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LES INVERTEBRÉS & LES VERTEBRÉS

2nd year Agronomy

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Module

ANIMAL PHYSIOLOGY

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THE INVERTEBRATES & THE VERTEBRATES

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SYSTEMS CIRCULATORY AND TRAFFIC

General

The first Metazoans developed an external rather than an internal circulation system. THE sponges And THE Cnidarians don't have neither heart, neither system circulatory differentiated. THE Transport of O2 and nutrients takes place from cell to cell by diffusion. It's the middle exterior which serves as a transport medium thanks to a permanent renewal ensured by the activity of ciliated, flagellated or muscular cells. In all other cases, transport isassured by internal fluid movements : blood or hemolymph.

I/ THE circulatory systems

The most primitive circulatory systems appear as lacunae and channels atinside of the organisms. In THE mesoderm at the house of some towards dishes ; In THE pseudocoelom in nematodes and rotifers and in the coelom in echinoderms. This are THE movements of body Who ensure a certain traffic of the liquids interstitials

1. Case of Annelids: The circulatory system is closed. It is made up of two vessels, one ventral and a dorsal connected by lateral cores on either side of the metamers near the partitions (fig.1).

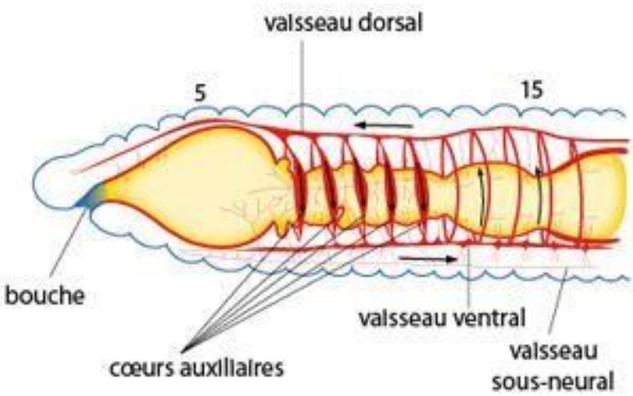


figure 1 System circulatory of an annelid

2. Case of Arthropods: the circulatory system East open To inside the tegument. He born possesses neither veins And venules, neither arteries And arterioles. At the house of THE Insects, THE heart East tubular which extends almost the whole length of the body and it bears pores, the ostioles . He understand a ventricle For each segment (fig.2).

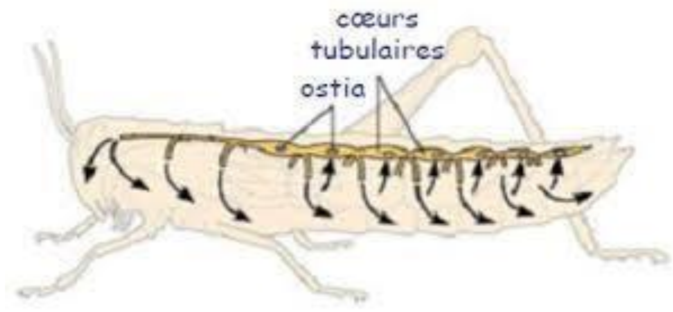


figure 2 System circulatory of one Bug

In Crustaceans , the circulatory system is a set of ducts, without a heart in Small crustaceans with a heart in decapod crustaceans, example crayfish (fig.3). THE system is open.

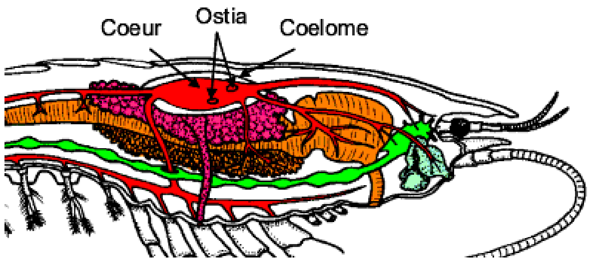


figure 3 System circulatory of one crayfish

3. Case of Molluscs: In Lamellibranchs, the heart has 2 atria (or auricles) and a ventricle. In cephalopods, the heart is made up of 2 atria and a ventricle and it a network of capillaries develops which controls the distribution of blood quantitatively. THE heart is composed of striated muscle fibers in cephalopods while it is composed of smooth fibers in others Molluscs.

II/ Traffic

In invertebrates, circulation is open except in annelids and the Cephalopods . The heart can pump hemolymph and pours it through an artery into the hemocoel (between endoderm and mesoderm).

- Blood does not circulate in closed vessels. The liquid described in the body of real currents to reach the various regions. There are one or more pulsating hearts, or a dorsal vessel as in Insects (fig.4). The circulation in these animals is almost always lacunar, because the blood bathes in the visceral cavity and circulates in a deviceof vessels incompletely closed.

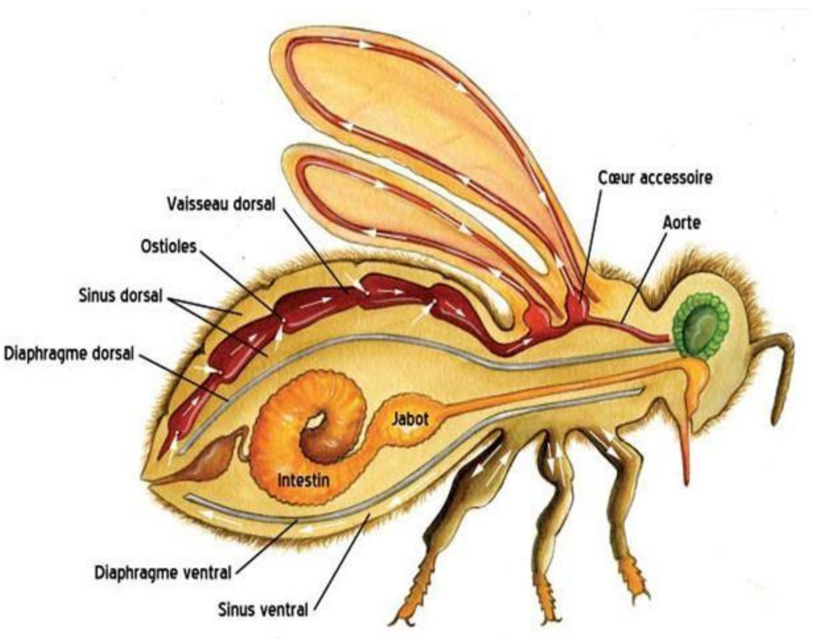


figure 4 Plan simplified of system circulatory of one Bug.
hemolymph busy there totality of there cavity internal until In THE appendages.

You have to get to molluscs to find channels of two kinds, the veins and the arteries ; but he there To blend continual between THE blood arterial and venous.

- Hemolymph has no respiratory role. It therefore does not carry colored pigments. She irrigates all tissues, providing them with nutrients, hormones, immune cells And of there coagulation… And taking away THE waste of metabolism. She born transported notoxygen. Her traffic East assured by several devices anatomical And controlled finely speak system nervous.

- In the first Coelomate and Pseudocoelomate Invertebrates, it is the contractions of the Peripheral muscles that allow the circulation of internal fluids. Pigments fix _ Already THE dioxygen.
- At the house of THE Invertebrates superiors, THE bedrooms contractile are specialized In there circulation of hemolymph. It is at the level of the sinuses (hemocoele = lacunae) that THE exchanges between cells and the hemolymph.

RESPIRATORY SYSTEMS IN INVERTEBRATES

1- Respiratory Systems - Movements of Oxygen and Carbon Dioxide:

In many cases, $O_2/CO_{2\ exchanges}$ between an organism and its environment involve specialized organs.

In some cases, however, diffusion through the outer tegument or directly between the cells and the external environment is sufficient to ensure suitable exchanges; this is the case in all diploblasts: sponges, cnidarians and ctenarians. This is also the case in many triploblastic invertebrates with low metabolism: flatworms, nemerteans, rotifers, nemathelminths, pogonophores, most echiurians and various annelids.

Most echinoderms also lack a respiratory system. Only holothurians have "lungs" (also called tree organs). They are voluminous, highly branched sacs that open through a common trunk into the rectal ampulla. In various other classes, asterids in particular, respiration is ensured via: disseminated papules mainly on the dorsal surface. They correspond to thinned integumentary zones consisting simply of two epithelial cilia separated by a thin connective-muscular layer.

The different types of respiratory organs will intervene in so-called branchial, cutaneous, pulmonary or tracheal systems. The branchial and cutaneous systems are involved in aquatic respiration; the pulmonary and tracheal systems in aerial respiration, although the tracheae can also be used for O_2 /CO_2 exchanges in the aquatic environment in certain species of insects returned to the water.

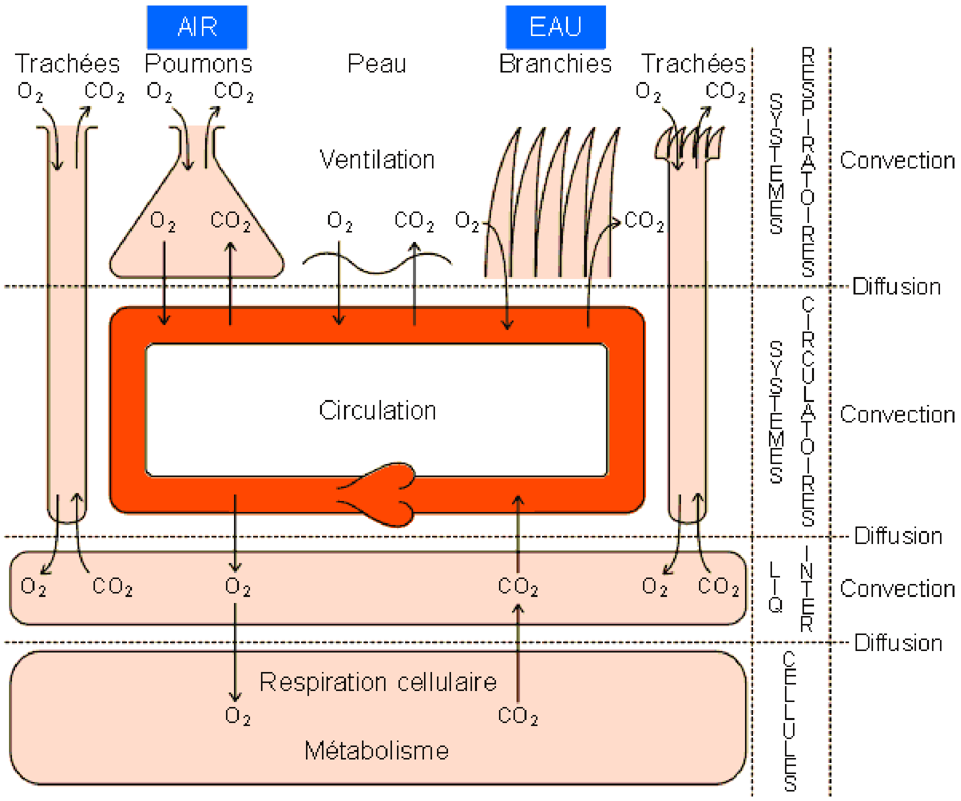


Figure 5: Schematic representation of the different types of respiratory systems and their relationship

to metabolism and cellular respiration. Liq Inter: interstitial liquid.

There are no active transport mechanisms for O_2, nor for CO_2. The exchanges will therefore always be made by broadcast. In the branchial, cutaneous and pulmonary systems, the diffusion of dissolved gases takes place between the blood and the external environment on the one hand and between the blood and the cells on the other hand. The blood therefore exercises an important respiratory function here which, in most species, is aided by the presence of "pigments" which greatly increase its oxygen carrying capacity. In the tracheal system, specific to insects, the diffusion of gases takes place almost directly between the external medium and the cells. The blood therefore has hardly any respiratory function here. It will be devoid of oxygen-binding "pigments", except in a few special cases.

If there is no active transport of CO_2, this can take part in a Cl/HCO^-_3 exchange at the level of different epithelia (gills, kidney, skin: cell physiology). These systems will contribute significantly to the elimination of CO_2, mainly in aquatic species.

(See breathing boards).

NUTRITION IN INVERTEBRATES AND VERTEBRATES

General:

The body's cells need nutrients: carbohydrates, lipids, proteins, vitamins, mineral salts and water; these nutrients exist in our food, but in a complex form, unable to cross cell membranes.

Digestion therefore has the role of simplifying the food bolus, gradually bringing it into physical and chemical forms, compatible with their digestive absorption and their transfer into the cellular distribution system: *blood* and *lymph* . This role is performed by the digestive tract, the functioning of which can be summarized by:

- *Mechanical activity* : aspiration, chewing, swallowing, stirring, filling and emptying.
- *A chemical and biochemical activity* , **especially enzymatic** , involving juices produced by cells or glands.

The temperature, osmolarity, pH of the food bolus, the size of the particles, their liposolubility and their water solubility will be gradually brought by the work of the different segments of the digestive system to characteristics favorable to transmembrane passage.

The digestive system includes the digestive tract whose elements are the *mouth* , the *pharynx* , *the esophagus* , *the stomach* , *the small intestine* , the *colon* , the *rectum* and the *accessory glands* , such as the *salivary glands* , the *gallbladder* and some parts of the liver and pancreas.

We can liken the digestive tract to a duct of variable caliber, crossing the body from the mouth to the anus, its length is *about 5m*, its lumen is in continuity with the external environment, so that its contents do not integral part of the body: this is the example of bacteria very present in the terminal part of the intestine where they are harmless and even useful but, if they enter the body, they quickly become pathogenic, it is what happens during attacks of appendicitis.

General mechanisms of digestive secretions.

Thanks to mucus glands, the digestive tract secretes a lubricating and protective film against the mechanical and chemical aggression of food. This movie contains:

- Of the *glycoproteins* , or *mucopolysaccharides* , secreted by *superficial glands* , or by *the superior glands of the crypts* ; they participate in the adjustment of the pH, thanks to their buffering power, their secretion is permanent but accelerated by food contact.
- juices secreted by very diverse glands; these juices generally contain:
  - of the *bicarbonates* of plasma origin (for a small part) but mostly synthesized.
  - of the *electrolytes* which also come from the plasma in variable concentration, due to secretion and reabsorption mechanisms.
  - of the *enzymatic proteins* synthesized in a classical way by cells.

These secretions are under the double neuroendocrine control with vegetative innervation which acts directly on the secretory cells but also on the endocrine glands which release regulating hormones (activators or inhibitors) of the secretion of juices. Their release can be done under the action of the SNV but also under the effect of the *mechanical and chemical actions of food* , this last factor being preponderant.

There is a constant functional, nervous and hormonal interrelation; the two systems can potentiate each other mutually, or self-regulate, by forming retro-inhibition or feedback loops.

***Examples* :**

- Stimulation of the vagus nerve sensitizes the stomach gland to the action of gastrin.
- Gastrin secretion activates HCl-secreting stomach cells; the released H^{+} ions lower the pH which inhibits gastrin secretion.

General conditions of enzymatic hydrolyses

The bolus will undergo physical and chemical changes.

- Fragmentation by chewing.
- Softening, dissolution and dispersion by water.
- Acid action of gastric juice.
- Action of numerous enzymes which split molecules.

These enzymatic reactions have a speed which depends on the temperature (in fact little increase because it is uniform in the digestive tract) and above all on the pH specific to each enzyme: pepsin -> acid pH – trypsin -> neutral pH.

Proteolytic enzymes are delivered by the gland in the form of inactive precursors:

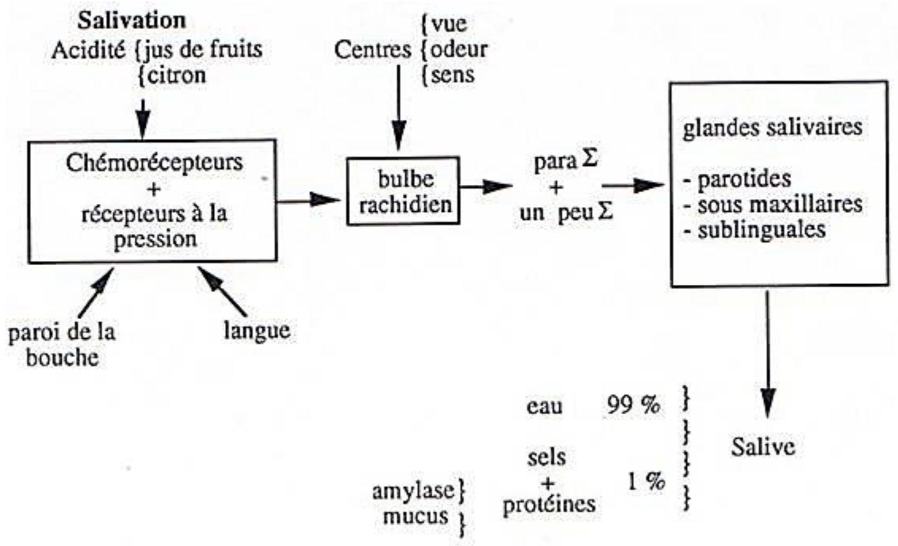
Pepsinogen, trypsinogen, etc. which are activated by amputation of a segment which masks the active site of the enzyme; these amputations are carried out by proteases, called kinases, more or less specific and which often require the presence of the Ca^{2+} ion .

Lipases only act when the substrate is in a fine and stable emulsion, hence the presence of emulsifying agents such as bile salts.

Chewing is an essential function of the teeth are to bite and chew to pick up and reduce that bite into fragments small enough to swallow. Prolonged chewing is a characteristic of humans. Many animals (cat, dog) swallow without chewing; the essential action of chewing is to reduce the size of the pieces.

The contraction of the masticatory muscles (temporal, masseter) is under *nervous control* , the origin of which would be a masticatory center in the medulla oblongata. Chewing can be voluntary but also *triggered by a reflex mechanism* with, as a starting point, receptors located in the mouth (a shelled animal retains chewing when food is placed in its mouth).

In addition to voluntary control (somatic nerves) of the skeletal muscles of the mouth and jaw, the rhythmic movements of chewing are triggered reflexively by the pressure of food on the gums, teeth, palate and tongue (at inhibition of the muscles that keep the mouth closed).



Saliva has multiple roles:

- Begin the hydrolysis of certain carbohydrates.
- Moisten the mouth (essential for speech).
- Solubilize chemical substances which can thus stimulate the taste buds.
- Coat the food bowl with mucus to allow it to be swallowed.

Swallowing: It is a complex reflex act that is caused when the bolus of food pushed by the tongue is propelled into the stomach. There are mechanical receptors in the pharynx that send sensory impulses to the bulbar center of swallowing. *Once started, swallowing cannot be stopped* ; it is the type of all or nothing reflex, coordinated, automatic, programmed by the synaptic connections.

Three stages are classically distinguished in this swallowing reflex:

- *oral time :* It is ensured by the tongue, under *voluntary control* : it allows to propel by its movements, the bolus towards the pharynx.
- *the pharyngeal phase* : The tongue closes the mouth orifice to prevent it from returning to the mouth; there is closure of the nasal fossae by the soft palate, closure of the respiratory tract

by the glottis, then by the epiglottis, thus preventing any false route of the bolus, opening of the upper esophageal sphincter and passage of food.

- *the esophageal phase* : In the esophagus, *the bolus is pushed towards the stomach by a peristaltic wave* which spreads step by step. It is controlled at the beginning by the vegetative nervous system then, at the end of the course, by the plexuses. Several waves may be necessary to empty the esophagus (bolus too large).

1. Digestion in the stomach

The stomach is a reservoir that secretes a strong acid, HCl and several enzymes. Stomach digestion consists of a *fragmentation of the food bolus into molecules* , or a set of molecules, still too large to be absorbed: we speak of *stomach chyme* .

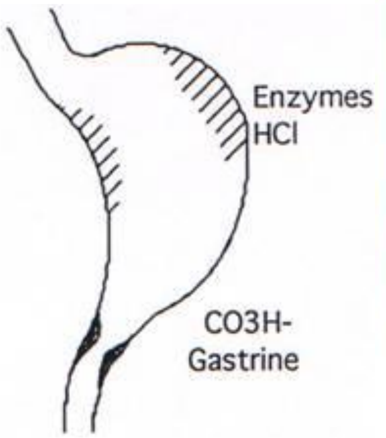
Mechanical Digestion : There is a basic electrical activity, in the form of waves, which causes slow muscular contractions which go from the cardia to the pylorus. The first bite swallowed stops this activity and the stomach remains motionless for 30 to 60 minutes after the start of the meal; the food ingested is arranged in successive layers.

After this delay, the waves resume, mixing the food and the juices; they push the bolus towards the pylorus whose sphincter is closed; the bolus flows back to the cardia and this mixing continues until the chyme meets the pH and particle size criteria. These actions are supplemented by the intervention of various hormones: gastrin increases them; glucagon, secretin.

Gastric acid.

On the secretory level, there are two functionally distinct parts in the stomach:

- **The mucous membrane of the main pocket** (fundus) which *elaborates the enzymes* (main cells) and whose **parietal cells** , or borders, *secrete the* H^{+} *ions* .
- **antro -pyloric region** (antrum or antrum), whose glands give off *alkaline secretions rich in bicarbonates* . Gastrin *is also secreted there* .



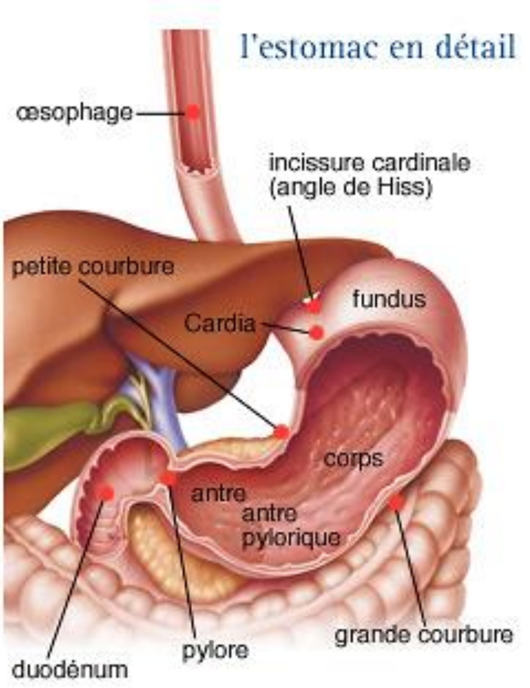


Figure 6 differ part of stomach

Thanks to the HCl, the gastric juice "cooks" the food; it dissolves the cellulose and the connective fibers of the muscle bundles of the meats which fragment. Its proteolytic action is due to pepsins. These are endopeptidases which act at pH 1-3.5, especially on the amine function of aromatic amino acids (phenylalanine, tyrosine); they therefore incompletely digest proteins. Gastric juice stimulates chemoreceptors and inhibits gastrin secretion.

Note: Gastric digestion is not essential; some individuals, partially or totally deprived of a stomach (ulcers, cancer, requiring a gastrectomy) digest food that is fragmented and supplemented with vitamin B_{12} .

The small intestine receives gastric chyme and pancreatic, bile and intestinal juices; it is the seat of most of the enzymatic digestion.

pancreatic juice.

Pancreatic juice is produced by the exocrine pancreas; it is discharged through a channel into the duodenum. For the location of the pancreas, (see the diagram of the digestive tract). Pancreatic juice is secreted at an average rate of 1 to 2 liters/24 h. It is a colorless mucous liquid, pH 8.5; it contains electrolytes: Na^+; K^+; Cl^- and CO_3H^- , secreted by the canalicular cells, enzymatic proteins including an amylase or 1-4 glucosidase which hydrolyzes disaccharides into simple sugars, a lipase which releases fatty acids and monoglycerides from emulsified triglycerides and phospholipases including phospholipase A, inactive pro-enzymes activated by the action of trypsin.

entérokinase ↓		
Trypsinogène --------------->	trypsine	(agissent à l'intérieur des (protéines pour donner des (peptides
Chimotrypsinogène -------->	chymotrypsine	
Proélastase ------------------>	élastase	
Procarboxypeptidase ------>	carboxypeptidase :	protéine --> AA-COOH libres
Lipase	Lipides	(DG ---> 2 AG (TG ---> AG + MG
Amylase	Polysaccharides ---> glucose ---> maltose	
Ribonucléase) Désoxyribonuléase)	Acides nucléiques ---> mononucléotides libres	

All this organic part of the pancreatic juice is secreted by the acinar cells.

SECRETINE : the main actions are:

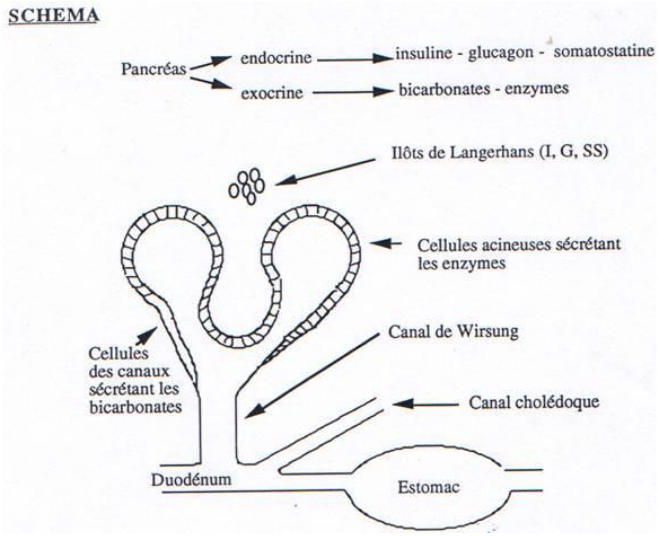
- Stimulate the secretion of gastric pepsin.
- Inhibit that of HCl.
- Stimulate biliary and intestinal secretions.
- Stimulate pancreatic secretion, especially that of bicarbonates but very little that of enzymes

Secretin secretion is stimulated by cholinergic fibers (vagus nerve), peptides, some amino acids and fatty acids and especially by H $^{+}$ ions .

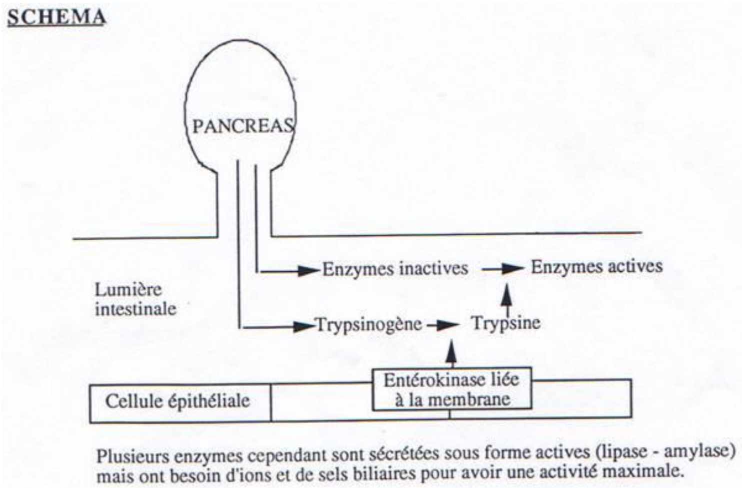
In summary, pancreatic secretion is dependent on:

- **From a cephalic phase** : *reflex* by vagal way,
- **From a gastric phase** by *gastrin* ,
- **From an intestinal phase** with *secretin* and *cholecystokinin* .

The action of the pancreas is decisive, because the bicarbonates bring the pH to a less aggressive value for the mucous membrane (more conducive to enzymatic activities which attack all types of nutrients), pancreatic amylase takes over from salivary amylase; lipase digests lipids and proteases further hydrolyze proteins.



Several enzymes, however, are secreted in active form (lipase – amylase) but need ions and bile salts to have maximum activity.



vs. Bile (Liver).

Biliary secretion is secreted at the rate of 0.5l/24h. Bile is secreted by the liver; then it is excreted through the bile ducts into the duodenum.

1. Membership.

Bile is a yellow, amber liquid, which turns green by oxidation; it consists of several elements:

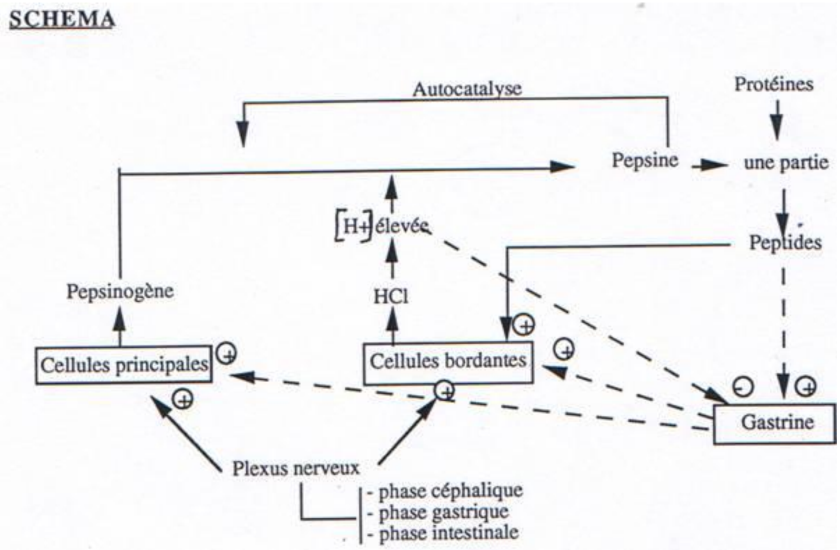
- *Aqueous solute of ions* : Na^+, K^+, Ca^{2+}, Cl^-, CO_3H^-.
- *Organic substances* : pigments, proteins, mucus;
- *Lipids such as bile salts* (70%), lecithins (25%) and cholesterol (5%).

Among the pigments, mention should be made of *bilirubin* , produced by the liver from the heme of hemoglobin resulting from the lysis of old red blood cells. Cholesterol and lecithins emulsify lipids.

Bile salts are physiologically important: they are synthesized from taurocholic and glycocholic acids, which are made by the liver, from cholic and deoxycholic acids , which have a hydrophilic part and are conjugated to two amino acids, taurine and glycocoll, to be even more hydrophilic. Bile salts play the role of detergents which, through the formation of micelles, solubilize lipids in water; they are partly reabsorbed by the intestine and return to the liver by the portal vein; they are then reused thanks to the ENTERO-HEPATIC cycle.

3. Role.

Thanks to the bicarbonates, the bile participates in the neutralization of the gastric chyme; thanks to bile salts, it allows the stable emulsion of dietary lipids (cholesterol, fat-soluble vitamins [A, D, E, K] and lipids) allowing their absorption. Bile salts increase colonic motility and promote defecation.



Intestinal juice.

The duodenal mucosa secretes mucus and bicarbonates (especially by *Brünner 's glands*), whose role is to *protect the mucosa* and *neutralize the pH* . The mucosa is very wrinkled, with numerous villi covered with a *unicellular layer of enterocytes* , the apical pole of which is bristling with microvilli giving the appearance of a brush border.

The enzymatic activity of the intestinal juice comes from the enzymes released by the rupture of the desquamated cells (200 g/24 h). Between the villi, crypts open, the *Lieberkuhn glands* , whose wall is made up of various types of cells:

- gastrin cells (G cells);
- secretin cells (S cells);
- cholecystokinin cells (Cells I);
- somatostatin cells (D cells);
- enteroglucagon cells (E cells);
- As well as other cells which would secrete other hormonal peptides.

Intestinal juice contains electrolytes, mucus and few enzymes except enterokinase which activates trypsinogen.

3. Digestive activity of the intestinal mucosa.

The digestive activity of the intestinal mucosa consists of a series of hydrolyses, more and more advanced, by osidases (lactase, maltase, sucrase) and by peptidases to give oses and amino acids. These simple molecules (oses or diosides , amino acids or peptides, fatty acids or monoglycerides, water and electrolytes) have sizes and physicochemical characteristics compatible with intestinal absorption.

3. "Digestion" in the large intestine (colon).

Due to digestive absorption, the colon receives only a still liquid mixture, which corresponds to food residues (cellulose fibers) and desquamated intestinal cells.

To. Colonic motility and defecation.

The colon consists of 3 segments the *right ascending colon* , the *transverse colon* , and the *left descending colon* ; then it opens into the rectum through the *sigmoid colon* .

Segmentation movements are very slow and non-propulsive; they allow the bolus to remain in the colon for 18 to 24 hours for the bacteria to multiply. Two to three times a day, the motricity increases to give mass contractions, in the ascending colon and in the transverse colon, thus pushing the bolus towards the descending colon, whose peristaltic movements bring the faeces to the *rectum* . Distention of the rectum by feces triggers the *defecation reflex* .

b. Chemical phenomena in the colon.

The cholinergic system increases colonic secretion and the adrenergic system reduces it. The colon is above all a place where the reabsorption of water and electrolytes takes place.

EXCRETORY SYSTEMS AND EXCRETION

General

A very wide variety of excretory structures exist in invertebrates, but they all function in the same way. They are classified into pulsatile vacuoles, nephridia, Malpighian tubes and antennal glands.

In Cnidarians and Echinoderms, there is no excretory apparatus because their internal environment is practically the same as the external environment. Excretion can therefore take place cell to cell (elimination by diffusion).

1. Pulsatile vacuoles

They exist in sponges. Two vacuoles work alternately. They swell with water and reject it. They can thus regulate their water content. The interior environment (the cytoplasm) is more concentrated than the exterior environment, so there is an entry of water. The membrane of the vacuole is dotted with micro-vacuoles which pour inside as a phenomenon of exocytosis. It must be hypotonic to swell while having a higher osmolarity on the outside to reject. The system therefore switches from one action to another depending on the osmolarity.

2. Nephridia

They are found in organisms with bilateral symmetry. It is a tube which opens to the outside through a pore and the other end of which is closed by a more or less complex structure.

2.1. Protonephridia

They exist in acoelomates . The protonephridia is in the form of a tube closed in a cul-de-sac forming an ampulla (fig.7). Inside is a cell called the flagellate excretory cell. It is either with a single flagellum, they are solenocyte nephridia, or with many flagella, they are flame nephridia. The set of flagella are glued to each other resembling the waxes.

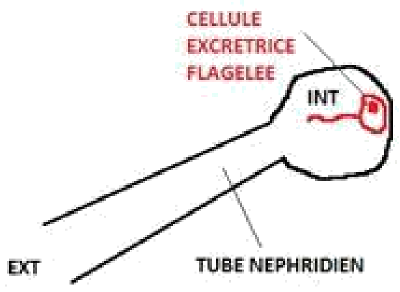


Figure 1 : Protonéphridie

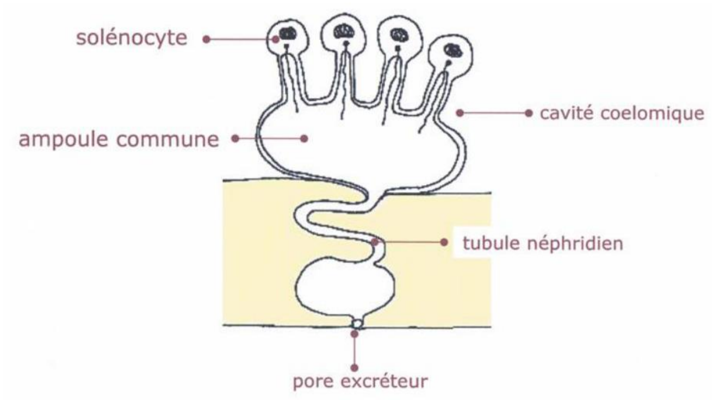


Figure 2 : Néphridie à solénocyte
(Chez les annélides)

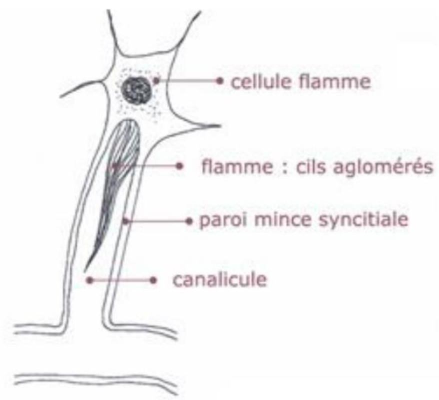


Figure 3 : Néphridie à flammes

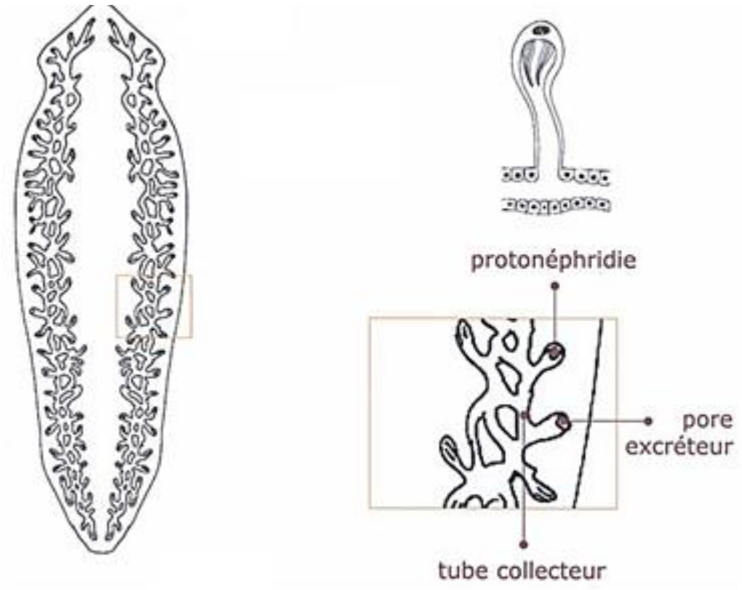


Figure 7 Système excréteur d'une planaire

- In trematodes much less nephridia then formation of 2 excretory ducts of larger diameter with a single urinary orifice in a posterior position.

- From the Nemerteans, there is a decrease in excretory cells then their association with the beginning of the circulatory system.
- In coelomates, the protonephridia do not open into the coelomic cavity and they do not evacuate gametes, just an excretory function. It is only in the most evolved polychaete annelids that the protonephridia is associated with a ciliated pavilion which opens into the coelom and evacuates the gametes (presence of coelomoducts = organ ensuring the role of evacuation of genital products).

- In Nematodes, the excretory system does not include protonephridia. The metabolic waste products of the internal cavity are collected by the Renette cells of ectodermal origin and evacuated by the excretory pore (fig.8). It is a system unique to Nematodes. In Ascaris, the Rénette cells are two long lateral canals which meet at the level of the excretory pore located just behind the mouth.

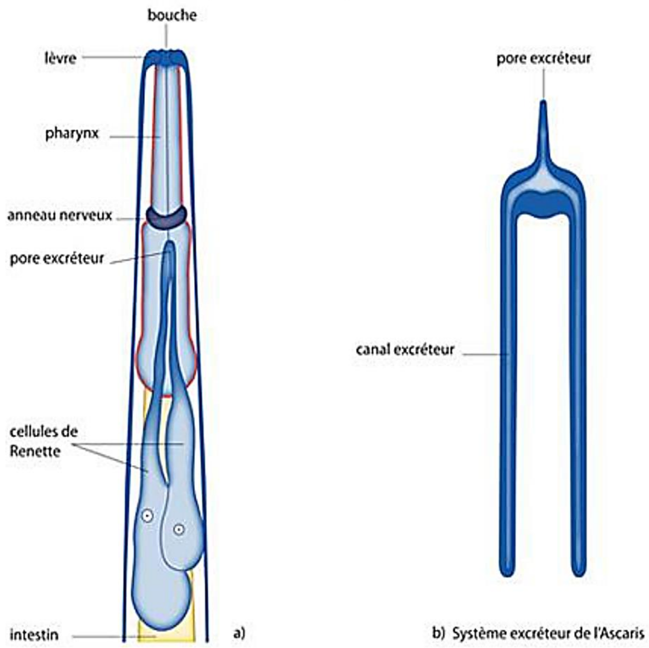


Figure 8 : Système excréteur d'un Nématode et de l'Ascaris

Nitrogenous wastes are released in the form of ammonia in the parasitic forms (these are ammoniotelics) and in the form of urea (these are ureotelics) or uric acid (these are uricotelics).

2.2. The Metanephredia (Coelomoducts with an excretory role)

They are found in less evolved coelomates such as Oligochaete Annelids. They are tubules open at both ends. The inner end of the nephridian tube opens into the coelomic cavity and will therefore drain coelomic fluid through cilia. At sexual maturity, the pavilion widens to allow the evacuation of gametes (fig.9). The liquid that leaves the coelom is isotonic with that of the coelomic medium. When he left, he was hypertonic. The nephridian tube reabsorbs water, amino acids and oses. The metanephridia will function more or less like a kidney: coupled mechanism of filtration and reabsorption .

- In the sedentary annelids (the sabellids), there are only 2 metanephridia in the interior region of the animal.

- In leeches, the auricle disappears, as well as the pore and the lumen of the tube. There is appearance of a pocket (bladder) which collects the waste produced by the cellular unit.

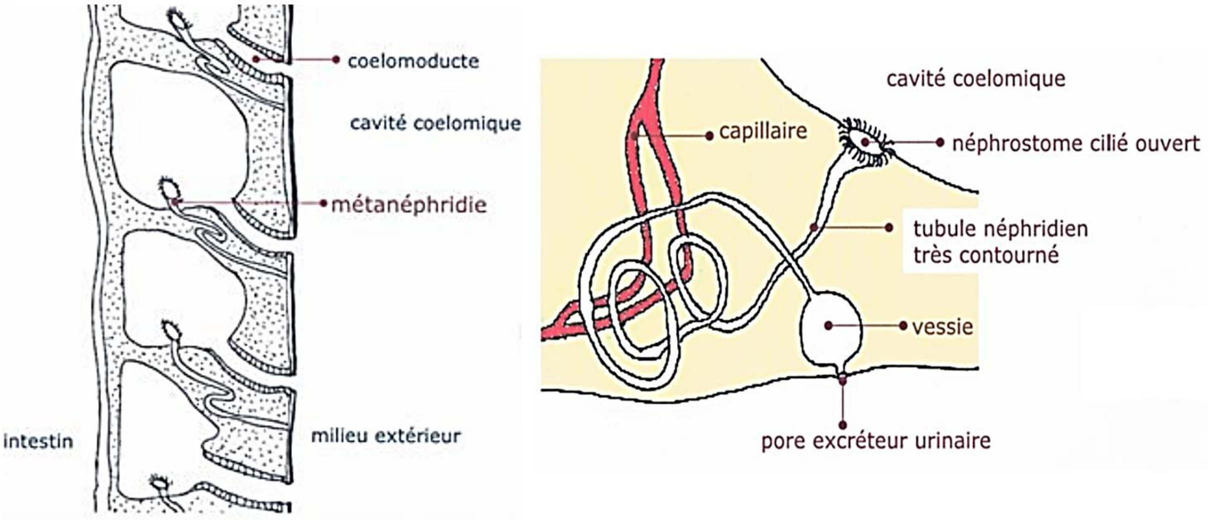


Figure 9 Métanéphrédies chez les annélides primitifs

Note : In earthworms, the nephridian tube is long, hence efficient reabsorption.

- In Molluscs, the metanephridia constitute the organ of Bojanus whose wall is pleated, giving rise to an exchange surface (fig.10). This organ is in relation on the one hand with the pericardial cavity by a reduced pericardial orifice and on the other hand with a ureter which supports the urine produced. It evacuates the waste by constituting the urine while reabsorbing other molecules. The nephridian sac is a place of concentration of urine

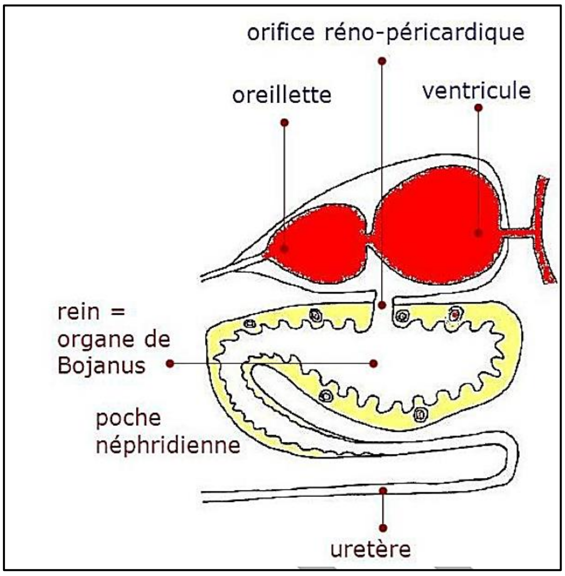


Figure 10 : Organe de Bojanus chez un Gastéropode

The pericardial glands or Weber's organ filter the blood and reject metabolic waste products into the pericardium where they are taken up by the Bojanus organ . Nitrogenous wastes are guanine in cephalopods; urea in Lamellibranchs; uric acid in terrestrial gastropods or ammonia in freshwater gastropods.

3. Malpighian tubules

Malpighian tubules are present in terrestrial arthropods. These are evaginations of the terminal part of the digestive tract. They have a tubular shape and have a structure related to that of nephrons vertebrates. Their number varies from two to more than one hundred depending on the species . They open into the intestine at the junction between midgut and hindgut. They allow excess water to circulate (ensure osmoregulation). They work as follows:

- In the distal part of the Malpighian tubes there is ultrafiltration by secretion: active transport transports ions (Na+, K+, urate) from the haemolymph towards the lumen of the Malpighian tube. By osmotic effect, the water will passively follow the exit of the ions. → Formation of primary urine.
- In their proximal part (basal) and especially at the level of the rectum, there is a reabsorption of water and ions (Na+, K+). → Formation of a definitive urine
- The urate will be eliminated with the excrements at the level of a cloaca (= common orifice for excretion and digestion). Thus in insects, there is no individualized excretory orifice, and the metabolic wastes are mixed with the digestive wastes.

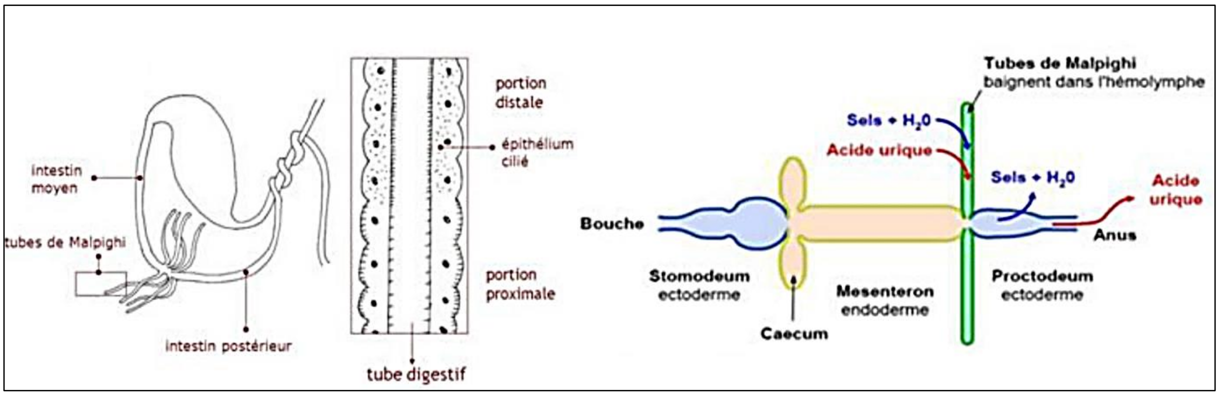


Figure 11 Tube de Malpighi et son fonctionnement (Myriapodes, Arachnides et insectes)

In a large number of insects, the regulation of excretion is regulated by serotonin (monoamine neurotransmitter secreted by the intestine).

4. The antennal glands

In Crustaceans, there is a significant regression in the number of metanephridia (max: 6 and 2 most of the time). The excretory apparatus consists of the antennal gland (= green gland). It is a complex gland which has the same role as the kidney of vertebrates. She comprises a coelomic part, an excretory canal and a bladder opening to the outside through the antennal pore (fig. 12). This excretory pore opens at the level of the basipodite of the antennae (second pair of appendages). The antennal gland secretes urine isotonic with hemolymph. Crustaceans eliminate their nitrogenous waste in the form of ammonia.

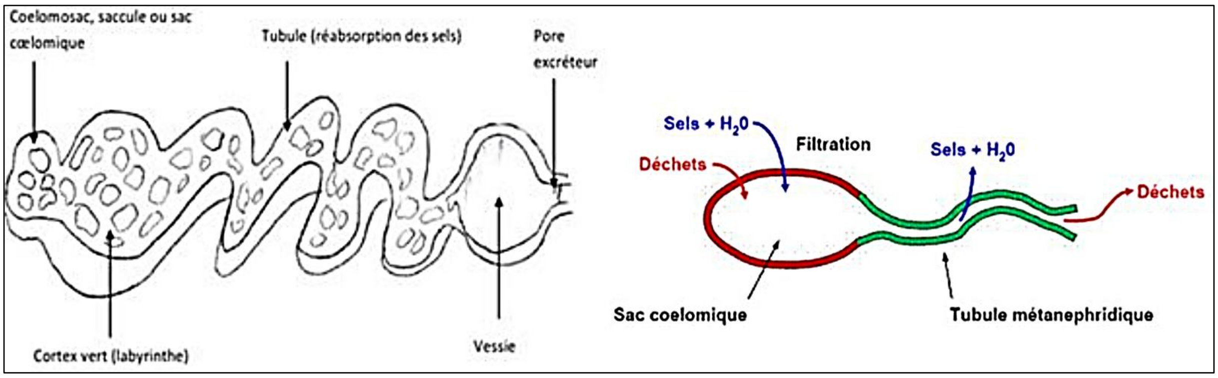


Figure 12 : Glande antennaire et son fonctionnement

Note : In other groups of Arthropods, a gland of the same structure exists, it is the maxillary gland which has the same functions. The gills also act as organs of excretion. In spiders, it is the coxal glands (located at hip level) that eliminate their waste products in the form of urea or uric acid .

Types of excretion

- **Ammoniotelic animals** : These are animals that break down uric acid to the point of ammonia formation. These are crustaceans and some marine invertebrates .

- **Uricotelic animals** : These are animals whose protein metabolism results in the formation of uric acid. These are aerial gastropods.

- **Ureotelic animals** : These are animals that eliminate urea CH4N2

Note : Non-specialized devices remove different types of solutes as urine.

The movements of water and ions at the level of the renal systems

The renal systems are major players in blood osmoregulation in most species. Since osmotic problems are not essential in isosmotic marine species, some of them have lost their renal structures. This is the case of echinoderms and urochordates (tunicates). The kidneys, when present, also play an essential role in the purification of the blood and in the elimination of soluble "waste products". This function of excretion, like that of osmoregulation, is directly linked to the significant movements of water that take place at the renal level.

Water movements in the renal systems can involve two different mechanisms: ultrafiltration under pressure or diffusion following an osmotic gradient generated by active ion transport. Except in insects, entry of water into the renal systems is by ultrafiltration. Some of this water can be reabsorbed in different species. This reabsorption always takes place by diffusion along an osmotic gradient.

In vertebrates, we speak of a glomerular filtration rate, ultrafiltration taking place in most of them at the level of a structure called Malpighian glomerulus. Knowing the quantity of ultrafiltered water and the quantity of urine formed at the same time, the quantity of reabsorbed water is obtained by simple subtraction.

The use of this technique has made it possible to show the existence of an ultrafiltration mechanism in all the animals studied so far possessing renal structures, except insects. In the latter, urine is formed in Malpighian tubes at the level of which the entry of water takes place by osmotic movement.

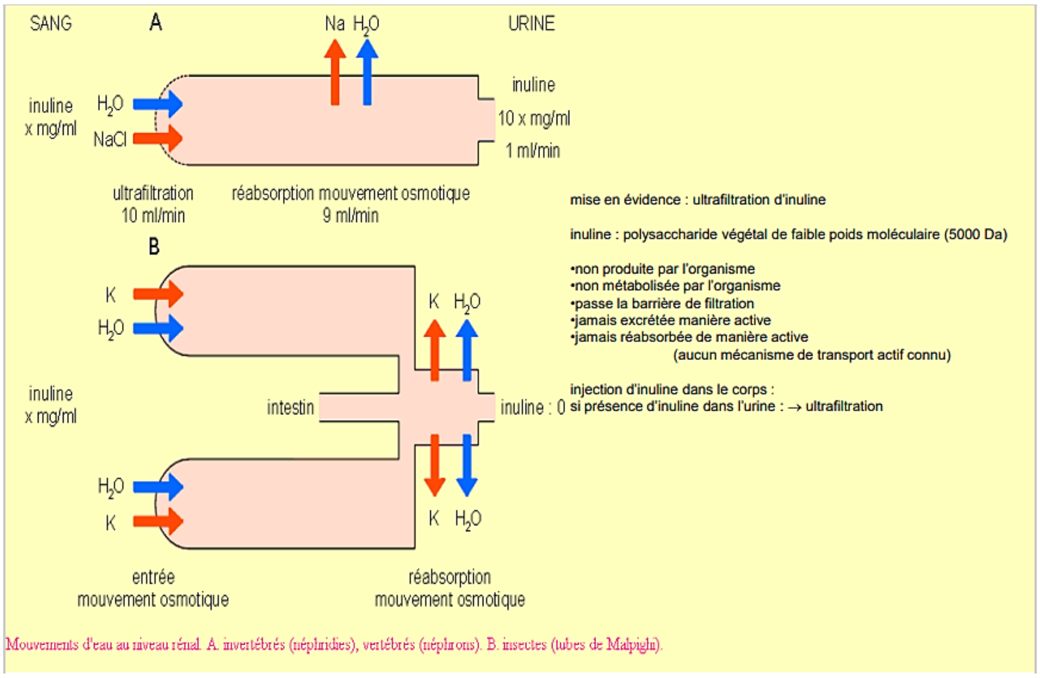


Figure 13: Water movements at the renal level. A: invertebrates (nephridia), vertebrates (nephrons). B: insects (Malpighian tubes).

Invertebrates have more or less complex excretory organs, thanks to which they reject waste products outside the body. These organs are made up of units called *nephrons* . These units can remain isolated, or group together in more complex structures which then bear the name of *kidneys* . The aspects that these organs can take are very variable, but they nevertheless present a great unity with regard to the cellular mechanisms of their functioning.

All living beings do not live in the same environmental conditions. In marine aquatic animals (fish) will have a living environment containing much more sodium chloride than a freshwater teleost . Certain living beings are said to be osmoconform because they adopt the osmotic pressure of the medium, if this remains more or less constant (for example sea water 1047 mosmol / L). Others are called osmoregulators, that is, it has a different osmolarity than their living environments. For terrestrial animals, the osmolarity regulation strategy is essentially based on the water factor.

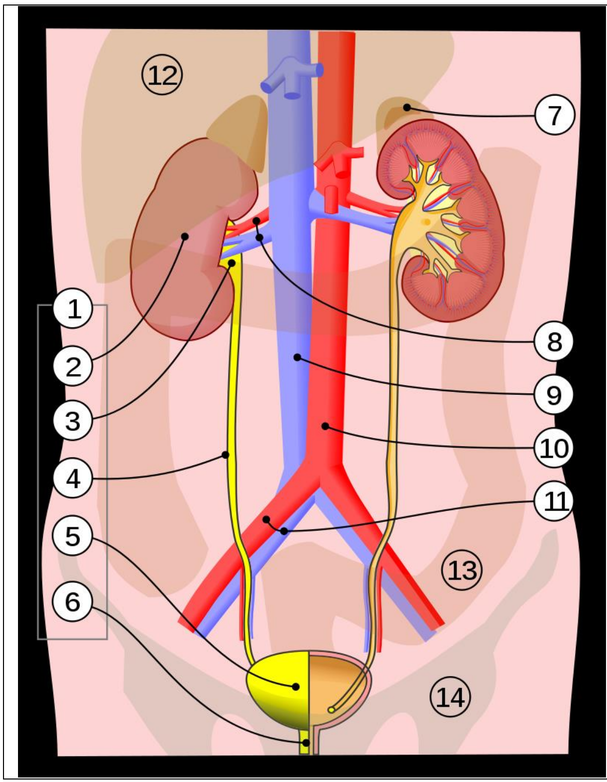
system in vertebrates

The urinary system consists of the kidneys , ureters , bladder , and urinary meatus . It forms and begins to function before birth. The role of this device is to form the urine which will be evacuated. Urea is excreted by the kidneys which make urine; the latter is conveyed by the ureter to the bladder, a pocket retaining the urine, then rejected outside the body during urination by the urethra opening into the urinary meatus.

The **kidney** has a secretory function (filtration of blood at the level of the glomeruli) then excretory from the pyelon (triangle based on the renal hilum) origin of the ureter. Each kidney contains approximately 1 million nephrons . Each kidney has adrenal glands . They secrete hormones that change the amount of urine produced. The blood is purified at the level of the nephron , in which certain elements are reabsorbed (mineral ions, glucose, water, amino acids) and will return to the blood circulation through the renal vein . The recovered waste constitutes a primitive urine which will be poured into the renal pelvis, then into the ureter adjoining the kidney from which it originates.

The urethra and an extension of the kidneys. Their role is to collect urine from the renal pelvis. They look like *tubes* whose upper end takes the form of a funnel, made up of smooth muscle fibers preventing urine reflux. The ureter runs downward to join the postero-superior part of the bladder.

The bladder is in the form of a pocket whose walls are made of smooth muscle (the detrusor) and epithelial tissue: we speak of the vesico-urethral neck. It collects urine that reaches it through the ureters. Urine passes through the urethra during urination . Control of urination is achieved by a smooth sphincter with involuntary control and by a voluntary striated sphincter used in case of forced restraint.



1. Human **urinary system** :
2. Kidney ,
3. Renal Pelvis ,
4. Ureter ,
5. Bladder ,
6. Urethra .
7. Adrenal gland ,
8. Renal artery and vein ,
9. Inferior vena cava ,
10. Abdominal aorta ,
11. Common iliac artery and vein ,
12. Liver ,
13. Large Intestine ,
14. Pelvis .

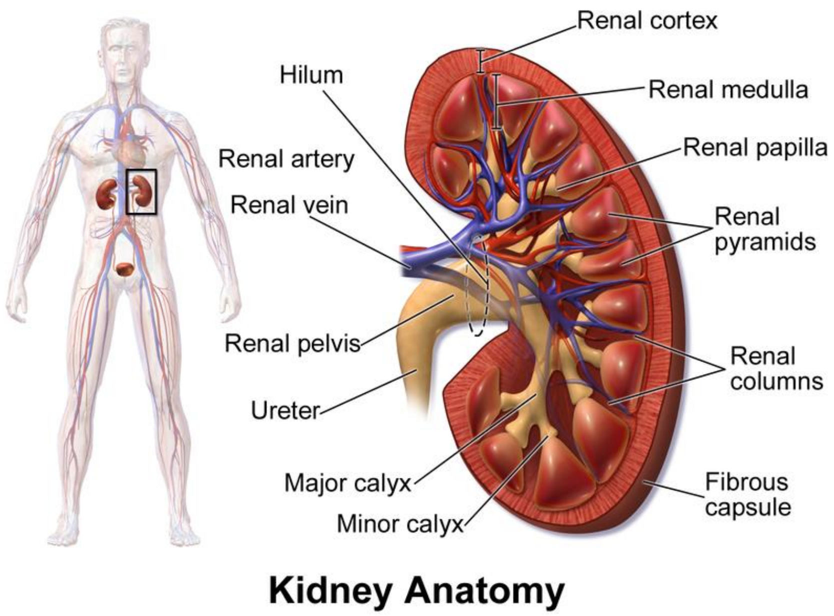


Figure 14: excretory system in vertebrates

NERVOUS SYSTEMS IN INVERTEBRATES

NEURO-SENSORY SYSTEM

I- THE NERVOUS SYSTEM

The nervous system of Decapod Crustaceans is divided mainly into two nerve masses: the brain and the ventral nerve chain. The latter is joined by perioesophageal commissures .

The brain appears as a flattened rectangular mass with fibrous bundles called neurophiles . It includes the protocerebron , deutocerebron, and tritocerebron .

The protocerebron is associated with the optic nerves and with the motor nerves of the ocular peduncle which is the best known neurocrine organ in Crustaceans. It is also the main neuroendocrine organ for various physiological processes.

The deutocerebron innervates the antennules and the integumentary epithelium. The tritocerebron innervates the antennae and commissures of the perioeusophageal collar .

The ventral nerve chain has the appearance of a stellate disc with a central orifice from which the sternal artery enters. The pairs of nerves which emanate from it are:

the nerves of the oral appendages,

the intestinal nerves,

the nerves of the periopods,

the braking and accelerating nerves,

the single nerve branching from the dorsal surface of the stomach.

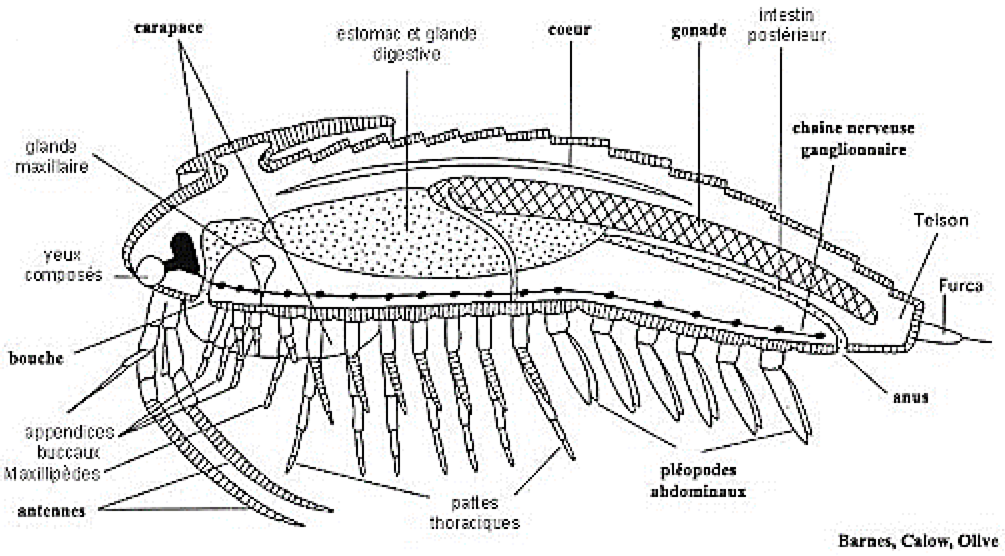
At the level of the commissural system, ganglia control the stomagastric or sympathetic system which innervates the digestive tract

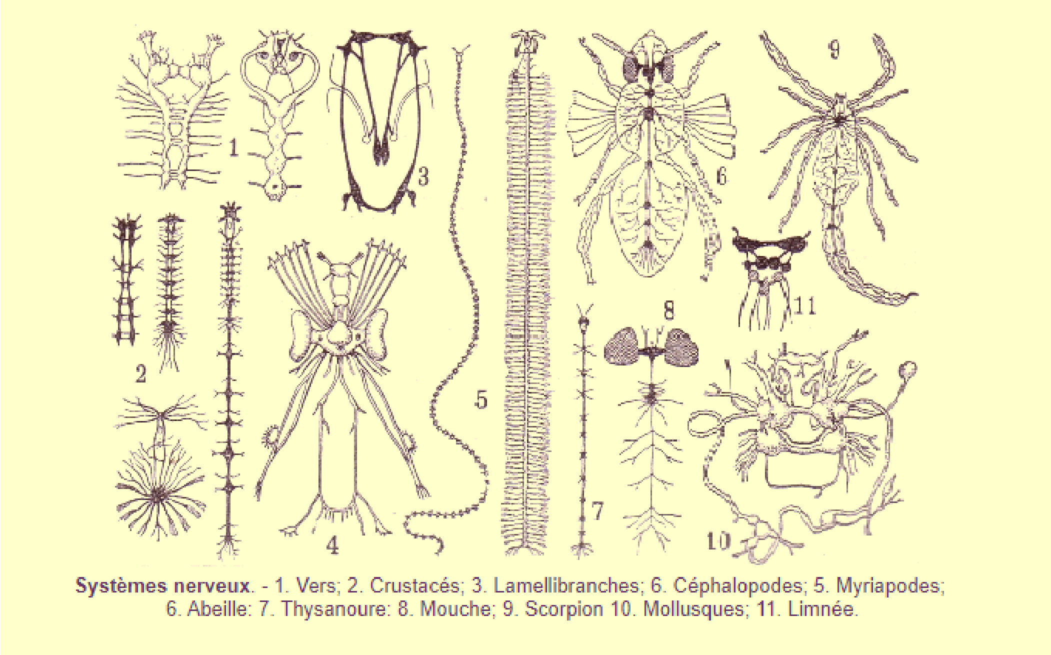
II THE SENSE ORGANS

The sense organs are specialized in the perception of physical (currents, moving object, etc.) and chemical (dissolved elements) factors of water. Overall, we distinguish the mechanoreceptors, the chemoreceptors, the balance organ or statocyst, the organ of hearing and the ocular peduncle.

Mechanoreceptors are for the perception of physical stimuli. They are represented by the bristles and barbules that completely cover the animal's body, including the antennules, antennae, pleopods and periopods. Chemoreceptors are generally distributed over the antennules and mouthparts, especially the maxillipeds.

The balancing organ is ensured by a statocyst located at the base of the antennules. It is lined internally with barbed or simple bristles and contains fluid and stotoliths (grains of sand coated in mucus). The movement of these in the liquid stimulates the bristles and informs the animal of its position in the water. The organ of hearing perceives acoustic waves but the mechanism of operation remains poorly understood. Finally, photoreception is ensured by the visual cells or ommatidia of the ocular peduncles.





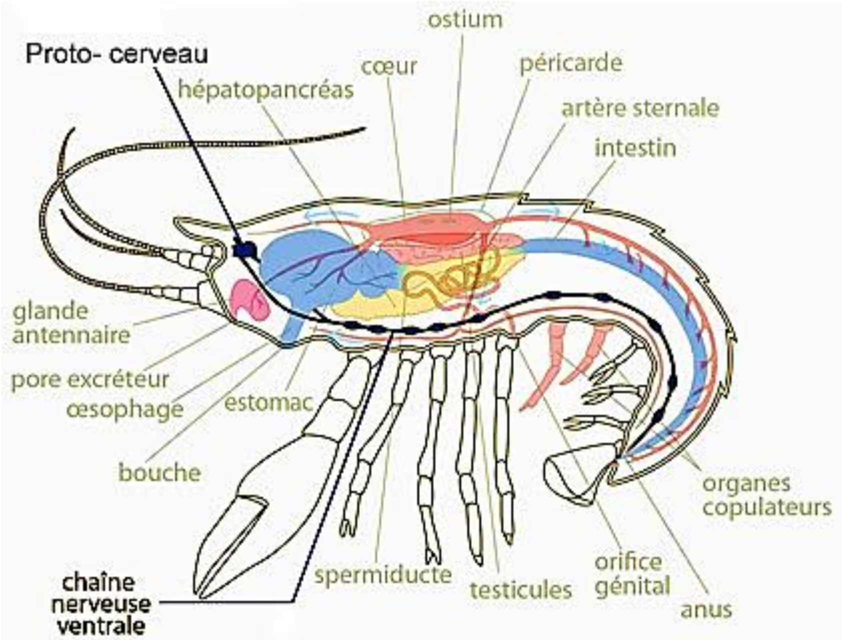


Figure 15 nervous system in different invertebrates

NERVOUS SYSTEMS IN VERTEBRATES

The central nervous system (CNS)

It is generally bilateral and symmetrical and is composed of two parts:

- *The central nervous system* is found in the bony structures and is formed by the spinal cord and the brain.

- *The peripheral nervous system* is made up of ganglia and nerves. These nerves contain bundles of fibers that connect at the base of the brain to the cranial nerves and the spinal cord.

The peripheral nervous system is divided into two components:

- *The somatic peripheral nervous system* receives sensory fibers from various sensory organs: skin, muscles, joints. It also includes the *primary motor fibers* (mainly) of the muscles.
- *The autonomic* (or vegetative) peripheral nervous system: its fibers innervate the smooth muscles, the heart and the glands.

The peripheral nervous system provides information to the central nervous system and executes its motor commands.

The central nervous system is divided into 7 main parts.

1 The spinal cord

2 The myelencephalon (rachidian bulb).

3 and 4 The metencephalon. It is made up of two structures: **the pons and the cerebellum** .

5 The midbrain. It controls eye movement and general motor skills. It is a relay center for visual and auditory information.

6 The diencephalon.

7 Telencephalon.

It is mainly made up of the *cerebral cortex* (the gray matter of the brain) and the *white matter* underlying this complex.

Note: The hippocampus and amygdala form the *limbic system* .

8 The cerebral cortex.

Note: The limbic lobe: neurons form a complex circuit and participate in motivation, memory and emotions. The lobes are divided into *functional areas* that will be involved in processing sensory information or motor activities.

2 Organization of functional systems. The organization follows four principles.

Each system includes relay centers organized into afferent (sensory) and efferent (motor) pathways. The neurons take turns at the level of the hyperstructures of the central nervous system: relay nuclei (spinal cord plus brain).

Note: the interneurons will allow a modification of the information.

II The sensory systems.

They come from the sensory organs of the periphery. We first have the sensation and then the perception of information at the cortical level.

2 Organization of sensory systems.

In each sensory system, sensation arises when environmental factors stimulate the cells corresponding to a modality. Specialized nerve cells are called sensory receptors.

Modalité	**Stimulus**	**Type de récepteur**
Vision	Lumière	Photorécepteur
Audition (équilibration)	Ondes de pression	Mécanorécepteur
Gustation et Olfaction	Chimique	Chémorécepteur
Somesthésique	Mécanique Thermique Chimique	Mécanorécepteur Thermorécepteur Chémorécepteur

B The somatosensory system.

It differs from other sensory systems because it is distributed throughout the body while the others are grouped into sensory organs.

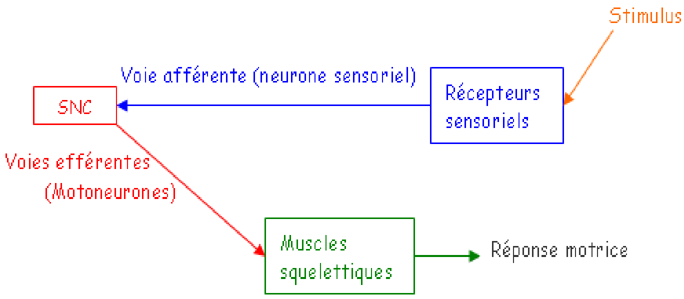
1 Receivers.

Modalités	**Récepteurs**	**Sensibilité**
Toucher	Mécanorécepteur	Pression Toucher Vibration
Proprioception	Propriocepteur – muscles< – articulations – tendons	Position relative des membres
Thermique	Thermorécepteur	Froid Chaud
Douleur	Nocirécepteur	Température Stimulation mécanique Stimulation chimique

III The motor system. They are organized on several levels.

A Reflex activities (at the level of the spinal cord).

A sensory-motor connection is called a reflex arc.



There are two types of reflexes:

- **Monosynaptic** : it is a fast reflex (myotatic reflex) which causes the contraction of a muscle to its own stretch. The sensory receptor is located in the muscle (it is intrinsic). We then have a fine control of the length of the muscle.
- **Polysynaptic** : information passes through two or more synapses. It has a protective role. It is an ipsilateral flexion **reflex whose receptor is** *extrinsic* (outside the muscle).

The reflexes are constantly controlled by the supraspinal structures which act on the motoneurons or via the interneurons of the spinal cord.

C Voluntary movements. A conscious motor act is controlled from motor cortical areas.

1 Motor cortical areas.

a Primary motor areas.

All the muscles are represented there. These areas are organized somatotopically (representation depends on the muscles). If we stimulate a point, we have a contraction of the opposite corresponding muscle. This motor area is therefore associated with the execution of movements.

b Higher-order motor areas.

A distinction is made between the premotor area (or premotor cortex) and the superior motor area (**AMS**).

They are also organized somatotopically but less finely. If we stimulate the premotor area, we can obtain the contraction of a whole limb.

Motor arcs are more or less complex . The first two areas are involved in the programming of a movement. The upper motor area is necessary to conceive and apprehend this movement.

2 The main motor pathways.

We have two large parallel systems that will transmit the commands of the motor areas.

a The direct system.

It consists of two main routes:

- **Cortico-bulbar** : it controls the voluntary motricity of the muscles of the face.
- **Cortico-spinal** (*pyramidal way*): it controls the voluntary motricity of all the other muscles of the body. It is divided into two corticospinal bundles, lateral and ventral.

b The indirect system. There is an indirect system, the cortico- **rubro -spinal pathway** , which carries out a relay at the level of the gray nucleus, in the midbrain. It serves to refine the movement.

3 Control of voluntary movements.

This control is carried out using three sources of information:

- *sensory pathway* : permanent information on the position of the body and muscles
- *information from the cerebellum*
- *information from the gray nuclei* .

a Sensory information.

This information comes directly from the sensory receptors or from the higher order and associative primary sensory cortical areas.

The posterior parietal cortex is a great source of information.

We therefore have an adaptation of the motor commands according to the circumstances.

b Information from the cerebellum.

The cerebellum also regulates the execution of movements when necessary . It receives many afferents, from the spinal cord and the motor cortex: it receives the copy of the motor program given by the motor areas.

The cerebellum also collects somatosensory and labyrinth sensory information .

There are three main regions of the cerebellum.

1 The spinal cerebellum. It is made up of the *vermis* and the *intermediate hemispheres* . It receives sensory (somesthetic) information and *supervises* postures (cf. the execution of voluntary movements). It *compares* the motor commands with the results of the execution of the motor act and can *possibly modify* this command.

The action is done by:

- **direct route** : from the cerebellum to the brainstem (spinal cord).
- **longer route** : from the cerebellum to the cerebral motor cortex and then to the spinal cord.

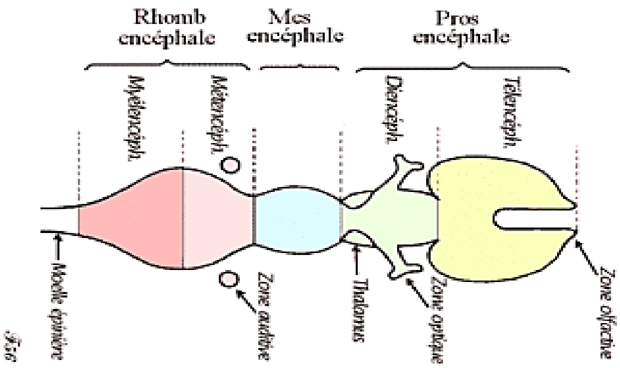
2 The cerebral cerebellum. It is constituted by the *lateral zone of the hemispheres* . This zone mainly establishes *relations with the cerebral motor cortex* (bilateral relations) during *programming* .

3 The vestibular cerebellum.

It corresponds to the *flocculo -nodular lobe* . It receives the labyrinth and visual information. It is *involved in all postural reactions* as well as in the combined movements of the head and eyes. It is also *somatopically organized* .

c The gray core of the base.

It comprises three large nuclei: the *bent nucleus* , the *putamen* (these two structures form the telencephalon), and the *pallidum* . These nuclei are connected to each other and to other structures such as the *subthallamus* (which belongs to the diencephalon) and to a *substantia nigra* (which is part of the midbrain). These structures involve many transmitter neurons. They would seem to select the most suitable movements in a given condition. Parkinson's disease (slowness and poverty of movement) is the problem of a path going from the *substantia nigra to the striatum* (with, as neurotransmitter: dopamine **)** .


Rhomb encéphale
Mes encéphale
Pros encéphale
Myélencéph.
Métencéph.
Diencéph.
Télencéph.
Moelle épinière
Zone auditive
Thalamus
Zone optique
Zone olfactive

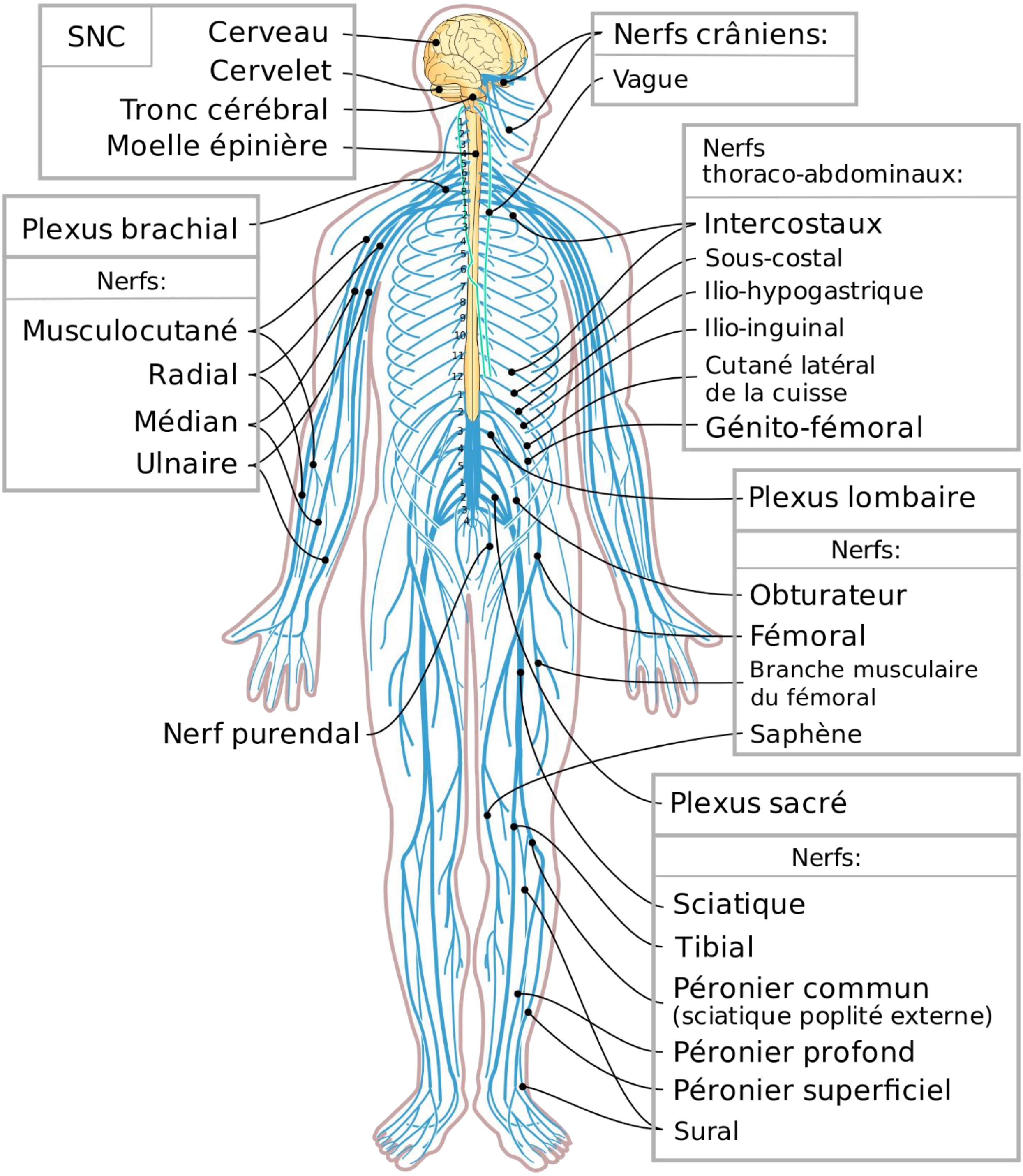
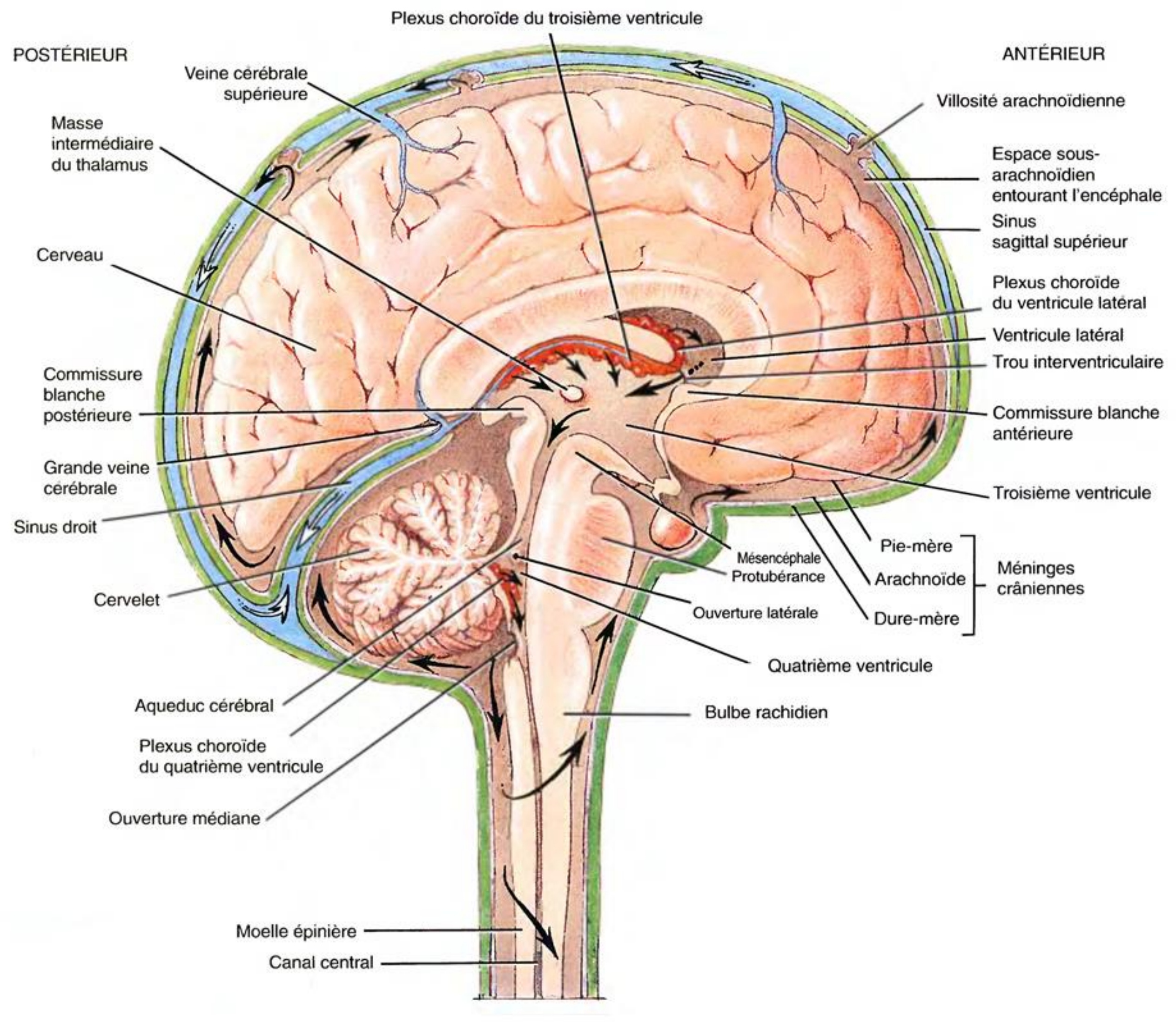


Figure 16 nervous system in vertebrates (case of man)



Coupe sagittale de l'encéphale, des ventricules, de la moelle épinière et des méninges

Figure 17 nervous system (sagittal section of the brain, ventricles, spinal cord and meninges)

THERMOREGULATION

Thermoregulation is the set of mechanisms that allows an organism or a system to maintain itself at a **desired** temperature . In the living world, there are **homeothermic organisms poikilothermic** organisms . Poikilotherms are organisms whose internal temperature varies with the temperature of their environment, unlike homeotherms which have effective thermoregulation allowing control of their temperature. Thermoregulation occurs through thermolysis (heat loss) and thermogenesis (heat production).

endotherms (mammals and birds) are distinguished from **ectotherms** , according to the mode of thermoregulation they express. In endotherms, thermoregulation is overwhelmingly physiological since these organisms have developed capacities for massive and permanent production of internal heat thanks to multiple adaptations.

On the other hand, the ectotherms, which represent more than 99% of animal diversity, produce a negligible quantity of metabolic heat, not making it possible to establish a temperature differential with the environment. Significant heat production in ectotherms is limited to rare exceptions (certain flying insects, large fish, some pythons, in particular). However, most ectotherms can maintain stable temperatures despite environmental thermal variations by adjustments.

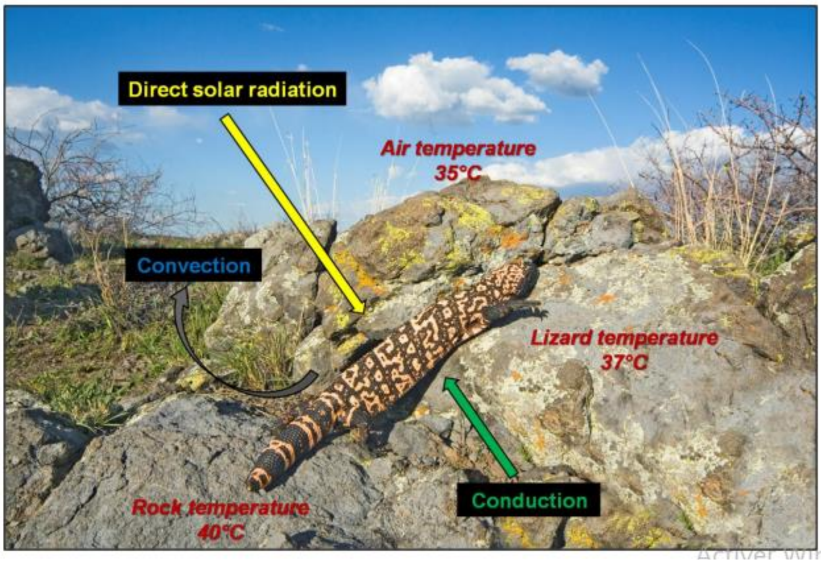


Figure 18. Heat exchanges favoring thermoregulation in an ectotherm. The diagram shows 3 pathways of exchange: 1. gain by radiation, 2. gain by conduction if the body temperature of the animal is lower than that of the substrate, 3. loss by convection if the body temperature of the animal is lower to that of air.