ANIMAL PHYSIOLOGY
AND PHYSIOLOGICAL CHEMISTRY
PAPER MZO503
PART II

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COMPARATIVE PHYSIOLOGY
OF
IMMUNE SYSTEM

What is an Immune System?

The immune system is made up of special organs, cells and chemicals that fight infection (microbes). The main parts of the immune system are: white blood cells, antibodies, the complement system, the lymphatic system, the spleen, the thymus, and the bone marrow. These are the parts of your immune system that actively fight infection.

Parts of the immune system

The main parts of the immune system are:

- white blood cells
- antibodies
- complement system
- lymphatic system
- spleen
- bone marrow
- thymus

White blood cells

•White blood cells are the key players in your immune system. They are made in your bone marrow and are part of the lymphatic system.

•White blood cells move through blood and tissue throughout your body, looking for foreign invaders (microbes) such as bacteria, viruses, parasites and fungi. When they find them, they launch an immune attack.

•White blood cells include lymphocytes (such as B-cells, T-cells and natural killer cells), and many other types of immune cells.

Antibodies

•Antibodies help the body to fight microbes or the toxins (poisons) they produce.

•They do this by recognizing substances called antigens on the surface of the microbe, or in the chemicals they produce, which mark the microbe or toxin as being foreign.

• The antibodies then mark these antigens for destruction. There are many cells, proteins and chemicals involved in this attack.

Complement system

•The complement system is made up of proteins whose actions complement the work done by antibodies.

Lymphatic system

The lymphatic system is a network of delicate tubes throughout the body. The main roles of the lymphatic system are to:

manage the fluid levels in the body

•react to bacteria

•deal with cancer cells

•deal with cell products that otherwise would result in disease or disorders

•absorb some of the fats in our diet from the intestine.

The lymphatic system is made up of:

•lymph nodes (also called lymph glands) -- which trap microbes

•lymph vessels -- tubes that carry lymph, the colorless fluid that bathes your body's tissues and contains infection-fighting white blood cells

•white blood cells (lymphocytes).

Spleen

The spleen is a blood-filtering organ that removes microbes and destroys old or damaged red blood cells. It also makes disease-fighting components of the immune system (including antibodies and lymphocytes).

Bone marrow

Bone marrow is the spongy tissue found inside your bones. It produces the red blood cells our bodies need to carry oxygen, the white blood cells we use to fight infection, and the platelets we need to help our blood clot.

Thymus

The thymus filters and monitors your blood content. It produces the white blood cells called T-lymphocytes.

The body's other defenses against microbes

As well as the immune system, the body has several other ways to defend itself against microbes, including:

Skin - a waterproof barrier that secretes oil with bacteria-killing properties

Lungs - mucous in the lungs (phlegm) traps foreign particles, and small hairs (cilia) wave the mucous upwards so it can be coughed out

Digestive tract - the mucous lining contains antibodies, and the acid in the stomach can kill most microbes

Other defenses - body fluids like skin oil, saliva and tears contain anti-bacterial enzymes that help reduce the risk of infection. The constant flushing of the urinary tract and the bowel also helps.

Immune System in invertebrates

•From the lowliest **protozoans** to the higher marine tunicates, invertebrates have means of distinguishing self components from nonself components.

•**Sponges** from one colony will reject tissue grafts from a different colony but will accept grafts from their own.

•When tissue grafts are made in animals higher up the evolutionary tree—between individual **annelid worms** or **starfish**, for example—the foreign tissue is commonly invaded by phagocytic cells (cells that engulf and destroy foreign material) and cells resembling lymphocytes (white blood cells of the immune system), and it is destroyed.

•Yet tissues grafted from one part of the body to another on the same individual adhere and heal readily and remain healthy.

• So it seems that something akin to cellular immunity is present at this level of evolution.

•Insects engulf and eliminate foreign invaders through the process of phagocytosis ("cellular eating").

• They have factors present in their circulatory fluids that can bind to foreign cells and cause clumping, or agglutination, of a number of these cells, an event that facilitates phagocytosis. Insects also seem to acquire immunity to infectious agents.

Immune capacity among vertebrates

•The most sophisticated immune systems are those of the vertebrates.
•Recognizable lymphocytes and immunoglobulins (Ig; also called antibodies) appear only in these organisms.
•The most primitive living vertebrates—the jawless fishes (hagfish and lampreys)—do not have lymphoid tissues corresponding to a spleen or a thymus, and their immune responses, although demonstrable, are very weak and sluggish.
•Farther up the evolutionary tree, at the level of the cartilaginous fishes (sharks and rays) and the bony fishes, a thymus and a spleen are present, as are immunoglobulins, although only those immunoglobulins of the IgM class are detectable.
•Fish lack specialized lymph nodes, but they do have clusters of lymphocytes in the gut that may serve an analogous purpose.
•It is not until the level of the terrestrial vertebrates—amphibians, reptiles, birds, and mammals—that a complete immune system with thymus, spleen, bone marrow, and lymph nodes is present and IgM and IgG antibodies are made.
•Antibodies of the IgA class are found only in birds and mammals, and IgE antibodies are confined to mammals.
•So it appears that the most primitive devices for producing specific, acquired immunity gradually diversified to meet the new environmental hazards as animals moved out of the sea onto the land.

In higher vertebrate defense system is broadly divided in innate and adaptive immune system

Innate immune system: Fast and broadly effective

- The strength of the innate, general defense is to be able to take action very quickly.
- It makes sure, for example that bacteria that have entered the skin through a small wound are detected and partly destroyed on the spot within a few hours.
- As the innate immune response is not specialized for specific pathogens, it does not need a long start-up phase. Because of this broad effect, it is only capable to a certain degree of stopping germs from entering and spreading in the body.
- The innate defense consists of several elements:
  - ❖The skin and all mucous membranes in the body openings, which form external barriers
  - ❖Different defense cells from the white blood cell group (leukocytes)
  - ❖Various substances in the blood and in body fluids
- All external and internal surfaces of the human body are a key element of the innate immune system.
- The closed surface of the skin and of all mucous membranes already forms a mechanical barrier for pathogens, which prevents them from entering.
- Additionally, chemical substances like acid, enzymes or mucus prevent the bacteria or viruses from gaining a foothold. Movements created, for example, by hair-like structures in the bronchi (cilia) or by bowel muscles stop germs from settling in the body.
- Tear fluid, sweat, or urine rinsing the urinary organs all have a similar effect.

The adaptive immune system: Precision and a long memory

•If the body's first line of defense – the innate immune system – is unsuccessful in destroying the pathogens, after about four to seven days the specific adaptive immune response sets in.

•This means that the adaptive defense takes longer, but it targets the pathogen more accurately. Another advantage: It can remember the aggressor and acts specifically against certain antigens.

•If there is new contact with an antigen that is already known, the defense response can then be quicker.

•This way the defense responses of the adaptive immune system are more efficient and faster than those of the innate defense, if the antigen is already known.

•The adaptive immune system can remember the antigens because it produces memory cells. This is also the reason why there are some illnesses you can only get once in your life, because afterwards your body becomes "immune."

•While after first contact with the pathogen it takes several days for the immune system to respond, a second infection often has no consequences, or at least the symptoms are weaker.

The adaptive immune system has several parts that react in different ways, depending on the place in the body where the pathogen is.
These parts of the adaptive defense include:

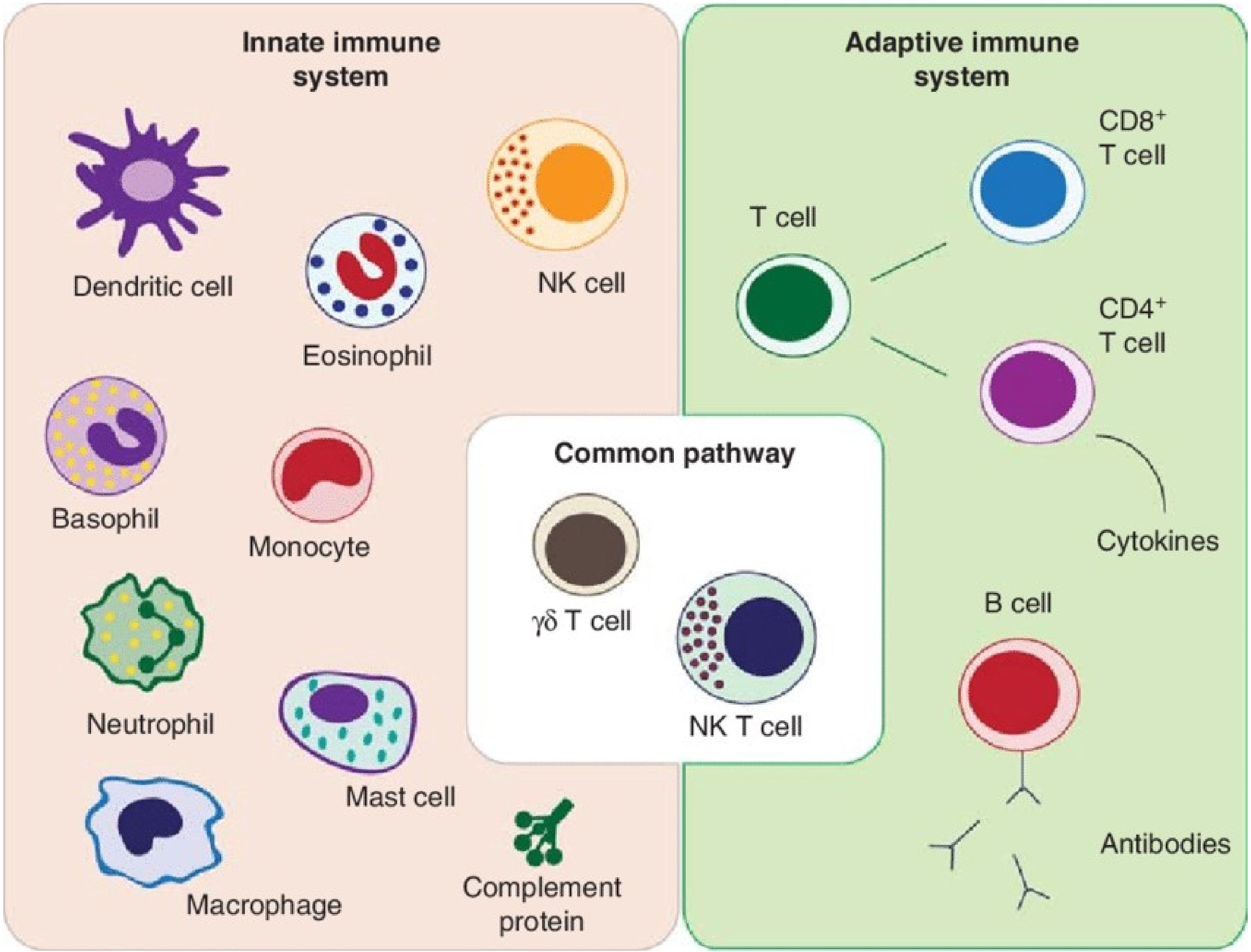
- T lymphocytes
- B lymphocytes
- antibodies as soluble proteins in the blood
- cytokines in the blood and tissue as hormone-like messenger substances

T lymphocytes

- T lymphocytes belong to the group of white blood cells and, in adults, are produced in the bone marrow.
- In the thymus gland, they mature into cells that are capable of recognizing self from non-self cells. T cells have characteristic structures on their surfaces that pathogens can bind to – similar to a lock that a specific key fits to.
- A pathogen that exactly fits a T cell stimulates this T cell to multiply quickly and to develop into specialized T cells.
- At the same time, the great number of newly produced T cells triggers other defense reactions. This leads to the pathogens being destroyed and eliminated from the body.

B lymphocytes

- B lymphocytes are an important pillar of the adaptive defense: They produce antibodies, which are in the blood as soluble proteins and are specialized for exactly one pathogen.
- The cells of the adaptive immune systems interact either directly by binding to the surface of different defense cells or they use soluble messenger substances like the cytokines. These messenger substances are mostly proteins and are produced by different cells in the organism.



INNATE V/S ADAPTIVE IMMUNE SYSTEM

COMAPARTIVE ENDOCRINOLOGY AND BIOLUMINESCENCE

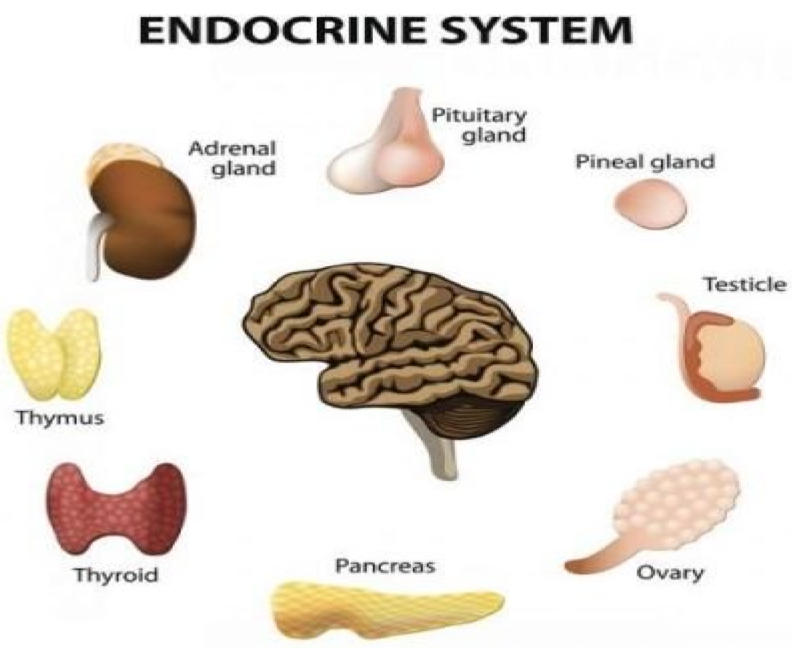
Endocrinology (from *endocrine+ -ology*)

•It is a branch of biology and medicine dealing with the endocrine system, its diseases, and its specific secretions known as hormones.

•It is also concerned with the integration of developmental events proliferation, growth, and differentiation, and the psychological or behavioral activities of metabolism, growth and development, tissue function, sleep, digestion, respiration, excretion, mood, stress, lactation, movement, reproduction, and sensory perception caused by hormones.

•The endocrine system consists of several glands, all in different parts of the body, that secrete hormones directly into the blood rather than into a duct system.

•Therefore, endocrine glands are regarded as ductless glands. Hormones have many different functions and modes of action; one hormone may have several effects on different target organs, and, conversely, one target organ may be affected by more than one hormone.



Hormones

Griffin and Ojeda identify three different classes of hormones based on their chemical composition:

Amines

Amines, such as norepinephrine, epinephrine, and dopamine (catecholamines), are derived from single amino acids, in this case tyrosine. Thyroid hormones such as 3,5,3'-triiodothyronine (T3) and 3,5,3',5'-tetraiodothyronine (thyroxine, T4) make up a subset of this class because they derive from the combination of two iodinated tyrosine amino acid residues.

Peptide and protein

Peptide hormones and protein hormones consist of three (in the case of thyrotropin-releasing hormone) to more than 200 (in the case of follicle-stimulating hormone) amino acid residues and can have a molecular mass as large as 31,000 grams per mole. All hormones secreted by the pituitary gland are peptide hormones, as are leptin from adipocytes, ghrelin from the stomach, and insulin from the pancreas.

Steroid

Steroid hormones are converted from their parent compound, cholesterol. Mammalian steroid hormones can be grouped into five groups by the receptors to which they bind: glucocorticoids, mineralocorticoids, androgens, estrogens, and progestogens. Some forms of vitamin D, such as calcitriol, are steroid-like and bind to homologous receptors, but lack the characteristic fused ring structure of true steroids.

INVERTEBRATE ENDOCRINE SYSTEM

Phylum Nemertea

•Nemertine worms are primitive marine animals that lack a coelom (body cavity) but differ from other acoelomates (animals that lack a coelom) by having a complete digestive tract.

•Three neurosecretory centres have been identified in the simple nemertine brain; one centre controls the maturation of the gonads, and all three appear to be involved in osmotic regulation.

Phylum Annelida

•The cerebral ganglion (brain) of *Nereis*, a marine polychaete worm, produces a small peptide hormone called nereidine, which apparently inhibits precocious sexual development.

•There is a complex just beneath the brain that functions as a neurohemal organ.

•The epithelial cells found in this complex may be secretory as well, but this has not been proved.

•Neurohormones are released from the infracerebral complex into the coelomic fluid through which they travel to their targets.

•In the lugworm, *Arenicola*, there is evidence for a brain neuropeptide that stimulates oocyte maturation.

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Phylum Mollusca

•Within the phylum Mollusca, the class Gastropoda (snails, slugs) has been studied most extensively.

•The cerebral ganglion (brain) of several species (*e.g., Euhadra peliomorpha, Aplysia californica*, and *Lymnaea stagnalis*) secretes a neurohormone that stimulates the hermaphroditic gonad (the reproductive gland that contains both male and female characteristics); hermaphroditism is a common condition among mollusks.

•This gonadotropic peptide hormone (a hormone that has the gonads as its target organ) is stored in a typical neurohemal organ until its release is stimulated.

•For example, phototropic information detected by the so-called optic gland (located near the eye) can direct the release of the gonadotropic hormone.

•The gonadotropic hormones that cause egg laying in *Aplysia* and *Lymnaea* have been isolated, and they are very similar small peptides.

•The hermaphroditic gonad of *Euhadra* secretes testosterone (identical to the vertebrate testosterone), which stimulates formation of a gland that releases a pheromone for influencing mating behavior.

•The optic gland of the octopus (of the class Cephalopoda) influences development of the reproductive organs on a seasonal basis. It is not known, however, whether any neurohormones are involved or whether this is purely a neurally controlled event.

Phylum Arthropoda

•The arthropods are the largest and most advanced group of invertebrate animals, rivaling and often exceeding the evolutionary success of the vertebrates.

•Indeed, the arthropods are the most successful ecological competitors of humans.

•There are several major subdivisions, or classes, within the phylum Arthropoda, with the largest being Insecta (insects), Crustacea (crustaceans, including crabs, crayfishes, and shrimps), and Arachnida (arachnids, including the spiders, ticks, and mites).

•Even within these major classes, few species have been studied. Those that have been studied are large insects (*e.g.,* cockroaches, grasshoppers, and cecropia moths) and crustaceans.

•The organizations of arthropod endocrine systems parallel those of the vertebrate endocrine system.

•That is, neurohormones are produced in the arthropod brain (analogous to the vertebrate hypothalamus) and are stored in a neurohemal organ (like the vertebrate neurohypophysis).

•The neurohemal organ of insects may have an endocrine portion (like the vertebrate adenohypophysis), and hormones or neurohormones released from these organs may stimulate other endocrine glands as well as nonendocrine targets.

Class Insecta

•Neurosecretory, neurohemal, and endocrine structures are all found in the insect endocrine system.
•There are several neurosecretory centres in the brain, the largest being the pars intercerebralis.
•The paired corpora cardiaca (singular, corpus cardiacum) and the paired corpora allata (singular, corpus allatum) are both neurohemal organs that store brain neurohormones, but each has some endocrine cells as well.
•The insect endocrine system produces neurohormones as well as hormones that control molting, diapause, reproduction, osmoregulation, metabolism, and muscle contraction.

Crustaceans

•The major neuroendocrine system consists of the neurosecretory X-organ and its associated neurohemal organ, the sinus gland.
•Both an X-organ and a sinus gland are located in each eyestalk, and together they are termed the eyestalk complex. Two endocrine glands are well known: the Y-organ and the androgenic gland.
•As in insects, hormones and neurohormones of the crustacean regulate molting, reproduction, osmoregulation, metabolism, and heart rate. In addition, the regulation of colour changes is well developed in crustaceans, whereas only a few insects exhibit hormonally controlled colour changes.

VERTEBRATE ENDOCRINE SYSTEM

Subphylum Tunicata

•The ascidians (also called sea squirts) have a tadpolelike larva that lives free for a short period.

•The larva eventually attaches itself to a solid substrate and undergoes a marked metamorphosis into the sessile adult sea squirt. The larva and adult have a mucus-secreting gland, the endostyle, that is believed to be the evolutionary ancestor of the vertebrate thyroid gland.

•Metamorphosis in ascidians can be induced by application of thyroid hormones.

•Neurosecretory neurons in the cerebral ganglion (brain) contain the vertebrate peptide gonadotropin-releasing hormone (GnRH).

•Directly adjacent to the brain is the neural (or subneural) gland that may be the forerunner of the vertebrate pituitary gland.

•Extracts prepared from ascidian neural glands stimulate testicular growth in toads, demonstrating the presence of a gonadotropic factor in the neural gland. A protein similar to human prolactin has been found in the neural gland of *Styela plicata*.

Subphylum Cephalochordata

•The cephalochordate brain contains neurosecretory neurons that possibly are related to a structure called Hatschek's pit, located near the brain.

•Hatschek's pit appears to be related to the neural gland and hence to the vertebrate pituitary gland.

•Treatment of amphioxus with GnRH or luteinizing hormone (LH) reportedly stimulates the onset of spermatogenesis in male gonads. Furthermore, extracts prepared from Hatschek's pit can stimulate the testis of a toad.

•Amphioxus has a mucus-secreting endostyle like that of the ascidians. and studies have shown that the cephalochordate endostyle can synthesize thyroid hormones, too.

•Thus, the basic organization of the vertebrate endocrine system appears to show its early beginnings in the simple organs of these invertebrate chordates.

The hypothalamic-pituitary-target organ axis

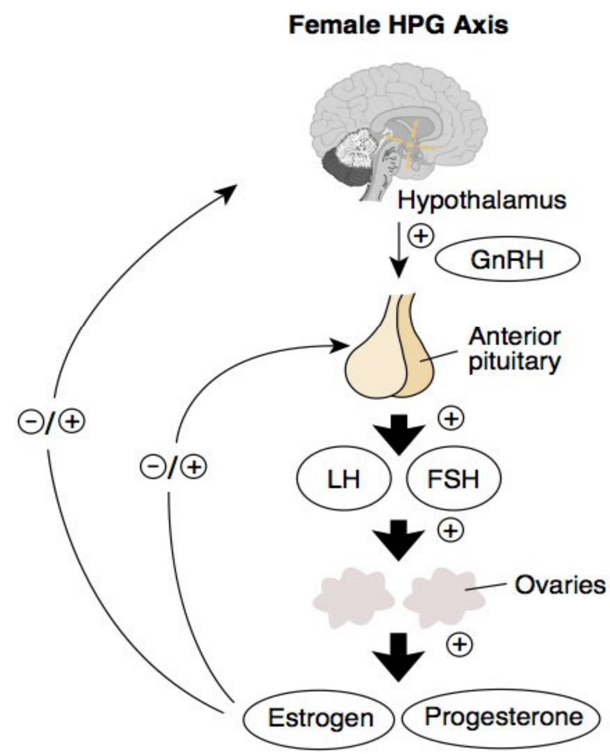
•The hypothalamic-pituitary-target organ axes of all vertebrates are similar.

•The hypothalamic neurosecretory system is poorly developed in the most primitive of the living Agnatha vertebrates, the hagfishes, but all of the basic rudiments are present in the closely related lampreys.

•In most of the more advanced jawed fishes there are several well-developed neurosecretory centres (nuclei) in the hypothalamus that produce neurohormones.

• These centres become more clearly defined and increase in the number of distinct nuclei as amphibians and reptiles are examined, and they are as extensive in birds as they are in mammals.

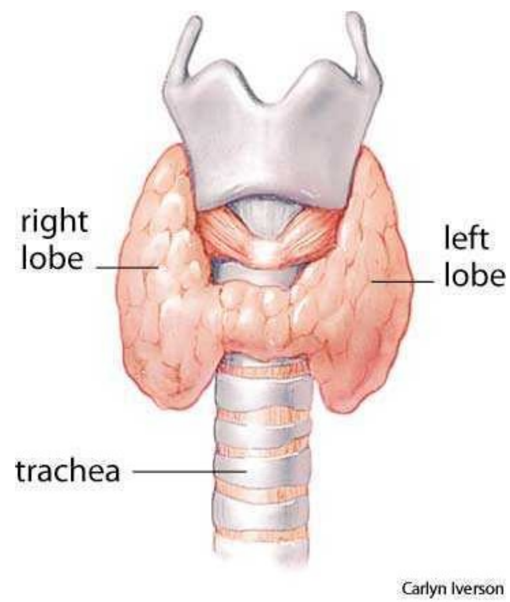
•Some of the same neurohormones that are found in humans have been identified in nonmammals, and these neurohormones produce similar effects on cells of the pituitary as described above for mammals.



VERTEBRATE ENDOCRINE ORGANS

Thyroid

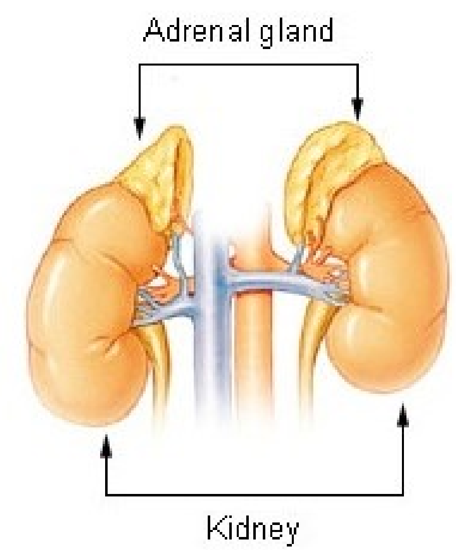
Thyrotropin secreted by the pituitary stimulates the thyroid gland to release thyroid hormones, which help to regulate development, growth, metabolism, and reproduction. In humans, these thyroid hormones are known as triiodothyronine (T_3) and thyroxine (T_4). The evolution of the thyroid gland is traceable in the evolutionary development of invertebrates to vertebrates. The thyroid gland evolved from an iodide-trapping, glycoprotein-secreting gland of the protochordates (all nonvertebrate members of the phylum Chordata. When these iodinated proteins are swallowed and broken down by enzymes, the iodinated amino acids known as thyroid hormones are released. Larvae of primitive vertebrate lampreys also have an endostyle like that of the protochordates. When a lamprey larva undergoes metamorphosis into an adult lamprey, the endostyle breaks into fragments. The resulting clumps of endostyle cells differentiate into the separate follicles of the thyroid gland. Thyroid hormones actually direct metamorphosis in the larvae of lampreys, bony fishes, and amphibians. Thyroids of fishes consist of scattered follicles in the pharyngeal region.



Adrenal

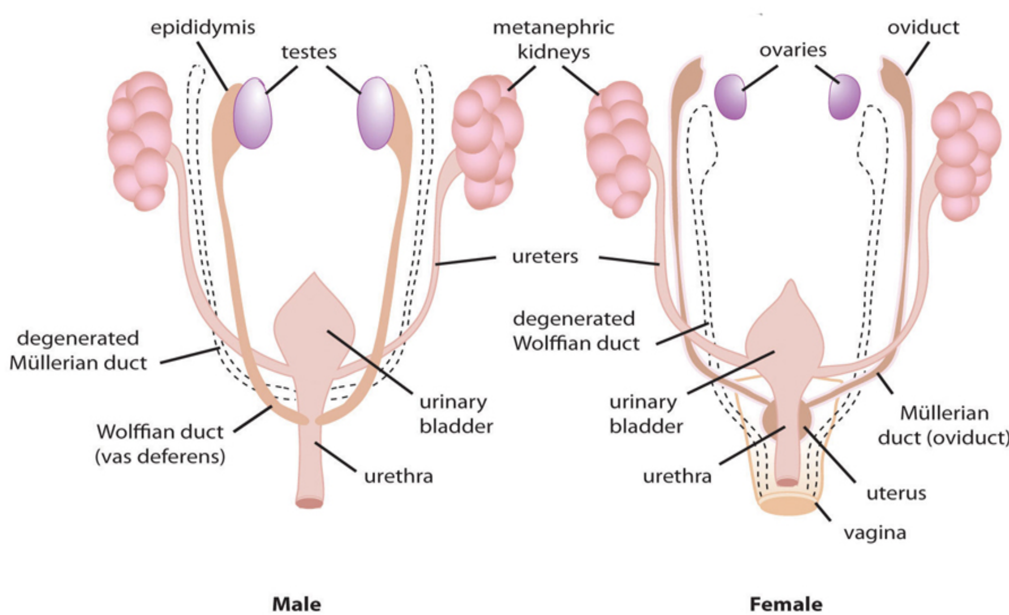
The adrenal axes in mammals and in nonmammals are not constructed along the same lines. In mammals the adrenal cortex is a separate structure that surrounds the internal adrenal medulla; the adrenal gland is located atop the kidneys. Because the cells of the adrenal cortex and adrenal medulla do not form separate structures in nonmammals as they do in mammals, they are often referred to in different terms; the cells that correspond to the adrenal cortex in mammals are called interrenal cells, and the cells that correspond to the adrenal medulla are called chromaffin cells. In primitive nonmammals the adrenal glands are sometimes called interrenal glands.

In fishes the interrenal and chromaffin cells often are embedded in the kidneys, whereas in amphibians they are distributed diffusely along the surface of the kidneys. Reptiles and birds have discrete adrenal glands, but the anatomical relationship is such that often the "cortex" and the "medulla" are not distinct units. Under the influence of pituitary adrenocorticotropin hormone, the interrenal cells produce steroids (usually corticosterone in tetrapods and cortisol in fishes) that influence sodium balance, water balance, and metabolism.



Gonads

Gonadotropins secreted by the pituitary are basically LH-like and/or FSH-like in their actions on vertebrate gonads. In general, the FSH-like hormones promote development of eggs and sperm and the LH-like hormones cause ovulation and sperm release; both types of gonadotropins stimulate the secretion of the steroid hormones (androgens, estrogens, and, in some cases, progesterone) from the gonads. These steroids produce effects similar to those described for humans. For example, progesterone is essential for normal gestation in many fishes, amphibians, and reptiles in which the young develop in the reproductive tract of the mother and are delivered live. Androgens (sometimes testosterone, but often other steroids are more important) and estrogens (usually estradiol) influence male and female characteristics and behaviour.



Gland (module)		Hormone	Chemical Class	Representative Actions	Regulated by
Thyroid gland (26.5–6)		Thyroxine (T_4) and triiodothyronine (T_3)	Amine	Stimulate and maintain metabolic processes	TSH
		Calcitonin	Peptide	Lowers blood calcium level	Calcium in blood
Parathyroid glands (26.5–6)		Parathyroid hormone (PTH)	Peptide	Raises blood calcium level	Calcium in blood
Thymus (26.3)		Thymosin	Peptide	Stimulates T cell development	Not known
Adrenal gland (26.9)					
Adrenal medulla		Epinephrine and norepinephrine	Amine	Increase blood glucose; increase metabolic activities; constrict certain blood vessels	Nervous system
Adrenal cortex		Glucocorticoids	Steroid	Increase blood glucose	ACTH
		Mineralocorticoids	Steroid	Promote reabsorption of Na^+ and excretion of K^+ in kidneys	K^+ in blood
Pancreas (26.7–8)		Insulin	Protein	Lowers blood glucose	Glucose in blood
		Glucagon	Protein	Raises blood glucose	Glucose in blood
Testes (26.10)		Androgens	Steroid	Support sperm formation; promote development and maintenance of male secondary sex characteristics	FSH and LH
Ovaries (26.10)		Estrogens	Steroid	Stimulate uterine lining growth; promote development and maintenance of female secondary sex characteristics	FSH and LH
		Progesterone	Steroid	Promotes uterine lining growth	FSH and LH

MAJOR VERTEBRATE ENDOCRINE GLANDS AND THEIR FUNCTION

Bioluminescence

•It is light produced by a chemical reaction within a living organism. Bioluminescence is a type of chemiluminescence, which is simply the term for a chemical reaction where light is produced. (Bioluminescence is chemiluminescence that takes place inside a living organism.)

•Most bioluminescent organisms are found in the ocean. These bioluminescent marine species include fish, bacteria, and jellies. Some bioluminescent organisms, including fireflies and fungi, are found on land. There are almost no bioluminescent organisms native to freshwater habitats.

•The chemical reaction that results in bioluminescence requires two unique chemicals: **luciferin** and either **luciferase** or photoprotein.

•Luciferin is the compound that actually produces light. In a chemical reaction, luciferin is called the substrate.

•The bioluminescent color (yellow in fireflies, greenish in lanternfish) is a result of the arrangement of luciferin molecules.

•Luciferase is an enzyme. An enzyme is a chemical (called a catalyst) that interacts with a substrate to affect the rate of a chemical reaction. The interaction of the luciferase with oxidized (oxygen-added) luciferin creates a byproduct, called oxyluciferin. More importantly, the chemical reaction creates light.

•Photoproteins were only recently identified, and biologists and chemists are still studying their unusual chemical properties. Photoproteins were first studied in bioluminescent crystal jellies found off the west coast of North America. The photoprotein in crystal jellies is called "green fluorescent protein" or GFP.

Bioluminescent Light

•The appearance of bioluminescent light varies greatly, depending on the habitat and organism in which it is found.

•Most marine bioluminescence, for instance, is expressed in the blue-green part of the visible light spectrum.

•These colors are more easily visible in the deep ocean. Also, most marine organisms are sensitive only to blue-green colors. They are physically unable to process yellow, red, or violet colors.

•Few organisms can glow in more than one color. The so-called railroad worm (actually the larva of a beetle) may be the most familiar. The head of the railroad worm glows red, while its body glows green. Different luciferases cause the bioluminescence to be expressed differently.

•Most organisms, however, use their light organs to flash for periods of less than a second to about 10 seconds. These flashes can occur in specific spots, such as the dots on a squid. Other flashes can illuminate the organism's entire body.

Adaptations

Bioluminescence is used by living things to hunt prey, defend against predators, find mates, and execute other vital activities.

1) Defensive Adaptations

•Some species luminesce to confuse attackers. Many species of squid, for instance, flash to startle predators, such as fish. With the startled fish caught off guard, the squid tries to quickly escape.

•The **vampire squid** exhibits a variation of this defensive behavior. Like many deep-sea squid, the vampire squid lacks ink sacs. (Squid that live near the ocean surface eject dark ink to leave their predators in the dark.) Instead, the vampire squid ejects sticky bioluminescent mucus, which can startle, confuse, and delay predators, allowing the squid to escape.

VAMPIRE SQID

2) Offensive Adaptations

•Bioluminescence may be used to lure prey or search for prey.

•The most famous predator to use bioluminescence may be the **anglerfish**, which uses bioluminescence to lure prey. The anglerfish has a huge head, sharp teeth, and a long, thin, fleshy growth (called a filament) on the top of its head.

•On the end of the filament is a ball (called the esca) that the anglerfish can light up. Smaller fish, curious about the spot of light, swim in for a closer look.

•By the time the prey sees the enormous, dark jaws of the anglerfish behind the bright esca, it may be too late.

ANGLER FISH

3) Attraction

•**Adult fireflies**, also called lightning bugs, are bioluminescent.

•They light up to attract mates. Although both male and female fireflies can luminesce, in North America most flashing fireflies are male.

•The pattern of their flashes tells nearby females what species of firefly they are and that they're interested in mating.

ADULT FIREFLY

THANK YOU