature can rise *above* its set point, and you’ll need to activate mechanisms that cool you down. Blood flow to your skin increases to speed up heat loss into your surroundings, and you might also start sweating so the evaporation of sweat from your skin can help you cool off. Heavy breathing can also increase heat loss.

Image showing temperature regulation in response to signals from the nervous system. When the body temperature falls, the blood vessels constrict, sweat glands don’t produce sweat, and shivering generates heat to warm the body. This causes heat to be retained the the body temperature to return to normal.

When the body temperature is too high, the blood vessels dilate, sweat glands secrete fluid, and heat is lost from the body. As heat is lost to the environment, the body temperature returns to normal.

On the other hand, if you’re sitting in a cold room and aren’t dressed warmly, the temperature center in the brain will need to trigger responses that help warm you up. The blood flow to your skin decreases, and you might start shivering so that your muscles generate more heat. You may also get goose bumps— so that the hair on your body stands on end and traps a layer of air near your skin—and increase the release of hormones that act to increase heat production.

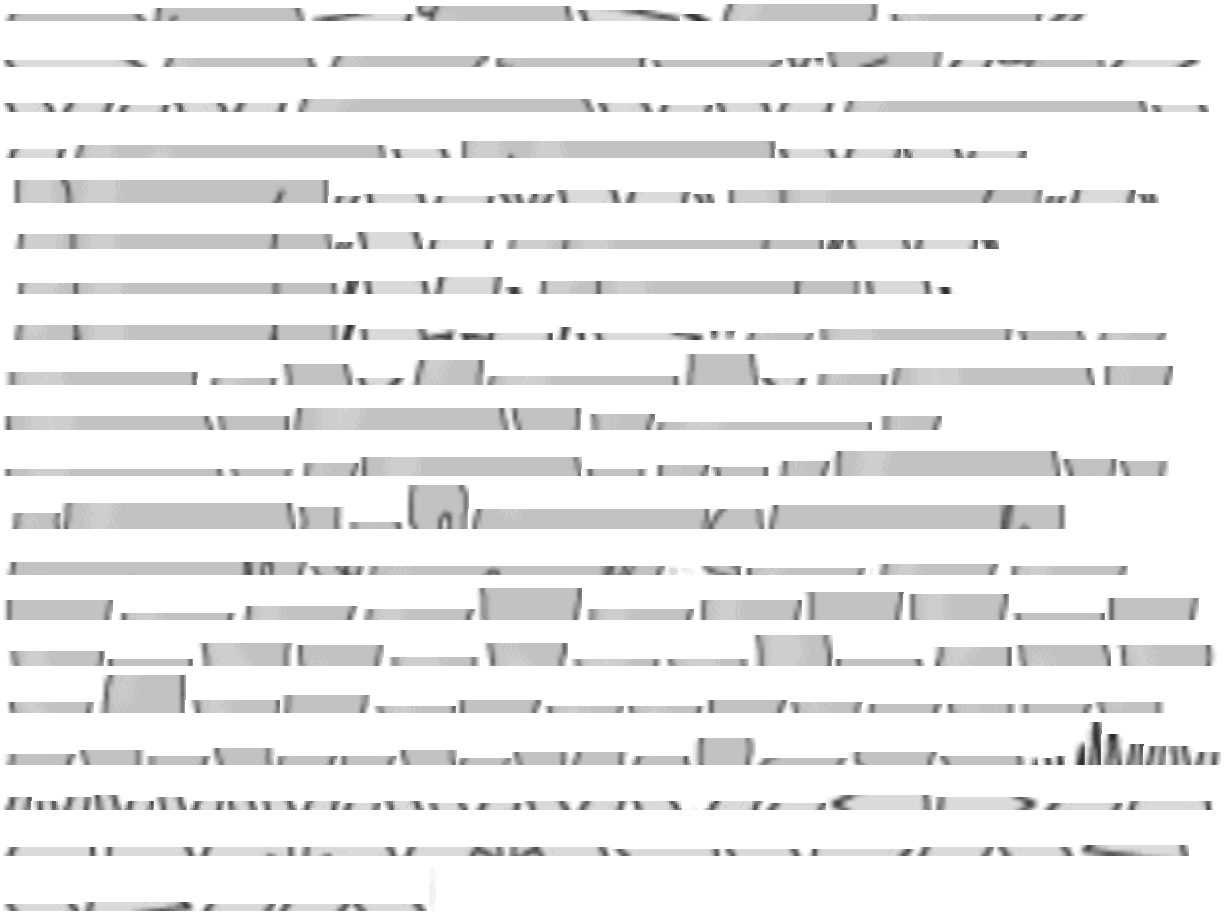


Figure 2.13

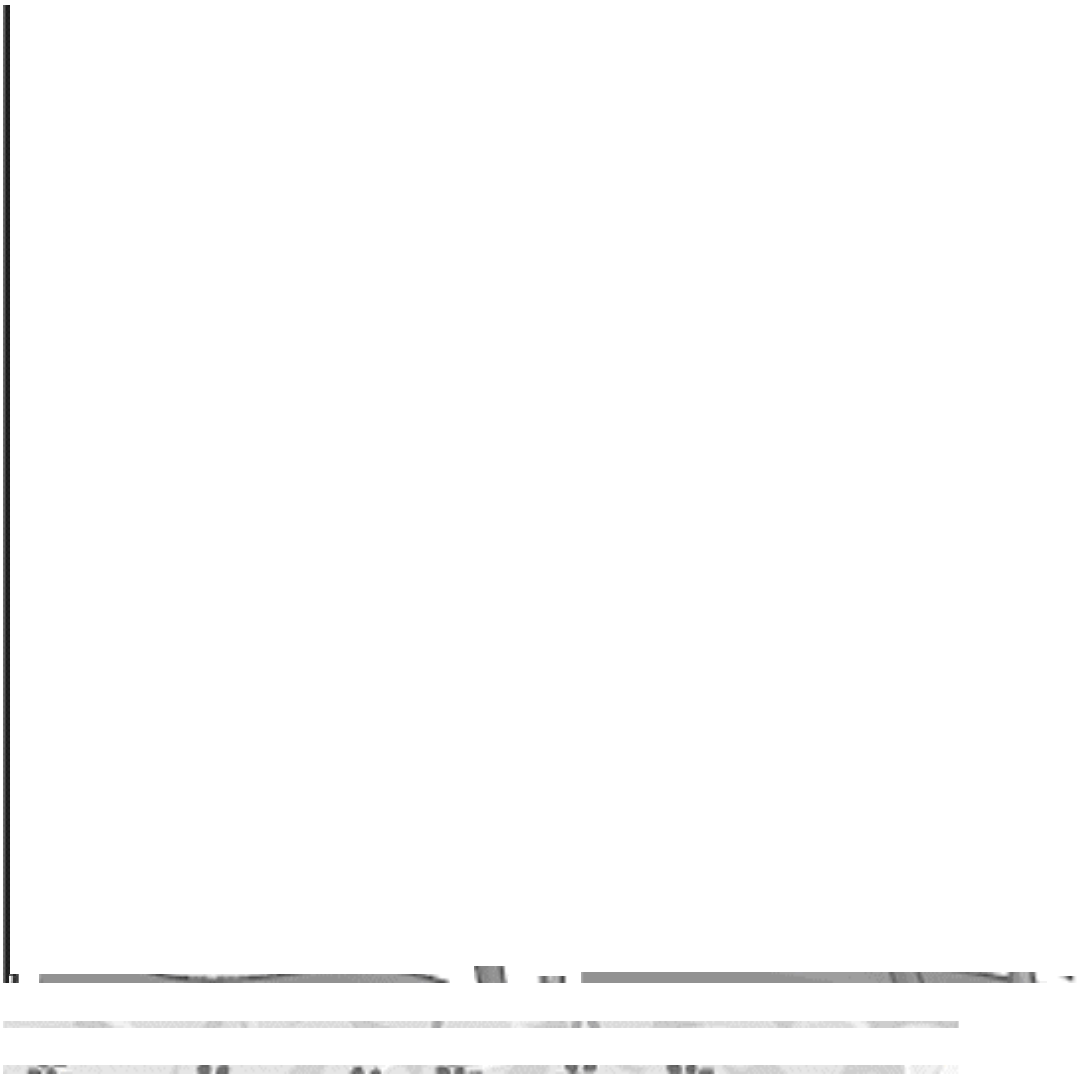
Notably, the set point is not always rigidly fixed and may be a moving target. For instance, body temperature varies over a 24-hour period, from highest in the late afternoon to lowest in the early morning. 22squared Fever also involves a temporary increase in the temperature set point so that heat-generating responses are activated at temperatures higher than the normal set point 33cubed.

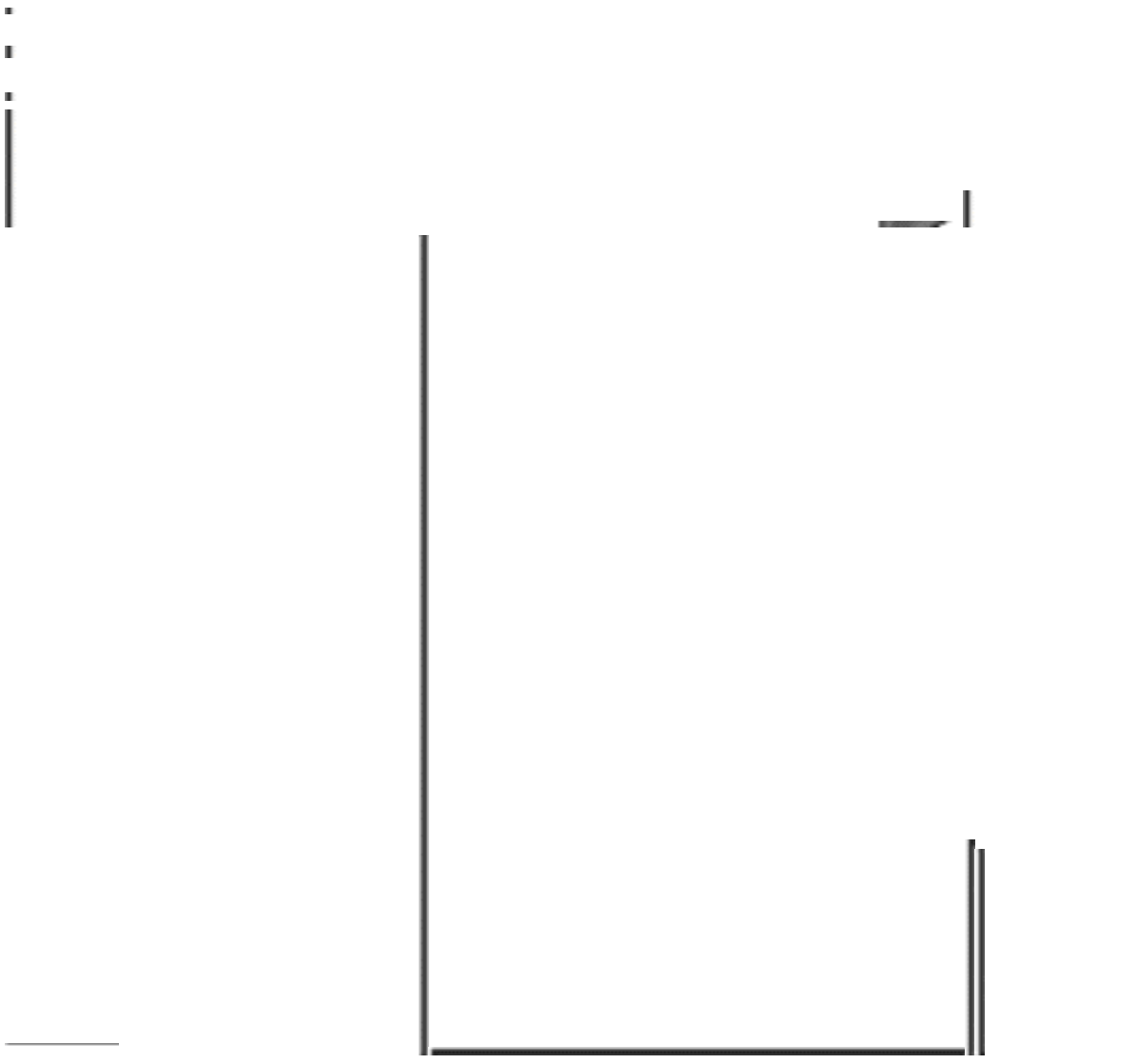
Disruptions to Feedback Disrupt Homeostasis

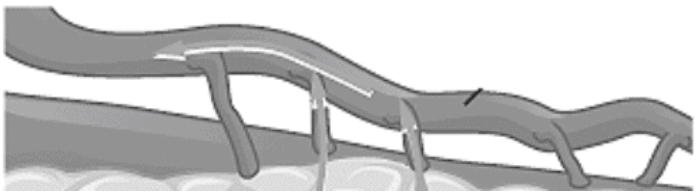
Homeostasis depends on negative feedback loops. So, anything that interferes with the feedback mechanisms can—and usually will! disrupt homeostasis. In the case of the human body, this may lead to disease.

Diabetes, for example, is a disease caused by a broken feedback loop involving the hormone insulin. The broken feedback loop makes it difficult or impossible for the body to bring high blood sugar down to a healthy level.

To appreciate how diabetes occurs, let’s take a quick look at the basics of blood sugar regulation. In a healthy person, blood sugar levels are controlled by two hormones: insulin and glucagon.







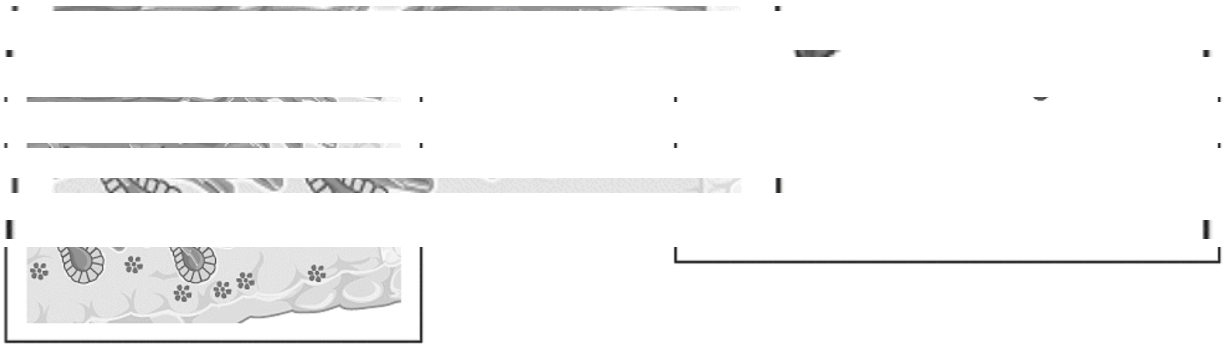


Figure 2.14
Insulin decreases the concentration of glucose in the blood.

After you eat a meal, your blood glucose levels rise, triggering the secretion of insulin from a cells in the pancreas. Insulin acts as a signal that triggers cells of the body, such as fat and muscle cells, to take up glucose for use as fuel. Insulin also causes glucose to be converted into glycogen—a storage molecule—in the liver. Both processes pull sugar out of the blood, bringing blood sugar levels down, reducing insulin secretion, and returning the whole system to homeostasis.

If blood glucose concentration rises above the normal range, insulin is released, which stimulates body cells to remove glucose from the blood. If blood glucose concentration drops below this range, glucagon is released, which stimulates body cells to release glucose into the blood.

Glucagon does the opposite: it increases the concentration of glucose in the blood. If you haven’t eaten for a while, your blood glucose levels fall, triggering the release of glucagon from another group of pancreatic cells, the b cells. Glucagon acts on the liver, causing glycogen to be broken down into glucose and released into the bloodstream, causing blood sugar levels to go back up. This reduces glucagon secretion and brings the system back to homeostasis.

Diabetes happens when a person’s pancreas can’t make enough insulin, or when cells in the body stop responding to insulin, or both. Under these conditions, body cells do not take up glucose readily, so blood sugar levels remain high for a long period of time after a meal. This is for two reasons:

• Muscle and fat cells don’t get enough glucose, or fuel. This can make people feel tired and even cause muscle and fat tissues to waste away.
• High blood sugar causes symptoms like increased urination, thirst, and even dehydration. Over time, it can lead to more serious complications.

Positive Feedback Loops
Homeostatic circuits usually involve negative feedback loops.

The hallmark of a negative feedback loop is that it counteracts a change, bringing the value of a parameter— such as temperature or blood sugar— back towards it set point.

Some biological systems, however, use positive feedback loops. Unlike negative feedback loops, **positive feedback loops** amplify the starting signal. Positive feedback loops are usually found in processes that need to be pushed to completion, not when the status quo needs to be maintained.

A positive feedback loop comes into play during childbirth. In childbirth, the baby’s head presses on the cervix—the bottom of the uterus, through which the baby must emerge— and activates neurons to the brain. The neurons send a signal that leads to release of the hormone oxytocin from the pituitary gland.

Oxytocin increases uterine contractions, and thus pressure on the cervix. This causes the release of even more oxytocin and produces even stronger contractions. This positive feedback loop continues until the baby is born.

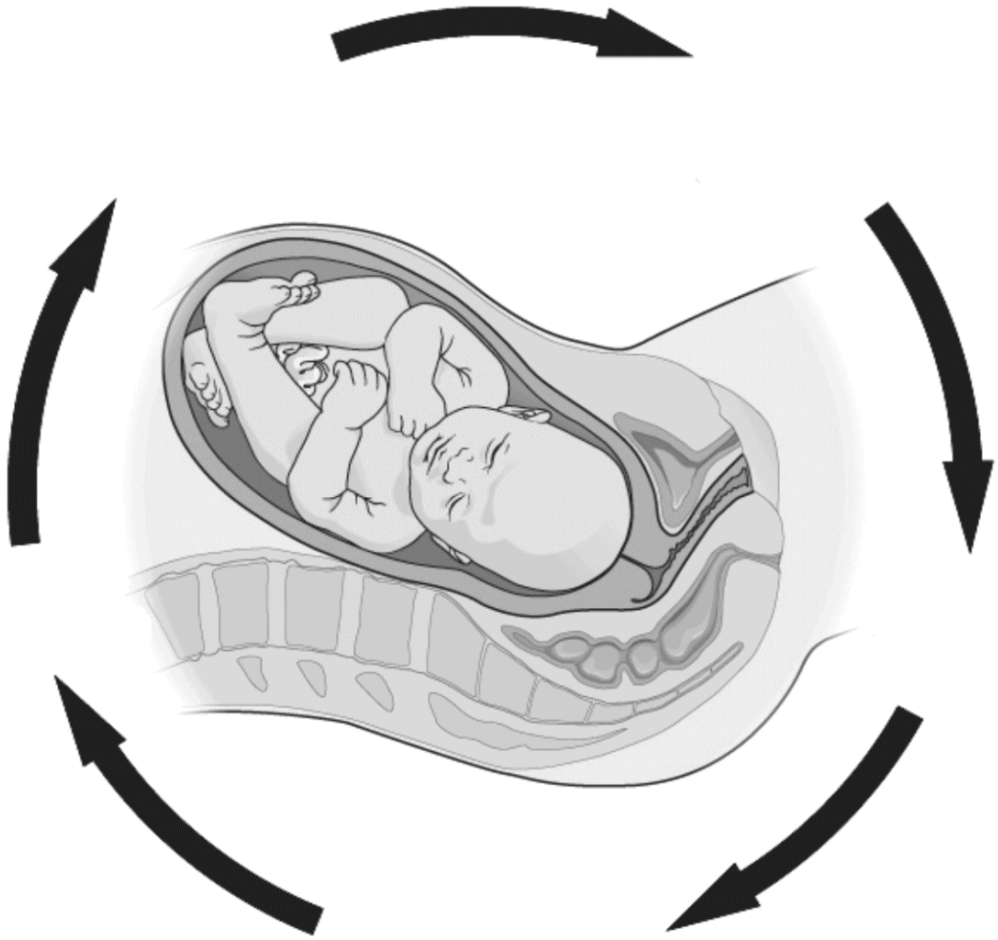


Figure 2.15

Normal childbirth is driven by a positive feedback loop. A positive feedback loop results in a change in the body's status, rather than a return to homeostasis. The feedback loop includes (the loops is drawn clockwise): Nerve impulses from the cervix being transmitted to the brain. The brain stimulates the pituitary gland to secrete oxytocin. Oxytocin carried in bloodstream to uterus, Oxytocin stimulates uterine contractions and pushes baby toward cervix, head of baby pushes against cervix, and so on in a loop.

Questions for study

1. Draw a labelled diagram of cell and its organelles.

2. Explain in detail about across membrane. Give the structure and function of mitochondria and golgi body.

3. Explain the process of cell division.

4.Define homeostatic and discuss in brief about negative and positive feedback.

3

Tissues of the Human Body

Chapter Outlines:

Key terms/learning objectives
Introduction
Body fluids
Question bank

KEY TERMS/LEARNING OBJECTIVES

This chapter gives a brief introduction to the types of tissues. The details about the function and location of each tissue are briefly described. The chapter also provides information on the types of fluids inside the body.

INTRODUCTION

A group of cells with similar structure and function combine to form **tissues.** The study of tissues is known as **histology.** In the human body, there are four basic types of tissues:

• Epithelial tissues (epithelium)
• Muscular tissues
• Nervous tissues
• Connective tissues

1. Epithelial Tissues or Epithelium:
Epithelial tissues include a continuous sheet of single or multiple layers of cells. They form an outer covering for the **45**

body and a lining for cavities, tubes, and hollow organs. The main functions of epithelial tissues are:

• They act as a selective barrier for the passage of substances;
• The surface of the epithelium releases various products secreted inside the cell; and
• They form a protective covering against the abrasive external environment.
• The cells are tightly packed and hence have a minimal intercellular matrix.
They lie on the basal membrane that is a connective tissue formed by the epithelial tissues.

Classification of Epithelial Tissues:
Based on the arrangement of cells in the layers, the epithelial tissues are classified into the simple and stratified epithelium.

1. Simple Epithelium:

The simple epithelium includes a single layer of a cell arranged over the basal membrane. They play a vital role in the secretion of substances and absorption of fluid and nutrients such as the digestive food from the intestine. They receive oxygen and nutrients through the blood supply to the connective tissues. Based on the shape of the cells, they are further classified into:

• Simple squamous epithelium
• Simple cuboidal epithelium
• Simple columnar epithelium (ciliated and non-ciliated)

(i) Simple Squamous Epithelium:

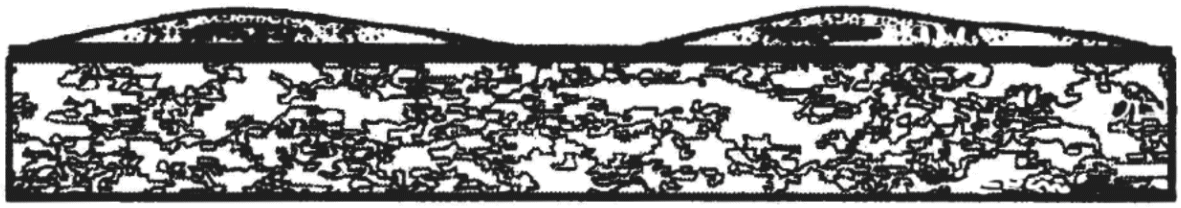


Figure 3.1: Simple Squamous Epithelium

The simple squamous epithelium is a single layer of **flat cells.** They are tightly packed together like flat-stones and form a very thin, smooth

membrane. It forms a smooth lining of the heart, lungs and kidneys. It allows the passage or diffusion of substances across the cells.

(ii) Simple Cuboidal Epithelium:

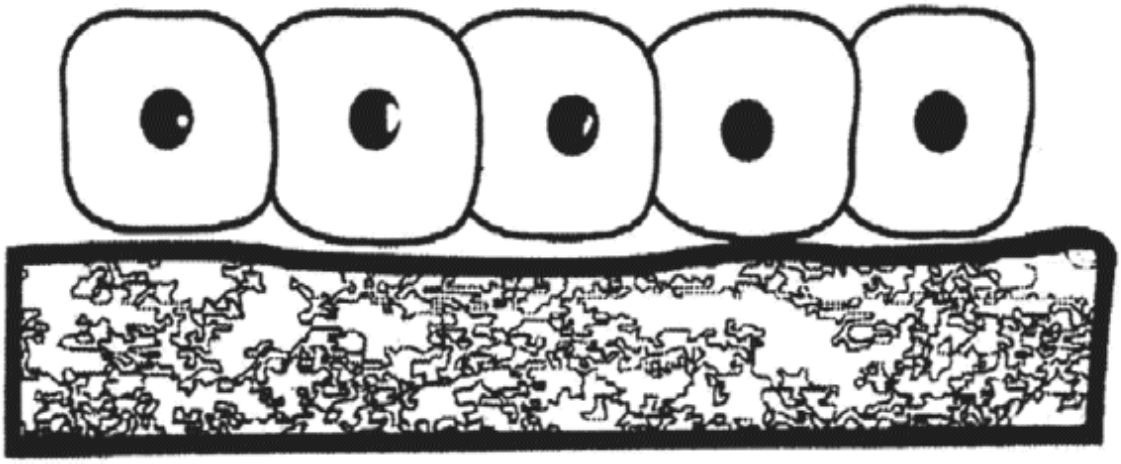


Figure 3.2: Simple Cuboidal Epithelium

The simple cuboidal epithelium comprises **cube-shaped cells** tightly aligned over the basal membrane. They play a vital role in the secretion, absorption and excretion processes. The cells that secrete substances form the glandular epithelium. For example, thyroid gland includes cuboidal epithelium that secretes thyroxine, a thyroid hormone. They are also majorly located in the kidney tubules for the reabsorption of essential nutrients back to the blood.

(iii) Simple Columnar Epithelium:

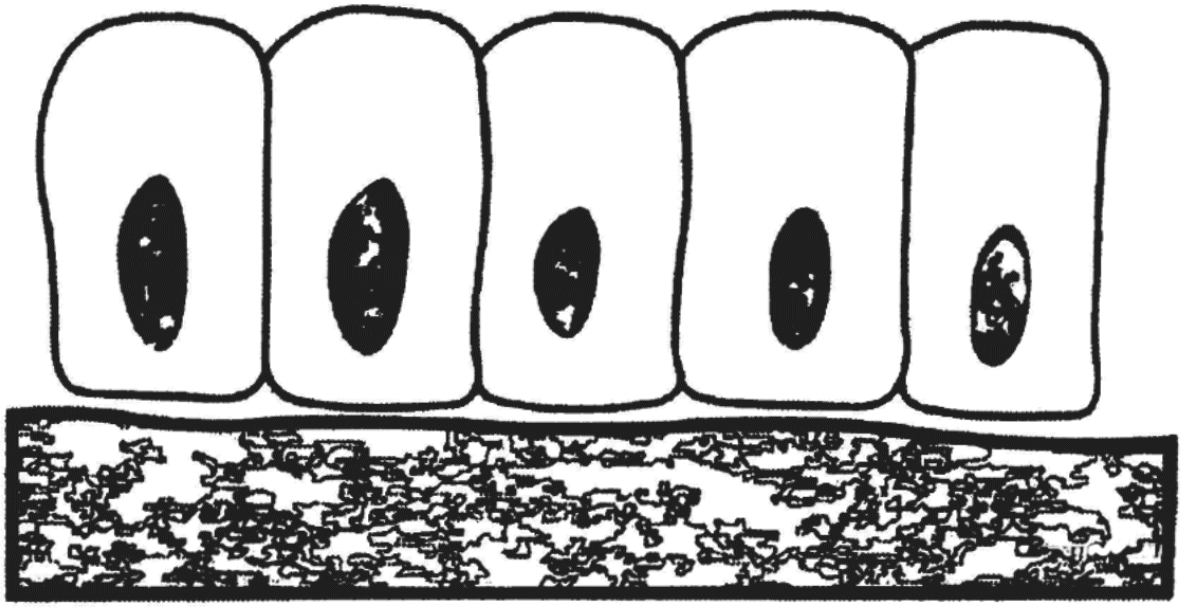


Figure 3.3: Simple Columnar Epithelium

The simple columnar epithelium has **tall column-shaped cells** on the basal membrane. There are two types of columnar epithelium: ciliated and non-ciliated. The non-ciliated columnar epithelial tissues have finger-like projections of the cytoplasm called **microvilli** on the surface. They provide a larger surface area to increase the rate of absorption of nutrients from the small intestine. Some of the columnar cells modify into goblet cells for the secretion of mucus.

The ciliated columnar epithelial tissues have **cilia** on the free surface. These cells form a lining of the respiratory tract and fallopian tube. In the respiratory system, the cilia play an important role in the removal of dust and bacteria that are entrapped in the mucus. In women, the lining inside the fallopian tube allows the passage of ovum from the ovary to the uterus.

2. Stratified Epithelium:

The stratified epithelium is made up of multiple layers of cells of different shapes. They usually lack a basal membrane. The main role of stratified epithelium is to protect the internal organs from external wear and tear.

There are two types of stratified epithelial tissues: stratified squamous epithelium and transitional epithelium.

(i) Stratified Squamous Epithelium

The stratified squamous epithelial tissues include the layers of **columnar** and **squamous** epithelium. They include two types: keratinised and non-keratinised epithelium. The **keratinised** epithelium is located on the dry surfaces of nails, hair and skin. The surface is made up of dead epithelial tissues and includes keratin protein instead of nuclei.

Figure 3.4: Stratified Squamous Epithelium

They form a waterproof layer over the surface to prevent dehydration of cells beneath them. The **non-keratinised** layer aligns the conjunctiva of the

eyes, mouth, the pharynx, the oesophagus and the vagina. It also prevents the loss of water and keeps the surface moist.

(ii) Transitional Epithelium:

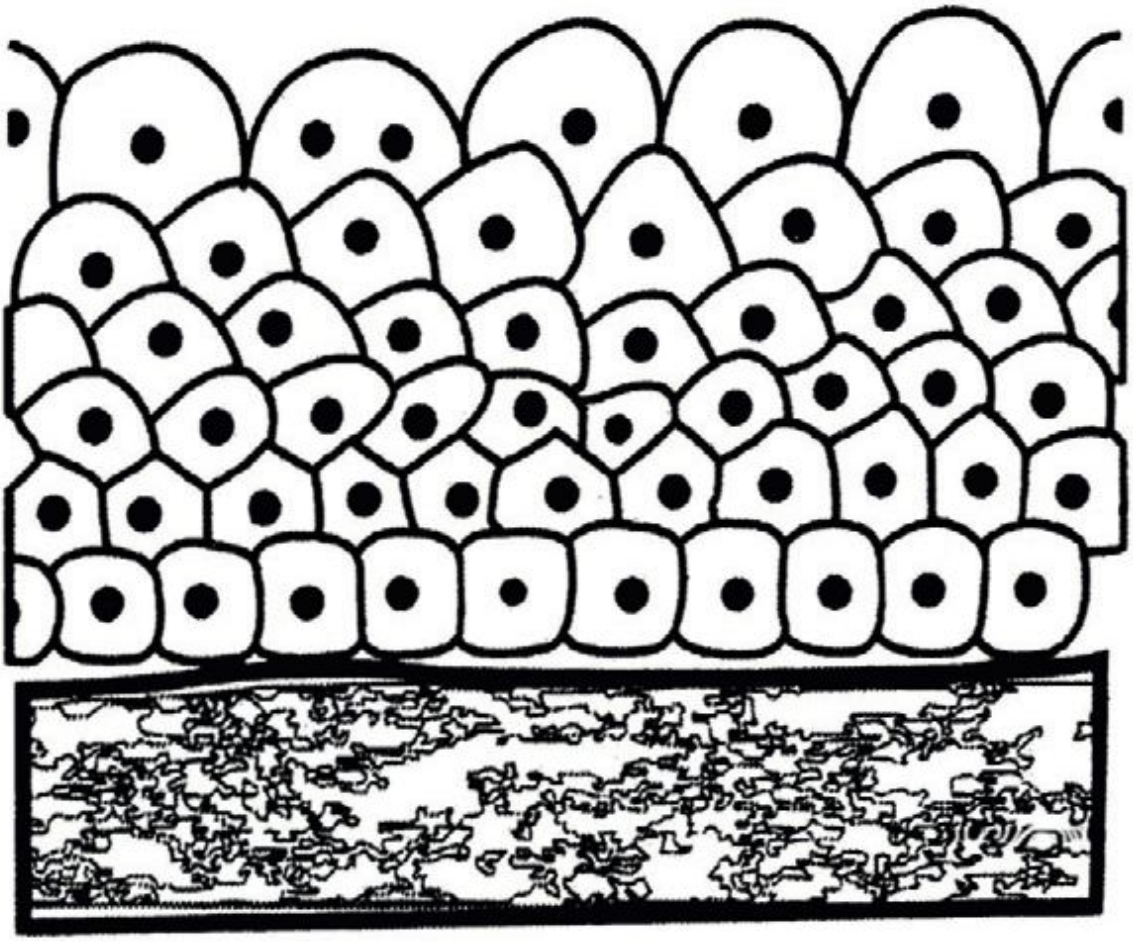


Figure 3.5: Transitional Epithelium

Transitional epithelium includes **pearl-shaped** cells. They form the lining of the urinary bladder. The cells on the surface can change their shape from round to flat. Hence, when the bladder is filled with urine, the cells can stretch without tearing the lining.

Glandular Epithelium:

The glandular epithelium contains glandular cells that play a major role in the secretion of substances (hormones). They are often found in clusters below the inner walls and lining epithelium. The glandular cells form a

gland that may either comprisea single cell or a group of cells that secrete substances directly into the blood inside the ducts or onto the surface.

A gland is classified into either endocrine or exocrine gland.

• **Endocrine:** The endocrine glands secrete hormones that directly enter into the bloodstream via interstitial fluid, namely, they enter the blood without flowing through a duct. Some of the examples of endocrine glands include pancreas near stomach, ovaries in the pelvic cavity, pineal gland in brain, thyroid near larynx (voice box) and so on. **Exocrine:** The exocrine glands secrete their products into the ducts that drain the substances on the surface of the walls and lining epithelium. Based on the number of cells, the exocrine glands are distinguished as unicellular and multicellular glands.

• **Unicellular Glands:** It means single-celled glands. For example, goblet cells that secrete mucous in the lining of the epithelium.
• **Multicellular Glands:** The multicellular glands include multiple cells that form a distinctive structure or organ. For example, salivary glands, sebaceous glands or sweat glands.

Classification of Multicellular Glands:
Structurally, the multicellular glands are categorised based on the following criteria:

• Branched or unbranched ducts
• Shape or structure of the secretory portion of the gland
• **Branched or Unbranched Ducts:**

• **Simple Gland:** The unbranched duct of the gland is known as a simple gland.
• **Compound Gland:** The gland with branched ducts is known as a compound gland.

• **Shape or Structure of the Secretory Portion of the Gland:** Based on the shape or structure of the secretory portion, the multicellular glands are further classified into:

• **Tubular Glands:** These glands contain a tube-shaped secretory portion.
•**Acinar Glands:** The acinar glands have rounded secretory portions. They

are also known as alveolar glands.
•**Tubulo-acinar Glands:** They have both tubular and rounded secretory portions.

Combining the above two features, the classification scheme of multicellular glands is as follows:

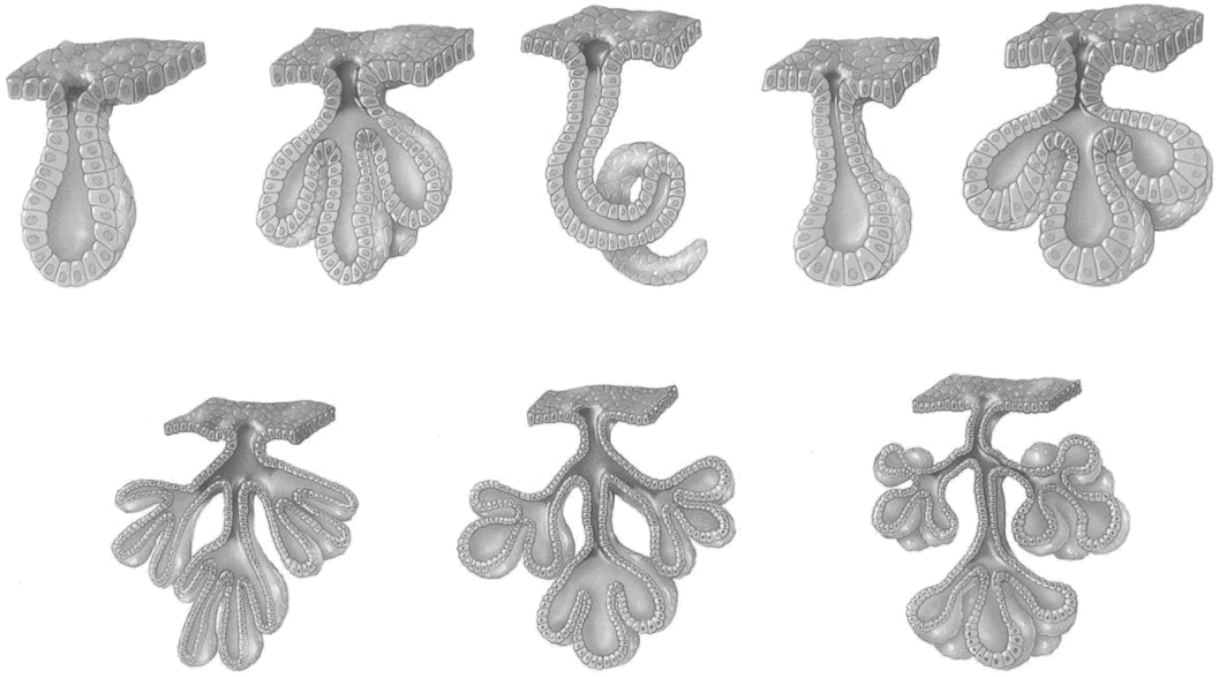


Figure 3.6: Multicellular Exocrine Glands

1. Simple Glands:
• **Simple Tubular:** A straight tubular secretory portion with an unbranched duct, such as glands present in the large intestines.

• **Simple Branched Tubular:** A branched straight tubular secretory portion with an unbranched duct, such as gastric glands.
• **Simple Coiled Tubular:** The coiled tubular secretory portion with an unbranched duct, such as, sweat glands.
• **Simple Acinar:** The rounded secretory portion having an unbranched duct, such as, glands of the penile urethra.
•**Simple Branched Acinar:** The branched rounded secretory portion with an unbranched duct, such as, sebaceous glands.

2. Compound Glands:

• **Compound Tubular:** The tubular secretory portion is joined to the branched duct, such as, bulbourethral gland.
• **Compound Acinar:** The rounded secretory portion with the branched duct, such as, mammary glands.
•**Compound Tubule-acinar:** It includes tubular and rounded secretory portions with a branched duct, such as, acinar glands of the pancreas.

2. Muscular Tissue:

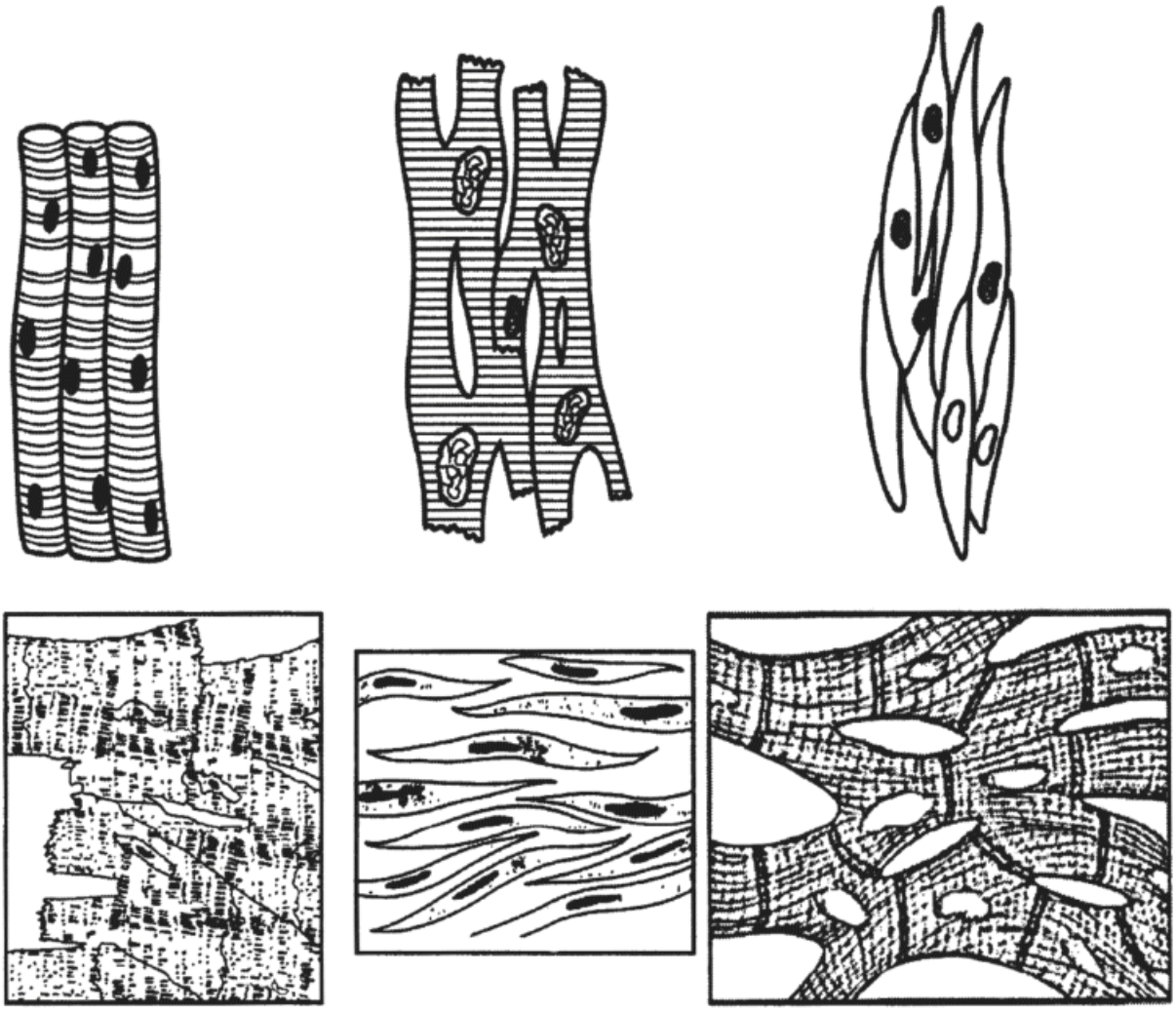


Figure 3.7: Muscular Tissues

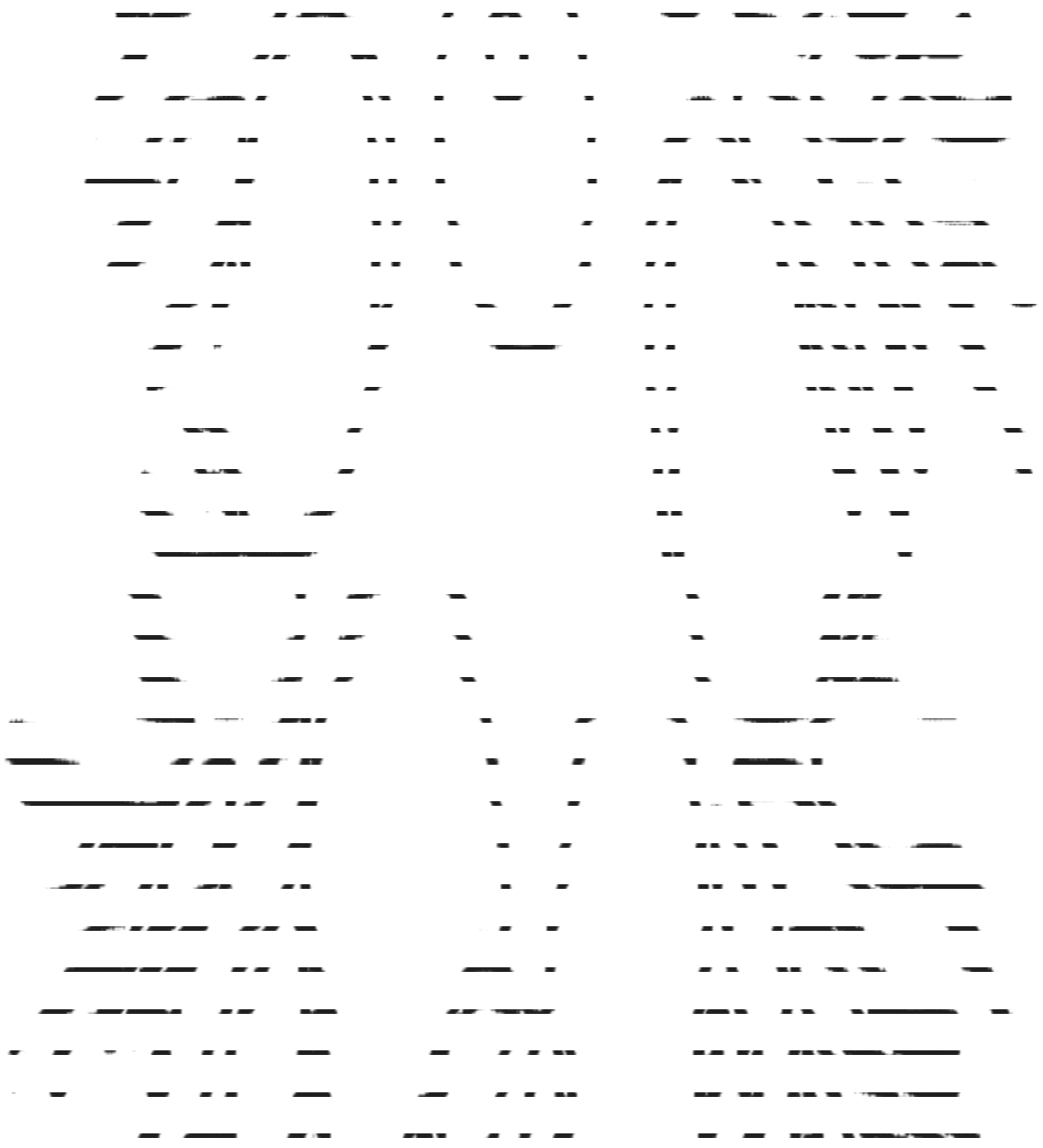
Muscular tissues are made up of **elongated cells** called **myocytes** or**muscle fibres.** These cells can shorten and cause contraction. Hence, they help in the movement of bones (skeleton). Muscle contraction requires an adequate amount of oxygen and nutrients, including calcium . They are classified into three types: skeletal muscles, smooth muscles, and cardiac muscles.

• **Skeletal Muscles:** The skeletal muscles are **cylindrical cells** with multiple nuclei. These cells consist of contracting proteins that appear like striations. Hence, they are known as **striated muscles.** The skeletal muscles are attached to the bones by the tendon. Their movement can be controlled consciously; thus, they are also known as **voluntary muscles.** The functions of skeletal muscles are the movement of the body, maintenance of body posture, generation of heat and protection.
• **Smooth Muscles:** Smooth muscles, also known as **visceral muscles,** are made up of nonstriated muscle fibres. They have spindle-shaped cells that taper towards each end with only one nucleus. Unlike skeletal muscles, they cannot be controlled consciously. Hence, they are known as **involuntary muscles.** They are mainly located in the walls of the hollow organs. The function of the smooth muscle depends on the organ. For example, in the stomach and intestines, the smooth muscles contract in waves (known as peristalsis) to pass food through the digestive tract, whereas smooth muscles of the blood vessels constrict or dilate to maintain normal blood pressure.
• **Cardiac Muscles:** The cardiac muscles are located only in the heart wall. They have branched cells with a single nucleus and faint striations. The activities of the cardiac muscles are involuntary, i.e., they cannot be controlled consciously. The end of each cell membrane forms an interlocking fold with an adjacent cell. This fold is called an **intercalated disc** that appears as a thick dark line between two cells. The intercalated discs allow the passage of electrical impulses through cells without any nerve stimuli. The cardiac muscles form the myocardium of the heart. They contract and function in the pumping of blood through the heart. Thus, they help in maintaining normal blood pressure and supply of blood throughout the body.

1. Nervous Tissues:

The nervous tissue is made up of **nerve cells** or **neurons.** Neurons are the basic structural and functional units of the nervous system. The nervous

system is divided into the central nervous system (CNS) and peripheral nervous system (PNS). CNS includes nerves of the brain and spinal cord, whereas PNS consists of all nerves emerging from the brain and spinal cord. The nervous system can detect and respond to various stimuli. This is carried out by the conductionof electrical impulses called action potentials. Thus, neurons are called **excitable cells** as they generate and conduct the electrical signals. Some neurons generate nerve impulses, whereas others are associated with conduction to other nerve cells. Such neurons are known as relay stations. The basic structure of neuron is as follows:



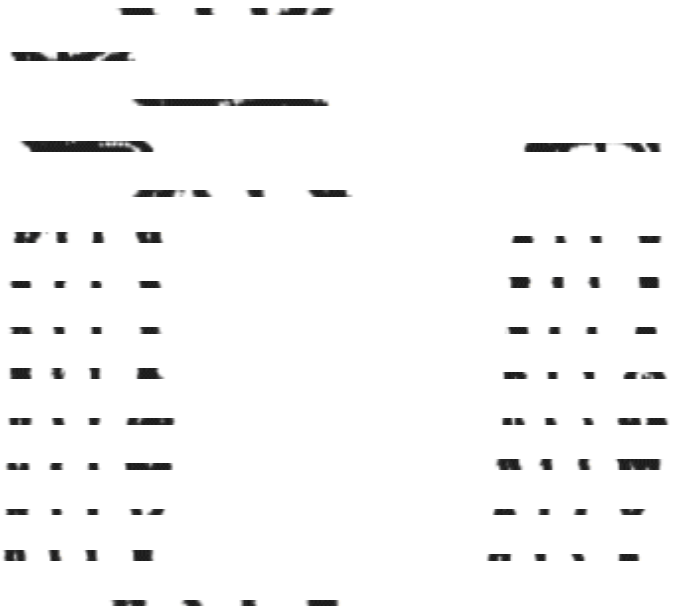


Figure 3.8: Structure of a Typical Neuron

The structure of the neuron is divided into two parts: the cell body and neurites.

• **Cell bodies:** Cell bodies (soma) include nucleus and other cell organelles. They are necessary to keep the nerve cells alive and form the **grey matter** of the nervous system. The group of cell bodies in CNS is called nuclei, whereas in PNS they form the ganglia. The location of cell bodies may vary. In the brain, it is located at the periphery, whereas it forms the centre of the spinal cord.

• **Neurites:** Neurites are various processes that emerge from cell bodies. They form the **white matter** of the nervous system. They include axons and dendrites.

• **Axons:** An axon is a single long structure of the nerve cell. Each neuron has only one axon. Unlike cell bodies, axons are located in the brain and at the periphery of the spinal cord in groups (also known as tracts). An axon arises from a funnel-shaped extension of the cell body called **axon hillock** and can extend up to one metre. The outer membrane of axon is called **axolemma,** and the cytoplasm is known as **axoplasm.** A myelin sheath surrounds the surface of large axons and peripheral nerves. A **myelin sheath** is a series of **Schwann cells** that encircles the axon and forms a thin sleeve around it. There is a fatty substance called **myelin** between layers of Schwann cells. Each Schwann cell forms an individual segment around the axon. The outermost layer of Schwann cells is known as **neurilemma**. The

junction between two segments of Schwann cells is called **'Nodes of Ranvier'**. It allows the rapid transmission of electrical impulses in a myelinated nerve. The axon terminates into numerous branches that further terminate into small swellings called **synaptic knobs**. The space between the axon of one neuron and the dendrite of another neuron is known as the **synapse.** The synaptic knob **contains synaptic vesicles** that release chemicals called a **neurotransmitter** that help in the conduction of nerve impulses across two cells.

• **Dendrites:** Dendrites are multiple short processes that arise from cell bodies. They are responsible for the conduction of nerve impulse to the cell body. Their structure is similar to axon; however, the only difference is that dendrites are shorter and highly branched as compared to axons.

1. Classification of Neurons:

Neurons can be classified into various categories, such as:

• **Based on the Number of Poles:** Neurons can be classified

into three categories based on the number of poles from which the neurites arise. They include:

• **Unipolar:** It indicates the presence of a single pole that

processes into both axons and dendrites.

• **Bipolar:** Bipolar neuron has two separate poles for axons and dendrites.

• **Multipolar:** As the name suggests, this neuron has multiple poles. One of the pole processes into the axon and the rest gives dendrites.

2. Based on the Function of the Neuron:

•**Motor Neurons:** Motor neurons are also known as **efferent nerve cells.** They originate into the organs of the CNS. They have long axon and short dendrites. They carry nerve impulses from the brain and the spinal cord to the nerves of muscles, organs and blood vessels. They are associated with muscle contraction and secretion of glands.

• **Sensory Neurons:** Sensory neurons are known as **afferent nerve cells.** They conduct nerve impulses from PNS to the brain and the spinal cord. These cells have short axon and long dendrites. They are associated with the

sensation of smell, taste, vision, hearing, pain, touch, and maintenance of body posture.

3. Connective Tissues:

Connective tissue is the most abundant tissue with varied shapes and functions. It can strengthen other tissues, protect and insulate internal organs, act as a transport system for the supply of nutrients throughout the body, form storage for energy conservation, serve as a major source for immune responses and also divide structures into various compartments. It consists of extracellular matrix and multiple cells. The cells vary according to the type of tissue. Some of them are fibroblasts, plasma cells, macrophages, adipocytes and mast cells. The extracellular matrix is the material located between the space of two cells. It is made up of ground substance and protein fibres. The ground substance is a fluid or a semi-solid material present between the cells and fibres. It plays an important role in the storage of water and also acts as an exchange medium for substances between cells and blood.The fibres give support and strength to connective tissues. There are three types of fibres: collagen fibres, elastic fibres and reticular fibres.

• **Collagen Fibres:** Collagen fibres are very strong fibres of **collagen** protein. They are found in parallel bundles that increase their tensile strength. Although they are strong fibres, they possess some flexibility. They are commonly found in the bones, cartilages, tendons and ligaments.
• **Elastic Fibres:** Elastic fibres are small fibres of **elastin** protein. They can stretch and return to their original shape after stretching. This property is known as elasticity. They combine to form a network of fibres inside the connective tissues. They are primarily located in the skin, lung tissues, and blood vessels.
• **Reticular Fibres:** Reticular fibres are highly branched collagen fibres with fine bundles wrapped in glycoproteins. They are located in the walls of blood vessels and soft organs like spleen and lymph nodes.

Types of Connective Tissues:
There are different types of connective tissues inside the body; they include:

- Loose or areolar connective tissue
- Adipose tissue
- Dense connective tissue
- Cartilage
- Bone
- Liquid connective tissue

1. Loose or Areolar Connective Tissue:

Figure 3.9: Areolar Connective Tissue

Loose connective tissues are made up of fibroblast cells with the semisolid matrix. The cells are separated by elastic and collagen fibres. They are generalised tissues that are found in almost every part of the body, including under the skin, around blood vessels, nerves and organs. They provide strength, elasticity and support to the underlined structures.

2. Adipose Tissues:

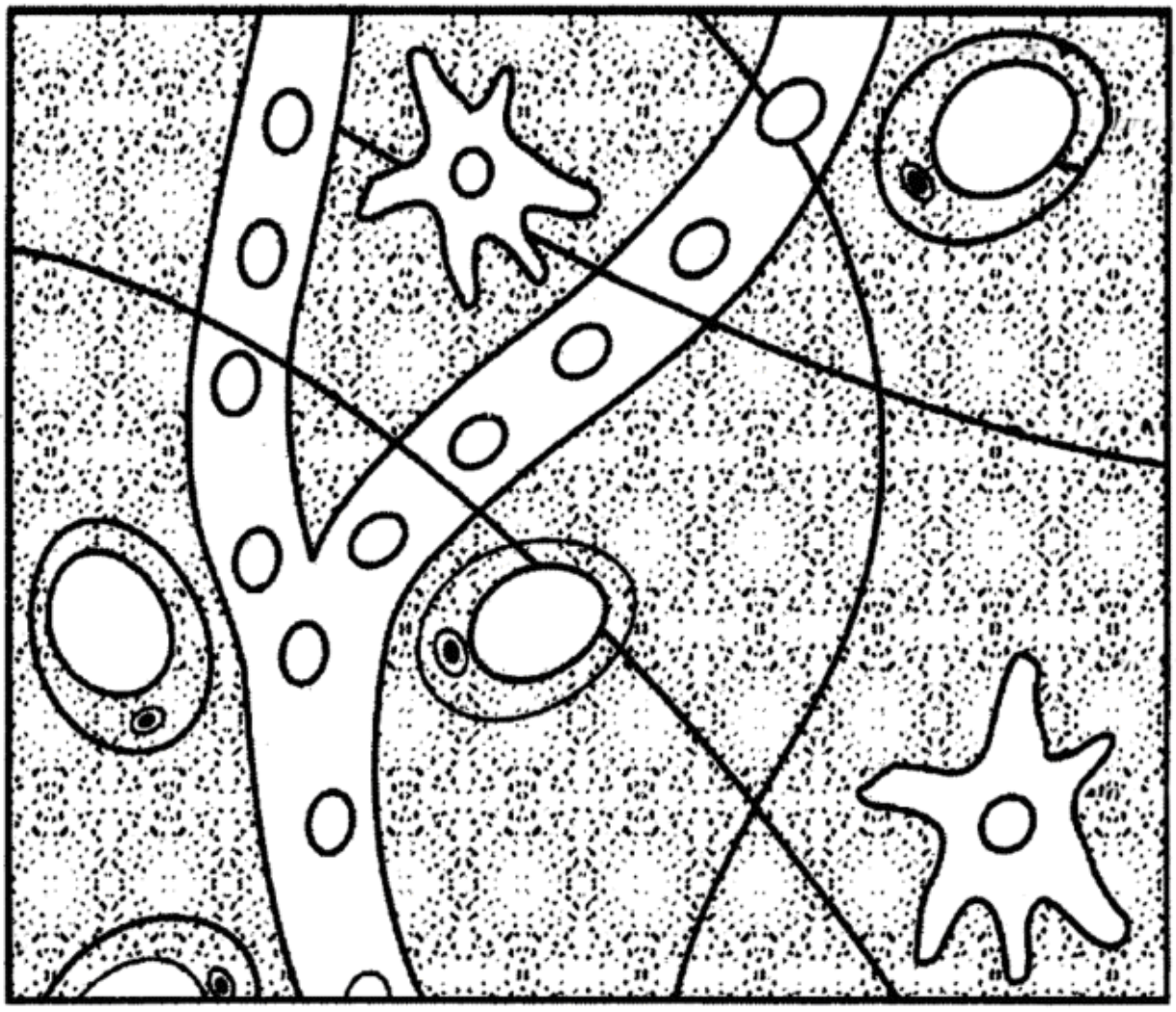


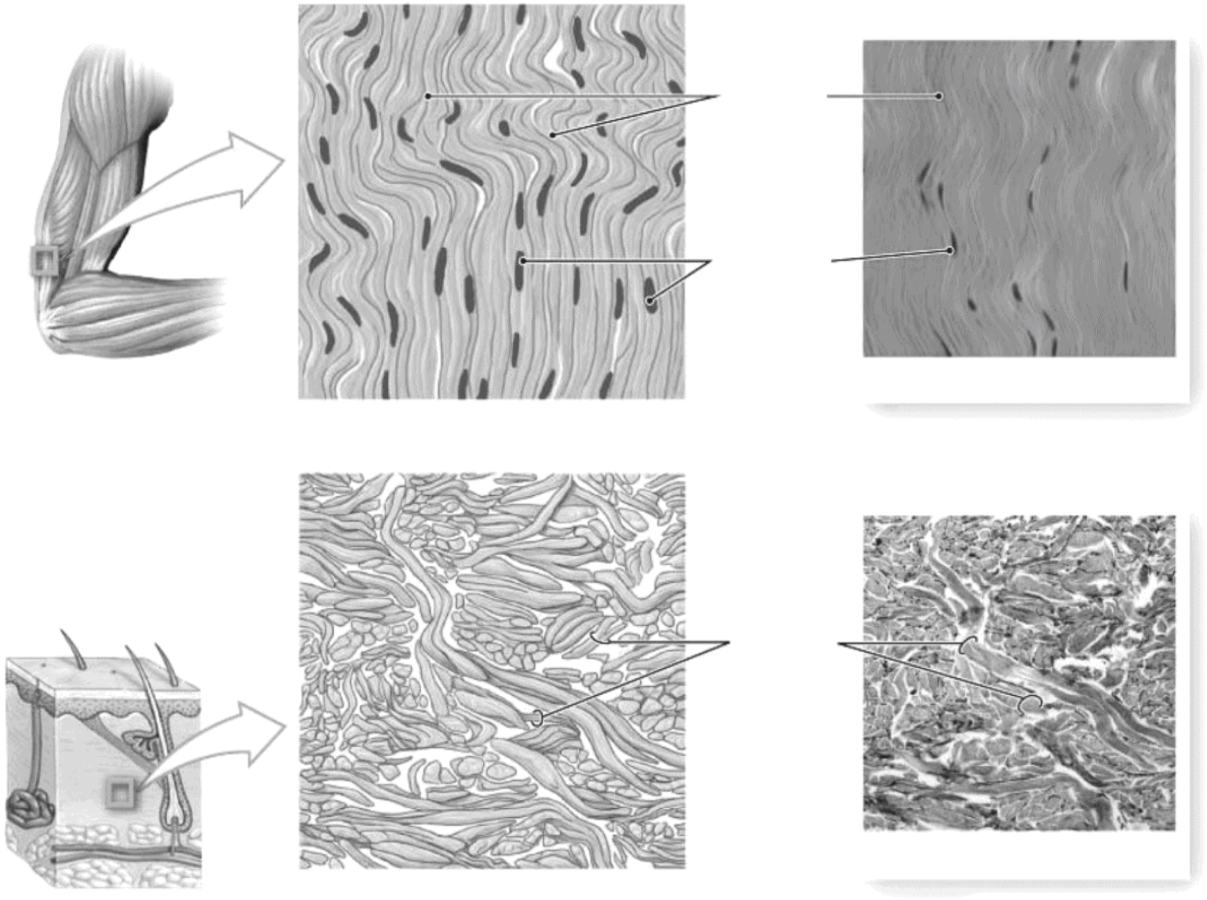
Figure 3.10: Adipose Tissues:

Adipose tissues are made up of adipocyte cells that contain large fat globules. There are two types of adipose tissues: white adipose tissue and brown adipose tissue. The brown adipose tissues are majorly located in the newborns, whereas the white adipose tissues are situated mainly in adults. They are found in the kidneys, the eyes, under the skin and between muscle fibres. They have the following functions:

- Serves as an energy reserve
- Acts as an insulator (retains body heat)
- Supports and protects organs

3. Dense Connective Tissue:

Dense connective tissues have plenty of fibres and fewer cells as compared to loose connective tissues. There are two types of dense connective tissues: fibrous tissues and elastic tissues. The **fibrous connective tissues** include parallel or irregularly placed collagen fibres with a few fibroblasts. They are tough, flexible tissues that are found in some of the tendons, cartilages and ligaments. They are also located in the liver, kidneys, lymph nodes and testes. The **elastic tissues** are made up of elastin fibres that form the lining of the large arteries of the heart. They help in maintaining normal blood pressure. Besides arteries, elastic tissues are also located in the alveoli of the lungs, trachea, bronchial tubes and ligaments.



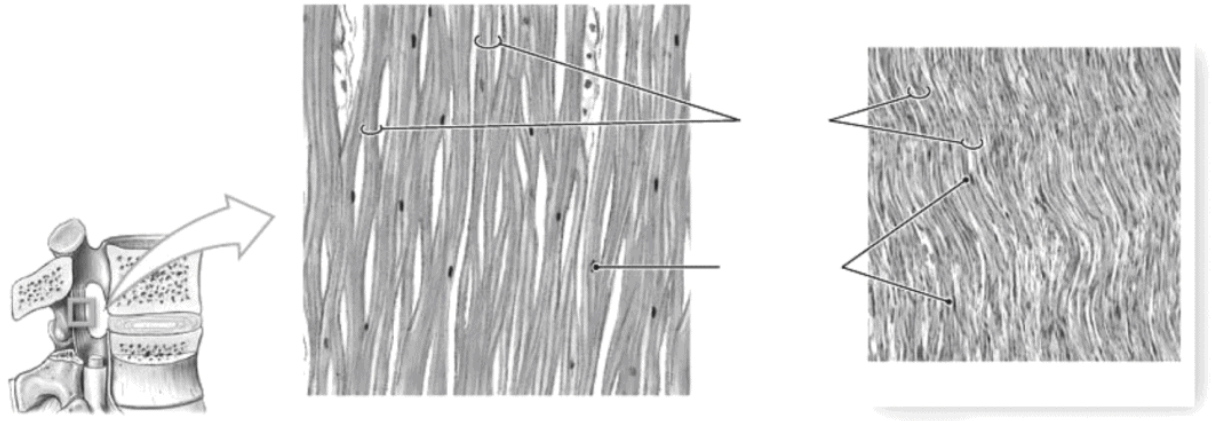


Figure 3.11: Dense Connective Tissues

4. Cartilage:

Cartilage is a specialised tissue made up of **cartilage cells** or **chondrocytes.** These cells are embedded in both collagen and elastic fibres. There are three types of cartilages: hyaline cartilage, fibrocartilage and elastic fibrocartilage.

• **Hyaline Cartilage:** Hyaline cartilage is a smooth tissue with a small group of chondrocytes within cell nests. The matrix is smooth and solid. Under the microscope, the hyaline cartilage appears bluish-white. It provides flexibility, support and resists compressive force at the site where two bones join. Hence, it is located at the ends of long bones. Besides this, it attaches ribs to sternum and also formsa lining of the respiratory tract.

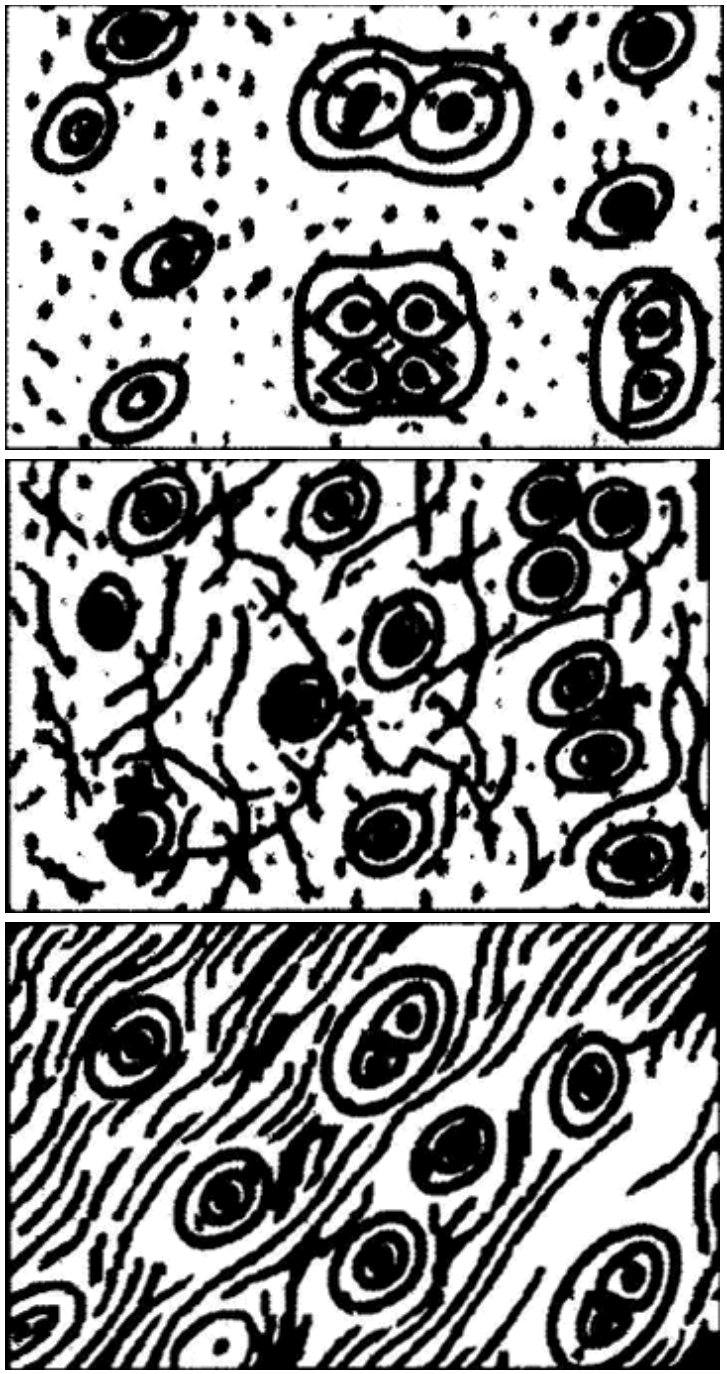


Figure 3.12: Cartilages

• **Fibrocartilage:** Fibrocartilage is made up of white collagen fibres embedded in a smooth solid matrix. It is tough and can resist high degree of tension. However, they do possess some flexibility. They are commonly found in the intervertebral discs (pads between two vertebrae), between the articulating surface where bones meet each other, around the rim of socket

bone of hip and shoulder joints, and ligaments that join bones.
• **Elastic Fibrocartilage:** Elastic fibrocartilage is made up of yellow elastic fibres embedded in a solid matrix. The chondrocytes are entrapped between these fibres. This cartilage is found in the pinna of the ear, the epiglottis and lining of the blood vessels.

5. Bone:

Bones are strong and durable connective tissues that form a part of the skeletal system. They are made up of multiple cells, including bone cells or **osteocytes.** These cells are embedded in the matrix of mineral salts and collagen fibres. The bones are classified into two categories: compact bones and cancellous bone.

(i) Compact Bones:

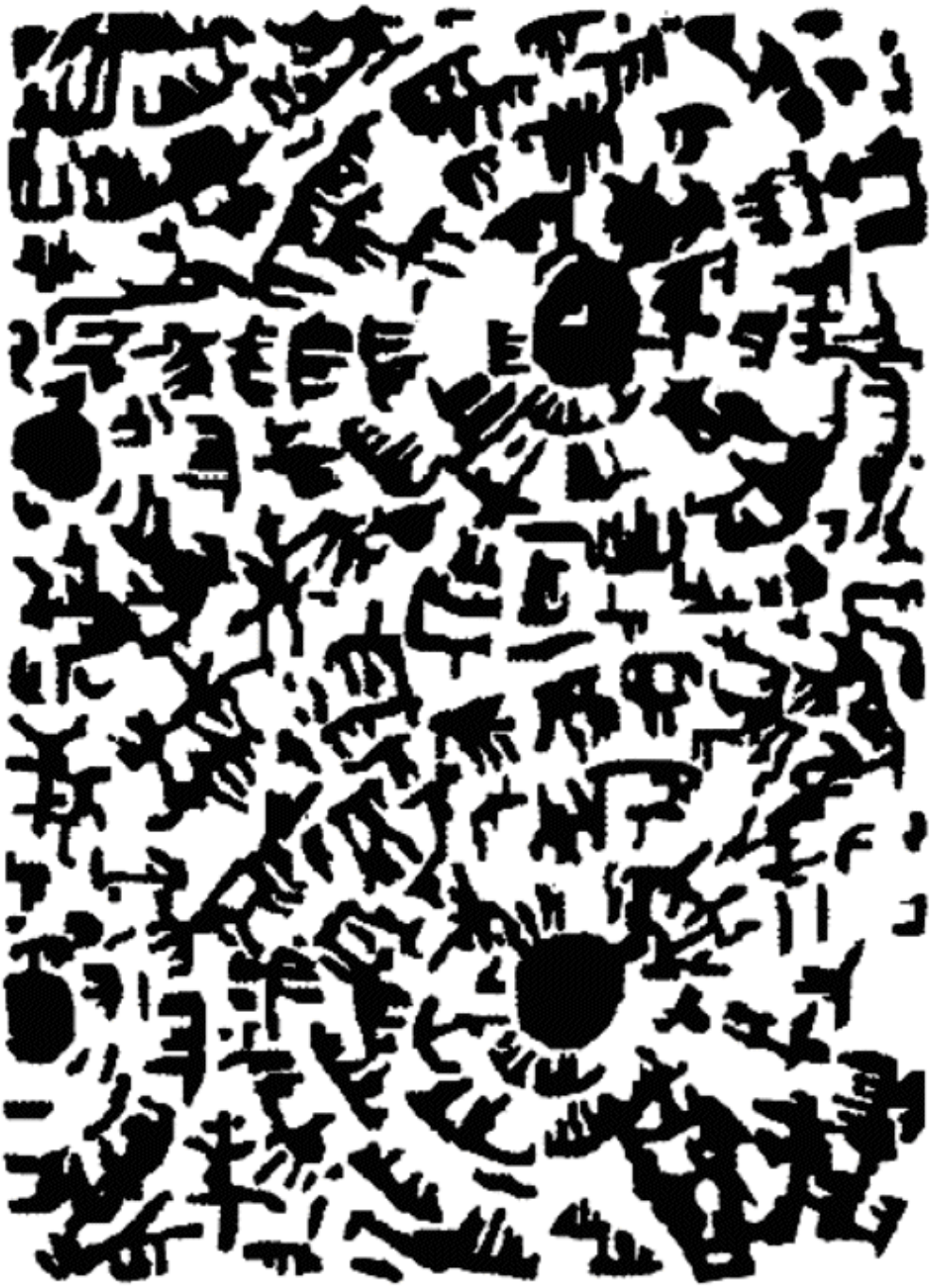


Figure 3.13: Compact Bone.

Compact bones form a major part of the skeletal system. In these bones, the osteocytes, matrix and blood vessels are arranged in a particular pattern.

This arrangement is known as **an osteon** or **Harversian system.** It forms a fundamental unit of compact bones. An osteon consists of four parts:

• **Lamellae:** The lamellae contain matrix in concentric rings with mineral salts and collagen fibres. The salts of calcium and phosphorus give rigidity and strength, whereas collagen fibres give tensile strength to the bones.
• **Lacunae**: They are the small spaces between lamellae that contain osteocytes.
• **Canaliculi:** The lacunae projects into various canals called canaliculi. They form the transport system for the supply of nutrients and removal of wastes to and from the osteocytes.
• **Central Canal or Harversian Canal:** The central canal includes all the nerves, blood vessels and lymphatic vessels that supply to the bones.
• **Cancellous Bones:** Cancellous bones are also known as **spongy bones** that appear like a honeycomb. They include columns of bones called **trabeculae.** Trabeculae lack osteons but consist of lamellae, osteocytes, lacunae and canaliculi. The space between each trabecula is filled with **red bone marrow.**

6. Liquid Connective Tissues:

The liquid connective tissue includes lymph and blood that acts as a transport system for various substances across cells of the body.

BODY FLUIDS

The human body is made up of both solids and fluids. About 60% of fluids are made up of water. Water is the most important and principal constituent of the human body. The total amount of water is divided into two compartments, namely the intracellular and the extracellular fluid compartments. These compartments are separated by membranes that allow the passage of water. The composition of the compartments are as follows:

• **Intracellular Fluid Compartment:** Intracellular fluid is present inside cells. It contributes to about 40% of the total water level inside the body. It has a high proportion of proteins, ATP and potassium and low concentration of sodium as compared to the extracellular fluid.

• **Extracellular Fluid Compartment:** Extracellular fluid is the fluid outside cells. It forms 20% of the total water level inside the body. It includes a high concentration of sodium. It can be further divided into:

• **Plasma:** Plasma is the fluid component of blood that flows through the blood vessels.
• **Interstitial Fluid:** Interstitial or intercellular fluid is the fluid that bathes all the body cells. It is the medium for passage of nutrients between blood and cells.
•**Transcellular Fluid:** It is fluid located in the body cavities and secretion from the secretory cells. This fluid includes saliva, cerebrospinal fluid, sweat, synovial fluid in joints, intraocular fluid in eyes, pleural fluid in lungs and pericardial fluid in the heart.

The human body undergoes several mechanisms for the maintenance of the normal water level. An excess loss of water is known as dehydration, whereas an excess build-up of water is termed as oedema.

Questions for study

1. What is a tissue? Enlist the primary tissues of the body.
2. Explain epithelial tissues.
3. What is the function of transitional epithelial tissues?
4.Explain different types of muscle fibres.
5. Name the thick dark band between the cardiac muscles.
6. Explain the basic structure of a neuron.
7. Draw a neat label diagram of a neuron.
8. What are motor neurons?
9.Define cartilage. What are the different types of cartilages? **10.** Write a note on bone connective tissue.

11. Name the location of the transitional epithelium, areolar tissue, hyaline cartilage, cardiac muscles, nerves.
12. What are microvilli? Explain the location and function of microvilli.
13. Give the classification of the epithelial tissue.
14. Explain the compartments of the body fluid.
15. What is dehydration?
16. What do you mean by oedema?
17. What is intracellular fluid?

18. Explain the harversian system.
19. Explain the classification of glandular epithelium. **20.** What are exocrine glands?
21. Give an example of any exocrine gland.
22. Name any one example of compound acinar gland.

4

Osseous System

learning ObjeCtives:
After completing the chapter, students will be able:
To study the tissue system that forms the framework of the body. To learn and appreciate the structural characteristics of bones that constitute

the skeleton.
To study the types of bones and their related functions.
To learn the varied functions of bones and disorders in the joints.

INTRODUCTION
Skeleton constitutes the bony framework of the body.

The skeletal system consists of about 206 bones to make a strong, movable living framework for the body. It supports and protects softer, delicate tissues and organs and they form joints for the movement of the body. The bones making up the skeleton are of various types viz. long bones, short bones, flat bones, irregular bones etc.

The bones perform following important functions: **(i)** They form the supporting framework of the body;

(ii) They form boundaries for the cranial, thoracic and pelvic cavities;
(iii) They give protection to delicate organs;
(iv) They form joints which are essential for the movement of

the body;
65
(v) They provide attachment for the voluntary muscles. This helps in the movements of joints;

(vi) They form blood cells in the red bone marrow in cancellous bone; and
(vii) They act as a store house of calcium salts.

The bones of the skeleton are divided into two groups:

1. The Axial Skeleton: It consists of the bones which form the skull, the vertebral column and the thoracic cage.
2. The Appendicular Skeleton: It consists of shoulder girdles, upper limbs, pelvic girdle and lower limbs.

Can you reCaLL?

How many bones are present in human body?

THE AXIAL SKELETON

The bones of the axial skeleton constitute the central bony core of the body.

The Skull

It rests upon the upper end of the vertebral column and its bony structure is divided into two parts viz., cranium and face. **The Cranium:** It provides bony protection to the brain. It is described in two parts: base and vault. The base is a part on

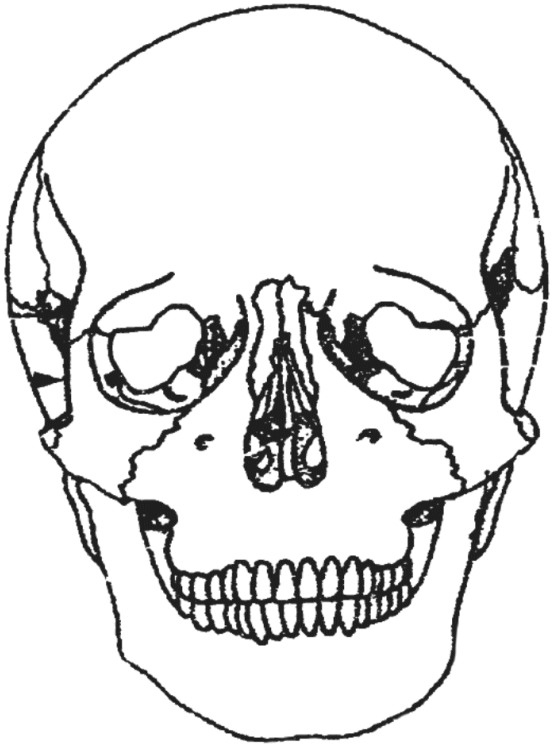


Figure 4.1 (a): The Bones of the Skull (Anterior View)

which the brain rests and the surrounding part is termed as the vault. The base is divided into the anterior, middle and posterior cranial fossae. The inner surfaces of all the cranial bones are supplied with blood vessels. The bones which form the cranium [Fig. 4.1 (a) and (b)] are: one frontal bone; two parietal bones; one occipital bone; one sphenoid bone; one ethmoid bone and two temporal bones.

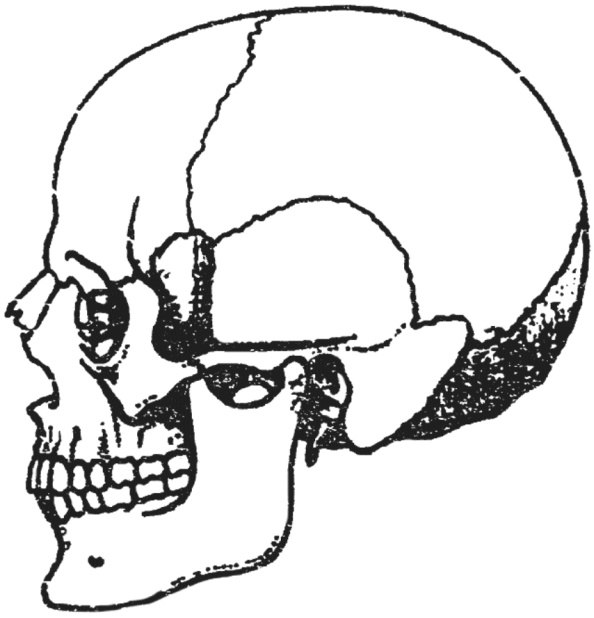


Figure 4.1 (b): The Bones of the Skull (Lateral View)

1. The Frontal Bone:

The frontal bone is a large flat bone which forms the forehead and also the upper part of the orbital cavities. It develops in two parts which gradually fuse into one bone. It contains two cavities called the frontal sinuses which lie one over each orbit. They contain air which enters by a small opening leading from nasal cavities. These sinuses give lightness to the bone and resonance to the voice, acting as sounding chambers.

2. The Parietal Bones:

The parietal bones are two flat bones forming sides and roof of the skull. They articulate with each other and with frontal, occipital and temporal bones. The inner surface is concave and is grooved by the brain and blood vessels.

3. The occipital Bone:

The occipital bone forms back of the head and part of the base of the skull. It forms immovable joints with parietal, temporal and sphenoid bones. On the outer surface, there is a roughened area called occipital protuberance. In this

bone, there is a large opening known as the foramen magnum, for the passage of spinal cord.

4. The Temporal Bones:
The temporal bones lie on each side of the head (Fig. 4.2).
Each temporal bone is divided into four parts. They are:

1. The squamous part is the fan shaped portion.
2. The mastoid process is a thickened part of bone and can be felt just behind the ear. It contains a large number of small air sinuses which communicate with middle ear. A styloid process projecting from it gives attachment to muscles.
3. The petrous portion is thick and forms a part of the base or floor of the skull and contains the organ of hearing.

Figure 4.2: The Temporal Bone (Lateral View) **4.** The zygomatic process is directed forward and articulates with the zygomatic bone to form zygomatic arch. **5. The Sphenoid Bone:**

The sphenoid bone is an irregular bone in the shape of a bat with its wings outstretched and lies in the centre of the base of the skull (Fig. 4.3).

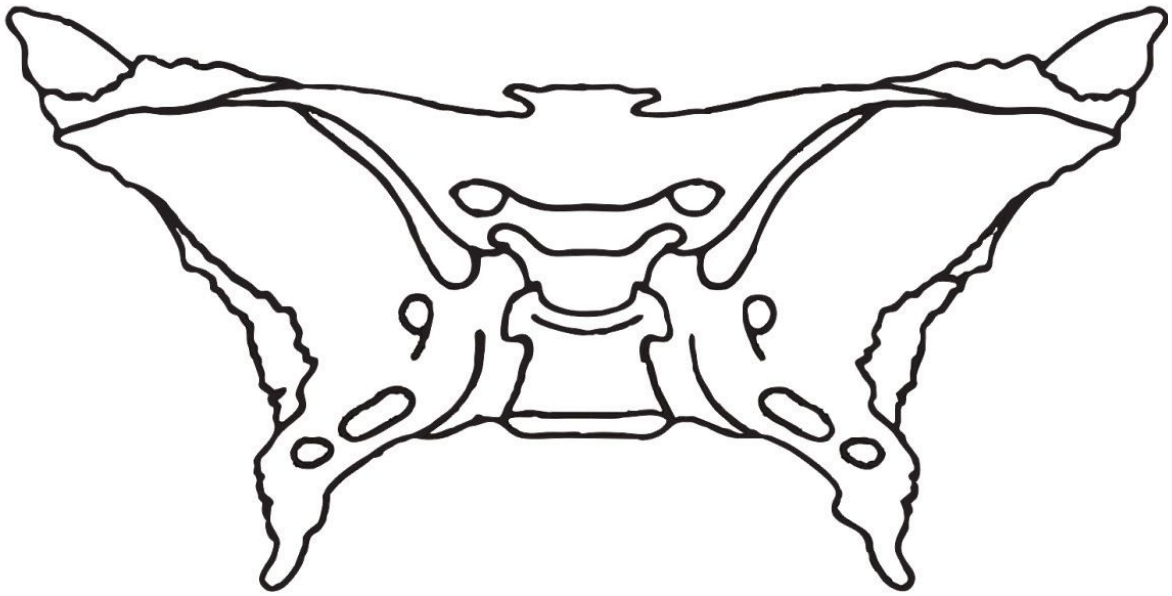


Figure 4.3: Sphenoid Bone (from Above)

On the superior surface of the middle of the bone, there is a depression in which the pituitary gland rests. The wings are perforated by many openings for the passage of nerves and blood vessels.

6. The ethmoid Bone:

The ethmoid bone is a very light, fragile, irregular bone and occupies an anterior part of the base of the skull and helps to form the orbital cavity, the nasal septum and the lateral walls of the nasal cavity (Fig. 4.4).

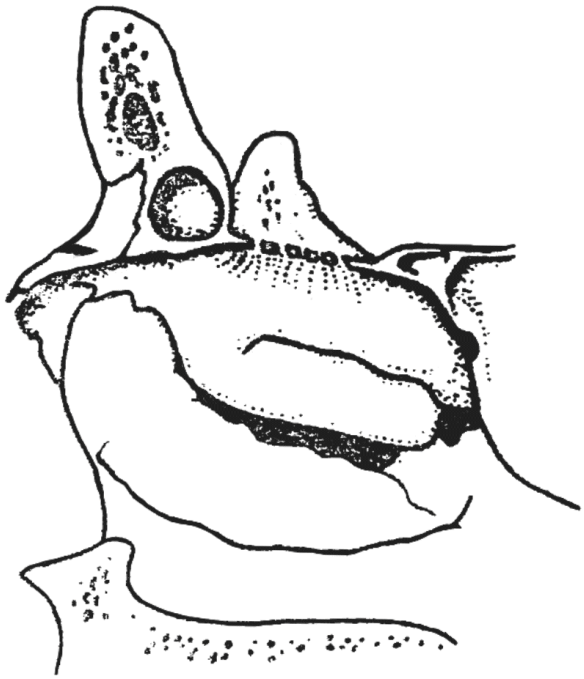


Figure 4.4: Ethmoid Bone

It has a horizontal flattened part called cribriform plate which has many fine openings like a sieve. The openings are for the passage of the nerves of smell called the olfactory nerves. It also contains a flat vertical portion between the two nasal cavities. Two spongy portions form an outer wall of the upper part of the nasal cavity and inner wall of the orbit. On each side, the spongy portions present two projections into nasal cavities which are called turbinated processes. The spongy portions contain a number of air cavities which communicate with the nose.

The Face: There are thirteen bones which form the skeleton of face. They are two zygomatic or cheek bones; one maxilla; two nasal bones; two lacrimal bones; one vomer; two palatine bones; two inferior conchae or turbinated bones and one mandible (Fig. 4.1).

Each zygomatic bone forms the prominence of cheek and part of the floor and lateral walls of orbital cavity. It articulates with zygomatic process of the temporal bone to form a zygomatic arch.

Maxilla or upper jaw bone forms the upper jaw, the anterior part of the roof of the mouth, the lateral walls of the nasal cavities and part of the floor of

orbital cavities. It presents the alveolar ridge which projects downwards and carries the upper teeth. On each side, there is a large air sinus, the maxillary sinus which is lined with ciliated mucous membranes and communicates with the nasal cavity.

The nasal bones are two small bones which form greater part of the lateral and superior surfaces of the bridge of the nose. They articulate with each other medially.

The lacrimal bones are two very small bones located in a position posterior and lateral to the nasal bones. They also form the inner wall of the orbit. They are grooved and the groove contains lacrimal sac and nasal duct. It carries tears or lacrimal fluid from eye down to the nasal cavity.

The vomer is a thin flat bone which extends upwards from middle of the hard palate to separate the two nasal cavities. The palatine bones are two irregular bones which form the back of the hard palate and extend upto the outer wall of the nasal cavity into the floor of the orbit. The turbinate bones are two small scroll-shaped flat bones which form a part of the lateral wall of the nasal cavity.

The mandible is the strongest bone of the face and is the only movable bone of the skull. It has two identical parts. Each part consists of (i) a curved body on the superior surface of which there is the alveolar ridge containing the lower teeth and (ii) a ramus which projects upward (Fig. 4.5). At the upper end, the ramus is divided into two processes; the condyloid process which articulates with the temporal bone and the coronoid process which gives attachment to muscles and ligaments. The point where the ramus joins the body is called the angle of the jaw.

The hyoid is an isolated horse-shoe-shaped bone lying in the soft tissue of the neck. It lies at the base of the tongue and gives attachment to the tongue muscle. It does not articulate with any other bone of the head or trunk but is attached to the styloid process of the temporal bone by ligaments.

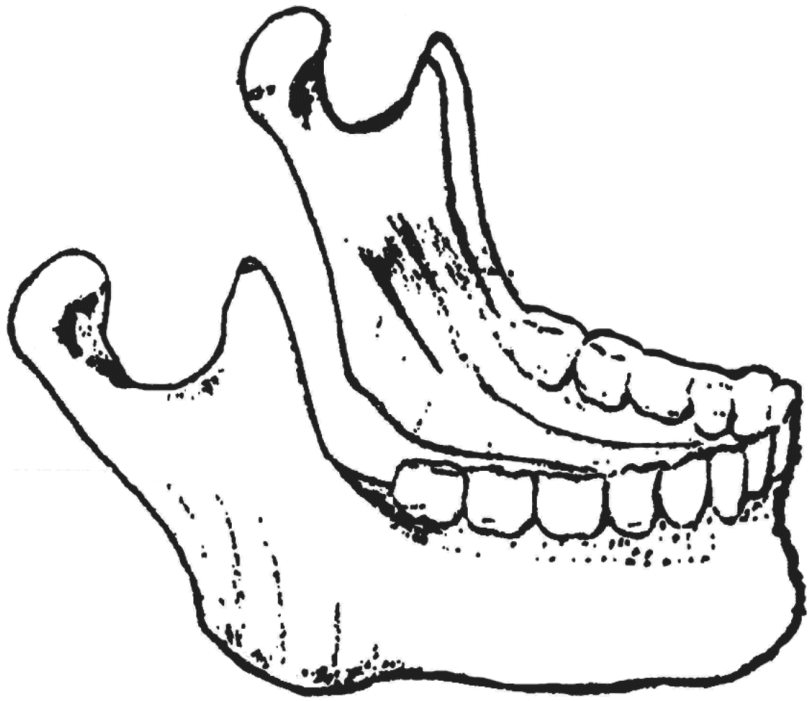


Figure 4.5: The Mandible (Lateral View)

The Vertebral Column

It consists of twenty-four separate, movable, irregular bones called vertebrae which are divided into three groups viz.; cervical (seven); thoracic (twelve) and lumbar (five). (Fig. 4.6). In addition, the sacrum consisting of five fused bones and the *coccyx* consisting of four fused bones which also form a part of the vertebral column. When viewed from the side, the vertebral column shows four anteroposterior curves. They are; cervical curve, in the neck which is convex forwards; thoracic curve, convex backwards; lumbar curve, convex forwards and the pelvic curve convex backwards. Posteriorly convex curves, thoracic and pelvic, are called primary curves and anteriorly convex curves are called secondary curves.

Each vertebra consists of: (1) A disc-shaped body lying in the front and (2) An arc of bone pointing backwards from the body and enclosing a space between body and arch called the neural or spinal canal through which the spinal cord passes. This arch carries three rough processes for muscle attachment. One spinous process which projects backwards and two transverse processes one on either side. On the superior and inferior surfaces of the neural arch, there are two articular processes (Fig. 4.7), which carry smooth surfaces to articulate with similar processes on the vertebrae above

and below. The arch carries a notch on either side on the under surface. The narrow part of the arch above the notch is known as the pedicle (Fig. 4.7). The wide part of the arch carrying the spinous process is known as the lamina, which forms the back wall of the vertebral column. The vertebrae lie body over body and arch, over arch forming a continuous column.

The bodies are joined to each other by thick pads of fibrocartilage called the intervertebral discs. The discs consists of a ring of fibrocartilage and a softer pulpy centre called the nucleus. The discs serve to allow slight movement of bone on bone and yet make very strong joints. They also absorb shock to prevent its passage to the brain.

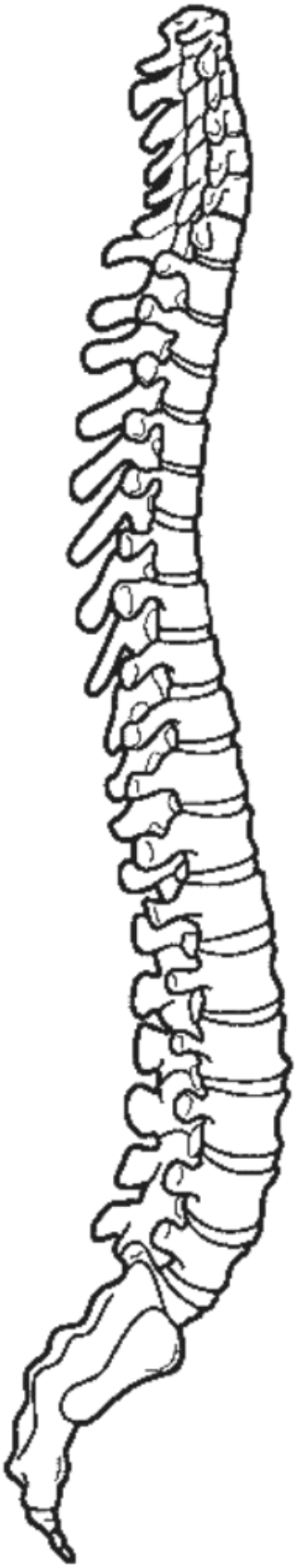


Figure 4.6: The Vertebral Column (Lateral View)

The Cervical Vertebrae: These are the smallest separate vertebrae with relatively large openings; they run down the neck forming a slightly forward curve. They have two special features: (a) Each transverse process carries an opening through which a vertebral artery passes upwards to the brain, (b) The spinous process is forked or bifid giving attachment to muscles and ligaments.

Figure 4.7: A Cervical Vertebra

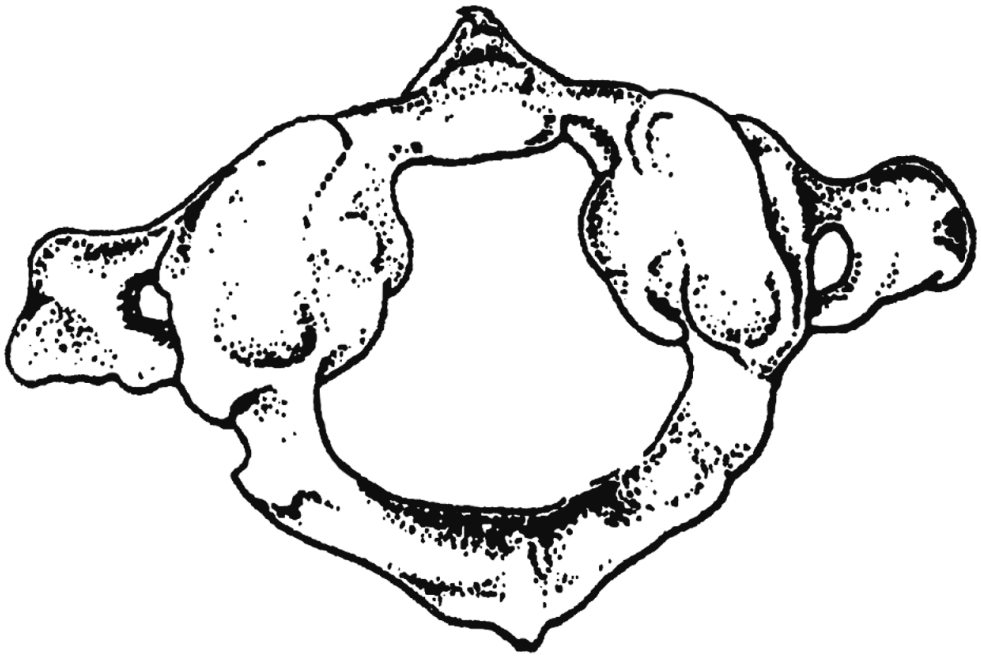


Figure 4.8: The Atlas

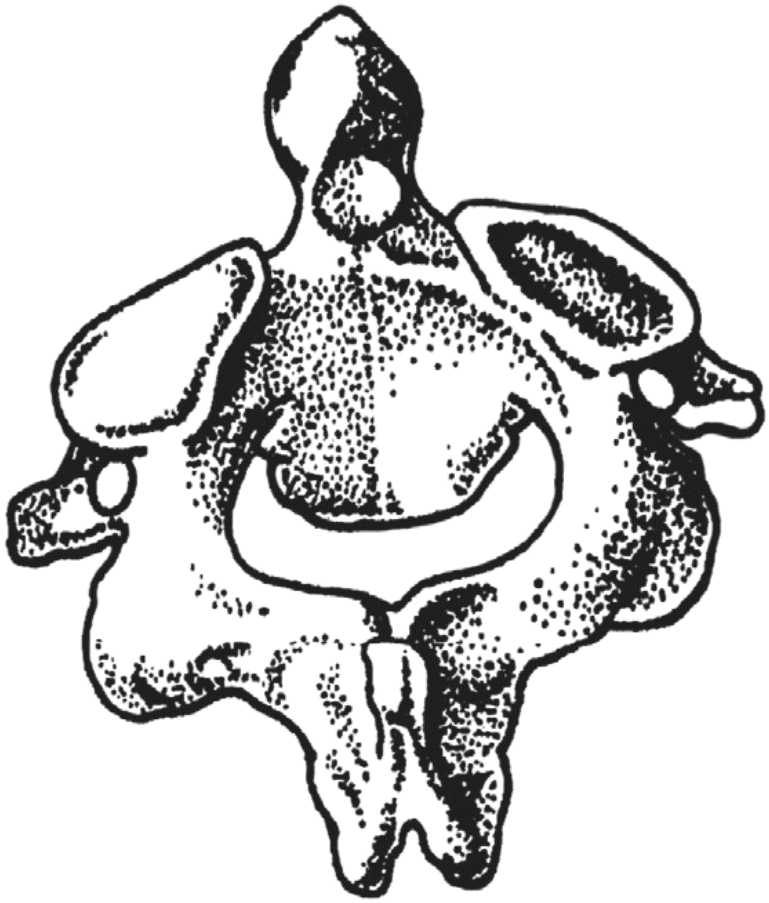


Figure 4.9: The Axis

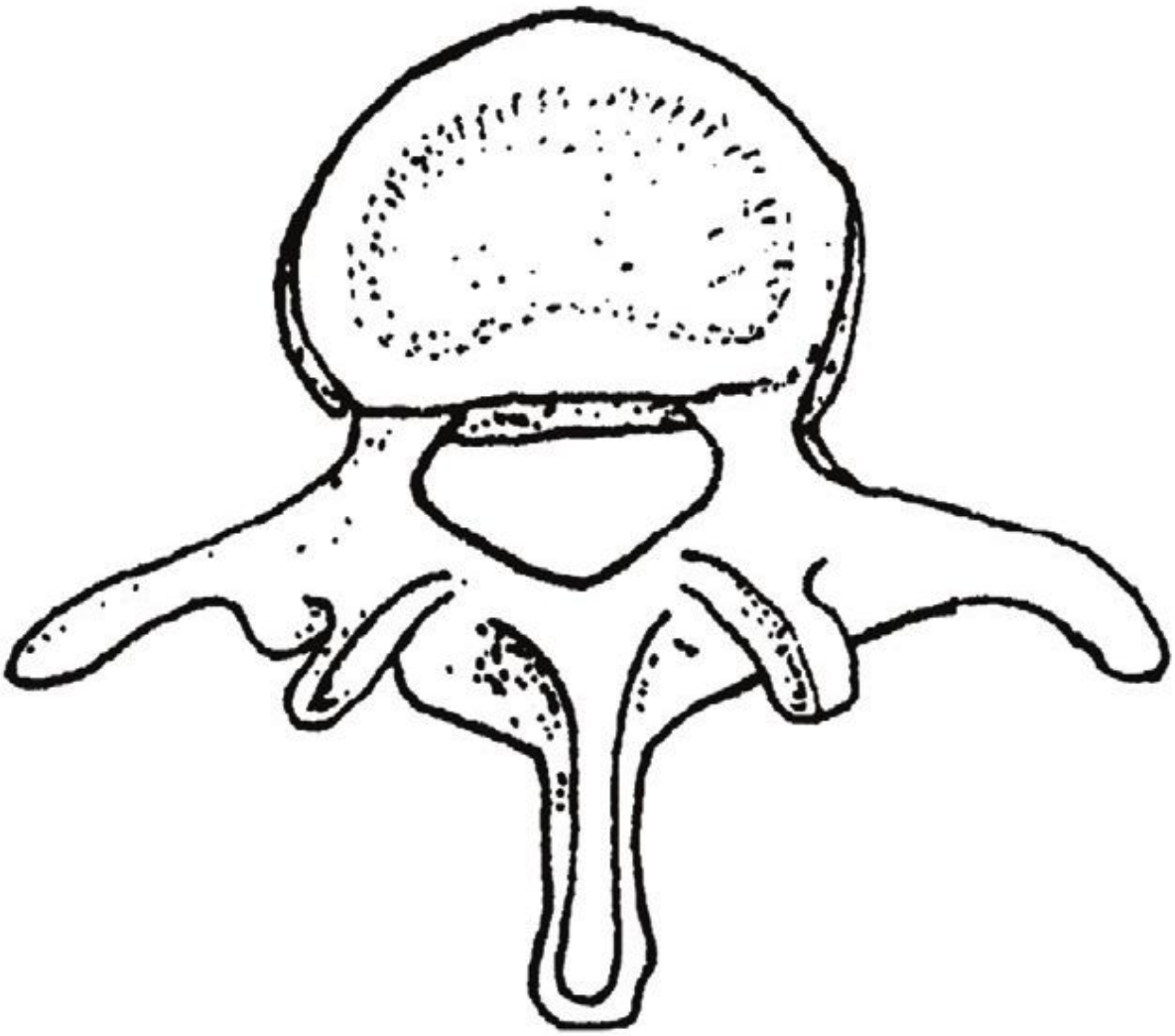


Figure 4.10: A Thoracic Vertebra

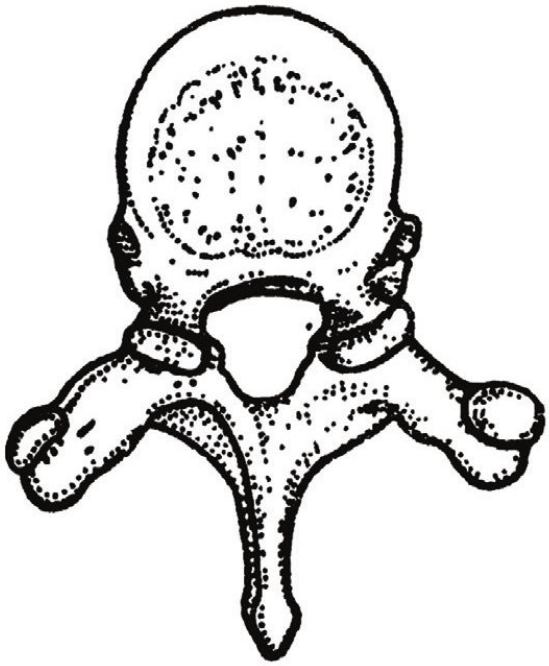


Figure 4.11: A Typical (Lumbar) Vertebra

Atlas (Fig. 4.8): It is the first cervical vertebra consisting of a ring of bone with two short transverse processes. The ring is divided into two parts.

(i) The anterior part is occupied by the odontoid process of the axis which is held in position by a transverse ligament. **(ii)** The posterior part is the vertebral foramen and is occupied by the spinal cord. On its superior surface, it has two facets which form joints with the condyles of the occipital bone. The nodding movements of the head takes place at these joints.

Axis (Fig. 4.9): It is the second cervical vertebra. The body is small and has an upward projecting tooth-like ‘odontoid process’ or the ‘dens’. This process articulates with the atlas (Fig. 4.9).

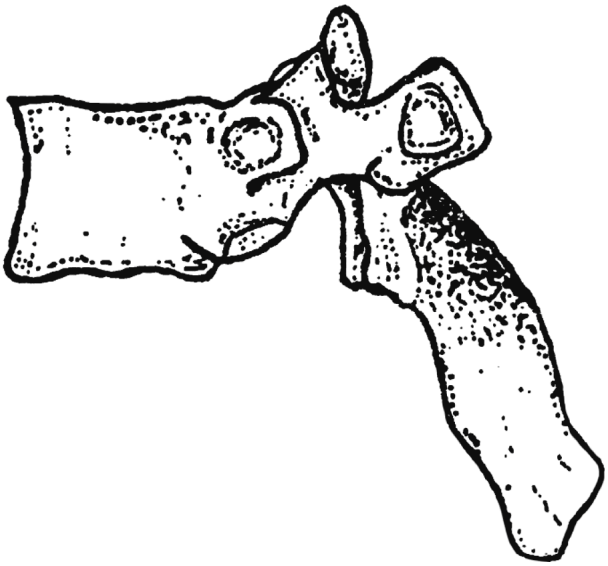


Figure 4.12: Thoratic Vertebra (Viewed from the Side)

Other cervical vertebrae are typical. The seventh cervical vertebra does not have a forked spinous process; its process projects considerably and is, therefore, an important anatomical land-mark.

The Thoracic Vertebrae: They have two special features (Figs. 4.10 and 4.12):

(a) The spinous processes are long and point downwards, so that they partly overlap each other.
(b) Since, the vertebrae articulate with the ribs, they have six facets, out of which four articulate with the ribs. The heads of the ribs lie between the vertebrae, and articulate with one facet on the vertebra above and the other below this vertebra being numbered according to the rib which lies above it.
The Lumbar Vertebrae: The bodies of these vertebrae are largest and the vertebral foramina are smallest. The spinous processes are short, flat-sided and project straight back (Fig. 4.11) giving attachment to the powerful muscles supporting the back.
The Sacral Vertebrae: These are fused together to form one bone known as sacrum (Fig. 4.13). This runs down the back of the pelvis forming a backward curve and the upper projecting curve forming the promontory of the sacrum. The upper part of the base of the bone articulates with the fifth lumbar vertebra. On each side, it articulates with the ilium to form sacroiliac joint and at its inferior tip, it articulates with the coccyx. On each side of the

vertebral foramina, there is a series of foramina, one below the other for the passage of the nerves.

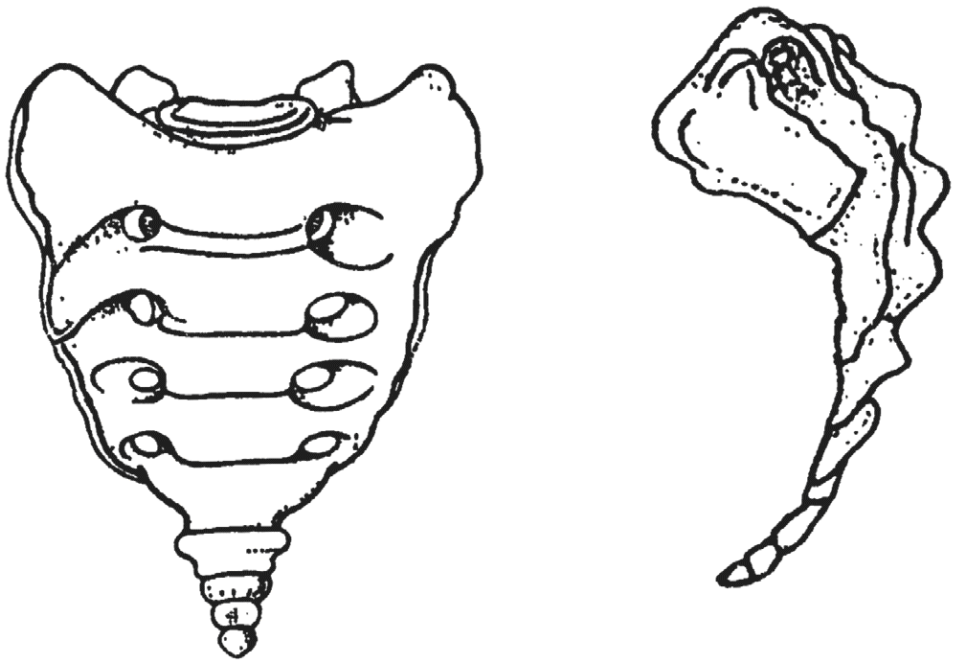


Figure 4.13: The Sacrum and Coccyx

The Coccygeal Vertebrae: Coccyx consists of four terminal vertebrae fused together to form a small triangular bone, the broad base of which articulates with the tip of the sacrum.

The movements of individual bones of the vertebral column are very limited. The movements of the column as a whole which include bending forward, backward, sidewise or turning around are quite extensive. There are more movements in the cervical and lumber regions than elsewhere.

Functions of the Vertebral Column:
(a) It provides a strong bony protection for the delicate spinal cord lying within it. Spinal nerves, blood vessels and lymph vessels pass through intervertebral foramina.

(b) It supports the skull which is protected from shock by the presence of the intervertebral discs.
(c) It forms the axis of the trunk and gives attachment to the ribs, the shoulder girdle and the upper limbs, the pelvic girdle and the lower limbs.

remember

What are regions of vertebral column?

Can yOu tell?

How travelling is related to defects in bones of vertebral column?

The Thoracic Cage

The bones of the thoracic cage (Fig. 4.14) are as follows: 1 sternum; 12 pairs of ribs and 12 thoracic vertebrae.

The Sternum [Fig. 4.15 (a)]: It is a flat bone in the middle of the chest. It is shaped like a dragger and is described in three parts.

1. The manubrium is the uppermost part and presents two articular facets on its lateral borders for articulation with the clavicles.

2. The body or middle portion is called gladiolus. It presents facets on the lateral borders for the attachment of the ribs.

3. The Xiphoid process is the tip of the bone which gives attachment to the diaphragm and muscles of the anterior abdominal wall. The process is also called Xiphisternum. The ribs join the sternum by strips of cartilage.

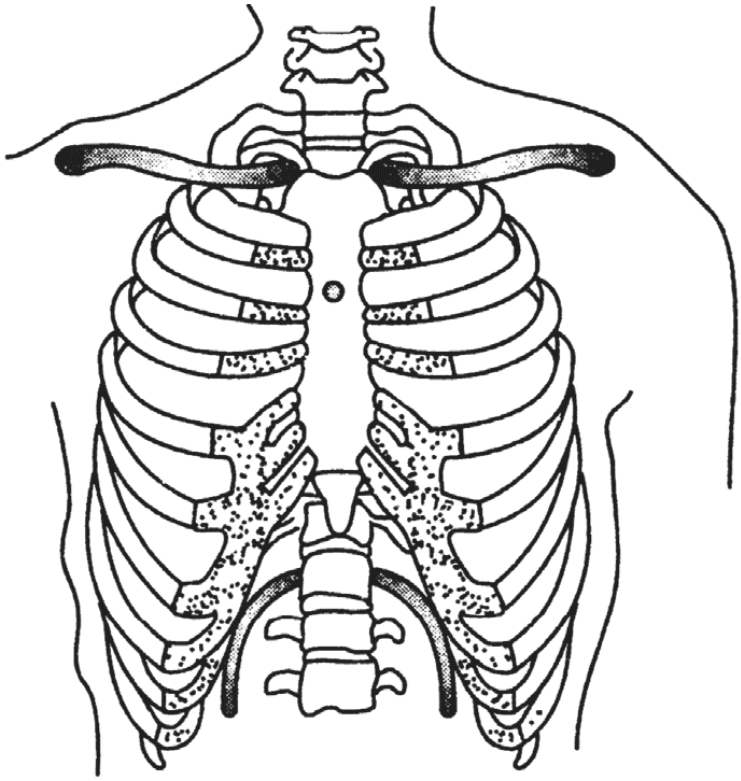


Figure 4.14: The Thoracic Cage

The Ribs [Fig. 4.15 (b)]: There are twelve pairs of ribs which form bony lateral walls of the thoracic cage. The first seven are described as true ribs; the eighth, ninth and tenth are called false ribs and the last two are called floating ribs. All the pairs articulate posteriorly with thoracic vertebrae. Anteriorly, the first seven ribs are directly attached to the sternum; the latter three are only indirectly attached to the sternum and the last two pairs have no anterior attachment.

Each rib is a flat curved bone having a head, neck, tubercle, angle, sternal end, anterior and posterior surface and a superior and inferior border.

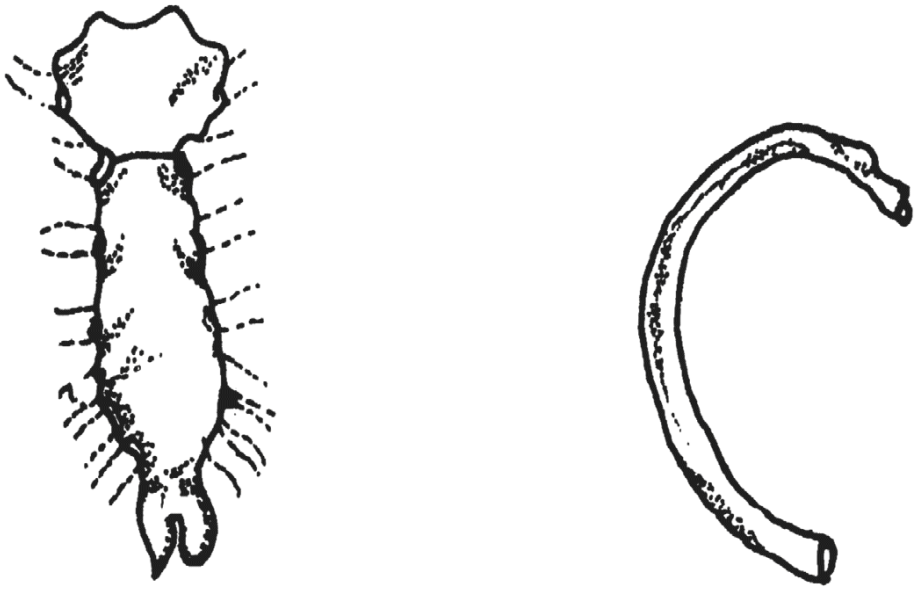


Figure 4.15: Bones of Thoracic Cage

The head articulates posteriorly with bodies of two adjacent vertebrae. The neck is a constricted portion next to head and between the head and the tubercle. The tubercle articulates with the transverse process of thoracic vertebra. The angle is the point at which the bone bends. The sternal end is attached to the sternum by a costal cartilage. The superior border is rounded and smooth while the inferior border exhibits a marked groove occupied by blood vessels and nerves. The first rib does not move during respiration.

Spaces between the ribs are occupied by intercostal muscles. During respiration, when these muscles contract, the ribs and sternum are lifted upwards and downwards increasing the capacity of thoracic cavity. The ribs

increase in size from above to downwards so that the thoracic cavity is roughly coneshaped. The thoracic vertebrae are described earlier.

THE APPENDICULAR SKELETON

It consists of shoulder girdles with upper limbs and pelvic girdle with lower limbs. Each shoulder girdle consists of one clavicle and one scapula. On each side of the shoulder girdle following bones are attached: one humerus, one radius, one ulna, eight carpal bones; five metacarpal bones and fourteen phalanges. (Fig. 4.16)

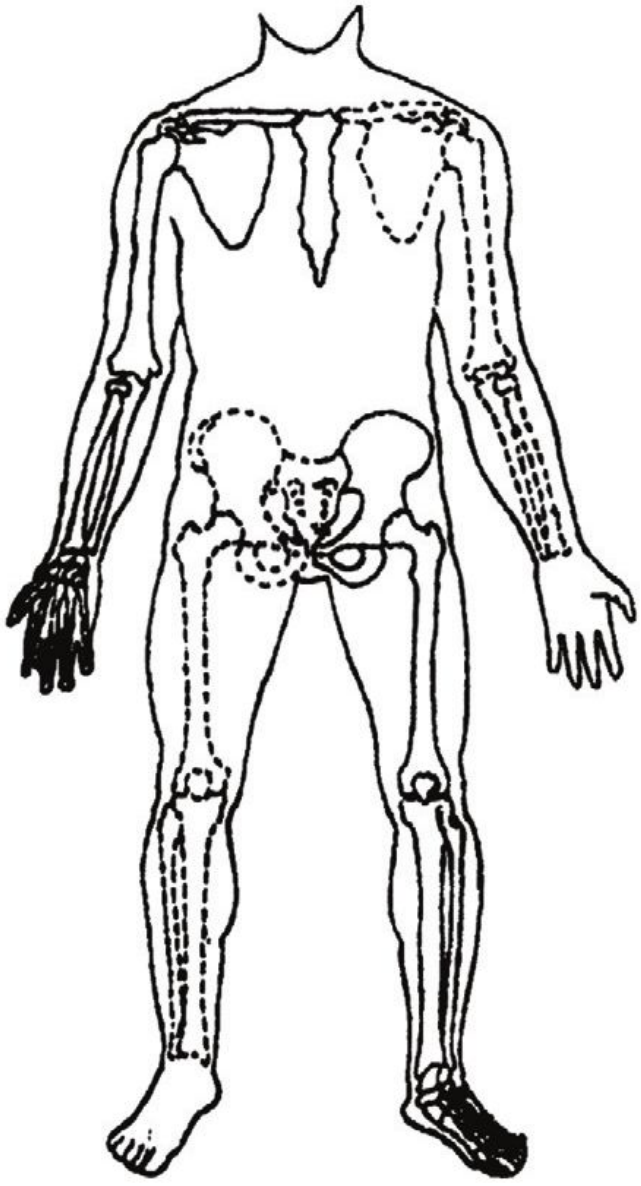


Figure 4.16: The Bones of the Appendicular Skeleton

Fig. 4.17: The Clavicle

Figure 4.18: The Scapula (Posterior View)

Scapula or shoulder blade is a flat triangular bone lying on the posterior chest wall, superficial to the ribs (Fig. 4.18). It is held in place by muscles which attach it to the ribs and the vertebral column. It has three borders called medial, superior and lateral and three angles named as superior, inferior and lateral. Superior and medial borders meet at superior angle and lateral and medial borders meet at inferior angle. The point at which superior, and lateral borders meet at lateral angles represents a shallow articular surface called glenoid cavity which together with the head of the humerus forms the shoulder joint. It has two processes; one of them is

coracoid process which projects forward from the superior border of the bone. The posterior surface of the scapula is divided by a spine.

The spinous process projects beyond the lateral angle as the acromion process and overhangs the shoulder joint. Both these processes give attachment to muscles and keeps the head of humerus in place preventing upward dislocation.

Humerus: It is a long bone and is the largest in the upper limb (Fig. 4.19). It consists of a proximal end or head, neck, shaft and distal end. The head is smooth and rounded and fits into glenoid cavity of the scapula forming the shoulder joint. The neck is a slightly constricted part next to the head. Between the neck and the shaft there are two tubercles called greater and lesser tubercles. These are divided by a deep groove which is occupied by one of the tendons of the biceps muscle. At the proximal end the shaft is cylindrical in shape but is flattened at its anterior and posterior surfaces towards the distal end. The distal end of the bone presents two articular surfaces, the capitulum and the trochlea (Fig. 4.19).

Figure 4.19: The Humerus

Immediately above the articular surface, the anterior side of the bone contains coronoid fossa and the posterior surface contains olecranon fossa (Fig. 4.19). The lower end of the bone also contains two condyles for articulation with the radius and ulna respectively. Above the condyles on either side are median and lateral epicondyles (Fig. 4.19).

Figure 4.20: The Radius and Ulna
Ulna and radius are the two bones of the forearm. There is an interosseous membrane between the bones.

Ulna: This is a long bone consisting of proximal end, shaft and distal end or head (Fig. 4.20). It is located on the inner side of the forearm and is slightly bigger than radius. The proximal end contains a semilunar notch called trochlear notch [Fig. 4.20] which articulates with the trochlea of the humerus. At its proximal end, there is the olecranon process which forms the point of an elbow and fits into the olecranon fossa of the humerus when the arm is straight. At its distal end of the trochlear notch lies the coronoid process which fits into the coronoid fossa of the humerus when the arm is bent. A smaller joint cavity, the radial notch, faces outwards and forms a pivot joint with the head of the radius which rotates against it. This joint produces turning movements of a hand.

Shaft of the bone is triangular in shape and carries a sharp ridge for its attachment to the sheet of fibrous tissue. The lower extremity is much smaller and is joined to a wrist joint by a pad of white fibrous tissue. It also carries a styloid process from the posterior end which gives attachment to ligaments.

Radius: It is a long bone and is the outer bone of a forearm. It consists of head, neck, tuberosity, shaft and distal extremity (Fig. 4.20). The head is disc-shaped and flat on the top and articulates with the capitulum of the humerus.

The circumference of head articulates with the radial notch of ulna. At the upper end of the shaft, there is a radial tuberosity which gives attachment to muscles. The shaft carries a sharp ridge facing ulna. The distal end of the bone is expanded. It articulates with the carpal bones to form a wrist joint and with the ulna to form a radiolunar joint (Fig. 4.20). It also carries a styloid process which is felt at the base of the thumb. It gives attachment to ligaments and muscles.

The **carpal bones** are eight in number and are arranged in two rows each consisting of four bonds (Fig. 4.21). The bones are as follows:

Proximal row: Scaphoid, lunate, triquetrum, pisiform. **Distal row:** Trapezium, trapezoid, capitate, hamate. The upper row forms the wrist joint, articulating with the

radius, and the lower row articulates with the metacarpus. These bones are closely fitted together and held in position by ligaments which allow certain amount of movements between them.

The metacarpal bones or the bones of hand are five in number and form a structure of palm of a hand. Their upper extremities articulate with carpus and the lower extremities with phalanges.

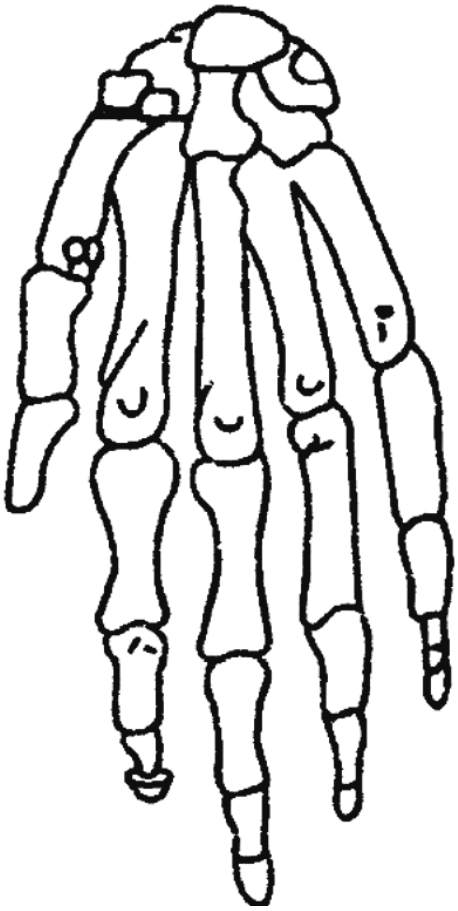


Figure 4.21: The Carpal Bones

Phalanges or bones of the fingers are fourteen in number and are so arranged that there are three in each finger and two in the thumb. The upper end of these bones is the largest and articulates with the corresponding metacarpal bone at one end and with the middle phalanges at the other end. The lower phalanges are the smallest and form tips of fingers.

The Pelvic Girdle and Lower Limb: Bones of pelvic girdle are two innominate bones and one sacrum. The bones of the lower extremity are as follows:

One femur; one tibia; one fibula; one patella; seven tarsal bones; five metatarsal bones and fourteen phalanges.

innominate Bone:
Each of the innominate or the hip bones consists of three bones; ilium, ischium and pubis, fused together to form one large irregular bone (Fig. 4.22). On its outer surface, it has a deep depression called acetabulum with which the head of femur forms the hip joint. Ilium is the upper flattened part of the bone and contains the iliac crest (Fig. **4.22).** Pubis is an anterior part of the bone and articulates with the pubis of the other hip bone at a cartilagenous joint called symphysis pubis. It also contains a large opening called obturator foramen (Fig. 4.22). Ischium is an inferior and posterior part of the bone which contains ischial tuberosity. The external surfaces of the innominate bones are markedly ridged for the attachment of muscles.

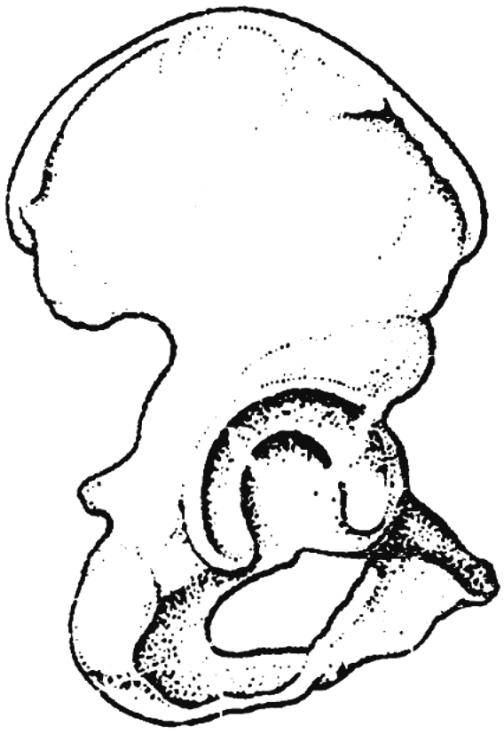


Figure 4.22: The Innominate Bone

Pelvis (Fig. 4.23) is formed by innominate bones which articulate anteriorly with symphysis pubis and posteriorly with sacrum. The two pubic bones join one another in the middle line. It is divided into greater or false pelvis above and lesser or true pelvis below. The ridge of the bone (Fig. 4.23) called the brim of the pelvis is a separating line for these two parts.

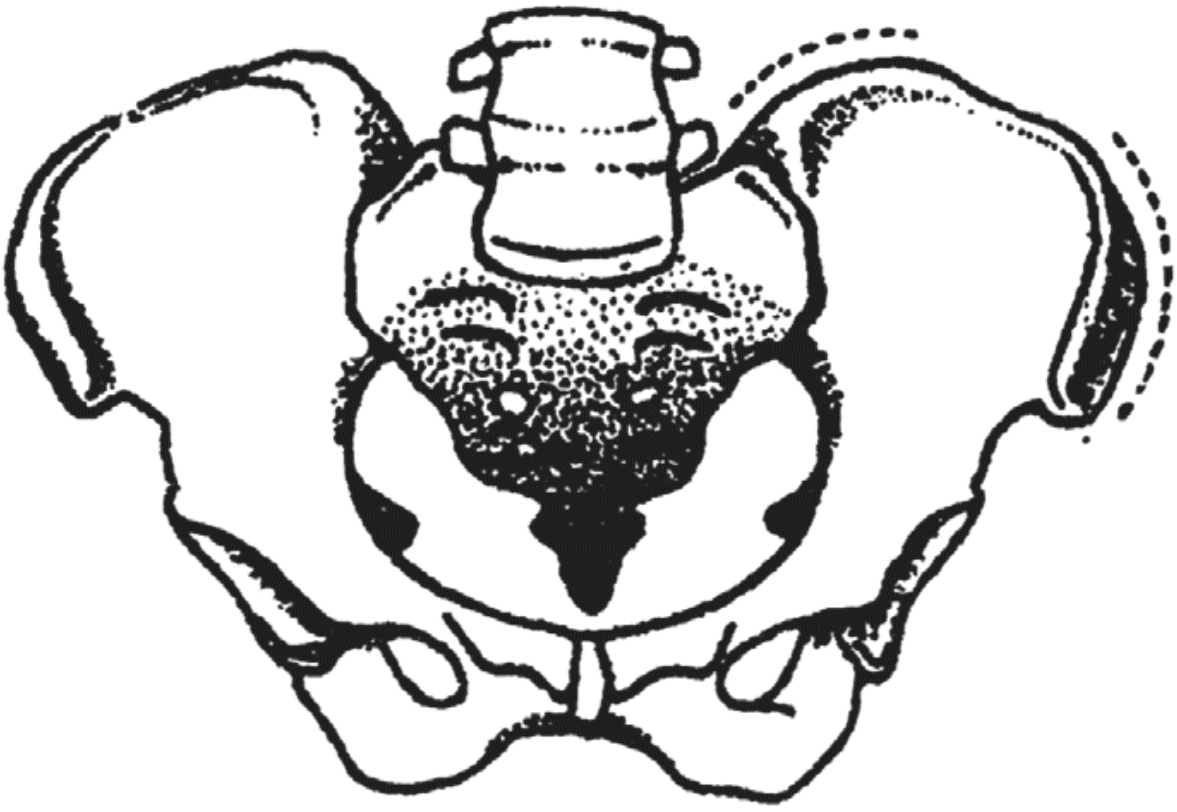


Figure 4.23: The Pelvis

There are distinct differences between pelvis of male and female. They are as follows:

Female
(i) Bones Lighter and smaller
(ii) Cavity Shallow and round
(iii) Sacrum More concave anteriorly, making

the true pelvis broader

(iv) Pubic-arch The angle made at the symphysis pubis is wider. The bones are movable for convenience in delivery

Male
Heavier and longer
Deep and funnel-shaped Less concave, making the true pelvis narrower at the outlet.
The angle of the pubic arch is narrower. The bones are immovable

Femur

Femur or a thigh bone is the longest and strongest of all the bones of the body (Fig. 4.24). Proximal extremity consists of head, neck and greater and lesser trochanters. The head is almost spherical and fits into acetabulum of

the hip bone. Two trochanters and intertrochanteric line (Fig. 4.24) give attachment to muscles which move hip joint.

The shaft of the bone is slightly convex anteriorly and is broader towards its distal end. Posterior surface forms a flat triangular area called popliteal surface. Distal extremity presents two condyles which take part in the formation of a knee joint. Between the condyles, there is a depression called intercondylar fossa.

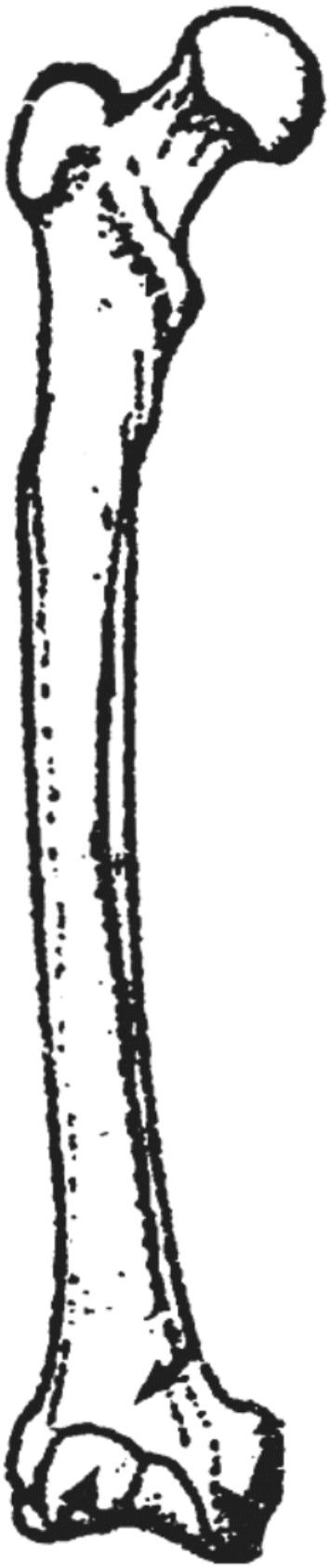


Figure 4.24: The Femur

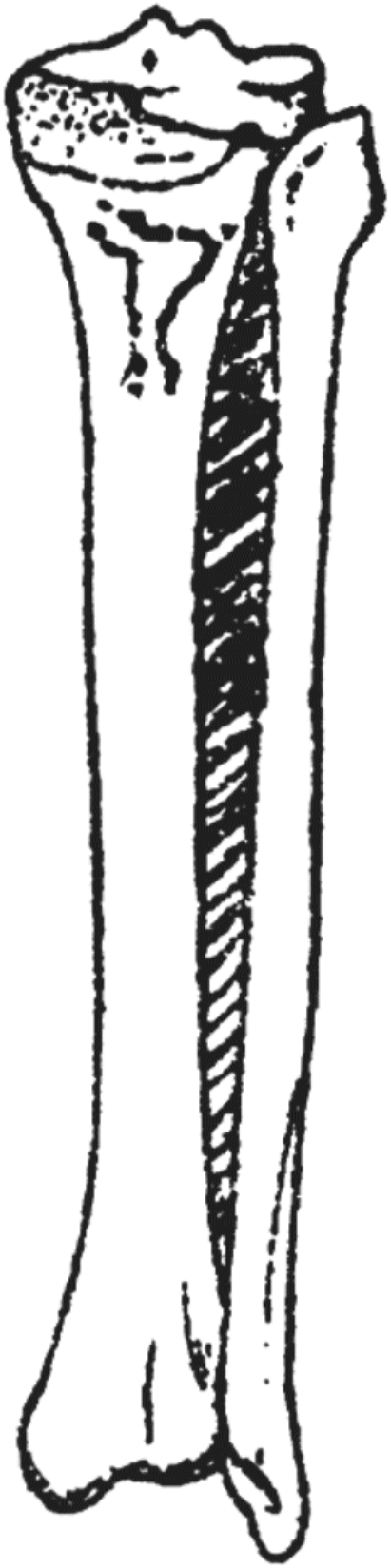


Figure 4.25: The Tibia and Fibula

Tibia

Tibia (Fig. 4.25) is a long bone running on the inner side of a leg. Its upper extremity is broad and thick and has two shallow condyles which receive the condyles of the femur, forming a knee joint. Between these condyles is the intercondylar eminence. On the front side, there is a tuberosity of tibia which gives attachment to muscles. The lateral condyle has a facet which articulates with the head of the fibula. The shaft of the bone is roughly triangular and the surfaces are called medial, lateral and posterior surfaces.

The crest of tibia is a ridge which can be felt very close to the surface on arterior aspect of leg. Distal extremity of tibia forms an ankle joint with talus. Tibia carries a process which projects downwards forming the prominence on the inner side of the ankle joint called the medial malleolus.

Fibula

Fibula is a long slender bone which is lateral to tibia (Fig. 4.25). The head articulates with the lateral condyle of tibia and the lower extremity articulates with its lower extremity and projects further to form lateral malleolus, and takes part in the formation of the ankle joint. The shaft of the bone is ridged for the attachment of muscles.

Patella

Patella or knee cap is a sesamoid (developed in a muscle tendon) bone associated with knee joint. It is roughly triangular and lies with the apex pointing downwards. Its anterior surface is in the patellar tendon and the posterior surface articulates with patellar surface of the femur in the knee joint.

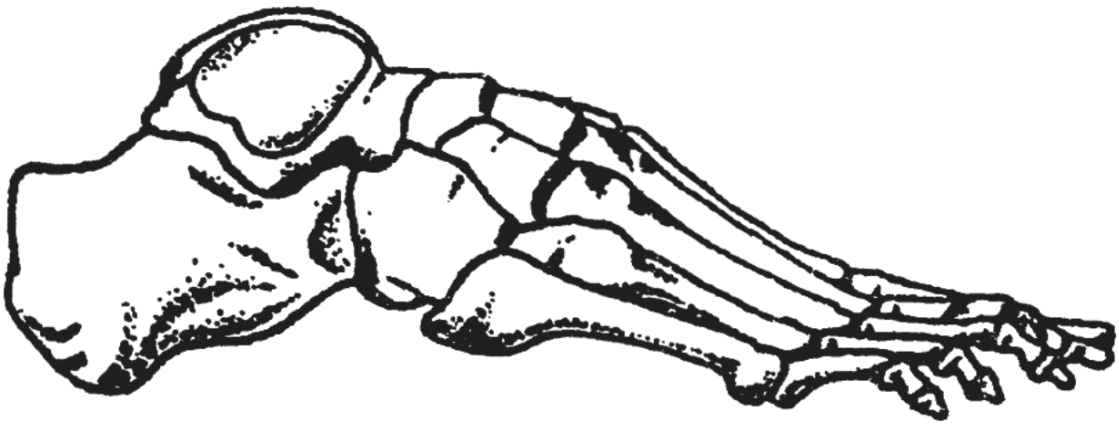


Figure 4.26: The Tarsal Bones

Tarsais

Tarsal or ankle bones (Fig. 4.26) are seven in number and form the posterior part of the foot. The bones are one talus; one calcaneous; one navicular; three cuneiform and one cuboid.

Talus articulates with tibia and fibula at the ankle joint. Calcaneous or heel bone is roughened for the attachment of muscles. Navicular is situated on the medial side of the foot distal to talus (Fig, 4.26). The medial, intermediate and lateral cuneiform and cuboid form a row of bones (Fig. 4.26) which articulate with the other three tarsal bones proximally and with the five metatarsal bones distally. The metatarsal bones are five in number. Their proximal ends articulate with the tarsal bones and the distal ends with phalanges. There are fourteen phalanges in each foot, two in the great toe and three each in other toes.

The arrangement of bones of a foot is such that it is not a rigid structure. The bones have a bridge-like arrangement and are supported by muscles and ligaments so that four arches such as medial longitudinal, lateral longitudinal and two transverse arches are formed.

inventiOn, updatiOn

Which is the longest and strongest bone of human body?

THE JOINTS

A joint is the site at which any two or more bones come together. The joints are classified as fibrous, cartilagenous and synovial. In fibrous or fixed joint,

there is no movement between the bones concerned. There is a fibrous tissue between their ends e.g., the joints between the bones of the skull and the joints between the teeth and the maxilla and mandible. In cartilagenous joints, there is a pad of white fibrocartilage between the ends of the bones. Movement is possible because of the compression of the pad of cartilage, e.g. symphysis pubis and joints between the bodies of the vertebrae.

Synovial joints are characterized by the presence of synovial membrane. A considerable amount of movement is possible. Limitations on movement is mainly due to the shape of the bony surface which forms the joint. They are subdivided according to the movements possible.
1. *Ball and Socket Joint:*A hemispherical head fits into a cupshaped socket e.g., shoulder and hip.

2. *Hinge Joints:* These joints allow movement in one direction only, e.g. elbow, knee and ankle.
3. *Double Hinge Joints (Condyloid):* These allow movement like a hinge in two directions, e.g. the wrist joints and the joints between metacarpus or metatarsus and the phalanges.
4. *Gliding joints:* The bones glide on one another, e.g. between various carpal and tarsal bones.
5. *Pivot joints:* One bone turns on another e.g., the radius on the ulna at the elbow and the atlas on the axis.
Some of the joints are capable of the following types of movements:
1. Flexion or bending, usually forward but occasionally backward.
2. Extension means strengthening or bending backward.
3. Abduction is the movement away from midline of the body.
4. Adduction is the movement towards midiine of the body.
5. Rotation is the movement round the long axis of a bone.
6. Pronation means turning the palm of the hand down.
7. Supination means turning the palm of the hand up.
8.Circumduction is the combination of flexion, extension, abduction, and adduction. It involves movements of the limbs through a circle.
9. Inversion is the turning the sole of the foot inwards. **10.** Eversion is turning the sole of the foot outward.

Different types of joints help to make different kinds of movements. The ball-and-socket joints are freely movable allowing flexion and extension,

abduction, adduction, circumduction and external and internal rotation. The hinge joints allow flexion and extension only. Double hinge joints allow flexion, extension, adduction, abduction and circumduction. In the gliding joints, there is only a slight movement increasing the range of movement in all directions. The pivot joints permit rotation around the point where they are pivoted.

The joints are movable, but the movements are carried out by the various muscles. The muscles also run from bone to bone and help to hold the bones in position and give support to the joint capsule, as long as the normal tone is sustained.

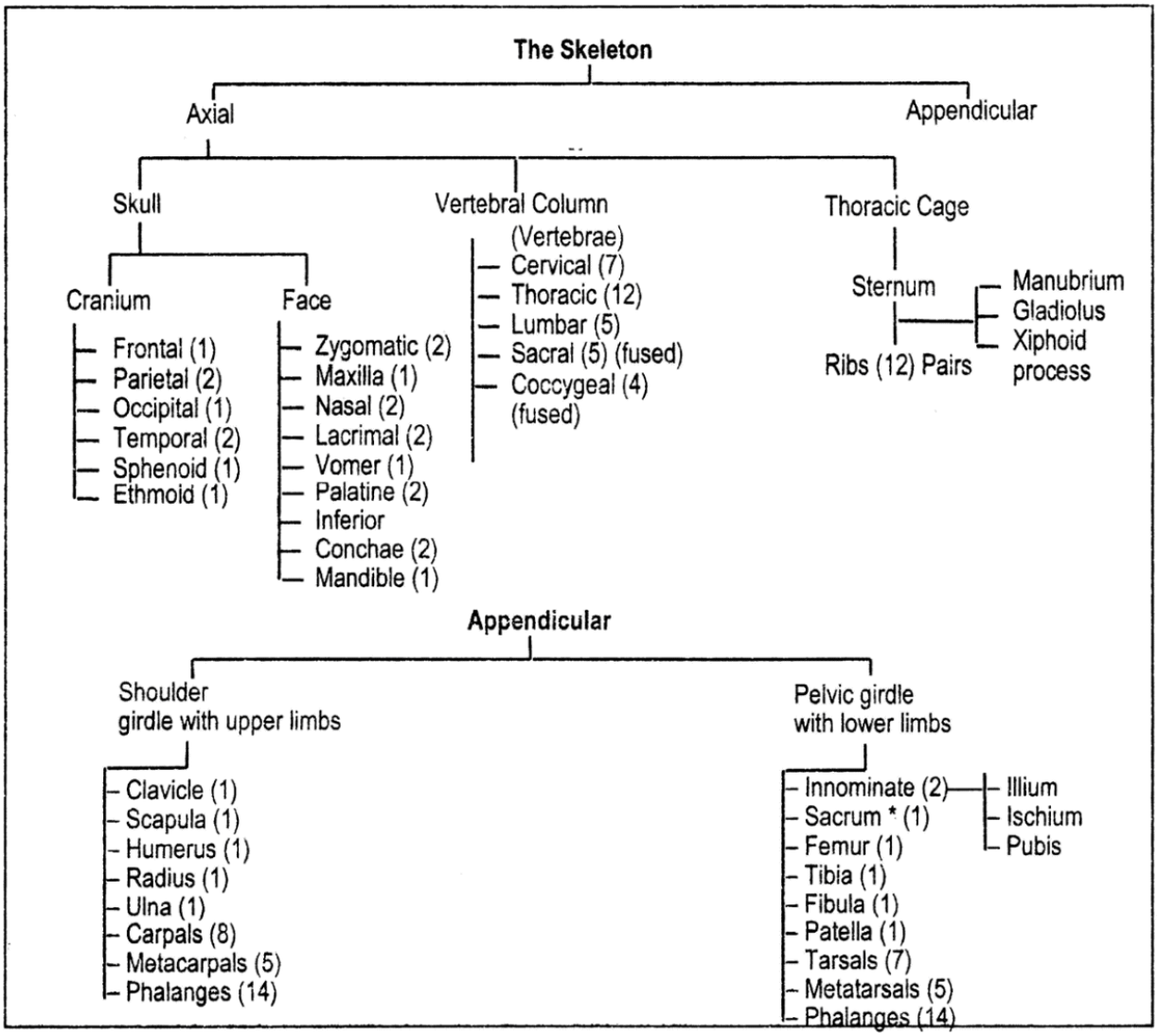
Disorders of joints: Any or all of the structures of joints may be damaged by disease.
Inflammation of the joints is called arthritis. Arthritis is of two types; acute and chronic.
(a) Acute Arthritis: In Rheumatic arthritis, there is an acute synovitis with the excess of turbid fluid in the joint. Extreme tenderness is the characteristics of a swollen and acutely inflammed joint. In the case of traumatic synovitis, the inflammation is confined to the synovial membrane without any destruction of tissue.
(b) Chronic Arthritis: There are various types of chronic arthritis. Tuberculous arthritis is a disease very common in children. When it occurs in an adult, it is more likely to be primary in the synovia! membrane. The synovial fluid is usually scanty but highly fibrous so that it contains flakes of fibrin which may develop into foreign bodies. Rheumatoid arthritis is a common, tragic and crippling disease particularly affecting small joints of hands and feet; the larger joints may affect later. It causes pains and swelling of the joints together with increasing stiffness and disability. In the later stages, the joints become distorted and deformed. During this condition, the patient may suffer from mild fever, anemia, sweating etc. Osteoarthritis involves degeneration of articular cartilage and bone. This is a disease which normally occurs in the old age. Large joints are commonly affected, very often only one joint, i.e., particularly the hip joint. Gout is yet another disease involving joints. The disease involves over-production of uric acid which is deposited in the joint and the surrounding soft tissues. The deposits occur in the synovial membrane and capsule. Kidneys may also suffer from the deposits.

The intervertebral disc also can be a site of disorder. The disc may be protruded or herniated into the vertebral canal and press the spinal cord or stretch the nerves. The disorder causes low back pain and sciatica or pain passing down the back of the leg along the course of the sciatica nerve.
A few other dysfunctions related to the joint may occur. If the bone from a joint is displaced, the condition is called dislocation. Individuals especially women past middle age, are frequently depleted of calcium. Bones of such individuals lack in calcium and therefore become relatively more fragile. This condition is called osteoporosis.

g.K.

What is arthritis?

SKELETON IN A NUTSHELL



* Sacrum shown as a part of pelvic girdle also forms part of the vertebral column.

Questions for study

1. Name the bones in the appendicular skeleton. Describe a shoulder joint.
2.Differentiate between male and female pelvic girdle.
3. Name the bones of axial skeleton.
4.Define skeleton, bone and articulation (Joint). Classify the bones with suitable examples.
5. Classify the joints with examples of each class.
6. Name the primary and secondary curves of vertebral column. Describe each.

7. What are the functions of bones?
8. Explain the features and functions of vertebral column. **9.** What is dislocation?
10. What is osteoporosis and rheumatic disorder?
11. Describe the structure and functions of typical synovial joint. **12.**Discuss characteristics and different types of synovial joint.

5

Hematopoietic System

HEMATOPOIETIC SYSTEM

The **hematopoietic system** is formed by bodies responsible for haematopoiesis, or the production of the cellular elements of blood: **red blood cells, white blood cells** and **platelets.** During embryonic development, this function is performed mainly in the spleen, liver and bone marrow, and after the birth the production of these elements is performed mainly by the bone marrow and the lymph nodes. The cellular elements supply oxygen (red blood cells), initiate coagulation (platelets), and protect against microbes and antigens (white blood cells). The **hematopoietic organs** together form a system through which the body produces red blood cells, white blood cells and platelets, that is, the so-called elements of the blood. The red blood cells **(erythrocytes)** constitute the largest portion of blood cells. They have a biconcave shape and a flexible membrane, which enables the red blood cells to change shape without breaking when passing through narrow blood vessels or capillaries. The number of red blood cells varies from person to person according to age, gender, and overall health. The white blood cells **(leukocytes)** are present in various forms and each type of leukocyte is somewhat essential to the immune system. These cells help the body fight infections and inflammations, and they produce antibodies. Platelets are the third category of blood cells and they are the smallest of the blood cells. They are formed from a bone marrow cell known as the megakaryocyte. Platelets are responsible for starting the repair process of

small, damaged blood vessels and produce substances that are essential to coagulation. The main producer of these elements is the bone marrow, in particular that located inside the vertebrae, sternum, ribs and shoulder blades. Among the white blood cells, however, the lymphocytes are produced especially at the level of the lymph glands, small spherical structures localized in different parts of the body. Some experts believe that the hematopoietic system also includes another element, the **reticule endothelial tissue,** distributed throughout the body.

Composition of Blood
Blood Plasma is the straw colored liquid portion of the blood.

92% is composed of water and the rest 8% is made up of plasma proteins. It is mostly composed of dissolved proteins, mineral ions, glucose, clotting factors and carbon dioxide. It circulates dissolved nutrients (amino acids, fatty acids and glucose) and removes waste products (carbon dioxide, lactic acid and urea) from the body. Other components of blood plasma are serum albumin, lipoprotein particles, immunoglobulins, electrolytes, etc.

Function of Blood

• Supplies oxygen and nutrients to different tissues of our body.
• Removes waste products like, urea, lactic acid and carbon dioxide from our body.
• Provides immunity to body against foreign particles.
• Helps in transportation of hormones throughout the body.
• Aids in blood clotting which is a natural repair mechanism of cells.
• Regulates and maintains normal temperature in our body.
• Maintains pH balance inside the body.
• The components of blood help in homeostasis.

The pH of blood lies in the range of 7.35 to 7.45, which is necessary for its normal functioning.
Plasma

The watery fluid portion of blood (90 percent water) in which the corpuscular elements are suspended. It transports nutrients as well as wastes throughout the body. Various compounds, including proteins, electrolytes, carbohydrates, minerals and fats are dissolved in it.

Albumin
It is formed in the liver. It is the most abundant plasma protein

and its main function to maintain the osmotic pressure of about 25 mm Hg.
Globulin

Some of them are formed in the liver and some in lymphoid tissue. They are associated with the following functions:
• The immune response to the presence of antigens.
• Transportation of some hormones and minerals salts, e.g. thyroid hormones, iodine, iron and copper.
• Inhibition of some proteolytic enzymes, e.g. trypsin, chymotrypsin.

CLOTTING FACTORS

The clotting factors are the group of chemicals that are constant circulation in the blood or present in tissues of the blood vessels. These compounds are responsible for the formation of a blood clot. Clotting factors are usually inactive but once there is tissue injury to the wall of the blood vessel, the first factor is activated. This has a cyclical effect with each factor activating the next. The ultimate aim is for these clotting factors to eventually convert the necessary components that will form a blood clot.

Factor number I
II
III
IV
V
VI
VII
VIII

IX
X
XI
XII
XIII

Fibrinogen

Alternative name Fibrinogen
Prothrombin
Thromboplastin
Calcium
Proaccelerin
Unassigned
Proconvertin
Antihemophlic factor
Plasma thromboplastin
Stuart-Prower factor
Plasma thromboplastin antecedent Hageman factor
Fibrin stabilizing factor

Fibrinogen is one of 13 coagulation factors responsible for normal blood clotting. When you start to bleed, your body initiates a process called the **coagulation cascade,** or **clotting cascade.** This process causes coagulation factors to combine and produce a clot that will stop the bleeding.

Nutrients

Post-digestion food is converted into monosaccharides amino acids, fatty acids and glycerol. Vitamins along with minerals are required by all body cells to provide energy, heat, materials, for repairs and replacement and for the synthesis of the other blood components and body secretion.

Organic Waste Products
Urea, creatinine and uric acid are the waste products of protein

metabolism. They are formed in the liver and transported to the kidney via. blood for secretion. Carbon-dioxide, excreted by all cells, is sent to the lungs

for excretion.

Hormones
These are chemical secretion originating from endocrine glands

poured directly into the blood stream to be carried to the target tissues and organ.
Antibodies
These are protective substances consisting of protein, produced by lymphoid cells to produce protective antibodies. Gases

Oxygen, carbon dioxide and nitrogen are transported in the body through plasma. Oxygen and carbon-dioxide are transported in combination with haemoglobin in red blood cells.

CELLULAR COMPONENTS OF THE BLOOD

The formed elements are cells and cell fragments suspended in the plasma. The three classes of formed elements are the erythrocytes (red blood cells), leukocytes (white blood cells), and the thrombocytes (platelets).

Erythrocytes (Red Blood Cells)

Erythrocytes, or red blood cells, are the most numerous of the formed elements. Erythrocytes are tiny biconcave disks, thin in the middle and thicker around the periphery. The shape provides a combination of flexibility for moving through tiny capillaries with a maximum surface area for the diffusion of gases. The primary function of erythrocytes is to transport oxygen and, to a lesser extent, carbon dioxide.

Leukocytes (White Blood Cells)

Leukocytes, or white blood cells, are generally larger than erythrocytes, but they are fewer in number. Eventhough they are considered to be blood cells, leukocytes do most of their work in the tissues. They use the blood as a transport medium. Some are phagocytic, others produce antibodies; some secrete histamine and heparin, and others neutralize histamine. Leukocytes are able to move through the capillary walls into the tissue spaces, a process called diapedesis. In the tissue spaces they provide a defense against

organisms that cause disease and either promote or inhibit inflammatory responses.

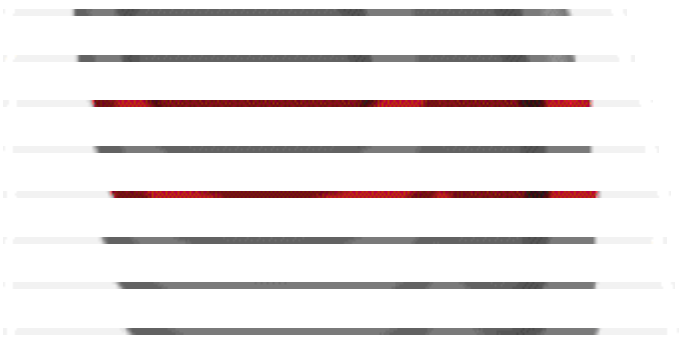
There are two main groups of leukocytes in the blood. The cells that develop granules in the cytoplasm are called granulocytes and those that do not have granules are called agranulocytes. Neutrophils, eosinophils, and basophils are granulocytes. Monocytes and lymphocytes are agranulocytes.

Neutrophils, the most numerous leukocytes, are phagocytic and have light-colored granules. **Eosinophils** have granules and help counteract the effects of histamine. Basophils secrete histomine and heparin and have blue granules. In the tissues, they are called mast cells. Lymphocytes are agranulocytes that have a special role in immune processes. Some attack bacteria directly others produce antibodies.

Thrombocytes (platelets)
Thrombocytes, or platelets, are not complete cells, but are small fragments of very large cells called megakaryocytes. Megakaryocytes develop from hemocytoblasts in the red bone marrow. Thrombocytes become sticky and clump together to form platelet plugs that close breaks and tears in blood vessels. They also initiate the formation of blood clots.

Development and Life Span of RBC’s

Erythrocytes are formed in red bone marrow, present in the ends of the long bones and in the flat and irregular bones. Their life span is about 120 days and they pass through the various stages of developments during this period. This process of development of RBC’s from haemocytes take about 7 days and is also called as erythropoiesis.



Process by which RBCs are formed. In the factors RBC are formed in the liver, spleen and red bone marrow. After birth, they are formed only in the red bone marrow of sternum ribs vertebrae.

Stages in the development of RBCs

Proerythroblast

Erythroblast

Reticulocyte

Erythrocytes (RBCs)

Proerythrocytes
It is a large cell having a nucleus. It does not have hemoglobin initially. In the better stages hemoglobin starts appearing.

• **Erythroblast/ Normoblast:** it is the 2nd stages. It is a smaller cell degenerated nucleus. But hemoglobin is fully present.
• **Reticulocytes:** develops from normoblast. It contains hemoglobin and reticulum in the cytoplasm.
• **Erythrocytes:** which is fully developed RBCs. It does not contain reticulum but contain adequate hemoglobin. Both vit B12 and folic acid are necessary for the development of RBCs.

HEMATOPOIESIS

Hematopoiesis is the production of all of the cellular components of blood and blood plasma. It occurs within the hematopoietic system, which includes organs and tissues such as the bone marrow, liver, and spleen. Hematopoiesis begins during the first weeks of embryonic development. All blood cells and plasma develop from a haemopoietic stem cell (HSC), reside in the medulla of the bone (bone marrow). Bone marrow is spongy gelatinous tissue found in hollow spaces in the interior of bones. In children hemopoiesis occurs in long bones femur & tibia. In adults bone marrow occurs in mostly pelvis, cranium, vertebra & sternum. Haemopoietic stem cells having power of self-replication. Also, these stem cells having power of differentiation.

• The process of blood cell formation is called as hemopoieses. Bone marrow is highly vascularized connective tissue located in bone marrow.
• Blood cell are synthesized mainly in red bone marrow some lymphocytes are produced in lymphoid tissue.
• All blood cells originate from pluripotent stem cells and go through several development stages before entering the blood.
• Different types of blood cell follow separate lines of development.

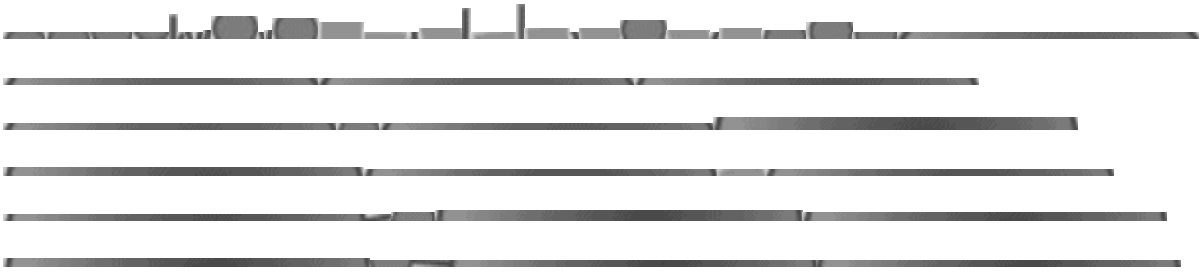
• The process of development of red blood cells from stem cell take about 7 days and is called erythropoiesis.
• In order to form blood cells, pluripotent stem cells produce 2 types of stem cells:

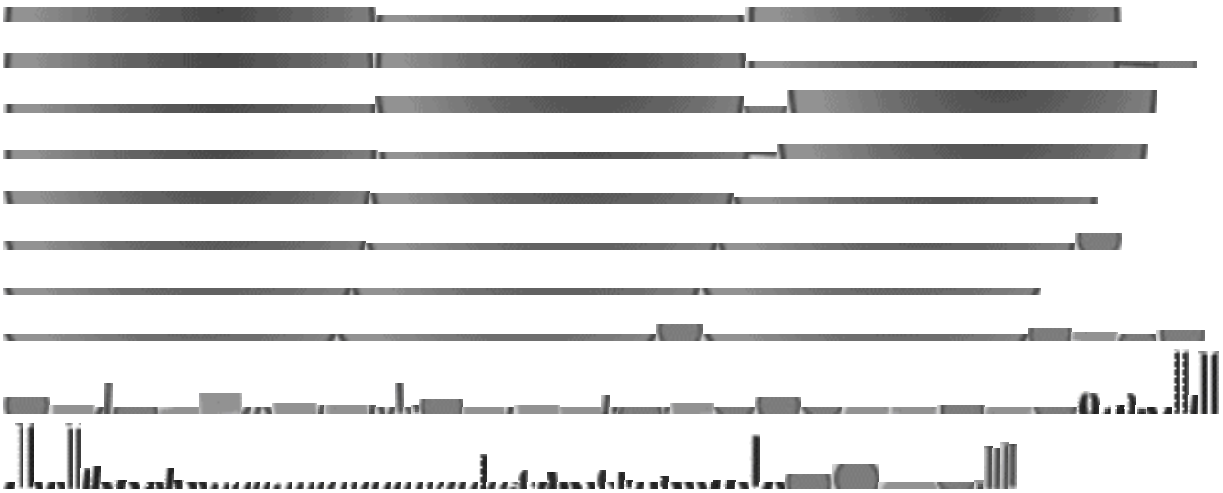
• Myeloid stem cells: development in red bone marrow and give rise to red blood cells, platelets, monocytes, neutrophils, eosinophils, basophils.
• Lymphoid stem cells: development in red bone marrow but complete it is lymphatic tissue they give rise to lymphocytes.

• Some progenitor cells are known as colony forming unit.
• CFU-E ultimately produce erythrocytes, CFU-Meg produces megakaryocytes and CFU-GM produces granulocytes (neutrophils and monocytes).
• In the next generation the cells are called as precursor cells also known as blasts.
• Mono blast develops into monocytes, eosinophils myeloblast develop into eosinophils and soon.
• EPO Erythropoietin increases the no of red blood precursor.
• Thromboplastin is a hormone by the liver that stimulate the formation of thrombocytes from megakaryocytes.
• Several different cytokines regulate the development of different blood cell types.

BLOOD GROUPS

Red blood cells (erythrocytes) have certain proteins on their surface, called antigens. Also, your plasma contains antibodies which will attack certain antigens if they are present. ABO and rhesus are both types of antigens found on the surface of red blood cells. There are lots of other types but these are the most important.





ABO blood types

• If you have type A antigens on the surface of your red blood cells, you also have anti-B antibodies in your plasma.
• If you have type B antigens on the surface of your red blood cells, you also have anti-A antibodies in your plasma.
• If you have type A and type B antigens on the surface of your red blood cells, you do not have antibodies to A or B antigens in your plasma.
• If you have neither type A nor type B antigens on the surface of your red blood cells, you have anti-A and anti-B antibodies in your plasma.

Rhesus types

Most people are ‘rhesus positive’. This means they have rhesus antigens on their red blood cells. But, about 3 in 20 people do not have rhesus antibodies and are said to be ‘rhesus negative’.

• A+ (A positive) if you have A and rhesus antigens.
• A– (A negative) if you have A antigens but don’t have rhesus antigens.
• B+ (B positive) if you have B and rhesus antigens.
• B– (B negative) if you have B antigens but don’t have rhesus antigens.
• AB+ (AB positive) if you have A, B and rhesus antigens.
• AB– (AB negative) if you have A and B antigens but don’t have rhesus antigens.
• O+ (O positive) if you have neither A nor B antigens but you have rhesus antigens.
• O– (O negative) if you don’t have A, B or rhesus antigens.

Mechanism of Coagulation

• It is a sequence of responses that stop bleeding.

• This mechanism reduced blood loss when blood vessels are damaged are ruptured.
• Vascular system (spasm), platelet plug, formation and blood clotting.
• When successful, hemostatic prevents hemorrhage.
• Vascular spasm: in this, the smooth muscle of blood vessels wall contracts which slow blood loss due to release activated platelets.
• Platelet plug: platelet adhesion, platelet stick to damaged blood vessels.
• Platelet release reaction.
• Platelet aggregation.
• Blood clotting: A clot is a network of insoluble protein fibres (fibrin) in which formed element of blood trapped.
• Clotting involves several substances known as clotting factor (coagulation). This factor includes Ca^{2+} ions, several inactive enzymes (synthesized by liver cells and release into the bloodstream). And various molecules associated with platelets or released by damaged tissue.

Disorder of Blood

Major disorders of blood are:

1. Anaemias
2. Leukaemias
3. Thalassemia
4. Lymphoma
5. Myelodysplastic syndrome (MDS)
6. Polycythemia:

• Lymphoma is a blood cancer that occurs in the body's lymphatic system. Your white blood cells change and grow out of control. Hodgkin's lymphoma and nonHodgkin's lymphoma are the two major types of lymphoma.
• Leukemia is blood cancer in which malignant white blood cells multiply inside your body's bone marrow. Leukemia may be either acute or chronic. Chronic leukemia advances more slowly.
• Myelodysplastic syndrome (MDS) is a condition affecting the white blood cells in your bone marrow. The body produces too many immature cells, called blasts. The blasts multiply and crowd out the mature and healthy cells.

Myelodysplastic syndrome may progress either slowly or quite fast. It sometimes leads to leukemia.
• Thalassemia is a group of inherited blood disorders. These disorders are caused by genetic mutations that prevent the normal production of hemoglobin. When red blood cells do not have enough hemoglobin, oxygen does not get to all parts of the body. Organs then do not function properly. These disorders can result in bone deformities, enlarged, heart problems, growth in children.
• Polycythemia is a blood cancer caused by a gene mutation. If you have polycythemia, your bone marrow makes too many red blood cells. This causes your blood to thicken and flow more slowly, putting you at risk for blood clots that can cause heart attacks or strokes. There is no known cure. Treatment involves phlebotomy, or removing blood from your veins, and medication.

Questions for study

1. Write composition and function of blood.
2. Discuss ABO and Rh factor of blood group.
3. Define the terms:
(a) Polycythaemias
(b) Thalassemia
(c) Anaemia
(d) Leukaemia

6

The Lymphatic System

The lymphatic system consists of three parts (1) network of lymphatic vessels, (2) lymph and (3) lymph nodes. The lymph nodes cleanes the lymph as it passes through them. In addition to them there are lymphoid organs and tissues in the body which include spleen, thymus, tonsils and other lymphoid tissues scattered throughout the body. The lymphoid organs house phagocytic cells and lymphocytes, which play an important role in the body’s defense mechanism and its resistance to disease. Together, the

lymphatic system and the lymphoid organs and tissues provide the structural basis of the immune system.

COMPOSITION OF LYMPH

Lymph consists of plasma and lymph corpuscules which are mainly lymphocytes. RBCs and platelets are not present in lymph. The composition of plasma is similar to that of blood plasma.

FUNCTIONS OF LYMPH
The major function of the lymphatic system is to drain body fluids and return them to the bloodstream.

• Lymph nodes produce lymphocytes which protect body from infections.
• It carries waste products from tissues to the blood.
• It transports dietary fats from the gastrointestinal system.

STRUCTURE OF THE LYMPHATIC SYSTEM
The lymphatic system comprises of lymphatic vessels, lymphatic capillaries and lymph nodes.
Lymphatic capillaries

They are single layer of endothelial cells like blood capillaries and begin as blind end tubes. Lymphatic capillaries are also called terminal lymphatics, as they are the vessels where the interstitial fluid enters the lymphatic system to become lymph fluid. They are present everywhere in the body except in central nervous system, bone marrow, teeth, bones, and the cornea of the eye.

Lymphatic Vessels

The lymphatic capillaries join together to form a mesh of network of tubes. These tubes join together to form larger structures called lymphatic vessels. They are similar to veins in terms of having three layers and presence of valves.

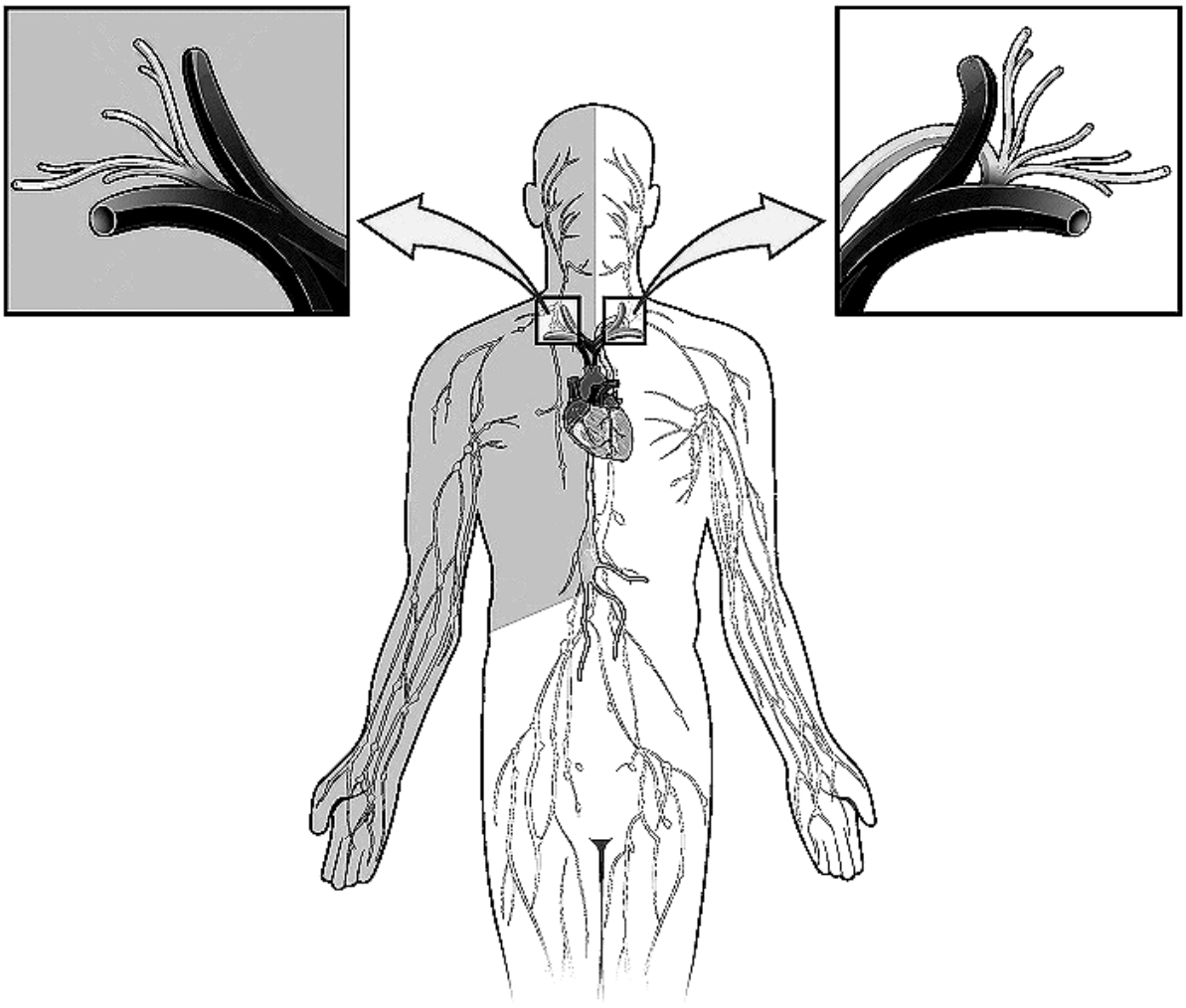
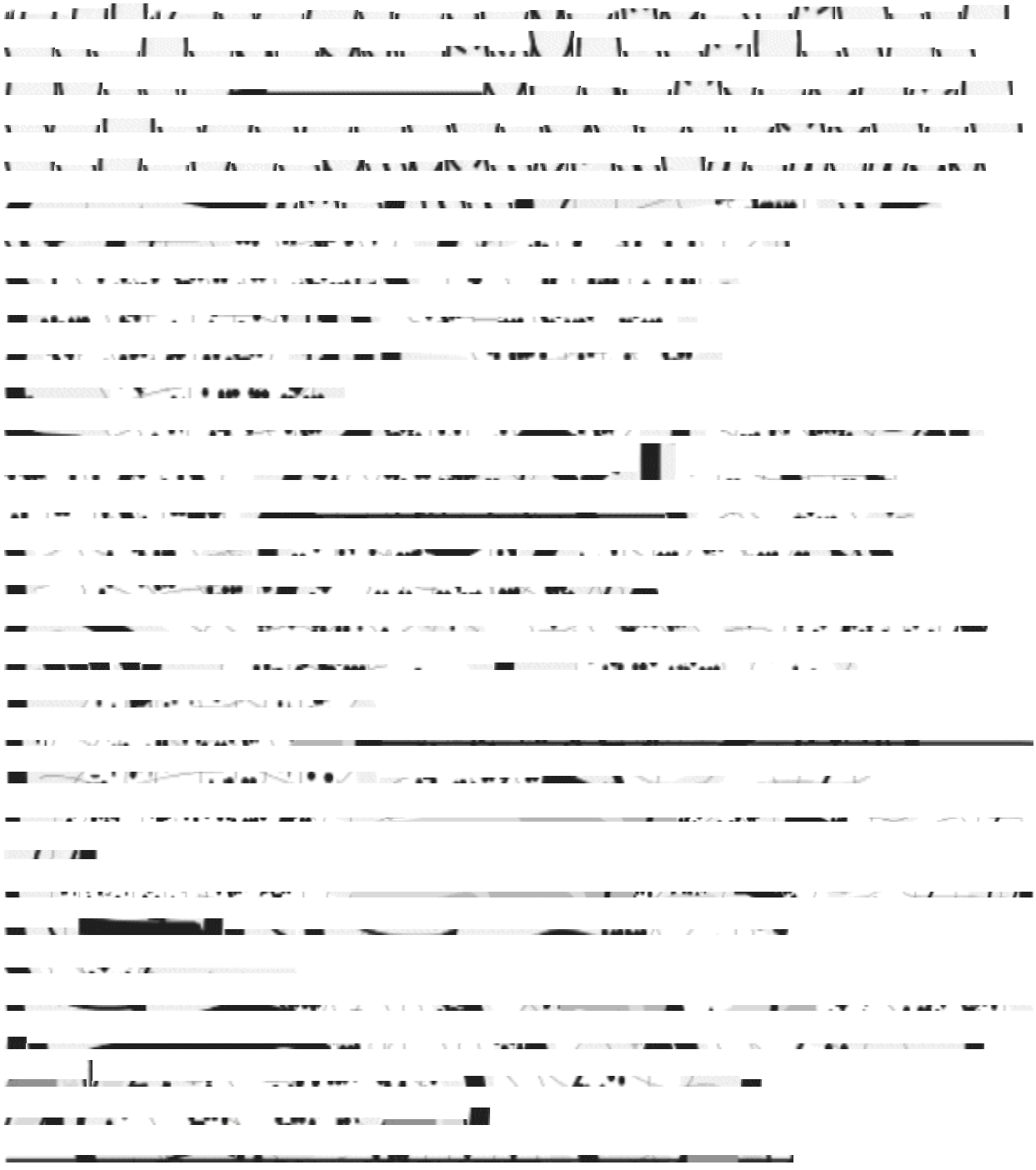


Figure 6.1: Major Trunks and Ducts of the Lymphatic System **Source: https://cnx.org/content/col 11496/**

As they converge, these lymphatics eventually merge to form larger lymphatic vessels called as lymphatic trunks. These lymphatic trunks merge together to form two major Lymphatic Ducts, right lymphatic duct and thoracic duct. The right lymphatic duct receives the lymph from the right side of the body (right sides of the head, thorax, and right upper limb) and drains into the right subclavian vein. The lymph from the remaining portions of the body are drained into the left subclavian vein via thoracic duct. Thoracic duct begins just below the diagpharm and receives the lymph from the lower abdomen, pelvis, and lower limbs by way of the left and right lumbar trunks and the intestinal trunk.

The overall drainage system of the body is asymmetrical. Lymph Nodes

Lymph nodes are found throughout the lymphatic system. These nodes are connected with the lymphatic vessels which allow the movement of fluid through them. They work as filters and remove pathogens such as viruses and bacteria.



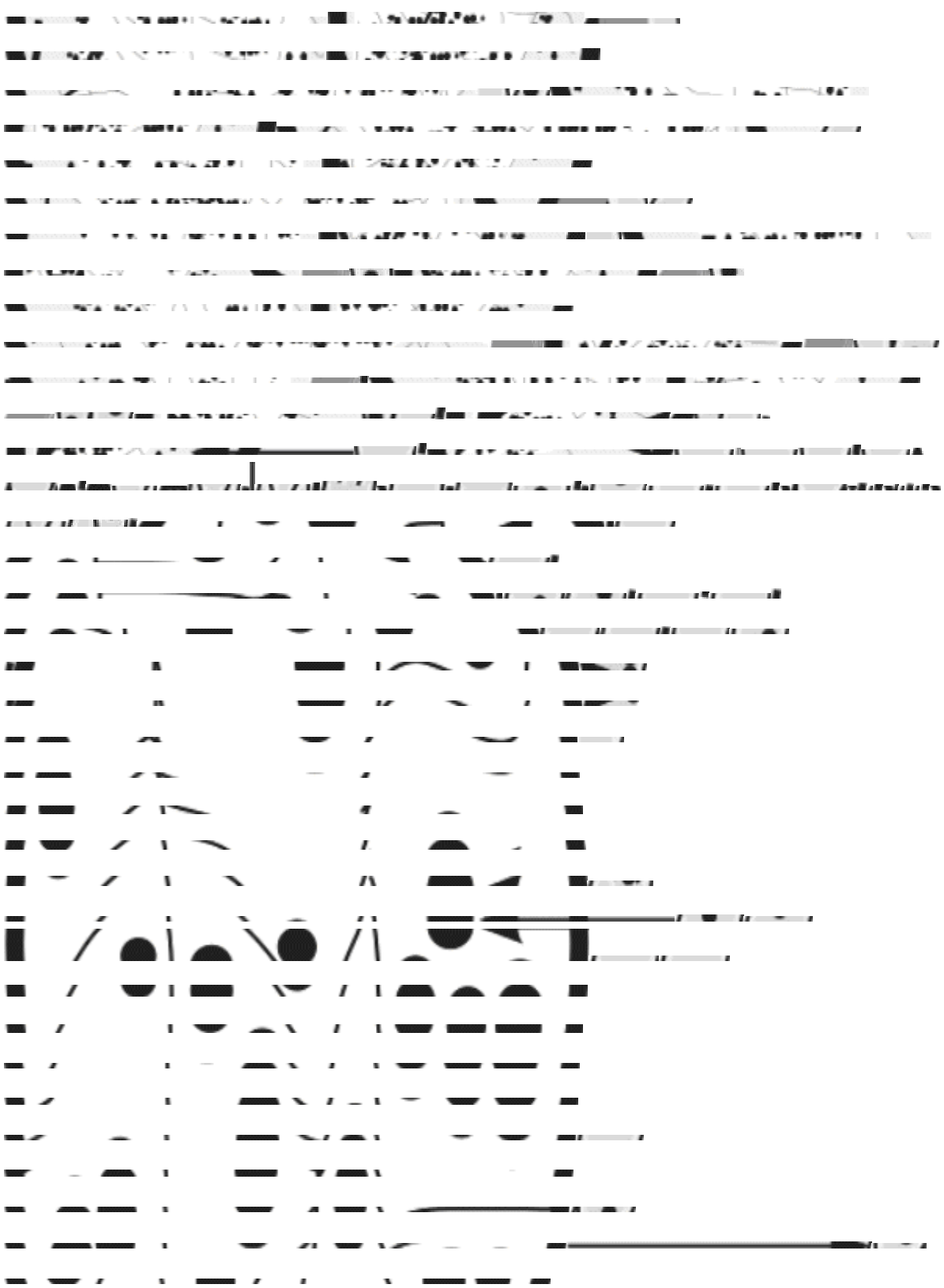


Figure 6.2: Schematic of lymph node showing lymph sinuses **Source: http://commons.wikimedia.org/wiki/File:**

Lymph nodes have outer covering of dense connective tissue and a trabeculated internal structure. The reticular connective tissue of the nodes forms an interconnected web like structure. The Vessels which enter the nodes are called as afferent vessels and the vessels leaving the nodes are called as efferent vessels.

Histologically, Lymph nodes have two parts, outer cortex and an inner medulla.
The superficial part of the cortex contains densely packed follicles, many with germinal centers heavy with dividing B cells. The deeper part of the cortex contains t cells. These T cells circulate freely between the blood, lymph nodes, and lymph, performing their role of surveillance. The medulla contains medullary cords which are thin inward extensions from the cortical lymphoid tissue. It contains both types of lymphocytes.

LYMPHATIC ORGANS

The organs associated with lympathetic system are spleen, thymus and tonsils. These organs contain lymphatic tissue primarily consisting of white blood cells known as macrophages and lymphocytes. Lymphocytes are of two types T and B lymphocytes. Both are produced in the bone marrow and are carried to the lymphatic system.

Spleen
The spleen is located in the left side of the abdominal cavity

generally close to the diaphragm. It has an outer covering of connective tissue known as capsule. From the capsule, trabaculae arise and pass into the inner portion containing red and white areas. The spaces between the trabaculae contain the splenic tissue. The spleen also contains venous sinuses. The white pulp of lymphatic tissue is linked with arteries and red pulp is linked with veins. The splenic artery and vein enter and exit the spleen at the hilum.

Functions of spleen
• During foetal life, it produces all types of blood cells.
• It destroys the worn out RBCs.
• It produces white blood cells that fight infection and

synthesize antibodies.
• It serves as a reservoir of blood.

Thymus
It is located just behind the sternum in the superior portion of the mediastinum. In early life the size of thymus is larger and decreases in size with age although it continues to produce white blood cells.

The thymus has two lobes. Each lobe has outer covering known as capsule. It consists of an outer cortex and inner medulla. The internal region of the thymus is trabeculated and filled with lymphocytes. The thymus produces large numbers of T-lymphocytes that can travel to the blood.

Tonsils
Tonsils are simplest lymphoid organs. They are collections of lymphoid tissue located along the inner surface of the pharynx and are important in developing immunity to oral pathogens.

7

Cardiovascular System

INTRODUCTION

The heart and circulatory system (also called the *cardiovascular system*) make up the network that delivers blood to the body's tissues. With each heartbeat, blood is sent throughout our bodies, carrying oxygen and nutrients to all of our cells. Each day, 2,000 gallons (more than 7,570 liters) of blood travel many times through about 60,000 miles (96,560 kilometers) of blood vessels that branch and cross, linking the cells of our organs and body parts. From the hard-working heart, to our thickest arteries, to capillaries so thin

that they can only be seen through a microscope, the cardiovascular system is our body's lifeline.

The circulatory system works closely with other systems in our bodies. It supplies oxygen and nutrients to our bodies by working with the respiratory system. At the same time, the circulatory system helps carry waste and carbon dioxide out of the body. Hormones – produced by the endocrine system
– are also transported through the blood in our circulatory system. As the body's chemical messengers, hormones transfer information and instructions from one set of cells to another.

The circulatory system is composed of the heart and blood vessels, including *arteries*, *veins*, and *capillaries*. Human body actually have *two* circulatory systems:

THE PULMONARY CIRCULATION
In the *pulmonary circulation*, blood low in oxygen but high in carbon dioxide is pumped out of the right ventricle into the

pulmonary artery, which branches off in two directions. The right branch goes to the right lung, and *vice versa*. In the lungs, the branches divide further into capillaries. Blood flows more slowly through these tiny vessels, allowing time for gases to be exchanged between the capillary walls and the millions of *alveoli*, the tiny air sacs in the lung. During the process called oxygenation, oxygen is taken up

by the bloodstream.

Oxygen locks onto

a molecule called

_____

hemoglobin in the

_____

red blood cells. The
newly oxygenated
blood leaves the

_____

lungs through the

_____

pulmonary veins

_____

and heads back to

_____

the heart. It enters
the heart in the left

_____

atrium, then fills the

_____

left ventricle so it can

be pumped into the **Figure 7.1:** Circulation of blod through the systemic circulation. heart and the pulmonary and systemic circulation THE SYSTEMIC CIRCULATION

In the *systemic circulation,* blood travels out of the left ventricle, to the aorta, to every organ and tissue in the body, and then back to the right atrium. The arteries, capillaries, and veins of the systemic circulatory system are the channels through which this long journey takes place. Once in the arteries, blood flows to smaller arterioles and then to capillaries. While in the capillaries, the bloodstream delivers oxygen and nutrients to the body's cells and picks up waste materials. Blood then goes back through the capillaries into venules, and then to larger veins until it reaches the vena cavae. Blood from the head and arms returns to the heart through the superior vena cava, and blood from the lower parts of the body returns through the inferior vena cava. Both vena cavae deliver this oxygen-depleted blood into the right atrium. From here the blood exits to fill the right ventricle, ready to be pumped into the pulmonary circulation for more oxygen.

HEART

The heart is the key organ in the circulatory system. The heart weighs between 7 and 15 ounces (200 to 425 grams) and is a little larger than the size of your fist. By the end of a long life, a person's heart may have beat (expanded and contracted) more than 3.5 billion times. In fact, each day, the average heart beats 1,00,000 times, pumping about 2,000 gallons (7,571 litres) of blood. Human heart is located between your lungs in the middle of your chest, behind and slightly to the left of your breastbone (sternum). A double-layered membrane called the *pericardium* surrounds your heart like a sac. The outer layer of the pericardium surrounds the roots of your heart's major blood vessels and is attached by ligaments to your spinal column, diaphragm, and other parts of your body. The inner layer of the pericardium is attached to the heart muscle. A coating of fluid separates the two layers of membrane, letting the heart move as it beats, yet still be attached to your body.

The heart gets messages from the body that tell it when to pump more or less blood depending on a person's needs. When we are sleeping, it pumps just enough to provide for the lower amounts of oxygen needed by our bodies at rest. When we are exercising or frightened, the heart pumps faster to get more oxygen to our bodies.

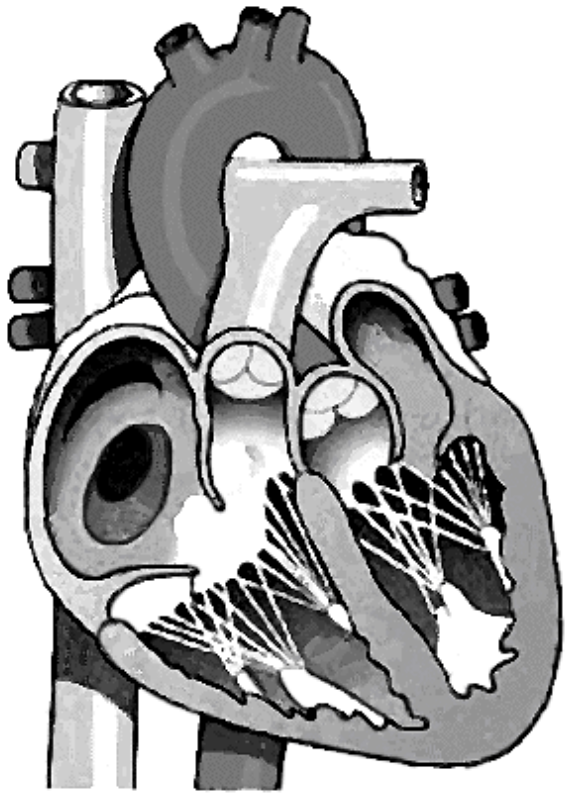


Figure 7.2: The interior of heart

STRUCTURE OF HEART

The heart wall is divided into three layers:

EPICARDIUM OR PERICARDIUM

The epicardium is the outer layer of the wall of the heart. It is composed of connective tissue covered by the epithelium. The epicardium is also known as the visceral pericardium. The pericardium is the fluid filled sac that surrounds the heart and the proximal ends of the aorta, vena cava, and the pulmonary artery. It provides an outer protective layer for the heart. The pericardium has several functions:

- Keeps the heart contained in the chest cavity.
- Prevents the heart from overexpanding when blood volume increases.
- Limits heart motion.

Pericardial Membranes

The pericardium is divided into three layers:

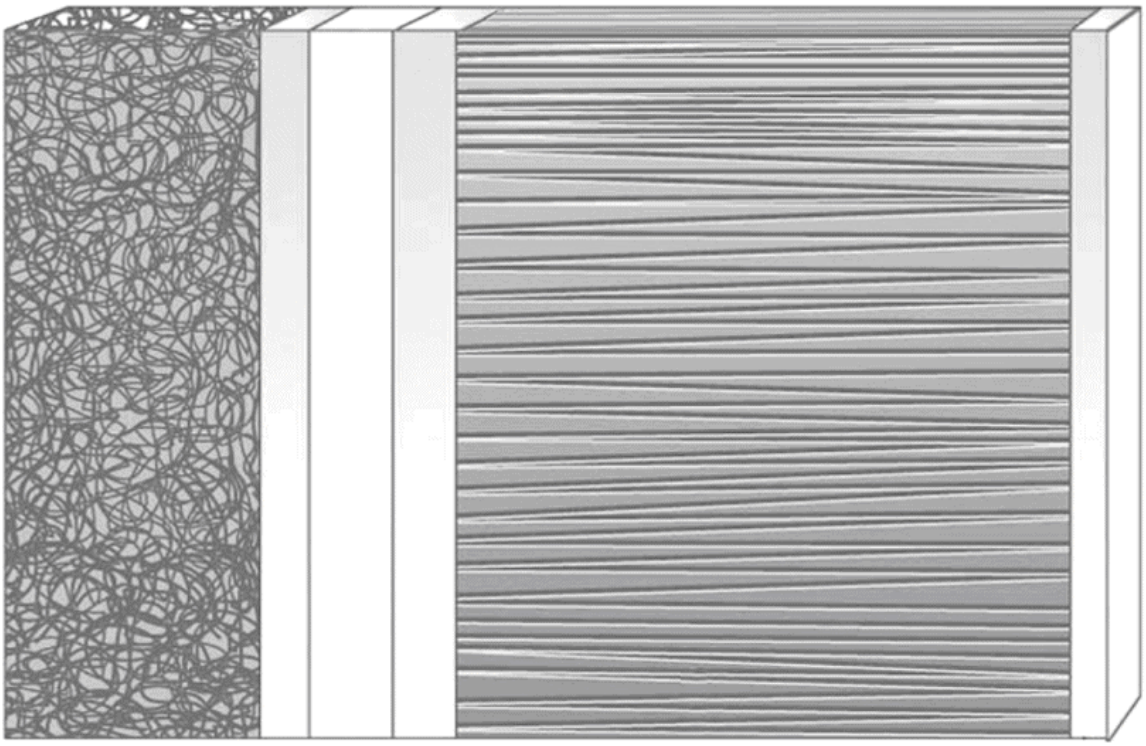


Figure 7.3: Layers of heart wall

• ***Fibrous Pericardium:*** The outer fibrous sac that covers the heart.
•***Partietal Pericardium:*** Lies between the visceral pericardium and the fibrous pericardium. It provides an additional layer of insulation for the heart.
• ***Visceral Pericardium:*** Also called the epicardium, this is the outer layer of the wall of the heart.

Pericardial Cavity
The pericardial cavity lies between the visceral pericardium and the parietal pericardium.

MYOCARDIUM
Myocardium is the muscular middle layer of the wall of the

heart. It is composed of spontaneously contracting cardiac muscle fibers which allow the heart to contract. It stimulates heart contractions to pump

blood from the ventricles and relaxes the heart to allow the artria to receive blood.

ENDOCARDIUM

The endocardium is the inner layer of the heart. It consists of epithelial tissue and connective tissue. Its functions are:

• Lines the inner cavities of the heart, covers heart valves and is continuous with the inner lining of blood vessels.
•*Purkinje fibers* are located in the endocardium. They participate in the contraction of the heart muscle. Purkinje fibers are fiber branches that extend from the atrioventricular bundle. It relays cardiac impulses to the ventricular cells causing the ventricles to contract.

ANATOMY OF HEART

The heart has four chambers that are enclosed by thick, muscular walls. It lies between the lungs and just to the left of the middle of the chest cavity. The bottom part of the heart is divided into two chambers called the right and left ventricles, which pump blood out of the heart. A wall called the interventricular septum divides the ventricles.

The upper part of the heart is made up of the other two chambers of the heart, called the *right* and *left atria.* The right and left atria receive the blood entering the heart. A wall called the interatrial septum divides the atria, and they are separated from the ventricles by the *atrioventricular valve.* The tricuspid valve separates the *right atrium* from the *right ventricle,* and the mitral valve separates the left atrium and the left ventricle.

Two other heart valves separate the ventricles and the large blood vessels that carry blood leaving the heart. These valves are called the *pulmonic valve,* which separates the right ventricle from the pulmonary artery leading to the lungs, and the *aortic valve,* which separates the left ventricle from the aorta, the body’s largest blood vessel.

THE HEART VALVES

Four types of valves regulate blood flow through your heart:

• The *tricuspid valve*regulates blood flow between the right atrium and right ventricle.
• The *pulmonary valve*controls blood flow from the right ventricle into the pulmonary arteries, which carry blood to your lungs to pick up oxygen.

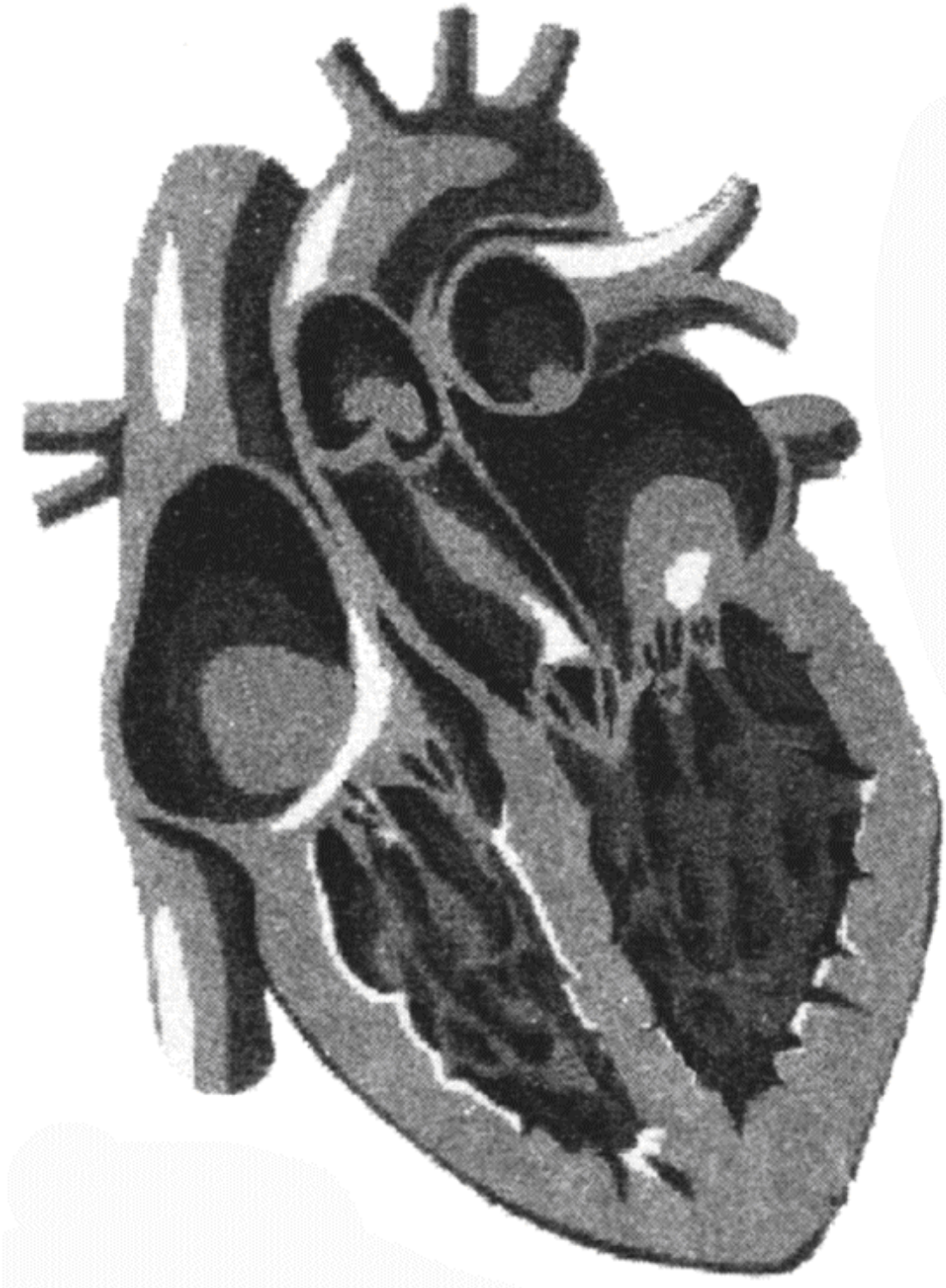


Figure 7.4: The heart valves

• The *mitral valve* lets oxygen-rich blood from your lungs pass from the left atrium into the left ventricle.
• The *aortic valve* opens the way for oxygen-rich blood to pass from the left ventricle into the aorta, your body's largest artery, where it is delivered to the rest of your body.

THE CONDUCTION SYSTEM

A unique electrical system in the heart causes it to beat in its regular rhythm. The heart's electrical system controls all the events that occur when your heart pumps blood. The electrical system also is called the *cardiac conduction system.* It is made up of three main parts:

• The ***sinoatrial*** (SA) node located in the right atrium of heart. The *sinoatrial* or *SA node.* The SA node is sometimes called the heart's "*natural pacemaker."* An electrical impulse from this natural pacemaker travels through the muscle fibers of the atria and ventricles, causing them to contract a small area of tissue in the wall of the right atrium, sends out an electrical signal to start the contracting of the heart muscle.
• The ***atrioventricular*** (AV) node located on the interatrial septum close to the tricuspid valve. These electrical impulses cause the atria to contract first; they then travel down to the *atrioventricular* or *AV node,* which acts as a kind of relay station.From here the electrical signal travels through the right and left ventricles, causing them to contract and force blood out into the major arteries.

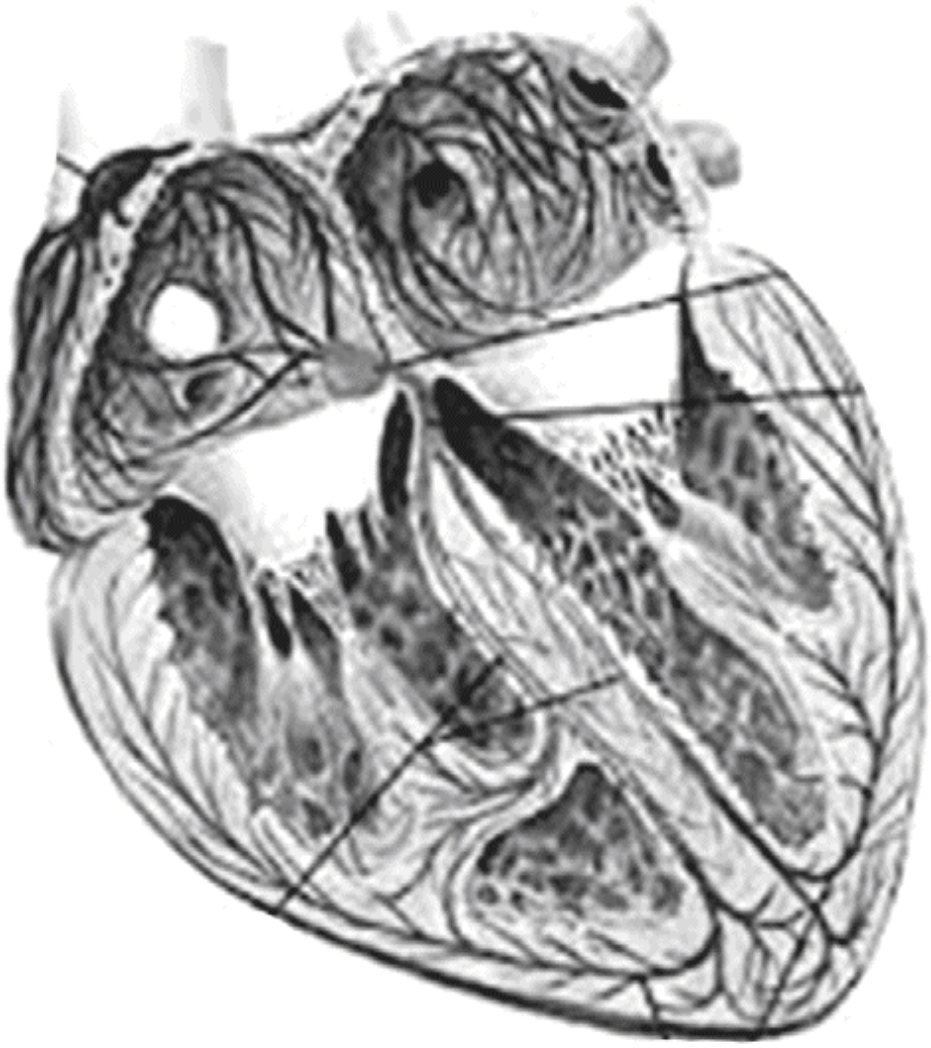


Figure 7.5: Cardiac conduction system of heart

• The ***His-Purkinje system*** located along the walls of heart's ventricles. This is a mass of specialised fibres from the AV node. The AV bundle crosses the fibrous ring that separate atria and ventricles then, at the upper end of the ventricular septum, it divides into *right and left bundle branches.*

The AV bundle, bundle branches and Purkinje fibres convey electrical impulses from AV node to the apex of themyocardium where the wave of ventricular contraction begins, then sweeps upwards and outwards, pumping blood into the pulmonary artery and aorta.

THE HEARTBEAT

A heartbeat is a two-part pumping action that takes about a second. As blood collects in the upper chambers (the right and left atria), the heart's natural pacemaker (the SA *node)* sends out an electrical signal that causes the atria to contract. This contraction pushes blood through the tricuspid and mitral valves into the resting lower chambers (the right and left ventricles). This part of the two-part pumping phase (the longer of the two) is called ***diastole***.

The second part of the pumping phase begins when the ventricles are full of blood. The electrical signals from the SA node travel along a pathway of cells to the ventricles, causing them to contract. This is called ***systole***. As the ***tricuspid*** and ***mitral valves*** shut tight to prevent a back flow of blood, the pulmonary and aortic valves are pushed open. While blood is pushed from the right ventricle into the lungs to pick up oxygen, oxygen-rich blood flows from the left ventricle to the heart and other parts of the body.

After blood moves into the pulmonary artery and the aorta, the ventricles relax, and the pulmonary and aortic valves close. The lower pressure in the ventricles causes the tricuspid and mitral valves to open, and the cycle begins again. This series of contractions is repeated over and over again, increasing during times of exertion and decreasing while you are at rest. The heart normally beats about 60 to 80 times a minute when you are at rest, but this can vary. As you get older, your resting heart rate rises. Also, it is usually lower in people who are physically fit.

[redacted]

Figure 7.6: The heartbeat

Your heart does not work alone, though. Your brain tracks the conditions around you—climate, stress, and level of physical activity — and adjusts your cardiovascular system to meet those needs. The human heart is a muscle designed to remain strong and reliable for a hundred years or longer. By reducing your risk factors for cardiovascular disease, you may help your heart stay healthy longer.

HEART SOUND “LUB-DUB”

A healthy heart makes a “lub-dub” sound with each beat. One complete heartbeat makes up a *cardiac cycle,* which consists of two phases. In the first phase, the ventricles contract (this is called *systole,* sending blood into the pulmonary and systemic circulation. To prevent the flow of blood backwards into the atria during systole, the atrioventricular valves close, creating the first (“*lub*”) sound.

When the ventricles finish contracting, the aortic and pulmonic valves close to prevent blood from flowing back into the ventricles. This is what creates the second sound (the *“**dub**”).* Then the ventricles relax (this is called *diastole)*and fill with blood from the atria, which makes up the second phase of the *cardiac cycle.*

The *atrioventricular* and *semilunar valves*prevent backflow as the heart contracts. Defects in any of these that allow some blood to leak backwards cause distinctive sounds through a *stethoscope,* thus are called *heart murmurs.*

A baby’s heart starts beating when it is about four weeks old (the mother’s period is two weeks late, and she’s just beginning to suspect she might be pregnant). A newborn’s heart rate is around 135 to 140 beats per minute (bpm). By age 15 to 30, the rate decreases to about 65-75 bpm, then speeds up slightly as the person ages. The pulse is a wave of contraction of the artery walls (which roughly corresponds to the heart rate) as blood is forced into the arteries. Pulse is usually measured using the radial artery (the one along the radius). To find your pulse, rest your right arm in the palm of your left hand. Curl the fingers of your left hand up around the thumb side of your

right wrist. Place several fingers of your left hand along and just to the outside (thumb side) of the tendon that runs along your wrist. With gentle pressure, you should be able to feel your pulse.

An ***electrocardiogram*** *(ECG)* measures changes in electrical potential across the heart, and can detect the contraction pulses that pass over the surface of the heart. There are three slow, negative changes, known as P, R, and T as shown in Fig. 7.7. Positive deflections are the Q and S waves. The P wave represents the contraction impulse of the atria, the T wave the ventricular contraction. ECGs are useful in diagnosing heart abnormalities.

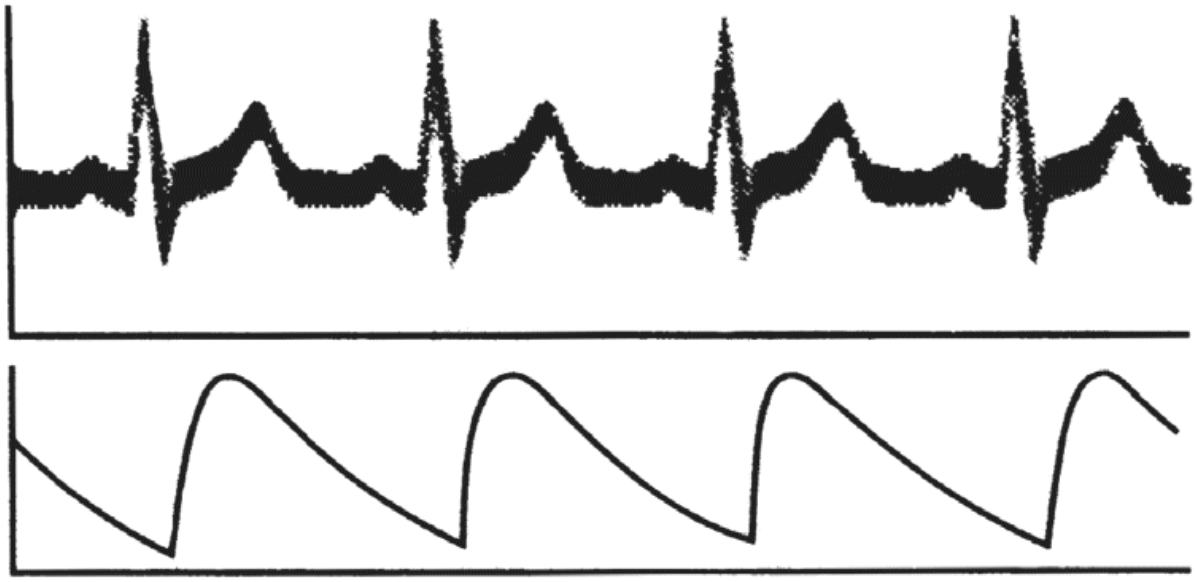


Figure 7.7: The EKG.

Blood vessels carrying blood away from the heart are called ***arteries***. They are the thickest blood vessels, with muscular walls that contract to keep the blood moving away from the heart and through the body. In the systemic circulation, oxygenrich blood is pumped from the heart into the aorta. This huge artery curves up and back from the left ventricle, then heads down in front of the spinal column into the abdomen. Two *coronary arteries* branch off at the beginning of the aorta and divide into a network of smaller arteries that provide oxygen and nourishment to the muscles of the heart.

Unlike the aorta, the body's other main artery, the *pulmonary artery,* carries oxygen-poor blood. From the right ventricle, the pulmonary artery divides

into right and left branches, on the way to the lungs where blood picks up oxygen. Arterial walls have three layers:

• The ***endothelium*** is on the inside and provides a smooth lining for blood to flow over as it moves through the artery.
• The ***media*** is the middle part of the artery, made up of a layer of muscle and elastic tissue.
• The ***adventitia*** is the tough covering that protects the outside of the artery.

As they get farther from the heart, the arteries branch out into *arterioles*, which are smaller and less flexible.

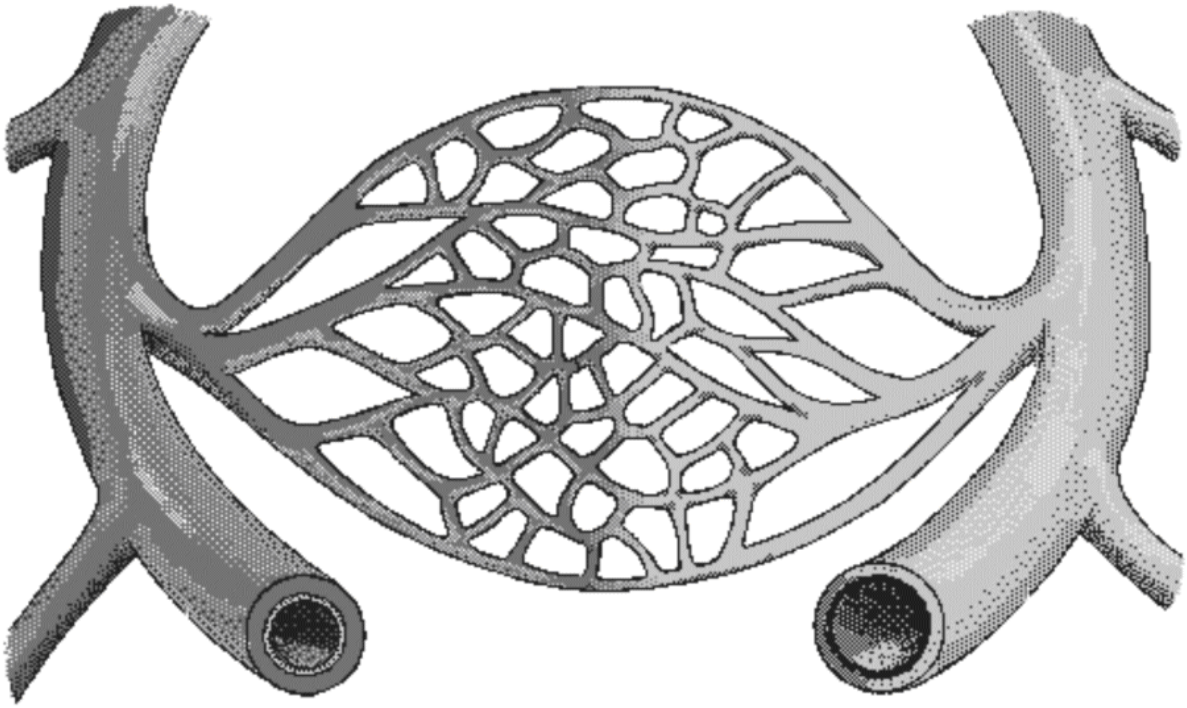


Figure 7.8: Blood vessel

Blood vessels that carry blood back to the heart are called ***veins***. They are not as muscular as arteries, but they contain valves that prevent blood from flowing backward. Veins have the same three layers that arteries do, but they are thinner and less flexible. The two largest veins are the *superior* and *inferior vena cavae.* The terms superior and inferior do not mean that one vein is better than the other, but that they are located above (superior) and below (inferior) the heart.

A network of tiny ***capillaries*** connects the arteries and veins. Even though they are tiny, the capillaries are one of the most important parts of the circulatory system because it is through them that nutrients and oxygen are delivered to the cell. In addition, waste products such as carbon dioxide are also removed by the capillaries.

BLOOD PRESSURE

Blood pressure is maximum during systole, when the heart is pushing, and minimum during diastole, when the heart is relaxed. In a living person, the blood pressure doesn't go to zero because the thick, elastic artery walls exert pressure on the blood. A sphygmomanometer is the instrument used to determine BP. The artery used to determine BP is the brachial artery, which runs down the upper arm, splitting into the radial and ulnar arteries near the elbow. The cuff of the sphygmomanometer is wrapped around the arm just above the elbow and pumped up to block off blood flow (the pressure exerted by the cuff is higher than the systolic pressure). The pressure in the cuff is gradually decreased, and when it equals the person's systolic pressure, the heart can force blood under the cuff, and a sound is heard as the pulses of blood surge under the cuff. As the pressure in the cuff is lowered, when it equals the diastolic pressure, blood can flow freely, so the sound disappears (not enough pressure is exerted by cuff to restrict blood flow). Thus, by listening for the first sound, and when the sound becomes faint, while watching the pressure indicator on the sphygomomanometer, it is possible to determine someone's blood pressure. Typically, when you go to the doctor's office, one of the first things that is done to you is that someone (a nurse?) takes your blood pressure. I have frequently had the experience that when I ask what the results were, I initially get the answer "It's OK." Here's a tip: you, not they, are in charge of your health. The only way you can educate yourself to how your body works is to keep re-asking the question until you get a real answer. You need to know the actual numbers to be able to evaluate if things have changed or are good or bad. Be persistent and eventually they'll tell you what your BP is.

A neonate's BP is around 80/45 mm Hg meaning that the systolic pressure is equivalent to air pressure that will support a column of mercury 80 millimeters high in a barometer, and the diastolic is equivalent to the air pressure that will support a column of mercury 45 millimeters high. For

adults in their 20s, 120/80 mm Hg is considered average for a male and 115/75 mm Hg for a female, thus the accepted average is said to be 120/80 mm Hg. With age, the arteries become less elastic (due in part to undesirable lipid deposits in their walls), so the BP rises. Hypertension is when the BP is too high. There are two ways this could happen: either the systolic pressure is greater than 145 to 160 mm Hg and/or the diastolic is greater than 90 to 100. Major contributing factors include the amounts of salt, cholesterol (and other lipids), and sugar in one's diet and the amount of exercise the person gets. Frequently, diuretics are prescribed to try to remove water from the person's blood, thus lowering the blood volume and hopefully thereby, the BP. However, many diuretics also remove potassium (and other beneficial minerals?) from the person's system, and if serum potassium levels are not carefully monitored and go to low, this could cause a heart attack!

THE LYMPHATIC SYSTEM

The lymphatic system is composed of lymph vessels, lymph nodes, and organs. The functions of this system include the absorbtion of excess fluid and its return to the blood stream, absorption of fat (in the villi of the small intestine) and the immune system function.

Lymph vessels are closely associated with the circulatory system vessels. Larger lymph vessels are similar to veins. Lymph capillaries are scatted throughout the body. Contraction of skeletal muscle causes movement of the lymph fluid through valves.

Lymph organs include the *bone marrow, lymph nodes, spleen*, and *thymus.* Bone marrow contains tissue that produces lymphocytes. B-lymphocytes (B-cells) mature in the bone marrow. T-lymphocytes (T-cells) mature in the thymus gland. Other blood cells such as monocytes and leukocytes are produced in the bone marrow. *Lymph nodes* are areas of concentrated lymphocytes and macrophages along the lymphatic veins. The spleen is similar to the lymph node except that it is larger and filled with blood. The spleen serves as a reservoir for blood, and filters or purifies the blood and lymph fluid that flows through it. If the spleen is damaged or removed, the individual is more susceptible to infections. The thymus secretes a hormone, thymosin, that causes pre-T-ells to mature (in the thymus) into T-cells.

THE VASCULAR SYSTEM

Two main routes for circulation are the *pulmonary* (to and from the lungs) and the *systemic* (to and from the body). Pulmonary arteries carry blood from the heart to the lungs. In the lungs gas exchange occurs. Pulmonary veins carry blood from lungs to heart. The aorta is the main artery of systemic circuit.

The vena cavae are the main veins of the systemic circuit. Coronary arteries deliver oxygenated blood, food, etc. to the heart. Animals often have a portal system, which begins and ends in capillaries, such as between the digestive tract and the liver.

Fish pump blood from the heart to their gills, where gas exchange occurs, and then on to the rest of the body. Mammals pump blood to the lungs for gas exchange, then back to the heart for pumping out to the systemic circulation. Blood flows in only one direction.

PULSE

In medicine, a person's pulse is the throbbing of their arteries as an effect of the heart beat. When the heart contracts, blood is ejected into the aorta and the aorta stretches. At this point, the wave of distention (pulse wave) is pronounced but relatively slow-moving (3-6 m/s). As it travels towards the peripheral blood vessels, it gradually diminishes and becomes faster. In the large arterial branches, its velocity is 7-10 m/s; in the small arteries, it is 15-35 m/s. The pressure pulse is transmitted fifteen or more times more rapidly than the blood flow.

Pulse is also used to denote the frequency of the heart beat, usually measured in beats per minute. In most people, the pulse is an accurate measure of heart rate. Under certain circumstances, including *arrhythmias*, some of the heart beats are ineffective, and the aorta is not stretched enough to create a palpable pressure wave.

The pulse is too irregular and the heart rate can be (much) higher than the pulse rate. In this case, the heart rate should be determined by auscultation of the heart apex, in which case it is not the pulse. The pulse deficit (difference

between heart beats and pulsations at the periphery) should be determined by simultaneous palpation at the radial artery and auscultation at the heart apex.

A normal pulse rate for a healthy adult, while resting, can range from 60 to 100 beats per minute (bpm), although well conditioned athletes may have a healthy pulse rate lower than 60 bpm. Bradycardia occurs when the pulse rate is below 60 per minute, whereas tachycardia occurs when the rate is above 100 bpm.

During sleep, this can drop to as low as 40 bpm; during strenuous exercise, it can rise as high as 150-200 bpm. Generally, pulse rates are higher in infants and young children. The resting heart rate for an infant is usually close to an adult's pulse rate during strenuous exercise (average 110 bpm for an infant).

Pulses are manually palpated with fingers. When palpating the carotid artery, the femoral artery or the brachial artery, the thumb may be used.

However, the thumb has its own pulse which can interfere with detecting the patient's pulse at other points, where two or three fingers should be used. Fingers or thumb must be placed near an artery and pressed gently against a firm structure, usually a bone, in order to feel the pulse.

Questions for study

1. Explain the structure of human heart. Describe the physiology of heartbeat.
2. What do you mean by blood vessels? Explain the types of blood vessels.
3. Explain in detailed the process of the circulation of blood.
4.Write short notes on:
(a) S-A Node;
(b) A-V Node;
(c) Bundle of 'His'; and
(d) ECG.

Respiratory System

RESPIRATORY SYSTEM

Respiratory system is the network of organs and tissues that help you breathe. This system helps your body absorb oxygen from the air so your organs can work. It also cleans waste gases, such as carbon dioxide, from your blood. Common problems include allergies, diseases or infections.

The respiratory system has many functions. Besides helping you inhale (breathe in) and exhale (breathe out), it:
• Allows you to talk and to smell.
• Warms air to match your body temperature and moisturizes it to the humidity level your body needs.
• Delivers oxygen to the cells in your body.
• Removes waste gases, including carbon dioxide, from the body when you exhale.
• Protects your airways from harmful substances and irritants.

Pulmonary Ventilation
Pulmonary ventilation is the inspiration and expiration of air between atmosphere and lungs.
External Respiration
External respiration describes respiration that occurs between the external environment and the cells of the body.
External respiration consists of two stages:

• Breathing **127**
• Gas exchange
Internal Respiration

Internal respiration involves exchange of gases between blood and tissue cells. The blood gives O, and receives CO, from the tissues.

The respiratory system consists of the nose, pharynx (throat), larynx (voice box) trachea (wind pipe), bronchi, and the lungs. But structurally, the respiratory system consists of two parts :

1. The upper respiratory tract which refers to the nose, pharynx and associated structures.
2. The lower respiratory tract refers to the larynx, trachea, bronchi and lungs.

Functionally, there is the conducting part which consists of nose, pharynx, larynx, trachea, bronchi, bronchioles and terminals of bronchioles. All these conduct air into the lungs. The respiratory part, on the other hand, consists of respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli. This part serves as a site for the exchange of gases.

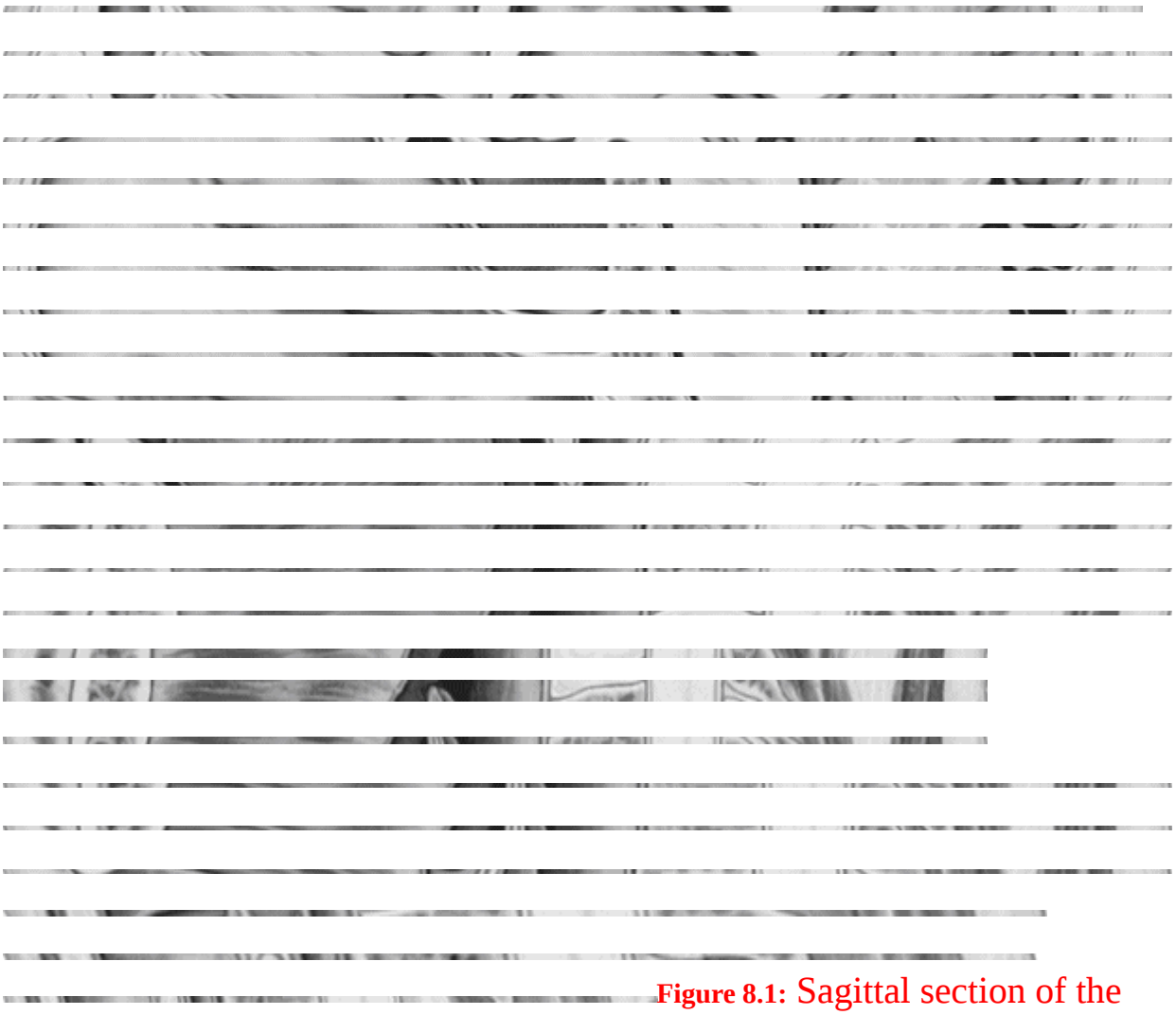


Figure 8.1: Sagittal section of the left side head and neck

Nose

The nose consists of an external part and an internal part in the side of skull. The nasal bone forms the bridge of the nose which holds it in a fixed position. It has a framework of pliable hyaline cartilage. The hyaline cartilage is covered with muscle and skin and is lined with mucous membrane. There are two nares or nostrils present on the surface of the external nose. The nose performs three main functions:

- It warm, Moistens and filters incoming airs.
- It's receiving olfactory stimuli.
- It's large hollow resonating chambers modify speech sounds.

Internally it communicates with the pharynx through two openings called the internal nares. Various sinuses from frontal, sphenoid, maxillary, ethmoidal and lachrymal ducts open into the internal nose, the ethmoidal, maxillae, lachrymal, palatine form walls of the internal nose. The roof is formed by the ethmoidal bone whereas floor of the nose is formed by palatine bones. The nasal cavity is divided into two parts by the nasal septum. Anteriorly, the septum consists of hyaline cartilage and remaining part is formed by vomer which is perpendicular plate of the ethmoidal bone.

From each lateral wall of the nasal cavity projections arise, which are termed superior, middle and inferior conches. The olfactory receptors lie in the membrane lining the superior nasal conches and adjacent to the septum. This portion is called as olfactory epithelium. The mucous membrane contains capillaries and ciliated columnar epithelium with many goblet cells. When air enters through the nasal cavity, the blood in the capillaries warms the air while mucous from goblet cells moistens the air and traps dust particles. The cilia move the dust particles towards the pharynx so that they can be eliminated from the respiratory tract by swallowing, spitting, or coughing.

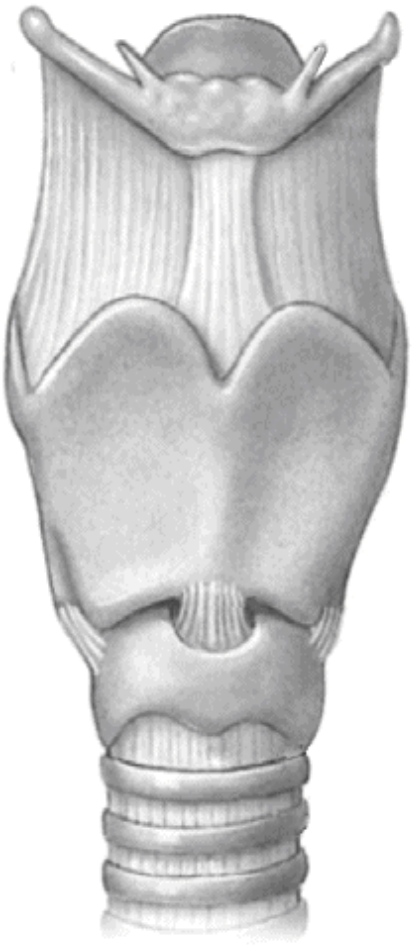
The pharynx is a tube-like structure about 05 inches in length; it lies between internal nares to the cricoid cartilage. It lies supe the larynx and posterior to the nasal and oral cavity Walls of the pharynx are composed of skeletal muscles and are lined with mucous membrane. The pharynx provides a passage for food and air and also serves as a resonating chamber for speech sounds. It also shows the presence of tonsils which help to eliminate foreign invaders by immunological reactions.

The nasopharynx lies superior to the pharynx, posterior to the nasal cavity and extends to the level of the soft palate. Overall, there are five openings in the walls of the nasopharynx two for the internal nares, two for auditory tubes, and one for the oropharynx. For equalization of pressure at the tympanic membrane, the nasopharynx conveys air through auditory tubes. At the posterior wall of the nasopharynx, pharyngeal tonsils are present.

The oropharynx is the intermediate of the pharynx. It lies posterior to the oral cavity and extends from the soft palate and inferior to the level of the hyoid bone. The portion of the pharynx used for digestive as well as

respiratory purposes, is called throat or faucets. The palatine and lingual tonsils are present in the oropharynx.

The laryngopharynx starts from hyoid bone and connects to the oesophagus with the larynx.



The Larynx Voice Box

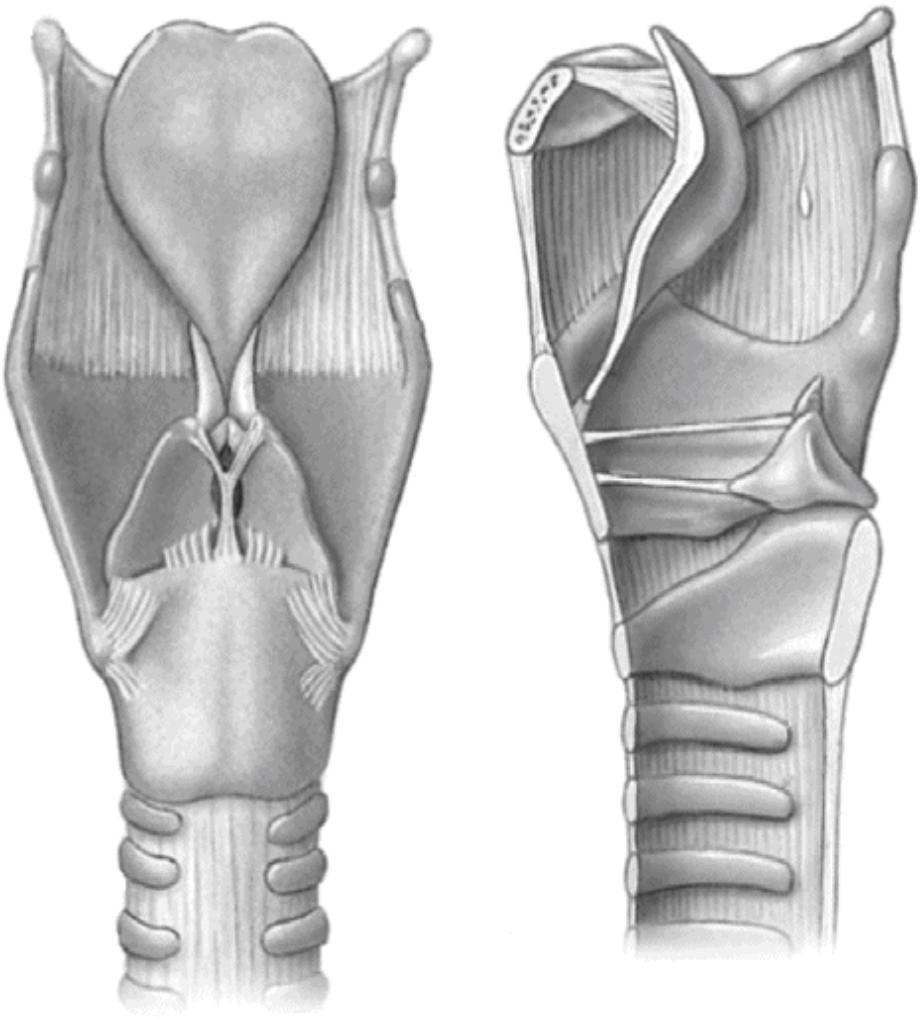


Figure 8.2

The larynx, commonly called the voice box, is a 2-inch long cartilaginous tube connecting the back of the nose (pharynx) and the windpipe (trachea) with each other. It is one of the most important structures of the respiratory system, also playing a crucial role in the production of speech in humans. The flexible structure is located at the anterior side of the neck, in front of the pharynx and above the windpipe suspended from the hyoid bone, it extends from C3 to C6, opening into the laryngeal portion of the pharynx.

The Epiglottis

The epiglottis is a cartilaginous flap covering the opening of the **windpipe** during swallowing to prevent food from entering the **lungs.** The flat, leaf-

like structure is attached to the superior end of the **larynx** (voice box), protruding into the **pharynx,** just behind the root of the tongue, in its relaxed state. Visible around the 5thweek of fetal development, the elastic cartilage flap originates from the fourth pharyngeal arch. Its lingual surface is covered by mucus membrane with the anterior surface consisting of non-keratinized stratified squamous epithelium, similar to the mouth and pharynx tissues, while the posterior surface is covered in pseudostratified columnar epithelium, similar to the tissues that line the larynx. The epiglottis is visible from the outside, posterior to the tongue, appearing like a flat flap, beneath the uvula.

Arytenoids Cartilage

The arytenoid cartilages are paired hyaline cartilages that articulate with the sloping upper border of the lamina of the cricoid cartilage by the cricoarytenoid joint. This joint allows movement of the arytenoid cartilages, which is vital in approximating, tensing and relaxing the vocal folds.

Trachea

The trachea, commonly known as the windpipe, is the large tube that delivers air from the upper respiratory tract (the nasal passages, throat, and **larynx)** to the **bronchi** (the two large airways that branch off into each lung). In the process, it warms and moisturizes the air and catches debris and microbes before they enter the lungs.

The trachea can become infected, inflamed, or damaged. In rare situations, this can lead to tracheal stenosis, in which the trachea narrows and restricts breathing. Tracheal cancer is an extremely rare form of cancer.

Bronchi

Bronchu’s or bronchi is also considered as main or primary bronchi. It represents the airway that conducts the air to the lungs through the respiratory tract. The trachea gets divided into the left and right bronchus, which is also called tracheal bifurcation. The right bronchus is wider than the left bronchus and it is shorter and vertical. The right main bronchi consist of three subdivisions. These subdivisions become secondary bronchi which

are also known as lobar bronchi. Initially, the right pulmonary artery lies below the right bronchus laters gets shifted to the front.

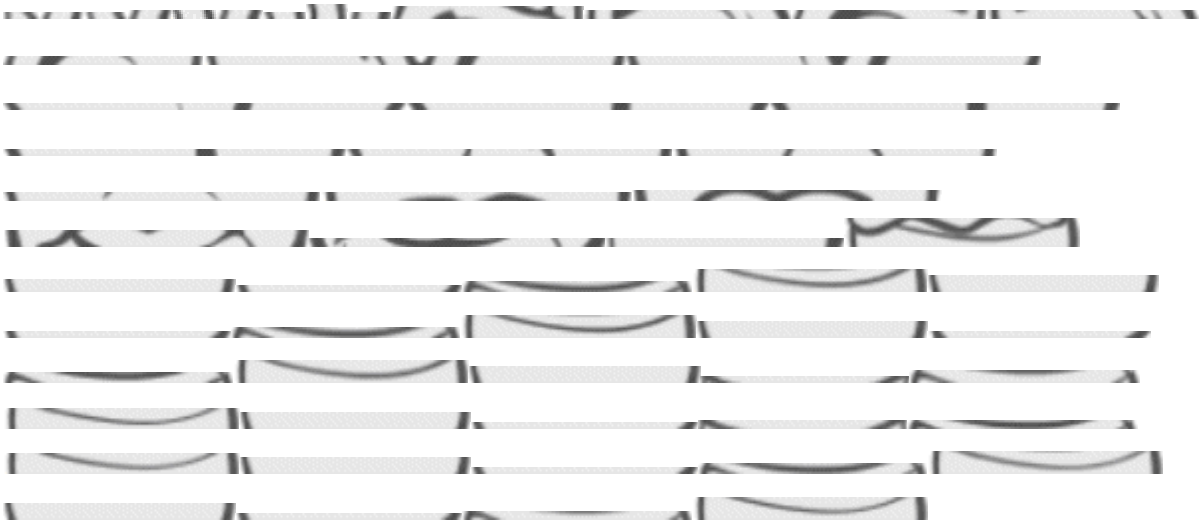
Function

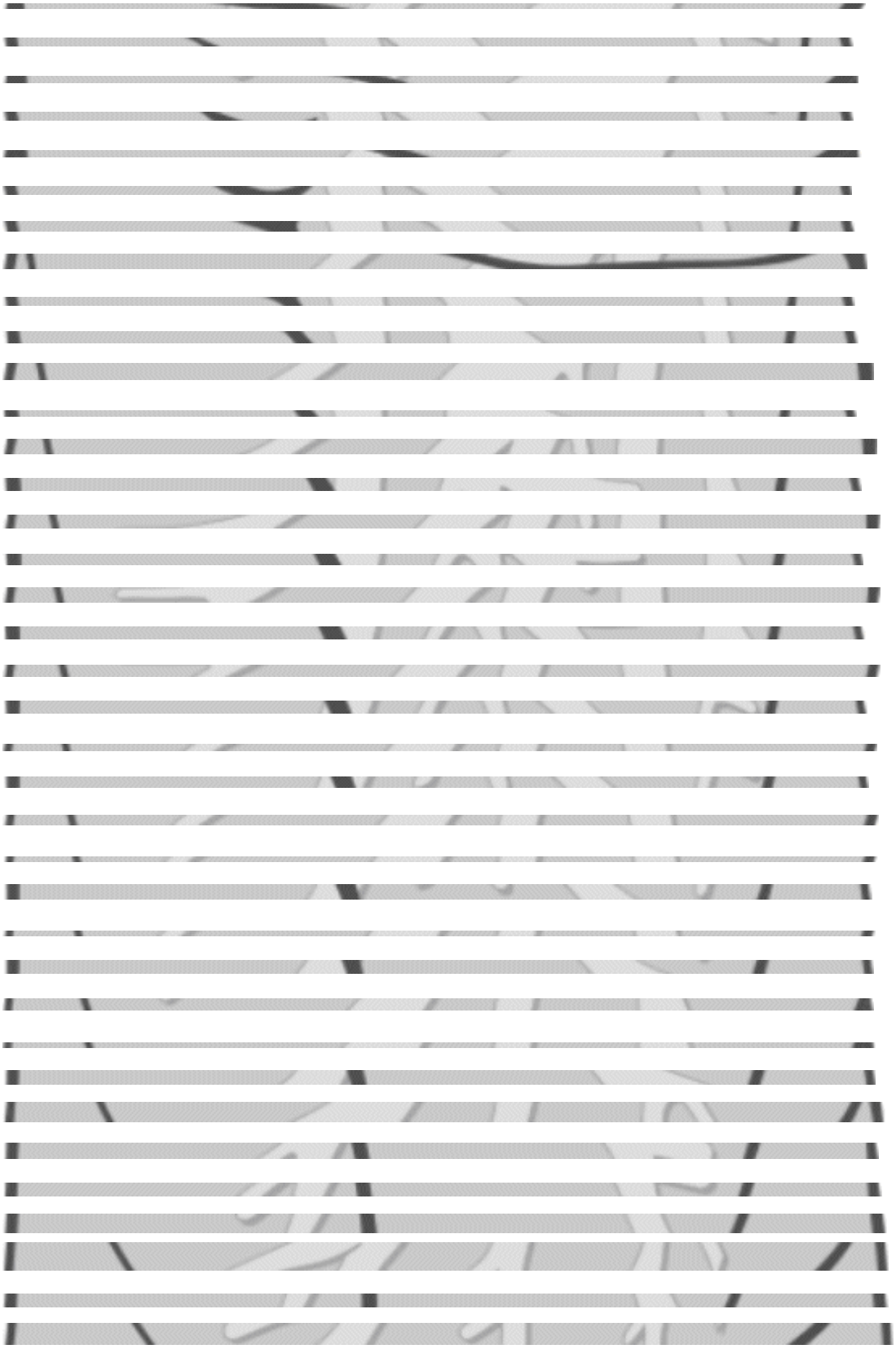
• The bronchi are mainly involved in the transportation of air to the lungs.
• It helps to remove the foreign particles.
• The airways are lined with mucus, this helps to keep the airways moist.
• Mucus acts as a trap for the virus, bacteria and other foreign particles to avoid infection.
• The bronchi are filled with tiny hair-like structures called cilia.
• The cilia help to remove the infection causing germs from the lungs. When a person sneezes or coughs the germs are removed through the mucus.

Bronchioles

Bronchioles are air passages inside the lungs that branch off like tree limbs from the bronchi—the two main air passages into which air flows from the trachea (windpipe) after being inhaled through the nose or mouth. The bronchioles deliver air to tiny sacs called alveoli where oxygen and carbon dioxide are exchanged. They are vulnerable to conditions like asthma, bronchiolitis, cystic fibrosis, and emphysema that can cause constriction and/or obstruction of the airways.

Function





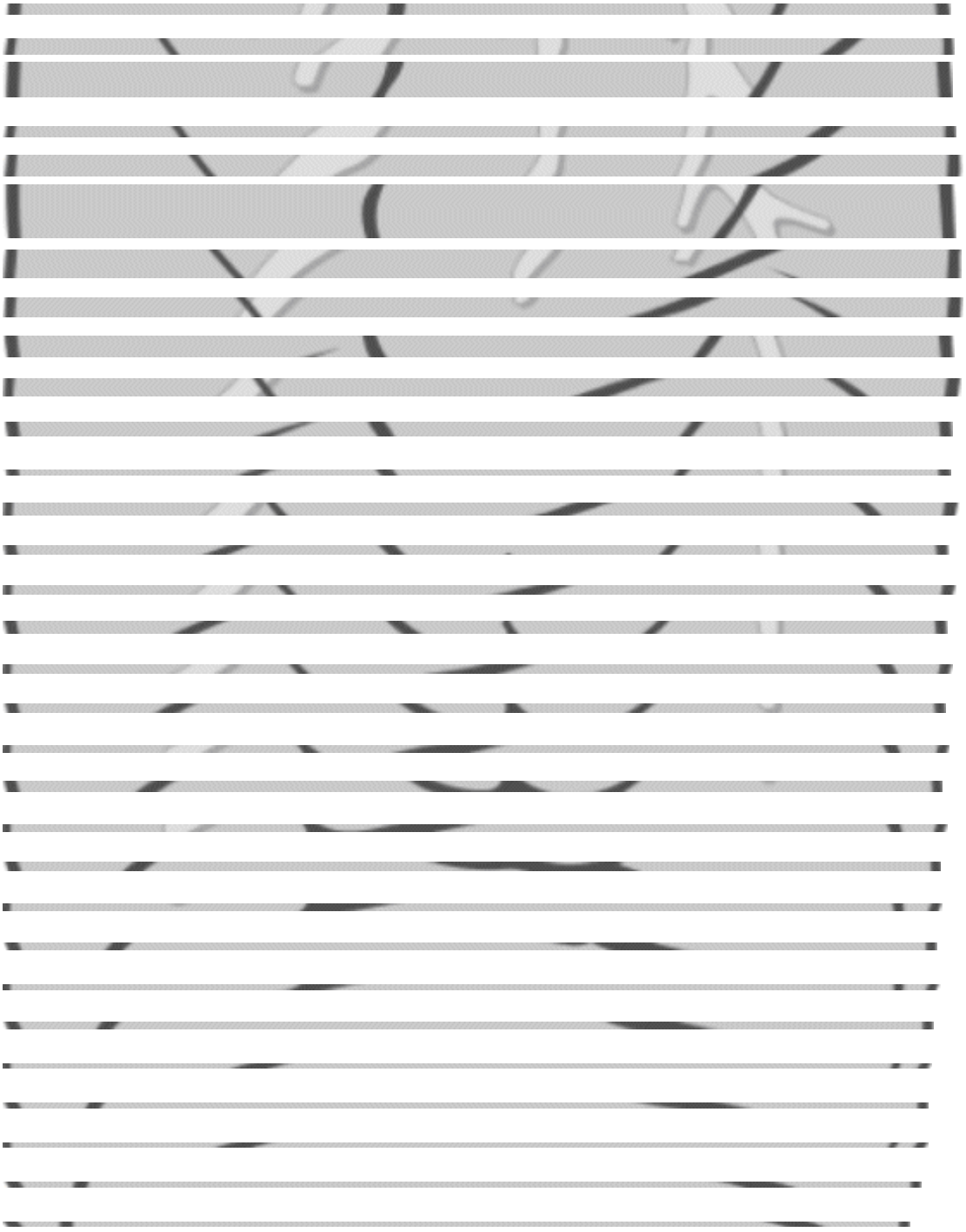


Figure 8.3
Bronchioles is to deliver air to a diffuse network of around 300 million alveoli in the lungs. Inhale, oxygenated air is pulled into the bronchioles. Carbon dioxide collected by the alveoli is then expelled from the lungs as you exhale.

THE LUNGS

The lungs are a pair of spongy, air-filled organs located on either side of the chest (thorax). The trachea (windpipe) conducts inhaled air into the lungs through its tubular branches, called bronchi. The bronchi then divide into smaller and smaller branches (bronchioles), finally becoming microscopic.

The bronchioles eventually end in clusters of microscopic air sacs called alveoli. In the alveoli, oxygen from the air is absorbed into the blood. Carbon dioxide, a waste product of metabolism, travels from the blood to the alveoli, where it can be exhaled. Between the alveoli is a thin layer of cells called the interstitial, which contains blood vessels and cells that help support the alveoli.

The lung is covered by a serious membrane known as pleura, which is composed of epithelial cells. The pleura is divided into two layers:
1. Parietal pleura
2. Visceral pleura

The **visceral pleura** is the thin, slippery membrane that covers the surface of the lungs and dips into the areas separating the different lobes of the lungs (called the hilum).

The **parietal pleura** is the outer membrane that lines the inner chest wall and diaphragm (the muscle separating the chest and abdominal cavities).

The lobules are separated by interlobular tissue i.e., areolar and elastic tissue. The pulmonary arteries bring the venous blood from right ventricles to the lungs and after entering it divides into branches in lung tissues. At the end, they form a network of capillaries around walls of the alveoli. Thus, exchange of gases takes place through capillary membrane and alveolar wall. The pulmonary capillaries join up to form of pulmonary veins which convey oxygenated blood to left atrium of the heart.

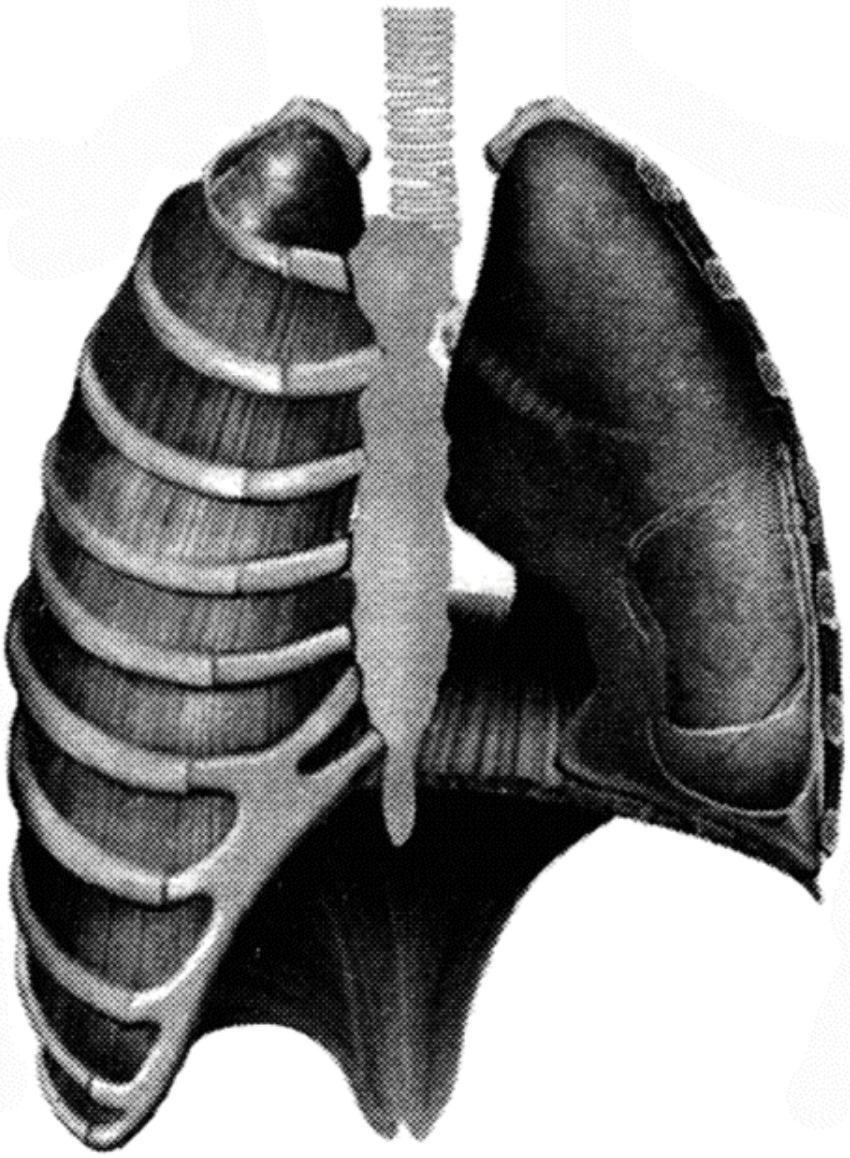
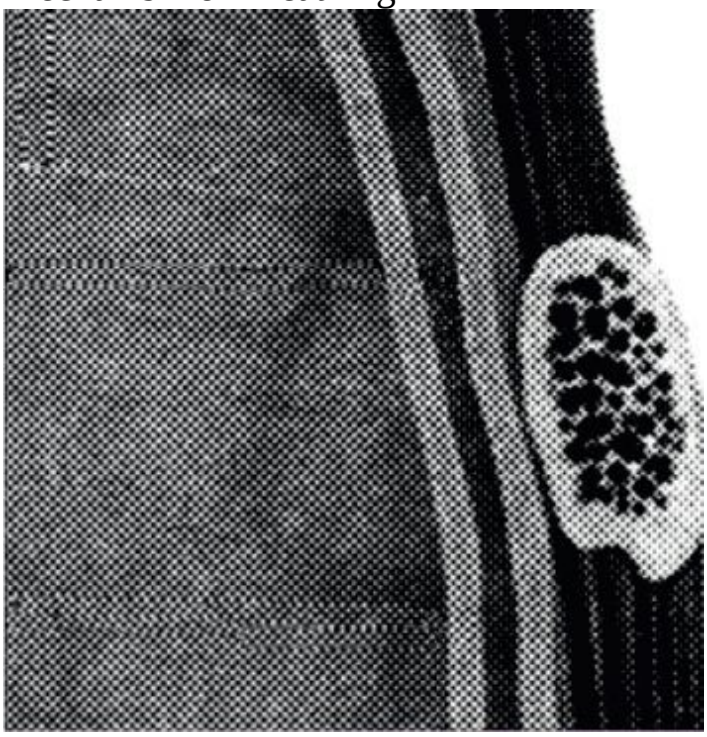


Figure 8.4

Mechanism of Breathing



The air which we breathe in and out of the lungs varies in its pressure. So basically when there is a fall in air pressure the alveolar spaces falls and the air enters the lungs (inspiration) and as the pressure of the alveoli within exceeds the atmospheric pressure, the air is blown from the lungs (expiration). The flow rate of air is in proportion to the magnitude of the pressure difference.

The breathing mechanism involves two processes:
• Inspiration
• Expiration

Inspiration
In the process of inspiration, there would be a contraction of

muscles attached to the ribs on the outer side which pulls out the ribs and results in the expansion of the chest cavity.

Later, the diaphragm, contracts, moves downwards and expands the chest cavity resulting in the contraction of the abdominal muscles.

The expansion of the chest cavity produces a partial vacuum which sucks air into the lungs and fills the expanded alveoli. ***Mechanism of Inspiration***

• The process of intake of atmospheric air is known as inspiration. It is an active process.
• When the volume of the thoracic cavity increases and the air pressure decreases, inspiration takes place.
• Contraction of external intercostal muscles increases the volume of the thoracic cavity.
• Contraction of the diaphragm further increases the size of the thoracic activity. Simultaneously, the lungs expand.
• With the expansion of the lungs, the air pressure inside the lungs decreases.
• The pressure equalizes and the atmospheric air rushes inside the lungs.

Expiration
The expiration process is considered once after the gaseous

exchange occurs in the lungs and the air is expelled out. This expulsion of air is called expiration.

During this process, muscles attached to the ribs contract, the muscles of the diaphragm and the abdomen relax which leads to a decrease in the volume of the chest cavity and increases the pressure of the lungs, causing the air in the lungs to be pushed out through the nose.

Mechanism of Expiration
• The process of exhaling carbon dioxide is called expiration.

It is a passive process.
• It occurs when the size of the thoracic activity decreases and the air pressure outside increases.
• Now the external intercostal muscles relax and the internal intercostal muscles contract.
• As a result, the ribs are pulled inwards and the size of the thoracic cavity is reduced.
• The diaphragm is relaxed and the lungs get compressed.
• Consequently, the pressure increases and the air is forced outside.

Mechanism of respiration

Mechanism of respiration involves the breathing mechanism and exchange of gases. The gaseous exchange occurs by diffusion in the alveoli. It depends upon the pressure differences between blood and tissues, or atmospheric air and blood. The **exchange of gases** takes place at the surface of the alveolus.

The mechanism of breathing has already been explained above. Let us have a look at the steps involved in the exchange of gases.

Exchange of Gases

The exchange of gases takes place in the following manner:

• Oxygen in the blood is carried to the tissue in two forms:

Oxyhaemoglobin- Chemical composition of oxygen with haemoglobin, and solution of oxygen in the blood plasma.

• The oxygen in the blood combines with haemoglobin when the concentration of oxygen is high in the blood.

• Oxyhemoglobin, being unstable, dissociates to release oxygen. Low oxygen, low pH and high temperatures stimulate the dissociation process.

INTERNAL RESPIRATION

The gaseous exchange taking place in the tissues is called internal respiration. Here, the oxygen carried in the form of oxyhaemoglobin gets dissociated to release oxygen.

This oxygen breaks down the glucose to release carbon dioxide, water, and energy. The energy is utilized by the body, while the carbon dioxide is diffused from the tissues.

Transport of Carbon dioxide from Tissues to Lungs

Carbon dioxide is transported by three mechanisms:

• Some carbon dioxide dissolves in the water of plasma to

form carbonic acid.

• Carbonic acid ionizes to form bicarbonate ions. The hydrogen ions are catalyzed by the enzyme carbonic anhydrase. Bicarbonate ions combine with sodium and

potassium to form sodium bicarbonate and potassium bicarbonate.
• Some carbon dioxide combines with haemoglobin for the formation of carbaminohaemoglobins.
• It is finally carried to the lungs and released out of the body through expiration.

Intrapleural Breathing

Intrapleural breathing is used to refer to the pressure that is present in the space between the pleura and the lungs. This space is referred to as the pleural cavity. The pressure in this region is normally less than the atmospheric pressure. This is the reason why pleural pressure is termed as negative pressure.

The lung movement is governed by the pressure gradient, the transpulmonary pressure, which exists between the pleura and the lungs. The difference in the pressures between the intrapulmonary and intrapleural pressures is known as transpulmonary pressure.

The pressure in the pleural cavity while breathing turns negative while there is an increase in the transpulmonary pressure causing the lungs to expand. While expiration, the lungs recoil as a result of an increase in the pleural pressure.

The competing forces inside the thorax results in the formation of the negative intrapleural pressure, one of these forces is associated with the lungs elasticity. The lungs have elastic tissues which cause it to be pulled inwards off the thoracic wall. An inward pull of the lung tissue is also generated by the surface tension of the alveolar fluid. The inward tension generated from the lungs is opposed by forces from the thoracic wall and the pleural fluid.

Respiratory Gas Transport

After the gases have scattered in the lungs, causing the blood to become oxygenated, leaving carbon dioxide, the next phase of transportation of oxygen-rich blood to the tissues takes place. Meanwhile, the next round of

deoxygenated blood needs to be brought to the lungs for the cycle to continue.

In the bloodstream, the transportation of gases occurs all through the body which is contributed to the cardiovascular system comprising of the blood vessels and the heart. The blood carrying oxygen leaves the lungs to flow into the heart through the pulmonary veins, which are pumped to the rest of the body from the left ventricle through the aorta and its corresponding branches.

Mechanism of Breathing

• Breathing is the physical process of inhaling oxygen and exhaling carbon dioxide.
• The mechanism of breathing involves two main processes: inspiration and expiration.
• Inspiration occurs when the diaphragm and the external intercostal muscles contract.
• Expiration occurs when the diaphragm and the intercostal muscles relax.
• The contraction or relaxation of muscles around the lungs changes the entire volume of air inside the lungs, and so does the pressure.
• If the pressure inside the lungs is more than the outside, the air rushes out. If the opposite happens, the air rushes in.
• Due to the high elasticity of the lung tissue and low surface tension of moisture in the lungs, the lungs have higher compliance.

RESPIRATORY VOLUMES AND CAPACITIES
Respiratory Volumes

Respiratory volume simply connotes the amount of air that our lungs can inhale, absorb or exhale under certain conditions. It can also be regarded as the lung volume definition.

There is an apparatus for the calculation of volumes of air present in the lungs. This apparatus is recognized as a ‘Spirometer’. It also enables us to check other criteria associated with the lungs.

The respiratory volume can be further categorized into:

1. Tidal Volume (TV): Tidal volume can be best explained as the quantity of air that we breathe in and out of the body at the time of normal breathing. It stands roughly around 500 ml. A normal person takes 12-16 breaths each minute. So, if we calculate the tidal volume in a minute, it stands around 6000-8000 ml per minute.

2. Inspiratory Reserve Volume (IRV): Whenever we inhale air beyond the normal capacity by exerting maximum force, that extra amount of inhaled air is termed as inspiratory reserve volume. It is calculated that the approximate value comes somewhat between 2500 ml to 3000 ml.

3. Expiratory Reserve Volume (ERV): Whenever we exhale air beyond the normal capacity by exerting maximum force, that extra amount of exhaled air is explained as expiratory reserve volume. It is calculated that the overall value comes around 1000-100 ml.

4. Residual Volume (RV): After releasing the air from the body, some amount of air still remains in the lungs. Thus, the amount of air still remaining in the lungs, subsequent to vigorous/energetic expiration is quoted as Residual volume. The approximate-data ranges between 1100 ml-1200 ml.

Human Lung Capacity
From the above discussion, it is clear that there are certain lung

volumes and capacities associated with the human respiratory system. Now, what is lung capacity? When two or more respiratory volumes/lung volumes are combined, the result we get is lung capacity or to be more precise respiratory capacity.

The respiratory capacity can be further categorized into:

1. Inspiratory Capacity (IC): Whenever person inhales air immediately followed by releasing it under usual condition (i.e., not forcibly), the air that is received by the body is designated as inspiratory capacity. Thus, inspiratory capacity is found to be a summation of tidal volume and inspiratory reserve volume.

2. Expiratory Capacity (EC): Just in an opposite manner, when person exhales air immediately followed by inhalation under usual condition (i.e. not forcibly), the air that is released out of the body is designated as expiratory capacity. Thus, expiratory capacity is found to be a summation of tidal volume and expiratory reserve volume.

3. Functional Residual Capacity (FRC): As mentioned earlier, some amount of air still stays in the lungs, even after exhalation of air under ordinary conditions. This amount of air can be mentioned as functional residual capacity. It is basically a combination of expiratory reserve volume and residual volume.

4. Vital Capacity (VC): The maximum amount of air taken in or released out by someone immediately followed by exhalation and inhalation of air respectively is defined as vital capacity. It is an aggregation of tidal volume, inspiratory reserve volume and expiratory reserve volume.

5. Total Lung Capacity: Total lung capacity is interpreted as the absolute amount of air remaining in the lungs prior to vigorous inhalation of air. This is a sum total of residual volume, expiratory reserve volume, inspiratory reserve volume and tidal volume. The total lung capacity formula is RV+ERV+TV+IRV. Total lung capacity in ml is around 5800 ml.

LUNG VOLUMES AND CAPACITIES VALUES

We can express lung volumes and capacities normal values as under:
1. Inspiratory capacity=3000 ml – 3500 ml
2. Expiratory capacity = 1500 ml –1600 ml
3. Functional residual capacity = 2500 ml
4. Vital capacity=3500ml – 4500ml
5. Total lung capacity = 5800 ml

Lung Volume vs Lung Capacity
There is a vast difference between Lung volume and lung capacity. The amount of air that the human lung can inhale, perceive or exhale is determined as Lung volume. On the other hand, the assimilation of two or more lung volumes gives us lung capacity.

Questions for study

1. Define Respiration. What do you mean by external respiration and tissue respiration?
2. What do you mean by vocal cords?
3. Explain in detail about the physiology of respiration.
4. What structural changes occur from trachea up to alveoli?
5.Define and give normal volume from vital capacity, tidal volume, inspiratory and expiratory reserve volumes, residual volume and functional residual capacity.
6.Draw a labelled the figure showing respiratory system

9

Digestive System

Chapter Outlines:

KEY TERMS/LEARNING OBJECTIVES

The chapter on the digestive system gives detailed information on various organs that aid in the digestion of food. It also describes the layers of the GI tract. The functions of each organ in the digestion process are described briefly. The chapter

also emphasises on the various outcomes of digestion in each organ. Lastly, the chapter gives details about the structure and physiology of the liver.

INTRODUCTION

The process of tissue development and repair requires a constant supply of nutrients. These nutrients are obtained through the food we eat. The food also acts as a source of energy for conducting various activities. However, the food we consume is highly complex and contains large molecules that do not pass through the cells. Hence, it must be broken down into smaller substances to absorb and distribute through each cell in the body. This process is known as digestion. Thus, in **digestion,** food substances are broken down into simple chemical substances that can be easily absorbed by the body cells. The organs that allow the breakdown of food form the digestive system. The functions of the digestive system are as follows:

- Intake of food substances
- Conversion of large molecules into small substances
- Passage of small substances through the digestive tract
- Secretion of substances that aid in the digestion of food
- Digestion of the food
- Absorption of food particles through blood
- Removal of wastes from the body

STRUCTURE OF THE DIGESTIVE SYSTEM

The digestive system is divided into the **alimentary canal** or **gastrointestinal (GI) tract** and **accessory organs.** The GI tract is a tube-like structure extending from the mouth to anus. The process of digestion occurs in the GI tract. It involves oral cavity, pharynx, oesophagus, stomach, small and large intestines. The accessory organs include teeth, tongue,

salivary glands, liver, gallbladder, and pancreas. The process of digestion does not happen in these organs; however, they help in the breakdown of food substance.The organs and glands of the digestive system are structurally and functionally linked together. Hence, the process of digestion and absorption on each stage is dependent on the previous stages.

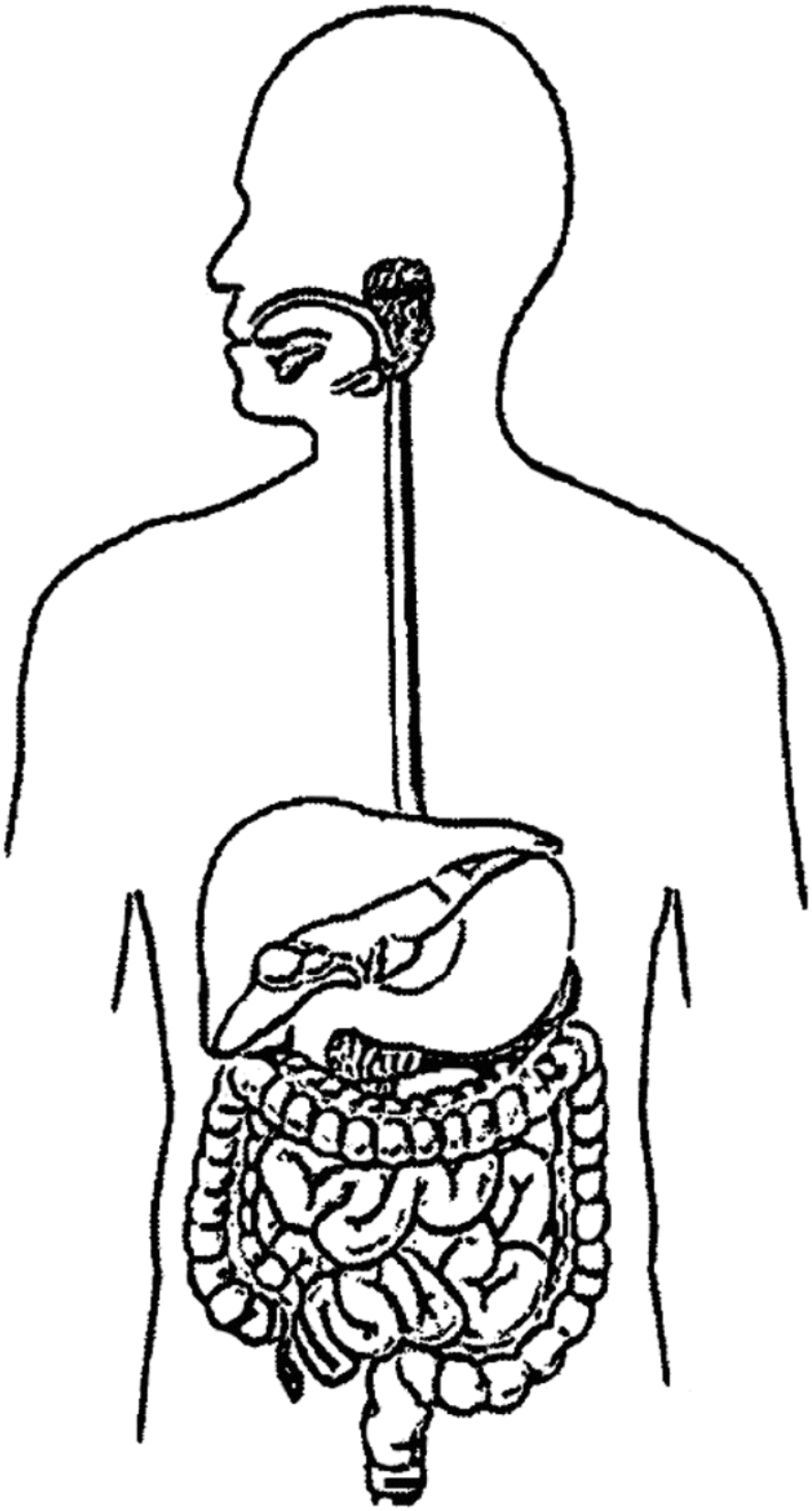


Figure 9.1: Digestive System

LAYERS OF THE GI TRACT

The walls of the GI tract from the oesophagus to the anus show the same basic layers of tissues with a few modifications. These layers include:

- Mucosa
- Submucosa
- Muscularis
- Serosa/adventitia

Mucosa:

The mucosa forms the innermost lining of the GI tract. It is composed of the mucous membrane, lamina propria, and muscularis mucosa.

- **Mucous Membrane:** The mucous membrane of the mouth, pharynx, oesophagus, and anus is made up of nonkeratinised stratified squamous epithelial cells, whereas the stomach and intestine contain simple columnar epithelial cells. There are a few exocrine cells between the epithelial cells that secrete mucous and fluids inside the lining of the GI tract. The mucous acts as a protective barrier against any damage by digestive enzymes and lubricates the GI tract. The mucous membrane also contains a few endocrine cells that secrete the hormone inside the GI tract.
- **Lamina Propria**: The lamina propria contains areolar connective tissues with multiple blood and lymphatic vessels. These vessels act as a route for transport of nutrients that are absorbed in the GI tract to the other body cells.
- **Muscularis Mucosa:** The muscularis mucosa is made up of smooth muscles. It causes folds of the mucous membrane in the stomach and small intestine. This increases the surface area that causes more absorption of nutrients.

Submucosa:

The submucosa is located between the mucosa and muscularis. It is made up of areolar connective tissue and contains a vast network of neurons known as the **submucosal plexus.** The neurons regulate the secretions of fluids in the

GI tract. Besides neurons, the submucosa also contains multiple blood vessels and lymphatic vessels that absorb nutrients from the GI tract.

Muscularis:

The muscularis layer of the mouth, pharynx, and upper oesophagus contains skeletal muscles. The skeletal muscles allow voluntary swallowing of the food. These muscles are also located in the anus that controls the output of faecal matter. The layer below the lower oesophagus contains smooth muscles. The smooth muscles cause involuntary contractions that lead to break down of large food particles, mixing it with digestive juices, and propulsion through the GI tract.

Serosa:

The serosa is the outermost layer of the GI tract. The serosa of the organs in the thoracic cavity is made up of loose fibrous tissue, whereas the abdominal organs are covered with peritoneum.

ORAL CAVITY

The oral cavity, also known as buccal cavity or mouth, is bounded by the cheeks, teeth, tongue, palate, and lips. The lips form the opening of the mouth, whereas cheeks are located on the lateral sides of the oral cavity. The lips and cheeks keep the food between teeth and ensure uniform chewing.

The palate forms the top part of the mouth. It separates the oral and nasal cavities. There are two types of palates, anterior bony hard palate and posterior muscular soft palate.

The tongue forms the floor of the mouth. It contains little projections called **papillae** with various taste buds. The taste buds are responsible for the sensation of taste. The tongue also helps in chewing, swallowing and aids in speech.

The teeth are the accessory digestive organs that are made up of crown, root, and neck. The crown is the visible white part of the tooth. It is covered with enamel made up of calcium salts. The **enamel** is the hardest part of the body. It forms a protective coating over the teeth that prevents the wear and tear of

teeth. It also prevents reactions against acid. The crown contains a large space called the **pulp cavity** that contains blood vessels and nerves.

Figure 9.2: Tooth

An adult contains 32 teeth, 16 in each jaw. Each jaw contains a pair of **three molars, two premolars, one canine** and **two incisors.**The main function of the teeth is chewing or mastication. However, each type of teeth has a different role in chewing. For example, incisors are responsible for cutting action, whereas canines tear the food substances. Similarly, premolars and molars are responsible for grinding action

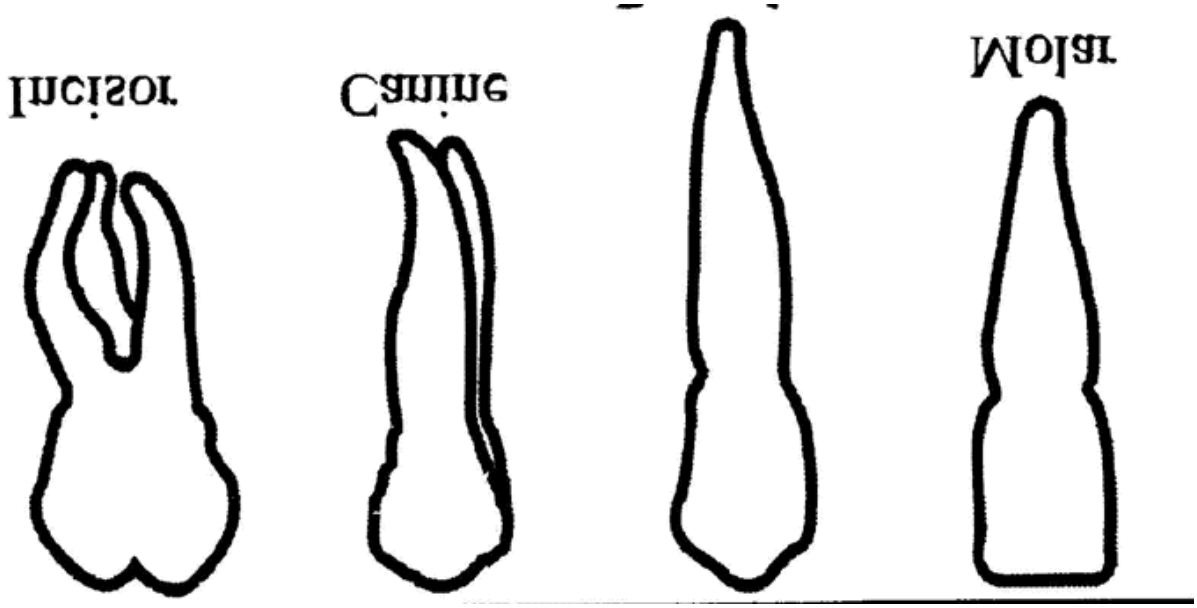


Figure 9.3: Types of Teeth

Salivary Glands:

The salivary glands are responsible for the secretion of saliva into the mouth. There are three pairs of salivary glands inside the oral cavity. They include parotid glands, submandibular glands, and sublingual glands. The **parotid** glands are the **largest glands** located on the sides of the face, below the ears. They release saliva through **Stensen duct.** The **submandibular** or **submaxillary** glands are located in the lower part (floor) of the mouth. They release saliva through **Wharton duct.** The **sublingual glands** are the **smallest** salivary glands. They are also located on the floor of the mouth. They drain saliva in the oral cavity by **Bartholin duct.** The salivary glands secrete saliva by sight, smell, and even the presence of food in the mouth.

Saliva is mainly made up of water and contains a small proportion of solids. The functions of the saliva include keeping the mouth moist and lubricating lips and tongue at the time of speech. It also contains a few enzymes that

help in the digestion of food. Some of the important enzymes are amylase, maltase, and lingual lipase. The **amylase,** also known as **ptyalin,** is responsible for the conversion of cooked starch into maltose. **Maltase** converts maltose into glucose. The **lingual lipase** is responsible for the digestion of lipids.

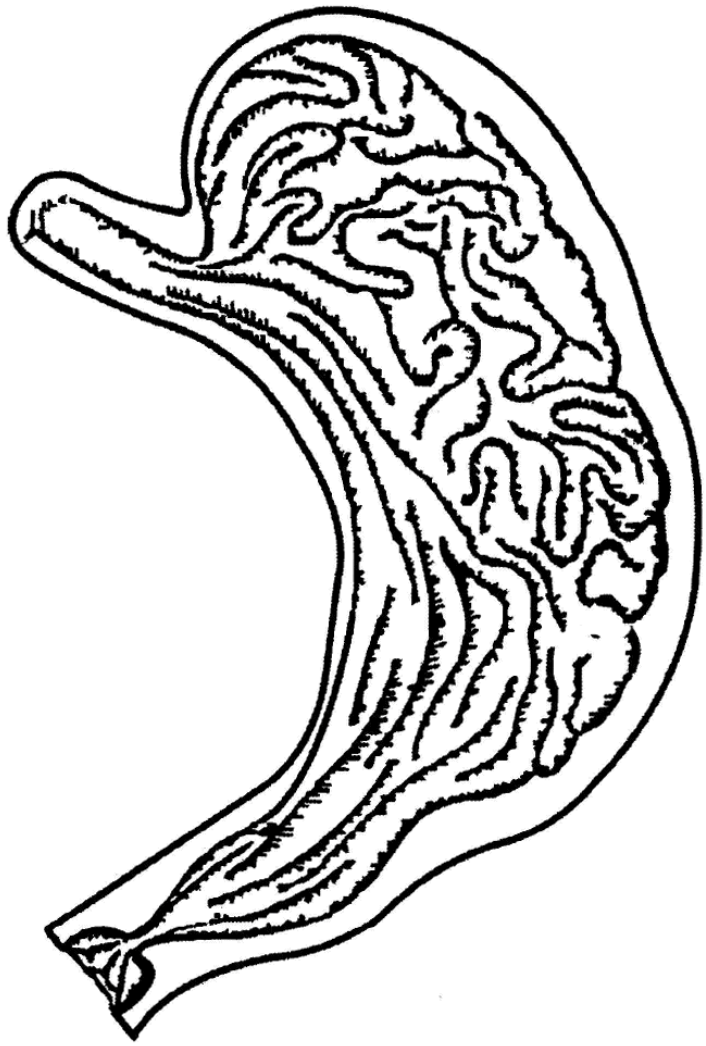
PHARYNX

The pharynx does not participate in the digestion of food. However, it propels the swallowed food down into the oesophagus and later into the stomach.

OESOPHAGUS

The oesophagus is a muscular tube that carries food to the stomach; digestion does not occur in the oesophagus. It pierces the diaphragm and joins the stomach. The junction between the oesophagus and stomach contains a ring of smooth muscles known as **lower oesophageal sphincter (LES)**. The LES controls the passage of food in the stomach. When it relaxes, the food enters the stomach, whereas the contraction prevents the passage of food back into the oesophagus.

STOMACH



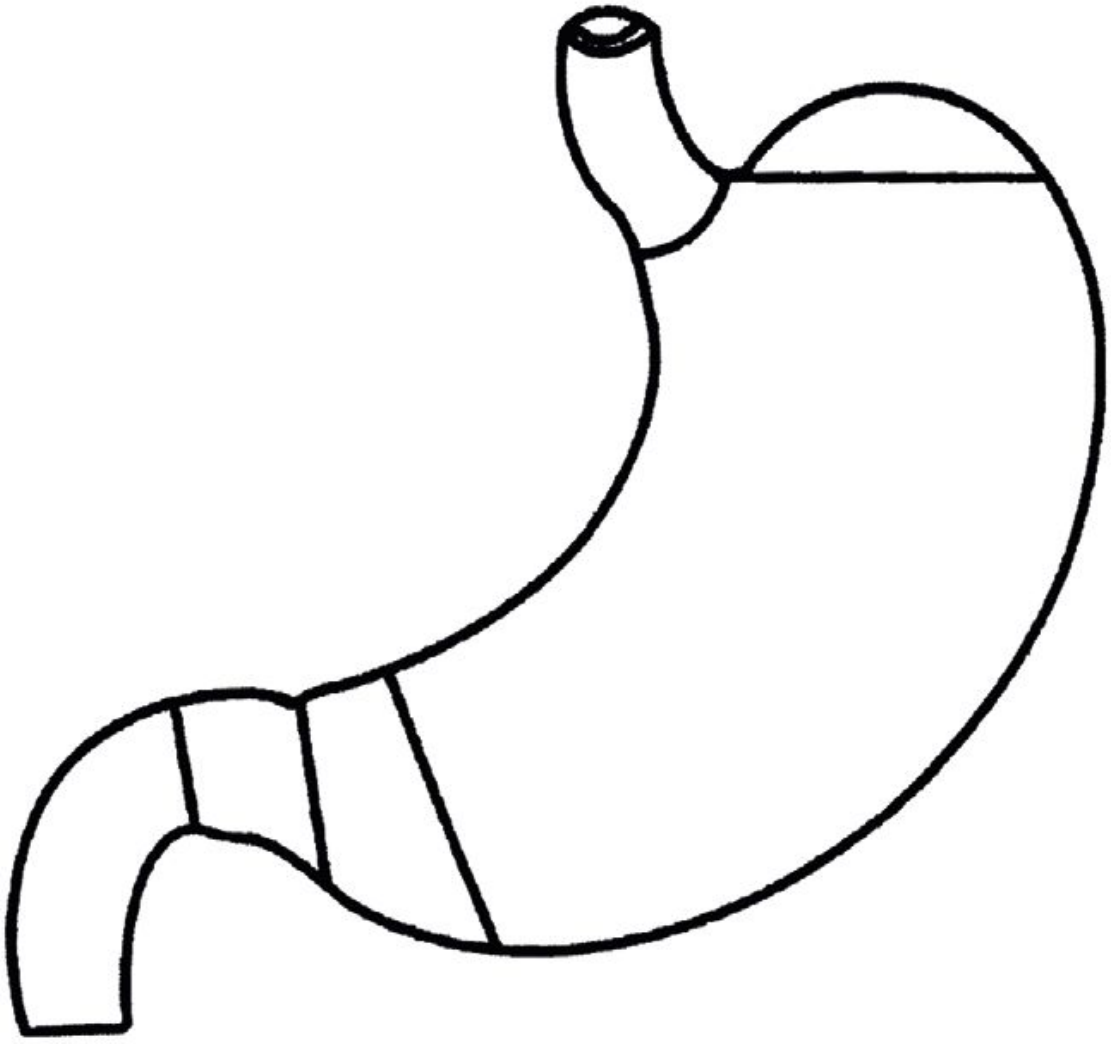


Figure 9.4: L.S. Stomach

The stomach is a J-shaped sac located between the oesophagus and small intestine. It is divided into four parts: the cardia, fundus, body, and pylorus. The cardia portion is the opening of the oesophagus into the stomach. The fundus is a rounded part to the left of the cardia. The body of the stomach extends from the fundus and forms the central part of the stomach. It is the largest part of the stomach. The food is mainly stored in the fundus and body. The pylorus forms the last part of the stomach. It communicates with the small intestine through the pyloric sphincter. The process of digestion mainly occurs in the pylorus.

The mucosa of the stomach contains wrinkles or folds known as **rugae.** It also has special cells that collectively form gastric juice. These include:

• **Mucous cells:** These cells secrete **mucous.**
• **Chief cells:** The chief cells secrete enzymes **pepsinogen** and **gastric lipase.**
• **Parietal cells:** The parietal cells secrete **hydrochloric acid (HCl).** The HCl converts pepsinogen to pepsin and maintains an acidic pH that helps in the destruction of microorganism that enters the stomach. These cells also produce **intrinsic factors** that play an important role in the absorption of vitamin B_{12}.

Besides these, the stomach also contains **G cells** that secrete **gastrin** hormone in the blood.

SMALL INTESTINE

The small intestine extends from the pyloric sphincter to the ileocecal sphincter of the large intestine. It is 6 m long that starts from the smallest part called the **duodenum,** followed by **jejunum** and then ends into the largest part called **theileum.** The small intestine is a site for maximum digestion and absorption of nutrients. This occurs due to the longer length and presence of circular folds, villi and microvilli. The circular folds are located in the mucosa and submucosal layer. They enhance the absorption process by increasing the surface area. The villi and microvilli are hairlike projections of the mucosa that further increases the surface area. The epithelial cells of the small intestine are specialised to secrete intestinal juice. These cells include:

• **Paneth cells:** They secrete lysozyme that destroys bacteria.
• **S cells:** They secrete secretin enzyme.
• **CCK cells:** They are responsible for the secretion of cholecystokinin.
• **K cells:** They secrete glucose-dependent insulinotropic peptide enzyme

Besides these, the small intestine contains brush-border enzymes that secrete alpha dextrinase, maltase, sucrase, lactase and peptidase.

PANCREAS, LIVER, AND GALL BLADDER

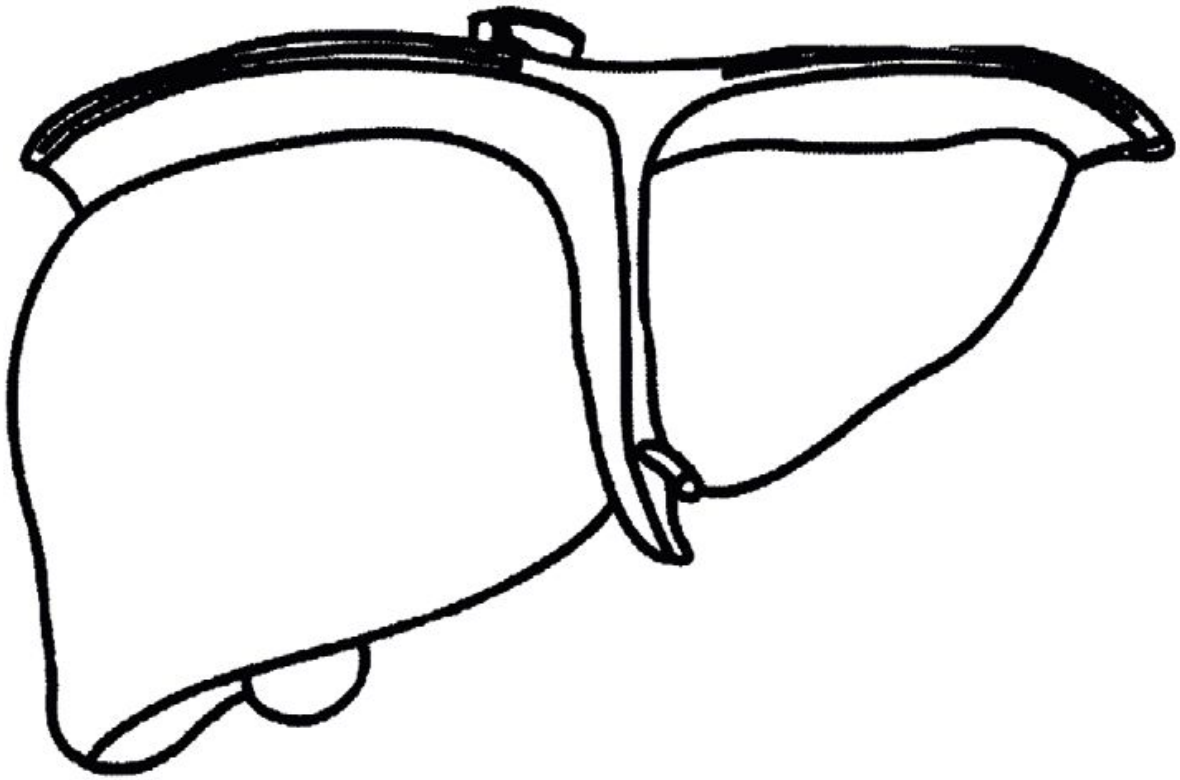


Figure 9.5 (a): Parts of Liver

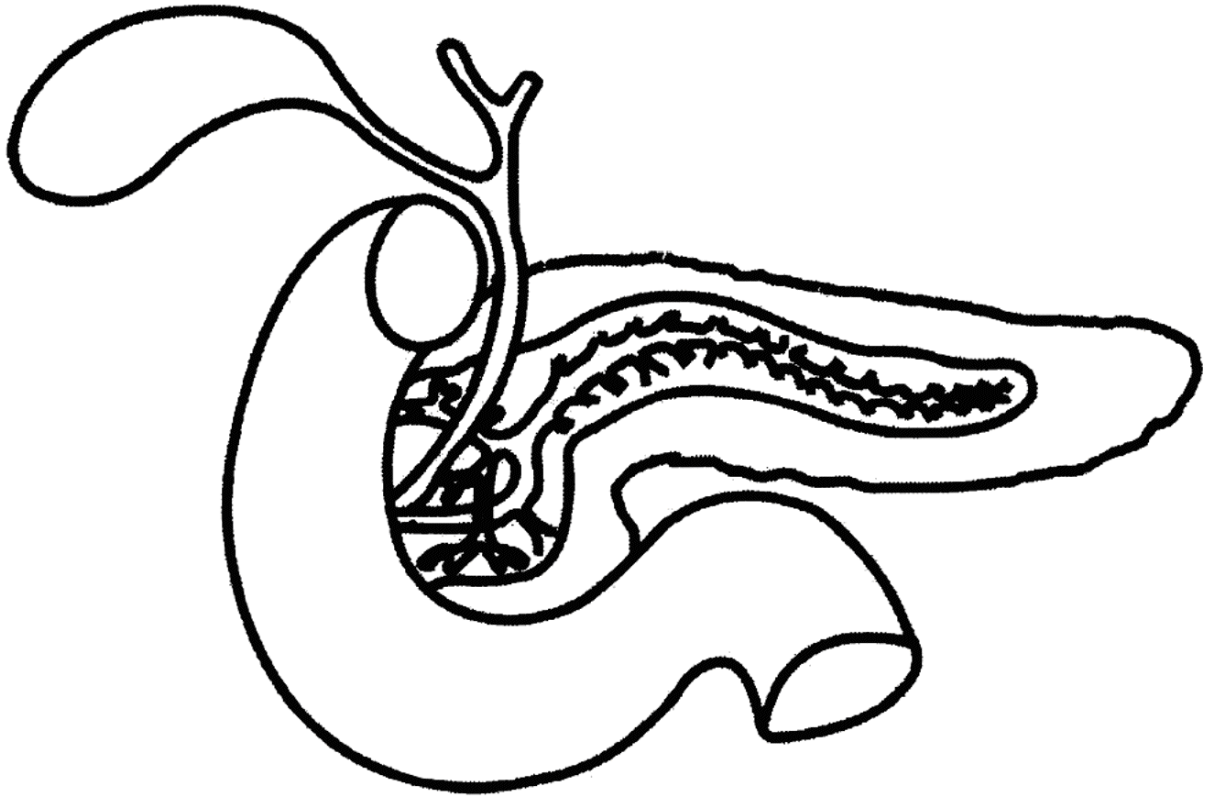


Figure 9.5 (b): Liver, Pancreas and Gall Bladder

The pancreas is a pale grey coloured organ located on the left side of the upper abdomen. It is divided into a broad head, body, and tapering tail. It contains lobules of glandular epithelial cells that have both exocrine and endocrine functions.

• **Exocrine function:** About 99% of glandular epithelial cells function as an exocrine gland. They are known as **acini.** They secrete **pancreatic juice,** a mixture of multiple digestive enzymes. The digestive enzymes include:

• **Starch-digesting Enzyme:** pancreatic amylase
•**Protein-digesting Enzyme:** trypsin, chymotrypsin, carboxypeptidase, and elastase
• **Lipid-digesting Enzyme:** pancreatic lipase
•**Nucleic Acid-digesting Enzyme:** ribonuclease and deoxyribonuclease

The exocrine cells release pancreatic juice into two ducts called the pancreatic duct and the accessory duct. The pancreatic duct unites with the

common bile duct to form the **hepatopancreatic ampulla.** The hepatopancreatic ampulla will release the pancreatic juice and bile into the duodenum. The release is regulated by a mass of smooth muscle called **sphincter of Oddi.**

• **Endocrine function:** The remaining 1% of the cells function as an endocrine gland. These cells are known as **islets of Langerhans.** They secrete hormones glucagon, somatostatin, insulin, and pancreatic polypeptide in the blood.

The liver is the heaviest gland located in the right abdominal area, just below the diaphragm. It secretes **bile juice** that emulsifies fats. **Emulsification** is a process by which the large fat molecules are broken down into small molecules. Bile is released into small bile canaliculi that unite to form the common hepatic duct. The structure and functions of the liver are explained further in this chapter.

The gallbladder is a pear-shaped sac located under the liver. It functions in the storage of bile. The bile from the hepatic duct enters the gallbladder through the cystic duct. The cystic duct and the common hepatic duct combine to form the **common bile duct** that releases bile into the duodenum. When the fatrich food enters the small intestine, it releases **cholecystokinin** hormone that promotes the release of bile from the gallbladder.

LARGE INTESTINE

The large intestine is the last part of the GI tract. It is 1.5 m long that extends from the ileum to the anus. It is divided into caecum, colon, rectum, and later into the anal canal. The colonis further divided into ascending colon, transverse colon, descending colon, and sigmoid colon. It forms an arch over the small intestine. The anal canal opens into the anus that allows the output of faecal matter. The process of defecation is controlled by the presence of anal sphincter. The large intestine contains absorptive and goblet cells that absorb water and secrete mucous, respectively.

PHYSIOLOGY OF DIGESTIVE ORGANS

The breakdown of food undergoes mechanical and chemical digestion. The mechanical digestion involves the reduction in the size of the food particles, whereas when the complex chemical molecules are converted into simple absorbable form, it is known as chemical digestion.

The digestion process begins in the mouth. The food particles are grinded into small particles through teeth. This process is known as mastication. It is mixed with saliva to form a soft, swallowable mass of food called a **bolus.** The salivary amylase or ptyalin converts disaccharide and polysaccharide starch into maltose (monosaccharide). The saliva also contains lingual lipase that breaks fats and oils into fatty acids and diglycerides. The bolus is then pushed down into the pharynx with the help of the tongue. The pharynx contains skeletal muscles that contract and propel food into the oesophagus. The oesophagus also undergoes peristaltic contraction and contains a mucous membrane that aid in the passage of food into the stomach.

In the stomach, the peristaltic contractions continue in the fundus. This pushes the food particles into the pylorus. Since the particles are too large for pyloric sphincter, they are made into smaller particles inside the body of the stomach. During this process, the food particles combine with the gastric juice to form a soupy liquid called **chyme.** The stomach may act as a temporary reservoir for food. The HCl produced by the parietal cells denatures the protein in the food. It converts the inactive pepsinogen into active pepsin that causes the digestion of proteins. It also stimulates the release of a hormone that promotes the flow of bile and pancreatic juice in the duodenum. The gastric juice also includes gastric lipase that digests triglyceride. The G cells of the stomach secrete gastrin hormone that promotes the production of HCl by parietal cells. The stomach does not promote the digestion of carbohydrates.

The absorption of nutrients is minimal in the stomach. It only absorbs some water, salts, fatty acids, certain drugs and alcohol.

The chyme then travels in the small intestine through two special movements called segmentation and migrating motility complexes. The food reaching the small intestine is already digested by saliva and gastric juice. However, the process of digestion is completed in the small intestine. It

takes place by pancreatic juice, bile and intestinal juice. The process of digestion and absorption in the small intestine is conducted as follows:

Digestion and absorption of carbohydrates: The smaller fragments of starch are broken down into glucose by alpha dextrinase. Sucrase breaks sucrose into glucose and fructose molecules. Lactase digest lactose into glucose and galactose. Similarly, the pancreatic amylase is released into the duodenum to covert polysaccharide into maltose and maltotriose. The maltose and maltotriose are then converted into glucose by maltase. In this way, the disaccharides are converted into monosaccharides in the small intestine. Glucose is absorbed by capillaries of villi and reach the liver through the hepatic portal vein.

Digestion and absorption of proteins: The enterokinase enzyme in the duodenum converts trypsinogen, chymotrypsinogen, procarboxypeptidase, and proelastase to trypsin, chymotrypsin, carboxypeptidase, and elastase, respectively. These enzymes convert protein into peptides. The peptidase enzyme then converts the peptides to amino acids. The amino acids are also absorbed by the capillaries of villi and reach the liver through hepatic portal vein.

Digestion and absorption of lipids: The intestinal and pancreatic lipases convert the triglycerides to fatty acids and glycerol. The bile also emulsifies lipid molecules into several small lipid globules. The triglyceride molecules are coated with protein molecules to form **chylomicrons.** The chylomicrons are absorbed in the lacteals of the villi that drain them into the thoracic duct of the lymphatic system.

About 90% of the absorption takes place inside the small intestine. The unabsorbed material is passed in the large intestine. The large intestine is a site for absorption of water, ions and vitamins. The remaining semisolid material is known as faces. The peristalsis of colon pushes the faecal matter into the rectum and later in the anus, where the elimination occurs.

Name of the Enzyme Saliva
Salivary amylase

Source Substrate Product
Salivary glands Starches

(polysacharides)
Lingual lipase Lingual gland

in tongue
Triglocerides (fats and oils) and other lipids
Maltose (di
saccharide),
maltotriose
(tricaccharide) and a-dextrins

Fatty acids and deglycerides
Gastric Juice
Pepsin (activated pepsinogen by HCl)

Gastric lipase
Stomach chief cells

Stomach chief cells
Proteins Products: Peptides

Triglycerides (fats and oils) and other lipids

Fatty acids and monoglycerides

Name of the Enzyme Pancreatic Juice
Pancreatic amylase

Source Substrate Product

Pancreatic acinar cells Starches
(Polysacharides)

Trypsin (activated from trypsinogen by enterakinase)
Chymotrypsin
(activated from
chymotrypsinoges by trypsin) Elastase (activated from
proelastase by
trypsin)

Carboxypeptidase (activated from
procarboxypeptidase by trypsin)

Pancreatic lipase
Pancreatic acinar cells Proteins Maltose (Di
saccharide), Maltotriose
(Tricaccharide) and a-dextrins

Peptides

Pancreatic acinar cells Amino acid at carboxyl end of peptides
Amino acids and peptides

Pancreatic acinar cells
Ribonuclease

Deoxyridonase Pancreatic acinar cells

Pancreatic acinar cells Triglycerides
(fats and oils)
emulsified by bile salts

Ribonucleic acid Faty acids and monoglycerides

Nucleotides
Deoxribonucleic acid
Nucleotides

Brush Border Enzymes a-Dextrinase
Maltase
Sucrase
Small intestine Small intestine Small intestine a-Dextrins Maltose
Sucrose

Lactase Small intestine Lactose
Enterokinese Small intestine Trysinogen

Glucose
Glucose

Glucose and fructose
Glucose and fructose
Trypsin

Name of the Enzyme Peptidases
Aminopeptidase

Source Substrate Product
Small intestine
Dipeptidase
Nucleosidases and phosphatases
Small intestine Small intestine

Amino acid and amino end of peptides

Dipeptides
Nucleotides
Amino acids and peptides
Amino acids

Nitrogenous
bases, peptoses and phosphates

Figure 9.6:

Chemical Digestion of Food
LIVER: STRUCTURE OF THE LIVER

As mentioned earlier, the liver is the heaviest gland in the body. It weighs about 1-2.3 kg. It is located on the right and upper side of the abdomen, just below the diaphragm. The upper part of the liver that is situated below the diaphragm is smooth and curved, whereas the posterior region is irregular. A **falciform ligament** separates the liver mainly into two lobes, right and left lobes. The right lobe is the largest lobe, which further divides into quadrate and caudate lobes.

The liver is made up of fundamental unit called **lobule** that forms a rough honeycomb-like structure of the liver cells. The liver cell, also known as **hepatocyte,** are arranged in plates to form a three-dimensional structure called **hepatic laminae.** The space between the two hepatic plates is filled with multiple blood capillaries called **hepatic sinusoids.** The hepatic sinusoids receive blood from the hepatic artery and hepatic portal vein. It then transfers the blood into the **central vein** that drains the blood into inferior vena cava.

The hepatocytes are responsible for the secretion of bile. The bile is released through small ducts between hepatocytes called the **bile canaliculi.** The bile canaliculi merge into the bile duct, which eventually forms two large **hepatic ducts.** The hepatic ducts combine to form the **common hepatic duct.** The common hepatic duct merges with the cystic duct of the gallbladder to form **common bile duct** that transfers the bile into the duodenum. The bile duct, the branch of a hepatic artery and the branch of a portal vein together forma **portal triad.** Each lobule is surrounded by multiple such **portal triads.**

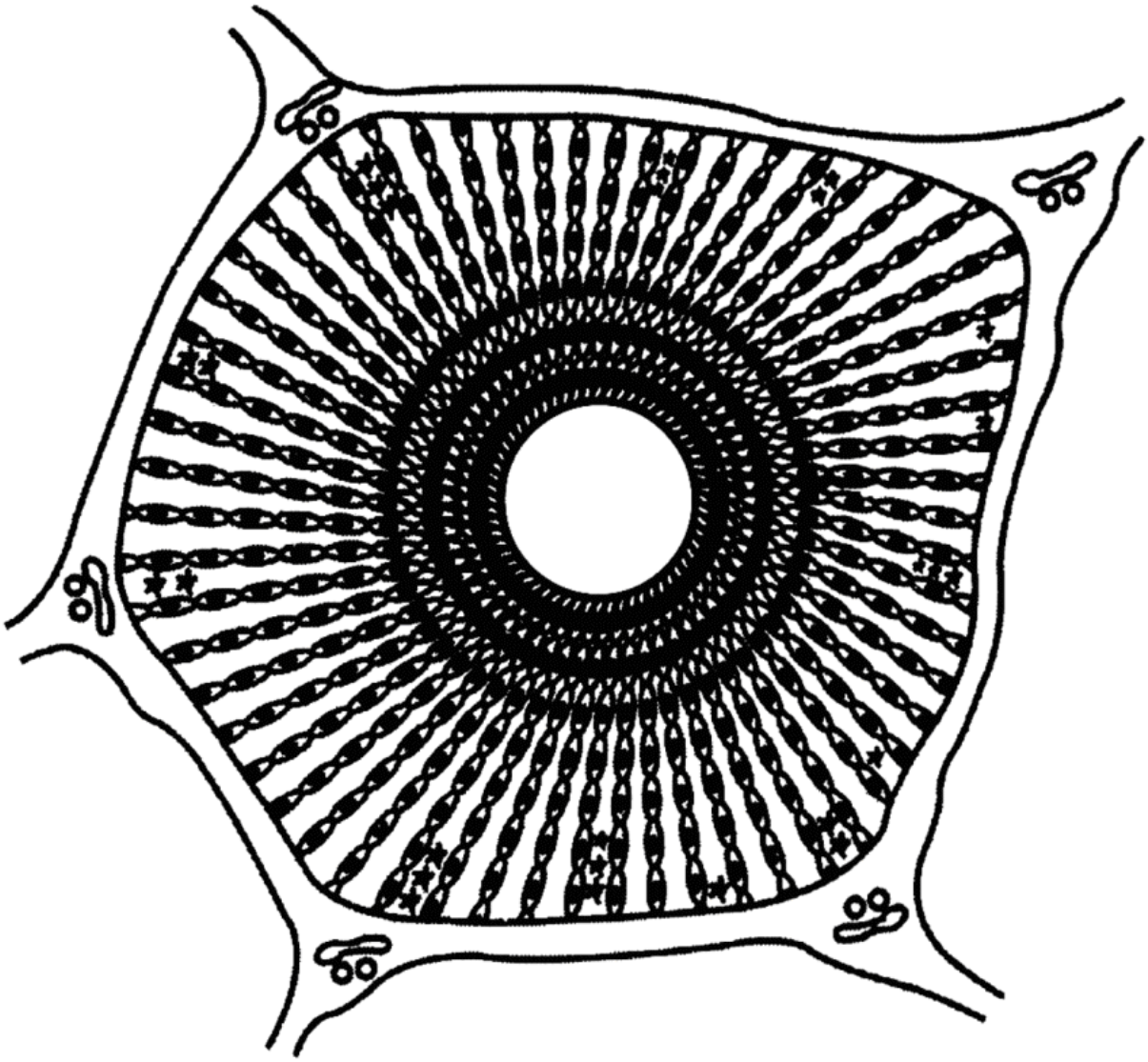


Figure 9.7 (a): Cross-section of Liver Cells

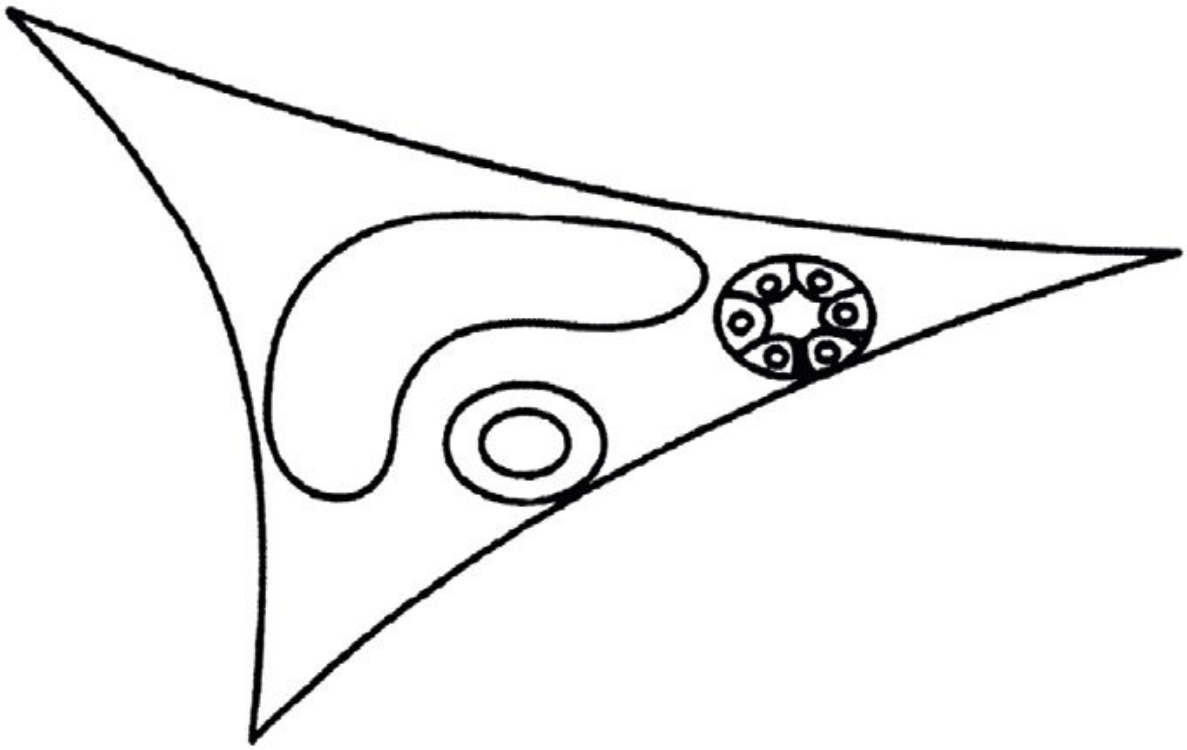


Figure 9.7 (b): Hepatic Lobule

PHYSIOLOGY OF LIVER

Some of the functions of the liver are as follows:

• **Secretion of bile:** Hepatocytes secrete an alkaline fluid called bile. It is made up of 97.6% of water and a few organic and inorganic substances. The organic substances include bile salts (salts of glycocholate and taurocholate), cholesterol, lecithin, bile pigment (mainly bilirubin) and mucin. The inorganic compounds in the bile are sodium, calcium, potassium, chloride and bicarbonate. Bile salts reduce the surface tension of the fatty molecules that lead to the process of emulsification.They also help in the absorption of fat molecules. The bilirubin is obtained through the phagocytosis of haemoglobin. It is then metabolised and excreted in the faeces.

• **Carbohydrate metabolism:** When the glucose and amino acids are produced after the digestion of food, they are carried to the liver through the hepatic portal vein. Glucose is stored in the form of glycogen in the liver. When the blood glucose level decreases, the glycogen is reduced into glucose and released directly into the blood. The liver also converts amino acids, lactic acid and other sugars like fructose and galactose into glucose. This increases the level of glucose in the blood. Similarly, when the blood

glucose level is high, the liver converts the glucose into glycogen and triglycerides. This reduces the blood glucose level. Thus, the liver helps in maintaining the blood glucose level.

• **Protein metabolism:** The liver cells cause deamination of the amino acids for the production of energy. The deamination is a process by which the amine group (NH_2) is removed.The excess amine group is then excreted in the form of urea.

• **Lipid metabolism:** The stored fatty acids are converted into simple carbohydrates for the production of energy. Hence, in this way, the liver helps in the desaturation of fats in the body. Besides this, the hepatocytes also synthesise cholesterol and lipoproteins.

• **Phagocytosis:** The Kupffer cells of the liver are responsible for the destruction of red blood cells, white blood cells and bacteria.

• **Activation of vitamin D:** The active form of vitamin D is synthesised inside the liver, kidneys, and skin.

• **Storage:** The liver acts as a storage house for iron, copper, and vitamins, such as A, B12, D, E, and K.

• **Functions related to blood:**

• Destruction of red blood cells for the production of bilirubin.

• Formation of plasma protein, albumin, and globulin.

• Production of blood clotting factors (prothrombin and fibrinogen).

•**Detoxification:** Liver can detoxify alcohol by converting it into a less harmful form. It also causes excretion of drugs like penicillin, erythromycin, and sulphonamides.

METABOLISM

Metabolism is referred as all the chemical reactions in the body that occur due to nutrients, which are absorbed after digestion. The nutrients undergo chemical oxidation to provide energy. There are two types of metabolic processes: anabolic and catabolic reactions. The catabolic reaction involves breakdown of large molecules into small molecules that releases chemical energy, whereas anabolic reaction is the conversion of small molecules into large molecules that require energy. Thus, the balance between the energy is maintained by these two reactions. The rate at which the metabolic reactions use energy is known as metabolic rate. However, as multiple factors can affect the metabolic rate, it is measured under the resting position with no

food for at least 12 hours. Such condition is known as basal state and such metabolic rate is termed as basal metabolic rate (BMR).

Figure 9.8: Summary of the Digestive System
Composition of digestive juices :

• Saliva: Salivary amylase, lingual lipase
• Gastric juice: Mucous, pepsinogen, gastric lipase, HCl, intrinsic factor
• Intestinal juice: Secretin, lysozyme, cholecystokinin, alpha dextrinase, maltase, sucrase, lactase, peptidase
• Pancreatic juice: Pancreatic amylase, pancreatic lipase, trypsin chymotrypsin, carboxypeptidase and elastase
• Bile: Water, salts, bilirubin, cholesterol

Questions for study

1.Explain the term: Digestion and mastication.
2. Where does mastication occur?
3. Draw a neat labelled diagram of digestive system.
4. Explain the role of oral cavity in digestion.
5.Name different types of teeth.
6. Name and describe various layers of the GI tract.
7. Explain the process of digestion in brief.
8. List the functions of liver.
9. Give composition of gastric juice and bile.
10. Write a note on structure of liver.
11. What are hepatic triads?
12. Explain the intestinal juice.
13. List the enzymes that act on carbohydrate, proteins and fats. **14.** Explain the chemical digestion.
15. What is metabolism? Explain the meaning of BMR. **16.** Describe the exocrine function of pancreas.
17. Give function and location of salivary glands.

10

Skeletal Muscles

Chapter Outlines:

After completing the chapter, students will be able:

To understand the structure of skeletal muscle.

To understand and appreciate the relationship between structural features and

the functions of skeletal muscle.

To know the details of functioning of neuromuscular junction.

To know the features of the skeletal muscle disorders of clinical relevance.

INTRODUCTION

Locomotion is a functional necessity of our lifestyle as a human being. Locomotion is a fundamental behaviour with crucial survival value and involves patterned contractions of musculature (muscles). Muscle is one of the soft tissues of the body. Skeletal muscle, also known as voluntary muscle, in vertebrates is most common of three types of muscles in the body. Skeletal muscles are attached to bones by tendons and they produce all the movements of the body parts in relation to each other. Skeletal muscle fibres are bound together by connective tissue and communicate with nerves and blood vessels. They constitute a large fraction of the body weight in humans.

THE STRUCTURE OF SKELETAL MUSCLE

It consists of muscle cells which are elongated and are often tapering to the ends. These cells show several nuclei situated

just under covering of the cell called sarcolemma. Such muscle cells are described as muscle fibres. The length of fibres varies from 10 to 40 milimeters. The muscle fibres lie parallel to one another and when viewed under microscope, they show well marked transverse dark and light bands, hence the name striated or stripped muscle. Each muscle fibre is covered by a fibrous tissue called endomycium. Small bundles of fibres are enclosed in perimycium and the whole muscle in epimycium.

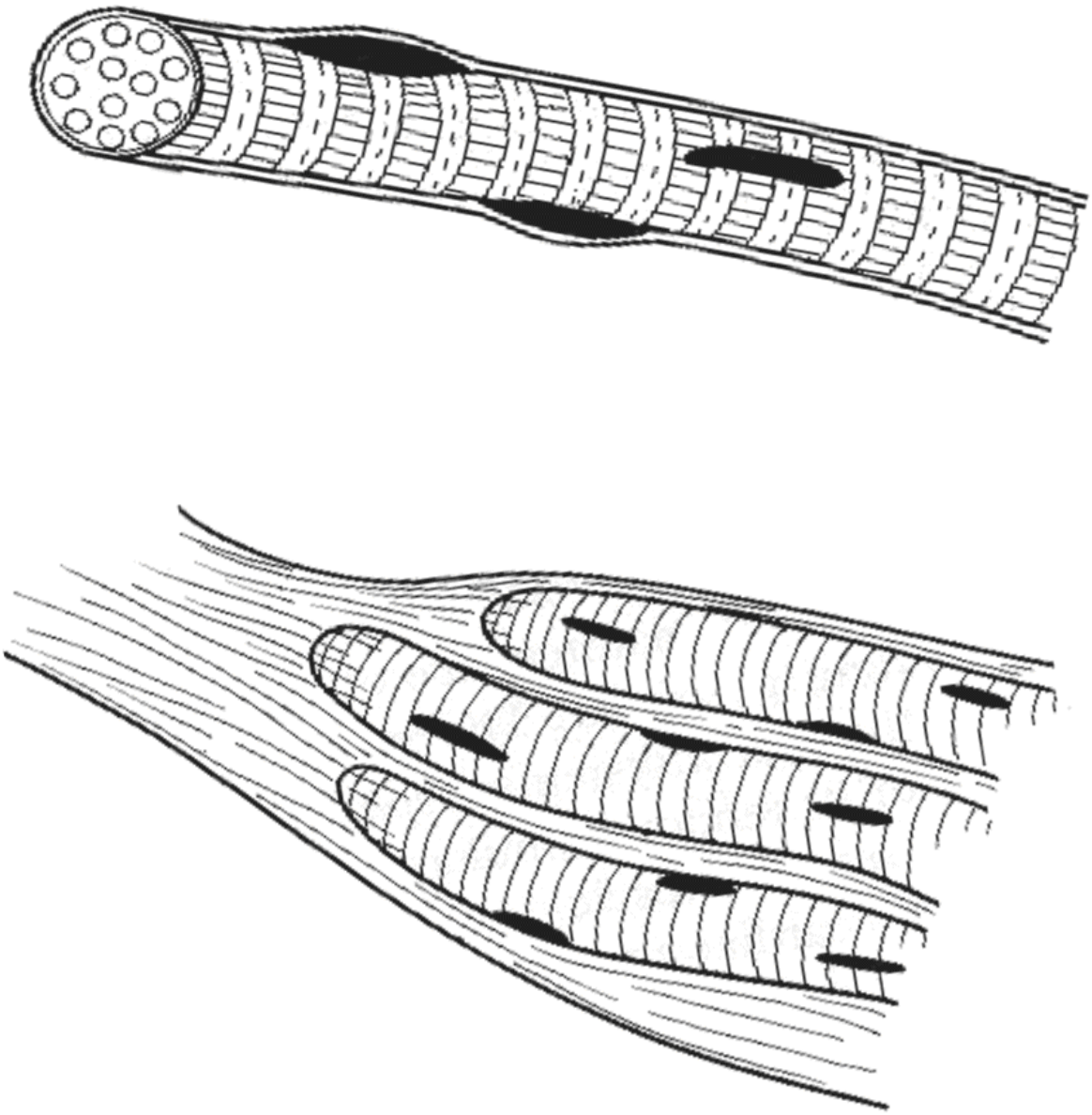


Figure 10.1

The fibrous tissue enclosing the fibres, the bundles and the whole muscle extends beyond the muscle to become the tendon which attaches the muscle to bone or skin. The contraction of this muscle is under the will power of the person, i.e., the conscious control of the person hence the muscle is called voluntary muscle. The skeletal muscle enables body movements.

dO yOu knOw?

Soft tissues are all the tissues in the body that are not hardened by ossification or calcification, such as bones and teeth. Soft tissues connects, surrounds and supports internal organs and bones and includes muscle tendons, ligaments, fat, fibrous tissue, fasciae and synovial membrane.

Properties of Muscles:

1. Contraction : The function of muscle is to contract and when it contracts it pulls. A muscle fibre contracts when it is stimulated by a stimulus (it may be electrical, chemical, mechanical or thermal). The muscle responds to the stimulus showing contraction. In the human body, the necessary stimulus is chemical and is supplied by nerves.

2. Muscle Tone : Muscle is never completely in relaxed condition. It is always in a state of partial contraction which is described as muscle tone. Muscle tone in skeletal muscles is responsible for a posture of the body. A degree of muscle tone is also maintained by smooth and cardiac muscles.

3. Muscle Fatigue : If a muscle is frequently stimulated to contract, its response to the stimulus progressively decreases. Finally, it may not contract by stimulation. Such a condition is called muscle fatigue. The muscle fatigue is usually due to inadequate blood supply.

PHYSIOLOGY QF MUSCLE CONTRACTION

Nerve stimulus is the origin for muscle contraction. Nerve stimulus sets in chemical changes in the muscle which includes breaking down of glucose, glycogen and fat as a result of their oxidation. The chemical changes liberate energy required for contraction. Only about one-fifth of the fuel food is completely oxidized and the remainder is built up again in the form of glycogen. Only about 30 per cent of the energy produced results in work, the remainder being released in the form of heat.

Glucose is a better fuel, because it is more easily burnt and burnt completely. If there is lack of glucose, fat is incompletely burnt and acid or acetone bodies are formed. Excess of acetone bodies produce fatigue in muscle. They neutralize natural alkalies in the blood and can cause acidosis. During muscle contraction, organic phosphates are broken down to inorganic

phosphates and other substances. Organic phosphates are regenerated from inorganic phosphates with the help of energy produced from oxidation of fuel-food.

Physiology of neuromuscular Transmission

The neuromuscular junction is the connection between the end of a large, myelinated nerve fibre and a skeletal muscle fibre. Each skeletal muscle, *in general, is* supplied with one neuromuscular junction. The muscle membrane through which the nerve fibre passes, is called sarcolemma. The nerve fibre then spreads to form *many branches* called hypolemmal axons. These axons in turn end in club like feet called sole feet. The entire nerve ending including hypolemmal axons and the sole feet is called end plate. Beneath the sole foot, is a small space called the synaptic cleft below which there many large folds of the muscle fibre membrane. The sole feet contains many large vesicles containing acetylcholine which is responsible for stimulating the muscle fibre.

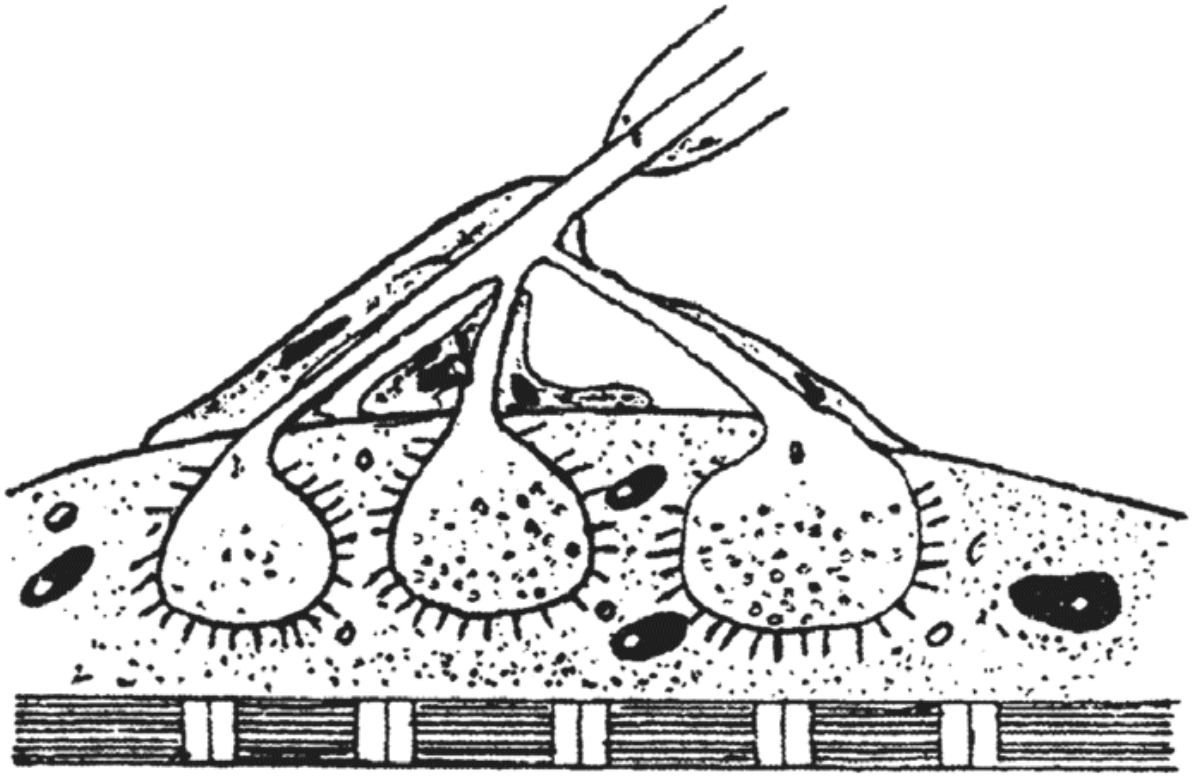


Figure 10.2: Neuromuscular Junction

When a nerve impulse reaches neuromuscular junction, passage of the action potential over the sole feet causes many of the small vesicles of acetylcholine to rupture into the synaptic cleft. The acetylcholine acts on the plasma membrane to increase its permeability. This in turn allows spontaneous leakage of sodium causing end plate potential. When the end plate potential becomes great enough, it stimulates the entire muscle fibre causing an action potential to travel in both directions along the fibre.

When the action potential spreads to the inside of the muscle fibre, then calcium ions are released into the fluid surrounding the fibres. It is the presence of calcium ions that elicits contractile process in the fibres. Immediately after the action potential is over, previously released calcium ions recombine with the reticulum and the muscle contraction ceases.

There is an enzyme called acetylcholinesterase which is responsible for splitting of acetylcholine. The enzyme is present in synpatic cleft. Because of immediate hydrolysis of acetylcholine, the membrane is repolarized again to receive successive stimuli. Acetylcholine provides an amplifying system that allows a very weak nerve impulse to stimulate a very large muscle fibre.

The main muscles of body are shown in the following Fig. 10.3, 10.4, 10.5, 10.6 and 10.7.

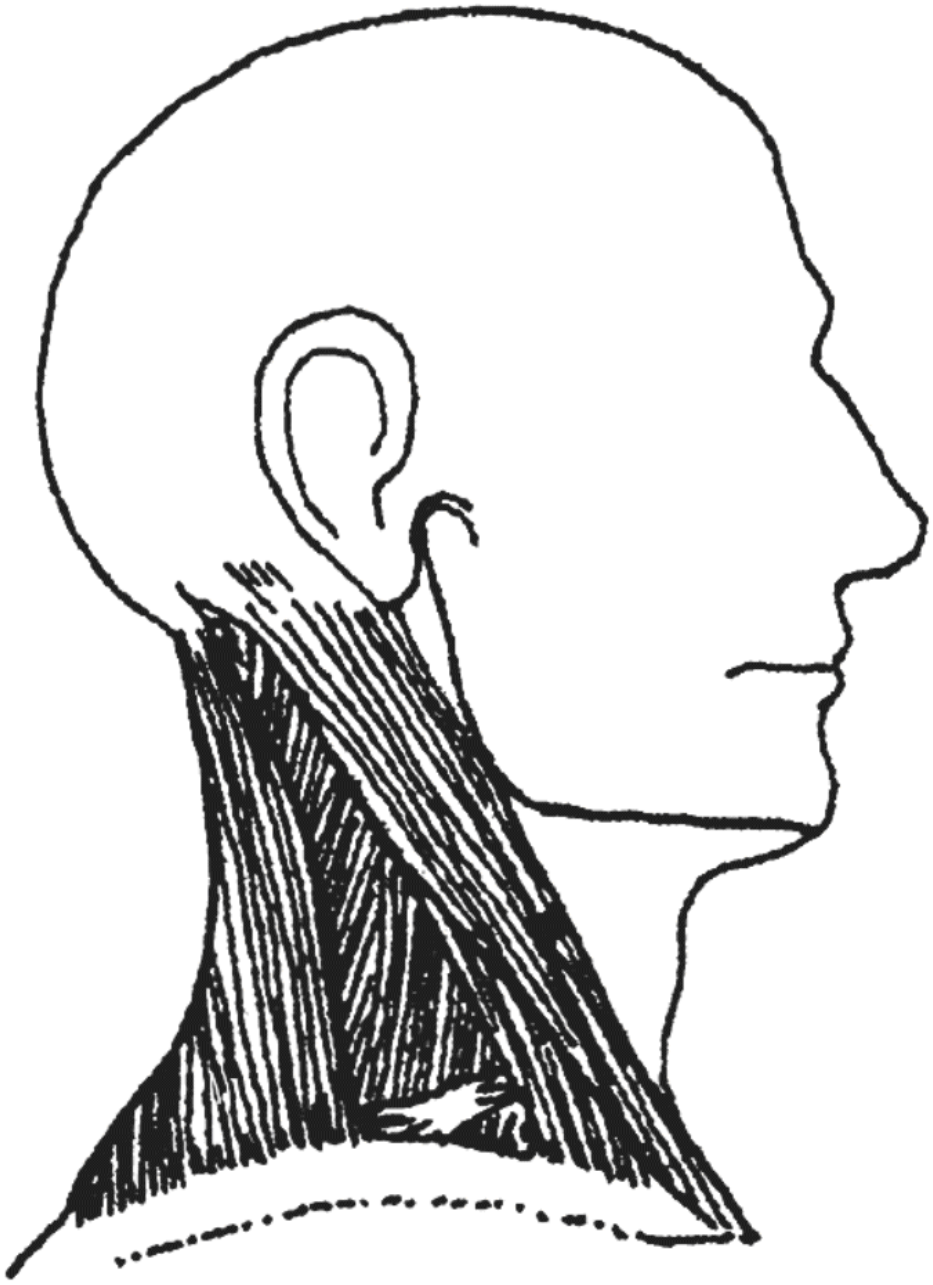


Figure 10.3: Muscles of the Neck

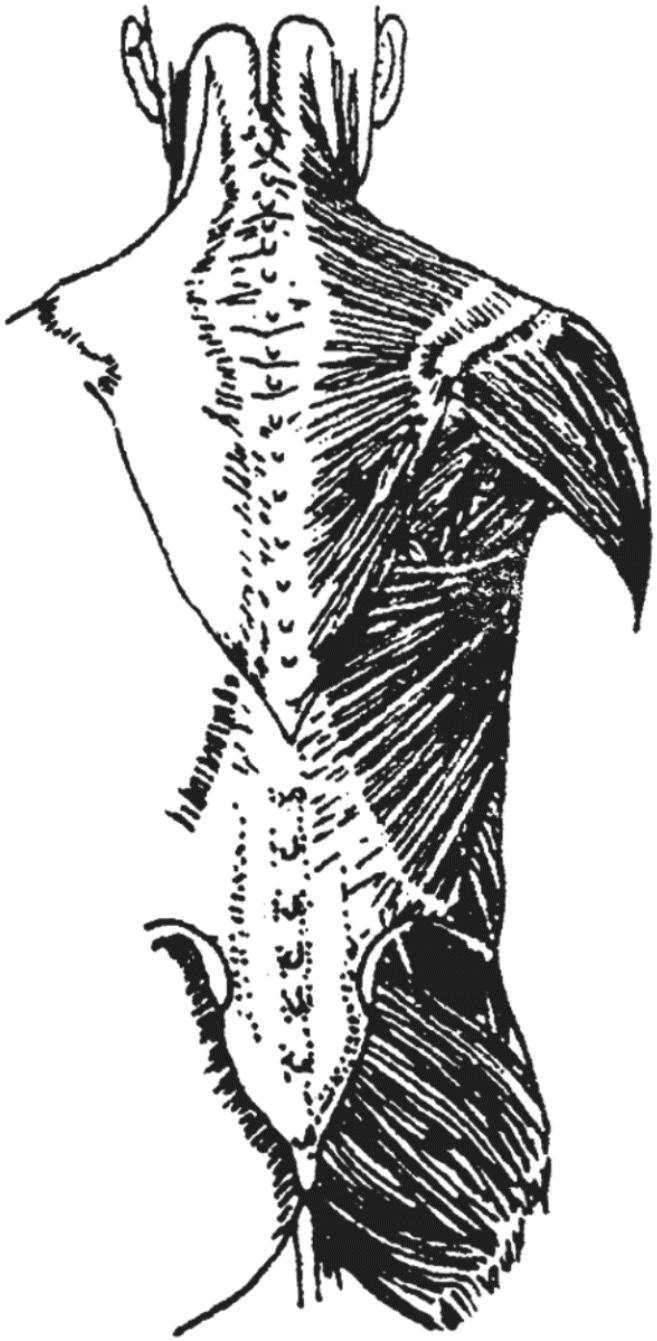


Figure 10.4: Muscles of the Shoulder

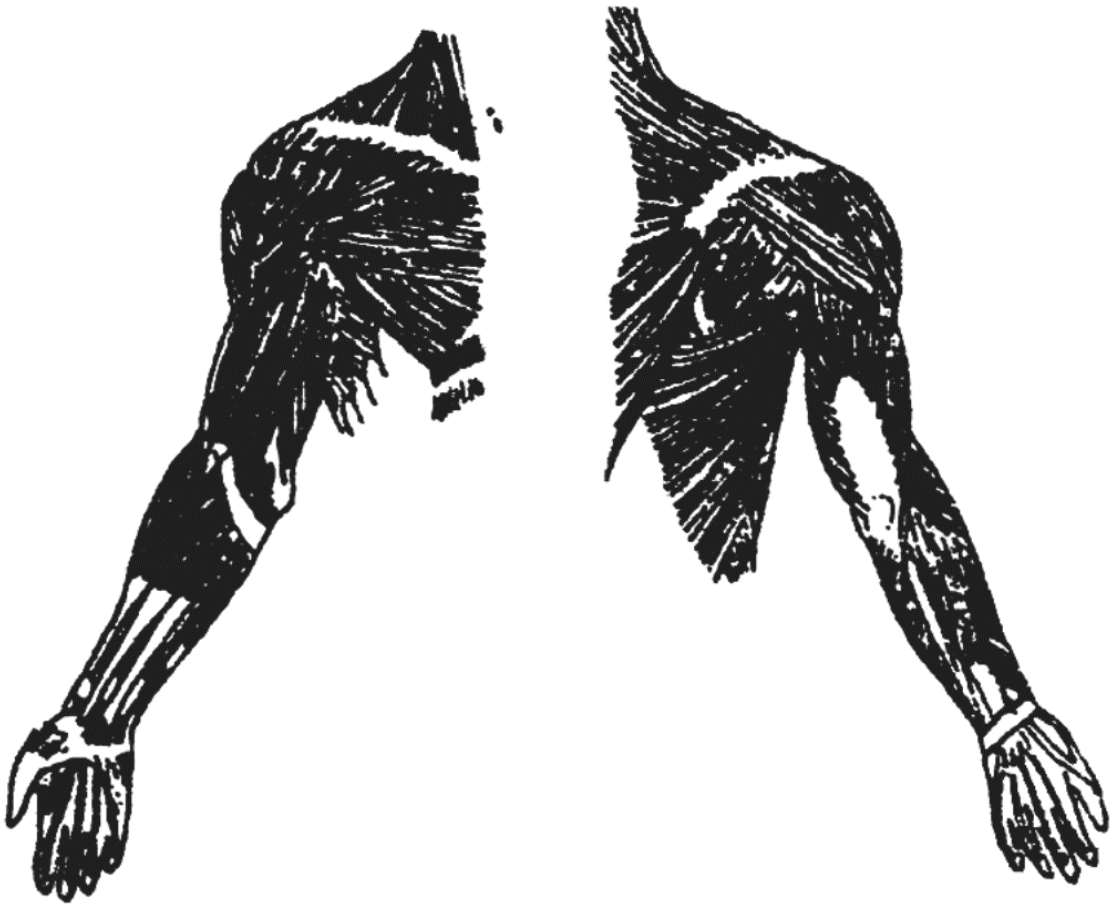


Figure 10.5: Muscles of the Arm

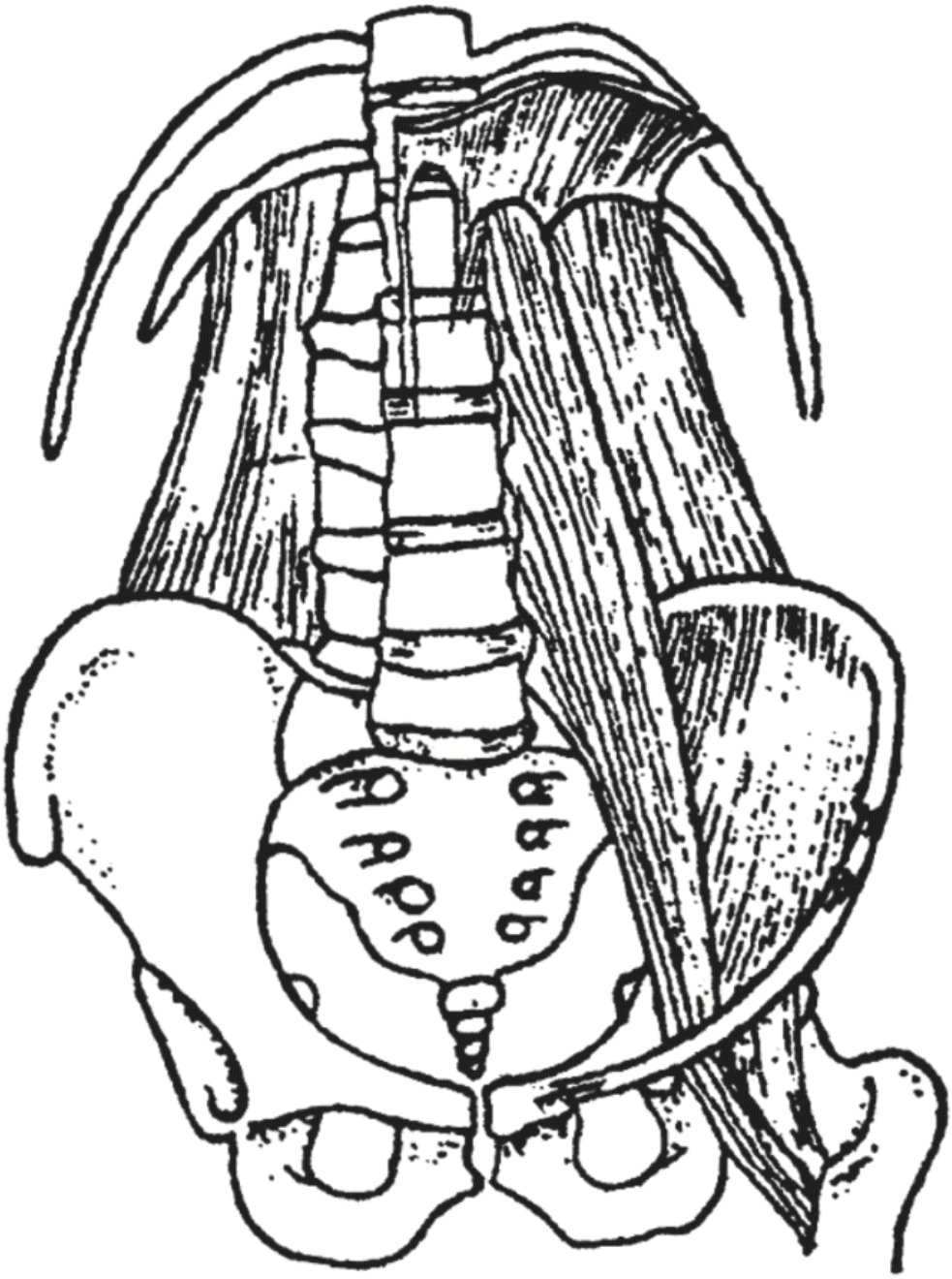


Figure 10.6: Muscles of the Trunk

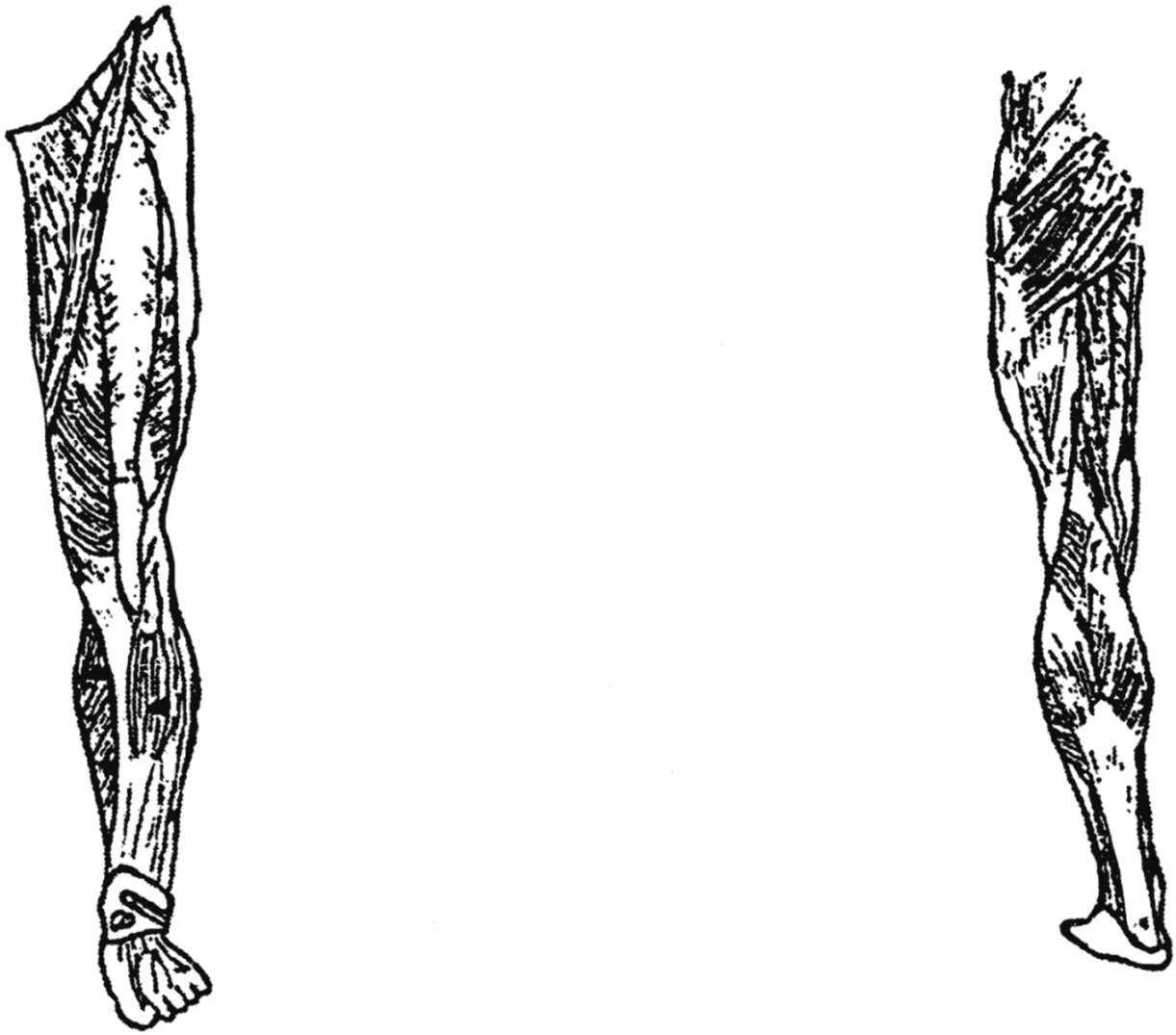


Figure 10.7: Muscles of the Thigh and Leg

DISORDERS OF SKELETAL MUSCLES

inventiOn, updatiOn

Risk factors for muscular skeletal disorders:

- Heavy physical work
- Smoking
- High body mass index
- High psychological work demands
- Presence of comorbidities

Most commonly reported biomechanicai risk factors include: Excessive repetition, awkward postures, heavy lifting

Following disorders of skeletal muscles are of clinical relevance:

1. Muscular Dystrophy (MD): Muscular dystrophy (MD) includes a variety of degenerative muscle diseases which are due to mutations in the genes coding for various components of the dystrophin-glycoprotein complex. Thus, it has genetic component.

•**Duchenne Muscular Dystrophy (DMD):** DMD is

the most common muscular dystrophy. It is also called as pseudohypertrophic MD. It is X-linked hereditary disease which affects male children. DMD is characterized by progressive muscular weakness which becomes apparent by age 4 and exhibits enlargement of affected muscles, especially of calf muscles. Enlargement occurs due to gradual degeneration and necrosis of muscle fibres that are replaced by more fibrous and fatty tissue. The symptoms indicate that the child uses his hands to climb up, while getting up from the floor. By age of 12, most sufferers are no longer ambulatory and death occurs by age 30. The pathology is the absence of dystrophin in the muscles, caused by mutations of dystrophin gene. Dystrophin gene is a large gene, located in the p21 region of the X chromosome and has a high mutation rate.

• **Baker's Muscular Dystrophy (BMD):** BMD is a less severe and rare form of muscular dystrophy. It is similar to DMD in presentation, but patients often survive into adulthood. In BMD patients, dystrophin is reduced in amount or present in an abnormal form. A gene expressing a truncated form of dystrophin called utorphin has been experimented in animals.

Can yOu reCall?

Muscular dystrophy is a group of inherited diseases characterized by weakness and wasting away of muscle tissue. There are nine types of muscular dystrophy. Each type involving an eventual loss of strength, increasing disability and possible deformity

2. Myopathies: Mutations in the gene coding for the protein "Desmin" causes skeletal and cardiac myopathies.

• **Metabolic Myopathies:** These occur due to mutations

in the genes coding for various enzymes involving in the metabolism of carbohydrates, proteins and fats. In these patients, muscle breakdown occurs

due to accumulation of toxic metabolites.
•**Inflammatory Myopathy:** It is an inflammatory

myopathy in which, weakness of proximal limb muscles is an early feature. It is due to destruction of motor neurons present in the anterior horn of spinal cord by the poliovirus, resulting in paralysis of skeletal muscles. Death may occur due to respiratory failure.

3. Myotonia: These are conditions where muscle relaxation is prolonged after voluntary contraction. They are due to abnormal genes on chromosomes 7, 17 or 19 that lead to malfunction of Na^+ or Cl^- channels.

4. Focal Dystonias: Dystonia means faulty contraction. Usually, abnormal contraction is limited to a small and specific region of muscles, so it is called focal dystonia. These are neuromuscular disorders characterized by involuntary and repetitive or sustained skeletal muscle contractions that cause twisting, turning or squeezing movements in a body part. They often result in abnormal postures, considerable pain and physical impairment. The common dystonias are spasmodic torticollis and cervical dystonia that usually affect neck and shoulder muscles, blepharospasm that affects eyelid muscles, strabismus and nystagmus that affect extra-ocular muscles, writer's cramp that affect finger muscles, spasmodic dysphonia that affect muscles of speech apparatus including vocal cord and hemifacial spasm that affect facial muscles.

5. Muscle sprain: Muscle sprain often occurs during sports activity or physical labour due to overstretching or forced extension of an active muscle. Very often the myotendinous junction is injured or sometimes there is separation of the fibres. Pain, soreness, weakness and swelling are the usual symptoms. Treatment includes ice packs, rest and immobility.

6. Muscle cramp: This is a painful condition due to involuntary titanic contraction of skeletal muscles. It is caused by generation of nerve action potentials at a very high rate. This abnormal activity of nerve occurs in conditions like electrolyte imbalances in the extracellular fluid surrounding both the muscle and nerve fibres due to over-exercise or persistent dehydration.

Questions for study

1. Draw and label the structure of skeletal muscle. Why is it so called?
2. What is the underlying cause of muscle fatigue?
3. Describe the ultrastructure of neuromuscular junction.
4. What is the role of calcium in muscle contraction?
5. Discuss and give examples of energy sources for muscle activity.
6. Name the main muscles of back, chest, abdomen, neck, shoulder, upper arm, forearm, thigh, buttocks, leg and pelvic floor.
7.Describe in short: Muscle tone and Muscle fatigue.
8. What is muscle ? Name the types of muscles. Mention their properties.
9. Describe the physiology of muscle contraction.
10. Explain the meaning of the terms : Baker's muscular dystrophy, Myotonia, Muscle sprain and Muscle cramp.

11

The Nervous System

INTRODUCTION

The nervous system monitors and controls almost every organ system through a series of positive and negative feedback loops. The nervous system consists of the *brain* and *spinal cord* and *peripheral nerves.*

The Central Nervous System (CNS) includes the *brain* and *spinal cord.* The Peripheral Nervous System (PNS) connects the CNS to other parts of the body, and is composed of *nerves* (bundles of neurons). The *nerves* involved are cranial nerves and spinal nerves.

FUNCTIONS OF NERVOUS SYSTEM
The nervous system has three main functions: *sensory input, integration and output; and endocrine output.*
1. SENSORY INPUT

Receptors are parts of the nervous system that sense changes in the internal or external environments. Sensory input can be in many forms, including pressure, taste, sound, light, blood pH, or hormone levels, that are converted to a signal and sent to the brain or spinal cord.

2. INTEGRATION AND OUTPUT

In the sensory centers of the brain or in the spinal cord, the barrage of input is integrated and a response is generated. The response, a motor output, is a signal transmitted to organs

that can convert the signal into some form of action, such as movement, changes in heart rate, release of hormones, etc. 3. ENDOCRINE OUTPUT

The nervous system coordinates rapid responses to external stimuli. The endocrine system controls slower, longer lasting responses to internal stimuli. Activity of both systems is integrated.

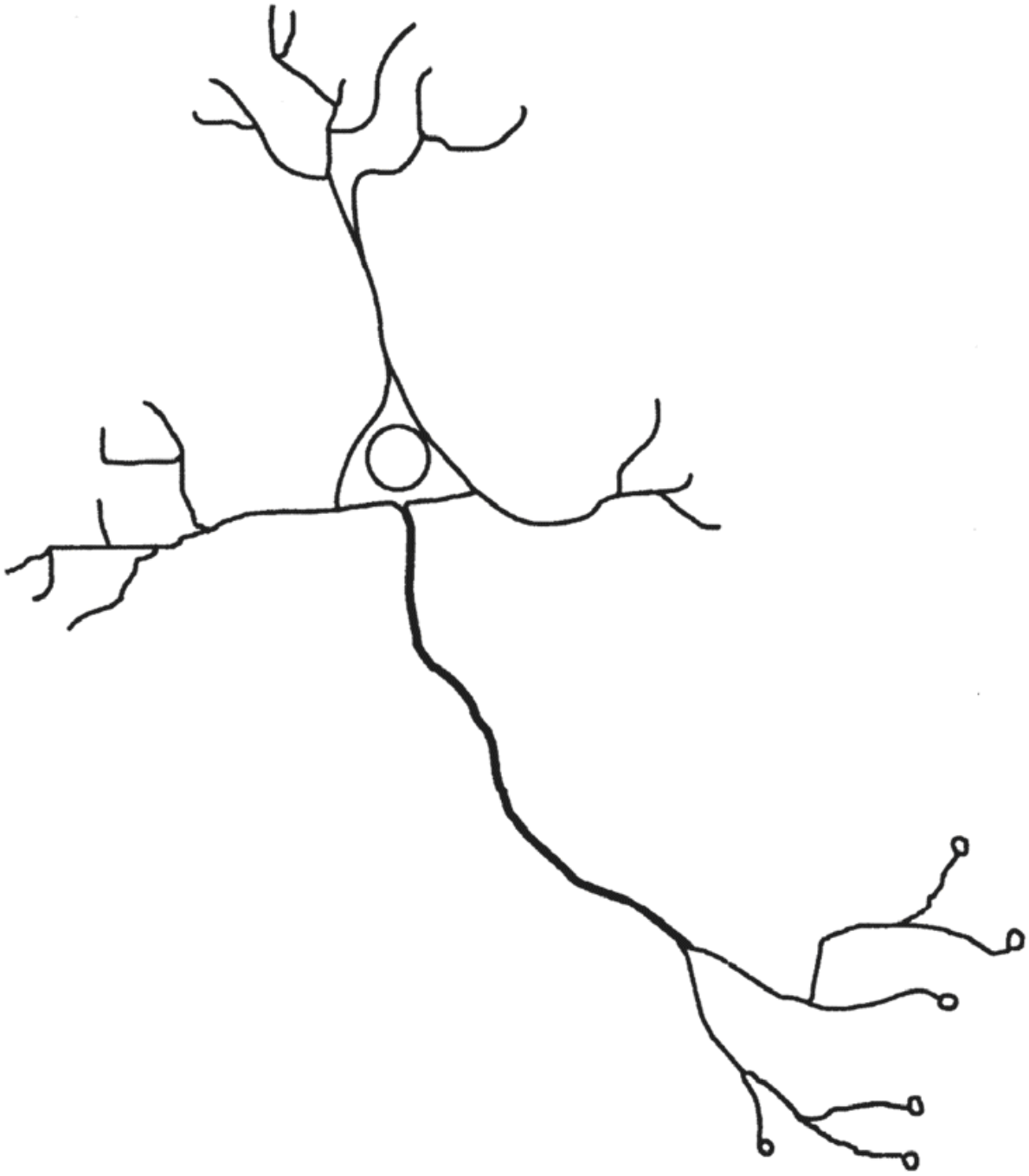
STRUCTURE OF NEURONS

The neuron is the functional unit of the nervous system. Humans have about 100 billion neurons in their brain alone. While variable in size and shape, all neurons have three parts:

Dendrites receive information from another cell and transmit the message to the cell body.
The *cell body* contains the nucleus, mitochondria and other organelles typical of eukaryotic cells.

The *axon* conducts messages away from the cell body. Some axons are wrapped in a myelin sheath formed from the plasma membranes of specialized glial cells known as *Schwann cells.* Schwann cells serve as supportive, nutritive, and service facilities for
neurons. The gap
between Schwann
cells is known as
the *node of Ranvier,*
and serves as points

along the neuron
for generating a sig
nal. Signals jumping
from node to node
travel hundreds of
times faster than sig
nals travelling along
the surface of the
axon. This allows
your brain to com
municate with your



toes in a few thou**Figure 11.1:** The structure of neuron sandths of a second.

There are *three* types of neurons in the body: *sensory neurons, interneurons,* and *motor neurons.* Neurons are sometimes called *nerve cells.* In vertebrates, neurons are found in the brain, the spinal cord and in the nerves and ganglia of the peripheral nervous system.The *main role* of neuron is to *process and*

transmit information. Neurons have excitable membranes, which allow them to generate and propagate electrical impulses. Sensory neuron takes nerve impulses or messages right from the sensory receptor and delivers it to the central nervous system. A sensory receptor is a structure that can find any kind of change in its surroundings or environment.

MYELIN SHEATH

Schwann cells contain a lipid substance called myelin in their plasma membranes. When Schwann cells wrap around axons, a myelin sheath forms. There are gaps that have no myelin sheath around them; these gaps are called nodes of Ranvier. Myelin sheaths make excellent insulators. Axons that are longer have a myelin sheath, while shorter axons do not. The disease multiple sclerosis is an autoimmune disease where the body attacks the myelin sheath of the central nervous system.

FUNCTIONS

Sensory afferent neurons convey information from tissues and organs into the central nervous system. Efferent neurons transmit signals from the central nervous system to the effector cells and are sometimes called motor neurons. Interneurons connect neurons within specific regions of the central nervous system. Afferent and efferent can also refer generally to neurons which, respectively, bring information to or send information from brain region.

The neurons of the brain release inhibitory neuro-transmitters far more than excitatory neurotransmitters, which helps explain why we are not aware of all memories and all sensory stimuli simultaneously. The majority of information stored in the brain is inhibited most of the time.

TRANSMISSION OF IMPULSE

The plasma membrane of neurons, like all other cells, has an unequal distribution of ions and electrical charges between the two sides of the membrane. The outside of the membrane has a positive charge, inside has a negative charge. This charge difference is a resting potential and is measured in millivolts. Passage of ions across the cell membrane passes the electrical

charge along the cell. The voltage potential is – 65 mV (millivolts) of a cell at rest *(resting potential).* Resting potential results from differences between sodium and potassium positively charged ions and negatively charged ions in the cytoplasm. Sodium ions are more concentrated outside the membrane, while potassium ions are more concentrated inside the membrane. This imbalance is maintained by the active transport of ions to reset the membrane known as the *sodium-potassium pump.* The sodium-potassium pump maintains this unequal concentration by actively transporting ions against their concentration gradients.

Changed polarity of the membrane, the *action potential*, results in propagation of the nerve impulse along the membrane. An action potential is a temporary reversal of the electrical potential along the membrane for a few milliseconds. Sodium gates and potassium gates open in the membrane to allow their respective ions to cross. Sodium and potassium ions reverse positions by passing through membrane protein channel gates that can be opened or closed to control ion passage. Sodium crosses first. At the height of the membrane potential reversal, potassium channels open to allow potassium ions to pass to the outside of the membrane. Potassium crosses second, resulting in changed ionic distributions, which must be reset by the continuously running sodium-potassium pump. Eventually enough potassium ions pass to the outside to restore the membrane charges to those of the original resting potential. The cell begins then to pump the ions back to their original sides of the membrane.

The action potential begins at one spot on the membrane, but spreads to adjacent areas of the membrane, propagating the message along length of the cell membrane. After passage of the action potential, there is a brief period, the refractory period, during which the membrane cannot be stimulated. This prevents the message from being transmitted backward along the membrane.

Figure 11.2: Transmission of impulses **Steps in an Action Potential**

At rest the outside of the membrane is more positive than the inside. Sodium moves inside the cell causing an action potential, the influx of positive sodium ions makes the inside of the membrane more positive than the outside.

Figure 11.3: Saltatory conduction of an impulse in a myelinated nerve fiber

Potassium ions flow out of the cell, restoring the resting potential net charges.
Sodium ions are pumped out of the cell and potassium ions are pumped into the cell, restoring the original distribution of ions.

SYNAPSES AND NEUROTRANSMITTERS

The junction between a nerve cell and another cell is called a *synapse.* Messages travel within the neuron as an electrical action potential. The space between two cells is known as the *synaptic cleft.* To cross the synaptic cleft requires the actions of *neurotransmitters.* Neurotransmitters are stored in small synaptic vesicles clustered at the tip of the axon.

Arrival of the action potential causes some of the vesicles to move to the end of the axon and discharge their contents into the synaptic cleft. Released neurotransmitters diffuse across the cleft, and bind to receptors on the other cell's membrane, causing ion channels on that cell to open. Some neurotransmitters cause an action potential, others are inhibitory.

Neurotransmitters tend to be small molecules, some are even hormones. The time for neurotransmitter action is between 0.5 and 1 millisecond.

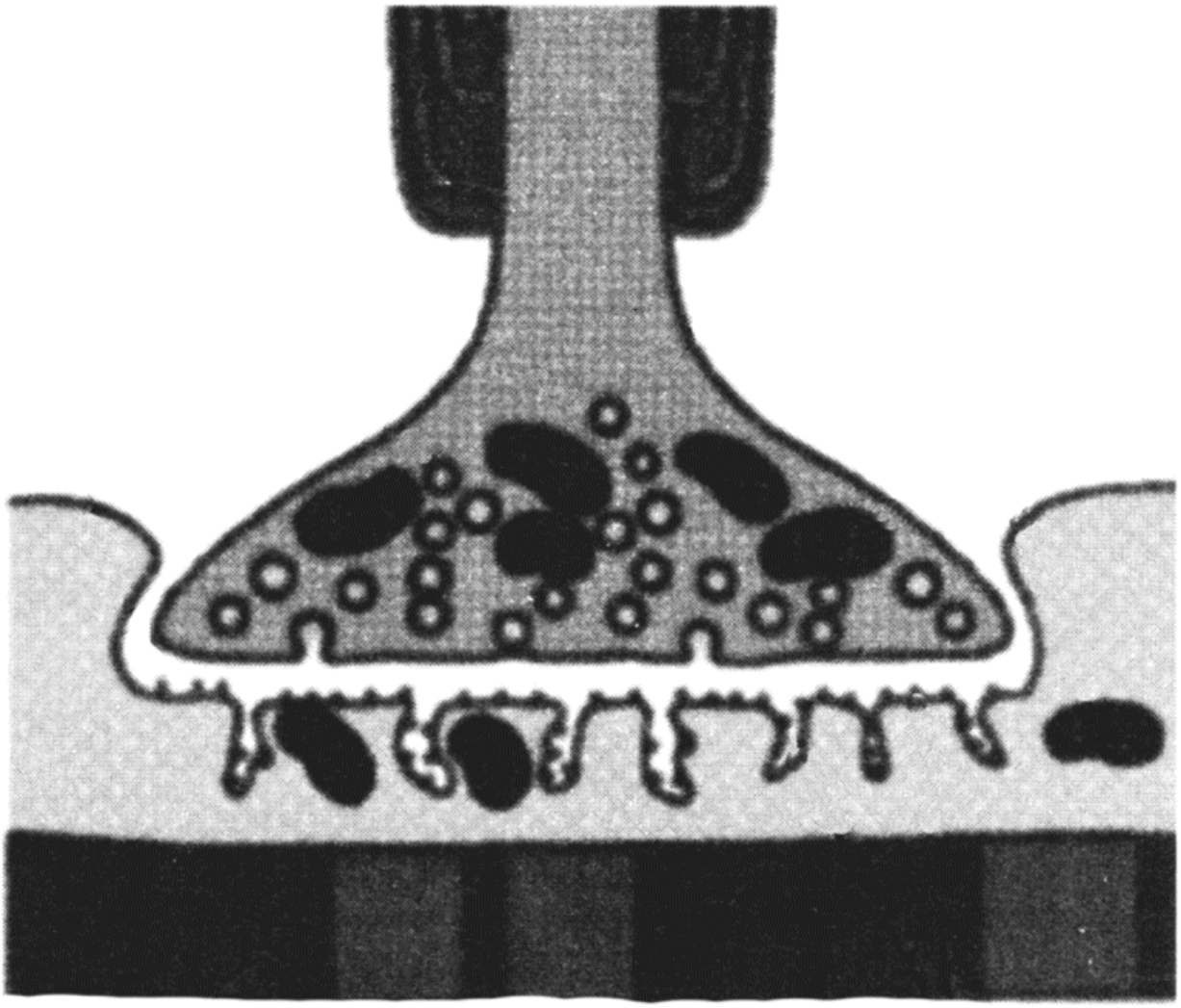


Figure 11.4: A synapse

Neurotransmitters are either destroyed by specific enzymes in the synaptic cleft, diffuse out of the cleft, or are reabsorbed by the cell. More than 30 organic molecules are thought to act as neurotransmitters. The neurotransmitters cross the cleft, binding to receptor molecules on the next cell, prompting transmission of the message along that cell's membrane.

Acetylcholine is an example of a neurotransmitter, as is norepinephrine, although each acts in different responses. Once in the cleft, neurotransmitters are active for only a short time. Enzymes in the cleft inactivate the neurotransmitters. Inactivated neurotransmitters are taken back into the axon and recycled.

Diseases that affect the function of signal transmission can have serious consequences. Parkinson's disease has a deficiency of the neurotransmitter dopamine. Progressive death of brain cells increases this deficit, causing tremours, rigidity and unstable posture.

L-dopa is a chemical related to dopamine that eases some of the symptoms (by acting as a substitute neurotransmitter) but cannot reverse the progression of the disease.

The bacterium Clostridium tetani produces a toxin that prevents the release of GABA. GABA is important in control of skeletal muscles. Without this control chemical, regulation of muscle contraction is lost; it can be fatal when it effects the muscles used in breathing.

Clostridium botulinum produces a toxin found in improperly canned foods. This toxin causes the progressive relaxation of muscles, and can be fatal. A wide range of drugs also operate in the synapses: cocaine, LSD, caffeine, and insecticides.

INFORMATION TRANSMISSION

Messages travel through the SNS in a bidirectional flow. Efferent messages can trigger changes in different parts of the body simultaneously. For example, the sympathetic nervous system can accelerate heart rate; widen bronchial passages; decrease motility (movement) of the large intestine; constrict blood vessels; increase peristalsis in the esophagus; cause pupil dilation, piloerection (goose bumps) and perspiration (sweating); and raise blood pressure. Afferent messages carry sensations such as heat, cold, or pain.

The first synapse (in the sympathetic chain) is mediated by nicotinic receptors physiologically activated by acetylcholine, and the target synapse is mediated by adrenergic receptors physiologically activated by either noradrenaline or adrenaline. An exception is with sweat glands which receive sympathetic innervation but have muscarinic acetylcholine receptors which are normally characteristic of PNS. Another exception is with certain deep muscle blood vessels, which have acetylcholine receptors and which dilate (rather than constrict) with an increase in sympathetic tone. The

sympathetic system cell bodies are located on the spinal cord excluding the cranial and sacral regions. The preganglonic neurons exit from the vertebral column and synapse with the postganglonic nerons in the sympathetic trunk.

The parasympathetic nervous system is one of three divisions of the autonomic nervous system. Sometimes called the rest and digest system, the parasympathetic system conserves energy as it slows the heart rate, increases intestinal and gland activity, and relaxes sphincter muscles in the gastrointestinal tract.

THE NERVOUS SYSTEM

The nervous system is comprised of two major parts, or subdivisions, the *central nervous system* (CNS) and the *peripheral nervous system* (PNS).

The *central nervous system* includes the brain and spinal cord. The brain is the body's "control center". The CNS has various centers located within it that carry out the sensory, motor and integration of data. These centers can be subdivided to lower centers (including the spinal cord and brain stem) and higher centers communicating with the brain via effectors.

1. PERIPHERAL NERVOUS SYSTEM

The Peripheral Nervous System (PNS) contains only nerves and connects the brain and spinal cord (CNS) to the rest of the body. The axons and dendrites are surrounded by a white *myelin sheath.* Cell bodies are in the central nervous system (CNS) or ganglia. *Ganglia* are collections of nerve cell bodies. Cranial nerves in the PNS take impulses to and from the brain (CNS). Spinal nerves take impulses to and away from the spinal cord. There are two major subdivisions of the PNS motor pathways: the *somatic nervous system* and the *autonomic nervous system.*

Two main functional parts of the Peripheral Nervous System (PNS) are:
1. *Sensory* (afferent) pathways that provide input from the body into the CNS.
2. *Motor* (efferent) pathways that carry signals to muscles and glands (effectors).

Most sensory input carried in the PNS remains below the level of conscious awareness. Input that does reach the conscious level contributes to perception of our external environment.

SPINAL NERVE

The peripheral nerves contain the axons of neurons that are running to and from the CNS. Many of the axons are myelinated, but others are not. These axons are bundled together to form a nerve. There are levels of axonal bundling. The *epineurium* is the connective tissue that wraps around the entire nerve. Axons within the nerve are bundled into large *fascicles* held together by *perineurium.* And connective tissue that runs along individual myelinated axons or groups of unmyelinated axons is called *endoneurium.*

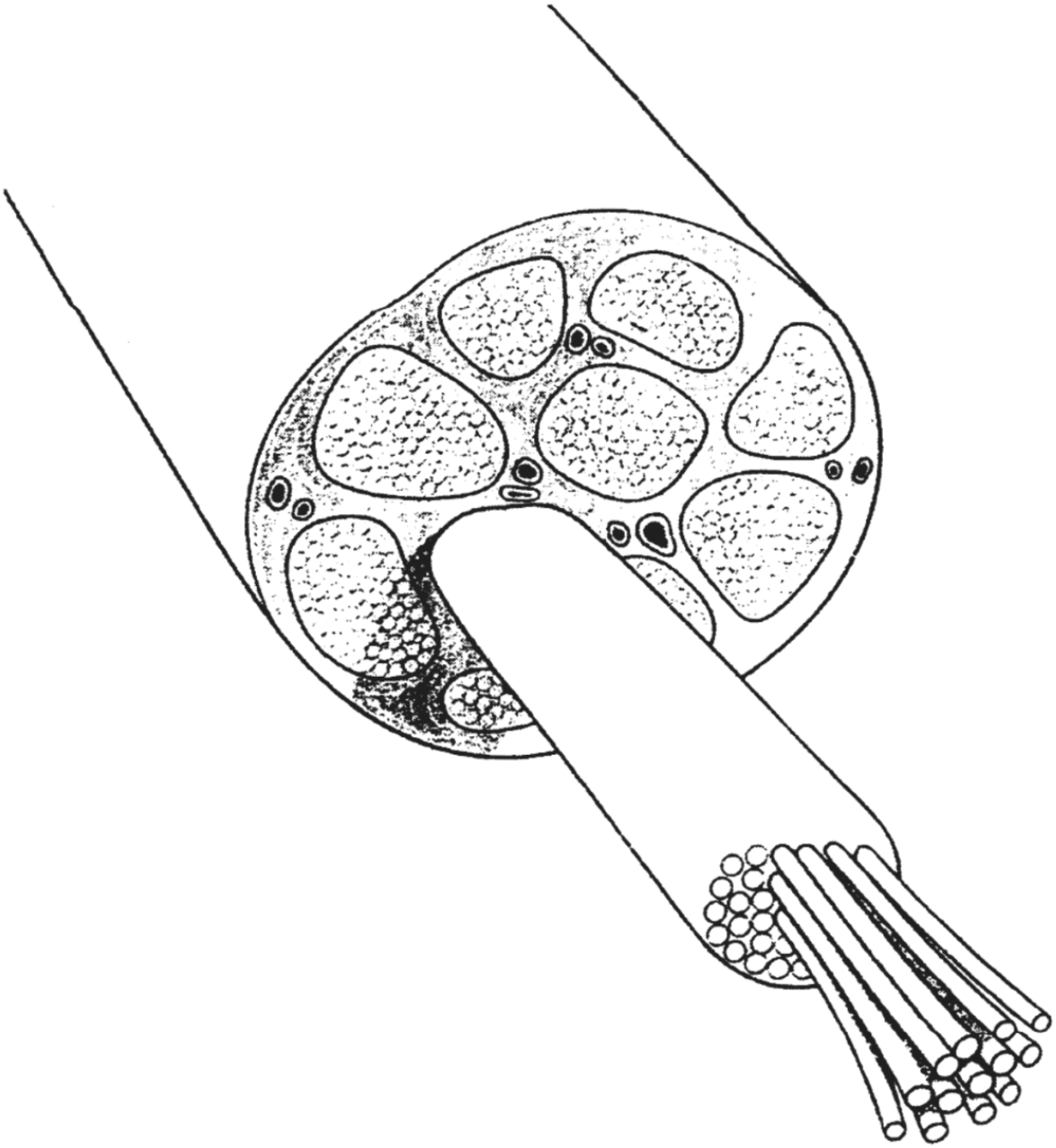


Figure 11.5: Transverse section of a peripheral nerve showing the protective coverings.

There are 31 pairs of spinal nerves. These nerves are mixed, having both a sensory and a motor aspect. Their motor fibers begin on the ventral part of the spinal cord at the anterior horns of the gray matter. The roots of their sensory fibers are located on the dorsal side of the spinal cord in the posterior root ganglia. When the motor and sensory fibers exit the spinal

column through the intervertebral foramina and pass through the meninges, they join together to form the spinal nerves.

Spinal nerves receive only contralateral innervation from first order neurons. Eight pairs of spinal nerves are located in the uppermost, cervical region of the cord:

• 12 pairs are found in the thoracic region.
• 5 pairs are in the lumbar area.
• 5 pairs are in the sacral area.
• 1 pair is found in the most inferior, coccygeal region.

Spinal nerves join together in *plexuses.* A plexus is an interconnection of fibers which form new combinations as the “named” or peripheral nerves. There are four voluntary plexuses (there are some autonomic plexuses which will be mentioned later): they are the cervical plexus, the brachial plexus, the lumbar plexus, and the sacral plexus. Each plexus gives rise to new combinations of fibers as the peripheral nerves. The nerves and plexuses you need to know are:

Cervical Plexus

This is formed by the anterior rami of the first four cervical nerves. It lies opposite the 1st, 2nd, 3rd, and 4th cervical vertebrae under the protection of the sternocleiodomastoid muscle.

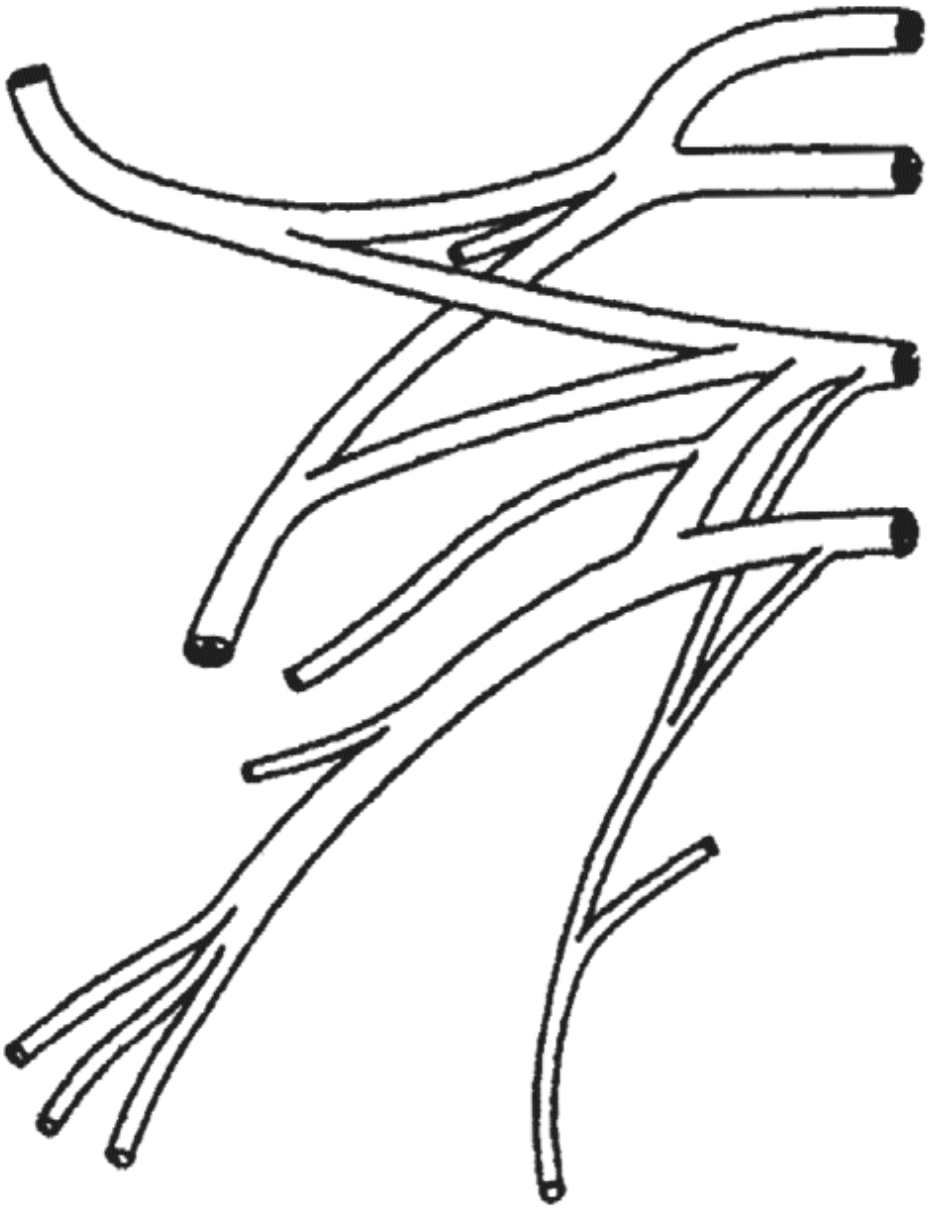


Figure 11.6:

Cervial plexus (Anterior view)

Brachial Plexus

• *Axillary nerve* innervates the deltoid muscle and shoulder, along with the posterior aspect of the upper arm.
• *Musculocutaneous nerve* innervates anterior skin of upper arm and elbow flexors.
• *Radial nerve* - innervates dorsal aspect of the arm and extensors of the

elbow, wrist, and fingers, abduction of thumb.
• *Median nerve* innervates the middle elbow, wrist and finger flexors, adducts the thumb.
• *Ulnar nerve* innervates the medial aspect wrist and finger flexors.

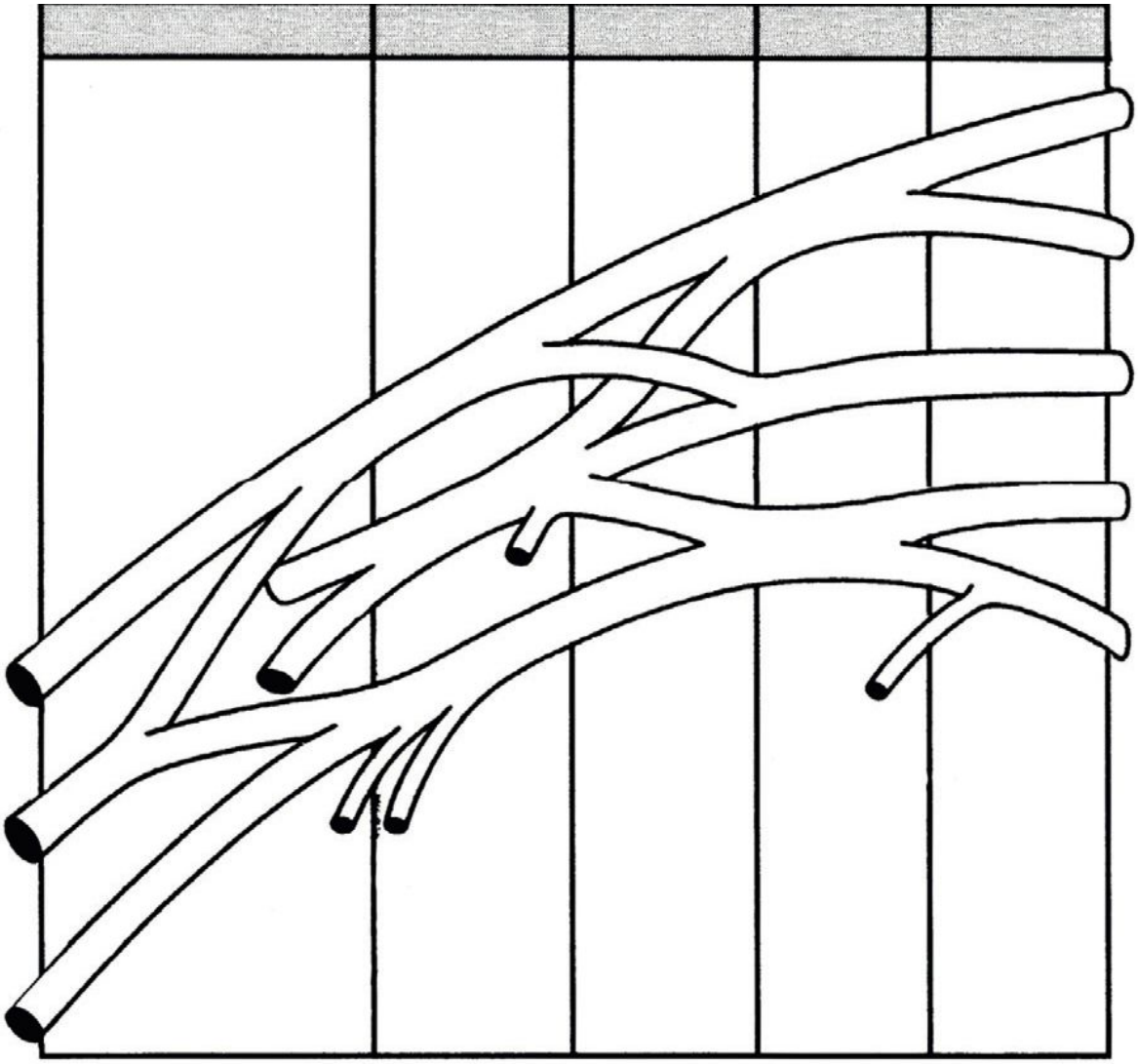


Figure 11.7: Brachial plexus. Anterior view. ant= anterior, post=posterior

Lumbar Plexus
• *Genitofemoral:* To the external genitalia.
• *Obturator:* To the adductor muscles.
• *Femoral:* Innervates the skin and muscles of upper thigh,

including the quadriceps.
• Iliohypogastric nerve.
• Ilioinguinal nerve.
• Lateral cutaneous nerve of thigh.
• Lumbosacral trunk.

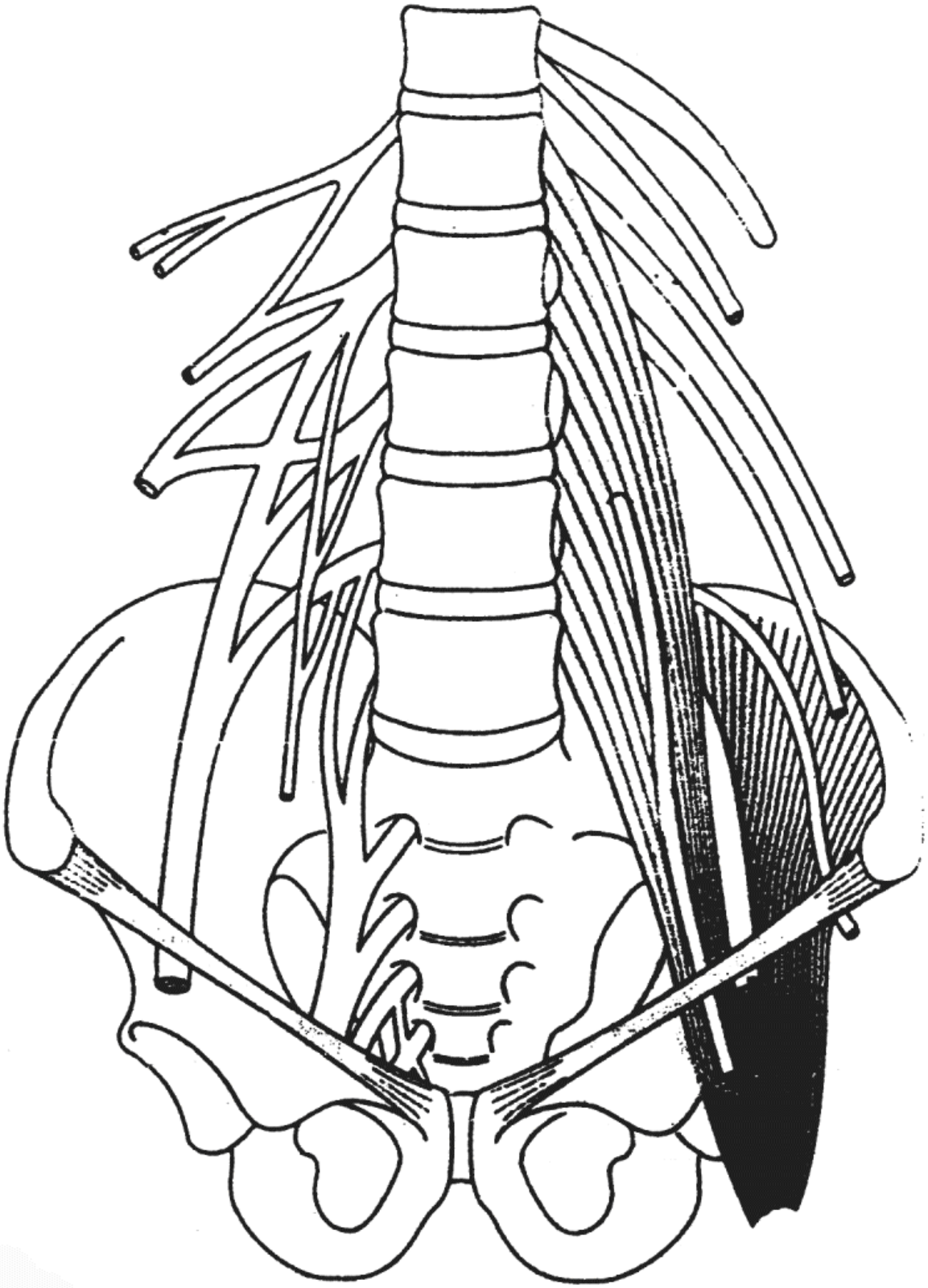


Figure 11.8: Lumber plexus

Sacral Plexus

• *Gluteal nerve* (superior and inferior): Superior innervates the gluteus medius and minimus, inferior innervates the gluteus maximus.
• *Sciatic nerve:* The body's largest nerve, consisting of two major branches, the tibial and common peroneal. Together they innervate most, all of leg including the flexors of the knee, part of adductor magnus, muscles for plantar flexion, dorsiflexion, and other movements of the foot and toes.
• *Tibia nerve* descends through the popliteal fossa to the posterior aspect of the leg where it supplies muscles and skin.
• The *common peroneal nerve* descends obliquely along the lateral aspect of the popliteal fossa, which is round the neck of the fibula in front of the leg where it divides into the deep peroneal and *supraficial peroneal nerves.*
• *The pudendal nerve:* The peroneal branch supplies the external and sphincter, the external urethral sphincter and adjacent skin.

Coccygeal Plexus

• The coccygeal plexus is a very small plexus fromed by part of the fourth and fifth sacral and the coccygeal nerves. The nerves from this plexus supply the skin around the coccyx andanal area.

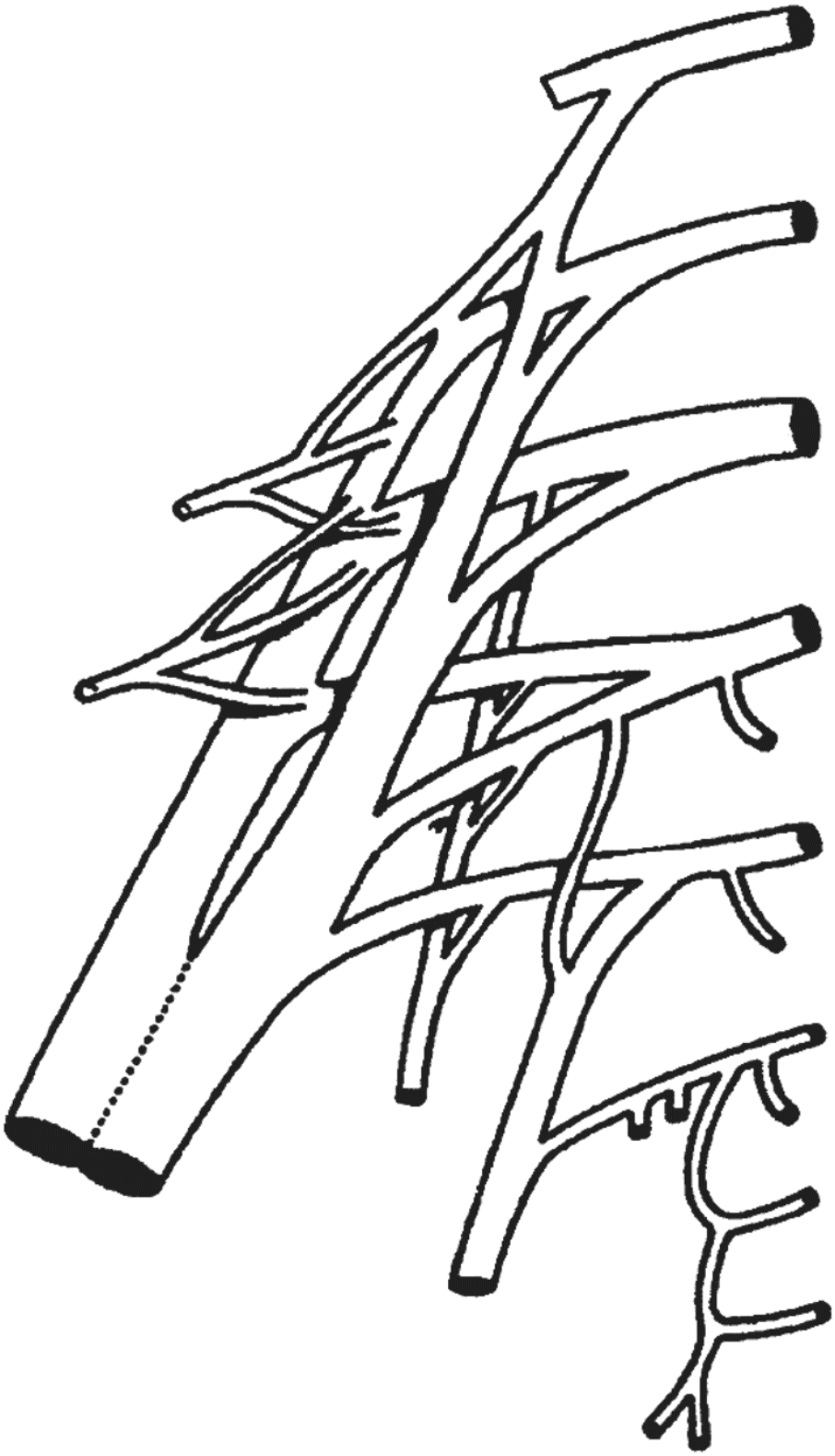


Figure 11.9: Sacral and coccygeal plexuses

CRANIAL AND SPINAL NERVES

The peripheral nervous system includes 12 cranial nerves, 31 pairs of spinal nerves. It can be subdivided into the somatic and autonomic systems. It is a way of communication form the central nervous system to the rest of the body by nerve impulses that regulate the functions of the human body. The twelve cranial nerves are:

1. Olfactory nerve for smell.
4. Optic nerve for vision.
5. Oculomotor for looking around.
6. Trochlear for moving eye.
7. Trigeminal for feeling touch on face.
8. Abducens to move eye muscles.
9. Facial to smile, wink, and help us taste.
10. Vestibulocochlear to help with balance, equilibrium, and hearing.
11. Glossopharyngeal for swallowing and gagging. **12.** Vagus for swallowing, talking, and parasympathetic actions of digestion.
13. Spinal accessory for shrugging shoulders.
14. Hypoglossal for tongue more divided into different regions as muscles.

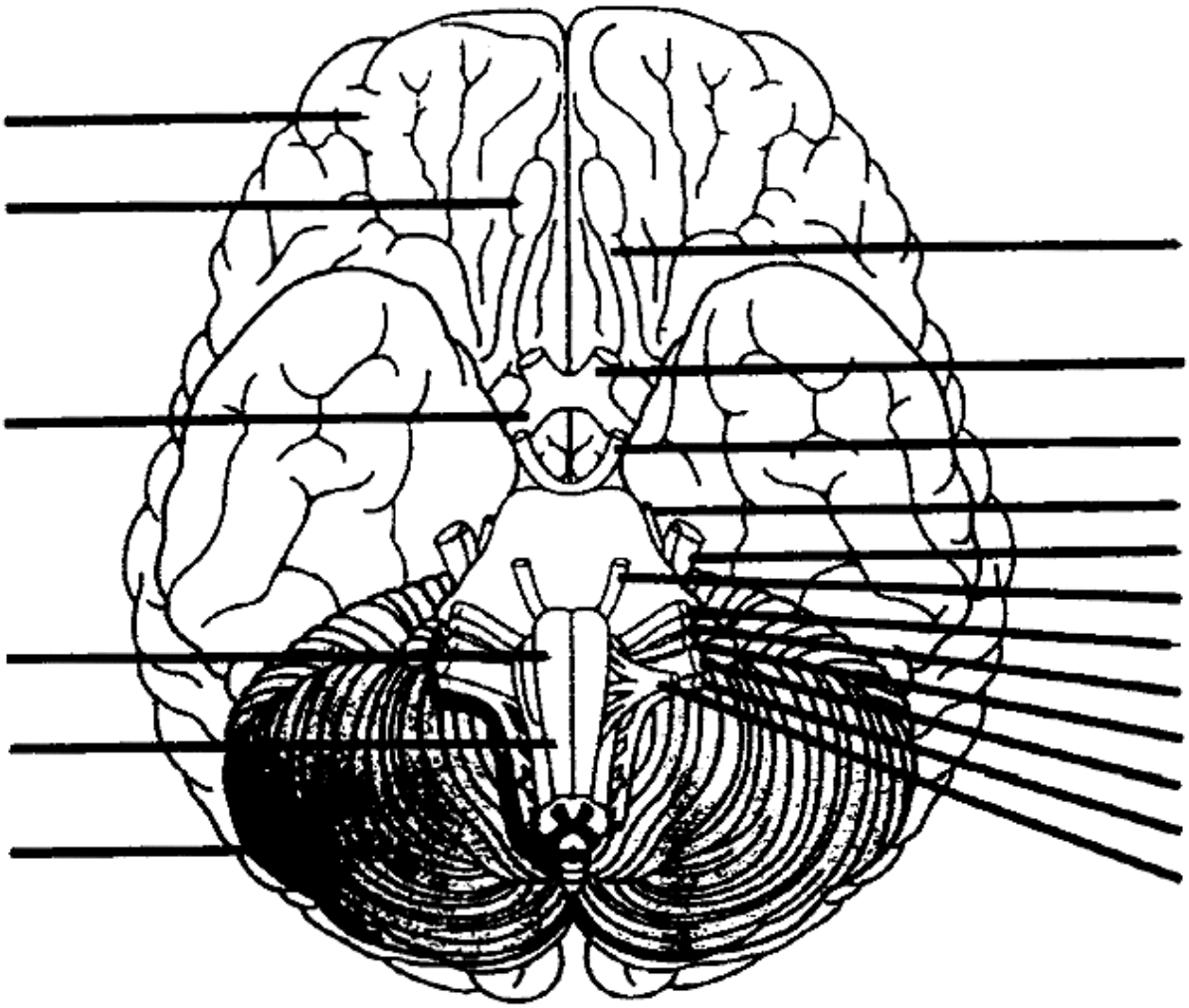


Figure 11.10: The inferior surface of the brain showing the cranial nerves

The 10 out of the 12 cranial nerves originate form the brainstem, and mainly control the functions of the anatomic structures of the head with some exceptions. CN X receives visceral sensory information from the thorax and abdomen, and CN XI is responsible for innervating the sternocleidomastoid and trapezius muscles, neither of which is exclusively in the head.

The Autonomic Nervous System

The autonomic nervous system is a part of the *peripheral nervous system* that functions to regulate the basic visceral (organ) processes needed for the maintenance of normal bodily functions. It operates independently of voluntary control, although certain events, such as emotional stress, fear,

sexual excitement, and alterations in the sleep-wakefulness cycle, change the level of autonomic activity.

The autonomic system is usually defined as a *motor system* that innervates three major types of tissue: cardiac muscle, smooth muscle, and glands. However, this definition needs to be expanded to encompass the fact that it also relays visceral sensory information into the central nervous system and processes it in such a way as to make alterations in the activity of specific autonomic motor outflows, such as those that control the heart, blood vessels, and other visceral organs. It also causes the release of certain hormones involved in energy metabolism (e.g., *insulin, glucagon, epinephrine)* or cardiovascular functions (e.g., *renin, vasopressin).* These integrated responses maintain the normal internal environment of the body in an equilibrium state called *homeostasis.*

Rami Communicantes

The rami of the autonomic nervous system are the axons *of pre-ganglionic* and *ganglionic fibers.* Most of the axons of preganglionic fibers are myelinated. Their cell bodies are found in the gray matter of the brain stem and spinal cord. Their axons synapse with neurons within the two ganglionic chains.

Pre-ganglionic cells of the autonomic nervous system are neurons located in some of the cranial nerves of the brain stem and in some of the spinal nerves that project to the ganglionic chains of the autonomic nervous system. The autonomic nervous system is closely connected with the central and peripheral nervous systems.

Ganglionic cells originate within the ganglia. They project to post-ganglionic neurons.

Post-ganglionic cells are neurons that are located in the target organs and muscles of the autonomic nervous system.
It can be said that the motor pathways of the autonomic nervous system are made up of its pre-ganglionic and ganglionic cells.
The fibers of the ganglionic chain of the parasympathetic system are not as well-defined as those of the sympathetic chain. All ***pre-ganglionic neurons***

of the sympathetic system synapse with the sympathetic chain. This is not true of the parasympathetic pre-ganglionic cells, however. Some of them synapse with the chain, but others go directly to lend organs or muscles.

Division of Autonomic Nervous System

The autonomic nervous system has two components, the sympathetic system and the parasympathetic system. These two aspects have antagonistic functions.

(a) Sympathetic System

The preganglionic motor neurons of the sympathetic system arise in the spinal cord. They pass into sympathetic ganglia which are organized into two chains that run parallel to and on either side of the spinal cord.

The *preganglionic neuron* may do one of *three* things in the sympathetic ganglion:

(i) *Synapse* with postganglionic neurons which then re-enter the spinal nerve and ultimately pass out to the sweat glands and the walls of blood vessels near the surface of the body.

(ii) Pass up or down the sympathetic chain and finally synapse with postganglionic neurons in a higher or lower ganglion.

(iii) Leave the ganglion by way of a cord leading to special ganglia (e.g., the solar plexus) in the viscera. Here it may synapse with postganglionic sympathetic neurons running to the smooth muscular walls of the viscera. However, some of these preganglionic neurons pass right on through this second ganglion and into the adrenal medulla. Here they synapse with the highly-modified postganglionic cells that make up the secretory portion of the adrenal medulla.

The neurotransmitter of the preganglionic sympathetic neurons is *acetylcholine* (ACh). It stimulates action potentials in the postganglionic neurons. The neurotransmitter released by the postganglionic neurons is *noradrenaline* (also called norepinephrine).

The action of noradrenaline on a particular gland or muscle is excitatory is some cases, inhibitory in others. (At excitatory terminals, ATP may be released along with noradrenaline.) The release of noradrenaline

• stimulates heartbeat,
• raises blood pressure,
• dilates the pupils,
• dilates the trachea and bronchi,
• stimulates the conversion of liver glycogen into glucose,
• shunts blood away from the skin and viscera to the skeletal muscles, brain, and heart,
• inhibits peristalsis in the gastrointestinal (GI) tract,
• inhibits contraction of the bladder and rectum, and
• at least in rats and mice, increases the number of AMPA receptors in the hippocampus and thus increases longterm potentiation (LTP).

In short, stimulation of the sympathetic branch of the autonomic nervous system prepares the body for emergencies: for “fight or flight” (and, perhaps, enhances the memory of the event that triggered the response).

Activation of the sympathetic system is quite general because a single preganglionic neuron usually synapses with many postganglionic neurons; the release of adrenaline from the adrenal medulla into the blood ensures that all the cells of the body will be exposed to sympathetic stimulation even if no postganglionic neurons reach them directly.

(b) Parasympathetic System

The main nerves of the parasympathetic system are the tenth cranial nerves, the *vagus nerves.* They originate in the *medulla oblongata.* Other *preganglionic* parasympathetic neurons also extend from the brain as well as from the lower tip of the spinal cord.

Each preganglionic parasympathetic neuron synapses with just a few *postganglionic* neurons, which are located near— or in — the effector organ, a muscle or gland. *Acetylcholine* (ACh) is the neurotransmitter at all the pre and many of the postganglionic neurons of the parasympathetic system.

However, some of the postganglionic neurons release nitric oxide (NO) as their neurotransmitter. Parasympathetic stimulation causes

- slowing down of the heartbeat,
- lowering of blood pressure,
- constriction of the pupils,
- increased blood flow to the skin and viscera, and
- peristalsis of the GI tract,

In short, the parasympathetic system returns the body functions to normal after they have been altered by sympathetic stimulation. In times of danger, the sympathetic system prepares the body for violent activity. The parasympathetic system reverses these changes when the danger is over.

The vagus nerves also help keep inflammation under control. Inflammation stimulates nearby sensory neurons of the vagus. When these nerve impulses reach the medulla oblongata, they are relayed back along motor fibers to the inflamed area. The acetylcholine from the motor neurons suppresses the release of inflammatory cytokines, e.g., tumor necrosis factor (TNF), from macrophages in the inflamed tissue.

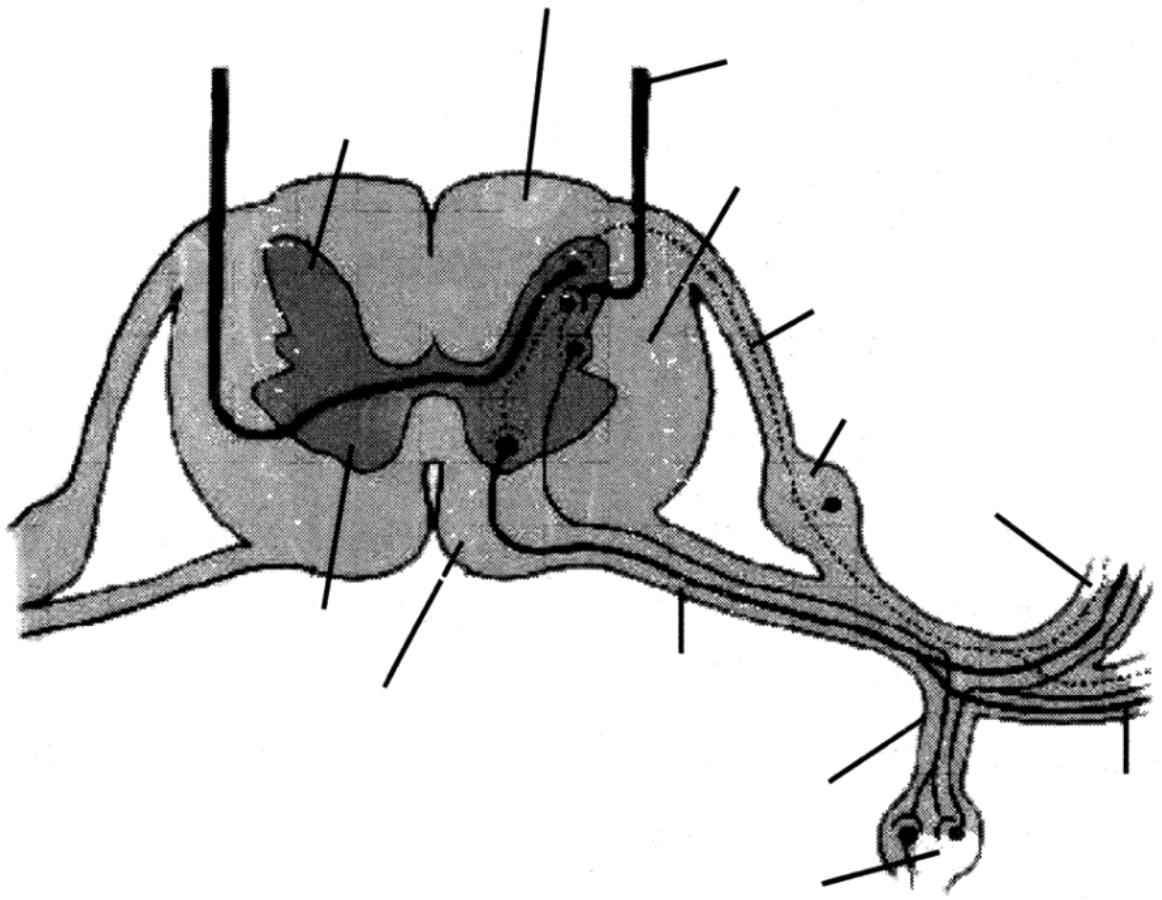


Figure 11.11: Spinal cord

2. SoMaTiC nerVouS SySTeM

The Somatic Nervous System (SNS) includes all nerves controlling the muscular system and external sensory receptors. External sense organs (including skin) are receptors. Muscle fibers and gland cells are effectors. The reflex arc is an automatic, involuntary reaction to a stimulus. When the doctor taps your knee with the rubber hammer, she/he is testing your reflex (or knee-jerk). The reaction to the stimulus is involuntary, with the CNS being informed but not consciously controlling the response. Examples of reflex arcs include balance, the blinking reflex, and the stretch reflex.

Sensory input from the PNS is processed by the CNS and responses are sent by the PNS from the CNS to the organs of the body.

Motor neurons of the somatic system are distinct from those of the autonomic system. Inhibitory signals, cannot be sent through the motor

neurons of the somatic system.

In the SNS and other components of the peripheral nervous system, these synapses are made at sites called ganglia. The cell that sends its fiber is called a *preganglionic cell*, while the cell whose fiber leaves the ganglion is called a *postganglionic* cell. As mentioned previously, the preganglionic cells of the SNS are located between the first thoracic segment and the second or third lumbar segments of the spinal cord. Postganglionic cells have their cell bodies in the ganglia and send their axons to target organs or glands.

The ganglia include not just the sympathetic trunks but also the superior cervical ganglion (which sends sympathetic nerve fibers to the head), and the celiac and mesenteric ganglia (which send sympathetic fibers to the gut).

3. CenTraL nerVouS SySTeM

The Central Nervous System (CNS) is composed of the *brain* and *spinal cord.* The CNS is surrounded by bone-skull and vertebrae. Fluid and tissue also insulate the brain and spinal cord.

NEUROGLIA

Neuroglia or glial cell are non-neuronal cells that provide support and nutrition, maintain homeostasis, form myelin, and participate in signal transmission in the nervous system. In the human brain, glia are estimated to outnumber neurons by about 10 to 1.

Glial cells provide support and protection for neurons, the other main type of cell in the nervous system. They are thus known as the “glue” of the nervous system. The four main functions of glial cells are to surround neurons and hold them in place, to supply nutrients and oxygen to neurons, to insulate one neuron from another, and to destroy pathogens and remove dead neurons.

Types of Glial Cells

Microglia

Microglia are specialized macrophages capable of phagocytosis that protect neurons of the central nervous system. They are derived from hemopoietic precursors rather than ectodermal tissue; they are commonly categorized as such because of their supportive role to neurons.

These cells comprise approximately 15% of the total cells of the central nervous system. They are found in all regions of the brain and spinal cord. Microglial cells are small relative to macroglial cells, with changing shapes and oblong nuclei. They are mobile within the brain and multiply when the brain is damaged. In the healthy central nervous system, microglia processes constantly sample all aspects of their environment (neurons, macroglia and blood vessels).

Macroglia

Astrocytes

The most abundant type of macroglial cell, astrocytes (also called astroglia) have numerous projections that anchor neurons to their blood supply. They regulate the external chemical environment of neurons by removing excess ions, notably potassium, and recycling neurotransmitters released during synaptic transmission. The current theory suggests that astrocytes may be the predominant “building blocks” of the blood-brain barrier. Astrocytes may regulate vasoconstriction and vasodilation by producing substances such as arachidonic acid, whose metabolites are vasoactive.

Astrocytes signal each other using calcium. The gap junctions (also known as electrical synapses) between astrocytes allow the messenger molecule IP3 to diffuse from one astrocyte to another. IP3 activates calcium channels on cellular organelles, releasing calcium into the cytoplasm. This calcium may stimulate the production of more IP3. The net effect is a calcium wave that propagates from cell to cell. Extracellular release of ATP, and consequent activation of purinergic receptors on other astrocytes, may also mediate calcium waves in some cases.

There are generally two types of astrocytes, *protoplasmic* and *fibrous*, similar in function but distinct in morphology and distribution. Protoplasmic astrocytes have short, thick, highly branched processes and are typically

found in gray matter. Fibrous astrocytes have long, thin, less branched processes and are more commonly found in white matter.

Oligodendrocytes

Oligodendrocytes are cells that coat axons in the central nervous system (CNS) with their cell membrane forming a specialized membrane differenciation called myelin, producing the so-called myelin sheath. The myelin sheath provides insulation to the axon that allows electrical signals to propagate more efficiently.

Ependymal cells

Ependymal cells, also named ependymocytes, line the cavities of the CNS and make up the walls of the ventricles. These cells create and secrete cerebrospinal fluid (CSF) and beat their cilia to help circulate that CSF.

Radial glia

Radial glia cells arise from neuroepithelial cells after the onset of neurogenesis. Their differentiation abilities are more restricted than those of neuroepithelial cells. In the developing nervous system, radial glia function both as neuronal progenitors and as a scaffold upon which newborn neurons migrate. In the mature brain, the cerebellum and retina retain characteristic radial glial cells. In the cerebellum, these are Bergmann glia, which regulate synaptic plasticity. In the retina, the radial Muller cell is the principal glial cell, and participates in a bidirectional communication with neurons.

Schwann cells

Similar in function to oligodendrocytes, Schwann cells provide myelination to axons in the peripheral nervous system (PNS). They also have phagocytotic activity and clear cellular debris that allows for regrowth of PNS neurons.

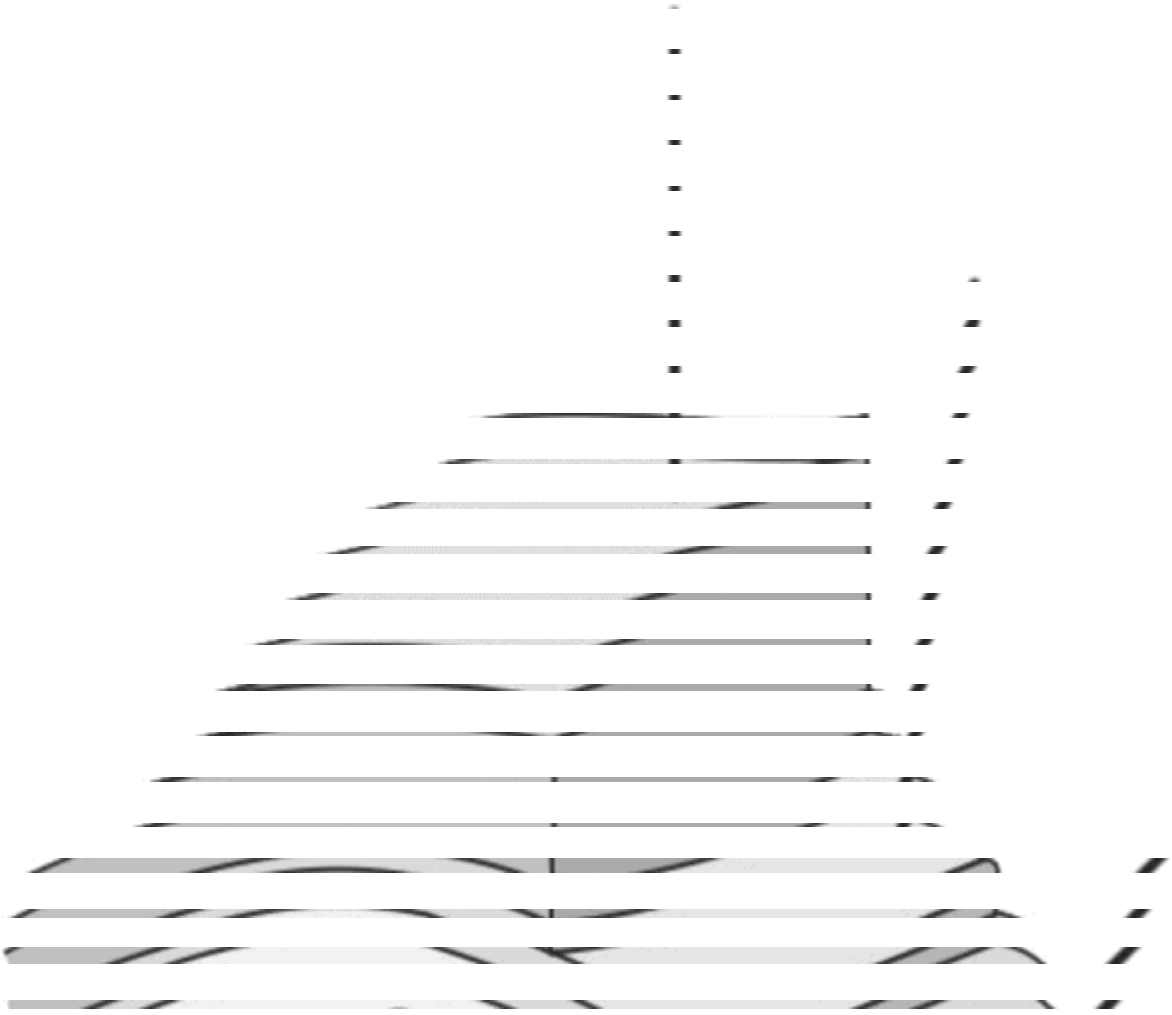
MENINGES

The meninges (singular meninx) is the system of membranes which envelops the central nervous system. The meninges consist of three layers: the pia

mater, arachnoid mater, and the dura mater. The primary function of the meninges and of the cerebrospinal fluid is to protect the central nervous system.

PIA MATER

The pia or pia mater is a very delicate membrane. It is attached to (nearest) the brain or the spinal cord. As such it follows all the minor contours of the brain (gyri and sulci). The pia mater is the meningeal envelope which firmly adheres to the surface of the brain and spinal cord. It is a very thin membrane composed of fibrous tissue covered on its outer surface by a sheet of flat cells thought to be impermeable to fluid. The pia mater is pierced by blood vessels which travel to the brain and spinal cord, and its capillaries are responsible for nourishing the brain.



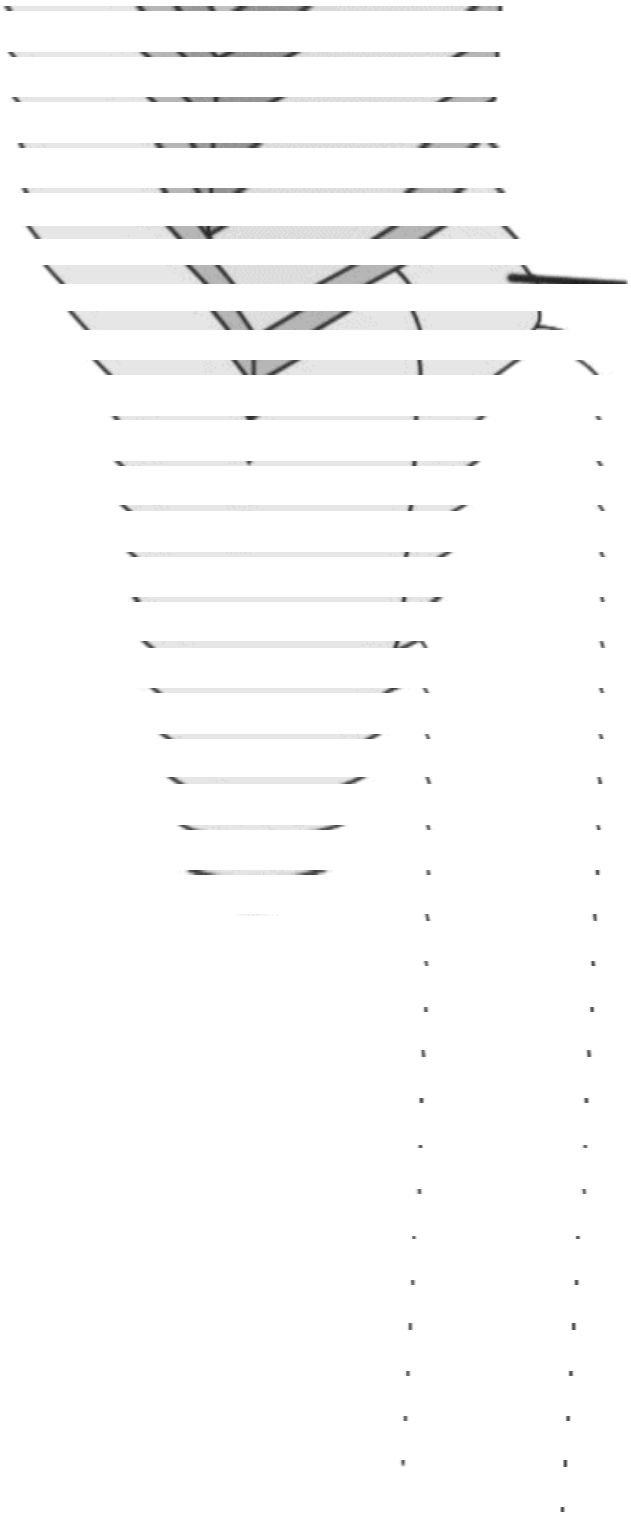


Figure 11.12: Meninges
ARACHNOID MATER

The middle element of the meninges is the arachnoid mater, so named because of its spider web-like appearance. It provides a cushioning effect for the central nervous system. The arachnoid mater exists as a thin, transparent membrane. It is composed of fibrous tissue and, like the pia mater, is covered by flat cells also thought to be impermeable to fluid. The arachnoid does not follow the convolutions of the surface of the brain and so looks like a loosely fitting sac. In the region of the brain, particularly, a large number of fine filaments called arachnoid trabeculae pass from the arachnoid through the subarachnoid space to blend with the tissue of the pia mater. The arachnoid and pia mater are sometimes together called the *leptomeninges*.

DURA MATER

The dura mater (also rarely called meninx fibrosa, or pachymeninx) is a thick, durable membrane, closest to the skull. It contains larger blood vessels which split into the capilliaries in the pia mater. It is composed of dense fibrous tissue, and its inner surface is covered by flattened cells like those present on the surfaces of the pia mater and arachnoid. The dura mater is a sac which envelops the arachnoid and has been modified to serve several functions. The dura mater surrounds and supports the large venous channels (dural sinuses) carrying blood from the brain toward the heart.

SuBaraCHnoiD SPaCeS

The subarachnoid space is the space which normally exists between the arachnoid and the pia mater, which is filled with cerebrospinal fluid.

Normally, the dura mater is attached to the skull, or to the bones of the vertebral canal in the spinal cord. The arachnoid is attached to the dura mater, and the pia mater is attached to the central nervous system tissue. When the dura mater and the arachnoid separate through injury or illness, the space between them is the subdural space.

CEREBROSPINAL FLUID (CSF)

Cerebrospinal fluid (CSF), liquor cerebrospinalis, is a clear bodily fluid that occupies the subarachnoid space and the ventricular system around and inside the brain. Essentially, the brain “floats” in it.

More specifically the CSF occupies the space between the arachnoid mater (the middle layer of the brain cover, meninges) and the pia mater (the layer of the meninges closest to the brain). Moreover it constitutes the content of all intra-cerebral (inside the brain, cerebrum) ventricles, cisterns and sulci (singular sulcus), as well as the central canal of the spinal cord.

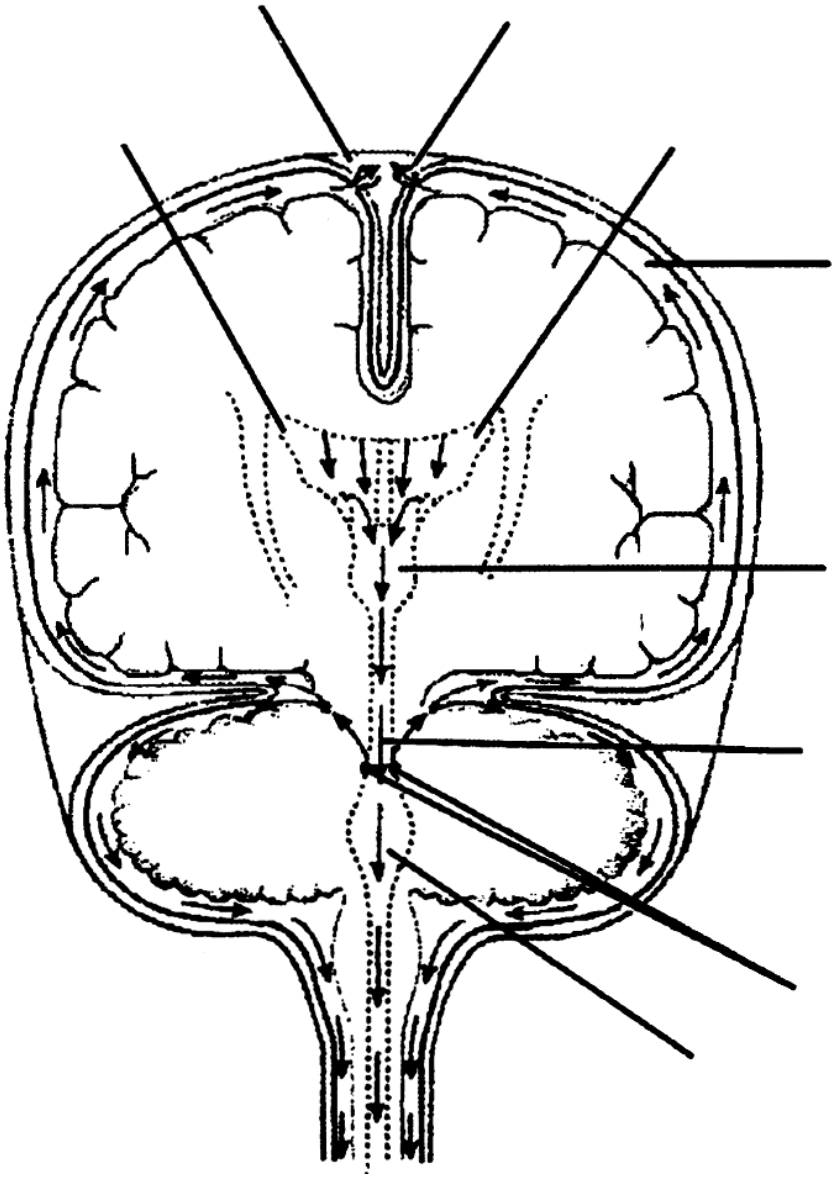


Figure 11.13: Arrow showing the flow of cerebrospinal fluid

It is produced in the brain by modified ependymal cells in the choroid plexus. It circulates from the choroid plexus through the interventricular foramina (foramen of Monro) into the third ventricle, and then through the mesencephalic duct (cerebral aqueduct) into the fourth ventricle, where it exits through two lateral apertures (foramina of Luschka) and one median aperture (foramen of Magendie). It then flows through the cerebromedullary cistern down the spinal cord and over the cerebral hemispheres.

It is an approximately isotonic solution and acts as a “cushion” or buffer for the cortex, providing also a basic mechanical and immunological protection to the brain inside the skull.

BRAIN

The human brain controls the central nervous system (CNS), by way of the cranial nerves and spinal cord, the peripheral nervous system (PNS) and regulates virtually all human activity. Involuntary, or “lower”, actions, such as heart rate, respiration, and digestion, are unconsciously governed by the brain, specifically through the autonomic nervous system. Complex, or “higher”, mental activity, such as thought, reason, and abstraction, is consciously controlled.

During embryonic development, the brain first forms as a tube, the anterior end of which enlarges into three hollow swellings that form the brain, and the posterior of which develops into the spinal cord. Sub-division and increasing specialization of the *forebrain*, *midbrain*, and *hindbrain.*

FOREBRAiN OR CEREBRUM OR TELENCEPHALON

During vertebrate embryonic development, the *prosencephalon,* the most anterior of three vesicles that form from the embryonic neural tube, is further subdivided into the *telencephalon* and *diencephalon.* The telencephalon then forms two lateral telencephalic vesicles which develop into the *left* and *right cerebral hemispheres.*

The cerebrum, or forebrain is the most anterior part of dorsal region of the vertebrate central nervous system. The cerebrum is also divided into symmetric left and right cerebral hemispheres.

The cerebrum is composed of the following sub-regions:
• Cerebral cortex, or cortices of the cerebral hemispheres.
• Basal ganglia, or basal nuclei (also often called the

striatum).
• Olfactory bulb.

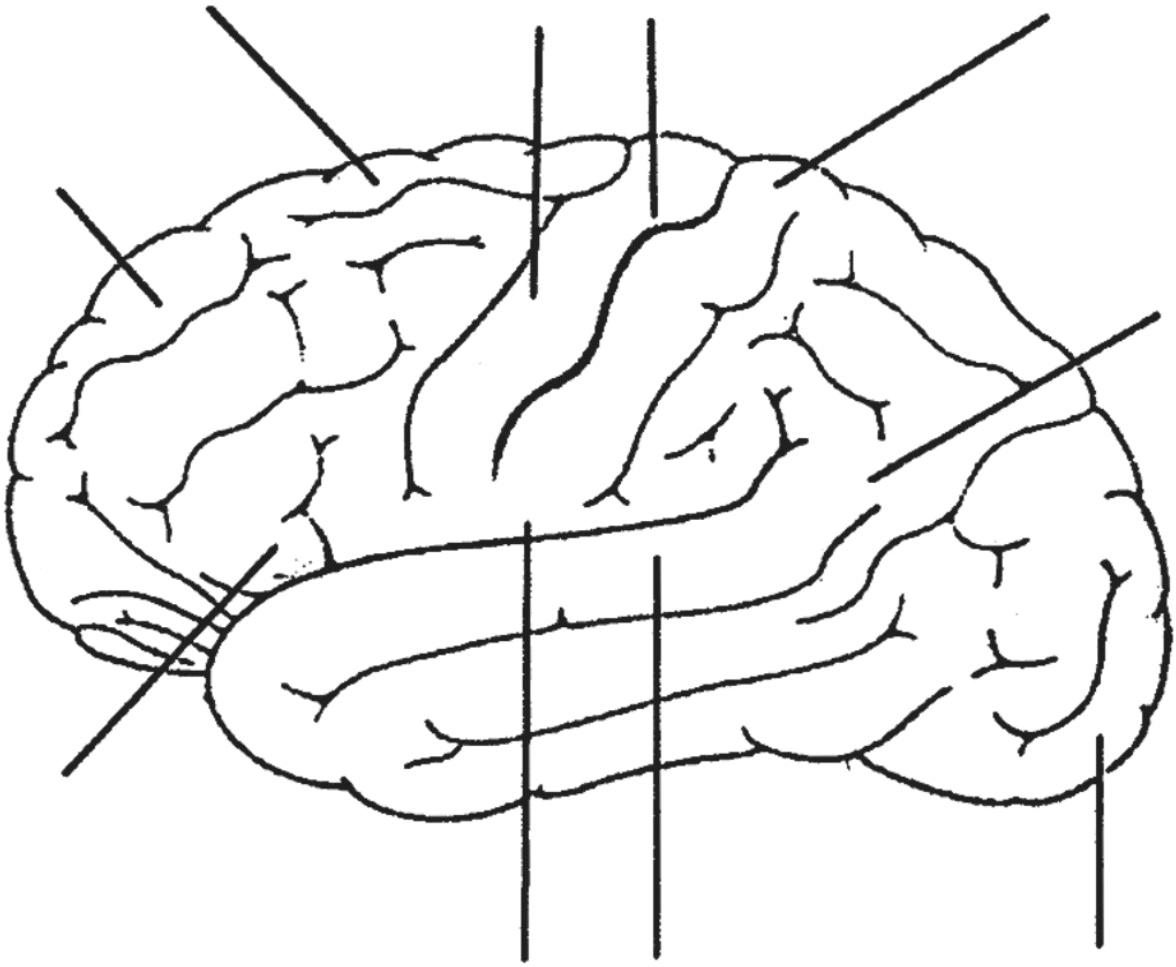


Figure 11.14: The cerebrum showing the main functional areas

In humans, the cerebrum surrounds older parts of the brain. Limbic, olfactory, and motor systems project fibers from the cerebrum to the brainstem and spinal cord. The cerebrum directs the conscious or volitional motor functions of the body. These functions originate within the primary motor cortex and other frontal lobe motor areas where actions are planned. Upper motor neurons in the primary motor cortex send their axons to the

brainstem and spinal cord to synapse on the lower motor neurons, which innervate the muscles. Damage to motor areas of cortex can lead to certain types of motor neuron disease. This kind of damage results in loss of muscular power and precision rather than total paralysis.

Cerebral Cortex

The cerebral cortex is a structure within the brain that plays a key role in memory, attention, perceptual awareness, thought, language, and consciousness. The cerebral cortex develops from the most anterior part of the neural plate, a specialized part of the embryonic ectoderm. The neural plate folds and closes to form the neural tube.

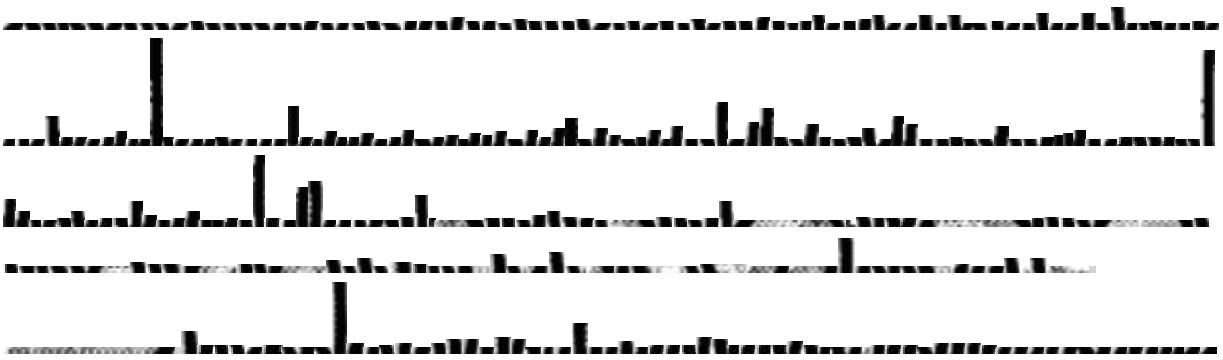


Figure 11.15: The cerebral cortex showing the mental functional areas

The most anterior (frontal) part of the neural tube, the telencephalon, gives rise to the cerebral hemispheres and cortex. The cerebral cortex is connected to various subcortical structures such as the *thalamus* and the *basal ganglia*, sending information to them along efferent connections and receiving information from them via afferent connections. Most sensory information is routed to the cerebral cortex via the thalamus. Olfactory information, however, passes through the olfactory bulb to the olfactory cortex (piriform cortex). The vast majority of connections are from one area of the cortex to another rather than to subcortical areas.

THE MIDBRAIN (MESENCEPHALON)

The mesencephalon is the most superior part of the brainstem. It is divided into an anterior and a posterior section by the ***Aqueduct of Sylvius*** which connects the third and fourth ventricles. Motor tracts, including the fibers of

the pyramidal system, pass downward on the midbrain's anterior surface. Sensory axons, including those of the spinothalamic tract also ascend, along the front of the midbrain behind the motor tracts.

The ***corpora quadrigetnina***, which is located on the posterior surface of the midbrain, is composed of two *superior colliculi* and two *inferior colliculi.* The superior colliculi are part of the visual system, relaying input from the optic tract to the lateral geniculate bodies of the thalamus. The inferior colliculi are part of the auditory pathway and send information to the medial geniculate bodies of the thalamus.

Several important nuclei are located in the midbrain, including the red nuclei, the substantia nigra, and the nuclei of cranial nerves III and IV.

The red nuclei connect the midbrain to the cerebellum and to the inner ear. It is also an important part of the extra pyramidal tract. The cerebellum compares input from muscles and joints with motor output from the cortex and relays subsequent adjustments to the cortex through the red nucleus and thalamus.

The substantia nigra is a group of dark-coloured, dopaminergic cells.

CN III is the oculomotor nerve.
CN IV is the trochlear nerve.
Both of these cranial nerves provide innervation for motor

movements of the eyes.

The cerebral pedunles (cruz cerebri) are two very large bundles of axons which are a continuation of the efferent projections within the internal capsule. It includes cortico bulbar (cortex to brain stem) and cortico spinal (cortex to spinal cord) axons.

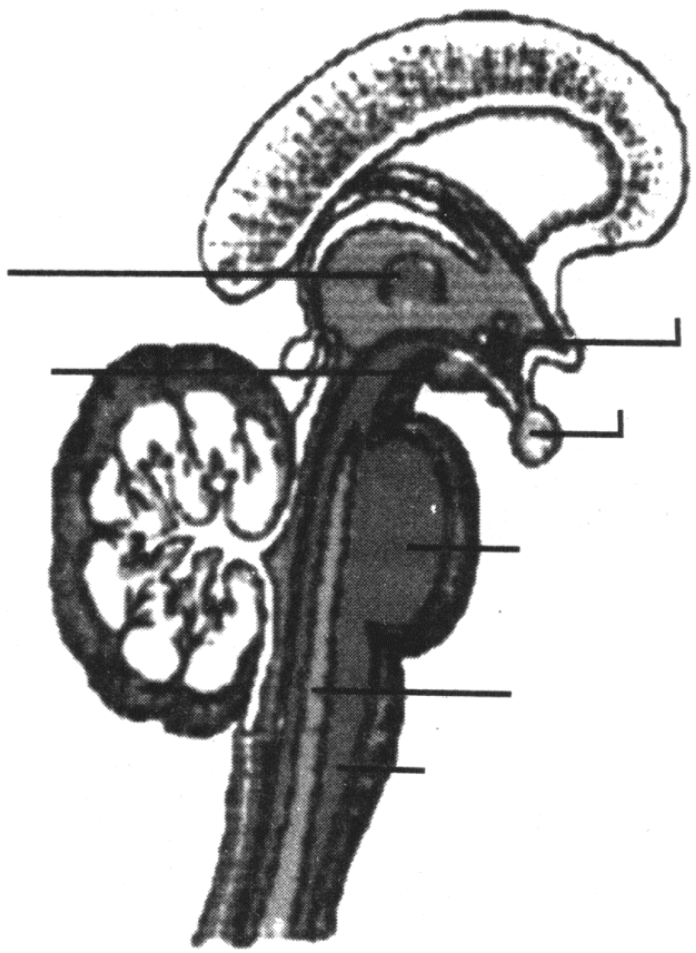


Figure 11.16: Midbrain

The Pons

The pons, which is also part of the brain stem, is inferior to the midbrain and superior to the medulla. Its posterior border is separated from the cerebellum by the *Aqueduct of Sylvius*, and more inferiorly, by the fourth ventricle. Motor and sensory tracts traverse the anterior surface of the pons. The sensory fibers are located behind the motor fibres.

The nuclei of cranial nerves V and VI are located in the pons. CN V, or the trigeminal, sends motor messages to the jaw and receives sensory messages from the teeth, tongue, and parts of the face. CN VI, or the abducens, provides motor innervation to the eye.

The motor nucleus of cranial nerve VII, the facial nerve, is located on the border of the pons and medulla. The upper part of the nerve innervates the

muscles of facial expression including the eye lids, forehead and the lips. The lower part innervates the voluntary muscles of the face below the eyelids. Cortico bulbar (pyramidal) fibres provide contralateral and ipsa innervation (bilateral) to the muscles of the upper face but only contralateral (unilateral) innervation to the lower face. Additionally, facial paralysis due to a pyramidal lesion will not permit voluntary control of the muscles but these paralyzed muscles will respond to emotional expression. This is due to extrapyramidal involuntary control.

The Medulla oblongata

The medulla is the most inferior part of the brainstem. The cell bodies of the following cranial nerves are located there:

- CN IX, the glossopharyngeal nerve.
- CN X, the vagus nerve.
- CN XI, the spinal accessory nerve.
- CN XII, the hypoglossal nerve.

Because the nuclei of the vagus nerve are found in the medulla, it is considered to be a center for circulation and respiration. It is also quite important to swallowing. It controls muscles of the pharynx, larynx and velum for swallowing.

The reticular Formation

The reticular formation is a set of interconnected nuclei that are located throughout the brain stem. Its dorsal tegmental nuclei are in the midbrain while its central tegmental nuclei are in the pons and its central and inferior nuclei are found in the medulla. The reticular formation has two components:

The *ascending reticular formation* is also called the reticular activating system. It is responsible for the sleep-wake cycle, thus mediating various levels of alertness. This part of the reticular system projects to the mid-line group of the thalamus, which also plays a role in wakefulness. From there, information is sent to the cortex.

The *descending reticular formation* is involved in posture and equilibrium as well as autonomic nervous system activity. It receives information from the hypothalamus. The descending reticular formation also plays a role in motor movement.

Interneurons of the reticular formation receive some of the cortico- bulbar fibers from the motor cortex. It is those fibers that innervate the three cranial nerves involved in eye movement. Other cortico- bulbar fibers innervate cranial nerves directly. The descending reticular nuclei in the brain are involved in reflexive behaviour such as coughing, chewing, swallowing and vomiting.

The *medulla oblongata* is closest to the spinal cord, and is involved with the regulation of heartbeat, breathing, vasoconstriction (blood pressure), and reflex centers for vomiting, coughing, sneezing, swallowing, and hiccuping. The hypothalamus regulates homeostasis. It has regulatory areas for thirst, hunger, body temperature, water balance, and blood pressure, and links the Nervous System to the Endocrine System. The midbrain and pons are also part of the unconscious brain. The thalamus serves as a central relay point for incoming nervous messages.

CEREBELLUM

The cerebellum is the third part of the hindbrain. It functions for muscle coordination and maintains normal muscle tone and posture.

The conscious brain includes the *cerebral hemispheres*, which are separated by the corpus callosum. In reptiles, birds, and mammals, the cerebrum coordinates sensory data and motor functions. The cerebrum governs intelligence and reasoning, learning and memory. While the cause of memory is not yet definitely known, studies on slugs indicate learning is accompanied by a synapse decrease. Within the cell, learning involves change in gene regulation and increased ability to secrete transmitters.

The *cortex* in each hemisphere of the cerebrum is between 1 and 4 mm thick. Folds divide the cortex into ***four lobes: occipital, temporal, parietal,*** and ***frontal.*** No region of the brain functions alone, although major functions of various parts of the lobes have been determined.

The *occipital lobe* (back of the head) receives and processes visual information. The *temporal lobe* receives auditory signals, processing language and the meaning of words. The *parietal lobe* is associated with the sensory cortex and processes information about touch, taste, pressure, pain, and heat and cold. The *frontal lobe* conducts three functions:

(i) Motor activity and integration of muscle activity. (ii) Speech.
(ii) Thought processes.

Most people who have been studied have their language and speech areas on the left hemisphere of their brain. Language comprehension is found in Wernicke's area. Speaking ability is in Broca's area. Damage to Broca's area causes speech impairment but not impairment of language comprehension. Lesions in Wernicke's area impairs ability to comprehend written and spoken words but not speech. The remaining parts of the cortex are associated with higher thought processes, planning, memory, personality and other human activities.

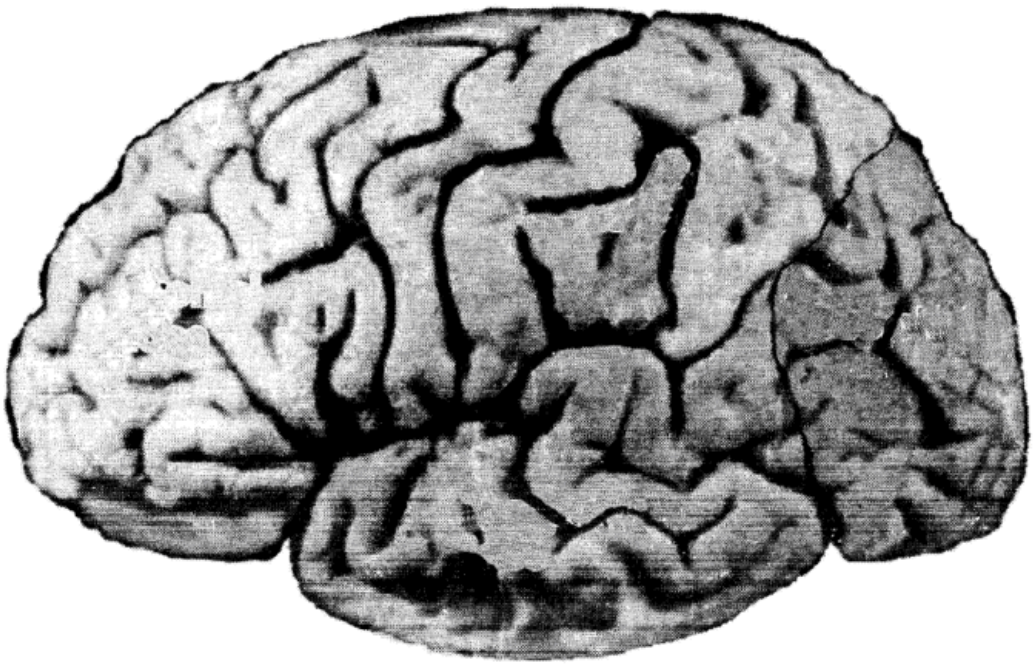


Figure 11.17: Cerebellum

THE SPINAL CORD

The spinal cord runs along the dorsal side of the body and links the brain to the rest of the body. Vertebrates have their spinal cords encased in a series of

(usually) bony vertebrae that comprise the vertebral column. The human spinal cord extends from the medulla oblongata and continues through the conus medullaris near the first or second lumbar vertebrae, terminating in a fibrous extension known as the filum terminale. It is about 45 cm long in men and 42 cm long in women, ovoid-shaped, and is enlarged in the cervical and lumbar regions. In cross-section, the peripheral region of the cord contains neuronal white matter tracts containing sensory and motor neurons. Internal to this peripheral region is the gray, butterfly shaped central region made up of nerve cell bodies. This central region surrounds the central canal, which is an anatomic extension of the spaces in the brain known as the ventricles and, like the ventricles, contains cerebrospinal fluid.

The three meninges that cover the spinal cord — the outer *dura mater,* the *arachnoid mater,* and the innermost *pia mater* — are continuous with that in the brainstem and cerebral hemispheres. Similarly, *cerebrospinal fluid* is found in the *subarachnoid space.*

The cord is stabilized within the dura mater by the connecting denticulate ligaments which extend from the enveloping pia mater laterally between the dorsal and ventral roots. The dural sac ends at the vertebral level of the second sacral vertebra.

The human spinal cord is divided into 31 different segments, with motor nerve roots exiting in the ventral aspects and sensory nerve roots entering in the dorsal aspects. The ventral and dorsal roots later join to form paired spinal nerves, one on each side of the spinal cord.

There are 31 spinal cord nerve segments in a human spinal cord:
(i) 8 cervical segments (cervical nerves exit spinal column above Cl and below C1-C7).
(ii) 12 thoracic segments (thoracic nerves exit spinal column below T1-T12).

(iii) 5 lumbar segments (lumbar nerves exit spinal column below L1-L5).
(iv) 5 sacral segments (sacral nerves exit spinal column below S1-S5).
(v) 1 coccygeal segment (coccygeal nerves exit spinal column at coccyx)

Because the vertebral column grows longer than the spinal cord, spinal cord segments become higher than the corresponding vertebra, especially in the

lower spinal cord segments in adults. In a faetus, the vertebral levels originally correspond with the spinal cord segments. In the adult, the cord ends around the L1/L2 vertebral level at the conus medullaris, with all of the spinal cord segments located superiorly to this.

REFLEX ACTION

A reflex action is an automatic neuromuscular action elicited by a defined stimulus. A reflex is a biological control system linking stimulus to response and mediated by a reflex arc.

The spinal cord is the medium by which motor and sensory impressions are conducted to and from the brain. It receives impressions from all parts of the body by means of the sensory nerves, and conveys them to the brain, where they produce sensation. It conducts the command of the brain to the voluntary muscles by the motor nerves, and thus causes movement. In all this the brain is the power, and the cord the conductor; but, as well as this, the cord has a special function — that of reflex action. If the connection of the cord with the brain is severed, and the skin supplied by afferent nerves below the injured part is irritated, movement will be produced in the part supplied by *efferent nerves* from the same part of the cord. This is *reflex action.*

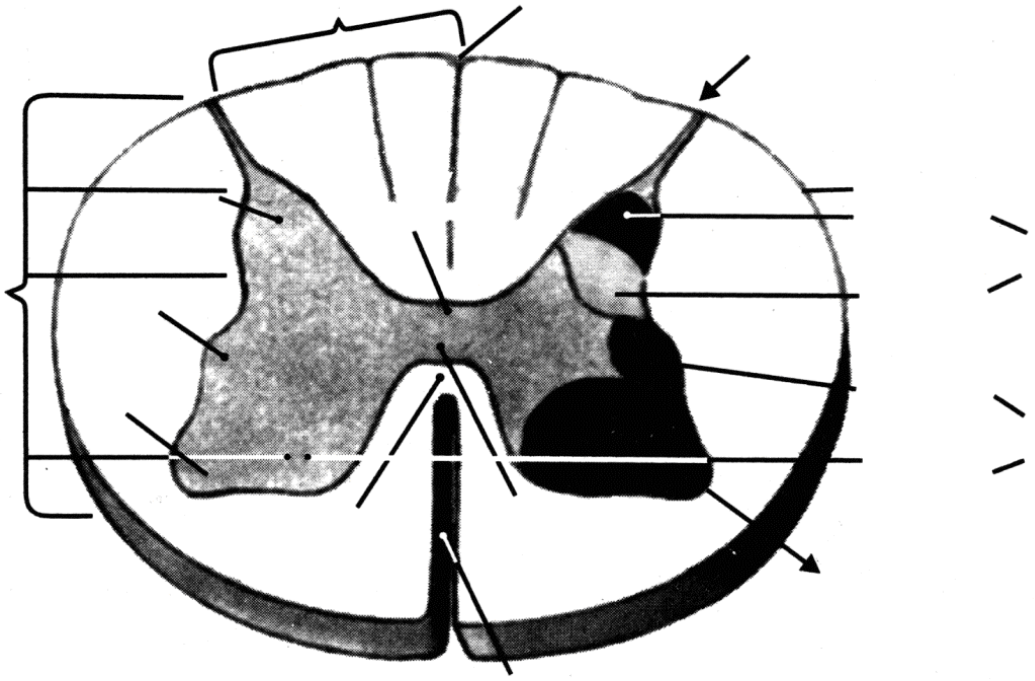


Figure 11.18 A simple reflex action

The irritation of an *afferent nerve* connected with the spinal cord sends an impulse to a nerve centre (*gray matter*) in the cord, and without communication with the brain this nerve centre has the power of sending back an impulse by an efferent nerve (or nerves), producing contraction of the muscle or muscles in which the efferent fibres terminate. A person paralysed from spinal injury will thus draw up his legs and kick out when the soles of his feet are tickled. Both in the brain and cord active power is confined to the gray matter. The brain itself gives rise to reflex actions—actions which take place without the will or consciousness of the individual, such as instinctive shrinking from a threatened blow, or blinking from a flash of light.

Reflexes are tested as part of a neurological examination to assess damage to or functioning of the central and peripheral nervous system. Reflexes may be trained, such as during repetition of motor actions during sport practice, or the linking of stimuli with autonomic reactions during classical conditioning.

FUNCTIONS OF THE CNS

The Central Nervous System (CNS) represents the largest part of the nervous system, including the brain and the spinal cord. The CNS is conceived as a system devoted to information processing, where an appropriate motor output is computed as a response to a sensory input. Many threads of research suggest that motor activity exists well before the maturation of the sensory systems, and senses only influence behaviour without dictating it. This has brought the conception of the CNS as an autonomous system. The central nervous system is the control center for the body. It regulates organ function, higher thought, and movement of the body. The central nervous system consists of the brain and spinal cord.

THALAMUS

Lesions or stimulation of the medial, dorsal, and anterior nuclei of the thalamus are associated with changes in emotional reactivity. However, the importance of these nuclei on the regulation of emotional behaviour is not due to the thalamus itself, but to the connections of these nuclei with other limbic system structures. The medial dorsal nucleus makes connections with cortical zones of the prefrontal area and with the hypothalamus. The anterior nuclei connect with the mamillary bodies and through them, via fornix, with the hippocampus and the cingulated gyrus, thus taking part in what is known as the Papez's circuit.

RECEPTORS

The parasympathetic nervous system uses only acetylcholine (ACh) as its neurotransmitter. The ACh acts on two types of receptors: the *muscarinic* and *nicotinic cholinergic* receptors. Most transmissions occur in two stages —when stimulated, the preganglionic nerve releases ACh at the ganglion, which acts on nicotinic receptors of the postganglionic nerve. The postganglionic nerve then releases ACh to stimulate the muscarinic receptors of the target organ.

The three main types of muscarinic receptors that are well characterised are:

(i) The M1 muscarinic receptors are located in the neural system. **(ii)** The M2 muscarinic receptors are located in the heart, and act to bring the heart back to normal after the actions of the sympathetic nervous system: slowing

down the heart rate, reducing contractile forces of the atrial cardiac muscle, and reducing conduction velocity of the atrioventricular node (AV node). Note, they have no effect on the contractile forces of the ventricular muscle.

(iii) The M3 muscarinic receptors are located at many places in the body, such as the smooth muscles of the blood vessels, as well as the lungs, which means that they cause vasoconstriction and bronchoconstriction. They are also in the smooth muscles of the gastrointestinal tract (GIT), which help in increasing intestinal motility and dilating sphincters. The M3 receptors are also located in many glands that help to stimulate secretion in salivary glands and other glands of the body.

ELECTROENCEPHALOGRAM (EEG)

An electroencephalogram (EEG) is a test that measures and records the electrical activity of your brain. Special sensors (electrodes) are attached to your head and hooked by wires to a computer. The computer records your brain's electrical activity on the screen or on paper as wavy lines. Certain conditions, such as seizures, can be seen by the changes in the normal pattern of the brain's electrical activity.

An electroencephalogram (EEG) may be done in a hospital or in a doctor's office by an EEG technologist. The EEG record is read by a doctor who is specially trained to diagnose and treat disorders affecting the nervous system (neurologist).

EEG (electroencephalographic) *biofeedback*, now more commonly known as *neurofeedback*, is a specialized form of biofeedback that aims to retrain brain waves.

BRAIN WAVES
Our brains generate electrical activity (brain waves) all the time.

The waves that one can measure at any one time depend on the state the brain. The state of the brain varies from being drowsy and sleepy, to being fully awake and focused. As we engage in different activities, the electrical activity of the brain also changes. In biofeedback, we are interested in three different brain waves:

(i) *Theta,*
(ii) *Alpha,* and
(iii) *Beta.*

These waves, which we see as tracings across the computer screen, differ from each other in two respects. Firstly, they differ in *size* or *amplitude.*

(i) *High: Small amplitude:* The waves also differ in the number of cycles per second (hertz abbreviated as Hz). They can be *slow waves,* or *fast waves.*

1. Theta Waves

Theta waves are slow high amplitude waves. There are only 4-7 cycles (Hz) per second, hence they are described as slow. They are present during sleep. Brain waves that are slower than 3 Hz are called Delta waves and they are found in coma.

Theta waves are abnormal in awake adults. They are implicated in anxiety, and in neurological conditions such as epilepsy, traumatic brain injury, and Attention Deficit Disorders (ADD/ADHD).

In neurofeedback, we treat epilepsy, traumatic brain injury (slowed information processing associated with inattention and memory problems), and ADD/ADHD, by retraining patients to inhibit theta waves, whilst they increase beta waves. In insomnia that is associated with tension and anxiety, some patients benefit from training to increase theta waves.

2. alpha Waves

Alpha waves have moderate amplitude and medium speed (8-12 Hz). They are associated with closing of one's eyes. Alpha waves are associated with calmness and relaxation. Interestingly, when we pray, or when we meditate, we tend to close their eyes. Perhaps we are unwittingly trying to get ourselves into alpha states. People in alpha states are awake but relaxed.

In neurofeedback, we use alpha training and sometimes alpha/ theta training for the treatment of depression, anxiety, post- traumatic stress disorder (PTSD), general stress, and addictions (alcohol, cigarettes, and other drugs). Healthy individuals may use alpha training to enhance their relaxation skills.

3. Beta Waves

3. Beta Waves 40 Hz. These waves are associated with arousal, problem solving, attention and concentration, and other intellectual processes. Beta waves are classified into low beta, also known as *Sensory-Motor Rhythm* [SMR (approx. 12-15 Hz)] Beta (16-20 Hz), and High Beta (22-40 Hz). Low beta is associated with the organization of brain processes, whilst the high beta is more associated with arousal, and is implicated in anxiety states.

In neurofeedback, retraining of beta waves is used in the treatment of epilepsy, ADD/ADHD, learning disorders, depression, migraines, traumatic brain injury, and premenstrual syndrome.. In insomnia, patients who are relaxed but are still sleepless benefit from training to increase the SMR.

Other tests that may also be done include:
1. Video eeg

Video EEG records seizures on videotape and on computer, so that the doctor can see what happens just before, during, and right after a seizure. This test can be very helpful in finding the specific area of the brain that the seizures may be coming from. It is also helpful in diagnosing psychogenic seizures, which may look like real seizures but do not affect the electrical activity in the brain. Video EEG may be used:

• *Short-term monitoring* is done on an outpatient basis and may last up to 6 hours.
• *Long-term monitoring* is done in the hospital and may last 3 to 7 days.

2. Brain Mapping
Brain mapping is a fairly new method that is very similar to EEG. With electrodes placed on the person's scalp to transmit the brain's electrical activity, a computer makes a colour-coded map of signals from the brain. It is sometimes done to find a specific problem area in the brain that has already shown up on a regular EEG. Doctors are still not certain how brain mapping could be best used.

3. ambulatory eeg Monitoring

In ambulatory EEG monitoring, the person is able to move around, and the test allows for long periods of time in recording of electrical activity in the brain. Fewer electrodes are attached to the person, and the person carries a small, portable recording unit. The recording may last for a full day or more, and the person is allowed to leave the hospital. Ambulatory EEG monitoring is not as accurate as a regular EEG.

In the past, EEGs played a bigger roll than they do now in the diagnosis of brain injury due to strokes and in the diagnosis and identification of brain tumors. Computer-assisted techniques such as CT-scans (an X-ray image of the body, also called a CAT scan); MRIs (magnetic resonance imaging, which uses radio waves and magnetic fields to produce and image); and PET scans (positron emission tomography, which uses a radioactive tracer that is injected into the body to help form a picture), have taken over most of the tasks of diagnosing these conditions, since they tend to be more sensitive and specific in the diagnosis of strokes and tumors and are simpler to do and easier to interpret than EEGs.

Questions for study

1. What is neuron? Describe the structure of neuron.
2.Explain the different parts of peripheral nervous system.
3. What is spinal cord?
4.Write short notes on:
(a) Brain (b) Cranial Nerve
(c) Sacral Nerve (d) Autonomic Nervous System. Introduction to Human Body 215

12

Sense Organs

Sense provide information about the body and its environment. Humans have five special senses namely olfaction (smell) gestation (taste), equilibrium (balance and body position), vision and hearing. The principal function of special sensor receptors is to detect environment stimuli and transducer them into electrical impulses. By far the most important organs of

sense are our eyes. Information form special senses is carried in special somatic afferents and special visceral afferents. Whereas the general (somatic) sense of touch, pain, heat, pressure etc is carried in general somatic afferents and general visceral afferents.

THE EYE

The eye contains the receptors for vision and a refracting system that focuses light rays on the receptors in the retina. The orbit of eye is formed by different bones which protect the eye ball.

Anatomically, the wall of the eye ball is divided into three layer:

(a) Outermost layer is the fibrous coat, consisting of sclera and cornea.
(b) The middle layer is a vascular coat, consisting of choroids, ciliary body.
(c) The innermost layer is made up of nervous tissue consisting of the retina.
There are six muscles, called as external muscles, these muscles connect the eyeball to the orbital cavity. These six

muscles are four rectus muscle, i.e., superior, inferior, lateral and medical and two oblique muscle, superior and inferior.

Figure 12.1
EYE STRUCTURE

The eyelids contain skeletal muscle that enables the eyelids to close and cover the front of the eyeball. Eyelashes along the border of The eyelids are lined with a thin membrane called the **conjunctiva,** which is also folded over the white of the eye and merges with the corneal epithelium. Inflammation of this membrane, called **conjunctivitis,** may be caused by allergies or by certain bacteria or viruses, and makes the eyes red, itchy, and watery.

Tears are produced by the **lacrimal glands,** located at the upper, outer comer of the eyeball, within the orbit Secretion of tears occurs constantly, but is increased by the presence of irritating chemicals (onion vapors, for example) or dust, and in certain emotional situations (sad or happy). Small ducts take tears to the anterior of the eyeball, and blinking spreads the tears and washes the surface of the eye. Tears are mostly water, with about 1% sodium chloride, similar to other body fluids. Tears also contain **lysozyme,** an enzyme that inhibits the growth of most bacteria on the wet, warm surface of the eye. At the medial comer of the eyelids are two small openings into the superior and inferior lacrimal canals. These ducts take tears to the **lacrimal sac** (in the lacrimal bone), which leads to the **nasolacrimal duct,** which empties tears into the nasal cavity. This is why crying often makes the nose run.

The Sclera and Choroids

The eyeball has three layers: the outer sclera, middle choroid layer, and inner retina (Fig. 9-5). The **sclera** is the thickest layer and is made of fibrous connective tissue that is visible as the white of the eye. The most anterior portion is the **cornea,** which differs from the rest of the sclera in that it is transparent. The cornea has no capillaries, covers the iris and pupil inside the eye, and is the first part of the eye that **refracts,** or bends, light rays.

The **choroid layer** contains blood vessels and a dark blue pigment (derived from melanin) that absorbs light within the eyeball and thereby prevents glare (just as does the black interior of a camera). The anterior portion of the choroid is modified into more specialized structures: the ciliary body and the iris. The **ciliary body** (muscle) is a circular muscle that surrounds the edge of the lens and is connected to the lens by **suspensory ligaments.** The **lens** is made of a transparent, elastic protein, and, like the cornea, has no capillaries. The shape of the lens is changed by the ciliary muscle, which enables the eye to focus light from objects at varying distances from the eye.

Just in front of the lens is the circular **iris,** the col-ored part of the eye; its pigment is a form of melanin. What we call “eye color” is the color of the iris and is a genetic characteristic, just as skin color is. Two sets of smooth muscle fibers in the iris change the diameter of the **pupil,** the central opening. Contraction of the radial fibers dilates the pupil; this is a

sympathetic response. Contraction of the circular fibers constricts the pupil; this is a parasympathetic response (oculo-motor nerves). Pupillary constriction is a reflex that protects the retina from intense light or that permits more acute near vision, as when reading.

The Retina

The retina lines the posterior two-thirds of the eyeball and contains the visual receptors, the rods and cones Rods detect only the presence of light, whereas cones detect colors, which, as you may know from physics, are the different wavelengths of visible light. Rods are proportionally more abundant toward the periphery, or edge, of the retina. Our best vision in dim light or at night, for which we depend on the rods, is at the sides of our visual fields. Cones are most abundant in the center of the retina, especially an area called the macula lutea directly behind the center of the lens on what is called the visual axis. The fovea, which contains only cones, is a small depression in the macula and is the area for best color vision.

An important cause of vision loss for people over 65 years of age is **age-related macular degeneration (AMD),** that is, loss of central vision, and some cases seem to have a genetic component. In the dry form of AMD, small fatty deposits impair circulation to the macula, and cells die from lack of oxygen. In the wet form of AMD, abnormal blood vessels begin leaking into the retina, and cells in the macula die from the damaging effects of blood outside its vessels. The macula, the center of the visual field, is the part of the retina we use most: for reading, for driving, for recognizing people, and for any kind of close work. People of all ages should be aware of this condition and that smoking and exposure to ultraviolet rays are risk factors.

When light strikes the retina, the rods and cones generate impulses. These impulses are carried by ganglion neurons, which all converge at the optic disc and pass through the wall of the eyeball as the optic nerve. There are no rods or cones in the optic disc, so this part of the retina is sometimes called the “blind spot.” We are not aware of a blind spot in our field of vision, however, in part because the eyes are constantly moving, and in part because the brain “fills in” the blank spot to create a “complete” picture.

Cavities of the Eyeball

There are two cavities within the eye: the posterior cavity and the anterior cavity. The larger, posterior cavity is found between the lens and retina and contains vitreous humor (or vitreous body). This semi-solid substance keeps the retina in place. If the eyeball is punctured and vitreous humor is lost, the retina may fall away from the choroid: this is one possible cause of a detached retina.

The anterior cavity is found between the back of the cornea and the front of the lens, and contains aqueous humor, the tissue fluid of the eyeball. Aqueous humor is formed by capillaries in the ciliary body, flows anteriorly through the pupil, and is reabsorbed by the canal of Schlemm (small veins also called the scleral venous sinus) at the junction of the iris and cornea. Because aqueous humor is tissue fluid, you would expect it to have a nourishing function, and it does. Recall that the lens and cornea have no capillaries; they are nourished by the continuous flow of aqueous humor.

Physiology of Vision

For us to see, light rays must be focused on the retina, and the resulting nerve impulses must be transmitted to the visual areas of the cerebral cortex in the brain.

Refraction of light rays is the deflection or bending of a ray of light as it passes through one object and into another object of greater or lesser density. The refraction of light within the eye takes place in the following pathway of structures: the cornea, aqueous humor, lens, and vitreous humor. The lens is the only adjustable part of the refraction system. When looking at distant objects, the ciliary muscle is relaxed and the lens is elongated and thin. When looking at near objects, the ciliary muscle contracts to form a smaller circle, the elastic lens recoils and bulges in the middle, and has greater refractive power.

When light rays strike the retina, they stimulate chemical reactions in the rods and cones. In rods, the chemical **rhodopsin** breaks down to form scotopsin and retinal (a derivative of vitamin A). This chemical reaction generates an electrical impulse, and rhodopsin is then resynthesized in a

slower reaction. Adaptation to darkness, such as going outside at night, takes a little while because being in a well-lit area has broken down most of the rhodopsin in the rods, and resynthesis of rhodopsin is slow. The opposite situation, perhaps being suddenly awakened by a bright light, can seem almost painful. What happens is this: In darkness the rods have resynthesized a full supply of rhodopsin, and the sudden bright light breaks down all the rhodopsin at the same time. The barrage of impulses generated is very intense, and the brain may interpret any intense sensation as pain. A few minutes later the bright light seems fine because the rods are recycling their rhodopsin slowly, and it is not breaking down all at once.

Chemical reactions in the cones, also involving retinal, are brought about by different wavelengths of light. It is believed that there are three types of cones: red-absorbing, blue-absorbing, and green-absorbing cones. Each type absorbs wavelengths over about a third of the visible light spectrum, so red cones, for example, absorb light of the red, orange, and yellow wavelengths. The chemical reactions in cones also generate electrical impulses.

The visual areas are in the **occipital lobes** of the cerebral cortex. Although each eye transmits a slightly different picture (look straight ahead and close one eye at a time to see the difference between the two pictures), the visual areas put them together, or integrate them, to make a single image that has depth and three dimensions. This is called **binocular vision.** The visual areas also right the image, because the image on the retina is upside down. The image on film in a cam-era is also upside down, but we don’t even realize that because we look at the pictures right side up. The brain just as automatically ensures that we see our world right side up.

Also for near vision, the pupils constrict to block out peripheral light rays that would otherwise blur the image, and the eyes converge even further to keep the images on the corresponding parts of both retinas. The importance of pupil constriction can be demonstrated by looking at this page through a pinhole in a piece of paper. You will be able to read with the page much closer to your eye because the paper blocks out light from the sides.

Eye Diseases

The diseases or a disorder that destroy eye tissue and other parts of eyes can be referred to as the eye diseases. There are different types of eye diseases, which can either be minor, which doesn't last for a longer time or some can also lead to a permanent loss of vision.

There are different factors behind the causes of eye diseases. These factors include age, stress, infections, heredity, nutritional deficiencies, injuries or accidents, etc.

Types of eye Diseases
There are different types of eye diseases that exist, all of these being common eye diseases.

The following is a list of human eye disease
Age-Related Macular Degeneration

Macular degeneration is also known as an irregularity that affects the centre of the retina, which is called the Macula. The Macula is responsible for everyday acute vision.

There are two types of Macular degeneration:
1. Dry Macular degeneration.
2. Wet Macular degeneration.

Causes of Macular degeneration: Age, Smoking, Obesity, High blood pressure, Exposure to sunlight.

Symptoms of Macular degeneration: Blurred vision, A dark or empty area in the central area of vision, Distortion of straight lines.

Treatments for Macular degeneration: People suffering from Dry AMD continue with the aid of low vision optical devices. But Wet AMD is treated with injected medications or laser surgery by sealing off the leaking blood vessels.

Bulging Eyes

Proptosis as it is also known as occurs due to the swelling of muscle fats and tissue behind the eye causing both eyes to protrude from the eye sockets

leaving the cornea exposed to air, making it difficult to keep the eyes moist and lubricated.

Causes of Bulging Eyes: It has been linked to Glaucoma, Hyperthyroidism, and Leukemia the most common being Graves disease a condition where thyroid glands mistakenly sense harmful cells and release **antibodies** which fuse to eye muscles causing inflammation.

Symptoms of Bulging Eyes: Common symptoms include Appearance of protruding eyes, Excessive dryness in eyes, visible whiteness between the top of iris and the eyelid, Eye pain, Eye redness.

Treatments for of Bulging Eyes: Lack of lubrication is the main problem hence artificial tears and eye drops are used for moisture and lubrication.

Glaucoms

It is a situation which is caused by the damage to the eye's optic nerve which gets severer over time. It is often associated with an increase in the pressure inside the eye. Glaucoma tends to be inherited and turns up late in life. There are four different types of Glaucoma which include Chronic Open-angle glaucoma, Acute closed-angle glaucoma, Secondary glaucoma, Normal-tension glaucoma.

Causes of glaucoma
Types of glaucoma are caused by different reasons:

1. Chronic open-angle glaucoma results from a pressure build-up in the eye and causes severe vision loss without any symptoms.

2. Acute closed glaucoma appears all of sudden which is very painful and is extremely serious.
3. Secondary glaucoma arrives as a result of something else like medical conditions and injuries, irregularities. **Symptoms of Glaucoma:** Blurred vision, severe eye pain, headache, rainbow halos, nausea, and vomiting.

Treatments for Glaucoma: Glaucoma could be treated with prescription eye drops which reduces eye pressure by slowing the production of fluids within the eye. Doctors also recommend highly focused laser beams to

create an alternate hole in the iris. Surgery could treat glaucoma but could not reverse the existing damage.

Lazy Eye

This is a condition where there is a lack of vision in one eye because the eye and the brain stop working together, the brain ignores the image from the amblyopic eye this only affects one eye resulting in the amblyopic eye pointing away from the other thereby appearing “Lazy”.

Causes of Lazy Eye: There are various causes behind this condition like Strabismus (Crossed Eyes) and cataracts, ptosis and refractive problems.

Symptoms of Lazy Eye: Symptoms include eyes that point in different directions, significant favouring of one eye, poor depth perception, poor vision in one eye.

Treatments for Lazy Eye: Improved sight in a lazy eye could be accomplished however in certain cases an untreated eye might become dysfunctional. Best possible methods are by patching or covering the strong eye: This method forces the weaker eye to work harder hence strengthening its ability to move and focus. Contact lenses and eyeglasses in some cases surgery to realign the muscles in the eye.

These were the most common eye diseases types that are caused by several factors.

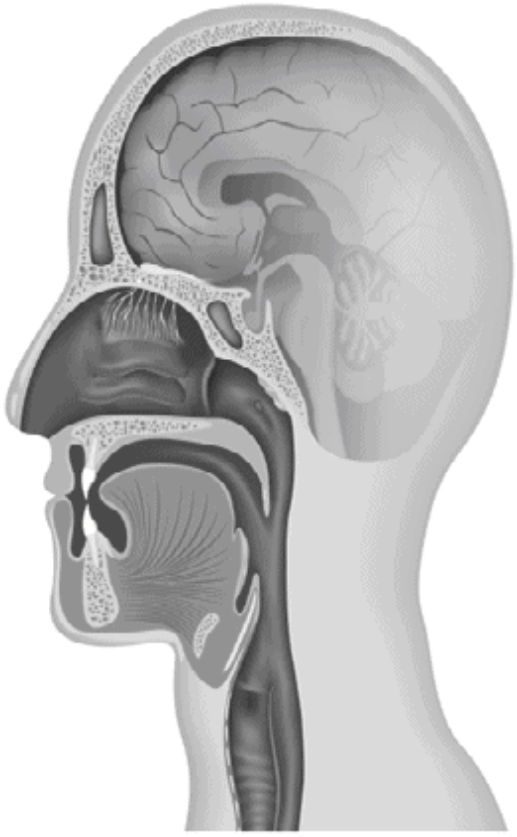
Listed below are the few eye diseases names which are caused by immune system disorders, age-related and some may even result in permanent loss of vision.

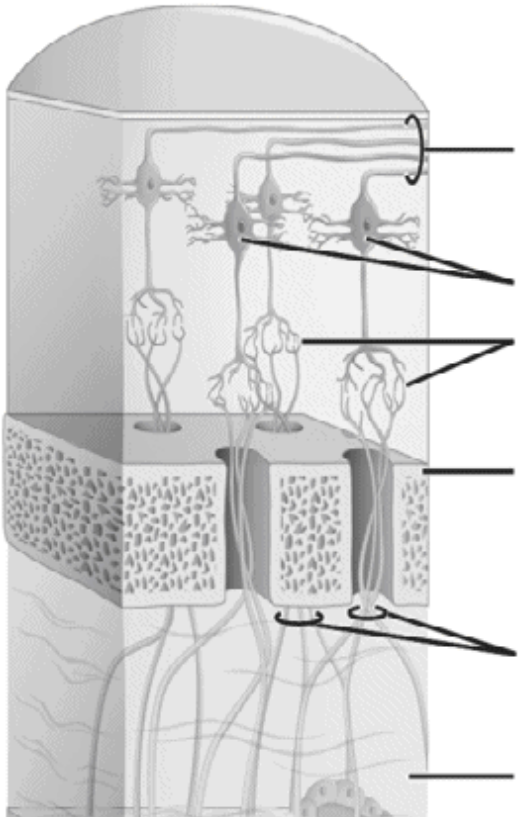
1. Floaters.
2. Cataracts.
3. Presbyopia.
4. Conjunctivitis.
5. Vision Changes.
6. Colour blindness.
7. Retinal disorders.
8. Dry and Itchy Eyes.

9. Optic nerve disorders.
10. Macular degeneration.

SENSE OF SMELL

Like taste, the sense of smell, or olfaction, is also responsive to chemical stimuli. The olfactory receptor neurons are located in a small region within the superior nasal cavity. This region is referred to as the olfactory epithelium and contains bipolar sensory neurons. Each olfactory sensory neuron has dendrites that extend from the apical surface of the epithelium into the mucus lining the cavity. As airborne molecules are inhaled through the nose, they pass over the olfactory epithelial region and dissolve into the mucus. These odorant molecules bind to proteins that keep them dissolved in the mucus and help transport them to the olfactory dendrites. The odorant-protein complex binds to a receptor protein within the cell membrane of an olfactory dendrite. These receptors are G protein-coupled, and will produce a graded membrane potential in the olfactory neurons.





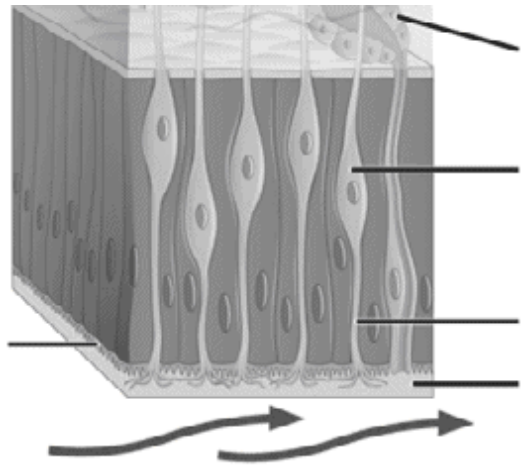


Figure 12.2

The axon of an olfactory neuron extends from the basal surface of the epithelium, through an olfactory foramen in the cribriform plate of the ethmoid bone, and into the brain. The group of axons called the olfactory tract connect to the olfactory bulb on the ventral surface of the frontal lobe. From there, the axons split to travel to several brain regions. Some travel to the cerebrum, specifically to the primary olfactory cortex that is located in the inferior and medial areas of the temporal lobe. Others project to structures within the limbic system and hypothalamus, where smells become associated with long-term memory and emotional responses. This is how certain smells trigger emotional memories, such as the smell of food associated with one's birthplace. Smell is the one sensory modality that does not synapse in the thalamus before connecting to the cerebral cortex. This intimate connection between the olfactory system and the cerebral cortex is one reason why smell can be a potent trigger of memories and emotion.

The nasal epithelium, including the olfactory cells, can be harmed by airborne toxic chemicals. Therefore, the olfactory neurons are regularly replaced within the nasal epithelium, after which the axons of the new neurons must find their appropriate connections in the olfactory bulb. These new axons grow along the axons that are already in place in the cranial nerve.

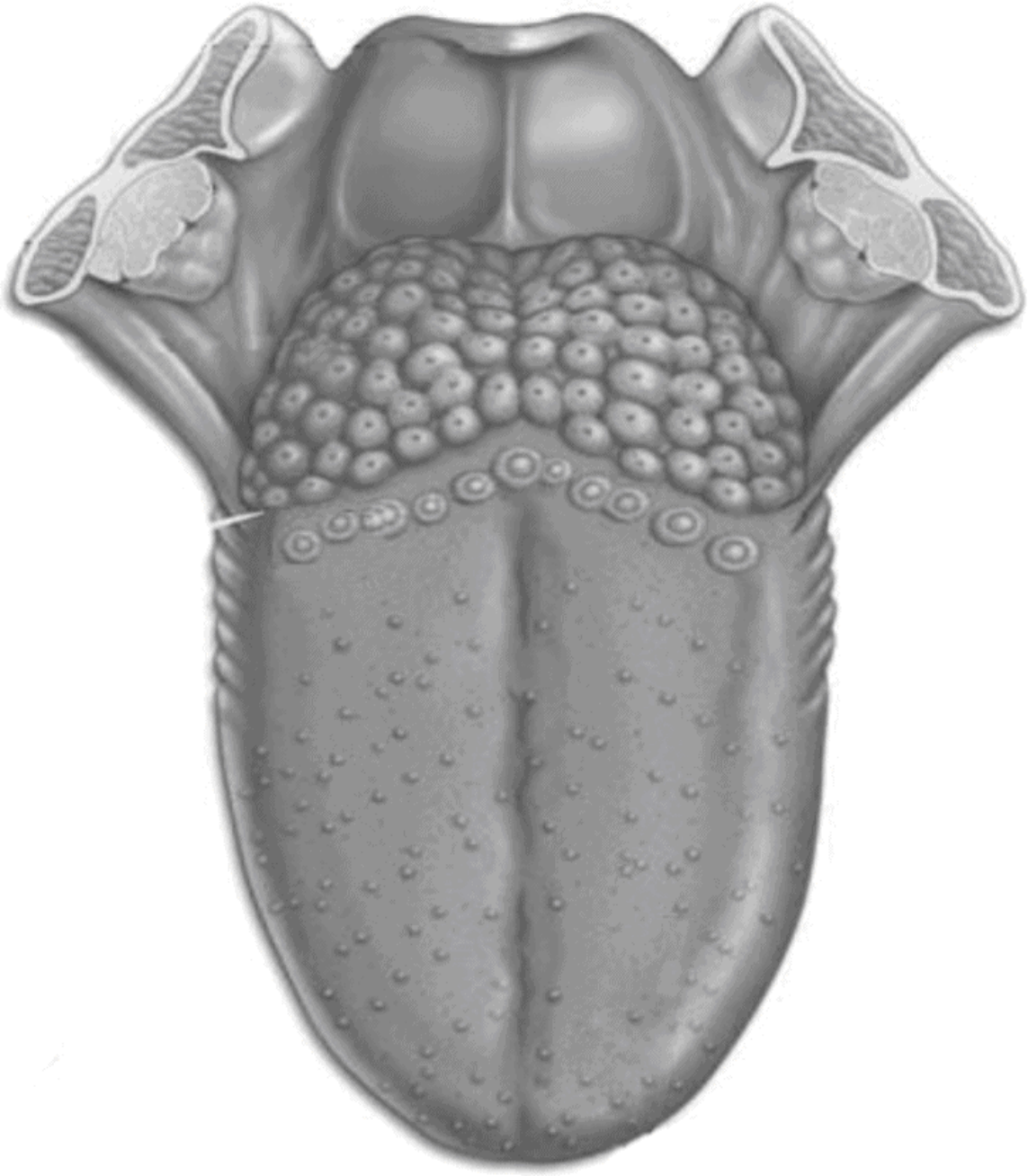


Figure 12.3
SMELL PHYSIOLOGY

The odorous materials spread chemical particles, and the particles during inhalation are carried towards nose. Particles stimulate nerve cells of the olfactory region when they dissolve in the mucous. When the air enters the nose, it is heated and the particles go to the roof of nose and olfactory

receptors cells get stimulated, perception of smell occurs. The sense of smell may affect the appetite, either it may increase or decrease, depending upon the smell. But when a person is more than familiar with a particular odour, the perception odour quickly decreases. When there is irritation to nasal muscosa, it prevents odours substances from reaching olfactory area of nose and may cause loss of sense of smell.

TASTE SENSATION

The sense of taste is equivalent to excitation of taste receptors, and receptors for a large number of specific chemicals have been identified that contribute to the reception of taste. Despite this complexity, five types of tastes are commonly recognized by humans:

- Sweet - usually indicates energy rich nutrients
- Umami - the taste of amino acids (e.g. meat broth or aged cheese)
- Salty - allows modulating diet for electrolyte balance
- Sour - typically the taste of acids
- Bitter - allows sensing of diverse natural toxins

Once taste signals are transmitted to the brain, several efferent neural pathways are activated that are important to digestive function. For example, tasting food is followed rapidly by increased salivation and by low level secretory activity in the stomach.

Among humans, there is substantial difference in taste sensitivity. Roughly one in four people is a “supertaster” that is several times more sensitive to bitter and other tastes than those that taste poorly. Such differences are heritable and reflect differences in the number of fungiform papillae and hence taste buds on the tongue.

In addition to signal transduction by taste receptor cells, it is also clear that the sense of smell profoundly affects the sensation of taste. Think about how tastes are blunted and sometimes different when your sense of smell is disrupted due to a cold.

Physiology of Taste

When the substance goes in solution form, the gustatory receptors get stimulated which produce changes in electrical potentials. The receptor potentials of taste cells generate impulses in sensory neuron ending which innervates the taste cells.

The facial cells nerve for anterior two third of tongue and glossopharyngeal nerve works for posterior two-third of tongue. Axons of these nerves go to taste nuclei in medulla, then to thalamus and from here to taste area of cerebral cortex of brain.

THE EAR
The ear is the organ of hearing and balance. The parts of the ear include:

• **External or outer ear, consisting of:**
• **Pinna or auricle.** This is the outside part of the ear.
• **External auditory canal or tube.** This is the tube that

connects the outer ear to the inside or middle ear.

• **Tympanic membrane (eardrum).** The tympanic membrane divides the external ear from the middle ear.
•**Middle ear (tympanic cavity),** consisting of:
• **Ossicles.** Three small bones that are connected and transmit the sound waves to the inner ear. The bones are called:
• Malleus
• Incus
• Stapes
• **Eustachian tube.** A canal that links the middle ear with the back of the nose. The eustachian tube helps to equalize the pressure in the middle ear. Equalized pressure is needed for the proper transfer of sound waves. The eustachian tube is lined with mucous, just like the inside of the nose and throat.
• **Inner ear,** consisting of:
• **Cochlea.** This contains the nerves for hearing.
• **Vestibule.** This contains receptors for balance.
• **Vestibule.** This contains receptors for balance.
•**Semi-circular canals.** This contains receptors for balance.

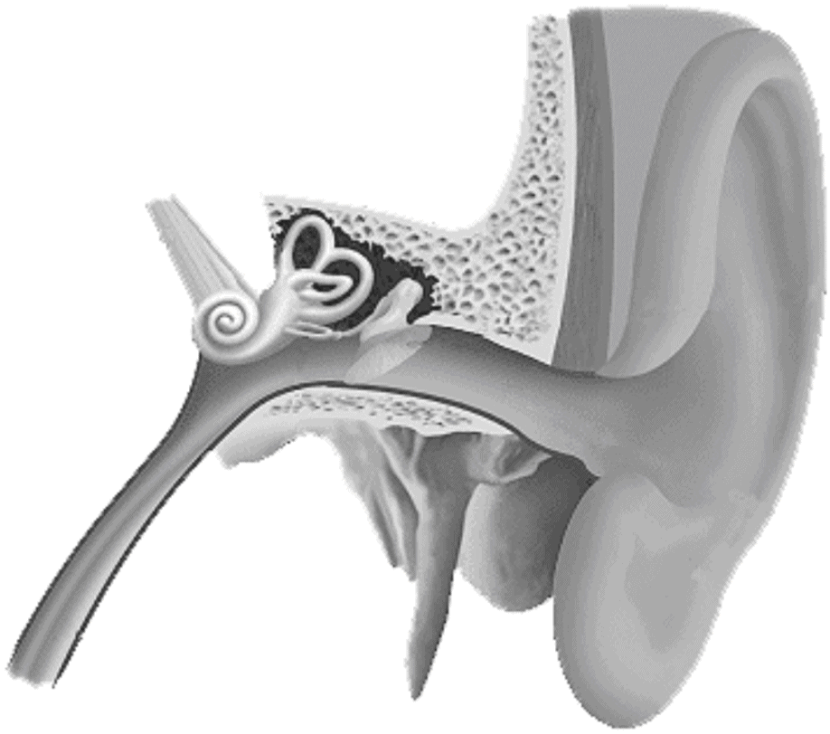


Figure 12.4

How do you hear?

Hearing starts with the outer ear. When a sound is made outside the outer ear, the sound waves, or vibrations, travel down the external auditory canal and strike the eardrum (tympanic membrane). The eardrum vibrates. The vibrations are then passed to 3 tiny bones in the middle ear called the ossicles. The ossicles amplify the sound. They send the sound waves to. the inner ear and into the fluid-filled hearing organ (cochlea).

Once the sound waves reach the inner ear, they are converted into electrical impulses. The auditory nerve sends these impulses to the brain. The brain then translates these electrical impulses as sound.

Physiology of hearing

Any sound in the atmosphere produces the sounds waves or vibrations and the sound waves travel at a certain speed, say about 1089 feet/per meter/second. Because of the shape of the auricle, it captures any sound wave, and relays it through the auditory canal, so that eardrum can vibrate.

Due to the vibration of eardrum, the auditory ossicle moves to and from and it sets the per lymph in motion and end lymph present inside the membranous labyrinths get stimulated, and thus kept in motion.

The nerve cells present on basilar membrane get stimulated and consequently the nerve fibres carry impulse through auditory nerve to hearing area of the cerebral cortex, where the interpretation of the waves take place.

Disorder of Ear
otitis Media

Otitis media is the inflammation of the middle ear and is very common in children. It is typically the result of a virus or bacterial infection that spreads into the middle ear.

Individuals in their children usually develop this condition and many children often experience recurrent ear infections. In starting phase ear infection medicine or ear infection drops can help to prevent infection.

Since the infections occur prior to a child being old enough to be able to communicate verbally, some physical signs may include tugging at the ears, excessive fussiness and crying, trouble sleeping, fever, fluid draining from the ears, and trouble hearing or responding to quiet sounds.

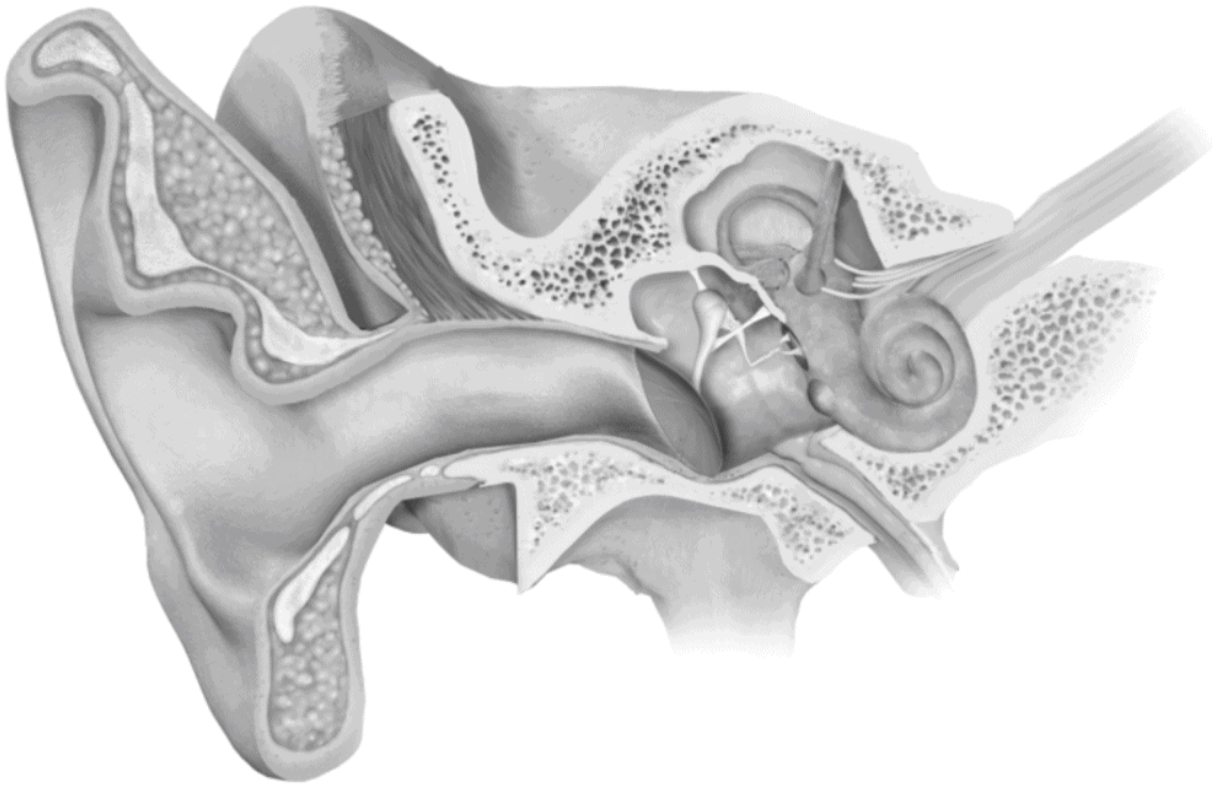


Figure 12.5

The treatment of otitis media require routinely prescribed antibiotics from a qualified doctor. Children with persistent or recurrent disease are often treated through the method of surgery, in which a tube is inserted through the tympanic membrane that allows ventilation of the middle ear cavity along with the localized delivery of topical antibiotic ear drops.

otitis Media Symptoms

• Irritability

• Ear pain
• A headache
• Neck pain
• Feel of fullness in the ear
• Liquid drainage from the ear
• Fever
• Vomiting

• Diarrhea
• Lack of balance

Earache

Earache is also called as Otalgia in pathology terms. It is common with individuals who travel by air, especially when they have a cold or stuffy nose.

The air pressure in the middle ear does not equalize during the flight's take off as well as landing, as it would if the Eustachian tube were unblocked.

When an individual suffers an earache, the pain often distracts every thought and absorbs every ounce of your attention and you may just want to end it as quickly as possible.

Earaches can be caused by a blocked Eustachian tube, which is a thin tube that connects the inner back portion of the nose with the middle ear.

The air in the middle ear is constantly absorbed by its membranous lining, but the air is never depleted, as long as the Eustachian tube remains open and is able to resupply air while swallowing.

In this manner, the air pressure on both sides of the eardrum stays equal. But when the Eustachian tube is blocked, the pressure in the middle ear cannot be equalized.

Thus, the air that is already absorbed with an incoming supply, a vacuum occurs in the middle ear, sucking the eardrum inwards and stretching it painfully.

earache Symptoms
• Ear pain
• Impaired hearing
• Fluid drainage from the ear
• Fever
• A sense of fullness in the ear
• A headache
• Loss of appetite

earache Causes
• Ear infections

• Labyrinthitis
• Change in pressure (like flying on a plane)
• Earwax build-up
• Foreign object in the ear
• Strep throat
• Sinus infection

Questions for study

1. Write a note on physiology of hearing.
2. Discuss physiology of sight.
3. Draw a neat diagram of section eye and explain structure of eye.
4. Write a note on otitis media.

13

Urinary System

The urinary system plays an important role in purifying the blood and cleansing the body of the wastes. The system also functions to maintain fluid, electrolyte and pH balance.

ORGANS OF URINARY SYSTEM
It consists of the kidneys, ureters, urinary bladder and urethra. The Kidneys

The kidneys are bean shaped organs located behind the peritoneal membrane. They are roughly about the size of an adult fist. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest. They are located at about the level of the twelfth thoracic vertebra to the third lumbar vertebra. Each kidney is surrounded by a layer of adipose tissue called perirenal fat. The outer layer of the kidneys is made up of fibrous connective tissue called as renal capsule. Each kidney has an indentation called a hilum that serves entry and exit site for the renal artery, vein, nerves and ureters.

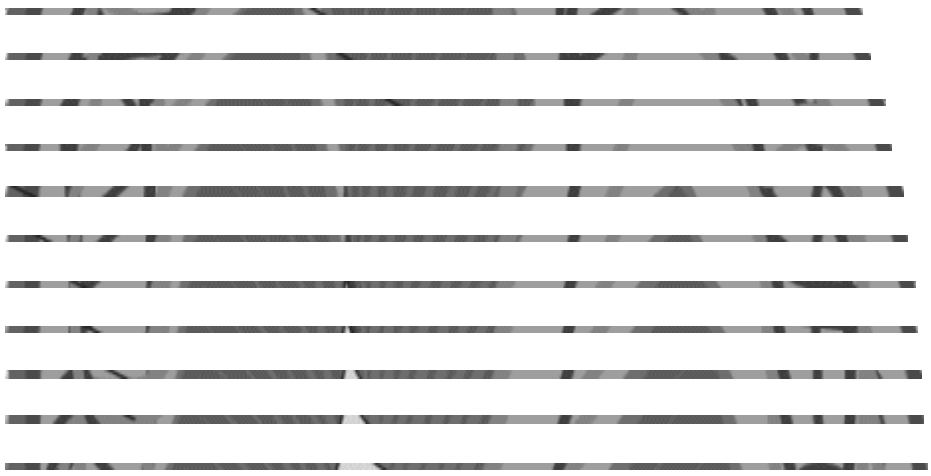
Internally the kidney is divided into two regions: an outer cortical region and an inner medulla. The cortex has connective tissue extensions known as renal columns which extend downwards towards the medulla to separate the most characteristic features of medulla, renal pyramid and renal papilla. The papillae are bundles of collecting ducts that connect with minor calcyces and serves to transport the urine made by nephrons. The minor calyces unite to form larger major calyces

233
that unite to form the renal pelvis that extends to form the ureter.

Each kidney gets blood supply from renal artery which divides into segmental arteries. The segmental arteries divide further to form interlobar arteries that pass through the renal columns and branch to form arcuate arteries. The arcuate arteries divide to form interlobular arteries that extend up to the cortex. The interlobular arteries then divide into afferent arterioles that supply blood to the nephron.

The blood leaves the nephron via efferent arteriole. The efferent arterioles of nephrons drain into the interlobular veins which in turn drain into the arcuate veins. The arcuate veins drain into the interlobular veins which drain into the renal vein.

The kidneys also have a nerve supply. The renal nerves which are sympathetic postganglionic neurons from the celiac plexus and inferior splanchnic nerves innervate the kidneys.



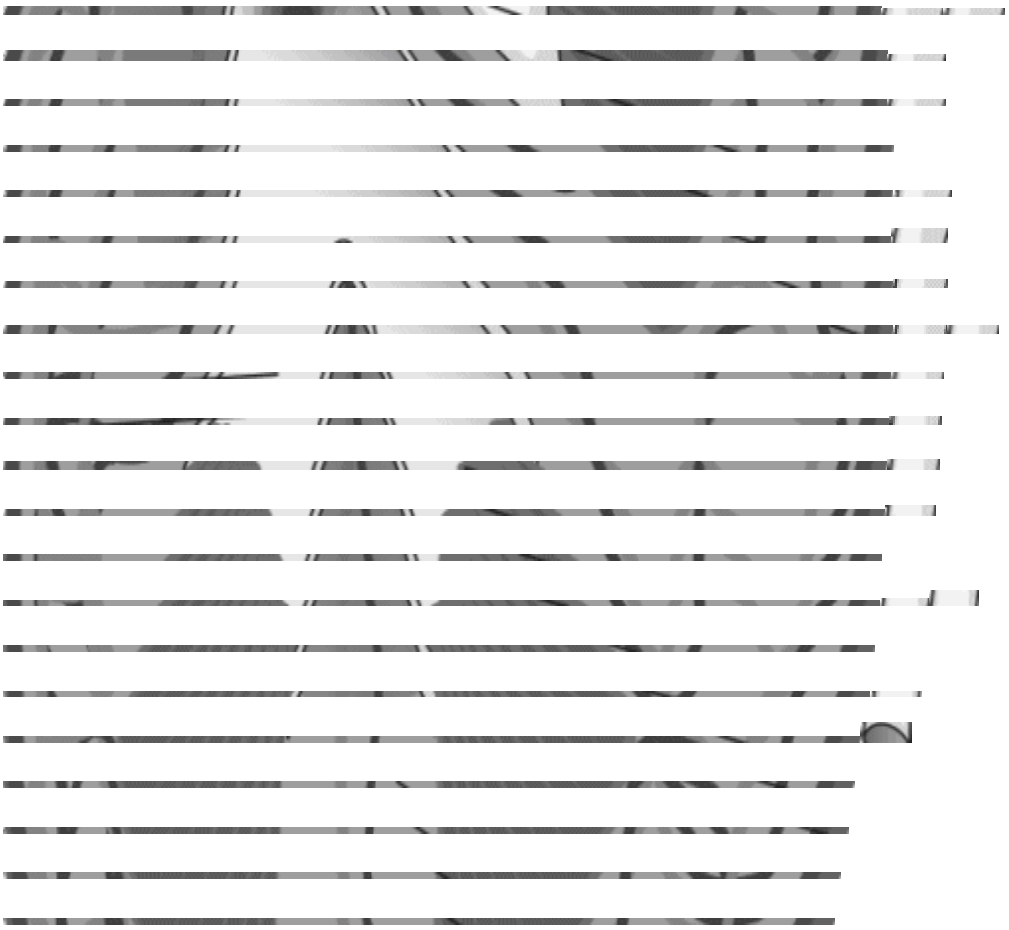


Figure 13.1: Structures of the kidney

1.Renal pyramid, 2.Interlobar artery , 3.Renal artery, 4.Renal vein, 5.Renal hylum,
6.Renal pelvis, 7.Ureter, 8.Minor calyx, 9.Renal capsule, 10.Inferior renal capsule,
11.Superior renal capsule, 12.Interlobar vein, 13.Nephron, 14.Minor calyx, 15.Major calyx, 16.Renal papilla, 17.Renal column
Source: http://commons.wikimedia.org/wiki/File:Kidney_PioM.png

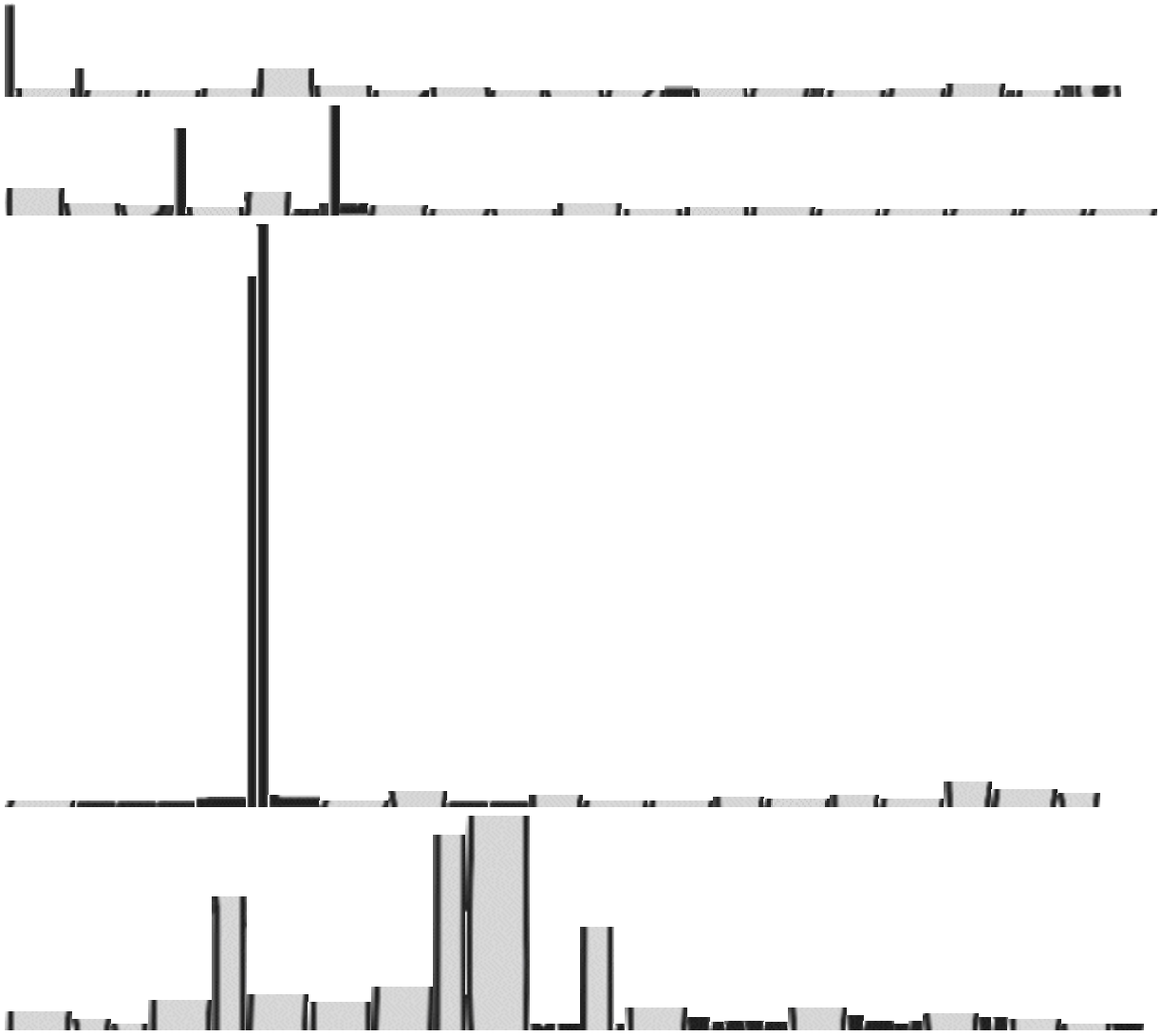
The Nephron

Nephron is the functional unit of the kidney. Each kidney has nearly one million nephrons. Some nephrons lie in the cortex and are known as cortical nephrons. Other nephrons lie near the medulla and travel deep in into the medulla. These are called juxtamedullary nephrons.

The nephron consists of two parts: a renal tubule and a renal corpuscle. The renal corpuscle is a spherical structure that encloses a tuft of capillaries known as glomerulus that is surrounded by a fibrous capsule known as glomerular capsule.

The tuft of capillaries is fed by an afferent arteriole and drained by an efferent arteriole. The filtration occurs in glomerulus and glomerular capsule.

The glomerular capsule is composed of two layers. The outer layer or parietal layer is made up of simple squamous epithelium. The inner layer or visceral layer is composed of special cells called podocytes. There is thin basement membrane between the podocytes and the capillaries.



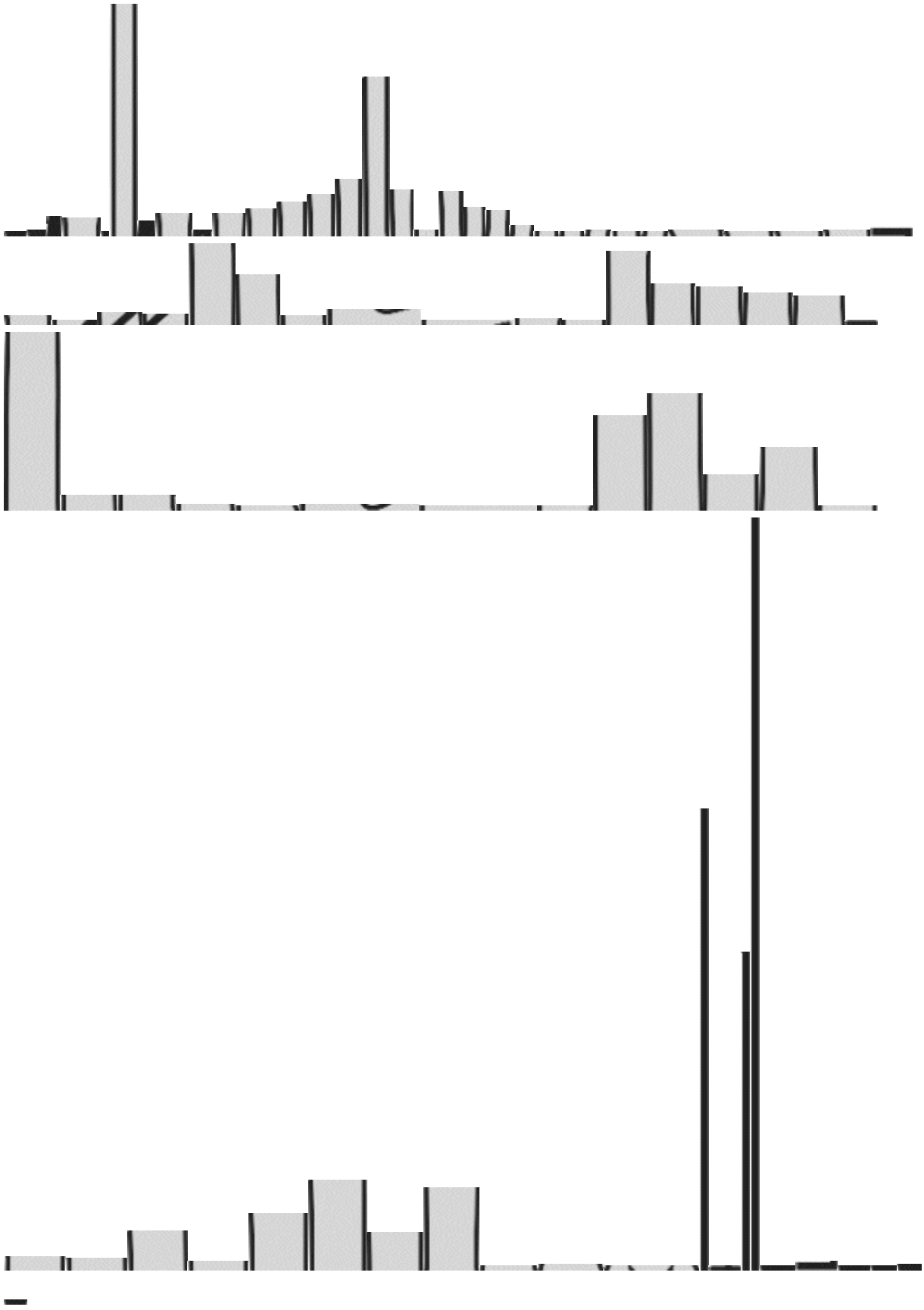


Figure 13.2: Nephron
Source: http://commons.wikimedia.org/wiki/File:Nephron_blank.svg

The podocytes extend finger like projections to cover the glomerular capillaries. The podocytes has small openings between them known as filtration slits that serves as holes in a filter. The glomerular capillaries also have small openings known as fenestrae. The combined action of these structures is to act as a filter.

From the glomerular capsule the filtrate flows through the proximal convoluted tubule, the first part of the renal tubule. The proximal convoluted tubule is followed by a hairpin shaped loop known as Henle's loop. It has decending and ascending limb. The ascending limb continues with another highly coiled tubular region called distal convoluted tubule.

These distal convoluted tubule leads to the collecting ducts. The collecting ducts receive filtrate from many nephrons and runs through the medullary pyramids and give them their striped appearance. As the collecting ducts approach the renal pelvis, they fuse together and deliver urine into the minor calyces via papillae of the pyramids.

The Ureters, Bladder, Urethra
Ureters

The ureters are narrow tubes that carry urine from the kidney to the bladder. There are two ureters one for each kidney. The ureters enter the bladder medially from the posterior side. The ureter wall has three layers. The inner layer is a mucous membrane made up of transitional epithelium. Mucus secreted by this membrane prevents the cells from coming in contact with urine. The second layer is muscularis layer, composed of inner longitudinal and outer circular layers of smooth muscle. The third layer is serosa, a layer of fibrous connective tissue. The serosa extensions hold the ureters in place.

Urinary Bladder

The urinary bladder is a pyramid shaped organ that resides in the pelvic cavity. It is anterior to the rectum in males. In females it is anterior to the vagina and inferior to the uterus. The bladder has three openings, two for

ureters and one for the urethra. These openings outlined the smooth, triangular region of the bladder base known as trigone which is important as the infections tend to persist in this area. The urinary bladder has three layers. The innermost layer, is a mucous membrane made up of transitional epithelium and an underlying lamina propria. Surrounding the mucosa is a thick muscular layer known as detrusor muscle. It consists of three layers of smooth muscle fibers: inner longitudinal layer, middle circular layer and outer longitudinal layer. The outermost layer on the superior surface of the bladder is formed of peritoneum. The rest of the urinary bladder has a fibrous connective tissue layer that is continuous with the same coat of the ureters.

The bladder is very distensible and uniquely suited for its function of urine storage. When the bladder is empty it collapses into its basic pyramidal shape and its walls are thick and thrown into folds *(rugae).* As the urine volume increases, the bladder expands, becomes pear shaped, and rises superiorly in the abdominal cavity. The muscular wall stretches and thins, and rugae disappear. These changes allow the bladder to store more urine without a significant rise in internal pressure.

Urethra

The urethra is a small tube that drains the urine from the bladder to the exterior of the body. It differs in males and females. But a sphincter is present in both. The male urethra is about 20 cm in length and consists of three parts: pelvic, perineal and pineal part. The female urethra is short measuring about 4 cm in length.

MICTURITION
It is a process of emptying the bladder. It involves both involuntary and voluntary actions.

In order to occur micturition, three things must happen simultaneously: (1) contraction of detrusor muscle, (2) opening of internal urethral sphincter and (3) opening of external urethral sphincter. The detrusor muscle and its internal urethral sphincter are made up of smooth muscle and are supplied with nerves of both types of nervous systems, parasympathetic and sympathetic. They have opposite actions. In contrast to it, the external

urethral sphincter, is a skeletal muscle, and therefore is innervated by the somatic nervous system.

The three events required for micturition are coordinated as: When the urine accumulates, the stretch receptors present on the walls of bladder gets activated. These receptors transmit nerve impulses through the visceral afferent fibers to the sacral region of the spinal cord to generate a spinal reflex. The parasympathetic neurons get excited which results in the contraction of detrusor muscle and relaxation of the involuntary internal urethral sphincter. Visceral afferent impulses also inhibit the somatic motor neurons that allow the relaxing of external urethral sphincter.

URINARY PHYSIOLOGY

Glomerular Filtration

Glomerulus and glomerular capsule together act as a filter. They remove water and small substances from the blood. The substances removed are less than 7 nm that can move through the filtration slits in the glomerular capsule. Larger substances and proteins do not pass through the membrane.

On average kidneys produce 177 liters of filtrate per day. But we don’t urinate 177 L per day, that means most of the filtrate is reabsorbed via tubular reabsorption. Only about 1% of the filtrate actually becomes urine rest is reabsorbed.

The glomerular filter consists of glomerular capillaries (an input), glomerular capsule (an output) and a filtration membrane (podocytes, fenestrae, basement membrane). In order to move substances through the filter there must be a pressure gradient. The pressure gradient is also called as filtration pressure or net filtration pressure. Net pressure is the sum of all pressures that exist in the renal corpuscle. These pressures are: glomerular capillary hydrostatic pressure, glomerular capsular hydrostatic pressure and colloid osmotic pressure.

Glomerular capillary hydrostatic pressure is the pressure created by the blood inside the capillaries. The glomerular capillary hydrostatic pressure is regulated partly by the diameter of the afferent and efferent arterioles. The efferent arterioles have a smaller diameter than the afferent arterioles which

works to increase the pressure inside the glomerular capillaries. This pressure is usually about 50 mm Hg.

The pressure inside the glomerular capsule is called the glomerular capsular hydrostatic pressure and is created by the fluid present inside the capsule. This pressure is usually about 10 mm Hg.

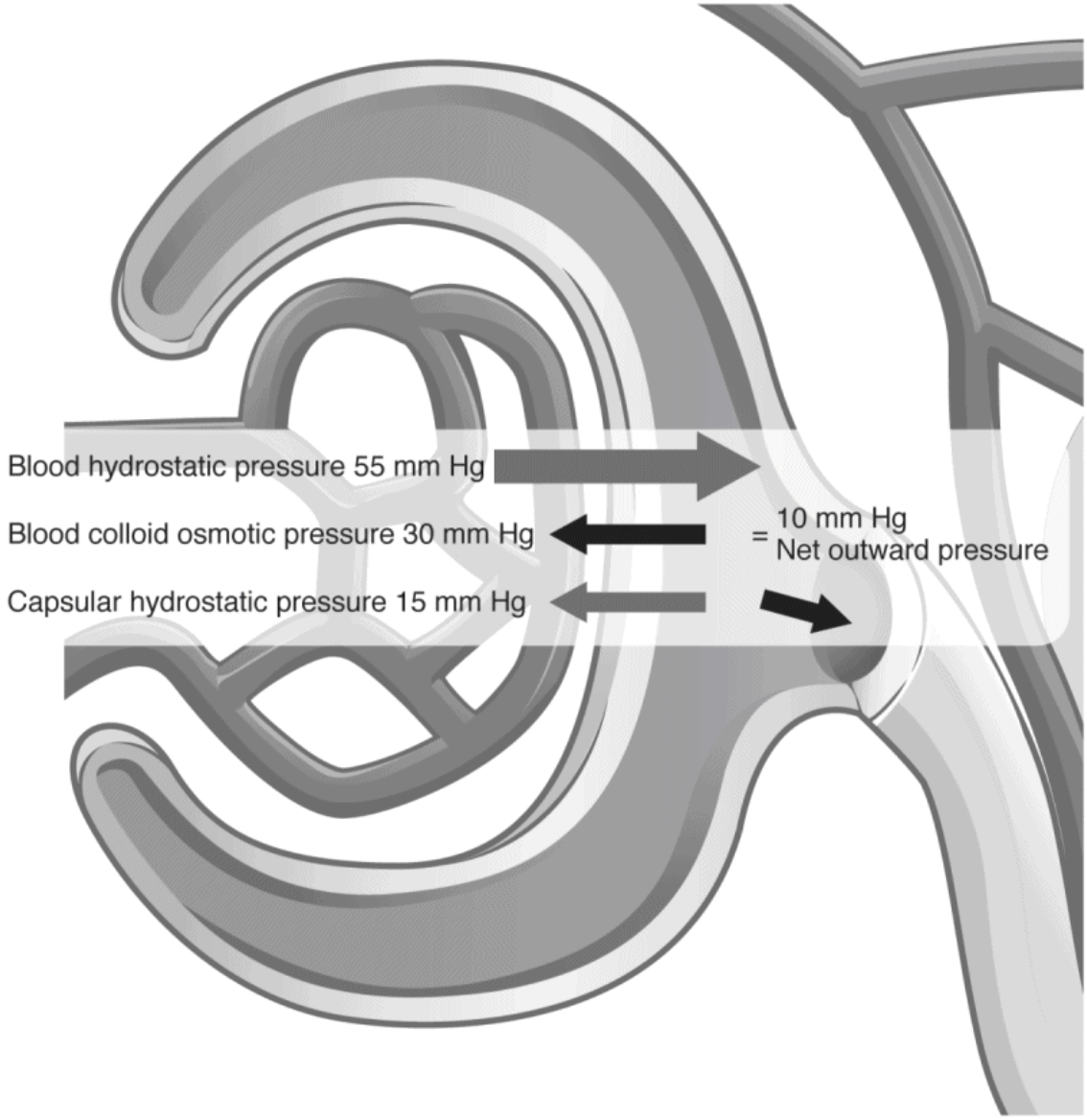


Figure 13.3: Net Filtration Pressure. The NFP is the sum of osmotic and hydrostatic pressures
Source: http://openstaxcollege.org/l/multiplier

Glomerular filtration occurs when the glomerular capillary hydrostatic pressure exceeds the glomerular capsular hydrostatic pressure.

Colloid osmotic pressure is the pressure produced by the plasma proteins in the capillaries. It causes water to move back into the glomerular capillaries. This pressure is usually about 30 mm Hg.

Thus, net filtration pressure can be calculated as:

Net Filtration Pressure = Glomerular capillary hydrostatic pressure – Glomerular capsular hydrostatic pressure – Colloid osmotic pressure

That is
NFP = 50 mm Hg – 10 mm Hg – 30 mm Hg
NFP = 10 mm Hg
So the net filtration pressure is about 10 mm Hg.

The Juxtaglomerular Apparatus

The juxtaglomerular apparatus is a specialized organ located near the glomerulus. It has two different types of cells: Juxtaglomerular cells and macula densa cells. Juxtaglomerular cells are modified, smooth muscle cell lining the afferent arteriole. These cells secrete renin in response to decreases in blood pressure and decreased urine solute concentration. Macula densa cells are specialized epithelial cells located on the nephron loop side. These cells sense the sodium and potassium in the luminal fluid and causes secretion of renin from Juxtaglomerular cells accordingly.

Renin secreted by juxtaglomerular cells activates the reninangiotensin mechanism. It cleaves several amino acids from angiotensinogen to conert it into angiotensin I. Angiotensin I is biologically inactive until it is converted to angiotensin II by angiotensin-converting enzyme (ACE) from the lungs.

Active renin is a protein comprised of 304 amino acids that cleaves several amino acids from angiotensinogen to produce angiotensin I. Angiotensin I is not biologically active until converted to angiotensin II by angiotensin-converting enzyme (ACE) from the lungs. Angiotensin II produces systemic vasoconstriction and causes sodium reabsorption in the kidney tubules both directly and through the action of aldosterone. It also stimulates the

hypothalamus to release antidiuretic hormone (ADH). The combined actions of angiotensin II work to retain fluid volume and consequently raise blood pressure.

Tubular Reabsorption

Tubular reabsorption occurs in proximal convoluted tubule, loop of Henle, distal convoluted tubule, and the collecting ducts. It works in association with tubular secretion and recovers the most of filtered substances. Tubular reabsorption takes place through different processes which involves diffusion, active transport, osmosis and facilitated diffusion. The tubules are surrounded by peritubular capillaries.

The cells of the kidney tubules form two membranes. These are basolateral membrane and apical membrane. In order to move substances from the tubules to the blood they have to move through these membranes (apical and basolateral) of the tubules as well as the peritubular capillary endothelium. Some substances move through passively while others move through active transport using ATP.

Sodium-Glucose Symporter

Symporters are special transport proteins present in the apical membrane of some tubular cells. One such symporter transports sodium and glucose. From the tubule, sodium moves inside the cell through the protein. This protein also takes glucose along for the ride inside the cell. Inside the cell sodium is removed by the Na+ ATPase pump through the basilar membrane, it then travels to the interstitium and blood. The glucose molecule then diffuses through the basal membrane via facilitated diffusion into the interstitium and from there into blood.

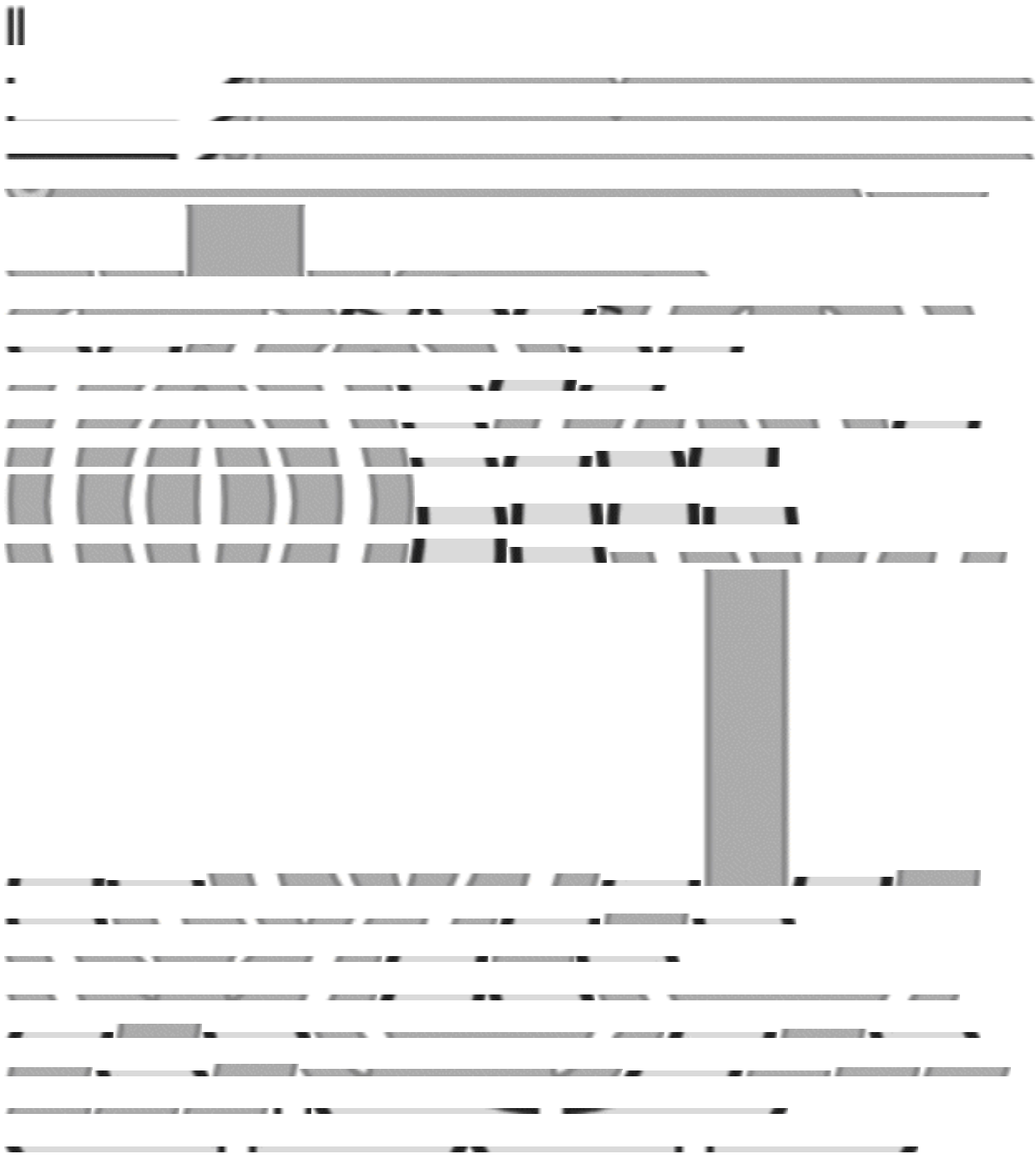
Due to reabsorbtion of sodium water is also reabsorbed by osmosis. The tubules have special water containing regions called aquaporins that helps in water reabsorption.

Tubular Secretion

Tubular secretion involves the movement of substances from the blood and interstitium to the kidney tubules. It primarily works to remove toxic

substances or byproducts of metabolism that are too large to be filtered or those that are in excess in the blood.

Tubular secretion can occur though active or passive transport. Passive diffusion involves the movement of molecules from the peritubular capillaries to the intersitial fluid within the nephron.



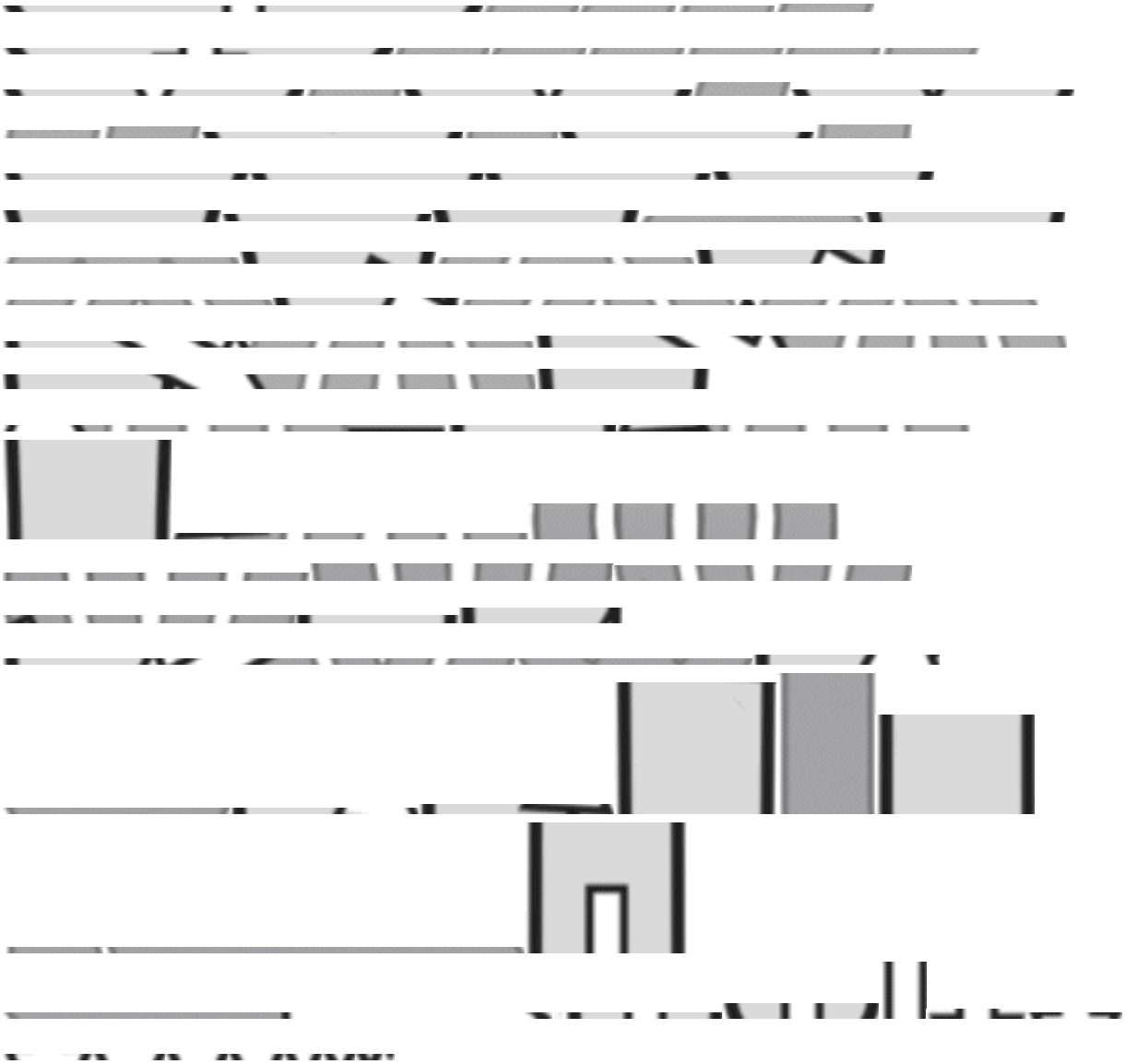


Figure 13.4: Physiological mechanism of kidney **Source: https://courses.lumenlearning.com**

An example of passive transport is the sodium hydrogen antiporter. This protein uses sodium gradient to move sodium from the tubules to inside the apical membrane cell and at the same time excess hydrogen ions move out of the cell into lumen of the tubule.

In the cell hydrogen ions are obtained from the combining of the water and bicarbonate. Sodium and bicarbonate travel into the cell by way of a symporter located in the basolateral membrane and move into the peritubular

capillaries. The production of hydrogen ions plays an important role in maintaining acid base balance.

Action of Aldosterone

The activation of the renin-angiotensin mechanism stimulates the adrenal cortex to produce aldosterone. Aldosterone attaches to the receptors of cells in the apical membrane that transports sodium. The cells respond by increasing tubular reabsorption of sodium. At the same time they also stimulate the tubular secretion of potassium.

Atrial Natriuretic Hormone

Atrial Natriuretic Hormone (ANH) is secreted by by heart atria in response to over-stretching of the atrial wall. The venous return increases when the blood volume increases causing increased stretching of the atrial wall. The subsequent release of ANH targets the kidneys to eliminate sodium. Water follows sodium by osmosis causing a decrease in fluid volume, blood volume and blood pressure.

The Nephron Loop

The nephon loop contains two segments: descending and ascending segment. Each segment has different characteristics. The majority of descending loop is made up of simple squamous epithelial cells.

The membranes of these cells have permanent aquaporin channel proteins that allow free movement of water from the descending loop into the surrounding interstitium. As a result concentration of the fluid increases dramatically which can be as high as 1200 mOsm (very hypertonic).

The thick segment of the ascending limb is impermeable to the water due to absence of aquaporin proteins but contains a series of active transport proteins that selectively move substances. Sodium, chloride, and potassium are moved actively out of the ascending loop into the intestitium by way of these active transport proteins. Concentration decreases as the fluid moves up in the ascending limb. Now 100 mOsm hypotonic solution exits in the ascending limb which enters the distal convoluted tubule.

Antidiuretic Hormone (ADH)

The blood solute concentration is continuously monitored by the osmoreceptors in the hypothalamus. In response to the increase in blood solute concentration, the osmoreceptors of the hypothalamus sends signals to the posterior pituitary to release ADH. ADH targets the tubular cells of kidney, particularly the distal convoluted tubule.

ADH affects the distal convoluted tubule by increasing its permeability to water. The fluid which enters the distal convoluted tubule is hypotonic in nature. If the tubules are impermeable to water then dilute urine is produced. Increased permeability of the tubules causes water reabsorption to the highly concentrated interstitium and blood.

RENAL CLEARANCE

Renal clearance is used to determine the function of kidney. It is the volume of blood plasma from which a substance is completely removed in one minute. Renal clearance reflects the three processes of urine formation which include glomerular filtration, tubular reabsorption and tubular secretion. Substances passing though the glomerulus are added to the substances moving from the peritubular capillaries into the tubules by way of secretion. The amount of the substance removed by tubular reabsorption is subtracted. However this method is not practical. We can use an indirect method to determine renal clearance that includes the rate of urine output and the concentration of the substance in blood plasma and urine.

URINE COMPOSITION

Urine is the final product of the kidney. Almost 95% of urine is water, with other solutes including nitrogenous wastes, electrolytes, pigments, and toxins.

Urine is usually clear or straw colored. An abnormal color indicates the presence of blood, bile, bacteria, drugs, food pigments, or high-solute concentration. Urine has a slight odor. The pH of urine is generally in the range of 4.6 and 8.0. The specific gravity is between 1.001 and 1.035.

Normal Chemical Composition of Urine
Urine is aqueous solution with water greater than 95%.
Other constituents present are:

• Urea 9.3 g/L.
• Chloride 1.87 g/L.
• Sodium 1.17 g/L.
• Potassium 0.750 g/L.
• Creatinine 0.670 g/L.
• Other dissolved ions, inorganic and organic compounds.

DISEASES OF THE URINARY SYSTEM
Kidney failure
It is usually divided into two types: acute kidney failure and chronic kidney disease.

Acute Kidney Failure
It is sudden loss of kidney function. In this disease, volume of urine decreases in majority of patients.

Chronic Kidney Disease

It is gradual, progressive and irreversible loss of kidney function over several months to years. In this disease, kidney function decreases slowly but continuously.

Kidney stones

Kidney stones are clumps of calcium oxalate that can occur anywhere in the urinary tract. They form when the chemicals in the urine become concentrated enough to form a solid mass.

Glomerulonephritis
It refers to a group of diseases that cause inflammation of glomeruli.

14

The Endocrine System

(Hormones and their Functions)

Chapter Outlines:

Key terms/learning objectives
Introduction
Endocrine glands
Question bank

KEY TERMS/LEARNING OBJECTIVES

The chapter on the endocrine system gives a brief introduction on the location, hormones, physiological role and disorders of some of the important endocrine glands in the human body.

INTRODUCTION

The physiological activities inside the body are regulated by the nervous and endocrine systems. The endocrine system comprises of group of secretory cells called **endocrine glands.** These glands produce chemical messengers called **hormones** that are released directly into the bloodstream. Hence, they are also calledductless **glands** because the hormones diffuse directly into the blood without any duct.From the blood, hormones reach specific organ or tissue to exert their effect. Such organs or tissues are called as **target organs** or **target tissues**.

The endocrine gland will release hormone only in response to the stimuli, i.e., when there is a need to exert its effect on the target site.Hence, the stimuli is like information that the endocrine gland uses to increase or decrease the level of hormone in the blood.

Once the hormone is released inside the blood, it will show its effect on the target site and the level of hormone decreases. This reverses the stimuli Thus, hormones show a negative feedback mechanism For example, when the level of glucose in the blood increases, it stimulates the secretion of insulin. Insulin is released into the blood that targets each cell to remove glucose molecule from the blood and uses it for energy production. This reduces the blood sugar level. Thus, insulin hormone reverses the stimuli for the secretion of insulin by decreasing the blood sugar levels. This shows a negative feedback mechanism.

The secretion of the hormone is triggered by the release of hormones from the hypothalamus. Thus, hypothalamus includes releasing hormones that trigger the release of hormones from endocrine glands. Once the hormone is secreted in the blood, it will inhibit the secretion of releasing hormones by the hypothalamus.

ENDOCRINE GLANDS

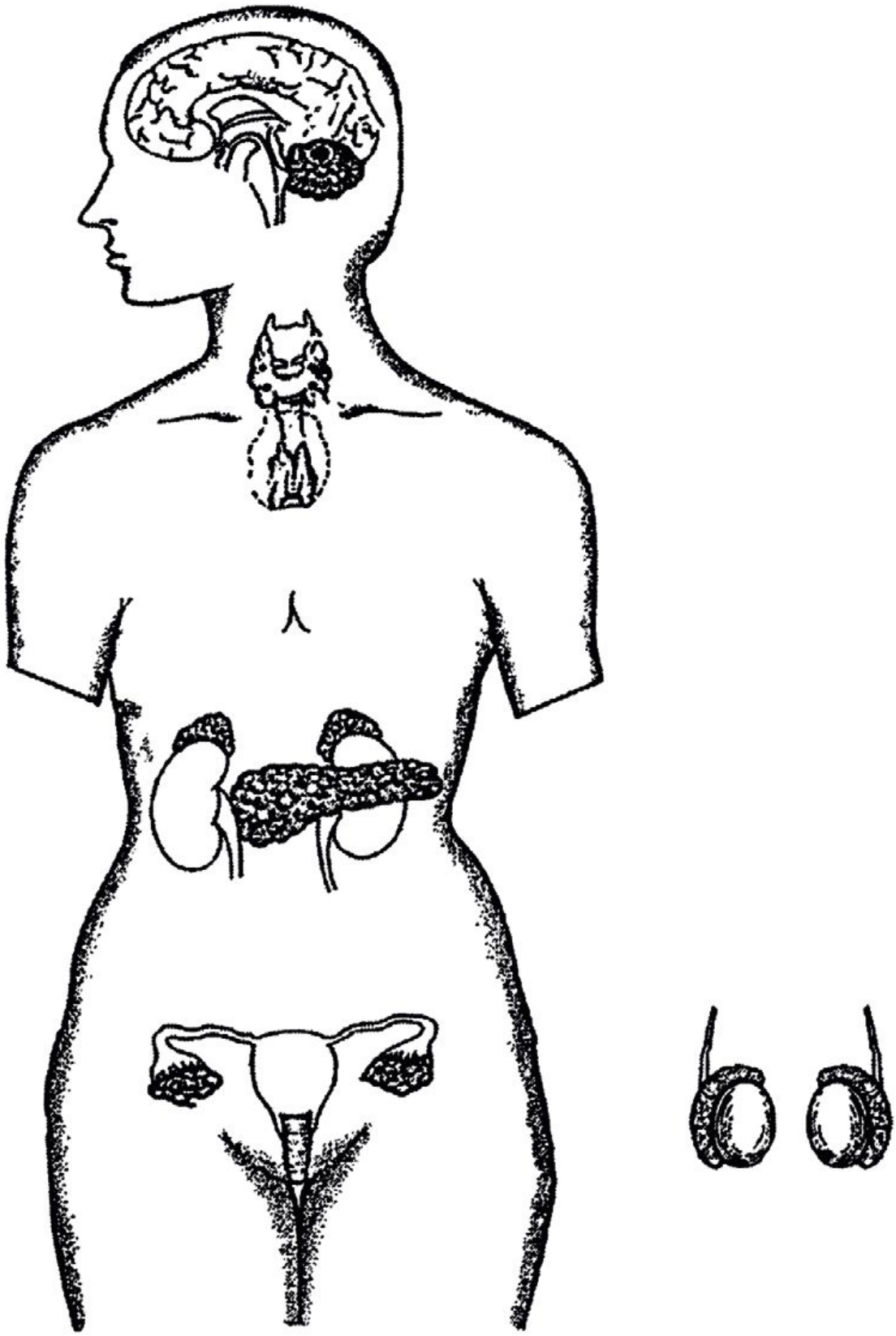


Figure 14.1: Locations of Endocrine Glands

Some of the important endocrine glands are as follows:
• Pituitary
• Thyroid
• Parathyroid
• Adrenal
• Pineal
• Pancreas
• Testes
• Ovaries

1. Pituitary Gland

The pituitary gland is a small pea-shaped structure located in the **hypophyseal fossa** of the sphenoid bone at the base of the brain. It is also known as the **master gland** because it controls other endocrine glands by secreting various hormones. The pituitary gland is linked with hypothalamus and together they regulate various activities like growth, development, metabolism and homeostasis.The pituitary gland is divided into two parts: posterior and anterior pituitary glands.

A. Posterior Pituitary Gland:

The posterior pituitary gland (neurohypophysis) does not secrete any hormone but stores two hormones secreted by the hypothalamus. It includes:

• Antidiuretic hormone
• Oxytocin
• **Antidiuretic Hormone:** The antidiuretic hormone (ADH) is also known as **vasopressin.** It has the following two functions:

• **Retention of Water:** ADH enhances the intake of water from distal convoluted tubule and collecting duct of kidneys. This decreases the urine output and increases the volume of blood. When the level of water decreases (dehydration), it acts as stimuli for the secretion of ADH from hypothalamus.
• **Vasopressor Action:** When ADH is secreted in a large amount, it causes

constriction of all arteries inside the body. This leads to an increase in blood pressure. This mainly occurs in cases of severe haemorrhage (bleeding) to increase the reduced blood pressure.
• **Oxytocin:** Oxytocin is released during the delivery of the baby. When labour begins, the hypothalamus secretes oxytocin that stimulates the contraction of smooth muscles of the uterus. It also stimulates the release of milk during breastfeeding.

B. Anterior Pituitary Gland

The anterior pituitary gland secretes hormones after the stimulation of release hormones from the hypothalamus. They include:

• Growth hormones
• Thyroid stimulating hormone
• Prolactin
• Gonadotropic hormones
• Adrenocorticotropic hormone

• **Growth Hormone:** Growth hormone is also known as **somatotropin.** It promotes growth by stimulating insulin-like growth factors in cells. It also increases the synthesis of proteins, carbohydrates and fats for the storage of energy.
•**Thyroid Stimulating Hormone:** Thyroid stimulating hormone (TSH) is also known as **thyrotropin.** It is responsible for the normal growth of thyroid gland and also stimulates the secretion of thyroid hormones.
• **Prolactin:** Prolactin, along with other hormones, initiates and maintains the production of milk in women during pregnancy.
• **Gonadotropic Hormones:** The gonadotropic hormones include luteinising hormone and follicle-stimulating hormones. The **follicle-stimulating hormone (FSH)** is responsible forthe development of egg (ovum) from the ovarian follicle in women. It also stimulates the synthesis of oestrogen. In males, the FSH stimulates the production of sperm in testes. In women, the **luteinising hormone (LH)** causes the release of an egg from the ovarian follicle. The ovarian follicles then mature into corpus luteum that secretes progesterone hormone. The LH is responsible for the production of testosterone in males.
•**Adrenocorticotropic Hormone:** Adrenocorticotropic hormone stimulates

the adrenal cortex to increasethe production of steroidal hormones including cortisol

Hypo/hypersecretion of Pituitary Hormones
Hypersecretion

• Hypersecretion of ADH causes an excessive loss of sodium through urine. This occurs in the **syndrome of inappropriate hypersecretion of ADH (SIADH) disease.**
• Hypersecretion of growth hormone leads to **gigantism,** a disease characterised by excess growth of long bones. A person with gigantism often attains a height of seven to eight feet and looks like a giant. The hypersecretion of growth hormone also causes **acromegaly,** a disease characterised by thickening and broadening of bones.
• An increase in the amount of adrenocorticotropic hormone causes **Cushing disease,** a rare disease with an increase in cortisol levels that causes obesity.

Hyposecretion
• Hyposecretion of ADH will lead to excess loss of water through urine. This condition is known as **diabetes insipidus.**

• Hyposecretion of growth hormone causes stunted growth or **dwarfism** in children before puberty. Such children reach a final height of only three to four feet.
• **The Simmond disease** is a rare disorder that occurs due to hyposecretion of all the hormones of the anterior pituitary gland.

2. Thyroid Gland

The thyroid gland is a butterfly-shaped gland situated at the top of the neck just below the larynx. It has two lobes located on either side of the trachea. They are connected by a strip called isthmus. The thyroid gland is made up of spherical thyroid follicles with follicular cells. The TSH hormone activates these cells. On activation, they produce the following hormones:

• Thyroxine (T_4) and T_3
• Calcitonin
• **Thyroxine and T_3:** Thyroxine and T_3 are two main thyroid hormones that

play an important role in the development of normal physical and mental growth, protein synthesis, maturation of reproductive organs, and regulation of energy generation. The thyroid gland requires iodine and tyrosine for the production of these hormones.

• **Calcitonin:** Calcitonin reduces the level of calcium and phosphate in the blood by decreasing its reabsorption from bones. This helps to maintain normal blood calcium levels and also preserves a stable, robust bone matrix.

Hyper/hyposecretion of Thyroid Gland

Hypersecretion

Increased secretion of thyroid hormone (hyperthyroidism) occurs due to Grave's disease and thyroid adenoma. **Grave's disease** is an autoimmune disease in which the body produces antibodies against the TSH hormone. This causes hypersecretion of thyroid hormones. Another cause of hyperthyroidism is **thyroid adenoma,** which is a tumour developed inside the thyroid cells.The hyperthyroidism is commonly characterised by **exophthalmos.** Exophthalmos is also called protruding eyeballs. It can cause difficulty in closing eyelids and may lead to blindness.

Hyposecretion

Hypothyroidism is decreased secretion of thyroid hormone. It causes **cretinism**, a disease with stunted mental and physical growth, in children, whereas in adults, it can lead to an autoimmune disease called **myxoedema**. This disease is characterised bydecrease in metabolic rate, swelling, hardening of the arterial walls, slower pulse rate and extreme tiredness.

3. Parathyroid Glands

Parathyroid glands are multiple round masses of tissues located behind the lobes of the thyroid gland. They release the parathyroid hormone that increases the level of calcium in the blood. This is achieved by increasing the absorption of calcium directly from the small intestine and causing the release of calcium from bone in the blood. Thus, parathyroid hormone acts oppositely as compared to calcitonin. These two hormones work together to maintain a normal level of calcium in the blood. This is particularly necessary for the transmission of nerve signals and muscle contraction.

Hyper/hyposecretion of Parathyroid Gland
Hypersecretion

Hyperparathyroidism is an increased secretion of parathyroid hormone. It leads to an increase in blood calcium levels (hypercalcaemia). This causes a reduction of calcium in bones that leads to bone diseases such as **osteitis.** It can also cause the development of calcium crystals in the renal tubules of kidneys.

Hyposecretion

Decreased secretion of parathyroid hormone is known as hypoparathyroidism. It leads to a decrease in the level of calcium in the blood (hypocalcaemia). This causes **tetany,** a disease characterised by violent and painful muscle contraction or spasm. This usually affects the muscles of hands and feet.

4. Pancreas

The pancreas is a flat organ located in the upper part of the abdomen, on the right side of the duodenum. It consists of hormone-secreting cells called **islets of Langerhans.** The islets of Langerhans are made up of alpha, beta and delta cells. The alpha cell produces glucagon, beta cells are associated with the secretion of insulin, whereas delta cells produce somatostatin.

• **Glucagon:** Glucagon is secreted by alpha cells. It increases the level of glucose in the blood. This is achieved by:
• Increasing the use of amino acids and fats for energy

generation
• Conversion of stored glycogen to glucose in the liver (glycogenolysis)
• Conversion of amino acids into glucose (gluconeogenesis) A low level of glucose in the blood (hypoglycaemia) acts as stimuli for the secretion of glucagon in blood.
• **Insulin:** The beta cells of the pancreas secretes insulin. Unlike glucagon, insulin reduces blood glucose levels. This is achieved by:
• Preventing glycogenolysis

• Conversion of glucose to glycogen (glycogenesis)
• Increase the uptake of glucose by cells for energy production
• Preventing gluconeogenesis

An increase in blood glucose level (hyperglycaemia) stimulates the production of insulin by beta cells.

• **Somatostatin:** Somatostatin is secreted by delta cells of the pancreas. It inhibits the secretion of glucagon and insulin from the islet cells. Besides this, somatostatin also inhibits the secretion of growth hormone and TSH from the anterior pituitary gland. Hence, it is also known as growth hormone inhibiting hormone.

Hypo/hypersecretion of Pancreatic Hormones

Hypersecretion

Hypersecretion of insulin is known as hyperinsulinism. It occurs due to tumour of beta cells. It can affect the central nervous system causing nervousness, tremors, and sweating. This can lead to convulsions and coma if not treated immediately. **Hyposecretion**

A deficiency of insulin or impairment in its function can cause **diabetes mellitus.** Diabetes mellitus may or may not be associated with another disease. When it occurs due to another disease, it is known as secondary diabetes, whereas unrelated diabetes is known as primary diabetes. The primary diabetes is mainly of two types: Type I and type II diabetes.

• **Type I diabetes:** This type of diabetes occurs due to deficiency of insulin hormone. The destruction of beta cells impairs the production of insulin hormone. A person with type I diabetes requires supplementation of insulin injection to control this disease.

• **Type II diabetes:** Type II diabetes occurs when insulin receptors do not respond to the insulin hormone (insulin resistance). This means the pancreas produces insulin, but the body is unable to utilise it. A person with type II diabetes requires oral hypoglycaemic drugs to control the disease.

5. Adrenal Gland

The adrenal glands, also called suprarenal glands, are two pyramidalshaped structures lying on the top of each kidney. They are also known as **life-saving glands** or **essential endocrine glands.** They are made up of two parts: an inner adrenal medulla and outer adrenal cortex.

A. Adrenal Medulla

An adrenal medulla forms the inner part of the adrenal gland. It is surrounded by the adrenal cortex. The adrenal medulla consists of **chromaffin cells** that secrete two catecholamines called epinephrine (adrenaline) and norepinephrine (noradrenaline). These hormones are associated with sympathetic system or 'fight or flight' responses. **Epinephrine** elevates the heart rate and force of contraction, whereas **norepinephrine** causes vasoconstriction of blood vessels inthe skin, skeletal muscles, and visceral organs. Thus, together these hormones increase blood pressure. Epinephrine also dilates bronchioles, decreases stomach movement, increases the production of glucose, and accelerates the use of fats for energy generation.

B. Adrenal Cortex

An adrenal cortex forms the outer part of the adrenal gland. It secretes three hormones, namely, mineralocorticoids, glucocorticoids, and sex hormones.

• **Mineralocorticoids: Aldosterone** is the main mineralocorticoid. It is secreted for the maintenance of water balance and electrolytes in the body. This is achieved by reabsorption of sodium in the blood and excretion of potassium in the urine. The sodium absorption causes retention of water that helps to adjust blood volume and blood pressure. It also increases the excretion of hydrogen ions in urine. The aldosterone secretion is stimulated by a high level of blood potassium levels and angiotensin. When the level of sodium or blood flow to kidneys decreases, an enzyme called renin is secreted inside the kidneys. This enzyme converts angiotensinogen protein into angiotensin 1. The angiotensin 1 is then converted into angiotensin 2 under the presence of an angiotensinconverting enzyme. Once the angiotensin 2 is produced, it stimulates the secretion of aldosterone hormone. This increases blood pressure and causes vasoconstriction.

• **Glucocorticoids:**
Glucocorticoids include **cortisol, corticosterone,** and **cortisone** They increase the utilisation of fat and amino acids for energy generation (gluconeogenesis) and decreases the use of glucose. Thus, it stores glucose for its utilisation by the brain. These hormones are released during stressful

situations such as hunger, anger, fear or injury. They also posses' anti-inflammatory properties, delay wound healing process and suppresses the immune responses.

• **Sex hormone:**
The adrenal cortex also secretes **androgen,** a male sex hormone. This hormone is secreted in both males and females. In females, it plays a vital role in promoting libido (sexual drive) and transforms into oestrogen.

Hyper/hyposecretion of Adrenal Gland:
Hypersecretion:

• **Hypersecretion of adrenal cortex can cause cushing syndrome, hyperaldosteronism, and adrenogenital syndrome**

We have already studied Cushing disease in the section of pituitary gland mentioned above. When the same disorder is caused due to tumour of the adrenal cortex, it is known as Cushing syndrome. In this syndrome, high secretion of corticosteroids causes obesity with swelling all over the face. Hyperaldosteronism is the hypersecretion of aldosterone hormone that causes high blood pressure, increased blood volume and kidney failure due to low potassium levels. Adrenogenital syndrome occurs due to hypersecretion of androgen that leads to the development of secondary sexual characters of opposite sex. For example, women with this disorder may experience deepening of voice or masculinity due to excess muscle growth, whereas men experience enlargement of breasts or loss of interest in women.

• Hypersecretion of catecholamines causes **pheochromocytoma.** It occurs due to tumour of chromophil cells.

Hyposecretion:
• Deficiency of aldosterone and glucocorticoids causes **Addison disease.** This disease is characterised by excess pigmentation of skin and inability to withstand any stress.

6. Ovaries

Ovaries are oval-shaped two organs located on either side of the uterus in the pelvic cavity. It secretes three hormones, namely oestrogen, progesterone and inhibin.

• **Oestrogen:** Oestrogen is secreted by the ovarian follicles. The follicular cells secrete oestrogen after the stimulation

Table 14.: Endocrine Glands & Their Actions

Endocrine Gland
Location Hormone Physiological Role

Anti diuretic hormone
(ADH)
- Retention of water
- Vasocontraction

Hypo/Hypersecretion
Hypersecretion: Syndrome of
inappropriate hypersecretion of ADH
Hyposecretion: Diabetes
insipidus

Oxytocin
- Contraction of uterus
- Stimulates release of

milk during breastfeeding
–

Growth hormone

Pituitary gland
Hypophys eal fossa
of the
sphenoid bone at the base of the brain

Thyroid
stimulating hormone

Prolactin

Folliclestimulating
hormone

Luteinising hormone
- Promotes growth
- Increases synthesis of ptoteins, fats and carbohydrates
- Promotes norma - growth of thyroid gland
- Secretion of thyroid hormones

- Milk production during pregnancy
- Development of ovum from ovarian follicle

- Stimulates the syn - thesis of estrogen
- Sperm productin in males

- Release of egg from ovarian follicle
- Secretes progester- one hromone

- Testosterone hor - mone production in males

–

Adrenocorti cotropic
hormone

- Increases production

of cortisol hormones Hypersecretion: Gigantism;
acromegaly
Hyposecretion: Dwarfism

–
–
–

Hypersecretion: Cushing
disease

Endocrine Gland
Thyroid
Location
Top of the neck just
Hormone
Thyroxine (T_4) and T_3
Parathyroid gland
Calcitonin
Physiological Role

- Development of normal physical and mental growth, protein synthesis, maturation of reproductive organs, and regulation of energy generation
- Decreases the reab- sorption of calcium and phosphate from bones

Hypo/Hypersecretion
Hypersecretion: Grave's disease; Thyroid adenoma Hyposecretion: Cretinism:
myxoedema

–

Behind the lobes of the thyroid gland Parathyroid hormone

- Increases the calcium

level in the blood

Pancrease Upper part of the abdomen, on the right side of the duodenum
Clucagon
- Increases the blood

glucose level
Insulin
Somatostatin
- Decreases the blood glucose level

- Inhibits the secretion of glucagon and insulin

Hypersecretion: Hyposecretion: Tetany
Hypersecretion Hyperinsulinism Hyposecretion Diabetes mellitus

_

Endocrine Gland
Location Hormone Physiological Role

- Increases the heart rate and force of cotraction

Epinephrine
- Dilates bronchioles

Hypo/Hypersecretion
Hypersecre tion: Cushing syndrome; hyperaldosteronism; adrenogenital syndrome; pheochromocytoma Hyposecretion: Addison disease

Adrenal gland
On top of each kidney Norepinephrine

Aldosterone
Glucocorticoids
Androgen

- Decreases stomach movement
- Increases the prduction of glucose

- Accelerates the use of fats for energy generation
- Vasoconstriction of blood vessels in the skin, skeletal muscles and visceral organs

- Balances water and electrolytes inside the body
- Increase the utilisa- tion of fat and amino acids for energy

generation (gluconeogenesis)

- Decreases the use of glucose
- In females, if plays an important role in promoting libido and converts into oestrogen

–

–
–
–

Endocrine Gland
Location Hormone Physiological Role Hypo/Hypersecretion

Ovaries Located on either side of the uterus in the pelvic cavity
Estrogen

Progesterone
Inhibin

Testes Located in the scrotum Testosterone

Inhibin

- Generation of ovum of egg
- Preparation of uterus for fertilisation of egg and sperm

- Increases deposition of fats in hip and

thighs

- Lowers cholesterol levels

- Promotes the growth of ducts in the mammary glands
- Accelerates the

storage of glycogen in the liver

- Promotes growth of blood vessels in the endometrial lining of the uterus
- Promotes the produc- tion of secretory cells in mammary glands

- Inhibit the secretion of FSH
- Maturation of sperm

- Development of male sexual characteristics
- Inhibit the secretion of FSH

Pineal gland Located
behind the
third ventricle of the brain, above the hypothala mus Melationin

- Protects against

harmful oxygen-free radicals

of FSH from the anterior pituitary gland. This hormone converts the ovarian follicle into an ovum (egg). It prepares the uterus for the fusion of sperm and egg by increasing the blood vessels inside the endometrial lining of the

uterus. Oestrogen also increases deposition of fat in hips and thighs, lowers cholesterol levels and helps in the growth of ducts inside the mammary glands.
• **Progesterone:** After an ovum is released, the follicular cells

mature into corpus luteum. The corpus luteum produces progesterone hormone. This hormone is triggered by the release of LH from the anterior pituitary gland. The progesterone accelerates the storage of glycogen in the liver and promotes the growth of blood vessels in the endometrial lining of the uterus. It is also responsible for the production of secretory cells in mammary glands.

• **Inhibin:** Inhibin is a protem hormone secreted to inhibit the secretion of FSH from the anterior pituitary gland. 7. Testes

Testes are two oval-shaped organs located in the scrotum. It secretes two hormones: testosterone and inhibin.
• **Testosterone:** Testosterone is a steroidal hormone produced inside the testes. It regulates the maturation of sperm and development of male sexual characteristics, including the development of reproductive organs, beard growth, and deepening of the voice.
• **Inhibin:** Inhibin in males is also secreted to decrease the secretion of FSH from the anterior pituitary gland.

8. Pineal Gland

The pineal gland or epiphysis is a small gland located behind the third ventricle of the brain, above the hypothalamus. It secretes melatonin hormone that delays the onset of puberty in humans. The activity of pineal gland depends on the circadian rhythm (different periods of the day). It secretes melatonin maximum in darkness and decreases as the light enters the eye (daylight). Melatonin is also a good antioxidant that protects against harmful oxygen-free radicals.

Questions for study

1. What are endocrine glands? Name the important endocrine glands with the location.

2. Explain the term hormone.
3. What is the role of hypothalamus?
4.How is the secretion of hormones controlled?
5. Which gland is known as the master gland? Explain why? **6.** True or false. The posterior pituitary gland secretesantidiuretic hormone. If false, Justify?
7. Explain the role of hormones secreted by anterior pituitary gland?
8. Name the hormones that control the level of calcium in the blood. **9.** Explain mineralocorticoids.
10. Name the hormones from adrenal cortex with their functions. **11.** Explain the action of vasopressin on the kidney.
12. Explain the hypersecretion and hyposecretion effects of the pituitary gland.
13. Explain hormones secreted by the thyroid gland.
14. What is the difference between diabetes insipidus and diabetes mellitus?
15. Explain the role of aldosterone.

15

The Reproductive System

INTRODUCTION

Most organ systems of the body function almost continuously to maintain the well-being of the individual. The reproductive system, however, appears to “slumber” until puberty. The primary sex organs, or gonads, are the *testes* in males and the *ovaries* in females. The gonads produce sex cells, or gametes, and secrete sex hormones. The remaining reproductive system structures are *accessory reproductive organs.* Although male and female *reproductive systems* are quite different, their joint purpose is to produce offspring. Male reproductive organs are adapted for producing sperm cells and transporting them to a location where fertilization can occur. The female reproductive organs perform similar functions for eggs and, following fertilization, support and maintain the offspring.

The major function of the reproductive system is to ensure survival of the species. Other systems in the body, such as the endocrine and urinary

systems, work continuously to maintain homeostasis for survival of the individual. An individual may live a long, healthy, and happy life without producing offspring, but if the species is to continue, at least some individuals must produce offspring.

MALE REPRODUCTIVE SYSTEM

The male reproductive system, like that of the female, consists of those organs whose function is to produce a new individual, i.e., to accomplish reproduction. This system consists of:

TESTES

The male gonads, testes, or testicles, begin their development high in the abdominal cavity, near the kidneys. Each testis is an oval structure about 5 cm long and 3 cm in diameter. A tough, white fibrous connective tissue capsule, the tunica albuginea, surrounds each testis and extends inward to form septa that partition the organ into lobules. There are about 250 lobules in each testis. Each lobule contains 1 to 4 highly coiled *seminiferous tubules* that converge to form a single straight tubule, which leads into the rete testis. Short *efferent ducts* exit the testes. Interstitial cells (*cells of Leydig),* which produce male sex hormones, are located between the seminiferous tubules within a lobule.

SCROTUM

During the last two months before birth, or shortly after birth, testes descend through the inguinal canal into the *scrotum,* a pouch that extends below the abdomen, posterior to the penis. Although this location of the testes, outside the abdominal cavity, may seem to make them vulnerable to injury, it provides a temperature about 3°C below normal body temperature. This lower temperature is necessary for the production of viable sperm. The scrotum consists of skin and subcutaneous tissue. A vertical partition, of subcutaneous tissue in the center divides it into two parts, each containing one testis. Smooth muscle fibers, called the *dartos muscle,* in the subcutaneous tissue contract to give the scrotum its wrinkled appearance. When these

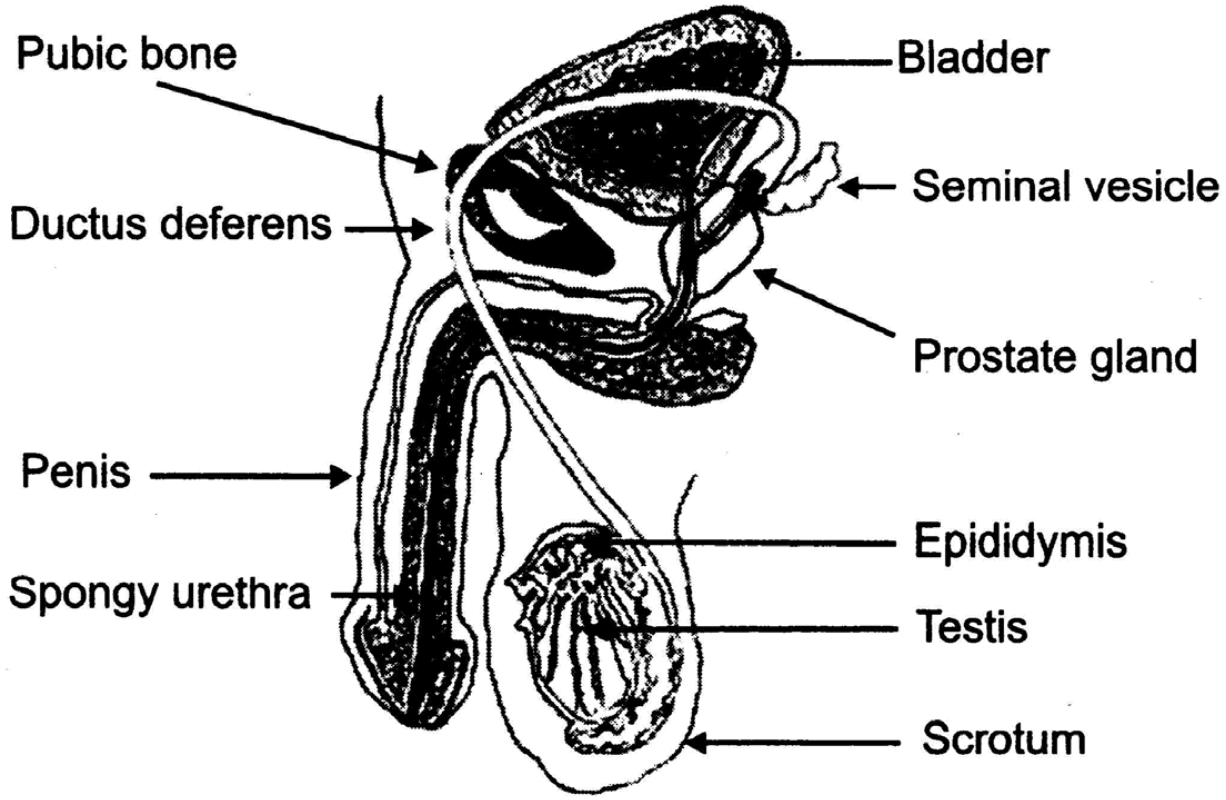


Figure 15.1: Male reproductive system

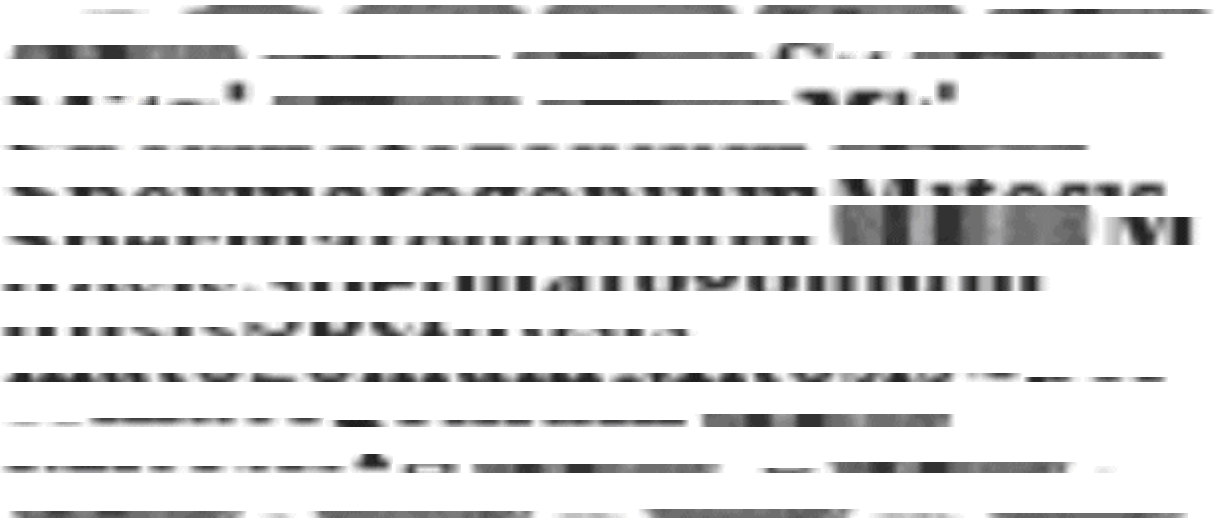
fibers are relaxed, the scrotum is smooth. Another muscle, the *cremaster muscle,*consists of skeletal muscle fibers and controls the position of the scrotum and testes. When it is cold or a man is sexually aroused, this muscle contracts to pull the testes closer to the body for warmth.

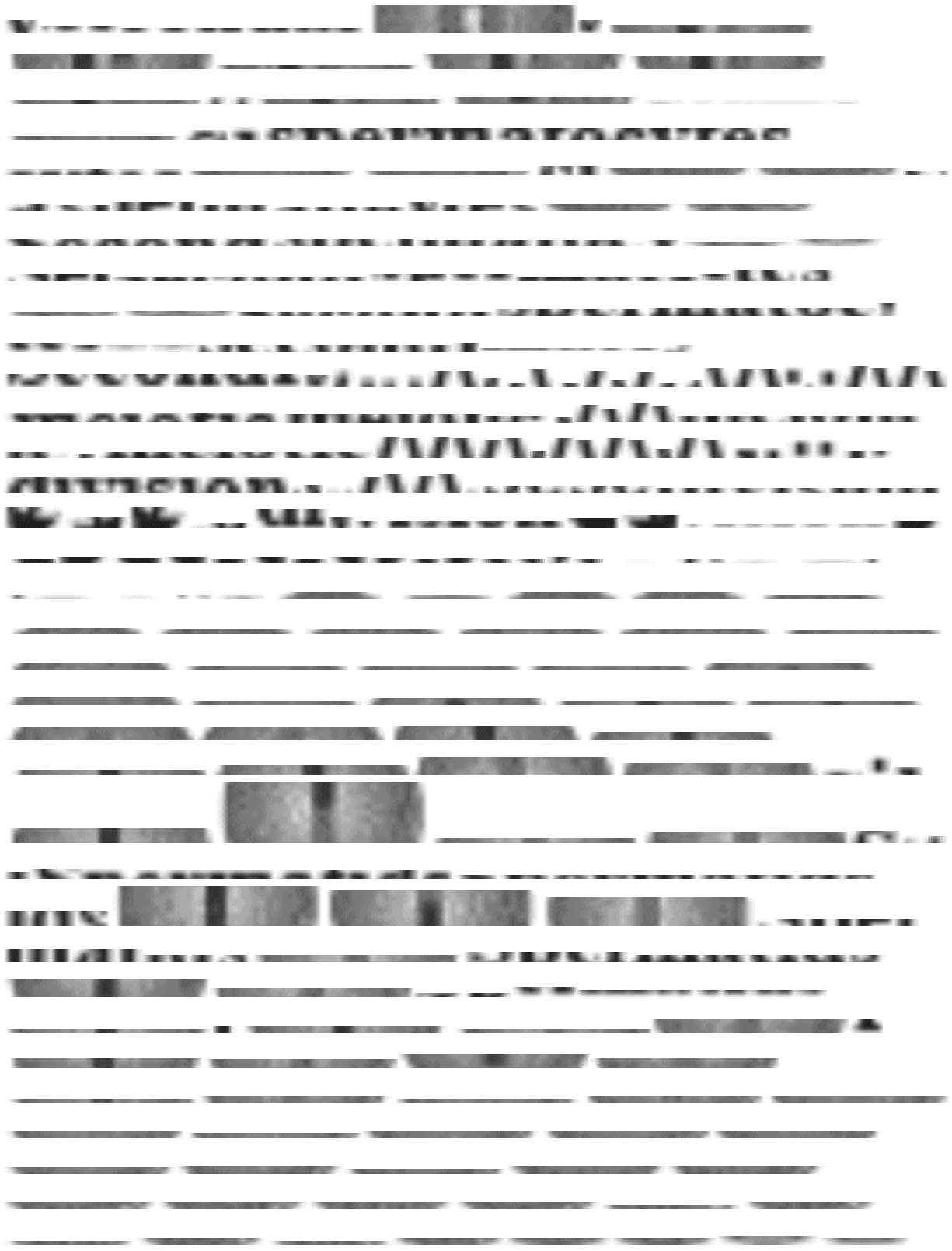
SPERMATOGENESIS
Sperm are produced by spermatogenesis within the *seminiferous tubules.*

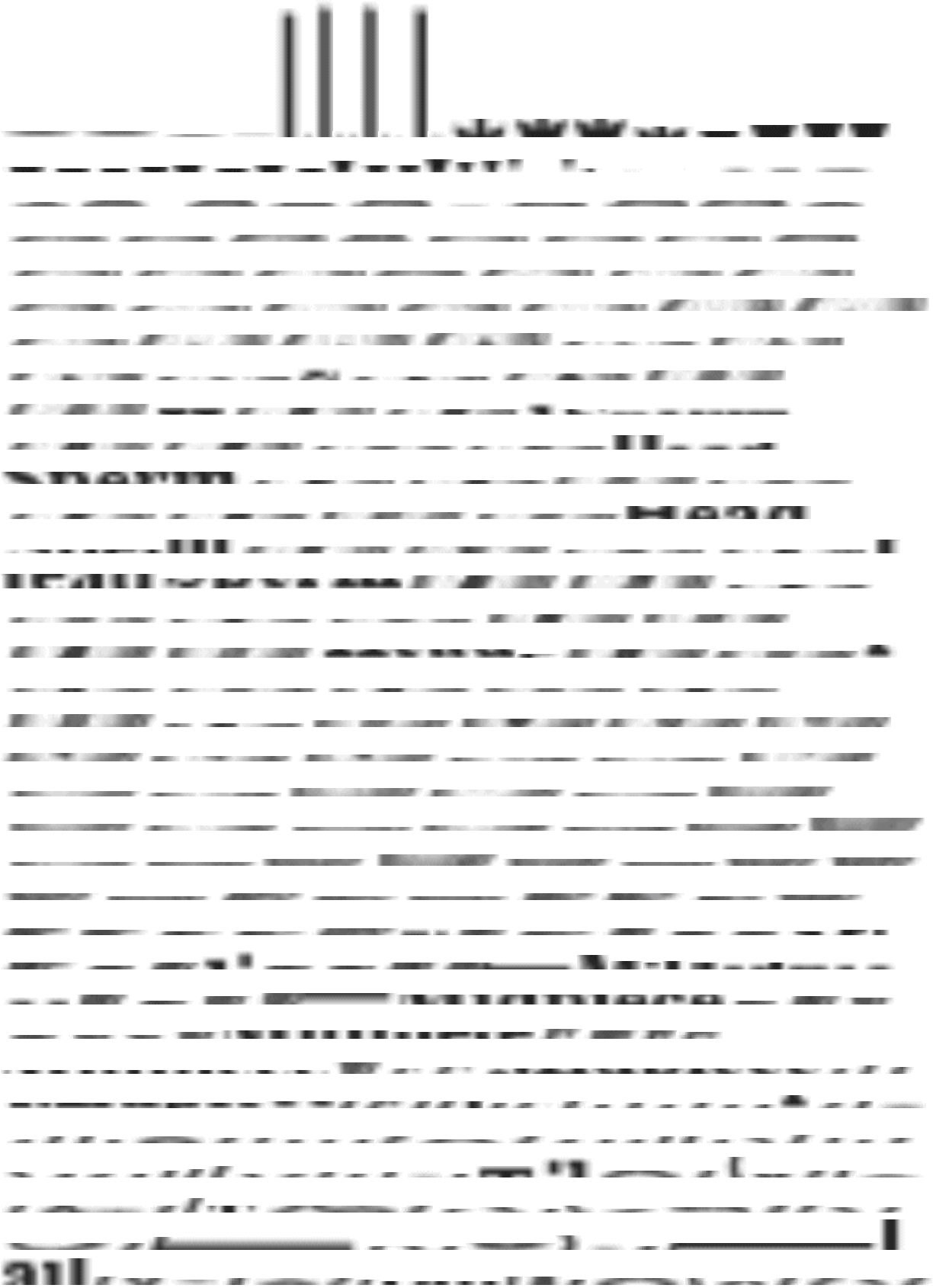
A transverse section of a seminiferous tubule shows that it is packed with cells in various stages of development. Interspersed with these cells, there are large cells that extend from the periphery of the tubule to the lumen. These large cells are the supporting, or sustentacular cells (*Sertoli's cells* or *nurse cell),* which support and nourish the other cells. Early in embryonic development, primordial germ cells enter the testes and differentiate into spermatogonia, immature cells that remain dormant until puberty.

Spermatogonia are diploid cells, each with 46 chromosomes (23 pairs) located around the periphery of the seminiferous tubules. At puberty, hormones stimulate these cells to begin dividing by mitosis. Some of the daughter cells produced by mitosis remain at the periphery as spermatogonia.

Others are pushed toward the lumen, undergo some changes, and become *primary spermatocytes.* Because they are produced by *mitosis,* primary spermatocytes, like spermatogonia, are diploid and have 46 chromosomes. Each primary spermatocytes goes through the first meiotic division, meiosis I, to produce two *secondary spermatocytes,* each with 23 chromosomes (haploid). Just prior to this division, the genetic material is replicated, so that each chromosome consists of two strands, called *chromatids,* that are joined by a centromere. During meiosis I, one chromosome, consisting of two chromatids, goes to each secondary spermatocyte. In the *second meiotic division,* meiosis II, each secondary spermatocyte divides to produce two spermatids. There is no replication of genetic material in this division, but the centromere divides so that a single-stranded chromatid goes to each cell. As a result of the two meiotic divisions, each primary spermatocyte produces *four spermatids.* During spermatogenesis there are two cellular divisions, but only one replication of DNA so that each spermatid has 23 chromosomes (haploid), one from each pair in the original primary spermatocyte. Each successive stage in spermatogenesis is pushed toward the center of the tubule, so that the more immature cells are at the periphery and the more differentiated cells are nearer the center.







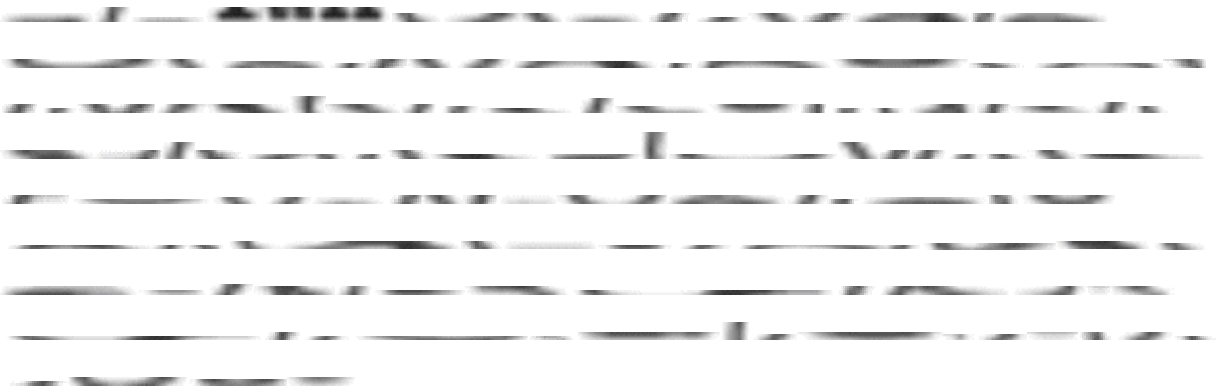


Figure 15.2: Spermatogenesis

Spermatogenesis (and oogenesis in the female) differs from mitosis because the resulting cells have only half the number of chromosomes as the original cell. When the sperm cell nucleus unites with an egg cell nucleus, the full number of chromosomes is restored. If sperm and egg cells were produced by mitosis, then each successive generation would have twice the number of chromosomes as the preceding one.

The final step in the development of sperm is called s*permiogenesis.* In this process, the spermatids formed from spermatogenesis become mature spermatozoa, or *sperm.*

Sperm

The mature sperm cell has a head, midpiece, and tail. The head, also called the nuclear region, contains the 23 chromosomes surrounded by a nuclear membrane. The tip of the head is covered by an *acrosome*, which contains enzymes that help the sperm penetrate the female gamete. The midpiece, metabolic region, contains mitochondria that provide adenosine triphosphate (ATP). The *tail*, locomotor region, uses a typical *flagellum* for locomotion. The sperm are released into the lumen of the seminiferous tubule and leave the testes. They then enter the epididymis where they undergo their final maturation and become capable of fertilizing a female gamete.

Sperm production begins at puberty and continues throughout the life of a male. The entire process, beginning with a primary spermatocyte, takes about 74 days. After ejaculation, the sperm can live for about 48 hours in the female reproductive tract.

Sperm cells pass through a series of ducts to reach the outside of the body. After they leave the testes, the sperm passes through the epididymis, ductus deferens, ejaculatory duct, and urethra.

EPIDIDYMIS

Sperm leave the testes through a series of efferent ducts that enter the epididymis. Each epididymis is a long (about 6 meters) tube that is tightly coiled to form a comma-shaped organ located along the superior and posterior margins of the testes. When the sperm leave the testes, they are immature and incapable of fertilizing ova. They complete their maturation process and become fertile as they move through the epididymis. Mature sperm are stored in the lower portion, or tail, of the epididymis.

DUCTUS DEFERENS OR VAS DEFERENS

The ductus deferens, also called *vas deferens,*is a fibromuscular tube that is continuous (or contiguous) with the epididymis. It begins at the bottom (tail) of the epididymis then turns sharply upward along the posterior margin of the testes. The ductus deferens enters the abdominopelvic cavity through the inguinal canal and passes along the lateral pelvic wall. It crosses over the ureter and posterior portion of the urinary bladder, and then descends along the posterior wall of the bladder toward the prostate gland. Just before it reaches the prostate gland, each ductus deferens enlarges to form an ampulla. Sperm are stored in the proximal portion of the ductus deferens, near the epididymis, and peristaltic movements propel the sperm through the tube.

The proximal portion of the ductus deferens is a component of the spermatic cord, which contains vascular and neural structures that supply the testes. The spermatic cord contains the ductus deferens, testicular artery and veins, lymph vessels, testicular nerve, cremaster muscle that elevates the testes for warmth and at times of sexual stimulation, and a connective tissue covering.

EJACULATORY DUCT

Each ductus deferens, at the ampulla, joins the duct from the

adjacent seminal vesicle (one of the accessory glands) to form a short ejaculatory duct. Each ejaculatory duct passes through the prostate gland and

empties into the urethra.

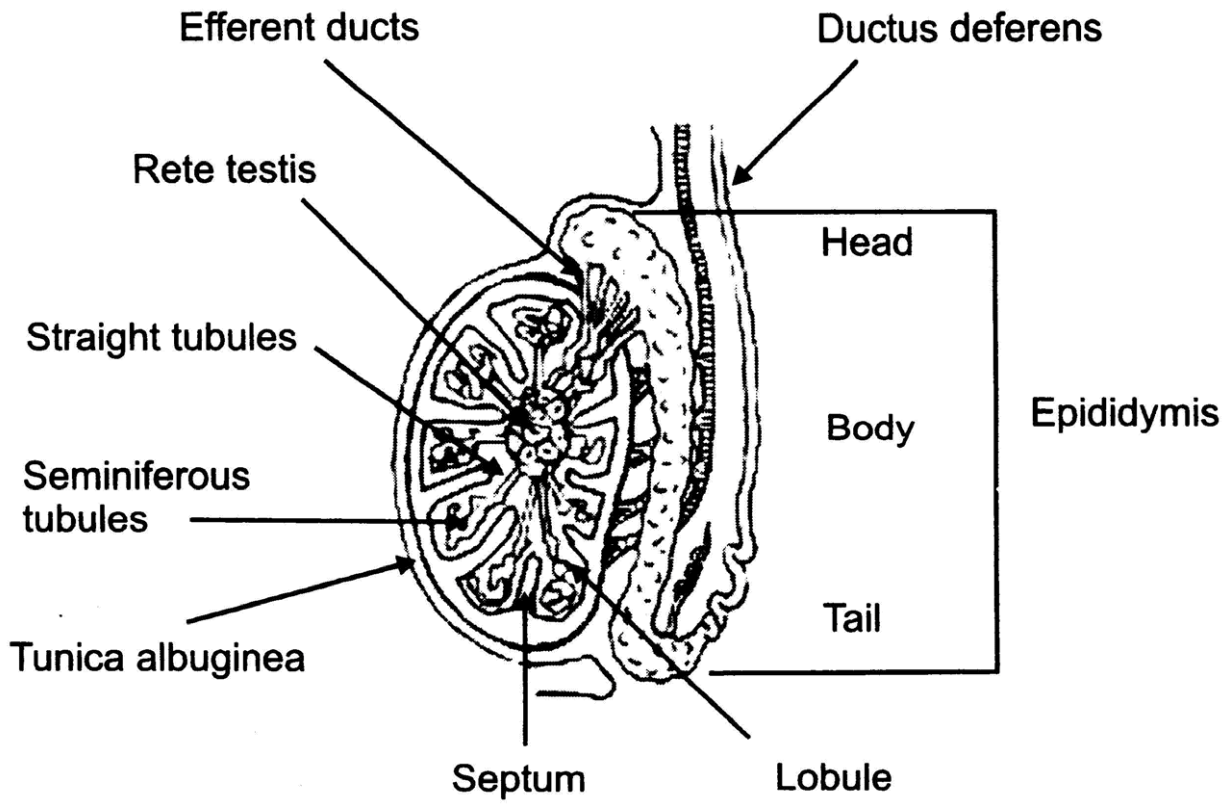


Figure 15.3: Sagittal section of a testis and epididymis

URETHRA

The urethra extends from the urinary bladder to the external urethral orifice at the tip of the penis. It is a passageway for sperm and fluids from the reproductive system and urine from the urinary system. While reproductive fluids are passing through the urethra, sphincters contract tightly to keep urine from entering the urethra.

The male urethra is divided into three regions. The prostatic urethra is the proximal portion that passes through the prostate gland. It receives the ejaculatory duct, which contains sperm and secretions from the seminal vesicles, and numerous ducts from the prostate glands. The next portion, the membranous urethra, is a short region that passes through the pelvic floor. The longest portion is the penile urethra (also called spongy urethra or cavernous urethra), which extends the length of the penis and opens to the outside at the external urethral orifice. The ducts from the bulbourethral glands open into the penile urethra.

ACCESSORY GLANDS

The accessory glands of the male reproductive system are the seminal vesicles, prostate gland, and the bulbourethral glands. These glands secrete fluids that enter the urethra.

Seminal Vesicles

The paired seminal vesicles are saccular glands posterior to the urinary bladder. Each gland has a short duct that joins with the ductus deferens at the ampulla to form an ejaculatory duct, which then empties into the urethra. The fluid from the seminal vesicles is viscous and contains fructose, which provides an energy source for the sperm; prostaglandins, which contribute to the mobility and viability of the sperm; and proteins that cause slight coagulation reactions in the semen after ejaculation.

Prostate Gland

The prostate gland is a firm, dense structure that is located just inferior to the urinary bladder. It is about the size of a walnut and encircles the urethra as it leaves the urinary bladder. Numerous short ducts from the substance of the prostate gland empty into the prostatic urethra. The secretions of the prostate are thin, milky coloured, and alkaline. They function to enhance the motility of the sperm.

Bulbourethral Glands

The paired bulbourethral (Cowper’s) glands are small, about the size of a pea, and located near the base of the penis. A short duct from each gland enters the proximal end of the penile urethra. In response to sexual stimulation, the bulbourethral glands secrete an alkaline mucus-like fluid. This fluid neutralizes the acidity of the urine residue in the urethra, helps to neutralize the acidity of the vagina, and provides some lubrication for the tip of the penis during intercourse.

Seminal Fluid

Seminal fluid, or semen, is a slightly alkaline mixture of sperm cells and secretions from the accessory glands. Secretions from the seminal vesicles

make up about 60 percent of the volume of the semen, with most of the remainder coming from the prostate gland. The sperm and secretions from the bulbourethral gland contribute only a small volume.

Volume of Semen

The volume of semen in a single ejaculation may vary from 1.5 to 6.0 ml. There are usually between 50 to 150 million sperm per milliliter of semen. Sperm counts below 10 to 20 million per milliliter usually present fertility problems. Although only one sperm actually penetrates and fertilizes the ovum, it takes several million sperm in an ejaculation to ensure that fertilization will take place.

PENIS

The penis, the male copulatory organ, is a cylindrical pendant organ located anterior to the scrotum and functions to transfer sperm to the vagina. The penis consists of three columns of erectile tissue that are wrapped in connective tissue and covered with skin. The two dorsal columns are the *corpora cavernosa.* The single, midline ventral column surrounds the urethra and is called the *corpus spongiosum.* The penis has a root, body (shaft), and glans penis. The root of the penis attaches it to the pubic arch and the body is the visible, pendant portion. The corpus spongiosum expands at the distal end to form the glans penis. The urethra, which extends throughout the length of the corpus spongiosum, opens through the external Urethral orifice at the tip of the glans penis. A loose fold of skin, called the *prepuce*, or foreskin, covers the *glans penis.*

MALE SEXUAL RESPONSE

The male sexual response includes erection and orgasm accompanied by ejaculation of semen. Orgasm is followed by a variable time period during which it is not possible to achieve another erection.

Three hormones are the principle regulators of the male reproductive system. Follicle-stimulating hormone (FSH) stimulates spermatogenesis; luteinizing hormone (LH) stimulates the production of testosterone; and testosterone

stimulates the development of male secondary sex characteristics and spermatogenesis.

FEMALE REPRODUCTIVE SYSTEM

The organs of the female reproductive system produce and sustain the female sex cells (egg cells or ova), transport these cells to a site where they may be fertilized by sperm, provide a favourable environment for the developing fetus, move the fetus to the outside at the end of the development period, and produce the female sex hormones. The female reproductive system includes the ovaries, fallopian tubes, uterus, vagina, accessory glands, and external genital organs.

OVARIES

The primary female reproductive organs, or gonads, are the two ovaries. Each ovary is a solid, ovoid structure about the size and shape of an almond, about 3.5 cm in length, 2 cm wide, and 1 cm thick. The ovaries are located in shallow depressions, called ovarian fossae, one on each side of the uterus, in the lateral walls of the pelvic cavity. They are held loosely in place by peritoneal ligaments.

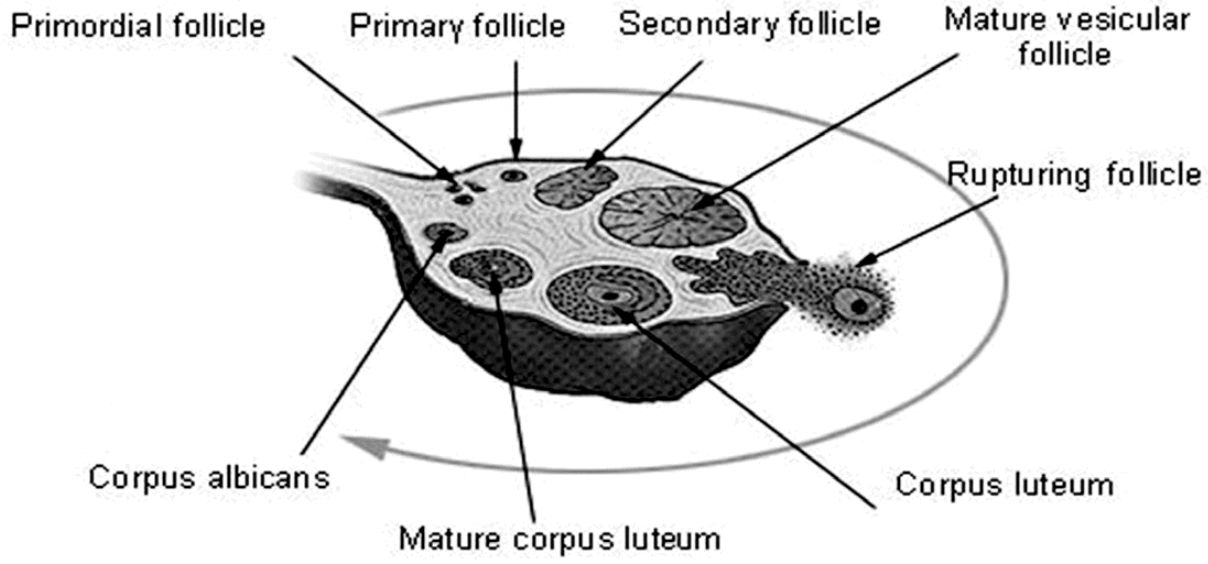


Figure 15.4: Structure of ovary

Structure

The ovaries are covered on the outside by a layer of simple cuboidal epithelium called germinal (ovarian) epithelium. This is actually the visceral peritoneum that envelops the ovaries. Underneath this layer there is a dense connective tissue capsule, the tunica albuginea. The substance of the ovaries is distinctly divided into an outer cortex and an inner medulla. The cortex appears more dense and granular due to the presence of numerous ovarian follicles in various stages of development. Each of the follicles contains an oocyte, a female germ cell. The medulla is loose connective tissue with abundant blood vessels, lymphatic vessels, and nerve fibers.

Oogenesis

Female sex cells, or gametes, develop in the ovaries by a form of meiosis called oogenesis. The sequence of events in oogenesis is similar to the sequence in spermatogenesis, but the timing and final result are different. Early in fetal development, primitive germ cells in the ovaries differentiate into oogonia. These divide rapidly to form thousands of cells, still called *oogonia*, which have a full complement of 46 (23 pairs) chromosomes. Oogonia then enter a growth phase, enlarge, and become *primary oocytes.* The diploid (46 chromosomes) primary oocytes replicate their DNA and begin the *first meiotic division*, but the process stops in prophase and the cells remain in this suspended state until puberty. Many of the primary oocytes degenerate before birth, but even with this decline, the two ovaries together contain approximately 7,00,000 oocytes at birth. This is the lifetime supply, and no more will develop. This is quite different than the male in which spermatogonia and primary spermatocytes continue to be produced throughout the reproductive lifetime. By puberty the number of primary oocytes has further declined to about 4,00,000.

Beginning at puberty, under the influence of folliclestimulating hormone, several primary oocytes start to grow again each month. One of the primary oocytes seems to outgrow the others and it resumes meiosis I. The other cells degenerate. The large cell undergoes an unequal division, so that nearly all the cytoplasm, organelles, and half the chromosomes go to one cell, which becomes a secondary oocyte. The remaining half of the chromosomes go to a smaller cell called the first polar body. The *secondary oocyte* begins the second meiotic division, but the process stops in metaphase. At this point *ovulation* occurs.

If fertilization occurs, meiosis II continues. Again this is an unequal division with all of the cytoplasm going to the *ovum*, which has 23 single-stranded chromosome. The smaller cell from this division is a second polar body. The first polar body also usually divides in meiosis I to produce two even smaller polar bodies. If fertilization does not occur, the second meiotic division is never completed and the secondary oocyte degenerates.

There are obvious differences between the male and female. In *spermatogenesis,* four functional sperm develop from each primary spermatocyte. In *oogenesis,* only one functional fertilizable cell, develops from a primary oocyte. The other three cells are polar bodies and they degenerate.

Figure 15.5: Process of oogenesis

OVARIAN FOLLICLE DEVELOPMENT

An ovarian follicle consists of a developing oocyte surrounded by one or more layers of cells called *follicular cells.* At the same time that the oocyte is progressing through meiosis, corresponding changes are taking place in the follicular cells. Primordial follicles, which consist of a primary oocyte surrounded by a single layer of flattened cells, develop in the fetus and are the stage that is present in the ovaries at birth and throughout childhood.

Beginning at puberty follicle-stimulating hormone stimulates changes in the primordial follicles. The follicular cells become cuboidal, the primary oocyte enlarges, and it is now a primary follicle. The follicles continue to grow under the influence of follicle- stimulating hormone, and the follicular cells proliferate to form several layers of granulose cells around the primary oocyte. Most of these primary follicles degenerate along with the primary oocytes within them, but usually one continues to develop each month. The granulosa cells start secreting estrogen and a cavity, or antrum, forms within the follicle. When the antrum starts to develop, the follicle becomes a secondary follicle. The granulose cells also secrete a glycoprotein substance that forms a clear membrane, the zona pellucida, around the oocyte. After about 10 days of growth the follicle is a mature vesicular (graafian) follicle, which forms a “blister” on the surface of the ovary and contains a secondary oocyte ready for ovulation.

Ovulation

Ovulation, prompted by luteinizing hormone from the anterior pituitary, occurs when the mature follicle at the surface of the ovary ruptures and releases the secondary oocyte into the peritoneal cavity. The ovulated secondary oocyte, ready for fertilization is still surrounded by the *zona pellucida* and a few layers of cells called the *corona radiata.* If it is not fertilized, the secondary oocyte degenerates in a couple of days. If a sperm passes through the corona radiata and zona pellucida and enters the cytoplasm of the secondary oocyte, the second meiotic division resumes to form a polar body and a mature ovum.

After ovulation and in response to luteinizing hormone, the portion of the follicle that remains in the ovary enlarges and is transformed into a corpus luteum. The *corpus luteum* is a glandular structure that secretes progesterone and some estrogens. Its fate depends on whether fertilization occurs. If fertilization does not take place, the corpus luteum remains functional for about 10 days then it begins to degenerate into a corpus albicans, which is primarily scar tissue, and its hormone output ceases. If fertilization occurs, the corpus luteum persists and continues its hormone functions until the placenta develops sufficiently to secrete the necessary hormones. Again, the corpus luteum ultimately degenerates into corpus albicans, but it remains functional for a longer period of time.

FALLOPIAN TUBES
There are two uterine tubes, also called *fallopian tubes* or *oviducts.*

There is one tube associated with each ovary. The end of the tube near the ovary expands to form a funnel-shaped *infundibulum,* which is surrounded by finger-like extensions called *fimbriae.* Because there is no direct connection between the infundibulum and the ovary, the oocyte enters the peritoneal cavity before it enters the fallopian tube. At the time of ovulation, the fimbriae increase their activity and create currents in the peritoneal fluid that help propel the oocyte into the fallopian tube. Once inside the fallopian tube, the oocyte is moved along by the rhythmic beating of cilia on the epithelial lining and by peristaltic action of the smooth muscle in the wall of the tube. The journey through the Fallopian tube takes about 7 days. Because

the oocyte is fertile for only 24 to 48 hours, fertilization usually occurs in the Fallopian tube.

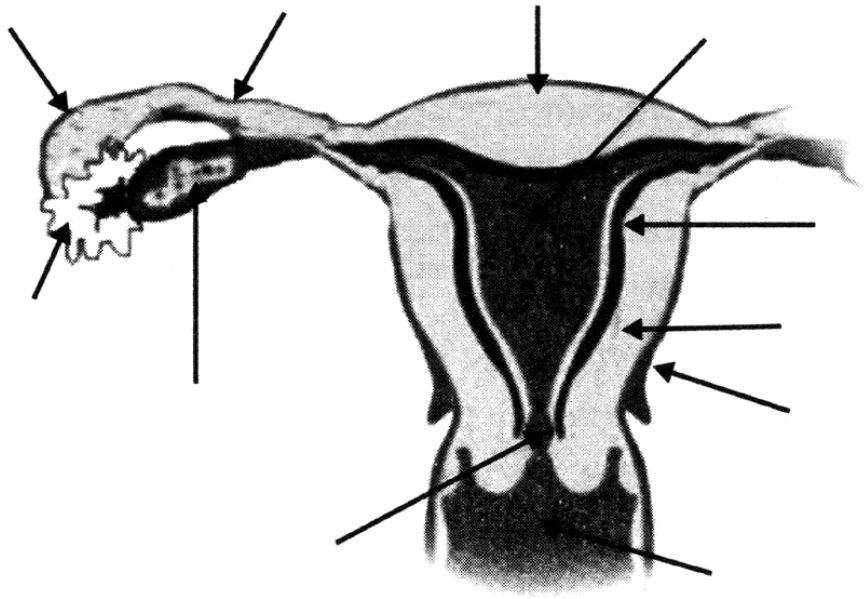


Figure 15.6: Female reproductive parts

UTERUS

The uterus is a muscular organ that receives the fertilized oocyte and provides an appropriate environment for the developing fetus. Before the first pregnancy, the uterus is about the size and shape of a pear, with the narrow portion directed interiorly. After childbirth, the uterus is usually larger, then regresses after menopause. The uterus is lined with the *endometrium.* The stratum functionale of the endometrium sloughs off during menstruation. The deeper stratum basale provides the foundation for rebuilding the stratum functionale.

VAGINA

The vagina is a fibromuscular tube, about 10 cm long, that extends from the cervix of the uterus to the outside. It is located between the rectum and the urinary bladder. Because the vagina is tilted posteriorly as it ascends and the cervix is tilted anteriorly, the *cervix* projects into the vagina at nearly a right angle. The vagina serves as a passageway for menstrual flow, receives the erect penis during intercourse, and is the birth canal during childbirth.

EXTERNAL GENITALIA

The external genitalia are the accessory structures of the female reproductive system that are external to the vagina. They are also referred to as the vulva or pudendum. The external genitalia include the *labia majora*, *mons pubis*, *labia minora*, *clitoris*, and *glands* within the vestibule. The clitoris is an erectile organ, similar to the male penis, that responds to sexual stimulation. Posterior to the clitoris, the urethra, vagina, paraurethral glands and greater vestibular glands open into the vestibule.

The *female sexual response* includes arousal and orgasm, but there is no ejaculation. A woman may become pregnant without having an orgasm.

Follicle-stimulating hormone, luteinizing hormone, estrogen, and progesterone have major roles in regulating the functions of the female reproductive system.

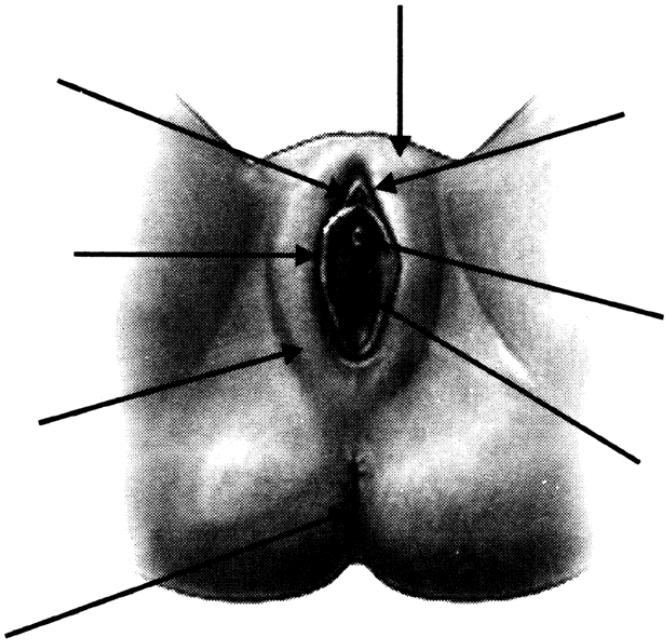


Figure 15.7: External genitalia

At puberty, when the ovaries and uterus are mature enough to respond to hormonal stimuliation, certain stimuli cause the hypothalamus to start secreting gondadotropin-releasing hormone. This hormone enters the blood

and goes to the anterior pituitary gland where it stimulates the secretion of follicle-stimulating hormone and luteinizing hormone. These hormones, in turn, affect the ovaries and the monthly cycles begin. A woman's reproductive cycles last from menarche to menopause.

The monthly ovarian cycle begins with the follicle development during the follicular phase, continues with ovulation during the ovulatory phase, and concludes with the development and regression of the *corpus luteum* during the luteal phase.

The uterine cycle takes place simultaneously with the ovarian cycle. The uterine cycle begins with menstruation during the menstrual phase, continues with repair of the endometrium during the proliferative phase, and ends with the growth of glands and blood vessels during the secretory phase.

Menopause occurs when a woman's reproductive cycles stop. This period is marked by decreased levels of ovarian hormones and increased levels of pituitary follicle-stimulating hormone and luteinizing hormone. The changing hormone levels are responsible for the symptoms associated with menopause.

MAMMARY GLANDS

Functionally, the mammary glands produce milk; structurally, they are modified sweat glands. Mammary glands, which are located in the breast overlying the pectoralis major muscles, are present in both sexes, but usually are functional only in the female.

Externally, each breast has a raised nipple, which is surrounded by a circular pigmented area called the *areola.* The nipples are sensitive to touch, due to the fact that they contain smooth muscle that contracts and causes them to become erect in response to stimulation.

Internally, the adult female breast contains 15 to 20 lobes of glandular tissue that radiate around the nipple. The lobes are separated by connective tissue and adipose. The connective tissue helps support the breast. Some bands of connective tissue, called suspensory (Cooper's) ligaments extend through the breast from the skin to the underlying muscles. The amount and

distribution of the adipose tissue determines the size and shape of the breast. Each lobe consists of lobules that contain the glandular units. A lactiferous duct collects the milk from the lobules within each lobe and carries it to the nipple. Just before the nipple the lactiferous duct enlarges to form a lactiferous sinus (ampulla), which serves as a reservoir for milk. After the sinus, the duct again narrows and each duct opens independently on the surface of the nipple.

Mammary gland function is regulated by hormones. At puberty, increasing levels of estrogen stimulate the development of glandular tissue in the female breast. Estrogen also causes the breast to increase in size through the accumulation of adipose tissue. Progesterone stimulates the development of the duct system. During pregnancy these hormones enhance further development of the mammary glands. Prolactin from the anterior pituitary stimulates the production of milk within the glandular tissue, and oxytocin causes the ejection of milk from the glands.

COPULATION AND FERTILIZATION

For fertilization to occur, sperm must be deposited in the vagina within a few days before or a day or two after ovulation. Sperm transfer is accomplished by copulation. Sexual excitation dilates the arterioles supplying blood to the penis. Blood accumulates in three cylindrical spongy sinuses that run lengthwise through the penis. The resulting pressure causes the penis to enlarge and erect and thus able to penetrate the vagina.

Movement of the penis back and forth within the vagina causes sexual tension to increase to the point of ejaculation. Contraction of the walls of each vas deferens propels the sperm along. Fluid is added to the sperm by the seminal vesicles, Cowper’s glands, and the prostate gland. These fluids provide a source of energy (fructose) and perhaps in other ways provide an optimum chemical environment for the sperm.

The mixture of sperm and accessory fluids is called semen. It passes through the urethra and is expelled into the vagina.

Physiological changes occur in the female as well as the male in response to sexual excitement, although these are not as readily apparent. In contrast to

the male, however, such responses are not a prerequisite for copulation and fertilization to occur.

Once deposited within the vagina, the sperm proceed on their journey into and through the uterus and on up into the fallopian tubes. It is here that fertilization may occur if an “egg” is present (strictly speaking, it is still a secondary oocyte until after completion of meiosis II).

Although sperm can swim several millimeters each second, their trip to and through the fallopian tubes may be assisted by muscular contraction of the walls of the uterus and the tubes. There is also evidence that they respond to a chemical attractant produced by the egg or the tissues surrounding it. In any case, sperm may reach the egg within 15 minutes of ejaculation. The trip is also fraught with heavy mortality. An average human ejaculate contains over one hundred million sperm, but only a few dozen complete the journey. And of these, only one will succeed in fertilizing the egg.

Fertilization begins with the binding of a sperm head to the outer coating of the egg (called the zona pellucida). Exocytosis of tire acrosome at the tip of the sperm head releases enzymes that digest a path through the zona and enable the sperm head to bind to the plasma membrane of the egg. Fusion of their respective membranes allows the entire contents of the sperm to be drawn into the cytosol of the egg. (Even though the sperm’s mitochondria enter the egg, they are almost always destroyed and do not contribute their genes to the embryo. So human mitochondrial DNA is almost always inherited from mothers only.)

Within moments, enzymes released from the egg cytosol act on the zona making it impermeable to the other sperm that arrive. Soon the nucleus of the successful sperm enlarges into the male pronucleus. At the same time, the egg (secondary oocyte) completes meiosis II forming a second polar body and the female pronucleus.

The male and female pronuclei move toward each other while duplicating their DNA in S phase. Their nuclear envelopes disintegrate. A spindle is formed (following replication of the sperm’s centriole), and a full set of dyads assembles on it. The fertilized egg or zygote is now ready for its first

mitosis. When this is done, 2 cells — each with a diploid set of chromosomes — are formed.

MENSTRUAL CYCLE

Menstruation — having periods — is part of the female reproductive cycle that starts when girls become sexually mature at the time of puberty. During a menstrual period, a woman bleeds from her uterus (womb) via the vagina. This lasts anything from three to seven days. Each period commences approximately every 28 days if the woman does not become pregnant during a given cycle.

Menstruation is a very complicated process involving many different hormones, the woman's sex organs and the brain. A woman's internal sex organs consist of two ovaries, the Fallopian tubes, the uterus (womb) and the vagina. The ovaries contain the eggs with which the woman is bom and, during each period, a single egg will usually ripen and mature due to the action of hormones circulating in the bloodstream.

When the egg is mature it bursts from the ovary and drifts through the Fallopian tube down into the uterus. The lining of the uterus — the endometrium — has been thickened by the action of hormones and made ready to receive the fertilised egg.

If the egg is fertilized and the woman becomes pregnant, it will fasten itself onto the endometrium. If the egg is not fertilized, however, resultant hormonal changes cause the endometrium to slip away and menstruation begins.

Menstrual discharge is composed of the endometrium itself, together with a little fresh blood caused by the breaking of very fine blood vessels within the endometrium as it detaches itself from the inside of the uterus.

The amount of blood lost due to the normal monthly period is usually less than 80 ml.
During menstruation, girls begin to menstruate when they are about 10 to 14 years-old. The average age is approximately 12. Women will continue to menstruate until the age of 45 to 55, when menopause begins. A woman will

have approximately 500 periods in her lifetime.
Ovulation usually takes place roughly 14 days after the first day of the start of a period; however, the exact timing can vary greatly from woman tc woman. Some women know when they are ovulating because they can feel a slight pain in their lower abdomen. Other women may bleed slightly in the middle of their cycle.
Vaginal discharge also changes at ovulation. It increases in amount and becomes more watery due to hormonal changes. This is one of the ways that women who wish to practice natural family planning (NFP) using the mucus test can find out whether it is safe to have sex or not.
Women who do not experience such symptoms during ovulation can find out when they are ovulating by taking their temperature. This will rise by 0.5 degrees Celsius when ovulation occurs. To measure temperature effectively, it must be taken at the same time every morning before getting out of bed. Temperature readings taken from different parts of the body such as the mouth, under the arm, in the ear or in the rectum will all give a slightly different measurement. For this reason, it is important to choose one location and stick to it. When checking for temperature, rises can occur for a variety of reasons and, therefore, should not be used as the only method of detecting ovulation.

PREGNANCY

Development begins while the fertilized egg is still within the fallopian tube. Repeated mitotic divisions produces a solid ball of cells called a *morula.* Further mitosis and some migration of cells converts this into a hollow ball of cells called the *blastocyst.* Approximately one week after fertilization, the blastocyst embeds itself in the thickened wall of the uterus, a process called *implantation,* and pregnancy is established. The blastocyst produces two major divisions of cells:

(i) Three or four blastocyst cells develop into the inner cell mass, which will form
(a) 3 extraembryonic membranes: amnion, yolk sac, and (b) (a vestigial) allantois and in about 2 months, become

the fetus and, ultimately, the baby.

(ii) The remaining 100 or so cells form the trophoblast, which will develop into the chorion that will go on to makeup most of the placenta. All the extraembryonic membranes play vital roles during development but will be discarded at the time of birth.

The placenta grows tightly fused to the wall of the uterus. Its blood vessels, supplied by the fetal heart, are literally bathed in the mother's blood. Although there is normally no mixing of the two blood supplies, the placenta does facilitate the transfer of a variety of materials between the fetus and the mother.

(i) Receiving oxygen and discharging carbon dioxide. **(ii)** Discharging urea and other wastes.

(iii) Receiving antibodies (chiefly of the IgG class). These remain for weeks after birth, protecting the baby from the diseases to which the mother is immune.

But the placenta is not simply a transfer device. Using raw materials from the mother's blood, it synthesizes large quantities of proteins and also some hormones. Link to discussion of the placenta as an endocrine gland.

The metabolic activity of the placenta is almost as great as that of the fetus itself. The umbilical cord connects the fetus to the placenta. It receives deoxygenated blood from the iliac arteries of the fetus and returns oxygenated blood to the liver and on to the inferior vena cava. Because its lungs are not functioning, circulation in the fetus differs dramatically from that of the baby after birth. While within the uterus, blood pumped by the right ventricle bypasses the lungs by flowing through the foramen ovale and the ductus arteriosus.

Although the blood in the placenta is in close contact with the mother's blood in the uterus, intermingling of their blood does not normally occur. However, some of the blood cells of the fetus usually do get into the mother's circulation — where they have been know to survive for decades. This raises the possibility of doing prenatal diagnosis of genetic disorders by sampling the mother's blood rather than having to rely on the more invasive procedures of amniocentesis and chorionic villus sampling (CVS).

Far rarer is the leakage of mother's blood cells into the fetus. However, it does occur. A few pregnant women with leukemia or lymphoma have transferred the malignancy to their fetus. Some babies have also acquired melanoma from the transplacental passage of these highly-malignant cells from their mother.

During the first two months of pregnancy, the basic structure of the baby is being formed. This involves cell division, cell migration, and the differentiation of cells into the many types found in the baby. During this period, the developing baby — called an *embryo* — is very sensitive to anything that interferes with the steps involved. Virus infection of the mother, e.g., by *rubella* ("German measles") virus or exposure to certain chemicals may cause malformations in the developing embryo. Such agents are called *teratogens* ("monster-forming"). After about two months, all the systems of the baby have been formed, at least in a rudimentary way. From then on, development of the *fetus*, as it is now called, is primarily a matter of growth and minor structural modifications. The fetus is less susceptible to teratogens than is the embryo. Pregnancy involves a complex interplay of hormones.

ASSISTED REPRODUCTIVE TECHNOLOGY (ART)

Louise Brown recently celebrated her 25th birthday. She was the first of what today number around one million "test tube babies"; that is, she developed from an egg that was fertilized outside her mother's body — the process called *in vitro fertilization (IVF).*

IN VITRO FERTILIZATION (IVF)
IVF involves:

(i) Harvesting mature eggs from the mother. This is not an easy process. The mother must undergo hormonal treatments to produce multiple eggs, which then must be removed (under anesthesia) from her ovaries.

(ii) Harvesting sperm from the father. Harvesting is usually no problem, but often the sperm are defective in their ability to fertilize (so setting the stage for ICSI).

(iii) Mixing sperm and eggs in a culture vessel (in vitro). **(iv)** Culturing the fertilized eggs for several days until they have developed to at least the 8-cell stage.

(v) Placing two (usually) of these into the mother's uterus (which her hormone treatments have prepared for implantation).

(vi) Keeping one's fingers crossed — only about one-third of the attempts result in a successful pregnancy).

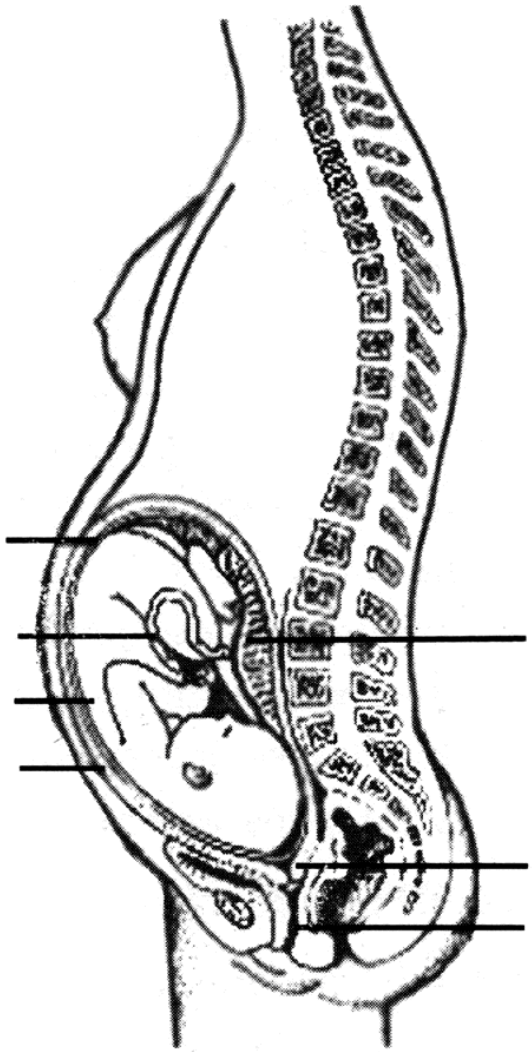


Figure 15.9: In Vitro Fertilization (IVF)

Intracytoplasmic Sperm Injection (ICSI)

Successful IVF assumes the availability of healthy sperm But many cases of infertility arise from defects in the father's sperm. Often these can be

overcome by directly injecting a single sperm into the egg.

Ooplasmic Transfer

Infertility in some cases may stem from defects in the cytoplasm of the mother's egg. To circumvent these, cytoplasm can be removed from the egg of a young, healthy woman *(Donor egg)* and injected — along with a single sperm — into the prospective mother's egg. One reason for concern is that ooplasmic transfer results in an egg carrying both the mother's mitochondria and mitochondria from the donor. This condition — called *heteroplasmy* — creates a child having two different mitochondrial DNA genomes in all of its cells.

In normal fertilization, all the mitochondria in the father's sperm are destroyed in the egg, and perhaps this is important. Although a few healthy children have been born following o plasmic transfer, but the current.

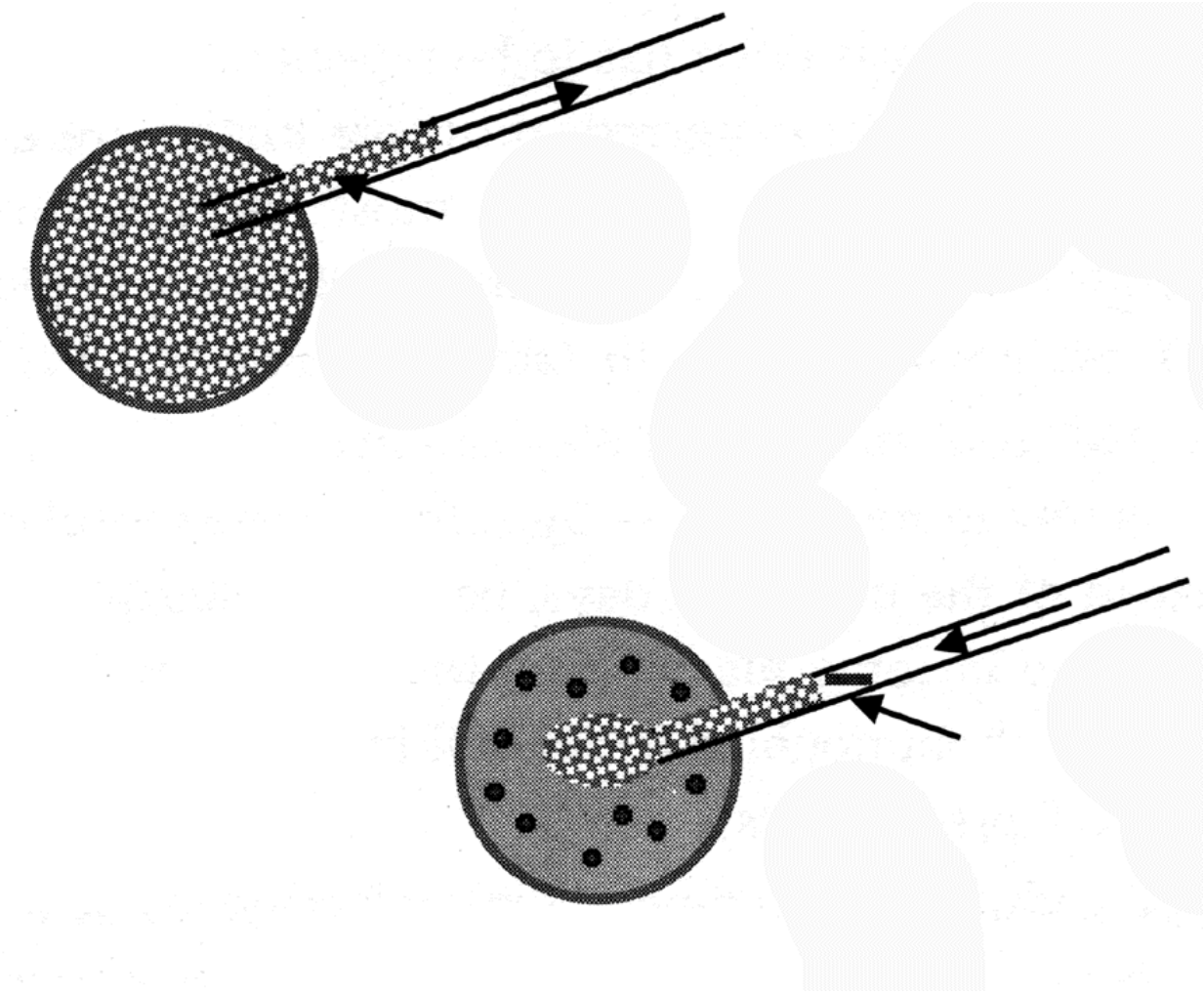


Figure 15.10: Ooplasmic transfer

The Upside of ART

(i) It has allowed hundreds of thousands of previouslyinfertile couples to have children.
(i) It permits screening (on one cell removed from the 8-celled morula) for the presence of genetic disorders — thus avoiding starting a pregnancy if a disorder is found. Link to a discussion.
(i) One can use frozen sperm allowing fatherhood for a man who is no longer able to provide fresh sperm.
(i) Because a number of morulas are created, the extras can be frozen, stored, and used later:
(a) If the initial attempt fails (the prospective mother must still receive hormones to prepare her uterus for implantation and the success rate is lower with thawed morulas).

(b) Where regulations permit, the extras can be used as a source of embryonic stem (ES) cells.

THE DOWNSIDE OF ART

Although improving, the success rate is still sufficiently low

(~30%) that the process often has to be repeated. Because several morulas are usually transferred, multiple births are common (about 40%), and as is the case with most multiple births, the babies weigh less. To reduce the number of twins, triplets, etc., more ART centers are turning to “single-embryo transfer” (SET).

Some ART centers find that they can increase the success rate — and thus rely more on SET — by culturing the morulas for 5-6 days, instead of the usual 2-3 days, before transferring them (by now they have become blastocysts) to the mother. The risk of birth defects is about doubled (from ~4% in “normal” pregnancies to ~8% in ART pregnancies).

ART procedures in experimental animals often result in a failure of correct gene imprinting. Whether this will pose a problem for humans remains to be seen.

BIRTH AND LACTATION

Exactly what brings about the onset of labor is still not completely understood. Probably a variety of integrated hormonal controls are at work. The first result of labor is the opening of the cervix. With continued powerful contractions, the amnion ruptures and the amniotic fluid (the waters) flows out through the vagina. The baby follows, and its umbilical cord can be cut.

The infant’s lungs expand, and it begins breathing. This requires a major switchover in the circulatory system. Blood flow through the umbilical cord, ductus arteriosus, and foramen ovale ceases, and the adult pattern of blood flow through the heart, aorta, and pulmonary arteries begins. In some infants, the switchover is incomplete, and blood flow through the pulmonary arteries is inadequate. Failure to synthesize enough nitric oxide (NO) is one cause.

Shortly after the baby, the placenta and the remains of the umbilical cord (the after birth) are expelled. At the time of birth, and for a few days after, the mother's breasts contain a fluid called *colostrum.* It is rich in calories and protein, including antibodies that provide passive immunity for the newborn infant. Three or four days after delivery, the breasts begin to secrete milk.

(i) Its synthesis is stimulated by the pituitary hormone prolactin (PRL).
(ii) Its release is stimulated by a rise in the level of oxytocin when the baby begins nursing.

(iii) Milk contains an inhibitory peptide. If the breasts are not fully emptied, the peptide accumulates and inhibits milk production. This autocrine action thus matches supply with demand.

Questions for study

1. Discuss the various parts of male reproductive system in male.

2. Discuss the various parts of female reproductive system in female.
3.Write short notes on the following:

(a) Mammary Glands
(b) Menstrual Cycle
(c) Pregnancy
(d) Birth and Lactation
(e) Assisted Reproductive Technology (ART).

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seminars/conferences/workshops at na onal and interna onal levels. He has wri en 04 books and 08 chapters with na onal & interna onal publishers of repute respec vely. He has delivered the keynote address and also invited talks and guest lectures at more than 10 conferences/seminars at na onal and interna onal levels. He is an examiner/paper se er (B. Pharmacy, M. Pharmacy & Ph.D. Programmes) for many reputed universi es. He is a life member of pharmaceu cal professional bodies of the Pharmacy Profession, like APTI & IPGA. Dr. Jangra also received many awards and recogni on from professional organiza ons.

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