People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
National Higher School of Agronomy
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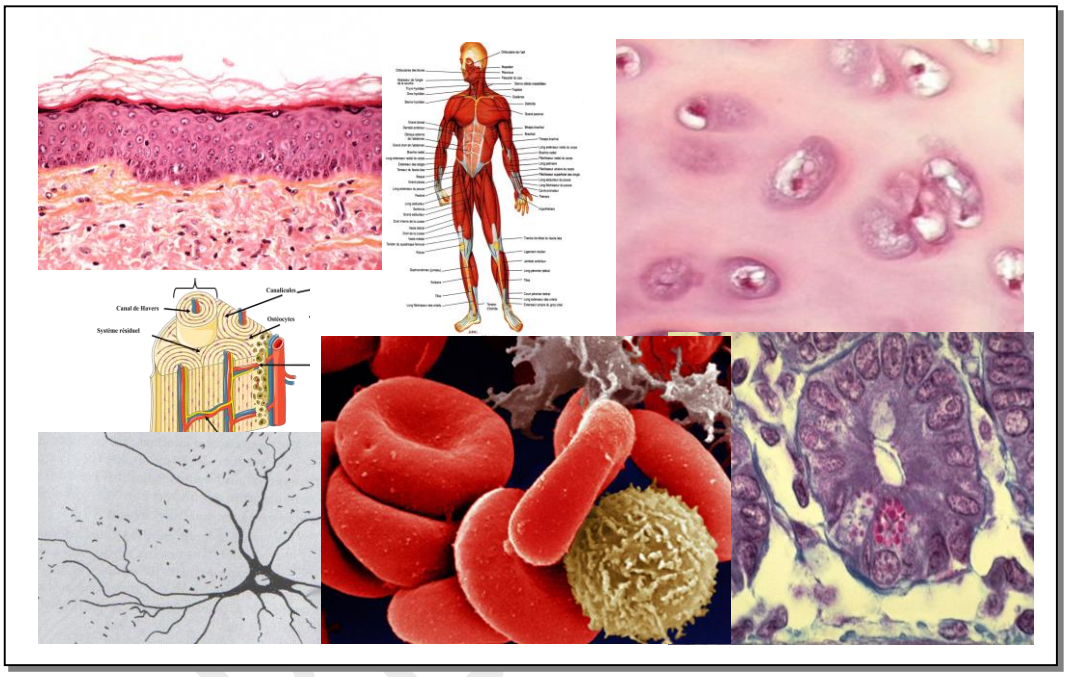

COURSE OF ANIMAL BIOLOGY

HISTOLOGY SECTION

FOR STUDENTS IN 1ST YEAR CP SNV

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Academic year 2023 – 2024

The present document is a complete English copy of the lecture handout for
the course Animal Biology – Histology section, originally published in French
at the central library of National Higher School of Agronomy ENSA.
The English translation was provided by Dr. Hassiba BERRAÏ, Lecturer at ENSA and
Pr. Ricardo Holgado, Lecturer at Norwegian Institute for Bioeconomic Research in Norway.

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PRÉFACE

This handbook is intended for first-year students in preparatory classes for Natural and Life Sciences and for anyone interested in general histology.

EDUCATIONAL OBJECTIVES

This educational material is designed to assist first-year students in preparatory classes for the Sciences of Nature and Life, as well as anyone interested in general histology.

AIMS

This pedagogical support is intended for first-year students who have followed a curriculum in the Arabic language. For them, note-taking may seem very difficult or even impossible. Indeed, a course taken by non-specialist students is ultimately a succession of errors that undermines its reliability. With this support, the pedagogical objectives are achieved: the student no longer struggles with how to write specific words or whether they have heard everything the instructor said. The student is less stressed and more able to understand, learn, and analyze the knowledge being imparted. Furthermore, this handout is a tool placed in the hands of the student, who must complement it with their note-taking. It represents a minimum amount of knowledge that a student must have in Histology to subsequently understand animal physiology, pathological anatomy, pathology, etc.

Histology courses often refer to physiological concepts, as the morphological structure of a given tissue is deduced from its physiological functions. Therefore, practical work is essential for students to supplement their morphological knowledge. Ultimately, personal understanding is achieved through microscope work.

Total time allocation: lectures: 22 hours and 30 minutes , practical work: 15 hours ,tutorials: 22 hours and 30 minutes ,other: 22 hours and 30 minutes

PRACTICAL WORK AND TUTORIALS

Five practical work sessions are scheduled to refine the knowledge acquired in class. Each session lasts for 3 hours.

Additionally, four tutorial sessions complement the course and practical work program. These sessions address points that have not been covered during the previous activities. Each tutorial session lasts for 1 hour and 30 minutes.

EVALUATION

Two mid-term exams are scheduled for the course and tutorial part. Continuous assessment is carried out in practical work through manipulation tests and/or reports.

Other activities are undertaken by the modular team teachers with the first-year students of CP SNV. Indeed, in parallel with the course, practical work, and tutorials, personal work is required from the students. This aims to develop a spirit of research in them, as well as teamwork. Finally, through this work, the teacher accompanies and guides the student, serving more as a mentor than an instructor.

I. Epithelial tissues

I.1. Definition

The epithelium is a predominantly cellular tissue, composed of closely packed and adjacent cells that play a protective role by covering the organism (e.g., skin) or lining cavities and ducts (as seen in lining epithelia), as well as an excretory role by secreting substances (as seen in glandular epithelia). Epithelia rest on a basement membrane that separates them from the underlying connective tissue. There is minimal free intercellular substance between epithelial cells (unlike connective tissue). Most of them undergo continuous renewal through mitosis. They are avascular and innervated.

I.2. Main characteristics of epithelia

The main characteristics of epithelia include polarity, epithelial morphology, the presence of cytokeratin intermediate filaments, and cohesion.

I.2.1. Polarity

Epithelial cells exhibit a highly asymmetric distribution of components within their cytoplasm. The term basal pole refers to the portion of cytoplasm located near the basement membrane, while the apical pole designates the 'top' of the cytoplasm. Epithelial cells also display an asymmetric distribution of components in their plasma membrane, distinguishing the basolateral domain from the apical domain.

I.2.2. Epithelial morphology

Due to strong cell-cell and cell-basement membrane interactions, epithelial cells always adopt a cuboidal or columnar shape, more or less flattened (not round like blood cells, star-shaped like astrocytes and neurons, or spindle-shaped like muscle cells).

I.2.3. Presence of cytokeratin intermediate filaments

Cytokeratins constitute a family of 20 proteins that are specific to epithelial cells.

I.2.4. Cohesion

The cohesion of epithelial cells is ensured by a set of junction systems (adhesion molecules and junctional complexes) that form between epithelial cells and between epithelial cells and the basement membrane (Fig. 1).

I.2.4.1. Adhesion molecules

Cadherins, selectins, immunoglobulins, and integrins.

I.2.4.2. Junctional systems

a. Cell-cell intercellular junction systems

- Tight junctions or zonula occludens;
- Anchoring junctions including adherens junctions or zonula adherens and desmosomes;
- Communicating junctions or gap junctions.

b. **Junction systems between cell and basement membrane**

- Hemidesmosomes
- Focal adhesions or focal contacts

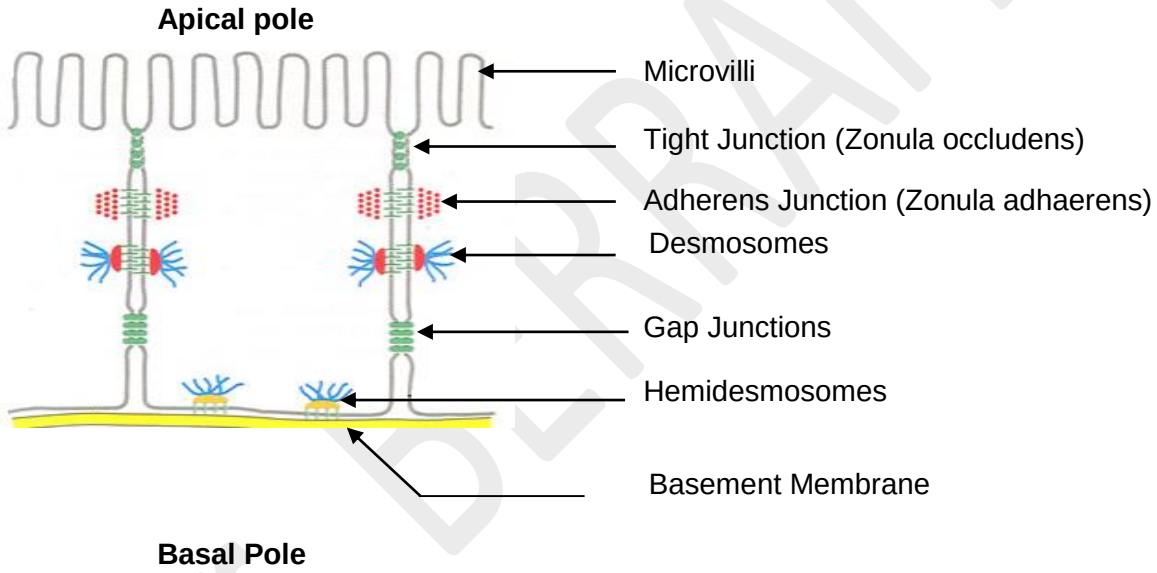


Figure 1. Diagram of the junctional system present in an epithelium

From an anatomo-physiological perspective, there are two types of epithelia: covering epithelium and glandular epithelium.

I.3. Covering epithelium

I.3.1. Classification criteria

Covering epithelia are classified based on: the shape of cells, the number of cellular layers, the nature of apical specializations of epithelial cells, and the presence of specific cell types.

I.3.1.1. Cell shape

Epithelial cells can be squamous (wider than tall), columnar or prismatic (taller than wide), or cuboidal (as wide as they are tall) (Fig. 2).

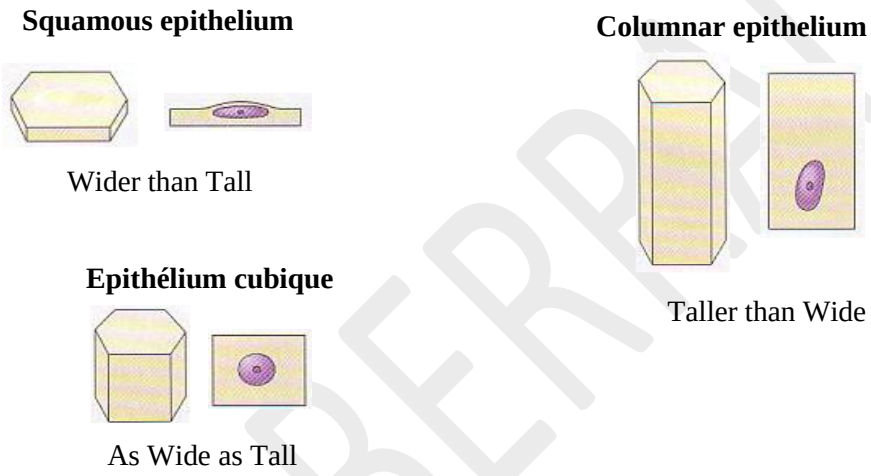


Figure 2. Epithelial cell shapes

I.3.1.2. Number of cellular layers

Covering epithelium is either composed of a single layer of epithelial cells, making it a simple epithelium. When it consists of two or more cellular layers, it becomes stratified or multistratified. Pseudostratified epithelium is an epithelium where all epithelial cells are anchored to the basement membrane, but some of them do not reach the apical pole. There is another type of specific covering epithelium, called transitional epithelium, as seen in the bladder. This epithelium is sometimes simple (when the bladder is full) and sometimes pseudostratified when it is empty (Fig. 3).

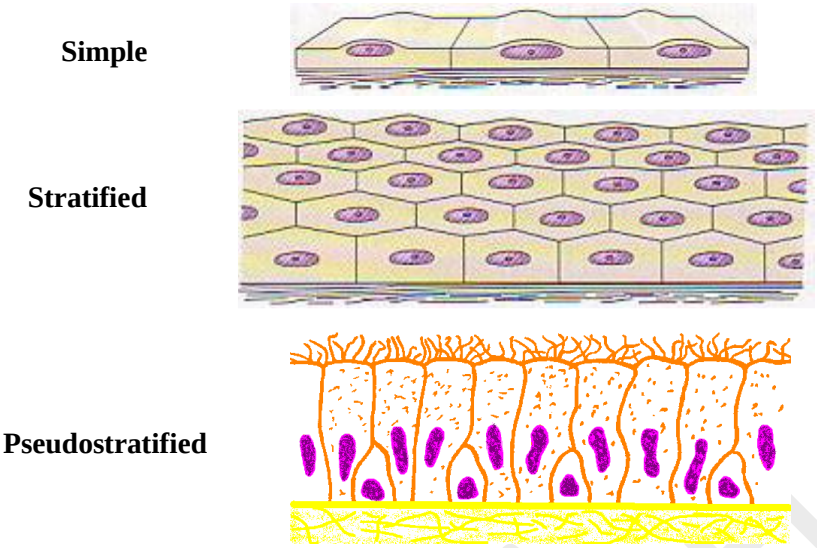


Figure 3. Number of cellular layers

I.3.1.3. Nature of apical specializations of epithelial cells

Epithelial cells may exhibit different features at the apical pole, referred to as apical specialization. If there are modifications at the plasma membrane of the apical pole, they are termed microvilli. Microvilli come in three forms. If the plasma membrane of the apical pole invaginates and evaginates uniformly (regular height), it is called a striated border. If the invagination and evagination of the plasma membrane occur unevenly (irregular height), it is referred to as a brush border. Finally, if the plasma membrane invaginates and evaginates, occasionally cutting or forming branches, they are known as stereocilia (Fig. 4). The plasma membrane of the apical pole may remain unaltered but instead has cilia inserted into it (Fig.4).

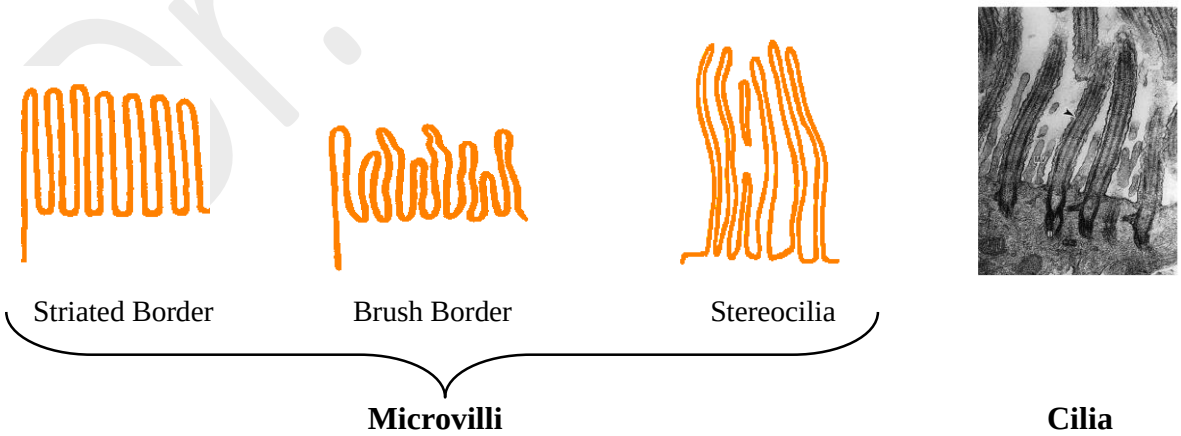


Figure 4. Nature of apical specialization

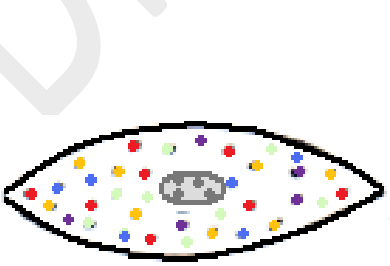
Thus, the name of the epithelium changes according to the type of apical specialization :

- Presence of a striated border at the apical pole of epithelial cells, it is called Striated Border Epithelium.
- Presence of a brush border at the apical pole of epithelial cells, it is called Brush Border Epithelium.
- Presence of stereocilia at the apical pole of epithelial cells, it is called Stereociliated Epithelium.
- Presence of cilia at the apical pole of epithelial cells, it is called Ciliated Epithelium.

I.3.1.4. Presence of specific cell types

Apart from epithelial cells, covering epithelium may contain particular cells within its cellular component, giving it a specific name. For example, keratinocytes, which make up 80% of the epidermal cell population, giving the name to the epidermis - Keratinized Epithelium. Their role is to protect the body against mechanical aggression (Fig. 5a). Although other specific cells exist in the epidermis, they do not contribute to its naming because they are present in low percentages, such as Merkel cells (0.5 to 5%), melanocytes (1%), and Langerhans cells (2 to 4%).

Caliciform cells are also specific cells, and they give the name to the epithelium where they are found (Fig. 5b). It is then called Epithelium with Caliciform Cells. They have a calyx shape, hence their name, and are considered the only unicellular exocrine gland. Indeed, caliciform cells secrete mucus that helps hydrate cilia, as seen in the epithelium of the trachea. They can also secrete mucus to protect the covering epithelium against the acidity of the environment, as observed in the epithelium of the stomach.

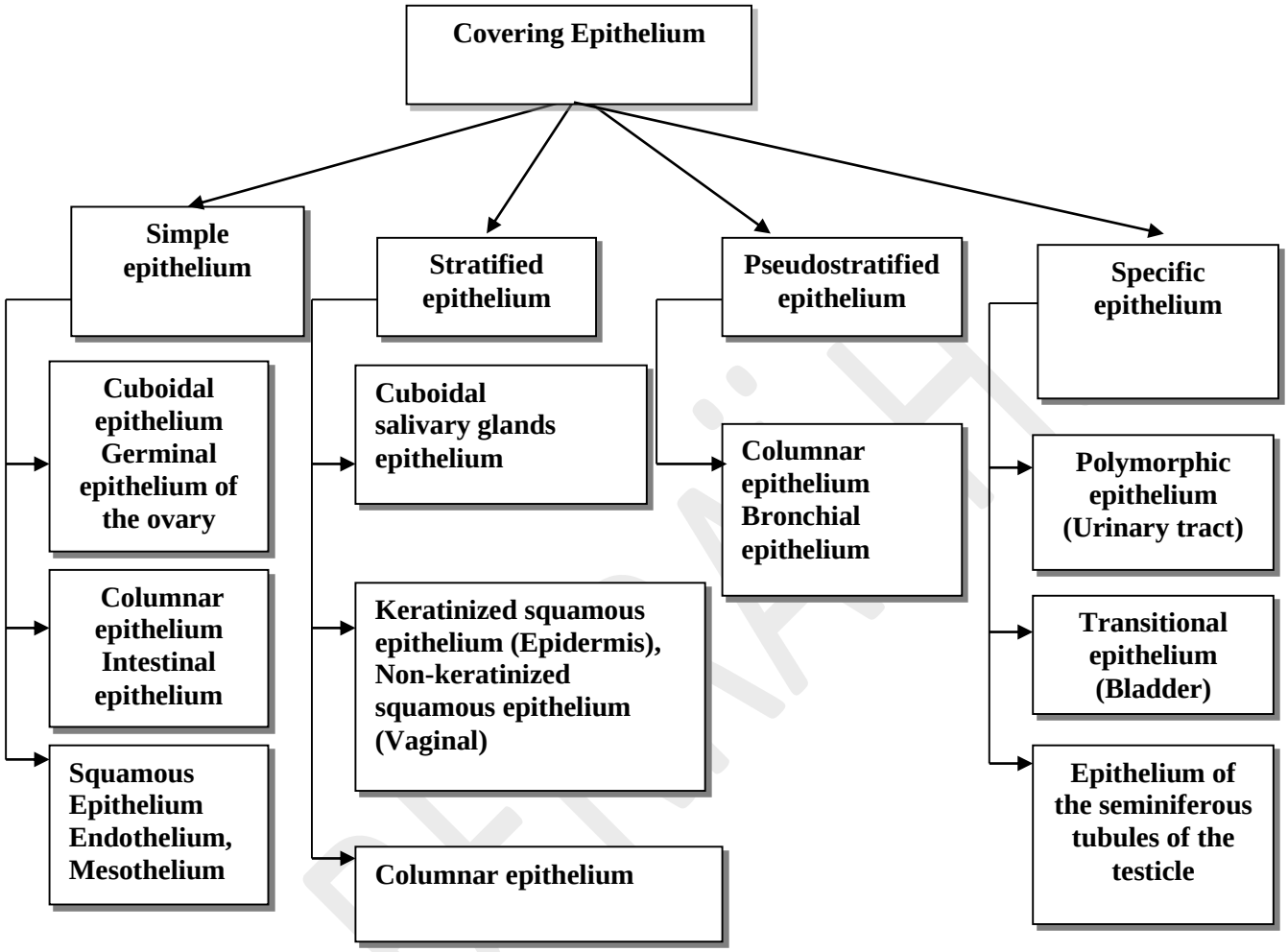


Keratinocyte

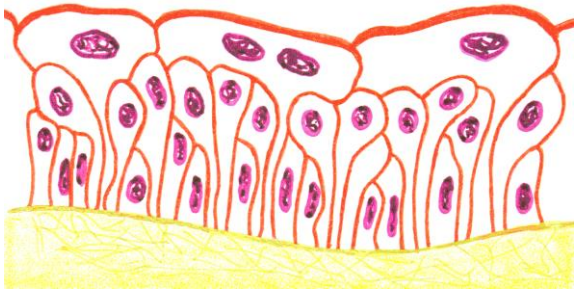
Caliciform Cell

Figure 5. Specialized cells

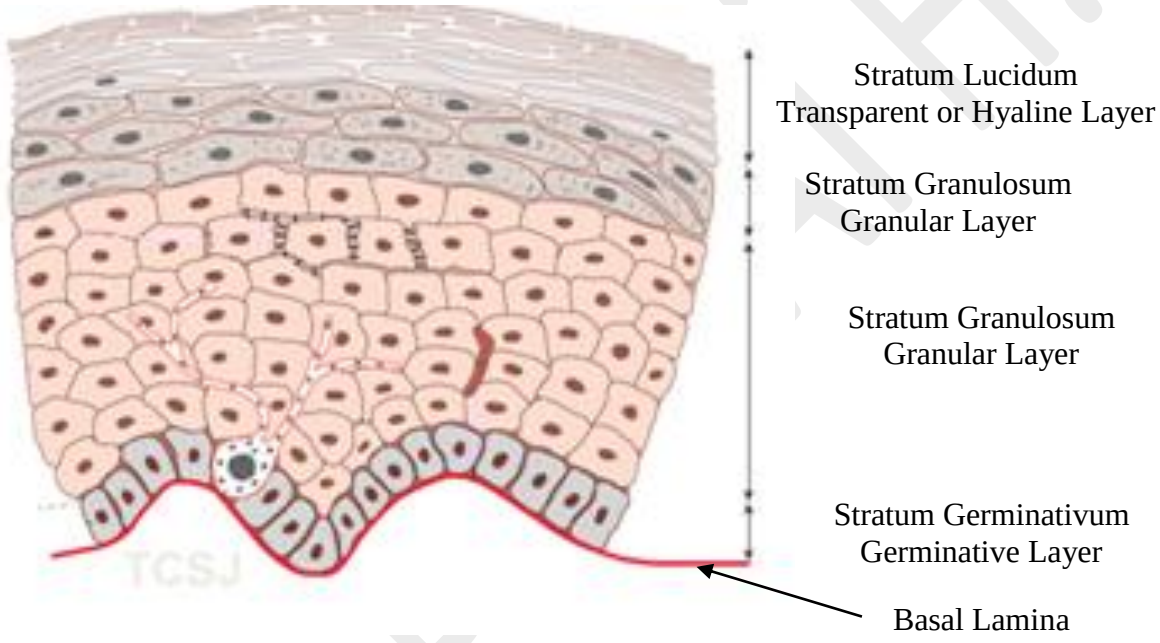
I.3.2. Examples of covering epithelia



Epithelium of the trachea: Pseudostratified Columnar Ciliated Epithelium with Caliciform Cells at the open mucous pole



Epithelium of the bladder: Pseudostratified Transitional Epithelium



Epidermis: Stratified squamous keratinized covering epithelium

I.4. Glandular epithelia

I.4.1. Gland histogenesis

Glandular epithelia differentiate by budding from a maternal covering epithelium. The epithelial bud proliferates and extends into the underlying mesenchyme. It will form an exocrine gland if it remains connected to the original epithelium. If it loses all contact with this epithelium, it will form an endocrine gland (Fig. 6).

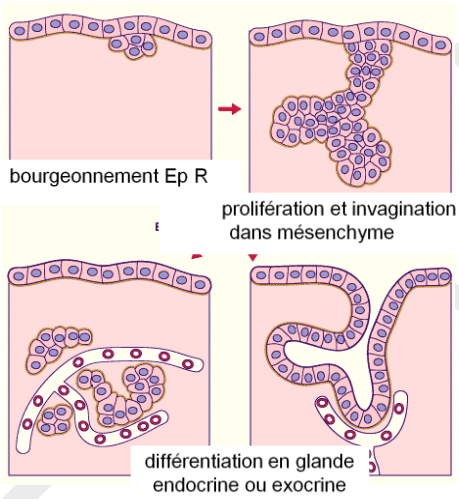


Figure 6. Gland histogenesis

I.4.2. Different types of glands

Glands

Endocrine glands	Exocrine glands	Amphicrine glands
- Pituitary gland (TSH, FSH...) - Thyroid gland: Growth hormones (T3, T4) and Calcitonin	- Salivary glands: Saliva - Sebaceous glands: Sebum - Sweat glands: Sweat - Mammary glands: Milk - Lacrimal glands: Tears	1. Homotypic amphicrine gland (same type of cells secrete and excrete): Liver 2. Heterotypic amphicrine gland (endocrine part different from exocrine part): Pancreas

I.4.2.1. Endocrine glands

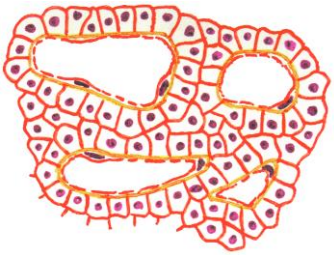
These are glands that secrete their products into the bloodstream.

I.4.2.1.1. Classification of endocrine glands

Endocrine glands are classified based on 2 criteria: the nature of the secreted hormones and the morphology or shape of the gland.

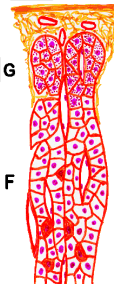
a. The nature of the secreted hormone s: The hormones secreted are either of a polypeptidic nature, for example glands: the pituitary gland, the thyroid gland and the parathyroid, or of a steroid nature, such as glands, the Leydig cells.

b. Morphology or form of the gland : The endocrine glands are presented in three different forms, the diffuse form, the vesicular or vesiculated or follicular form, and the reticulated form, which is subdivided into two types, oriented reticular and non-oriented reticulated (Fig.7).



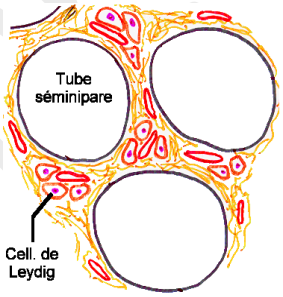
Non-oriented reticular

(Parathyroid)



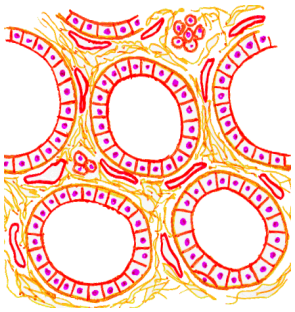
Oriented Reticular

(G. Adrenal)



Diffuse

(Leydig cells)



Vesicular or follicular

(Thyroid)

Figure 7. Morphology of endocrine glands

I.4.2.1.2. Example of endocrine glands: Thyroid

The thyroid is an endocrine gland that is located at the front of the neck (Fig. 8). It consists of thyroid cells that secret growth hormones T3 and T4 (responsible for the growth and differentiation of cells and tissues in the body). These cells are arranged in a vesicle around a colloid (a substance composed of iodized thyroglobulin molecules). The gland thus stores the iodine absorbed after digestion, which is why the thyroid is regarded as a jodium trap. It also has C cells that secret calcitonin. (responsible for decreasing the level of calcium in the blood

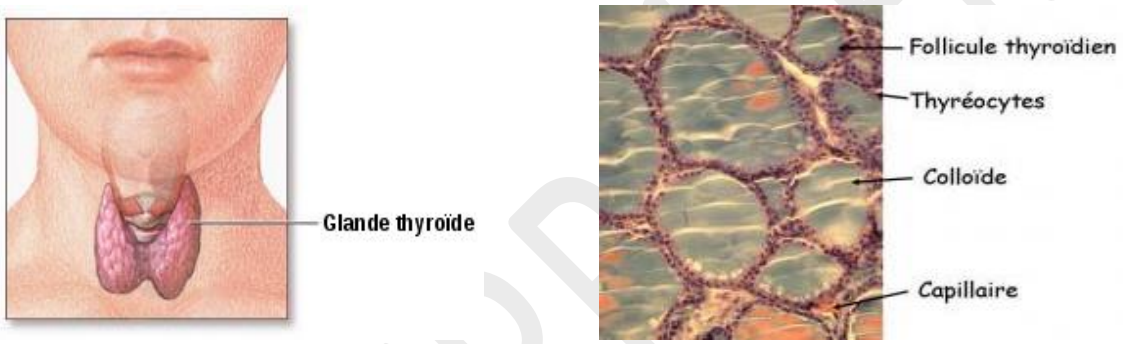


Figure 8. Thyroid

I.4.2.2. Exocrine glands

These are glands that secret their products in an external medium and not in the blood (in an excretory canal)(Fig. 9). They are composed by :

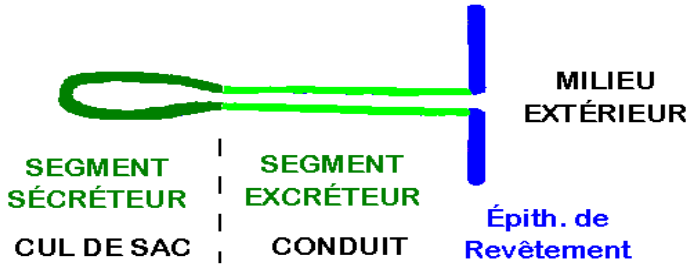
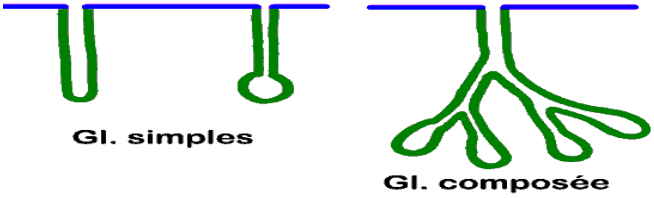


Figure 9. Formation of an exocrine gland

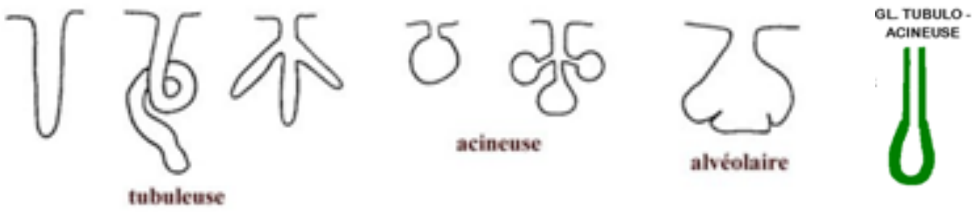
I.4.2.2.1. Classification of exocrine glands

Exocrine glands are multicellular except for the caliciform cell, which is a unicellular. Exocrine glands are classified according to 4 criteria: The shape of the excretory canal, the shapes of the bag ass, the nature of the secreted product, and the mode of secretion.

a. Shape of the excretory canal



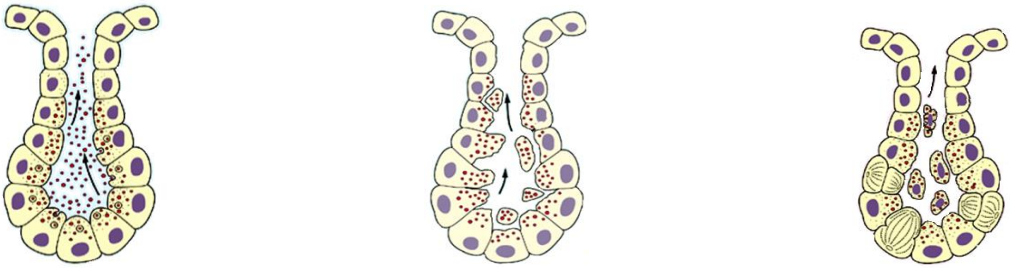
b. Shape of the secretory part or bag ass



c. Nature of the excreted product

Mucous product **Serous product** **Sero-mucous product**

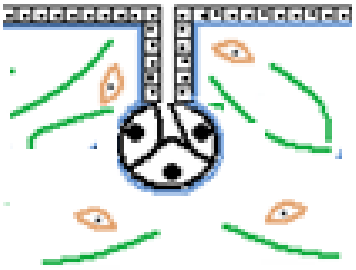
d. Secretion mode



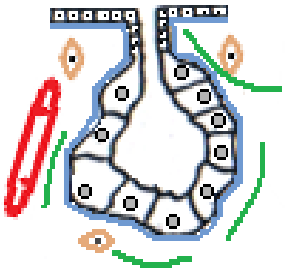
Merocrine Mode (exocytose) **Apocrine Mode** **Holocrine Mode**

I.4.2.2.2. Examples of exocrine glands

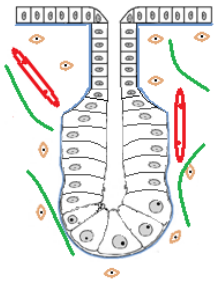
Unicellular gland (Caliciform cell)



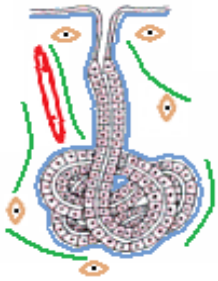
Simple G. acineous



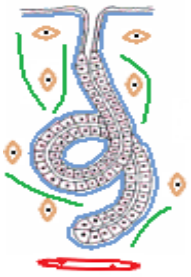
Simple G. alveolar



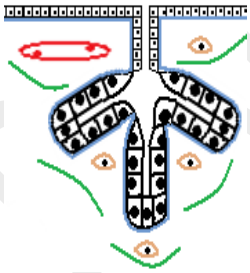
Simple G. tubular



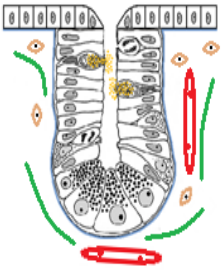
Simple G. tubular coiled



Simple G. tubular convoluted

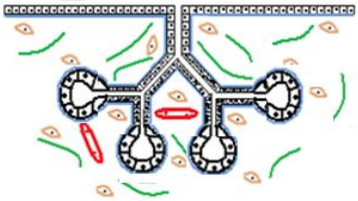


Simple G. tubular branched

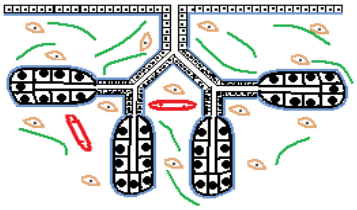


Glande without excretory canal

Compound acinar gland

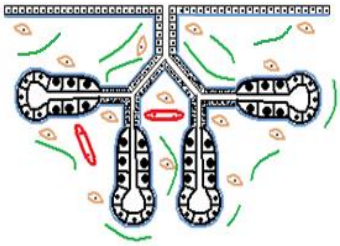


Compound alveolar gland



Compound tubular gland

Compound tubulo-acinar gland



Compound tubulo-alveolar gland

I.4.2.3. Amphicrine glands

An amphicrine gland is a gland that has both exocrine functions (secreting substances in dedicated channels) and endocrine (section of substances into the blood).

When the same cells have these two functions, the gland is called the homotypic amphicrine, which is the case f or hepatocytes in the liver.

When it is different types of cells that each have one of these two functions, the gland is called heterotypic amphicrine: this is the case of the pancreas, where the cells of the Langerhans islands are endocrine, while the acineous cells are exocrine.

II. Conjunctive tissue

II.1. Definition

These are tissues whose cells are separated by the Extra Cellular Matrix 'MEC' (Fibers + Fundamental Substance), unlike the epitheliums where the cells is joint and juxtaposed. These tissues constitute the majority of the body mass of animals (2/3 of the total volume in humans)

II.2. Characteristics

The connective tissues have no contact with the environment, are innervated and irrigated.

II.3. Constitutes of connective tissue

All connective tissues have a common histological structure, with three fundamental elements: the basic substance, fibers and cells (Fig. 10).

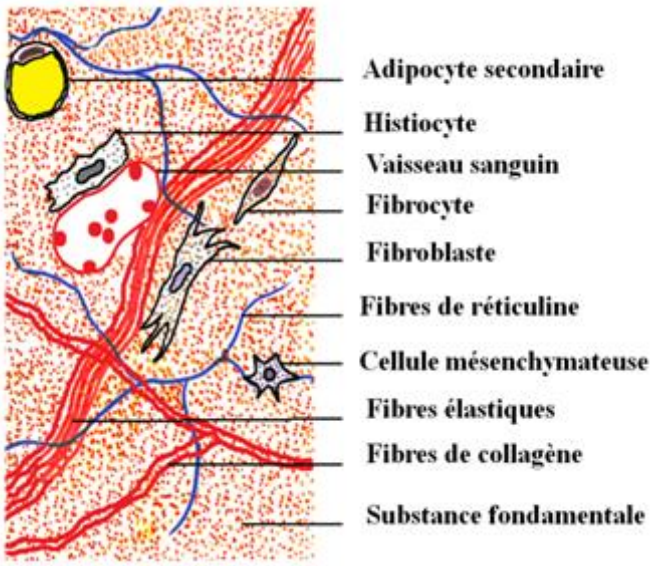


Figure 10. Constituents of connective tissue

II.3.1. Basic substance

It is an amorphous jelly that allows the diffusion of oxygen and dissolved molecules in water.

II.3.2. Fibers

There are three varieties :

- Collagen fibers (1 to 12 micrometers) are the most common. They are long and curved, solid, and flexible, providing high strength without elasticity (found in tendons and ligaments).
- Elastic fibers (0.2 to 1 micrometer) offer high expansion and contraction capacity with high resistance in one direction. They contain elastin and are found in arteries, vocal cords, trachea, respiratory tract, and elastic ligaments.
- Reticulin fibers (0.2 to 2 micrometers) can bifurcate and anastomose. They are dense, unextensible, flexible, and offer high resistance in several directions. They form layers around organs.

II.3.3. Cells

They are either resident or migrant.

a. Resident or fixed cells

Mesenchymal cells or stem cells (1) differentiate into various types of support cells, including fibroblasts, adipocytes, chondroblasts, and osteoblasts. Fibroblasts (2) are active young cells that synthesize all three types of fibers and some components of the extracellular matrix. Fibrocytes (3), adipocytes (4, 5), and histiocytes (quiescent macrophages) (6) are also present (Fig. 11).

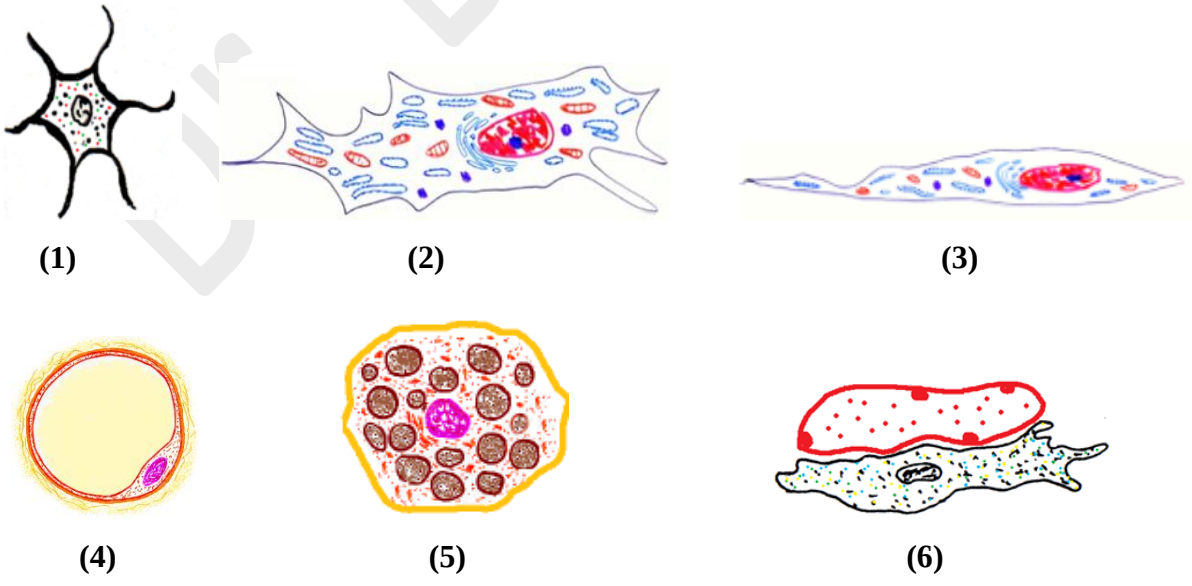
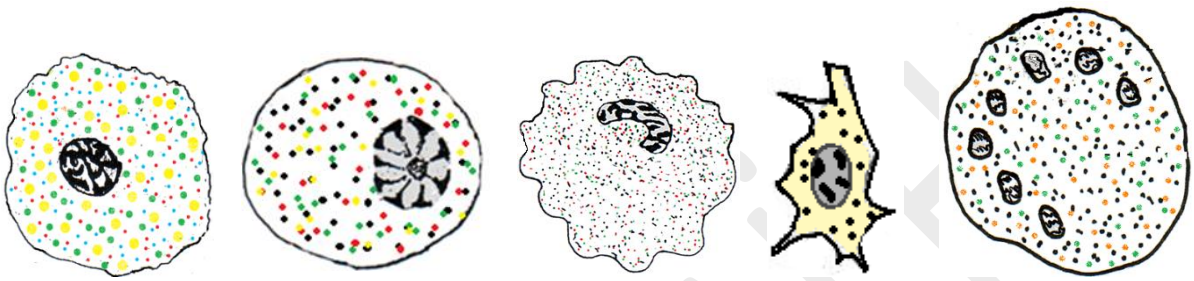


Figure 11. Resident connective tissue cells

b. Migrant or mobile cells

Mastocytes (1) secrete heparin (blood coagulation), histamine (substance that dilates small blood vessels during inflammation) and hyaluronic acid (SF metabolism), plasmocytes (2) derive from lymphocytes and synthesize antibodies, macrophages (3), reticulosis (4) (in hematopoietic and lymphatic organs), giant irritation cells (5) in chronic infections, and blood leukocyte (Fig. 12).



(1) **(2)** **(3)** **(4)** **(5)**

Figure 12. Mobile connective tissue cells

II.4. Varieties of connective tissue

There are two main types of connective tissue: proper connectivity tissue (embryonic, loose, fibrous, cellular) and specialized connectives. (sang et lymphe, cartilage, os).

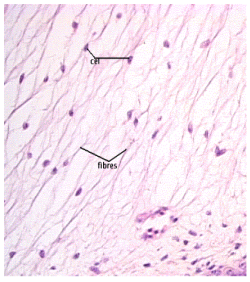
II.4.1. Proper connective tissue

The connective tissue itself is classified according to its proportion of cells, fibers or basic substance. If:

C = F = SF : Loose Connective Tissue,
C >>> : Adipose Connective Tissue,
F >>> : Fibrous Connective Tissue,
SF >>> : Embryonic Connective Tissue or Mucoid or Wharton's Jelly.

II.4.1.1. Mucous connective tissue (mucoid) (Wharton jelly)

It is found mainly in the umbilical cord. The basic substance is gelatinate and the fibers are collagen fiber

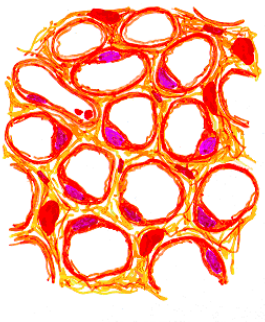


II.4.1.2. Loose connective tissue

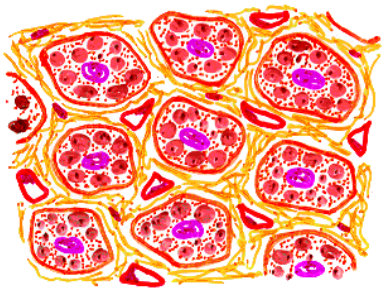
The most widespread in the body. It is composed of fibers (collagen, elastic) as well as fibroblast cells buried in a semi-liquid (balancing) basic substance. It is found in the dermis of the skin, the chorion of the respiratory, genital and urinary tract, chorion and under mucous membranes of the digestive tract, blood vessels, nerves and it fills the spaces between organs. It serves as a support for vascularization, ensures the passage of many substances between the blood and tissues and is the seat of the defence reactions of the body.

II.4.1.3. Cellular or adipose connective tissue

It is rich in cells (adipous) or adipocytes. It contains many blood capillaries and fat cells embedded in a thin network of reticulin fibers. There are two types of fat, white or secondary (white fat) and brown or primary fat. (graisse brune). It has a wide distribution in the body (skin hypoderma, mesenteric. It predominates on the neck and shoulders in men and on the chest, hips, thighs and buttocks in women. It ensures the synthesis and storage of lipids in the form of triglycerides. It is a good thermal and mechanical insulator and represents one of the most important energy reserves of the body (fasting, physical effort, fighting the cold...).



Secondary fatty tissue
(White fat)

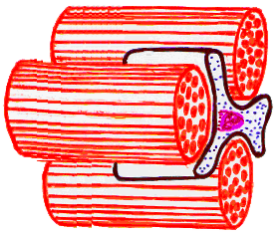


Primary fatty tissue
(Brown fat)

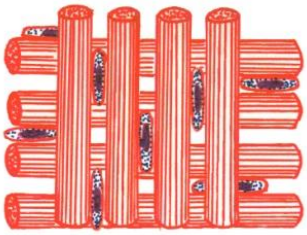
II.4.1.4. Fibrous connective tissue

It is rich in fiber, poor in cells and basic substance. It has 3 varieties depending on the nature of the fibers that make up it: dense fibre conjunctive tissue, elastic fiber conjunction tissue and reticulated fibre connectivity tissue.

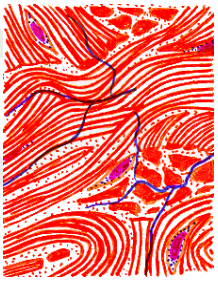
a. T.C. Fibrous dense : F. collagen is predominant [Non-Oriented (Dermal), Oriented (ligament, tendons)]. It gives strength, mainly in mechanical functions.



Oriented unidirectional fibrous



Bidirectionally oriented fibrous connective tissue



Non-oriented fibrous connective tissue

b. T.C. Elastic fibers: Elastical fibers are predominant. Elastic ligaments maintain a state of tension when stretched. They provide a traction force, but return to their primary state when the tension ceases (large-caliber artery and intervertebral yellow ligaments, conjunctive axis of vocal strings, bovine nucal ligament).

c. Reticular connective tissue: Predominantly composed of reticular fibers, forming a supportive network. Phagocytic reticular cells play a crucial role in the body's defense against bacteria (found in lymph nodes, spleen, liver, kidney, and bone marrow).

II.4.2. Specialized connective tissues

Blood tissue as well as skeletal tissues are considered specialized connective tissues. Indeed, they specialize in the roles they play, with blood involved in nutrition and skeletal tissues in structure and support. These tissues are classified based on the state of the extracellular matrix (ECM). It is liquid in blood tissue, solid in cartilage, and solid and mineralized in bone.

II.4.2.1. Blood tissue

Blood is a liquid that transports oxygen, nutrients (sugar, minerals, vitamins, etc.), and hormones essential for the life of our cells. In return, it removes waste to elimination organs, such as the kidneys or lungs (for carbon dioxide). Blood also plays a central role in the body's defense against pathogens (bacteria, viruses). In case of injury, it also ensures the repair of its vessels through the coagulation process. Blood carries chemical messengers - hormones - essential for the regulation and proper functioning of the body. It contributes to maintaining body temperature and regulating heat throughout the body.

II.4.2.1.1. Composition of blood

Although liquid, blood is a highly organized tissue. It consists of a saline fluid, plasma, in which circulate formed elements: red blood cells, white blood cells, and platelets (Fig. 12).

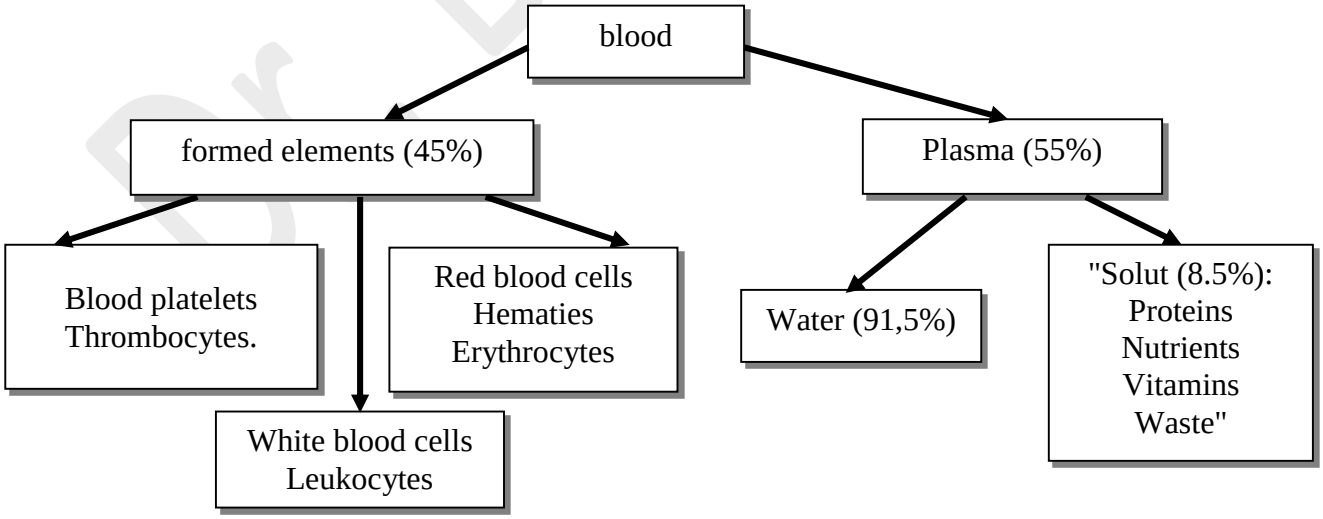


Figure 12. Blood composition

a. Plasma

Plasma constitutes 55% of the total blood volume. Composed of 90% water, salts, lipids, and hormones, plasma is primarily a protein-rich liquid. It contains albumin as its main protein, immunoglobulins, as well as coagulation factors and fibrinogen. Plasma serves several functions: transporting blood cells and nutrients, regulating the body's water and mineral balance, irrigating tissues, defending against infections, and blood coagulation.

b. Formed elements of blood

Red blood cells, white blood cells, and platelets are suspended in the plasma (Fig. 13).

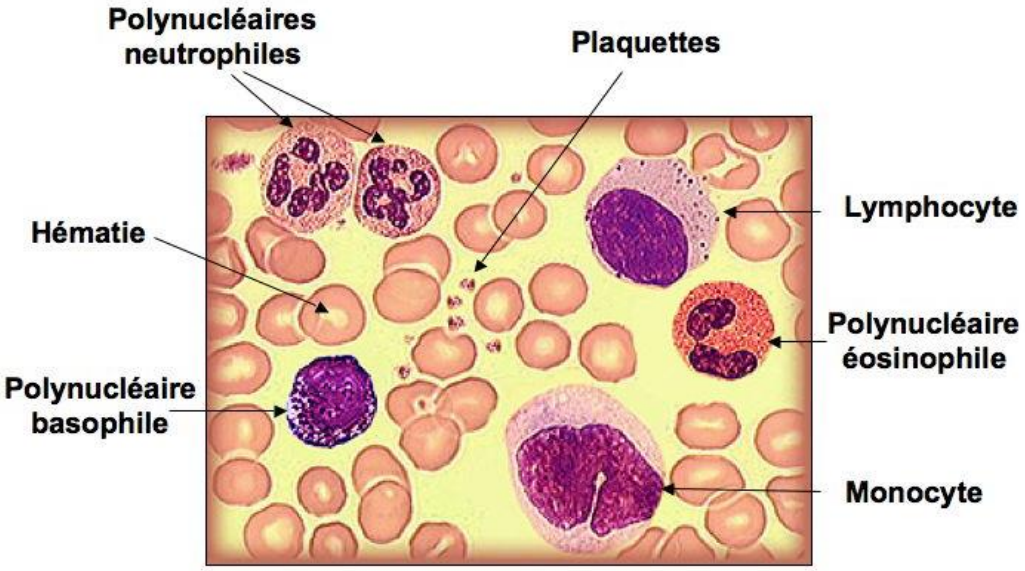


Figure 13. Blood smear

1) Red blood cells, erythrocytes, or red blood cells

Lifespan: 120 days.

Diameter: 7 micrometers.

No nucleus or cellular organelles.

Quantity: 5 million/mm3.

Origin: Bone marrow.

Role: Supply cells with O2 and eliminate produced CO2.

Note: Red blood cells (RBCs) in fish, birds, reptiles, and amphibians have a nucleus, while mammalian RBCs (erythrocytes) do not (Fig. 14).

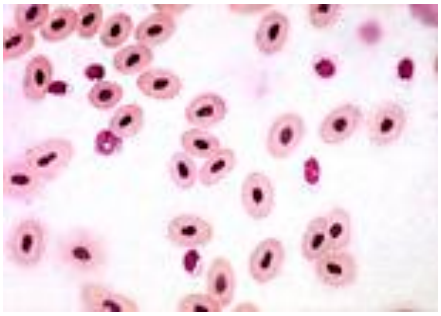


Figure 14. Blood smear of a bird

2) Blood platelets or thrombocytes

Lifespan: 8 to 10 days.

Quantity: 250,000 to 300,000/mm3.

No nucleus but numerous enzymes.

Origin: Fragmentation of large blood cells called megakaryocytes.

Role: Blood coagulation and initiation of wound healing. Platelets secrete enzymes that transform a soluble plasma protein, fibrinogen, into an insoluble protein, fibrin, forming a clot that traps red and white blood cells.

3) White blood cells or leukocytes

Lifespan: A few weeks.

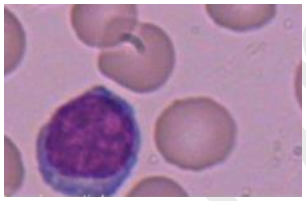
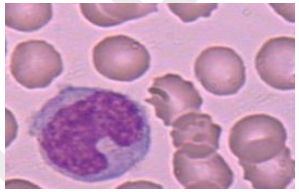
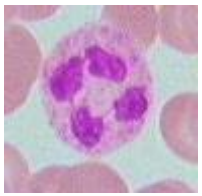
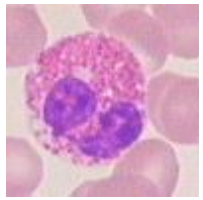
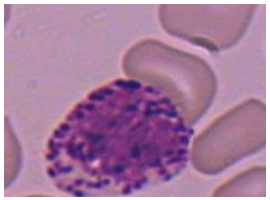
Quantity: 6,000 to 8,000/mm3 (1 white blood cell for 7,000 red blood cells).

Origin: Bone marrow and lymph nodes.

Role in immune protection.

White blood cells are subdivided into 2 major groups: Agranulocytes (without granules) or mononuclear (single nucleus) and granulocytes or polymorphonuclear (multiple nuclei, although it's technically a single lobed nucleus giving the impression of multiple nuclei) (Table 1).

Table 1. Differentiation criteria between the five categories of white blood cells

	Agranulocytes = Mononuclear cells		**Agranulocytes = Mononuclear cells**		
Criterion	**Lymphocyte**	**Monocyte**	**Neutrophile**	**Eosinophile**	**Basophile**
Percentage of presence = likelihood of encounter	**25% of leukocytes**	**10 % of Leucocytes**	**65% of Leucocytes** Most frequently encountered	**2 à 4 % of Leucocytes**	**0,5 à 1% of Leucocytes**
Function	Specific Immunity (Antibodies)	Phagocytosis	Antibacterial defense	Antiparasitic defense,	**Responsible for allergic and inflammatory responses**
White Blood Cell Size	7-16 µm	15-30 µm, the largest white blood cell	10 à 15 µm	12-14µ	11-13 µ
			Size is not a differentiation criterion for polymorphonuclear cells.		
Nuclear Shape	Circular, occupying almost the entire cell	Single irregular lobe, bears a notch. Can have a kidney, horseshoe, or bean-shaped appearance.	Polylobed 3-5 (most lobed)	2-3 lobes (often bilobed)	Relatively large and few lobes
Granulation	-	-	Neutrophils with regular, fine, and numerous violet granules	Acidophilic granules, pink, round, numerous	Very numerous granules, may cover the nucleus, dark blue-violet
	Granulation is not a differentiation criterion for mononuclear cells.				
Appearance of the leukocyte under an optical microscope					

II.4.2.1.2. Different blood groups according to the ABO system and the Rh system

Red blood cells have receptors for O2 and CO2 on their surface, as well as antigens belonging to the ABO and Rh blood group systems (Fig. 15). These antigens determine the blood group (Table 2). The presence of the Rh factor indicates a positive Rh group (Rh+), while its absence indicates a negative Rh group (Rh-).

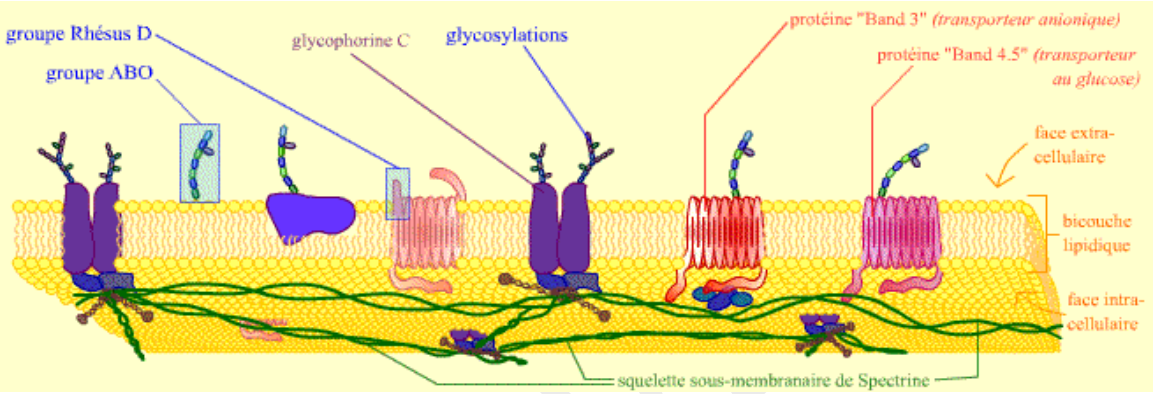
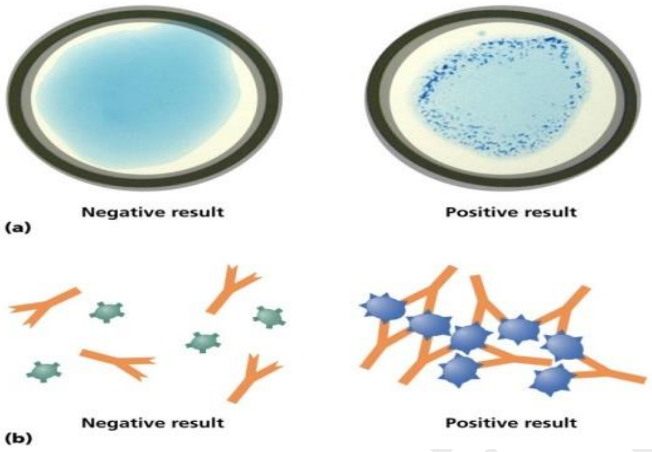


Figure 15. Presence of antigens on the surface of red blood cells

	Groupe A	Groupe B	Groupe AB	Groupe O
Globule Rouge	A	B	AB	O
Anticorps	Anti-B	Anti-A	Aucun	Anti-A et Anti-B
Antigène	Antigène A	Antigène B	Antigène A et B	Pas d'antigène

Table 2. Distribution of antigens and antibodies according to blood groups (ABO system)

During a blood transfusion, the donor's blood must be compatible with that of the recipient to avoid agglutination and, consequently, the death of the recipient (Fig. 16).



No Agglutination **Agglutination**

Figure 16. Agglutination phenomenon

When transfusing, apart from isogroup transfusions, the basic rule is always observed first: never inject red blood cells that will be destroyed by the natural antibodies present in the recipient's blood. In case of blood group incompatibility, severe hemolytic reactions occur:

- Toxic effects on the recipient's body, manifesting as chills, fever, chest pain, and sometimes fatal kidney dysfunction.

Group O is a universal donor. Group O Rh- is the true universal donor.

Group AB is a universal recipient. Group AB Rh+ is the true universal recipient (Fig. 17).

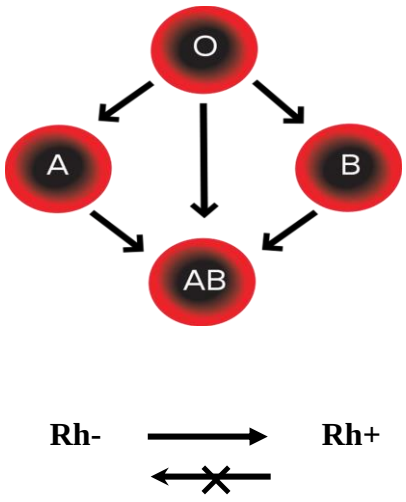


Figure 17. Blood group compatibility

II.4.2.2. Skeletal tissues

Cartilage and bone are two types of specialized connective tissues that form the skeletal framework of most vertebrates. In lower vertebrates, the permanent skeleton is composed of cartilage. In humans, most of the embryonic skeleton is initially cartilaginous, and it is later replaced by bone, but certain cartilages persist on certain surfaces.

II.4.2.2.1. Cartilaginous tissue

Cartilage is not vascularized; it is nourished by diffusion, and the extracellular matrix (ECM) is rigid and non-mineralized.

a. Role

It provides support, absorbs shocks, reduces friction, and ensures great flexibility and deformation capacity for organs.

b. Constituents

Cartilage consists of chondroblasts, chondrocytes enclosed in a chondroplast, and a rigid and non-mineralized ECM (Fig. 18). The perichondrium surrounds the cartilage except for articular cartilage and fibrous cartilage. It consists of two layers and blood vessels (external layer with regular fusiform cells and an internal chondrogenic layer where cells differentiate into chondroblasts) (Fig. 19). Thus, the volume of the cartilage increases (Fig. 20).

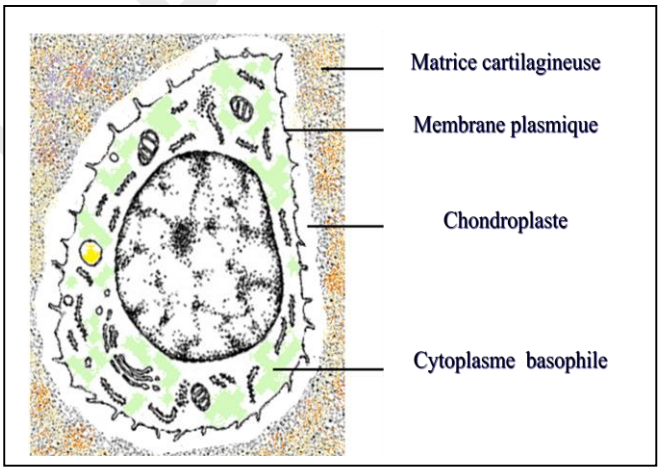


Figure 18. Ultrastructure of a chondrocyte

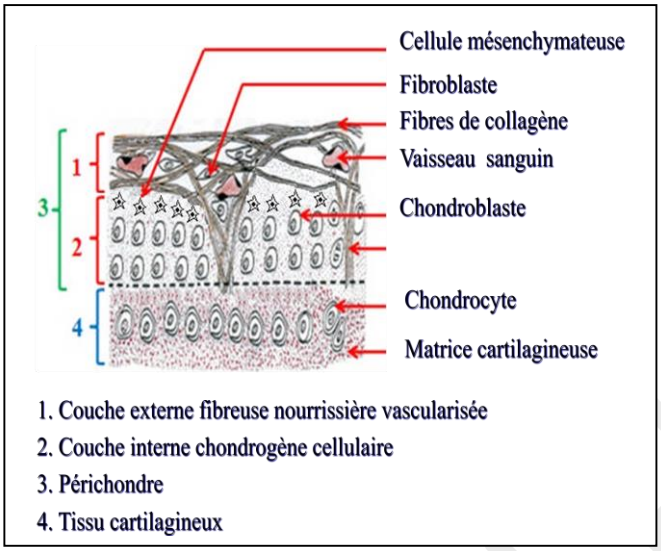


Figure 19. Structure of a perichondrium

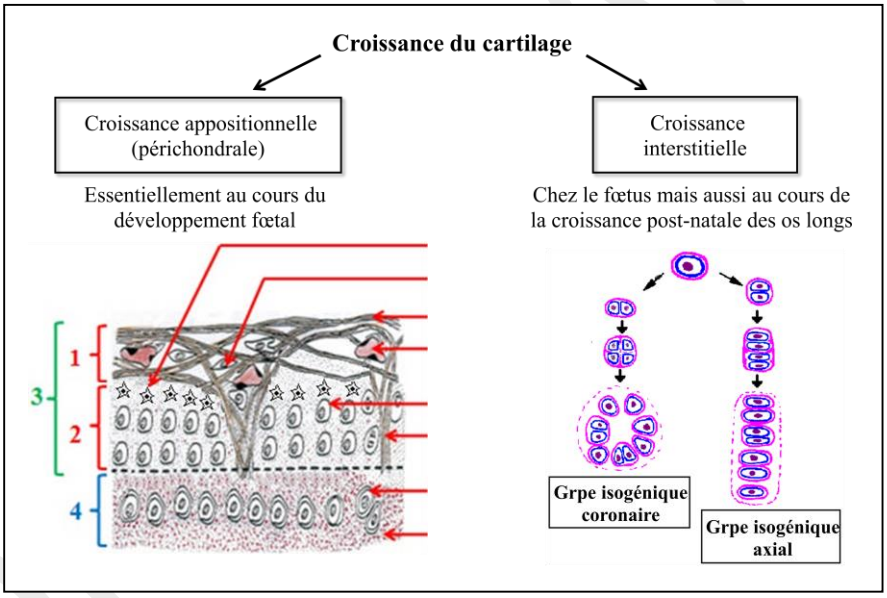


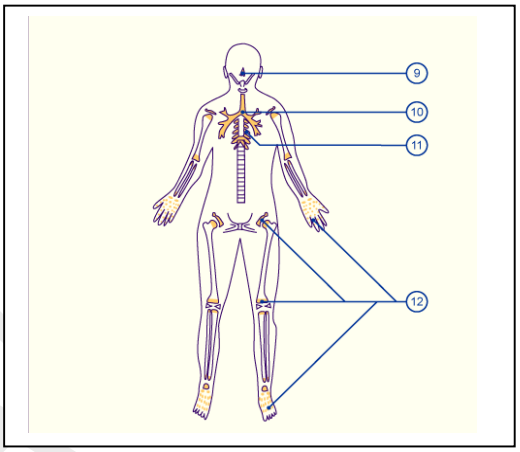
Figure 20. Cartilage growth

c. Different type of cartilage

1. Hyaline cartilage

The most prevalent type. Surrounded by perichondrium (except in articular cartilage). Consists of chondrocytes surrounded by ECM containing collagen type I and a lot of water. Rich in ground substance. ECM has a transparent appearance (Gr.Hyalos = glass).

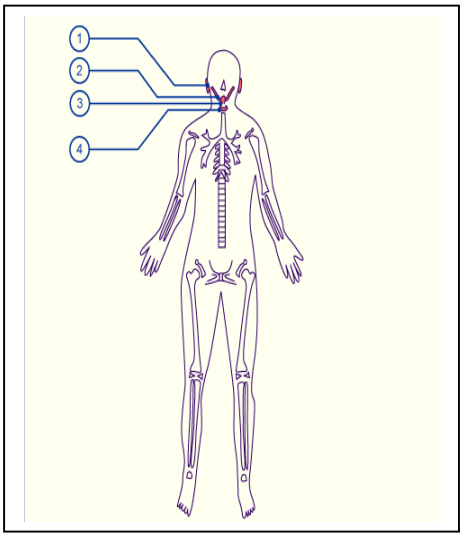
- Nasal cartilage
- Cartilage in the upper respiratory tract
- Rib cartilage
- Articular cartilage



2. Elastic cartilage

Consists of chondrocytes surrounded by ECM containing collagen type II and abundant elastic fibers. Few visible fibers

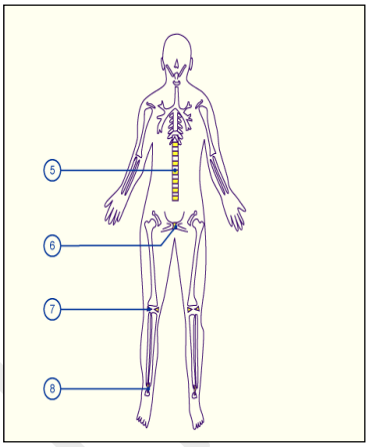
- External ear
- Eustachian tube (connects the middle ear
- to the back of the nose)
- Epiglottis
- Some cartilages of the larynx



3. Fibrous cartilage

Lacks perichondrium. Consists of chondrocytes surrounded by less rigid, opaque ECM. Low water content and abundant collagen fibers.

- Intervertebral discs
- Pubic symphysis
- Menisci
- Insertion of the Achilles tendon



II.4.2.2.2. Osseous tissue

It is richly vascularized, nourished from blood vessels, rigid, and mineralized extracellular matrix (ECM). It consists of:

- **Organic fraction :** Made of collagen fibers and ground substance. It provides the bone with its rigid framework and shape**.**
- **Mineral fraction:** Composed of complex mineral salts. It imparts hardness and strength to the bone.

a. Role

It plays a role in providing support and protection to organs (such as the skull). It serves as the site of hematopoiesis and facilitates movement.

b. Components

The bone cells are connective tissue cells that differentiate during ossification. They include:

- Osteoblasts: Young, ovoid cells with a cytoplasm rich in organelles. Located at the periphery of a bone lamella, they have a voluminous nucleus. They can multiply and transform rapidly into osteocytes surrounded by osteoplasts.
- Osteocytes: Star-shaped cells with long and thin extensions that connect bone cells. These are cells of mature bone tissue, responsible for the nutrition of bone tissue and participating in the processes of resorption and bone remodeling.
- Osteoclasts: Formed by the fusion of osteoblasts, these are massive, mobile cells that destroy bone. Simultaneously, osteoblasts rebuild the bone tissue. (Fig. 21).

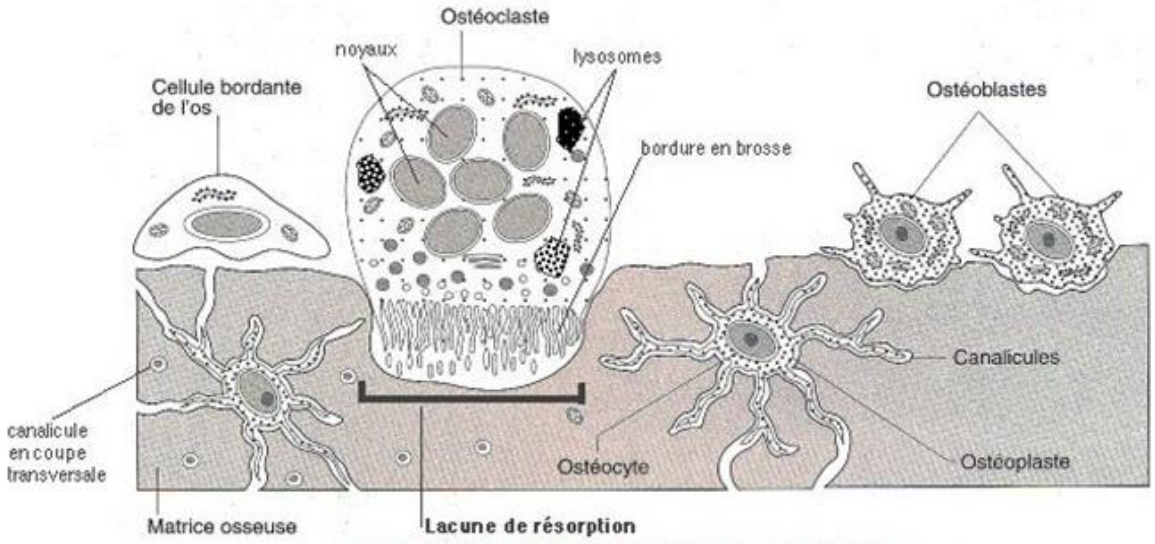


Figure 21. Components of bone tissue

Periosteum and endosteum

The periosteum covers the external surface of all bones except at joint cartilages. It consists of two layers: an inner layer containing connective tissue cells (osteoblasts) and an outer layer rich in collagen fibers and blood vessels.

The endosteum is a thin layer of connective tissue lining the walls of all vascularized cavities within the bone tissue. The mesenchymal cells of the endosteum have a dual osteogenic and hematopoietic potential.

c. Formation of bone tissue or ossification

Ossification occurs in two ways, either endochondral or intramembranous. The latter is a fundamental process that goes through four stages:

1. Differentiation of osteoblasts from stem cells.
2. Secretion of the organic matrix by osteoblasts.
3. Mineralization of the organic matrix.
4. Arrival of osteoclasts (Fig. 22).

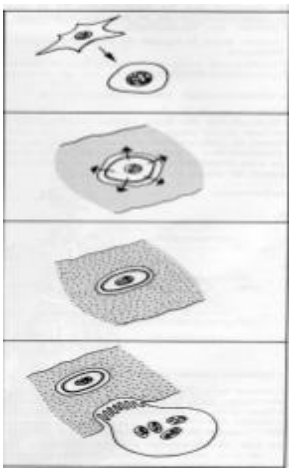


Figure 22. Formation of bone tissue (endochondral ossification)

Endochondral ossification occurs within hyaline cartilage tissue and takes place before adulthood. Initially, the hyaline cartilage tissue contains, among other things, disorganized chondrocytes and is entirely surrounded by the perichondrium. The chondrocytes will align and multiply in the direction of the length of the future bone by forming axial isogenic clusters. Once aligned, these chondrocytes will hypertrophy (enlarge enormously) until they die, leading to the calcification of the cartilaginous matrix. Simultaneously with this hypertrophy, vascular buds appear, bringing two essential elements to bone formation: mesenchymal cells and blood monocytes (Fig. 23). Mesenchymal cells differentiate into osteoblasts, and blood monocytes differentiate into osteoclasts. Osteoclasts dig tunnels within the calcified chondrocytes (resorption line), and osteoblasts form a pseudo-epithelial border on the side of the medullary cavity (Fig. 24).

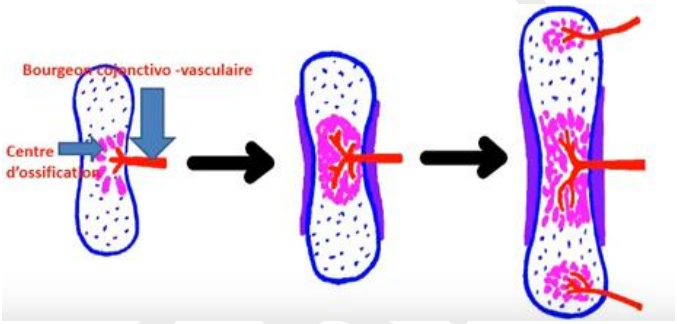


Figure 23. Penetration of conjonctivo-vascular buds

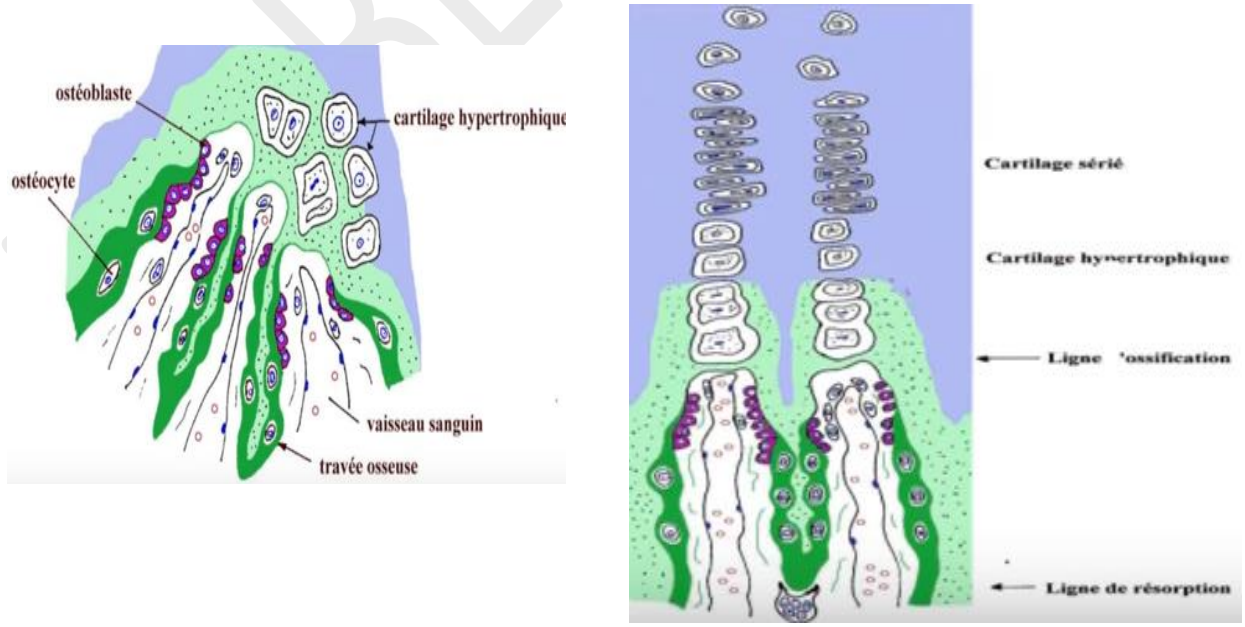


Figure 24. Endochondral ossification

d. Varieties of osseous tissue

There are two types of osseous tissues based on the organization of collagen fibers within the bone matrix: reticular or non-lamellar osseous tissue and lamellar osseous tissue (Fig. 25).

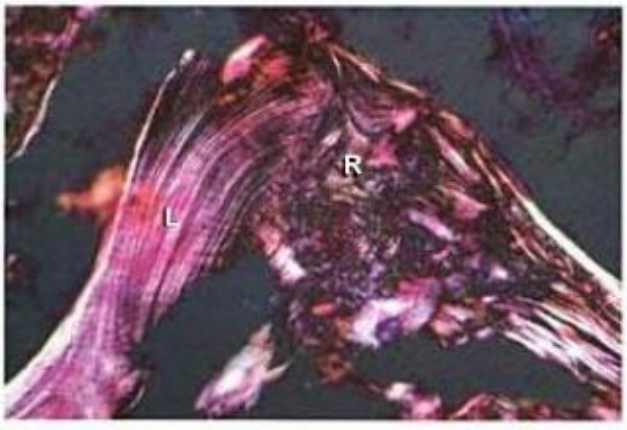


Figure 25. Lamellar bone tissue (L) and non-lamellar or reticular bone tissue (R)

1. Non-lamellar or reticular osseous tissue

This is a primary osseous tissue with low mineralization, where collagen fibers are oriented in all directions, giving a 'woven bone' appearance under optical microscopy. It is mechanically fragile. It exists in the fetus (as bone rudiments) and persists in some locations in adults and in cases of fractures. In other parts of the bone, it is replaced by secondary osseous tissue. It is a provisional osseous tissue.

2. Lamellar osseous tissue

This is a secondary osseous tissue formed from primary osseous tissue. Collagen fibers are parallel, forming lamellae. It is mechanically strong (Fig. 26).

Figure 26. Lamellar bone tissue

This tissue is subdivided into two types: Haversian or Compact or Cortical Lamellar Osseous Tissue and Non-Haversian or Spongy Lamellar Osseous Tissue. These two types of osseous tissue coexist in flat bones (skull, ribs, ...), long bones (humerus, femur, ...), and short bones (carpals, tarsals, vertebrae, ...) (Fig. 27)

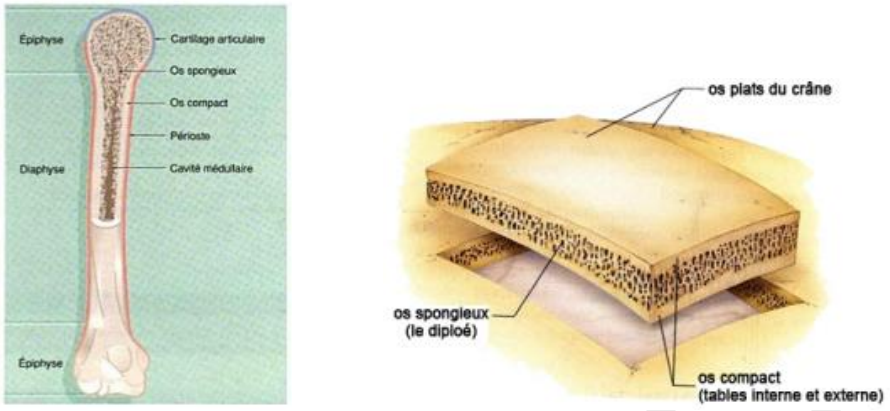


Figure 27. Coexistence of both compact and spongy bone tissues

A section at the level of the bone shows the existence of :

1. Spongy Bone:It presents visible spaces to the naked eye called trabeculae. It is found at the metaphysis, epiphysis, and in short bones.

2. Compact Bone: The canals are invisible to the naked eye. It is found in the diaphysis of hollow long bones. It is formed by osteons with Haversian canals and concentric lamellae, as well as Volkmann's canals and a residual system between these lamellae (Fig. 28).

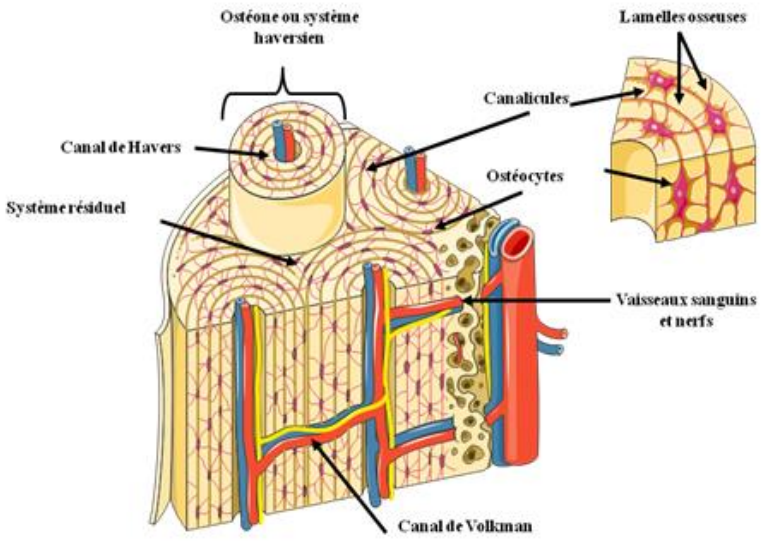


Figure 28. Organization of compact bone

From an anatomical point of view, three types of bones are distinguished: short bones, flat bones, and long bones (Fig. 29).

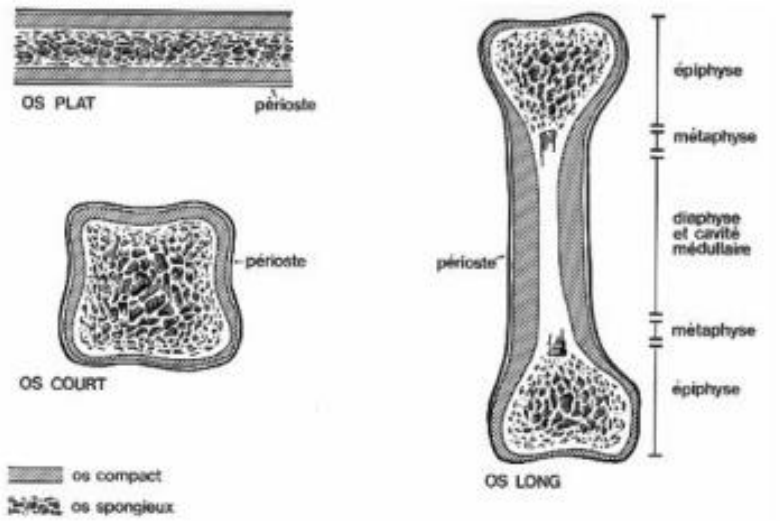


Figure 29. Varieties of bones from an anatomical perspective

III. Muscular tissues

III.1. Generalities

Muscles are composed of specialized cells called muscle fibers, muscle cells, or myocytes. They all have a dual component of actin and myosin myofibrils. The myocyte's plasma membrane is called the sarcolemma. The cytoplasm is called the sarcoplasm. The smooth endoplasmic reticulum is referred to as the sarcoplasmic reticulum.

III.2. Properties

Muscular tissue possesses four properties:

- Excitability (the ability to respond to stimuli),
- Contractility (the ability to contract),
- Extensibility (the ability of a muscle to stretch without tearing),
- Elasticity (the ability of a muscle to return to its normal size).

III.3. Role

- Ensure the maintenance of the bones of the skeleton together,
- Enable movements of body parts (skeletal muscles) or organs (smooth or cardiac muscles),
- Contribute to maintaining body posture.

III.4. Classification

There are two types of muscular tissues: striated muscle tissue and smooth muscle tissue. Striated muscle tissue further subdivides into two types: skeletal striated tissue and cardiac striated tissue.

III.4.1. Skeletal striated muscle tissue

Skeletal muscles typically insert into bones via tendons, allowing for motility (Fig. 30). Unlike other muscles, skeletal muscles can contract or relax voluntarily (consciously). This is a voluntary system operating under the control of the central nervous system. Not all fibers within skeletal muscles are identical in structure or function; their sizes can vary from 15 centimeters long to less than 1 meter. For example, they change color based on myoglobin content. There are white fibers that fatigue quickly (responsible for movements) and red fibers resistant to fatigue (postural maintenance).

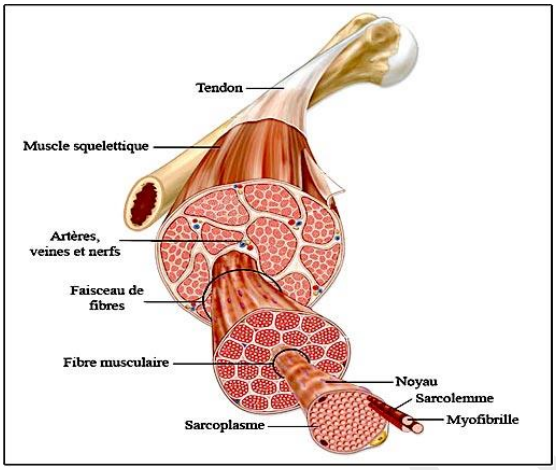


Figure 30. Organization of a skeletal striated muscle

Connective tissues of skeletal striated muscle

Skeletal muscle is composed of several thousand individual contractile cells (muscle fibers or myocytes), each covered by a connective tissue envelope called the endomysium. The cells are grouped into bundles called fascicles or bundles, which are surrounded by a loose connective tissue called the perimysium. The bundles are then grouped to form the muscle. The entire muscle is enveloped by a dense connective tissue called the epimysium (Fig. 31).

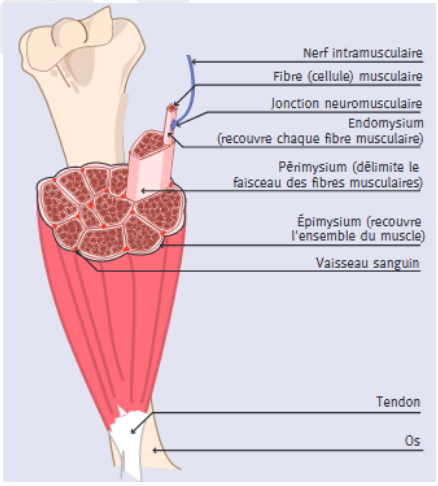


Figure 31. Connective tissues in a skeletal muscle

The skeletal striated muscle cells, called Rhabdomyocytes, are cylindrical, multinucleated, giant, and parallel to each other, with lengths that can reach several centimeters. The nuclei are flattened and peripheral (Fig. 32).

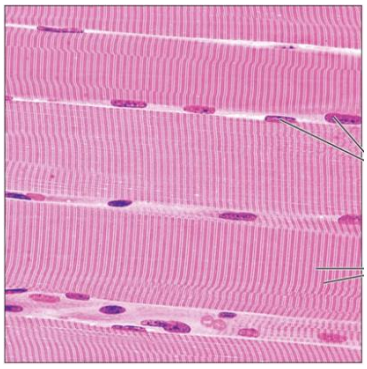


Figure 32. Rhabdomyocytes viewed under an optical microscope

Neuromuscular junction

It is a privileged area where neurotransmission occurs. The neuromuscular junction is a special synapse between each close contact, involving a motor axon terminal and a muscle fiber. The neurotransmitter, acetylcholine, released by the nerve ending, binds to the acetylcholine receptor on the sarcolemma and triggers an electric current: the action potential. This potential propagates along the entire sarcolemma and causes, at the triad level, the passage of an electrical signal from the T-tubule to the sarcoplasmic reticulum, which then releases calcium ions (Ca++). The released calcium ions diffuse between the actin and myosin protein filaments, causing the contraction of myofibrils (Fig. 33).

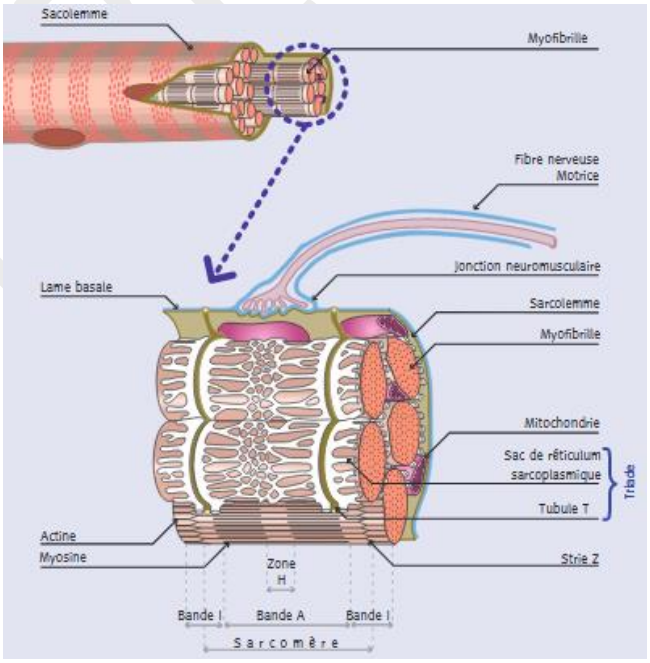


Figure 33. Neuromuscular junction

Contraction of skeletal striated muscle

Muscular contraction involves the shortening of sarcomeres due to the relative sliding of actin and myosin filaments: the two Z-discs delimiting a sarcomere move closer together. As this phenomenon occurs simultaneously for all sarcomeres in the cell, it results in an overall shortening of the muscle cell along the longitudinal axis. Muscle contraction is triggered by an increase in intracellular calcium concentration, and relaxation is achieved by returning to the initial concentration. The increase in intracellular calcium concentration lasts only a few milliseconds (Fig. 34).

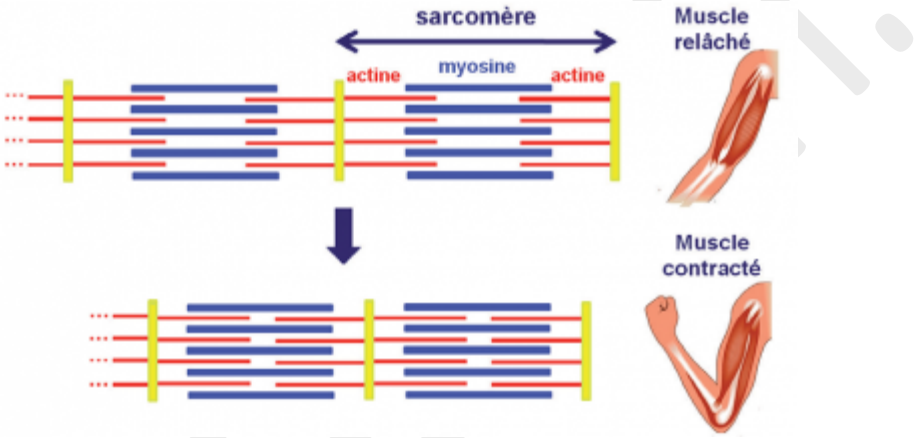


Figure 34. Relaxation and contraction of the sarcomere

III.4.2. Cardiac striated muscle tissue

Cardiac muscle forms the outer part of the heart. It is striated like skeletal muscle tissue, but unlike the latter, its contraction is involuntary (unconscious). The heart is located in the thoracic cage between the two lungs. It is a hollow muscle with automatism and is specialized in propelling blood to the organs. The walls of the heart are mainly composed of striated muscles; the cardiomyocytes are located in the myocardium (heart wall). The cardiac cavity is lined by endothelial cells, forming the endocardium, and the heart is enveloped in a fibrous sac, the pericardium. A histological study of the heart reveals that there are:

- 80% excitable and contractile cells, the cardiomyocytes,
- 1% self-excitable cells producing and conducting depolarization, nodal and conducting tissue
- 19% connective fibers, endothelial cells, nerve cells, etc.

Organization of cardiac striated muscle

The cardiac myocyte, also called cardiomyocyte, is a specific type of striated muscle; it is mononucleated or binucleated at the center. Unlike the rhabdomyocyte, its diameter and length are limited. In longitudinal section, cardiac striated muscle cells have the shape of long bifurcated and anastomosed cylinders. The ends of adjacent fibers are attached to each other at a structure called the intercalated disc or scalariform trait. However, each cell remains well individualized (Fig. 35). These cells are surrounded by connective tissue, the endomysium, and are grouped into trabeculae also surrounded by connective tissue, the epimysium.

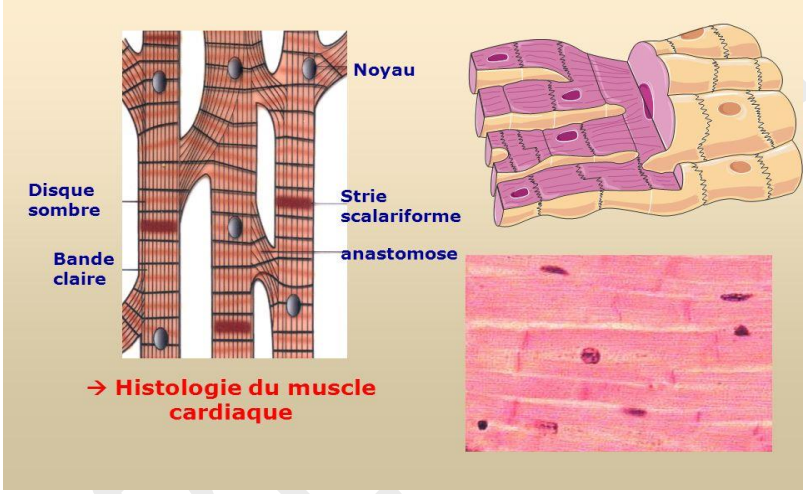


Figure 35. Appearance of cardiomyocytes

Contraction of cardiac striated muscle

Cardiac muscle is an involuntary muscle, and the myocytes constituting it contract rhythmically and automatically. The muscular contraction of the myocardium is comparable to the contraction of skeletal muscle with a few differences. For instance, unlike skeletal muscle, which requires a nervous stimulus, cardiac muscle excites itself; it is said to be myogenic. While rhythmic contractions occur spontaneously, their frequency can be influenced by nervous or hormonal influences such as exercise or the perception of danger.

III.4.3. Smooth muscle tissue

Smooth muscle, also called visceral muscle, is found in internal structures such as blood vessels, stomach, intestines, and bladder. Smooth muscle is not striated (as its name implies), and its contraction is generally involuntary (unconscious). Smooth muscle cells are also called leiomyocytes. They are spindle-shaped, mononucleated, non-striated, and present dark spots (dense bodies). Cells are arranged so that the swollen (median) part of one cell comes into contact with the tapered ends of adjacent cells. The junction area is called the nexus (where cell plasma membranes unite). The size of its fibers can vary from a few micrometers up to 0.5 millimeters long (Fig. 36).

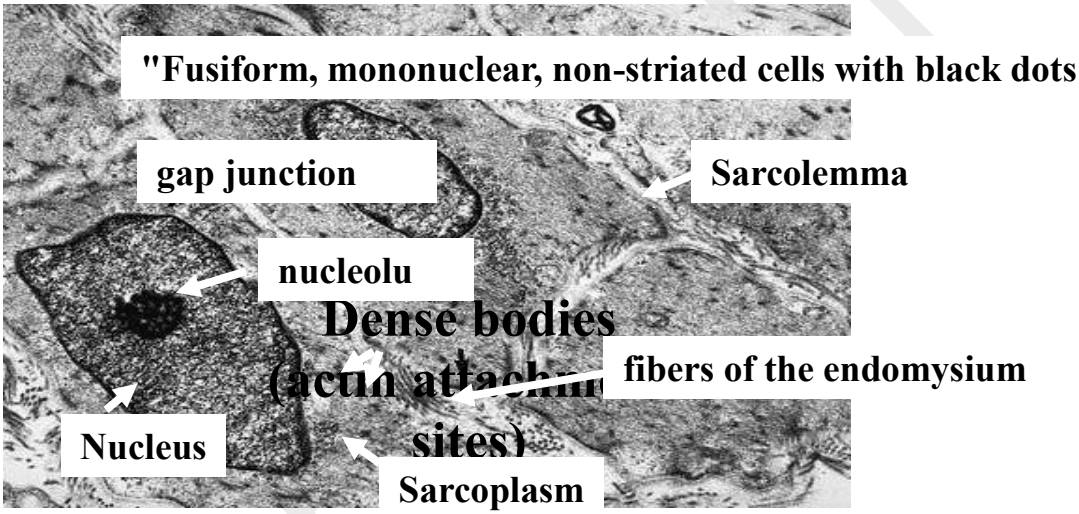


Figure 36 - Microphotography of leiomyocytes

Arrangement of actin and myosin myofilaments

Inside the leiomyocytes, there are myofibrils (in the form of myofilaments) oriented along the cell's major axis. The myofilaments are composed of two contractile proteins: thin filaments of actin and thick filaments of myosin. Thin myofilaments surround a thick myofilament, and contraction occurs in the presence of ATP (Fig. 37).

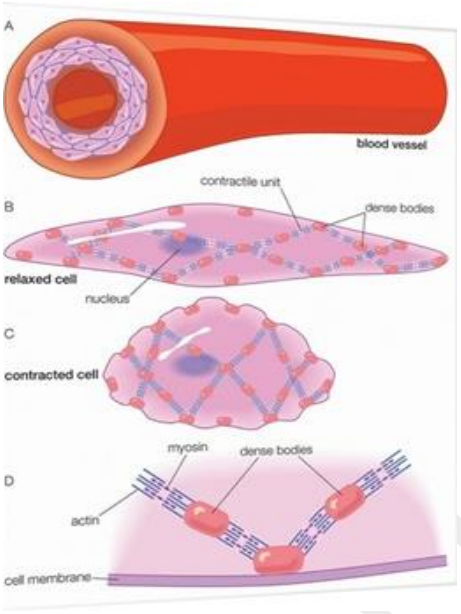


Figure 37. Arrangement of actin and myosin myofilaments in a smooth muscle cell

Role: Smooth muscle functions to assist in the transport of various substances within the body. These different substances include:

- Blood for the smooth muscle in blood vessels,
- Air for the smooth muscle in bronchi,
- Food for the smooth muscle in the digestive tract,
- Urine for the smooth muscle in the kidneys, bladder, and vessels carrying urine,
- Secretion product for myoepithelial cells (smooth muscle cells) in exocrine glands.

Smooth muscle contraction

The contraction of smooth muscle cells can be triggered by:

- Nervous influx
- Hormonal stimulation

The first event is the influx of calcium into the cytoplasm (Ca^{++} comes either from the smooth endoplasmic reticulum (SER) or from the extracellular milieu). Ca^{++} is the mediator of contraction. It binds to calmodulin, and the complex formed activates a kinase that phosphorylates myosin. Thus, activated myosin, with its bridges, can slide along actin and generate muscle tension. Contractions can be prolonged or slow (e.g., in the stomach) (Fig. 38).

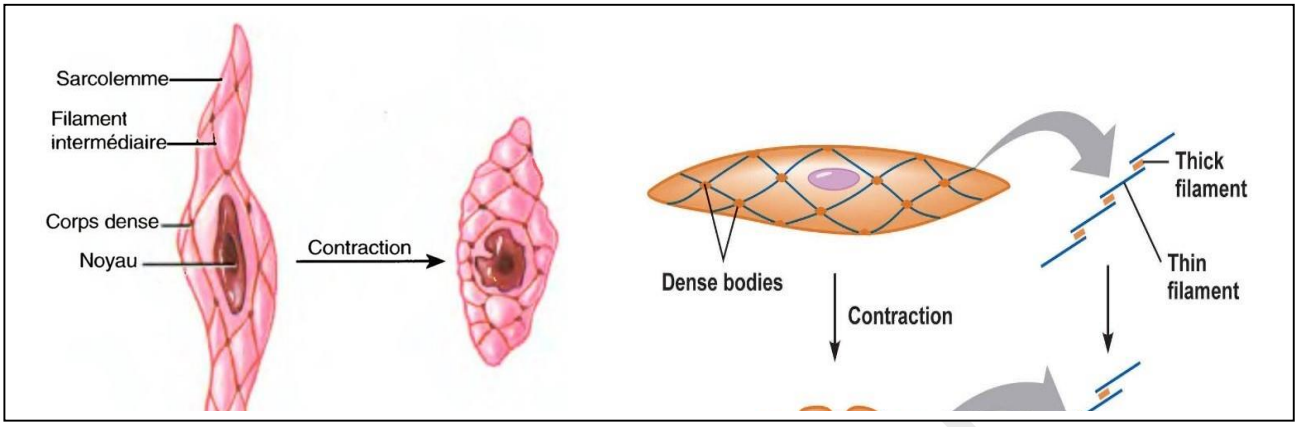


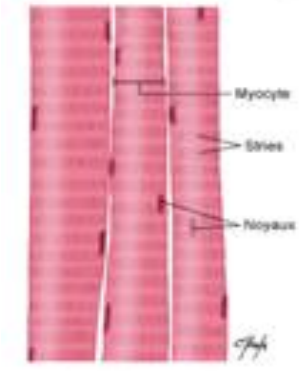
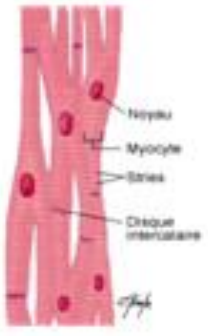
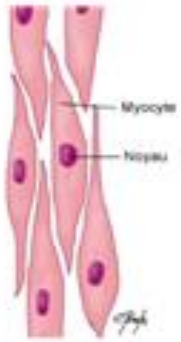
Figure 38. Contraction mechanism in leiomyocytes

III.5. Criteria for differentiation of the three muscle fibers

The three muscle fibers are differentiated based on the following criteria:

1. Shape and dimensions of muscle fibers
2. Cytoplasm appearance: striation
3. Nucleus appearance
4. Assembly mode
5. Types of relationships between cells
6. Appearance of connective tissue envelopes

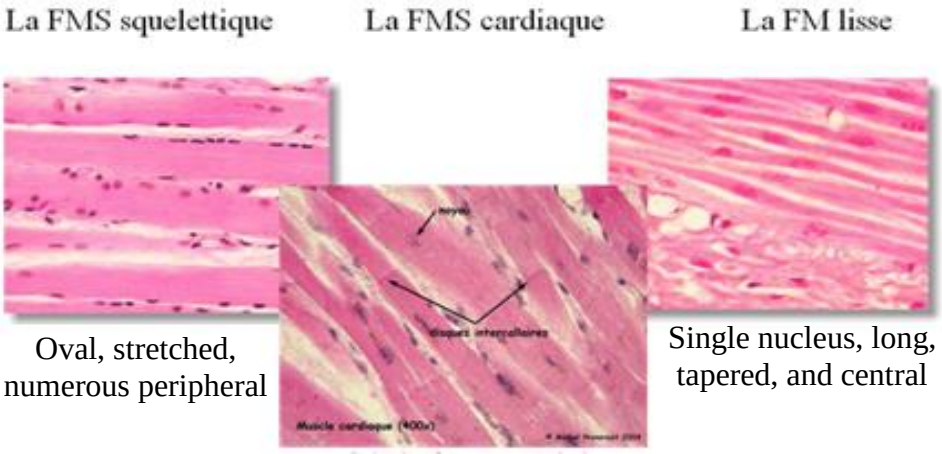
1. Shape and dimensions of muscle fibers

La FMS squelettique	La FMS cardiaque	La FM lisse
		
Cylindrical, wide long (several cm)	Cylindrical, bifurcated, Short (100 to 150 µm)	Fusiform, very short (20 to 200 µm)

2. Aspect of the cytoplasm: striation

Transverse striation, Transverse striation, No striation and longitudinal.

3. Nuclear appearance

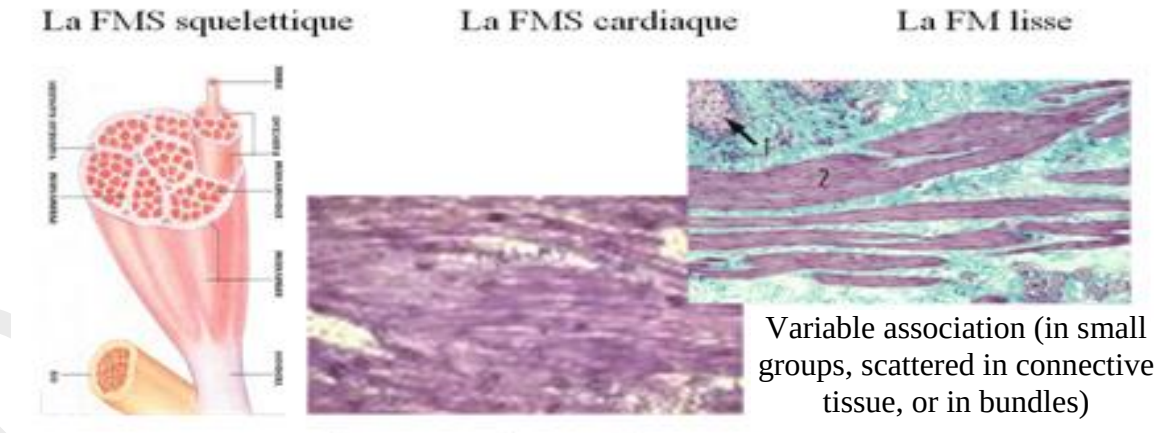


Oval, stretched, numerous peripheral

Single nucleus, long, tapered, and central

Generally 1 to 2 nuclei, oval, stocky, and central

4. Assembly mode

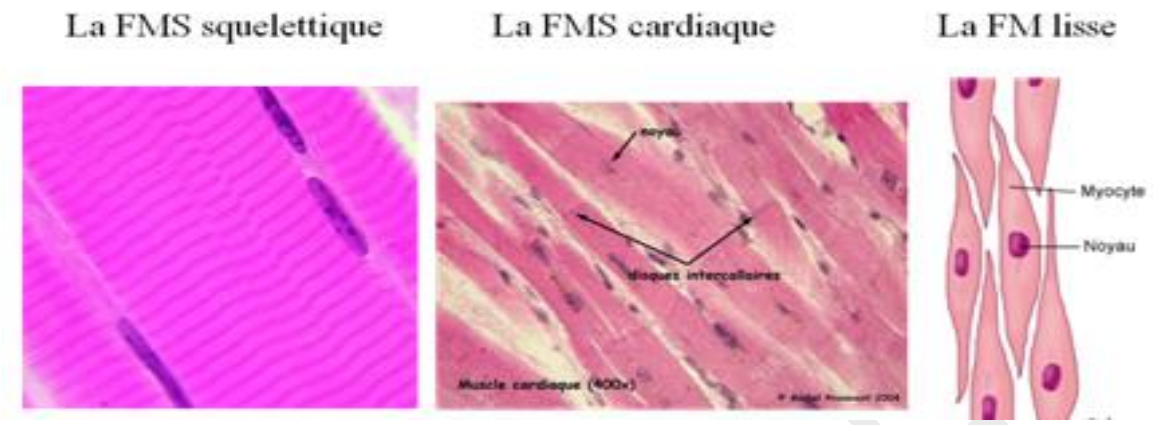


Variable association (in small groups, scattered in connective tissue, or in bundles)

Bundles of fibers parallel

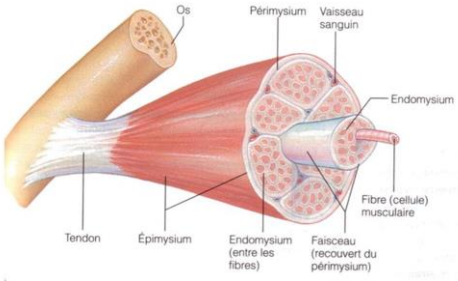
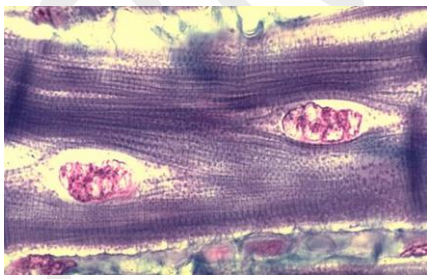
Anastomosed in a network through their branches

5. Types of cell-cell relationships



Independent fibers	United by intercalated discs	Generally separated by a space of 40 to 80 nm but remain connected by nexus

6. Appearance of connective tissue sheaths

FMS Squelettique	**FMS Cardiaque**	**FM Lisse**
		
Muscle (Epimysium) Bundle (Perimysium) Fiber (Endomysium)	By anastomosing, they delimit Henle's fissures. Grouped in rows (Epimysium) Fiber (Endomysium)	Each fiber is surrounded by collagen fibers in a spiral

IV. Nervous tissue

IV.1. Role of the nervous system

The nervous system (NS) plays a crucial role in sensing information, processing it, storing it, and ultimately sending appropriate signals. It is interconnected with the hormonal system, enabling the regulation of organ functions, especially in response to changes in the external environment. Using specific receptors, the NS detects alterations in the organism or the surroundings. It then transmits these signals to afferent nerve fibers leading to higher nervous centers, where they are processed. A response is generated and sent through efferent nerve fibers, triggering an adaptive reaction to the situation (Fig. 39).

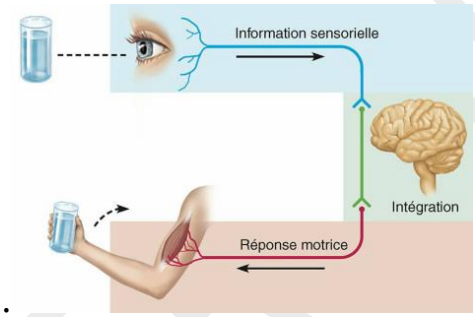


Figure 39. Translation of information into response

IV.2. Organization of the nervous system (NS)

According to its structure, the NS is divided into:

- Central Nervous System (CNS): Comprising higher centers such as the Brain, Cerebellum, Spinal Cord, and nerve parts of the eye.
- Peripheral Nervous System (PNS): Comprising Peripheral Nerve Ganglia, Nerves, and Nerve Endings (Fig. 40).

Based on their function and control mode, we distinguish:

- Voluntary (Somatic) Nervous System: Directs processes under conscious and voluntary control.
- Autonomic (Vegetative) Nervous System: Directs the functions of internal organs and is less influenced by conscious will.

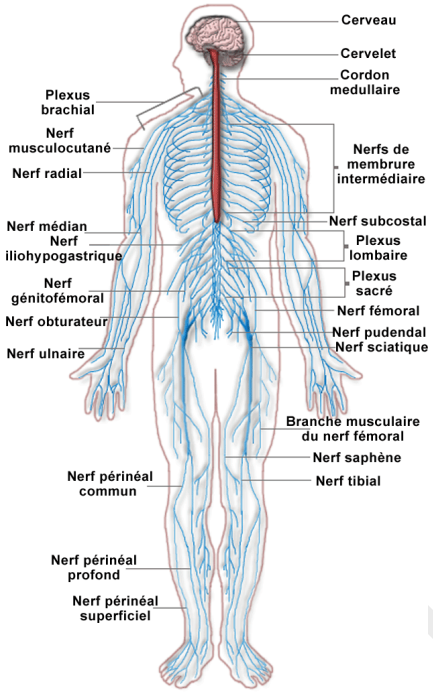


Figure 40. Organization of the nervous system

IV.3. Central nervous system (CNS)

The central nervous system comprises the brain and spinal cord. It consists of neurons, neuronal extensions, support cells (glial cells or neuroglia), and blood vessels. The CNS is protected by a bony covering (skull for the brain and vertebral column for the spinal cord) and surrounded by meninges, suspended in cerebrospinal fluid.

Macroscopically, the CNS consists of gray matter and white matter. Gray matter contains nearly all neuronal cell bodies and their dendritic extensions, serving as the essential part of the nervous system for receiving messages and analyzing information to formulate responses. White matter contains axons, the extensions of neurons, surrounded by myelin sheaths (imparting the white color to the substance) and non-neuronal cells (neuroglia) contributing to the interstitial neuronal tissue structure. Neuroglia nourish and protect nerve cells, and the role of white matter is to conduct nerve impulses.

IV.4. Cells of nervous tissue

The nervous tissue is composed of two types of cells: Neurons (nerve cells) and glial cells or neuroglia (protective cells).

IV.4.1. Neurons

Neurons constitute the functional unit of the nervous system, playing a major role in transmitting nerve impulses. They are highly specialized cells, numbering around 100 billion, non-dividing, with extreme longevity and high metabolic activity. Neurons possess two fundamental properties: Excitability, the ability to react to a stimulus and convert it into a nerve impulse, and Conductivity, the ability to propagate and transmit this nerve impulse. They consist of a cell body, dendrites, an axon, and axon terminals.

IV.4.1.1. Composition of a neuron

A neuron is composed of a cell body and variable numbers of extensions (nerve fibers); the larger ones are called axons, and the smaller ones are dendrites. The diameter of neuron cell bodies varies by type, ranging from 5 to 120 μm. The cell body, also known as the perikaryon or soma, contains the same elements as the basic cell but has neurofibrils in the cytoplasm and clusters of endoplasmic reticulum (ER) grouped into a special organelle called the Nissl body. Dendrites are extensions of the cell body with the same organelles except the nucleus and Golgi apparatus. They increase the available membrane surface for signals coming from other neurons (Fig.41).

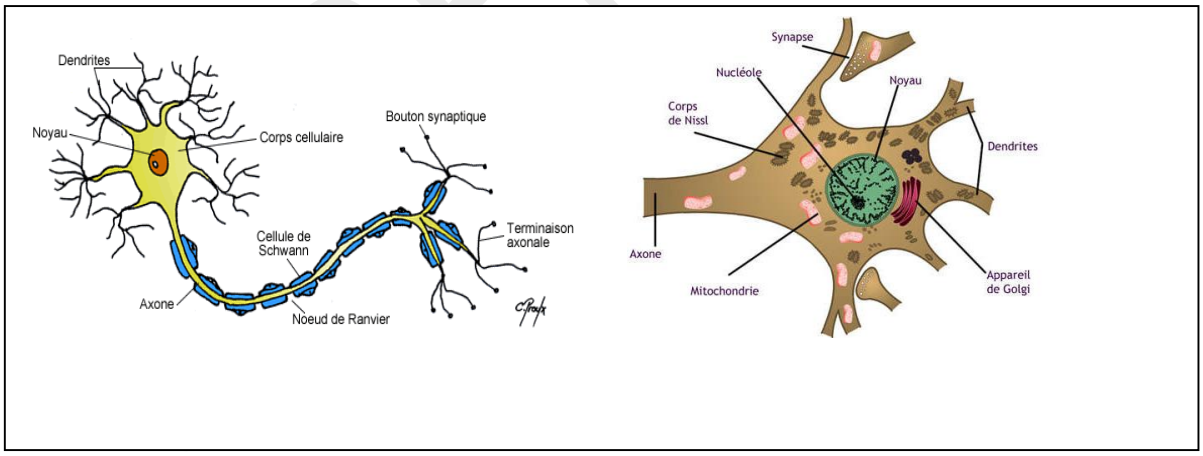


Figure 41. Structure and ultrastructure of a neuron

The axon (or nerve fiber) has a diameter ranging from 1 to 15 μm, with a length varying from one millimeter to over a meter, terminating in branching (terminal arborization). Each branch ends in a swelling, the terminal button or synaptic button. Some axons are covered by a myelin sheath, formed by glial cells—Schwann cells in the peripheral nervous system and oligodendrocytes in the central nervous system.

IV.4.1.2. Classification of neurons

A. According to function

- **Sensory Neurons (or Afferent):** This category includes neurons that carry information from sensory organs to the central nervous system. For example, neurons in the retina of the eye sensitive to light or neurons in the inner ear sensitive to sound vibrations. It also includes neurons responsible for the skin's sensitivity to various stimuli (heat, pressure, pain, etc.). When stimulated, these neurons generate an electric current that travels along a very long axon to the central nervous system.
- **Motor Neurons (or Efferent):** This category includes neurons whose axon is directly connected to an internal organ, most often a muscle cell. The cell body of these neurons is always located in the central nervous system (the brain or the spinal cord). A long axon emerges from the cell body and reaches the muscle cell controlled by this neuron. These neurons are responsible for movements.
- **Association Neurons:** The majority of neurons are not directly connected to a sense organ or muscle; these are association neurons. They form complex circuits serving various functions, from the simplest to the most sophisticated. These neurons determine your response (a shout, profanity, or a sigh of discouragement, depending on your temperament) after perceiving a painful sensation. They are also responsible for the memorization of such events. The vast majority of neurons in the nervous system are association neurons (Fig. 42)

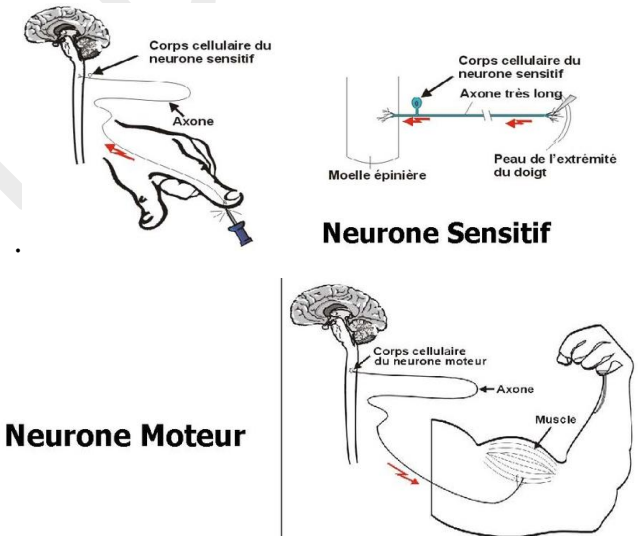
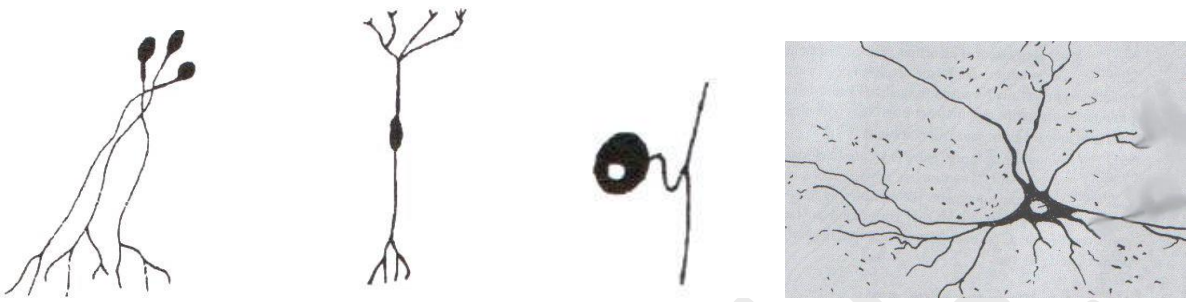


Figure 42. Types of neurons according to function

B. According to the type of cellular extension

According to the type of cellular extension, there are multipolar cells, bipolar cells, pseudounipolar cells, and unipolar cells (Fig. 43).



A **B** **C** **D**

Figure 43. Types of neurons according to cellular extension

A: Unipolar Neuron (1 single extension)

B: Bipolar Neuron (1 afferent extension and 1 efferent extension)

C: Pseudounipolar Neuron (single extension bifurcates away from the cell body into an afferent and an efferent)

D: Multipolar Neurons (multiple extensions: one axon but numerous dendrites; the most common in the human nervous system)

C. According to the shape of the cell body

According to the shape of the perikaryon, there are fusiform cells, stellate cells, pyramidal cells, and spherical cells (Fig. 44).

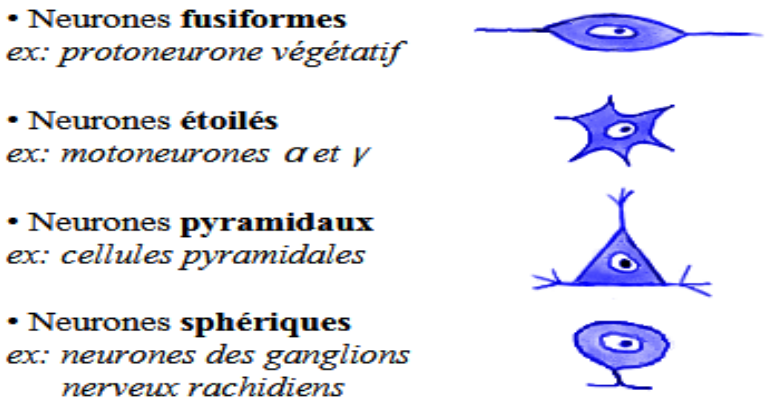


Figure 44. Types of neurons according to the shape of the perikaryon

IV.4.2. Glial cells

Glia cells are 5 to 50 times more numerous than neurons, and their role is crucial for neuronal functioning. Unlike neurons, they cannot initiate or transmit nerve impulses but perform protective, nutritional, and immunological functions for neurons. The term "neuroglia" refers to all glial cells. They belong to four types (Fig. 45):

- ☞ **Astrocytes (Macroglia):** The largest glial cells, star-shaped with multiple extensions from the cell body. They have nutritional roles (transporting blood to neurons) and support functions by filling all the empty spaces between neurons. Without their support, any movement would tear fragile neural connections. They aid in the migration of young neurons, synapse formation, and influence neuron functioning. Astrocytes play a significant role in repairing central nervous tissue after injury or disease.
- ☞ **Microglia (Microglia):** Relatively few in number, these small cells have numerous short extensions. They are representatives of the monocyte-macrophage system and eliminate damaged or infected neurons in the CNS. They have defensive and immunological functions, similar to immune cells in other tissues. Their presence is essential since immune cells cannot penetrate the CNS.
- ☞ **Oligodendrocytes (Oligodendroglia):** Special glial cells-oligodendrocytes in the CNS and Schwann cells in the PNS—that form myelin sheaths around axons. Unlike neurons, glial cells can reproduce. When a part of nervous tissue is destroyed, they multiply and fill all the spaces left by the vanished neurons. In some cases, a glial cell may lose control of its reproduction and form a cancerous tumor called glioma. Since neurons do not reproduce, they cannot form cancerous tumors.
- ☞ **Ependymocytes or Ependymal cells (Epithelial cells):** Form the blood-brain barrier isolating cerebrospinal fluid from the CNS. This specialized epithelium lines the ventricles and the spinal canal.

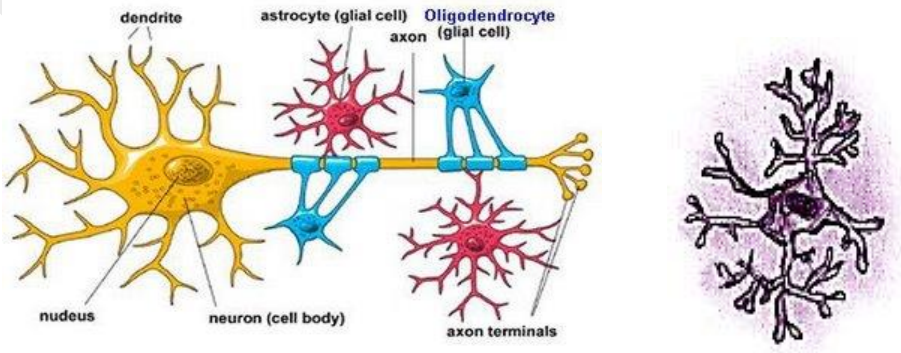


Figure 45. Glial cells (Astrocyte, Oligodendrocyte, Microglia)

IV.5. Nerve

A single neuron's nerve impulse is insufficient to elicit a muscular reaction, for example. It requires thousands of neurons stimulating thousands of muscle cells. All these axons, whether from sensory or motor neurons, are grouped into bundles forming gigantic cables that can consist of thousands of fibers: nerves. For instance, each spinal nerve is composed of approximately 600,000 sensory and motor axons.

Each nerve fiber or axon is enveloped by connective tissue called Endoneurium. A bundle of nerve fibers is surrounded by a connective tissue sheath called Perineurium. The nerve is wrapped in a layer of connective tissue known as Epineurium. A nerve can divide several times during its course or unite with other nerves. It can contain both motor and sensory fibers (= mixed nerve) (Fig. 46).

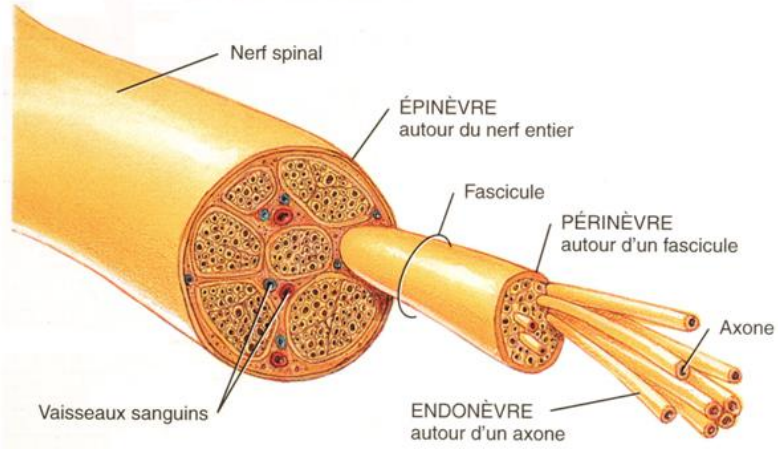


Figure 46. Structure of a nerve

IV.6. Nerve impulse

If the neuron acts as a messenger, the messages given or received are transported by the nerve impulse. The nerve impulse is an electrical potential moving along an axon after the neuron has been stimulated. This impulse then acts on the target organ. The stimulus can be conscious (voluntary command) or unconscious (without our will, e.g., heartbeat, intestinal movements). It must be sufficiently intense to trigger the passage of the nerve impulse. The speed of the impulse along the membrane depends on the fiber's diameter and the thickness of the myelin sheath.

IV.7. Structure of a synapse

Synapses connect neurons to each other, between neurons and muscle cells (motor endplate), or between neurons and glandular cells. The nerve impulse reaches the synapse, causing the release of the chemical substance (neurotransmitter) stored in vesicles of the synaptic button into the synaptic cleft. The nerve impulse arriving at the presynaptic cleft opens calcium channels, and calcium ions enable vesicle release into the synaptic cleft. The released neurotransmitter molecules then bind to specific receptors on the postsynaptic membrane. To prevent prolonged action of the neurotransmitter, it is transformed into an inactive chemical that returns to the terminal axon that released it.

A synapse consists of three parts:

- **Presynaptic neuron:** Branched end of an axon formed by a presynaptic button containing vesicles filled with neurotransmitters.
- **Postsynaptic cell:** With the postsynaptic membrane containing receptors for neurotransmitters.
- **Synaptic cleft:** The gap between presynaptic and postsynaptic cells filled with extracellular fluid (Fig. 47).

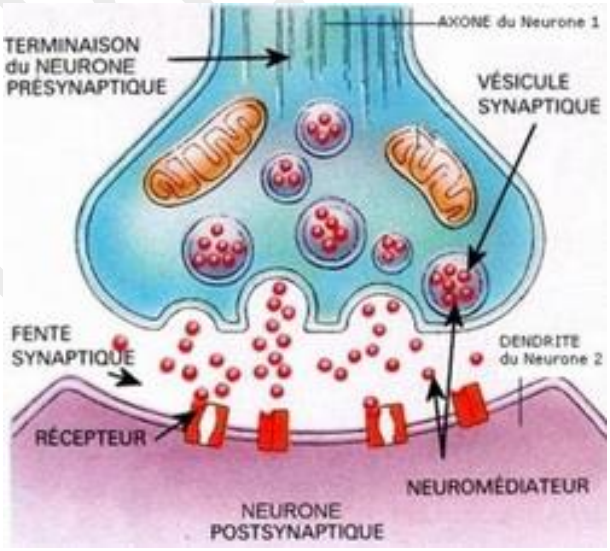


Figure 47. Structure of a synapse

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