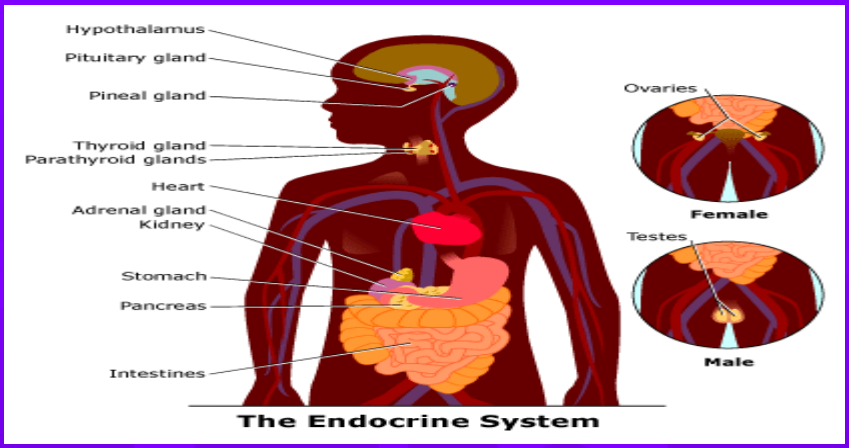
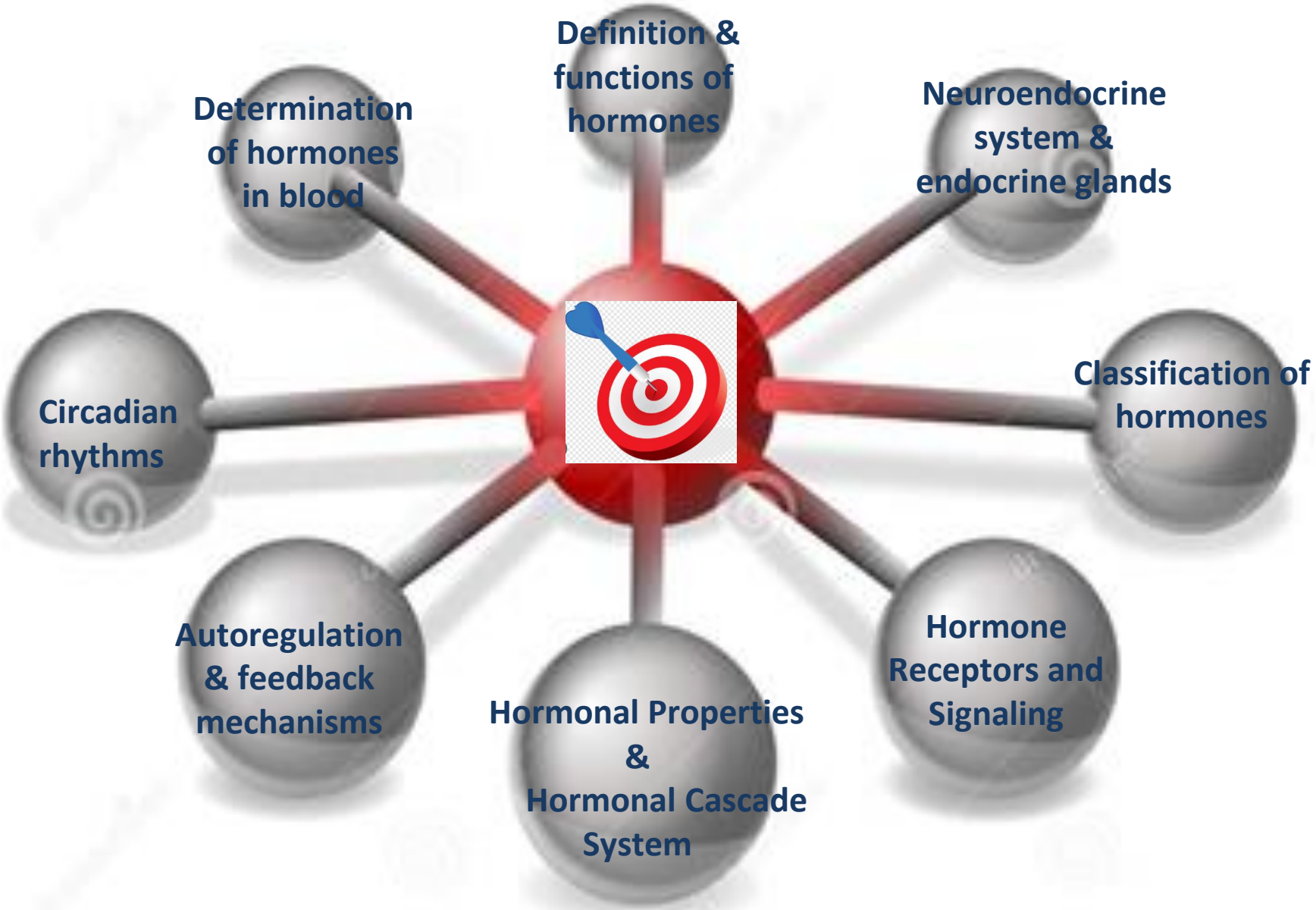


Introduction to hormone biochemistry and the hormonal cascade system. Hormone receptors and signaling

MARIANNA DALAMAGA, *MD, MSc, MPH, PhD*
Clinical Pathologist-Epidemiologist
PROFESSOR IN BIOLOGICAL CHEMISTRY-CLINICAL BIOCHEMISTRY
MEDICAL SCHOOL, NKUA

23 Hormonal Regulation and Integration of Mammalian Metabolism

EDUCATIONAL AIMS



1. What are hormones?

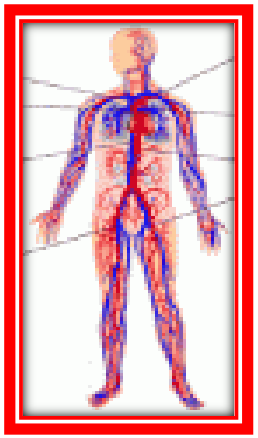
"HORMONES"

In June 1905, Ernest Starling, a professor of physiology at University College London, UK, first used the word 'hormone'

from the Greek participle ὁρμῶν, "setting in motion"

meaning practically «stimulate»

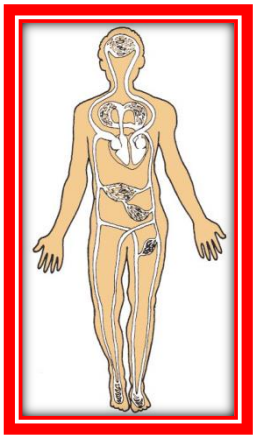
HORMONES

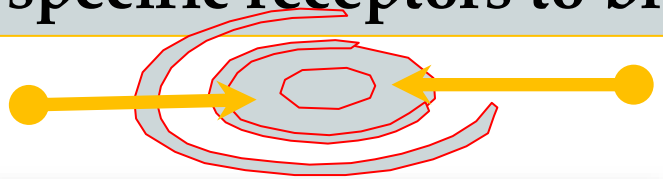


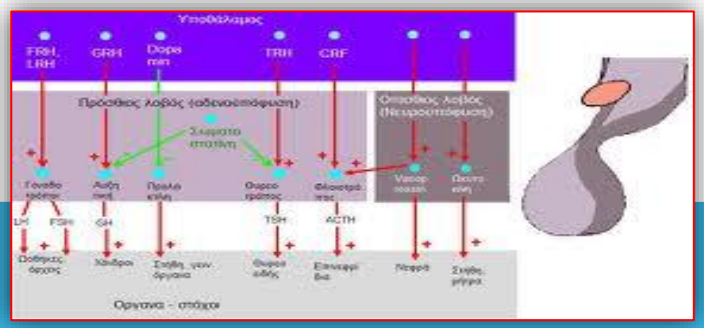
DEFINITION

Small molecules or proteins that are produced in one tissue, released into the bloodstream

and carried to other tissue, where they act through specific receptors to bring about







changes in cellular activities

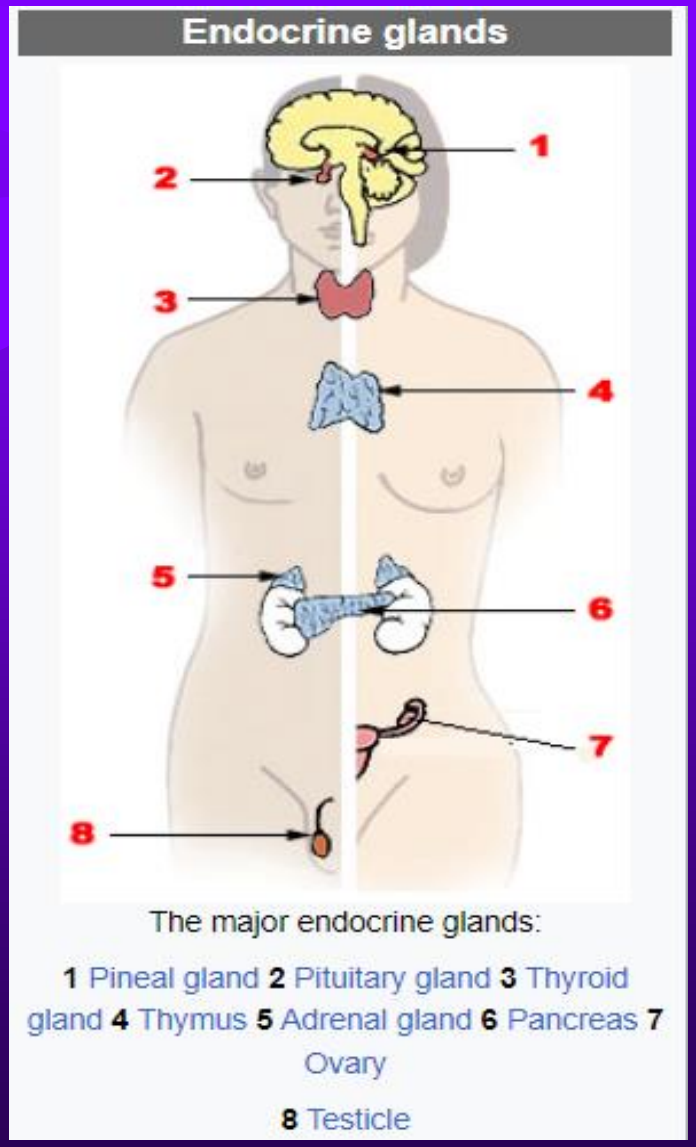
2. What are hormonal functions and effects on humans?

Virtually every process in a complex organism is regulated by one or more hormones:

- maintenance of blood pressure, blood volume, and electrolyte balance
- embryogenesis
- sexual differentiation, development, and reproduction
- hunger, eating behavior, digestion, and fuel allocation
- regulation of metabolism
- A hormone may also regulate the production and release of other hormones. Hormone signals control the internal environment of the body through homeostasis (maintenance of a stable, relatively constant internal environment.) .

3. What are endocrine glands?

- Endocrine glands are ductless glands of the endocrine system that secrete their products, hormones, directly into the blood.
- Endocrine glands can be organs, small nuclei (e.g. hypothalamus) or scattered specialized cells which secrete substances characterized as hormones (e.g. gastrointestinal tract → gastric or gut hormones
- The major endocrine glands include the hypothalamus & pituitary gland, pineal gland pancreas, ovaries, testes, thyroid gland, parathyroid gland, hypothalamus and adrenal glands.



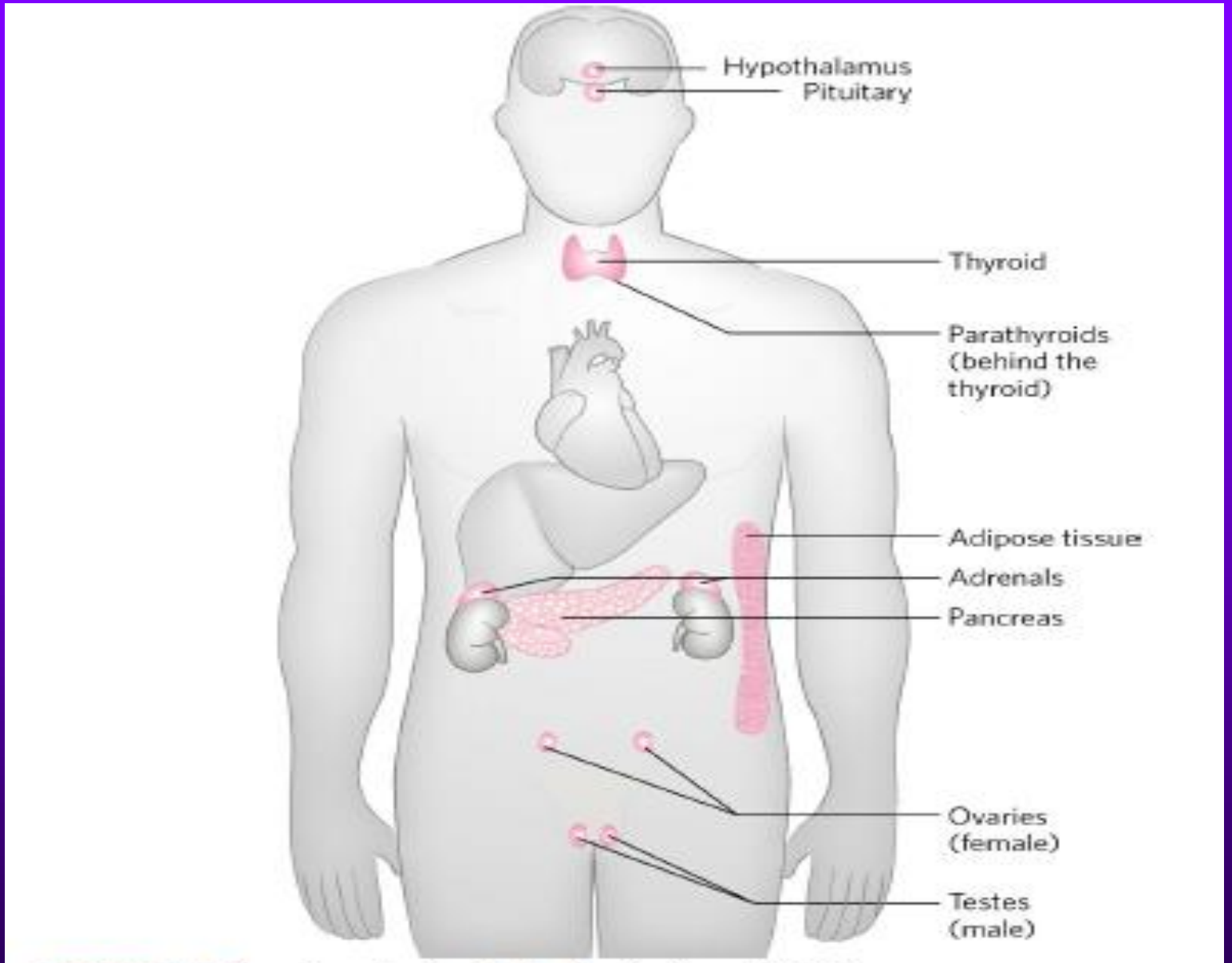
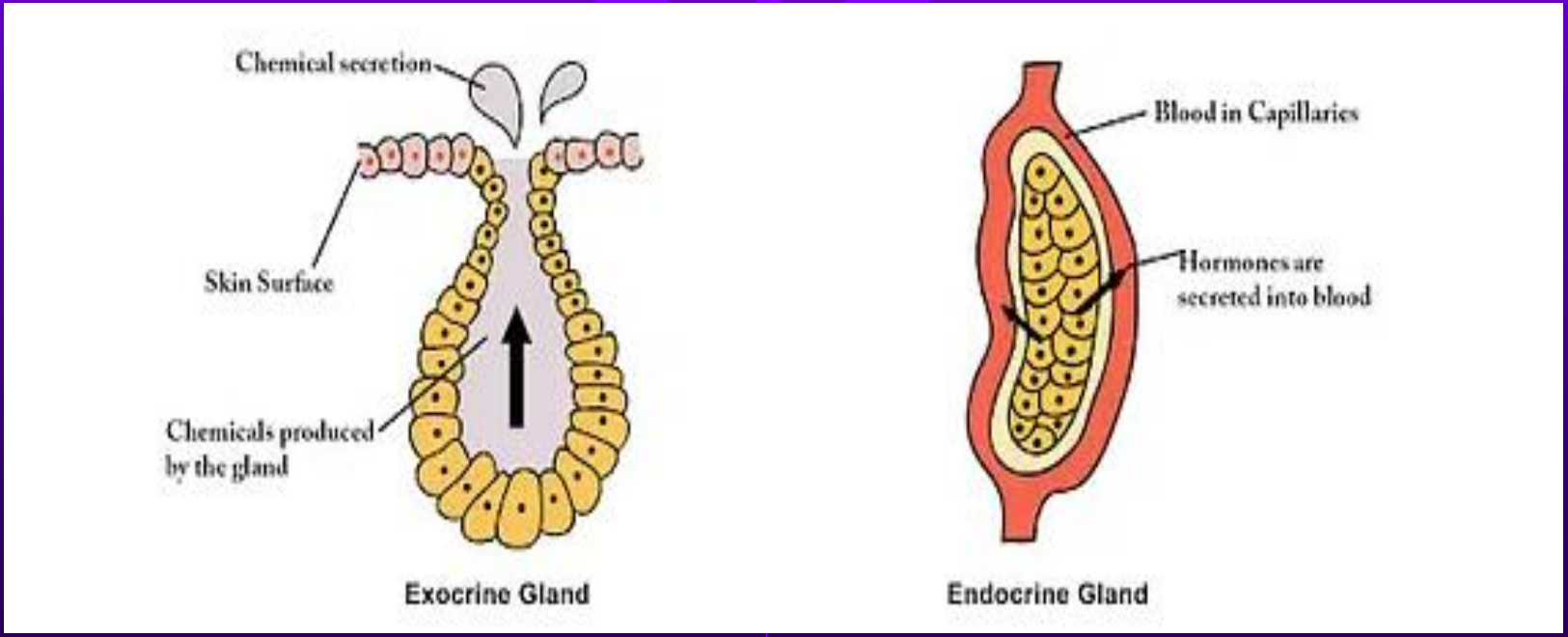


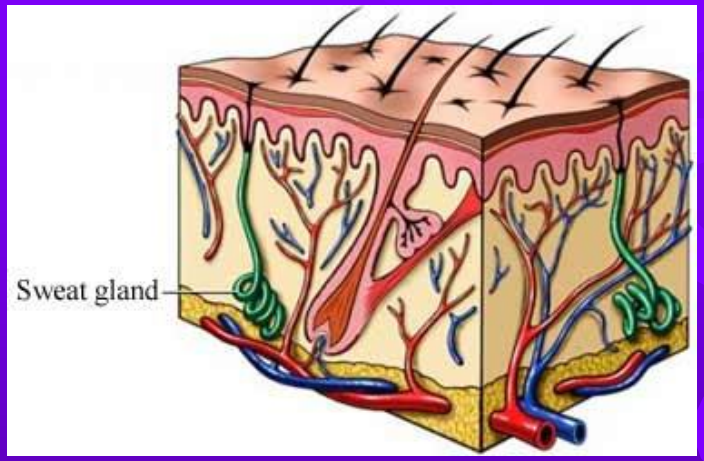
FIGURE 23-7 The major endocrine glands. The glands are shaded pink.

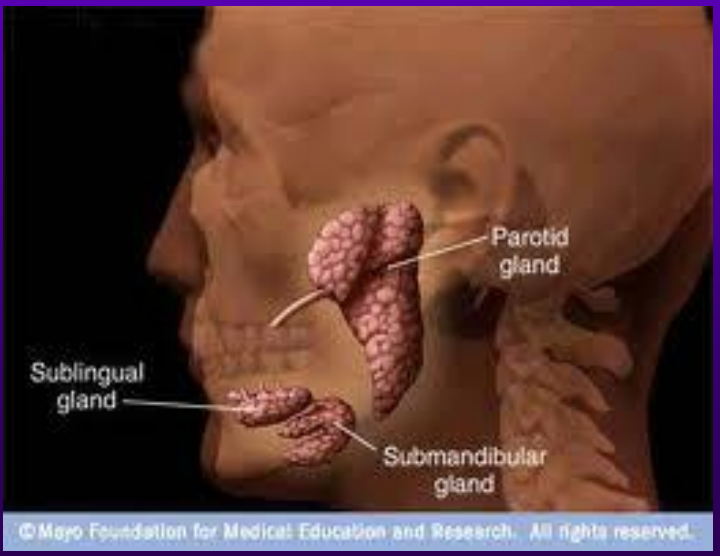
4. What are the differences between endocrine and exocrine gland?

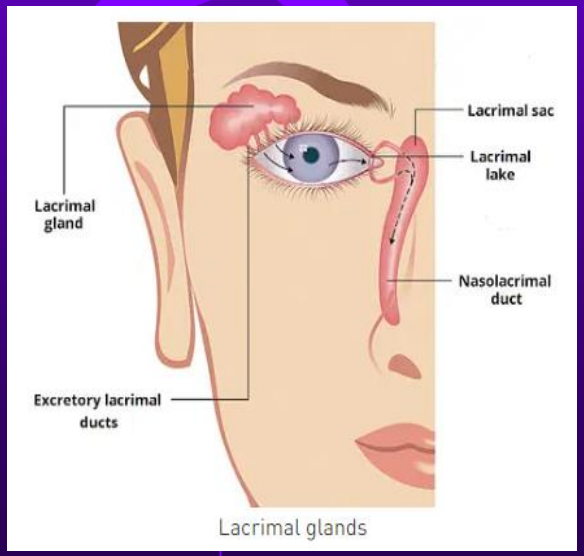
Two principal types of glands exist: exocrine and endocrine. The key difference between the two types is that, whereas exocrine glands secrete substances (ions, water, enzymes, sweat, saliva, digestive juices) into a ductal system to an epithelial surface, endocrine glands secrete hormones directly into the bloodstream

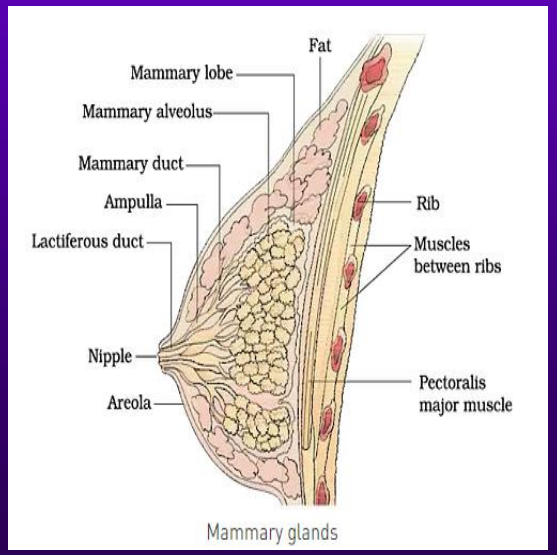


Examples of exocrine glands



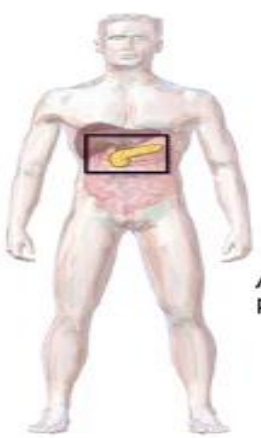


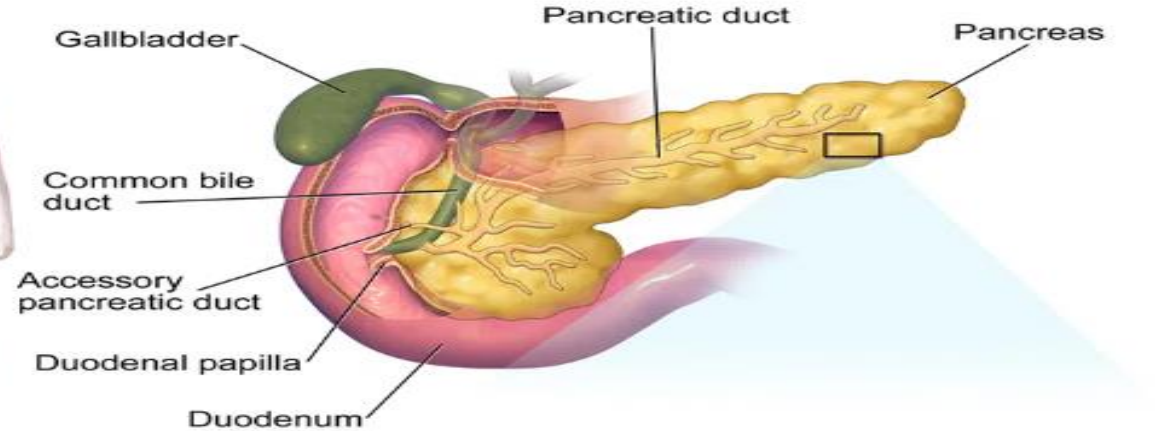


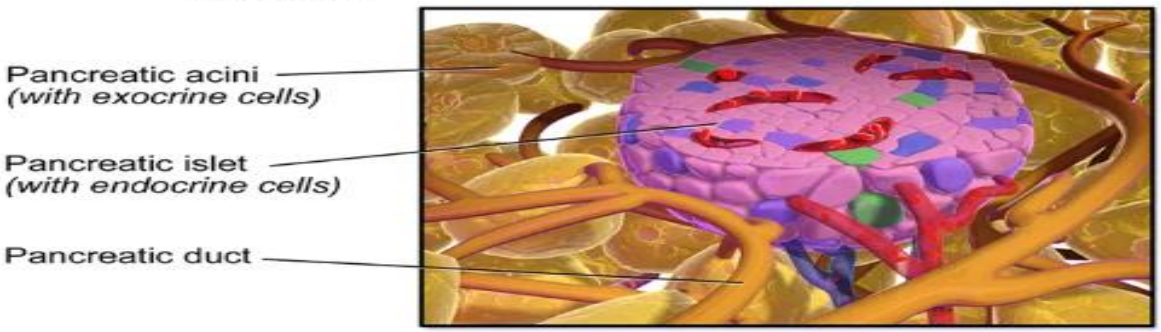


Examples of heterocrine (mixed) glands

Heterocrine glands (also known as mixed glands) are the glands which function as both exocrine gland and endocrine gland. These include mainly the pancreas and the gonads (testes and ovaries).



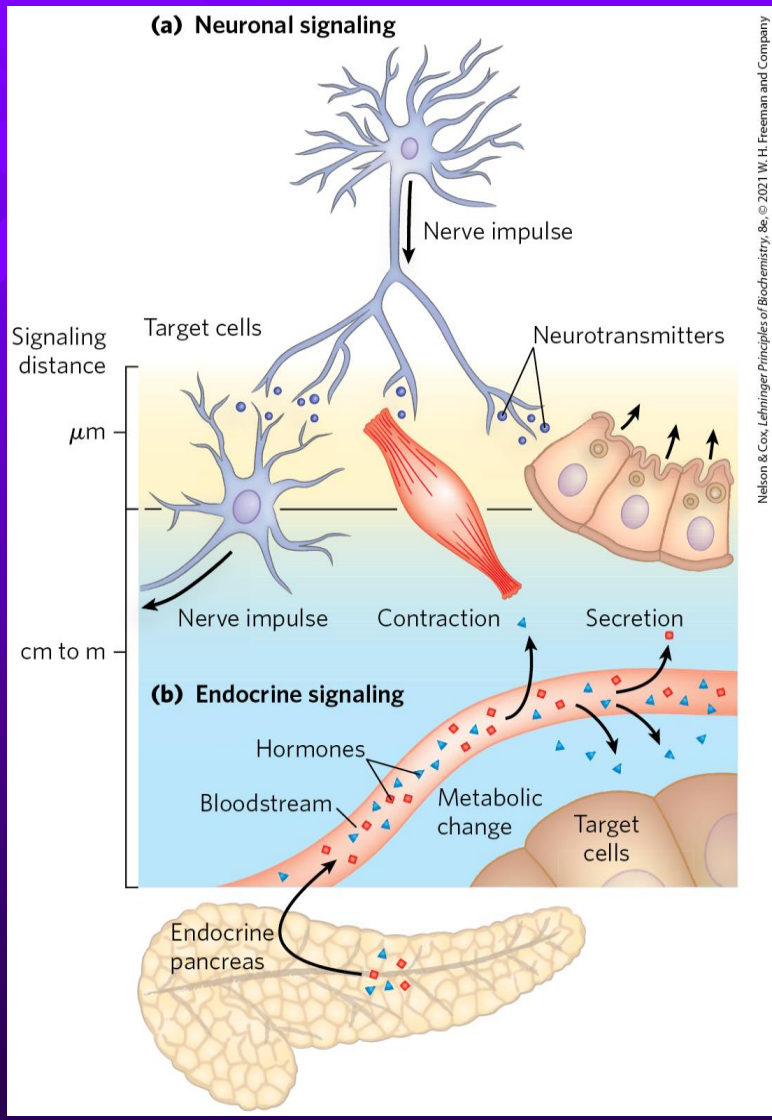




4. Which system coordinates metabolism in mammals? The neuroendocrine system

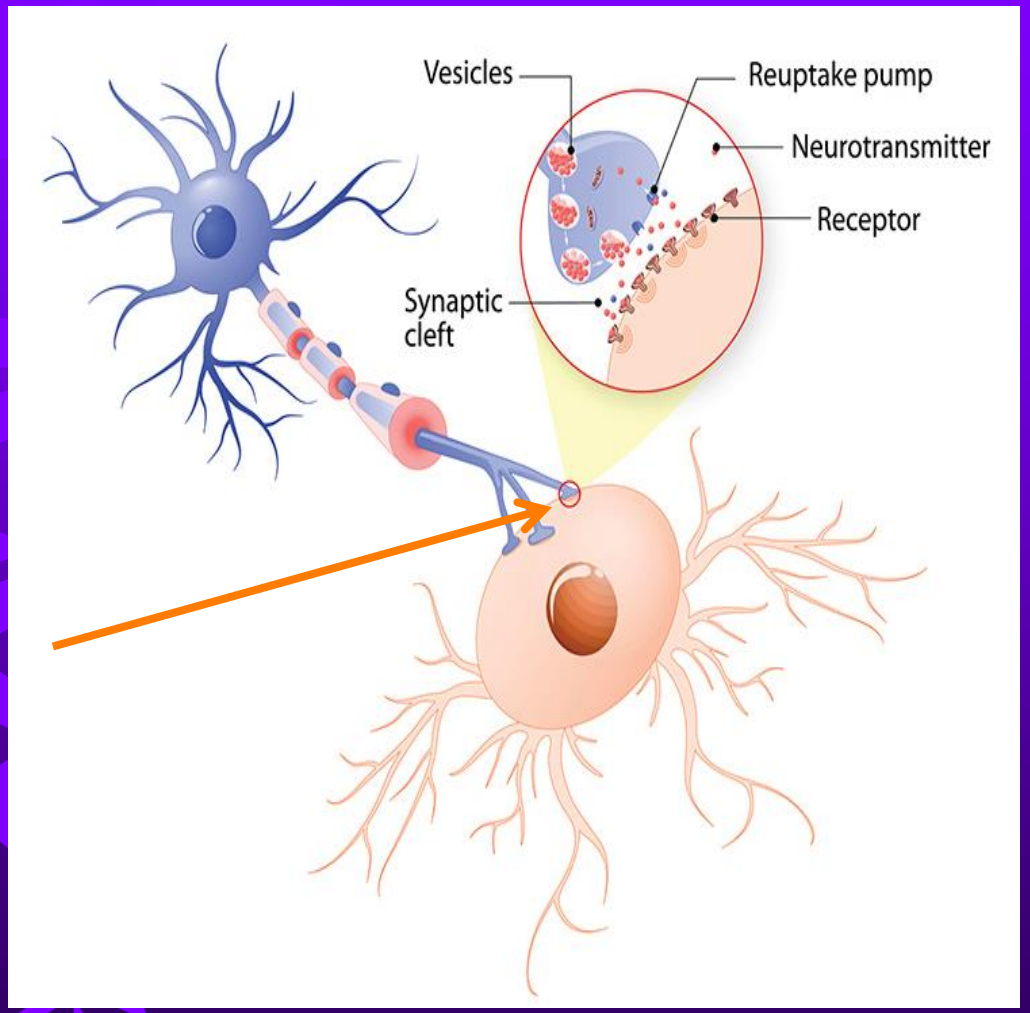
Neuronal and Endocrine Signaling

- These signaling mechanisms are remarkably similar
- Neuronal signaling = nerve cells release neurotransmitters that act on nearby cells
  - -distance may be small (<1 μm)
  - -great speed (v=100m/sec)
  - -action: short period of time
- Endocrine signaling = hormones are carried by the bloodstream to nearby cells or other organs
  - -distance may be great (>1 m)
  - -slow speed (v in blood=10 m/sec)
  - -action: prolonged



5. What is a neurotransmitter?

- Neurotransmitters are chemical messengers that carry chemical signals ("messages") from one neuron (nerve cell) to the next target cell. The next target cell may be another nerve cell, a muscle cell or a gland
- The same molecule can sometimes act as both neurotransmitter and hormone. Epinephrine and norepinephrine serve as neurotransmitters (at certain synapses of the brain and neuromuscular junctions of smooth muscle and as hormones regulating metabolism in liver and muscle.



6. How hormones can be classified?

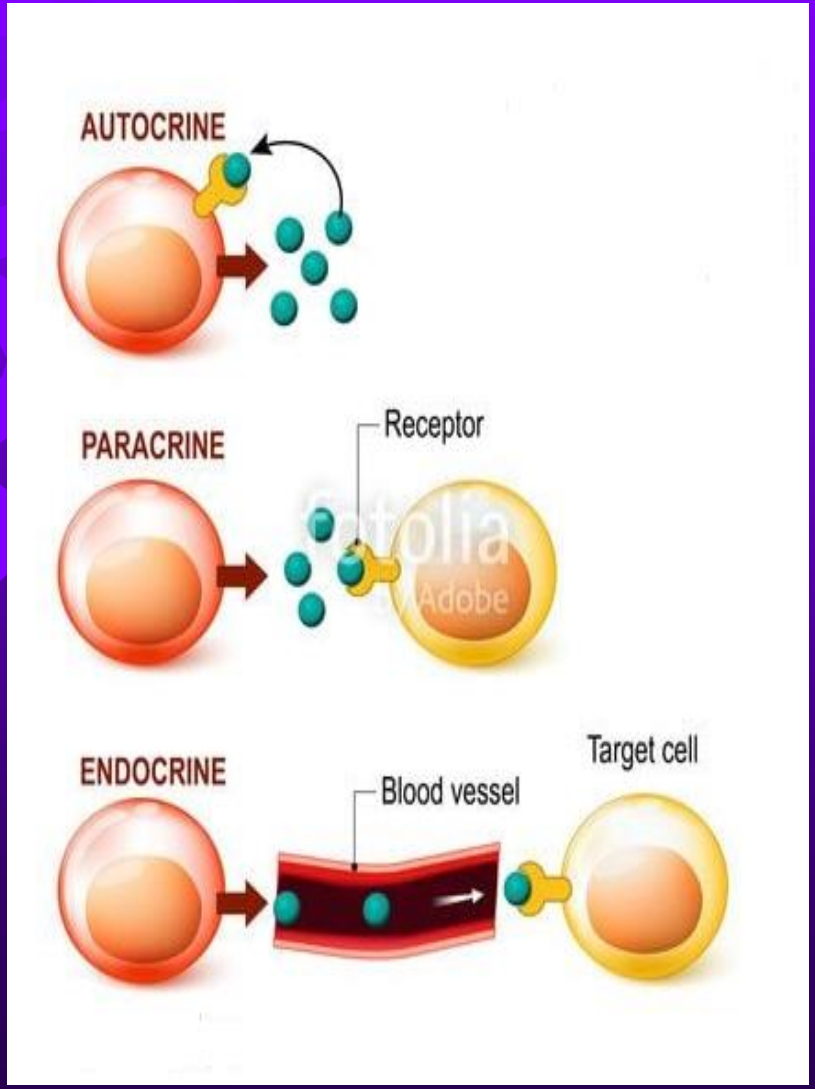
Mammals have several classes of hormones, distinguishable by:

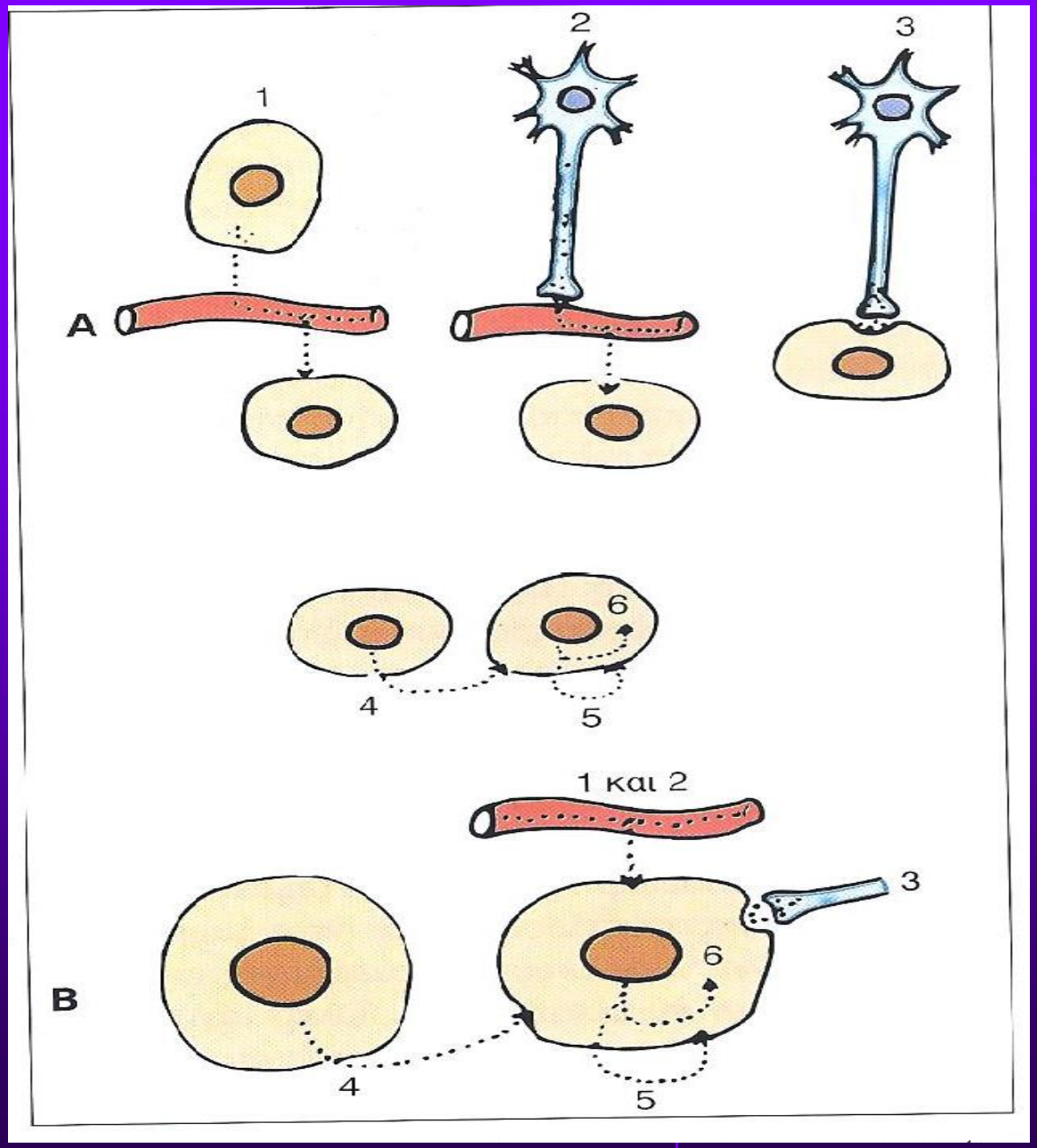
1) the way they get from their point of release to their target tissue
2) their chemical structure
3) their modes/mechanism of action

7. Classification of hormones based on the way they get from their point of release to their target tissue

- **autocrine** hormones = affect the same cell that releases them
- **paracrine** hormones = released into the extracellular space and diffuse to neighboring target cells
  - example: eicosanoid hormones
- **endocrine** hormones = released into the blood and carried to target cells throughout the body
  - examples: insulin and glucagon

REMEMBER RECEPTORS!!!





QUIZ#1

8. Classification of hormones based on their chemical structure

Hormones Are Chemically Diverse

TABLE 23-1 Classes of Hormones

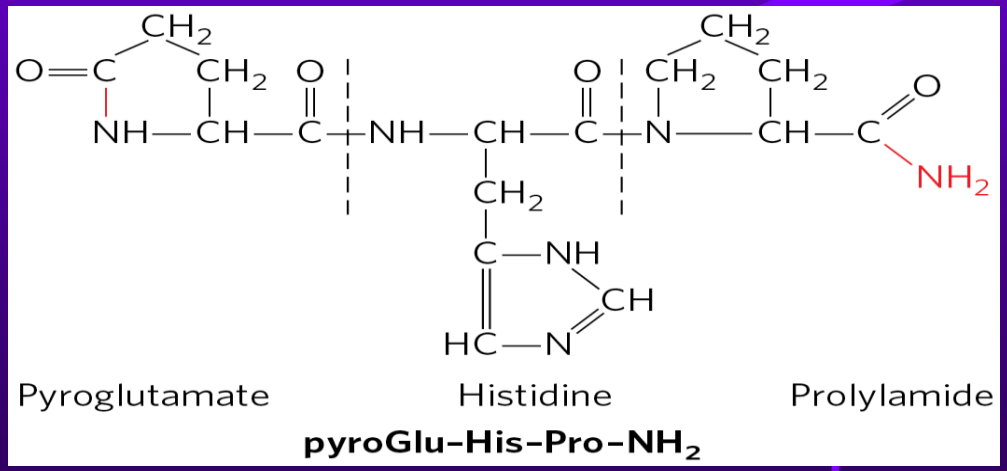
Type	Example	Synthetic path	Mode of action
Protein	Insulin (Fig. 23-4)	Proteolytic processing of prohormone	Plasma membrane RTK
Protein	Glucagon	Proteolytic processing of prohormone	Plasma membrane GPCRs; second messengers
Peptide	Vasopressin (p. 880)	Proteolytic processing of prohormone	Plasma membrane GPCRs; second messengers
Catecholamine	Epinephrine (Fig. 22-31)	From tyrosine	Plasma membrane GPCRs; second messengers
Eicosanoid	Prostaglandin E_2 (Fig. 10-17)	From arachidonate	Plasma membrane GPCRs; second messengers
Endocannabinoid	Anandamide (Fig. 23-40)	From arachidonate	Plasma membrane GPCRs; second messengers
Steroid	Testosterone (Fig. 10-18)	From cholesterol	Nuclear receptors; transcriptional regulation
Corticosteroid	Cortisol (Fig. 10-18)	From cholesterol	Nuclear receptors; transcriptional regulation
Vitamin D	Calcitriol (Fig. 10-19)	From cholesterol	Nuclear receptors; transcriptional regulation
Retinoid	Retinoic acid (Fig. 10-20)	From vitamin A	Nuclear receptors; transcriptional regulation
Thyroid	Triiodothyronine (T_3)	From Tyr in thyroglobulin	Nuclear receptors; transcriptional regulation
Nitric oxide	$NO^{\bullet}$ (Fig. 22-33)	From arginine	Cytosolic receptor; second messenger

8. Practical classification based on chemical structure

- Protein e.g. insulin, glucagon
- Peptide e.g. Vasopressin (ADH)
- Glycoprotein hormones: TSH, gonadotrophins (FSH, LH)
- Amine hormones (from amino acids): catecholamines and thyroid hormones from tyrosine,melatonin from tryptophan
- Steroid hormones: cortisol, testosterone (from cholesterol)
- Vitamin D/calcitriol (secosteroid, from cholesterol)
- Eicosanoid: prostaglandin E2 (from arachidonate)
- Retinoid: Retinoic acid (from vitamin A)
- Nitric oxide: NO (from arginine)

Protein/Peptide Hormones

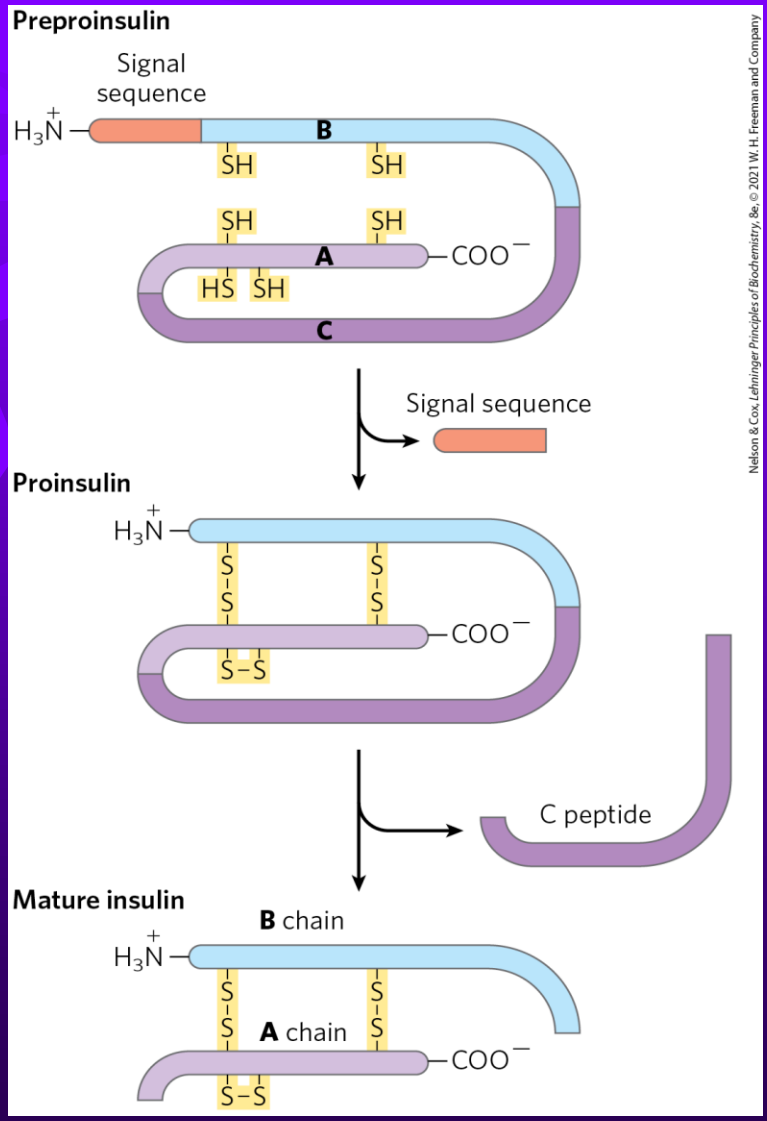
- **Peptide hormones** = hormones that are synthesized as proproteins (prohormones) that are activated upon release by proteolytic cleavage
  - vary in size from 3 to >200 amino acid residues
  - examples: insulin, glucagon, somatostatin, calcitonin, and all the hormones of the hypothalamus and pituitary



TRH: A derivative of the tripeptide Glu–His–Pro. In many peptide hormones the terminal residues are modified, as in TRH

Insulin is a Peptide Hormone

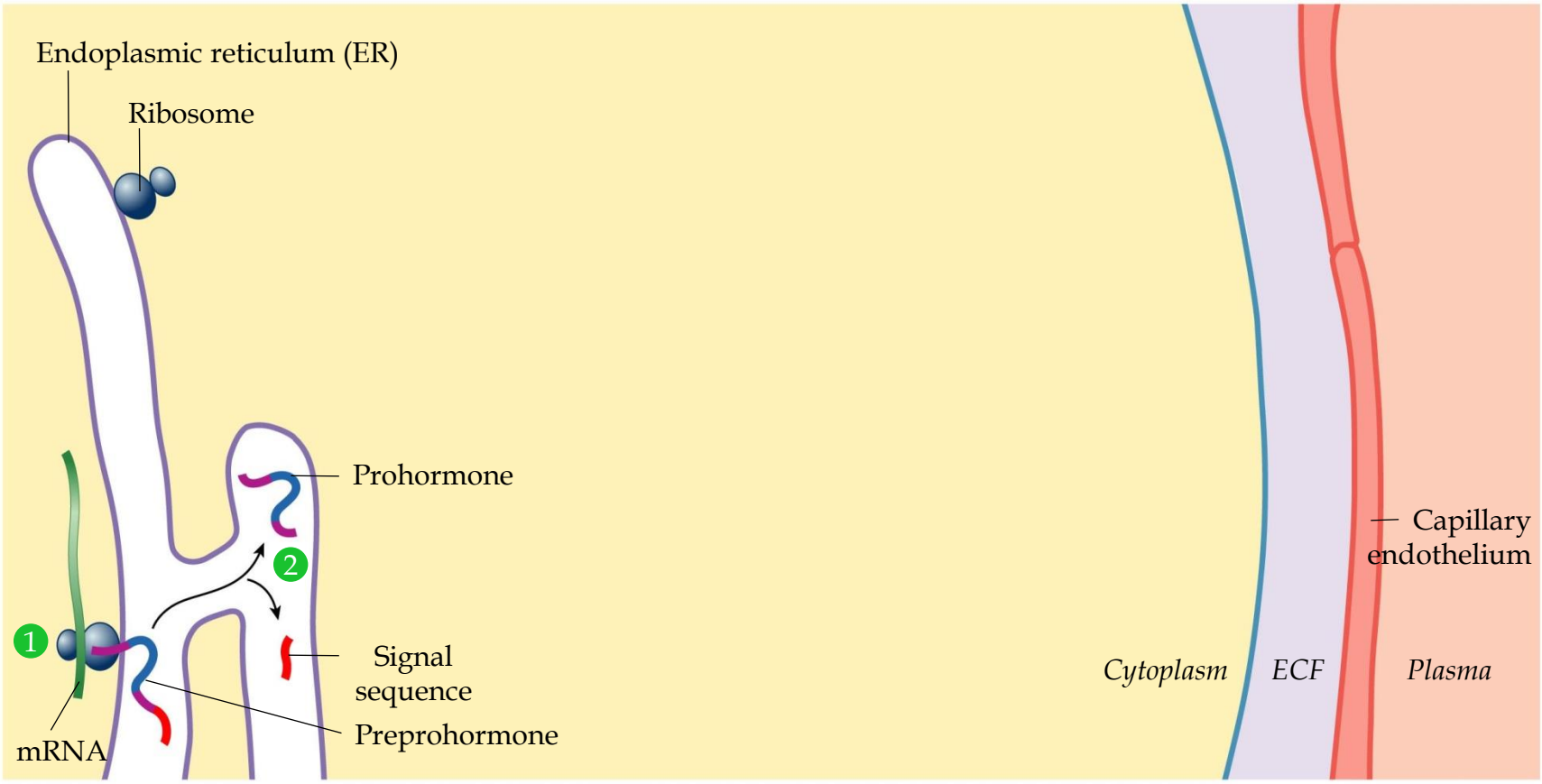
- **insulin** = a small protein (M: 5,800) with two polypeptide chains, A and B, joined by two disulfide bonds
  - synthesized on ribosomes in the pancreas as preproinsulin
  - stored as proinsulin in secretory vesicles
  - converted to active insulin by proteases when blood glucose is sufficiently elevated



Biosynthesis of insulin

1 Synthesized on ribosomes as preproinsulin

2 In the ER, Preproinsulin becomes proinsulin after cleavage of the Signal sequence .

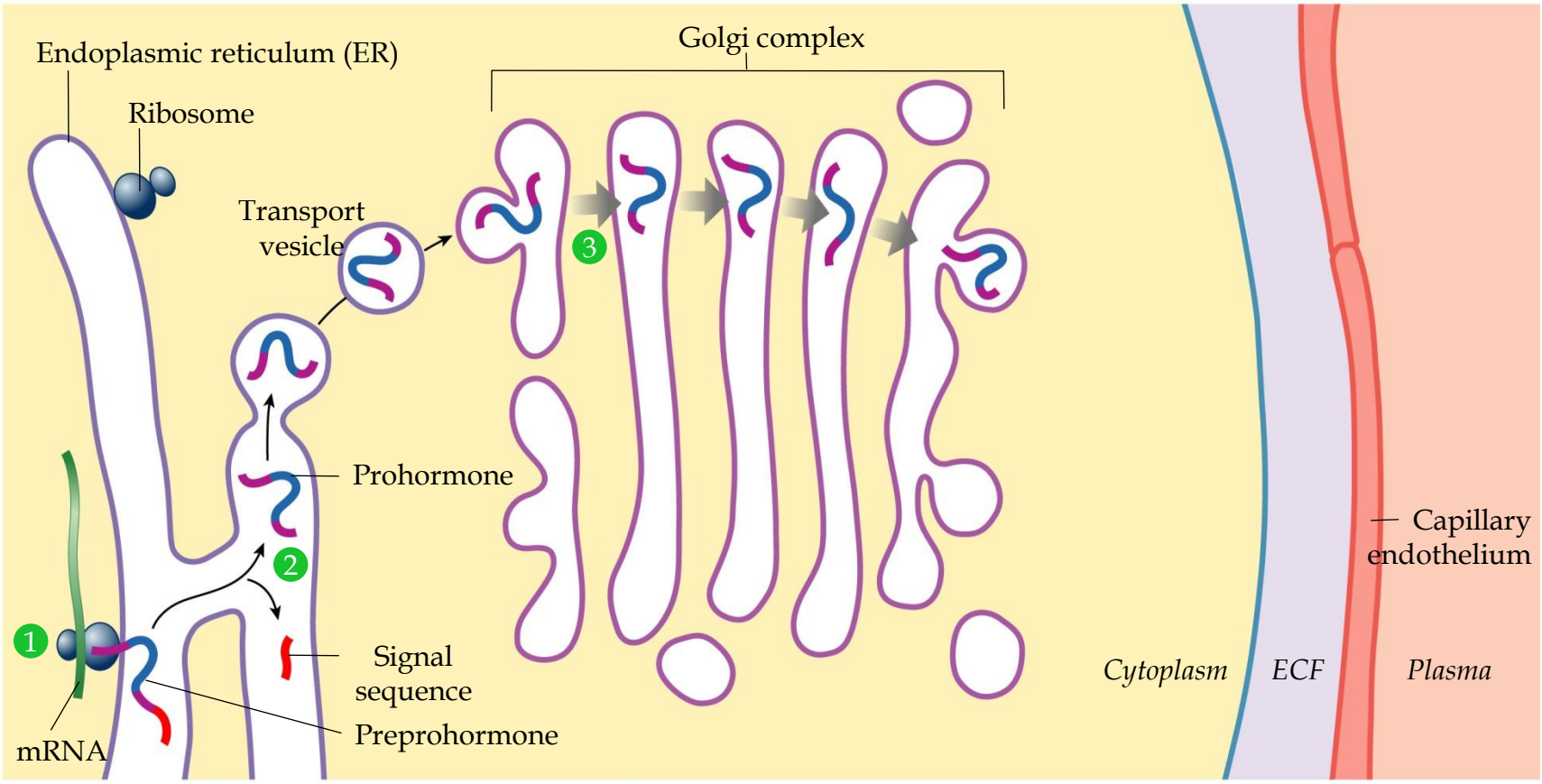


Biosynthesis of insulin

1 Synthesized on ribosomes as preproinsulin .

2 In the ER Preproinsulin becomes proinsulin after cleavage of the Signal sequence

3 Proinsulin enters the Golgi Complex



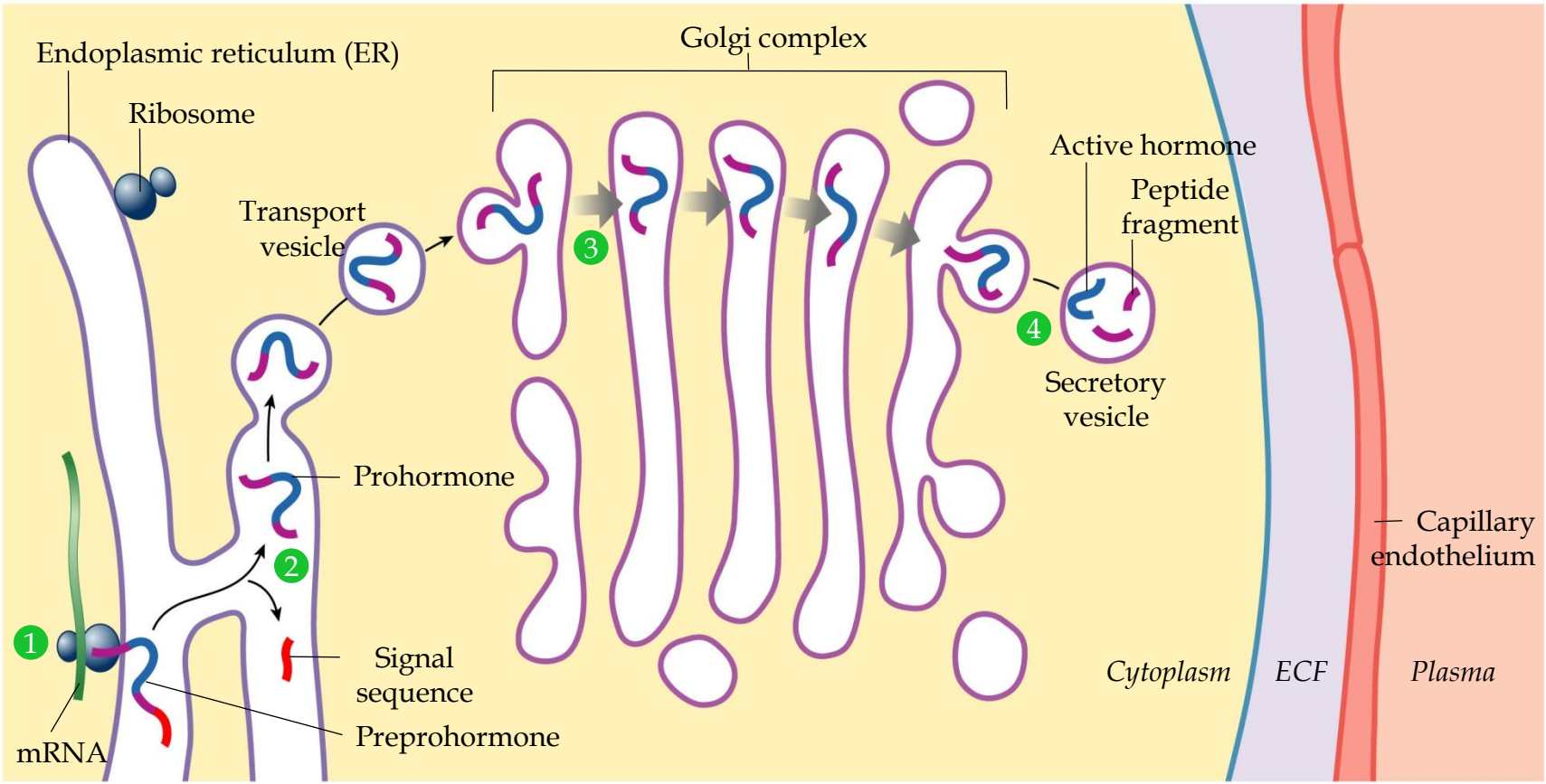
Biosynthesis of insulin

1 Synthesized on ribosomes as preproinsulin .

2 In the ER Preproinsulin becomes proinsulin after cleavage of the Signal sequence .

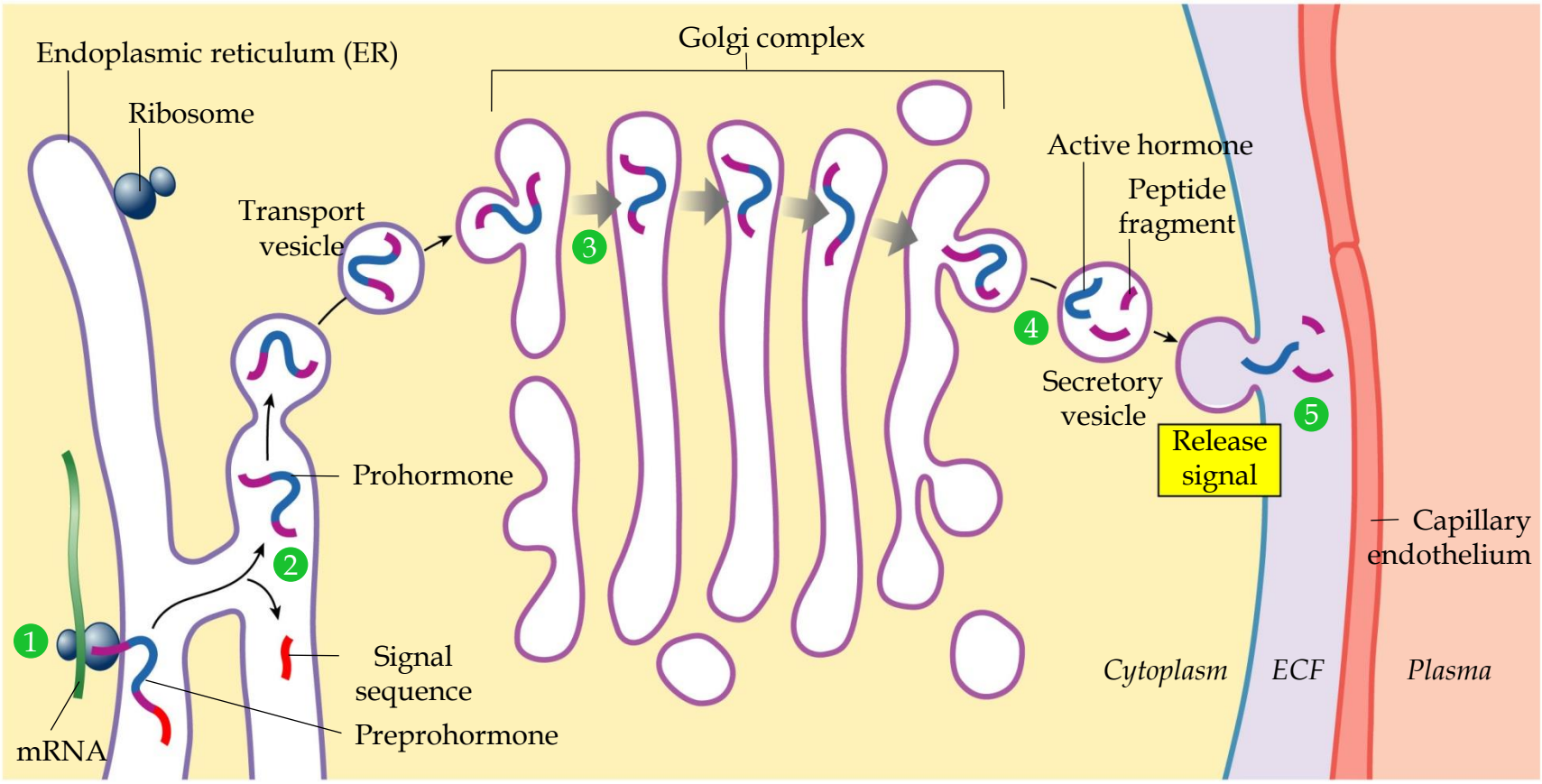
3 Proinsulin enters the Golgi Complex (secretory Vesicles)

4 Ssecretory vesicles have enzymes that will cleave Proinsulin to Active insulin and C-peptide



Biosynthesis of insulin

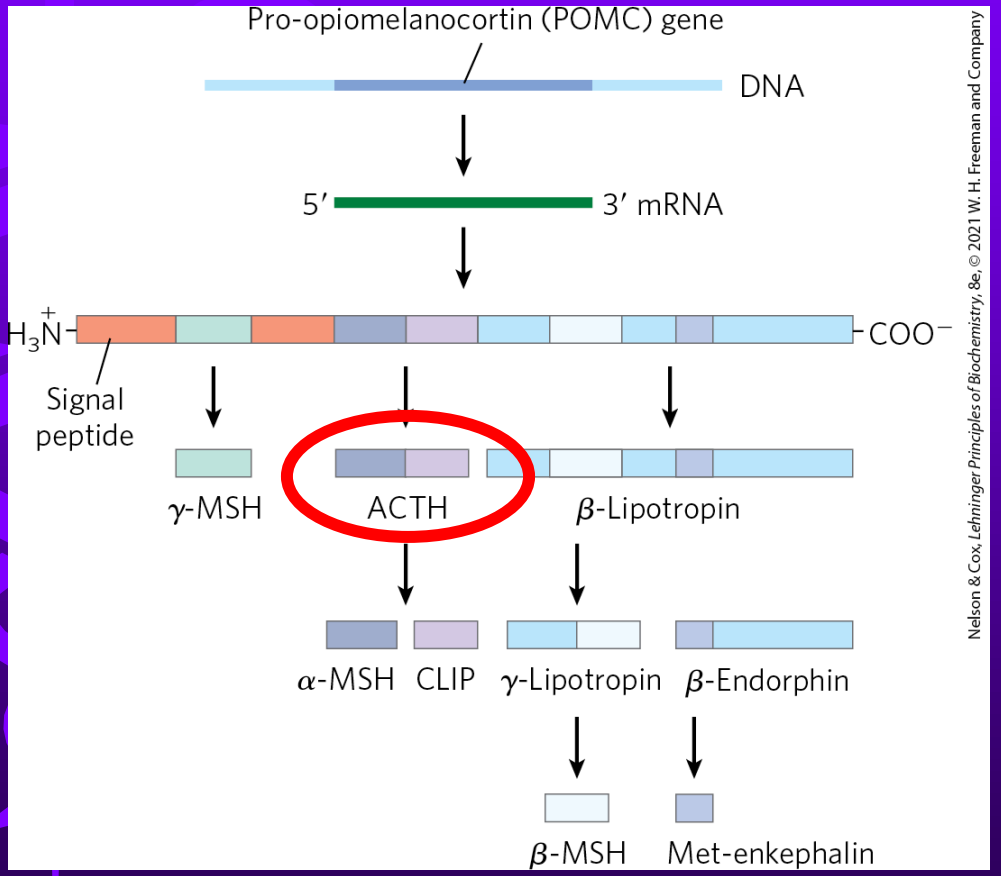
1. Synthesized on ribosomes as preproinsulin
2. In the ER Preproinsulin becomes proinsulin after cleavage of the Signal sequence
3. Proinsulin enters the Golgi Complex (secretory Vesicles)
4. Ssecretory vesicles have enzymes that will cleave Proinsulin to Active insulin and C-peptide
5. Secretory vesicles Release insulin In the extracellular Fluid and blood



Some Peptide Prohormones Can Yield Multiple Products

- **pro-opiomelanocortin (POMC)** = a proprotein that undergoes specific cleavage to produce several active hormones

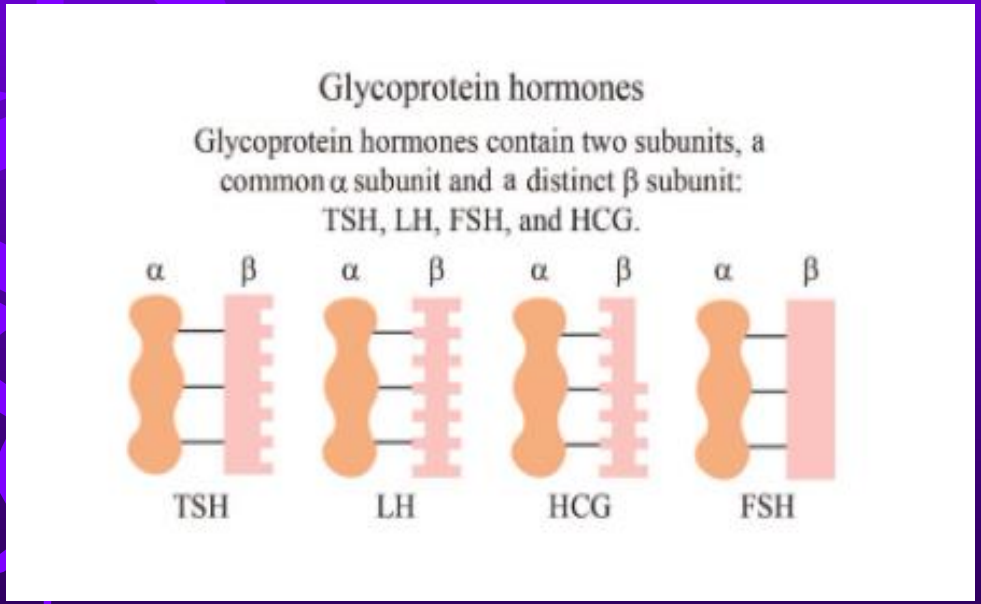
- the proprotein is processed differently in different tissues
  - depends on which proteases are expressed



Glycoprotein hormones

- Thyroid-stimulating hormone (TSH): It stimulates the thyroid gland to secrete T3 and T4 hormones
- Follicle-stimulating hormone (FSH): synthesized by the gonadotropic cells present in the anterior pituitary
- Luteinizing hormone (LH): produced by the anterior pituitary
- Human chorionic gonadotropin (HCG): the pregnancy hormone is produced by the trophoblast cells that are present in the placenta. It can be detected in pregnancy tests.

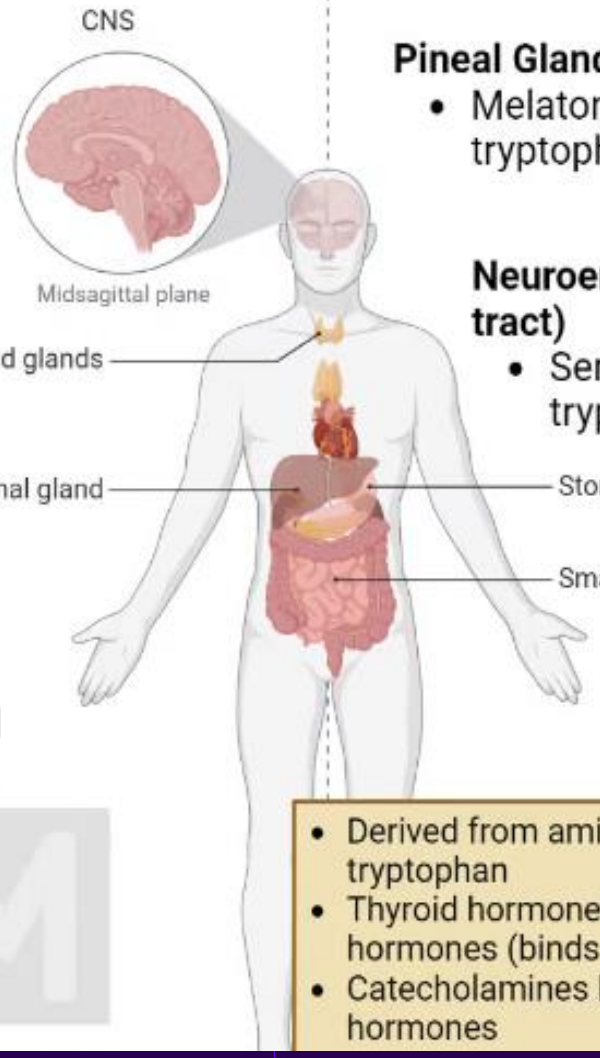
Complex protein hormones with additional carbohydrate side chains. They contain 2 subunits. The β subunit is distinct



Amine hormones from tyrosine and tryptophan

Thyroid Gland
- Triiodothyronine and thyroxine (derived from tyrosine)

Adrenal Medulla
- Epinephrine and norepinephrine (derived from tyrosine residues)

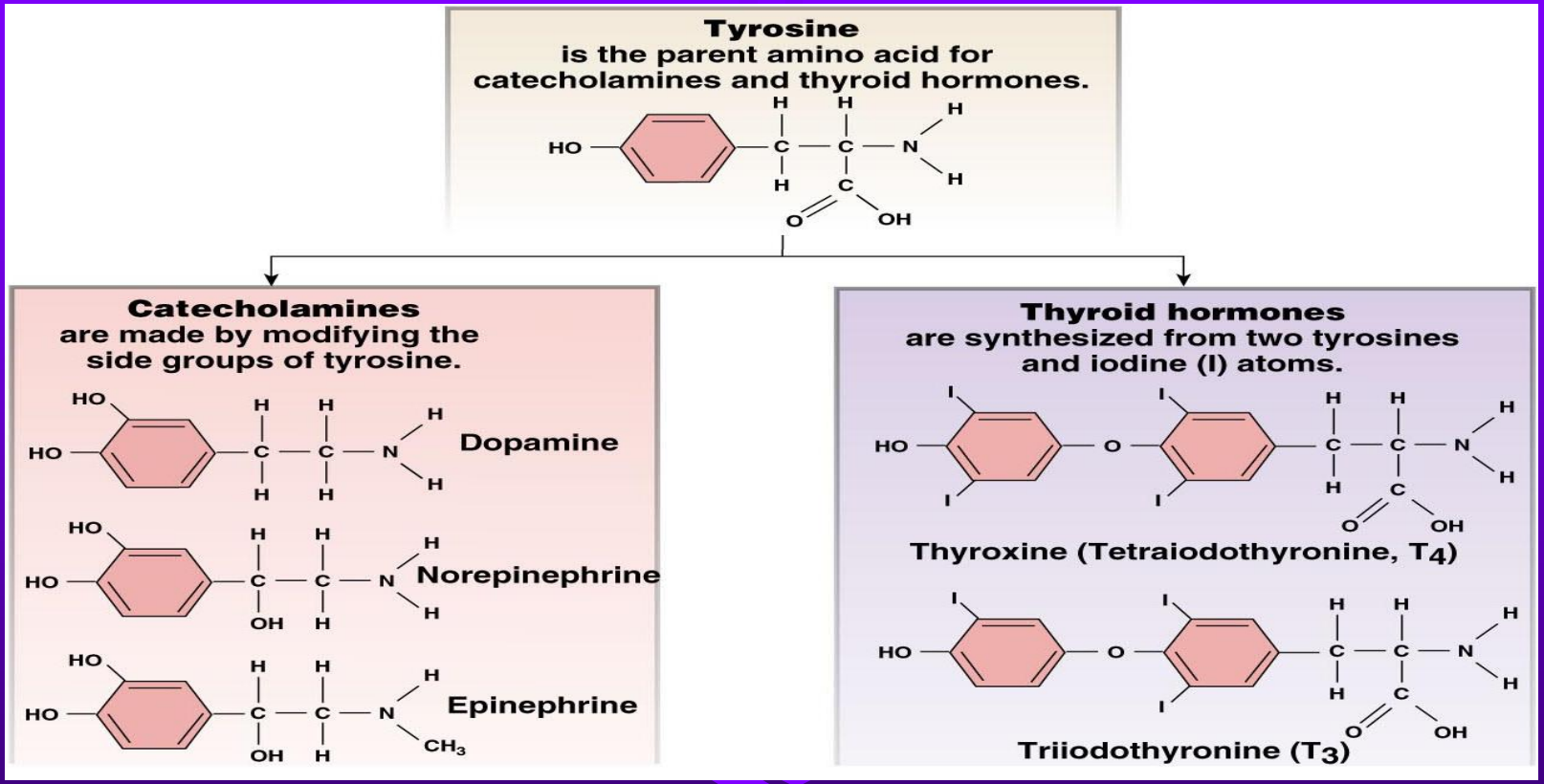


Pineal Gland
- Melatonin (derived from tryptophan)

Neuroendocrine Glands (CNS, GI tract)
- Serotonin (derived from tryptophan)

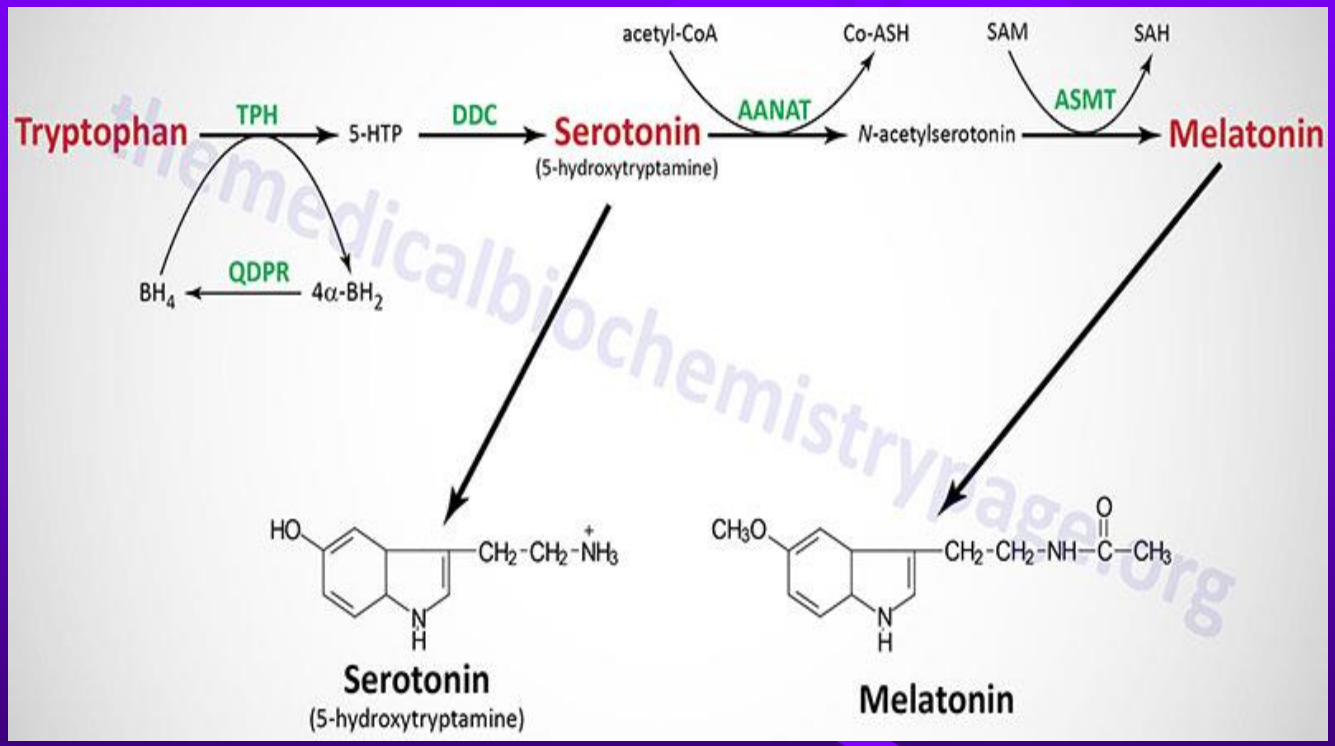
- Derived from amino acids tyrosine and tryptophan
- Thyroid hormones behave similarly to steroid hormones (binds to intracellular receptors)
- Catecholamines behave similarly to peptide hormones

Amine hormones from tyrosine: Catecholamines (water soluble hormones) and thyroid hormones (water insoluble hormones)

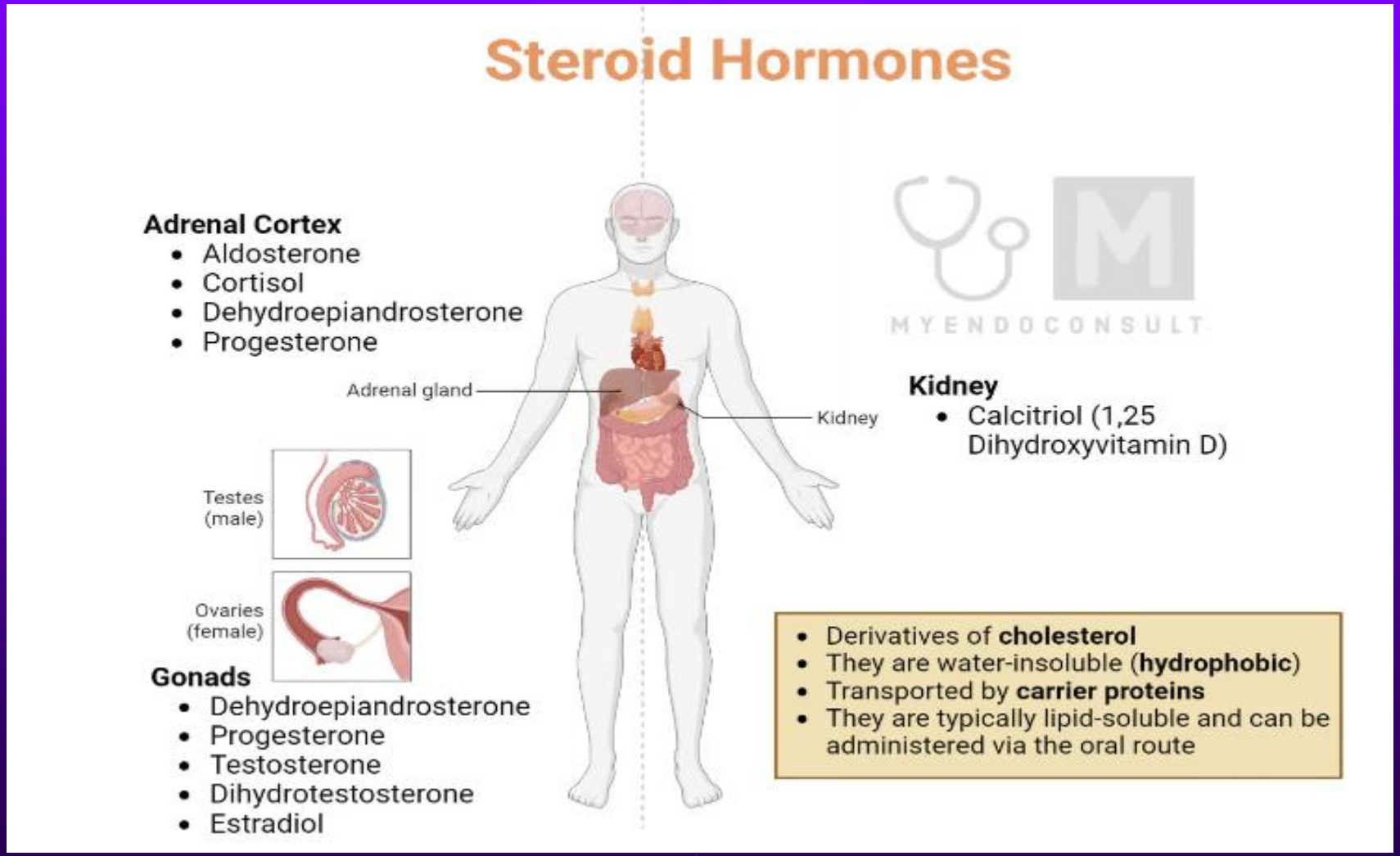


- ✓ Thyroid hormones behave similarly to steroid hormones (bind to nuclear receptors)
- ✓ Catecholamines behave similarly to peptide hormone (bind to plasma membrane receptors)

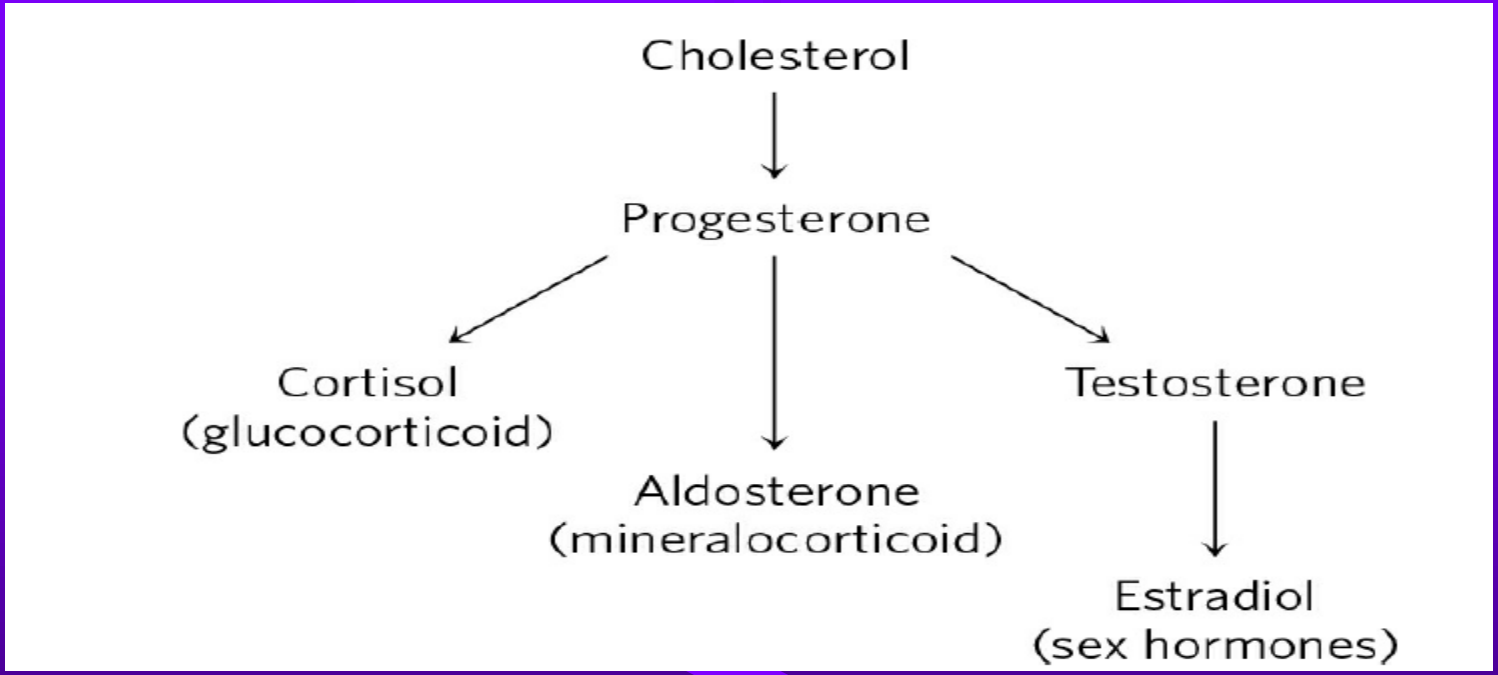
Amine hormones from tryptophan: Melatonin



Steroid hormones derived from cholesterol

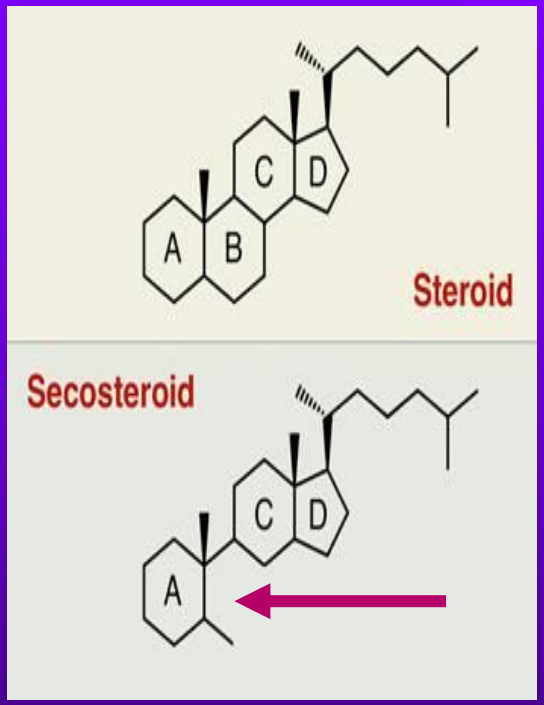


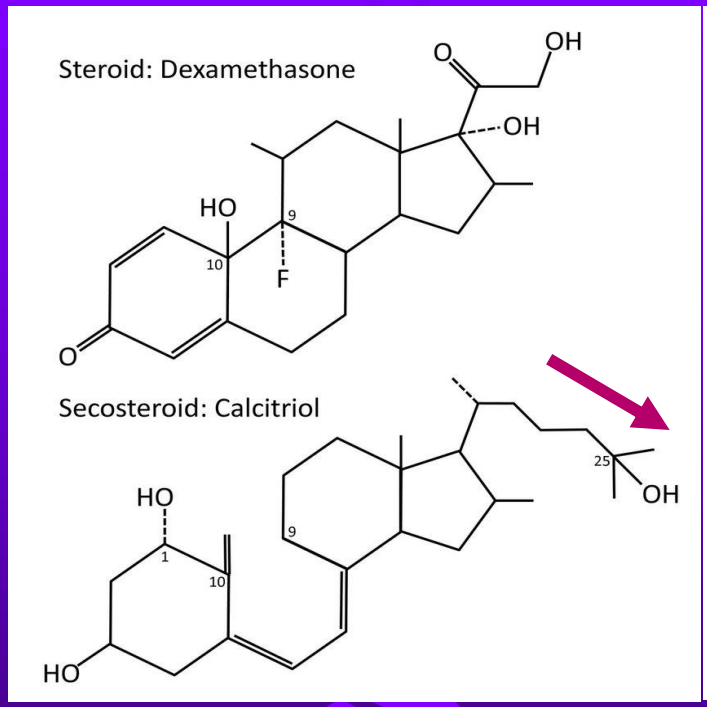
Steroid hormones

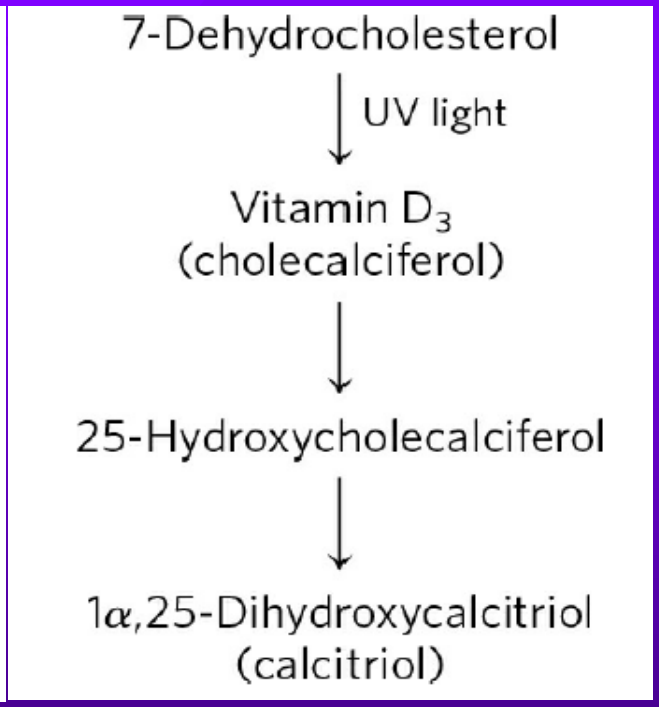


- ✓ The steroid hormones—corticosteroid (adrenocortical) hormones and sex hormones—are synthesized from cholesterol in several endocrine tissues.
- ✓ All steroid hormones act through nuclear receptors to change the level of expression of specific genes

Vitamin D is a secosteroid derived from cholesterol

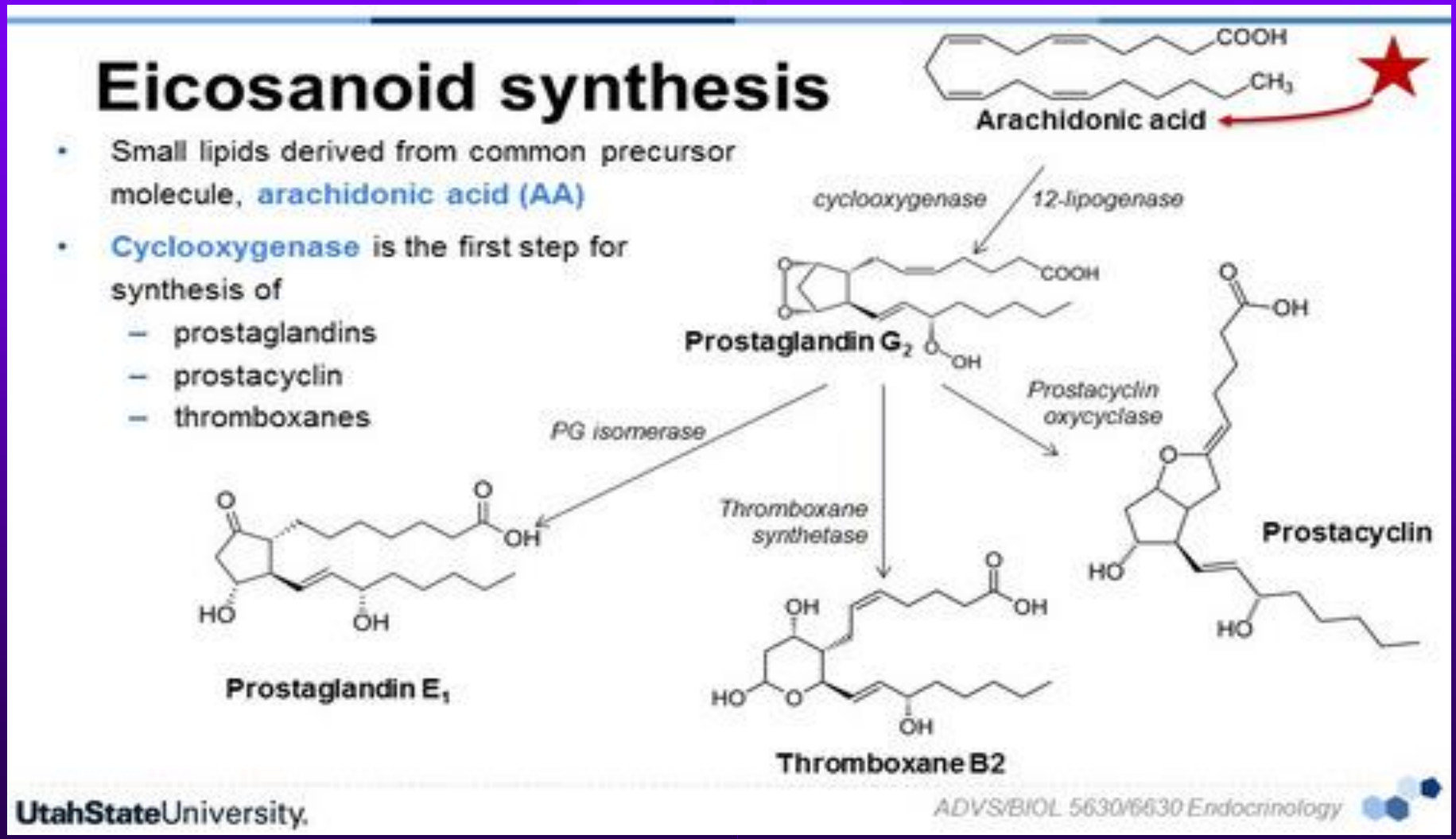


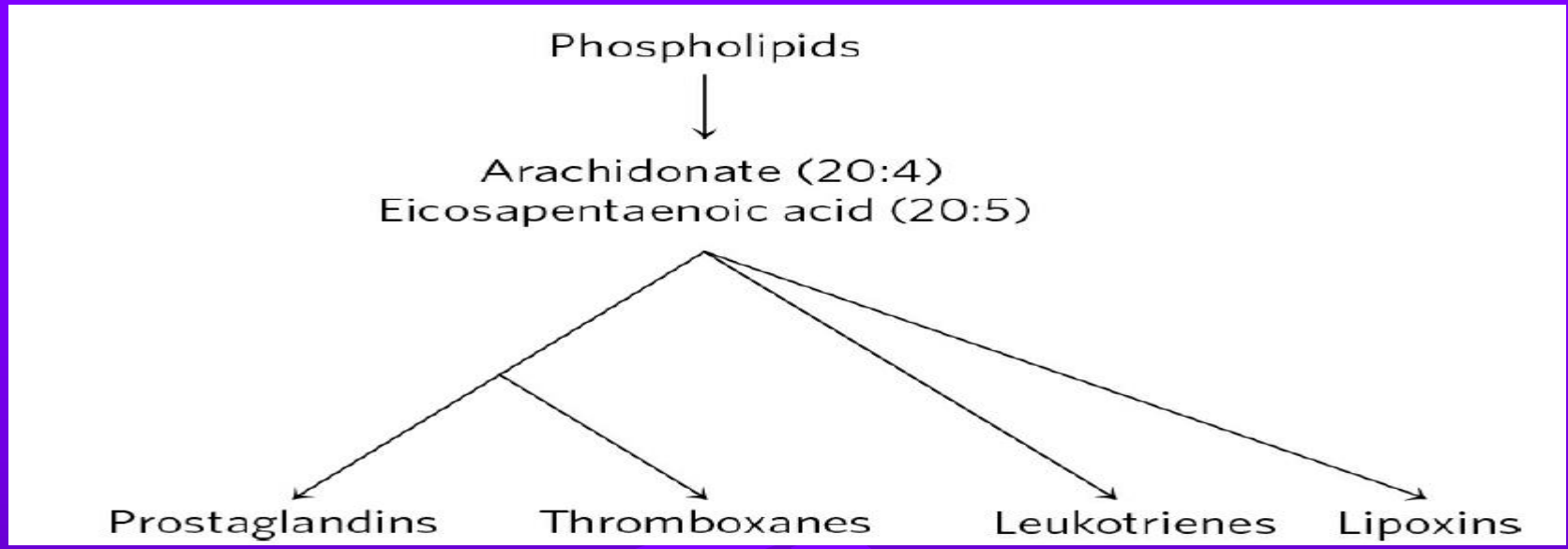




- ✓ Calcitriol (1α,25-dihydroxycalcitriol) is produced from vitamin D by enzyme-catalyzed hydroxylation in the liver and kidneys.
- ✓ Vitamin D is obtained from the diet or by photolysis of 7-dehydrocholesterol in skin exposed to sunlight

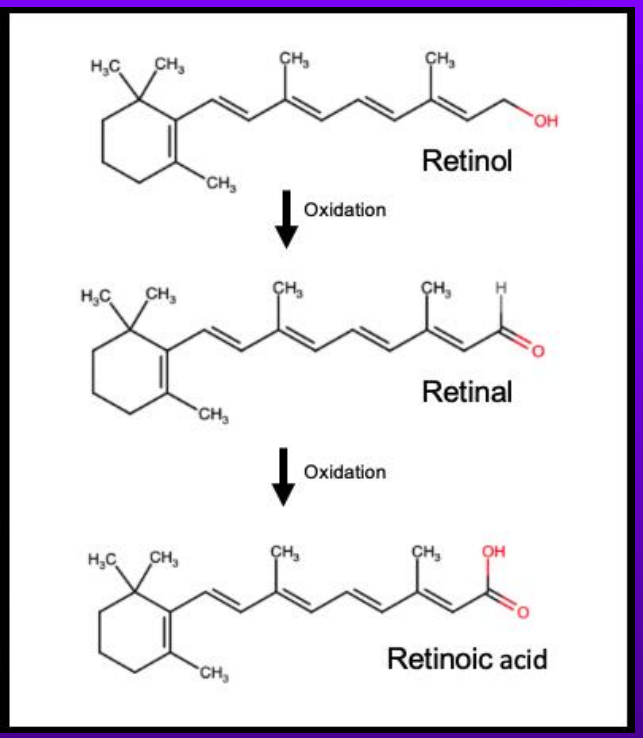
Eicosanoids: molecules derived from 20-carbon fatty acids

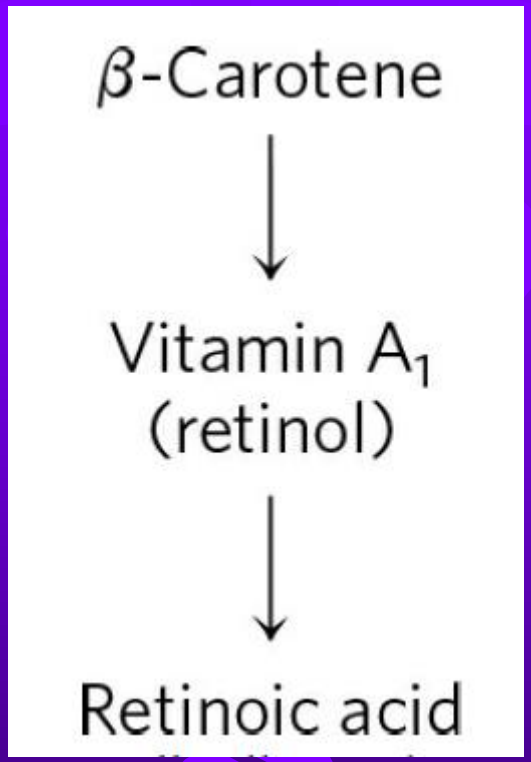




- ✓ The **eicosanoid hormones** are derived from the 20-carbon polyunsaturated fatty acids arachidonate (20:4(Δ5,8,11,14) and eicosapentaenoic acid (EPA)
- ✓ Unlike other hormones, they are not synthesized in advance and stored; they are produced when needed. They are **paracrine hormones**, secreted into the interstitial fluid (not primarily into the blood) and acting on nearby cells.
- ✓ Some prostaglandins promote the contraction of smooth muscle (intestine, uterus). They also mediate pain and inflammation in some tissues.
- ✓ Thromboxanes regulate platelet function and blood clotting.
- ✓ Leukotrienes stimulate contraction of smooth muscle. They are
- ✓ mediators of anaphylaxis, an immune overresponse that can include airway constriction, altered heartbeat, shock, and sometimes death.
- ✓ Lipoxins are short-lived eicosanoid derivatives with potent effects on immune function; they appear in the bloodstream as inflammation ends.

Retinoids: molecules derived from vitamin A

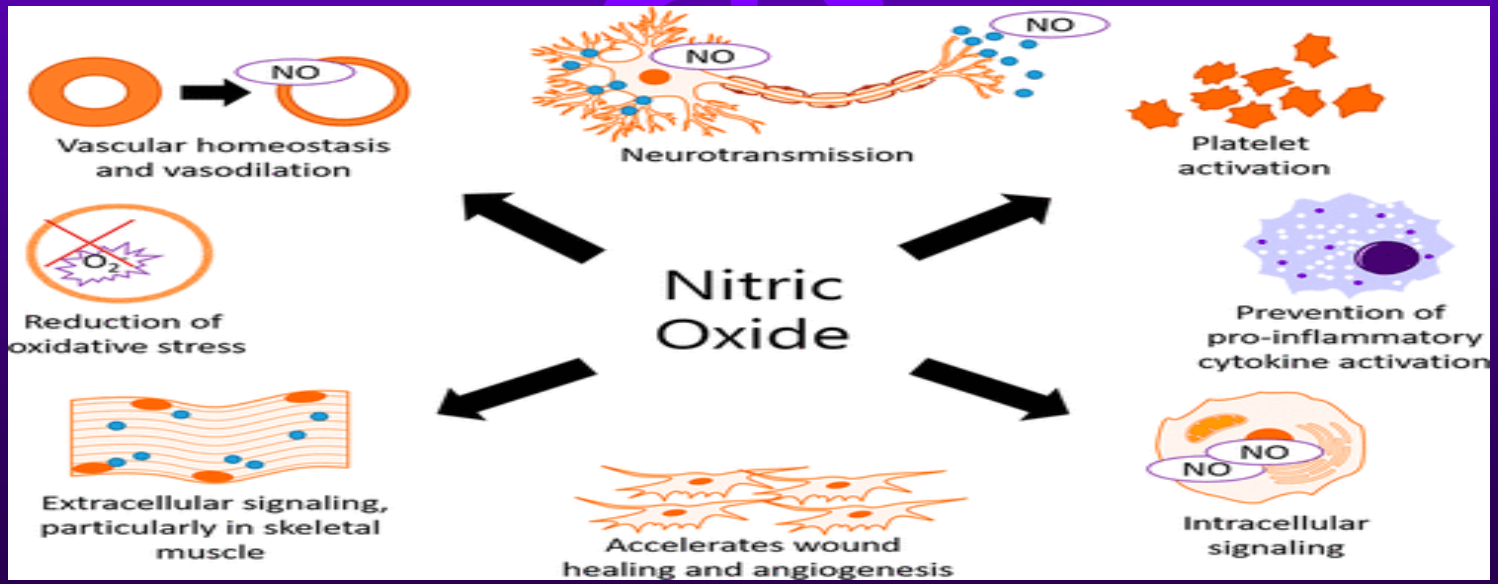




- ✓ Retinoids have many important functions including roles in vision, regulation of cell proliferation and differentiation, growth of bone tissue, immune function, and activation of tumor suppressor genes.
- ✓ The prohormone retinol is synthesized from β-carotene, primarily in liver, and many tissues convert retinol to the hormone retinoic acid (RA). RA binds to specific nuclear receptors.

Nitric oxide: molecule derived from L-arginine

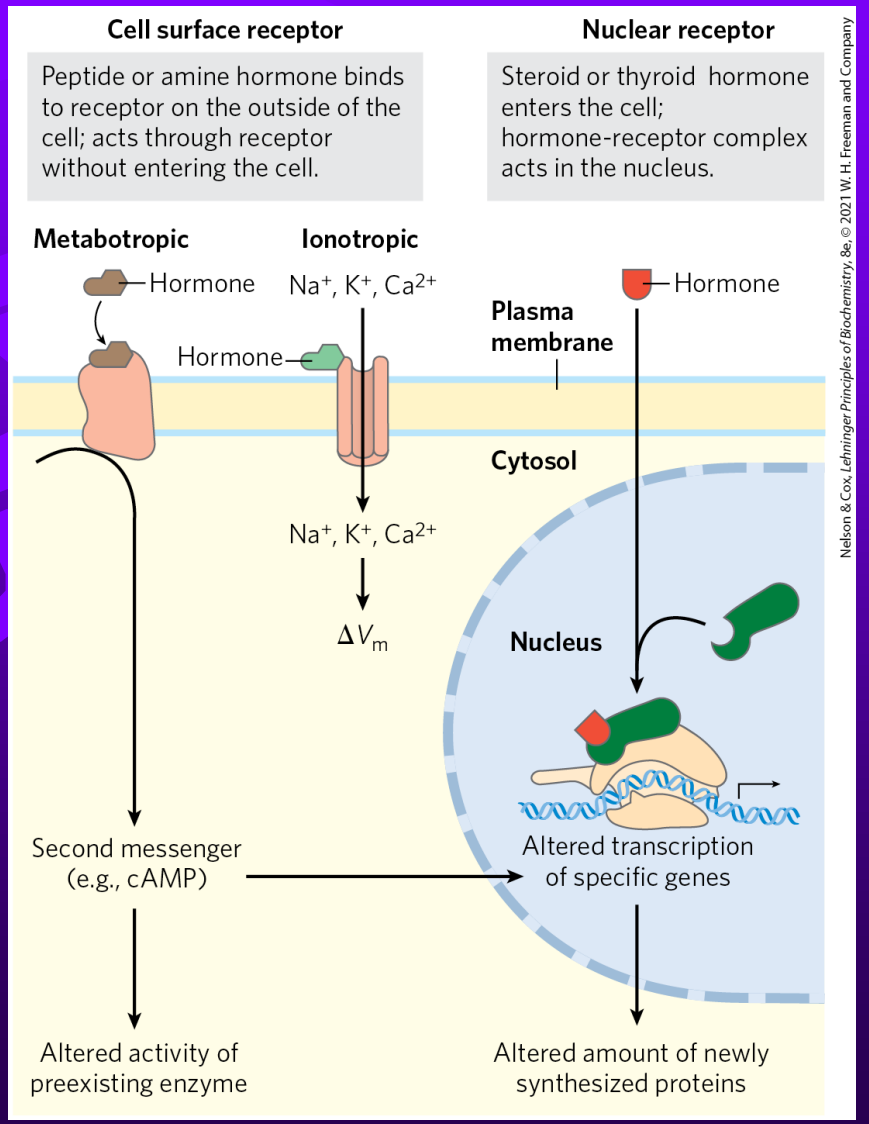
Nitric oxide (NO) is a relatively stable free radical synthesized from molecular oxygen and the guanidinium nitrogen of arginine, in a reaction catalyzed by NO synthase. NO acts near its point of release, entering the target cell and activating the cytosolic enzyme guanylyl cyclase, which catalyzes the formation of the second messenger cGMP.



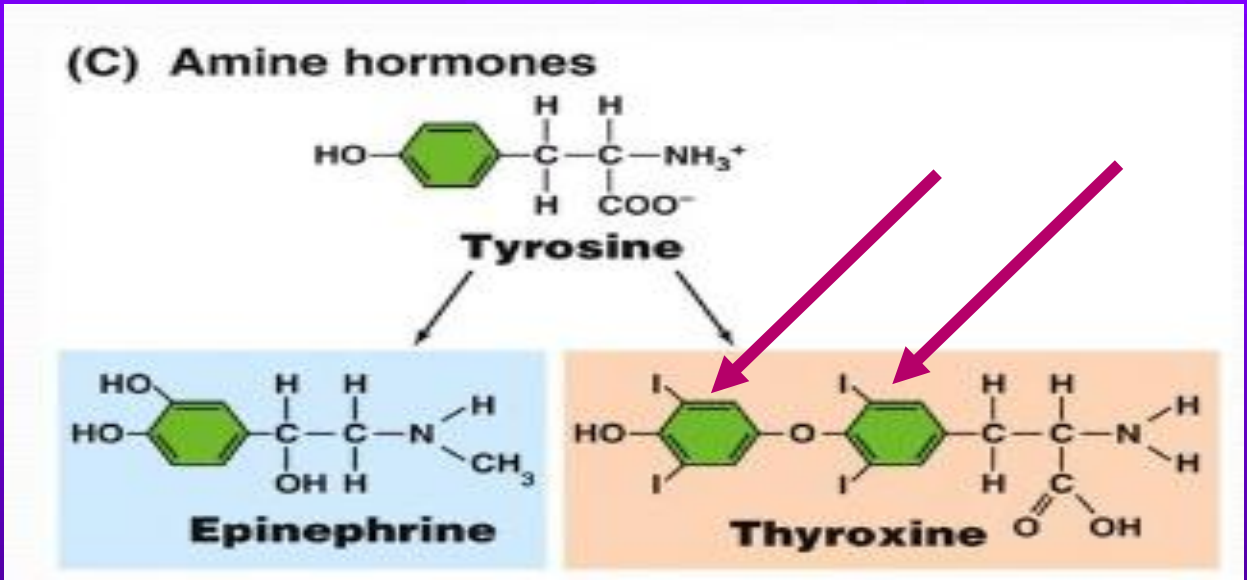
9. Classification of hormones based on their molecular mode of action

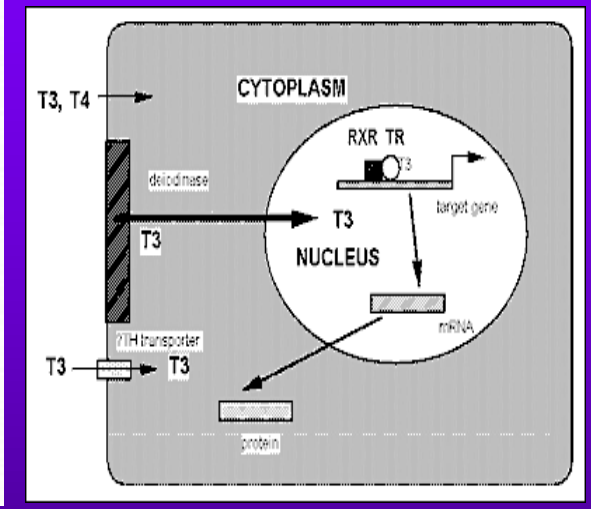
- Peptide, amine hormones (catecholamine but not thyroid hormones), and eicosanoid hormones act from outside the target cell via cell surface receptors.

- Steroid, vitamin D, retinoid, and thyroid hormones enter the cell and act through nuclear receptors.



Thyroid hormones are lipophilic hormones (lipid soluble, water insoluble) and act through nuclear receptors

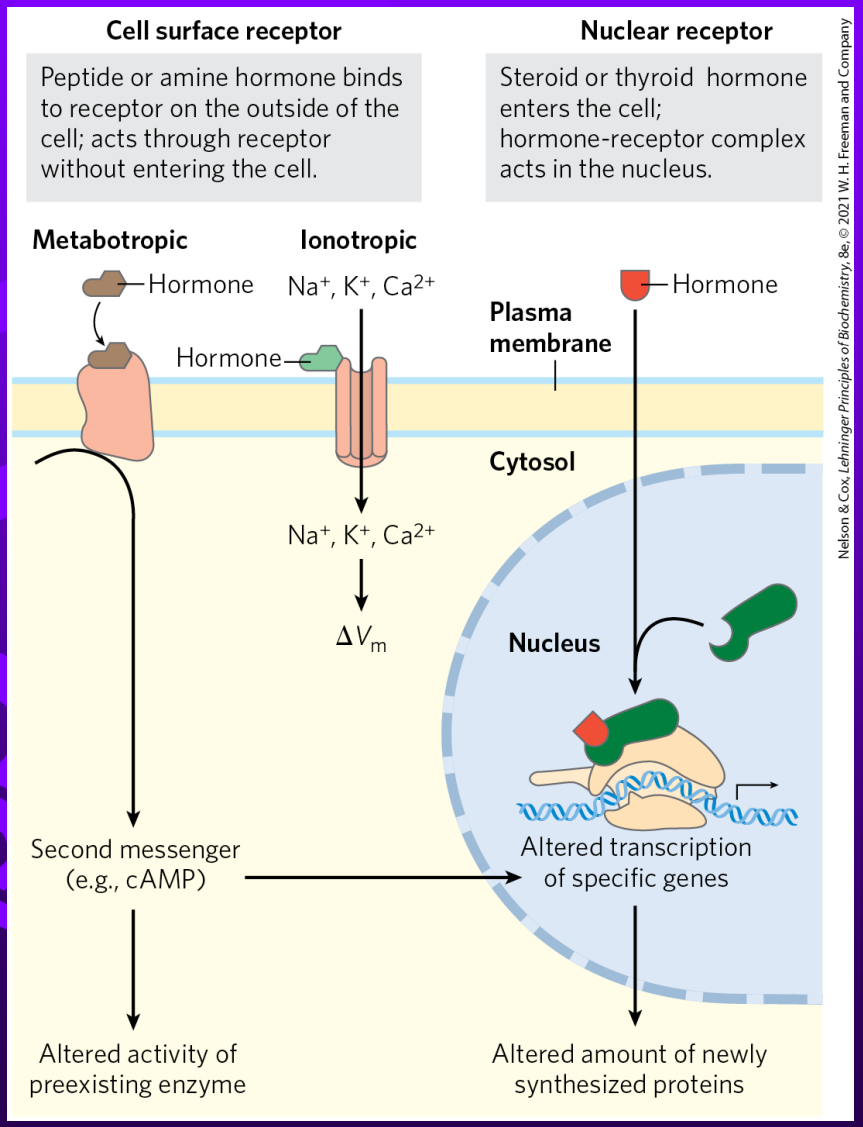




The presence of two iodinated benzene rings within a T3 or T4 (thyroxine) molecule makes these molecules very lipid-soluble.

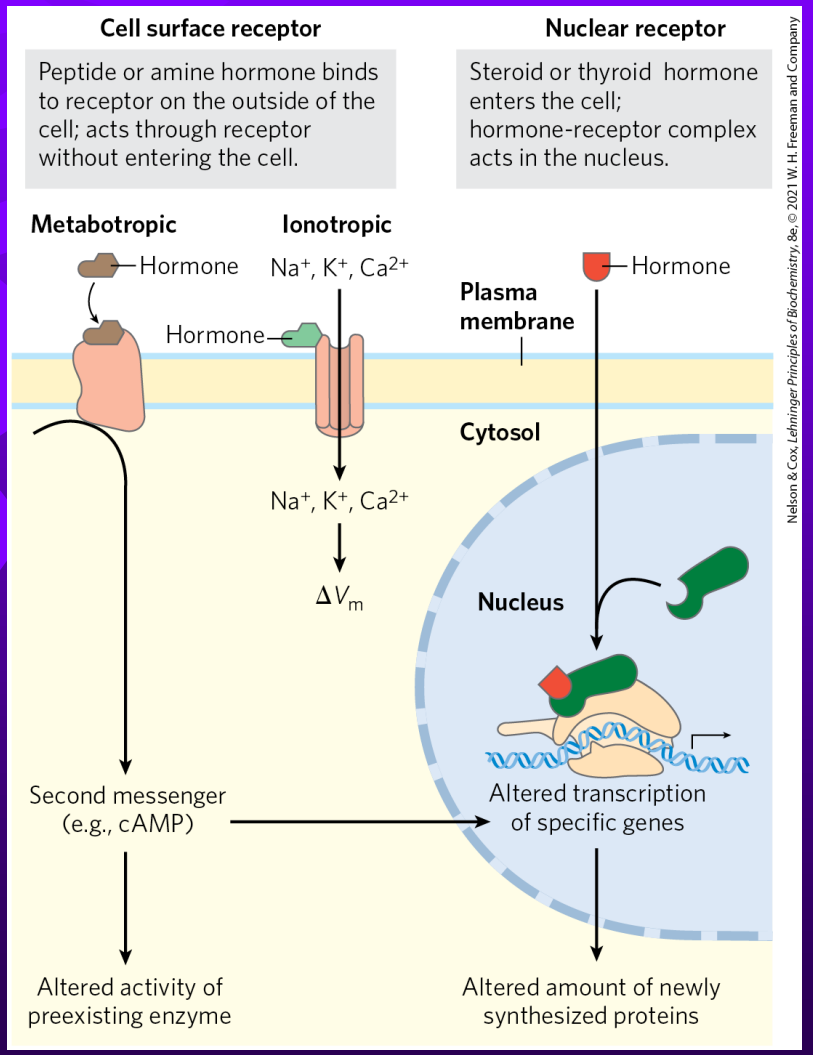
10. Hormones Act through Specific High-Affinity Cellular Receptors

- The high affinity of the interaction allows cells to respond to very low concentrations of hormone.
- **REMEMBER:** 4 general types of intracellular consequences of ligand-receptor interaction:
  - generation of a second messenger that acts as an allosteric regulator of one or more enzymes
  - activation of a receptor tyrosine kinase
  - opening or closing of an ion channel causes a change in membrane potential
  - a nuclear hormone receptor protein mediates a change in gene expression



Metabotropic and Ionotropic Surface Receptors

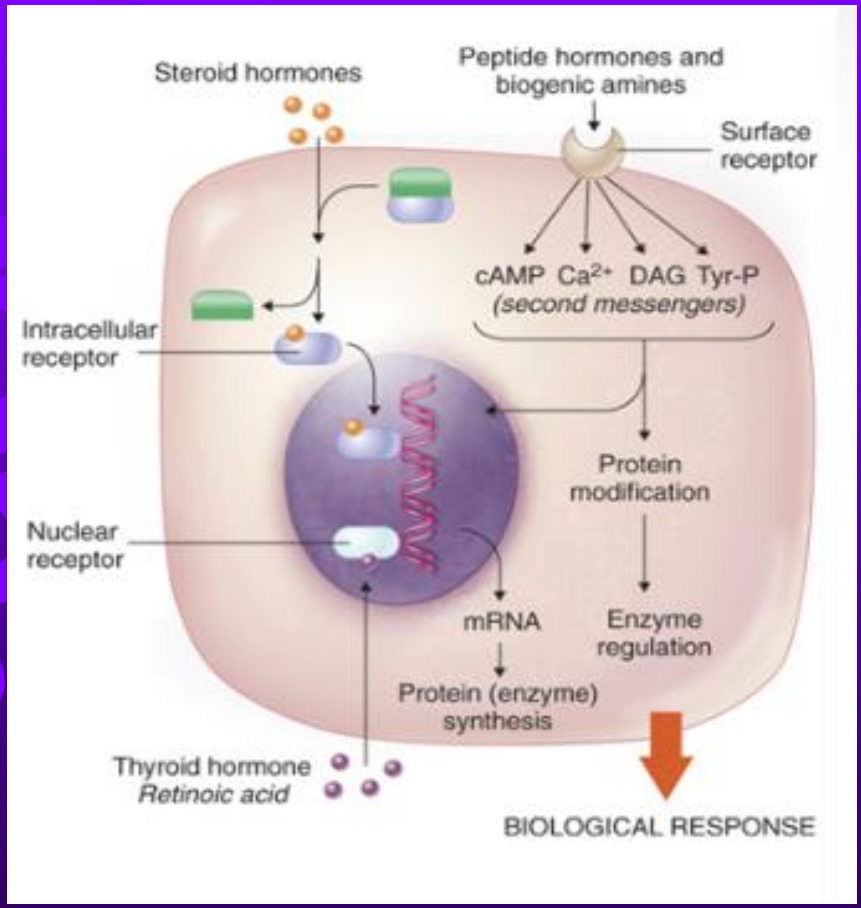
- **metabotropic** = cell surface hormone receptors that activate or inhibit a downstream enzyme
- **ionotropic** = those that open or close an ion channel in the plasma membrane, resulting in a change ΔV_m or ion concentration
- both trigger rapid physiological or biological responses



Water-Insoluble Hormones Pass Through the Plasma Membrane

- **Water-insoluble** (lipophilic, hydrophobic) hormones = readily enter the cell and bind receptor proteins in the nucleus to alter the expression of specific genes

- promote maximal responses after hours or days



11. What are the differences between water soluble and water insoluble hormones?

- **Water soluble**

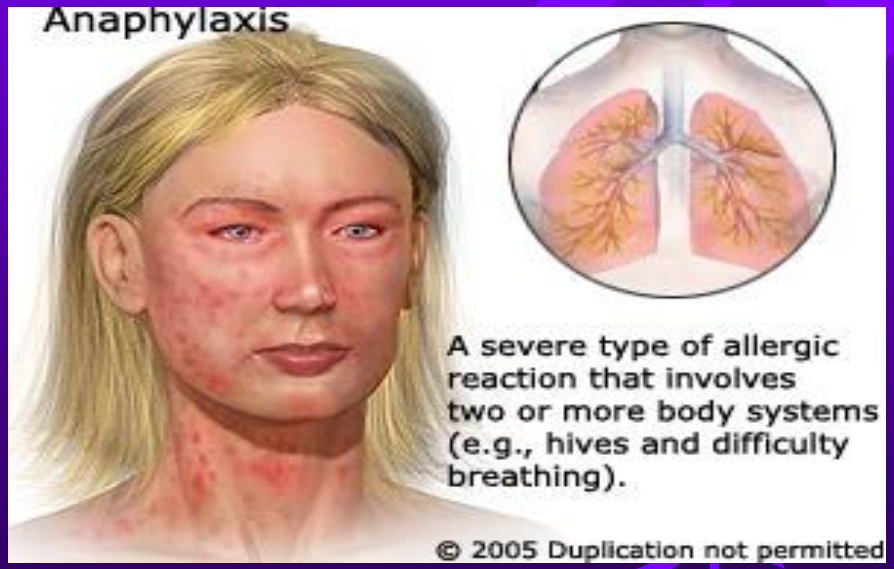
1. Transportation in the blood without proteins (generally)
2. They do not cross the cell membrane
3. They bind to cell surface receptors that activate or inhibit a downstream enzyme
4. They need a second messenger to enhance the signal
5. They trigger rapid physiological or biological responses (**FAST-ACTING**)
6. Example: Peptide, amine hormones (catecholamine but not thyroid hormones), and eicosanoid hormones

- **Water insoluble**

1. Transportation in the blood with proteins
2. They cross the cell membrane
3. They bind receptor proteins in the nucleus.
4. They interact with DNA and alter the expression of specific genes.
5. They promote maximal responses after hours or days (**SLOW-ACTING**)
6. Example: Steroid, vitamin D, retinoid, and thyroid hormones enter the cell and act through nuclear receptors

Clinical problem #1

What will we administer to the patient immediately and why? Adrenaline (catecholamine) or corticosteroid (steroid)?



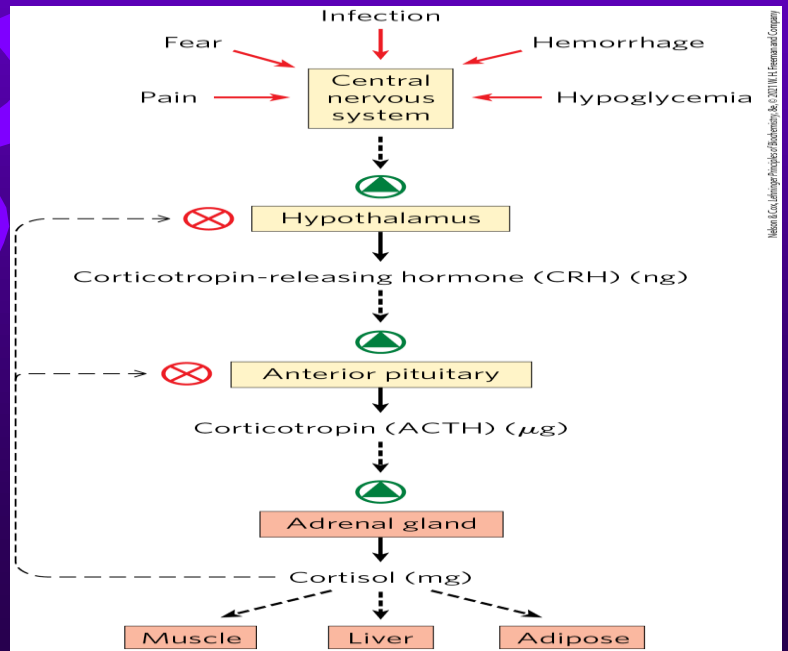
Some important hormonal properties…

1. Close connection with Central Nervous System (CNS)
2. Autoregulation and feedback mechanisms
3. Hormonal Cascades Result in Large Signal Amplifications
4. Several hormones were shown to have daily oscillations (circadian rhythm)

12. Many Hormones Are Released by a "Top-Down" Hierarchy of Neuronal and Hormonal Signals

- the **central nervous system** (CNS) receives input from many internal and external sensors and orchestrates the production of appropriate hormonal signals by the endocrine tissues

- **hypothalamus** = the coordination center of the endocrine system
  - receives and integrates messages from the CNS
  - produces releasing or inhibiting factors



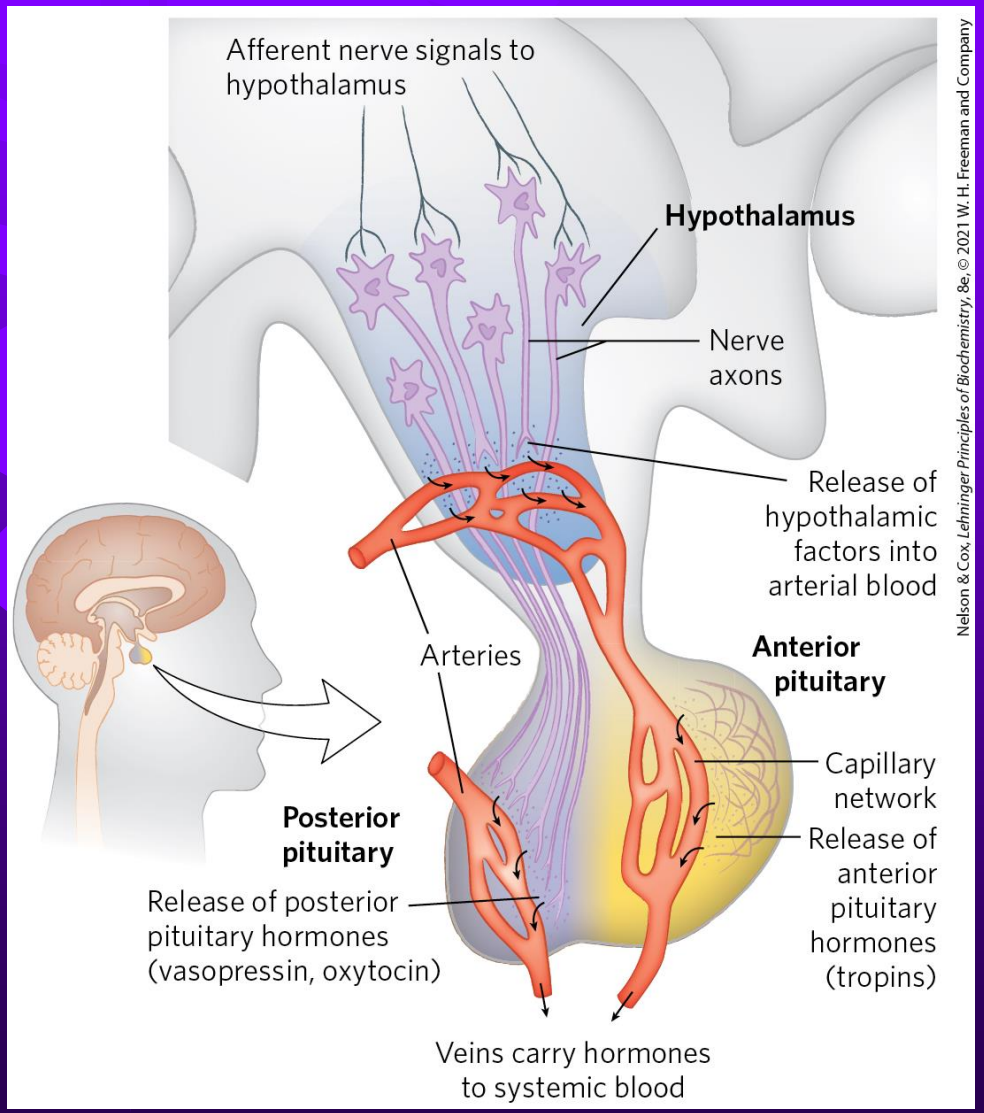
SMALL AND MIGHTY

THE HYPOTHALAMUS

Neuroendocrine Origins of Hormone Signals

- **posterior pituitary** = contains the end of axons from the hypothalmus

- **anterior pituitary** = the endocrine organ that receives releasing factors from the hypothalamus via blood vessels



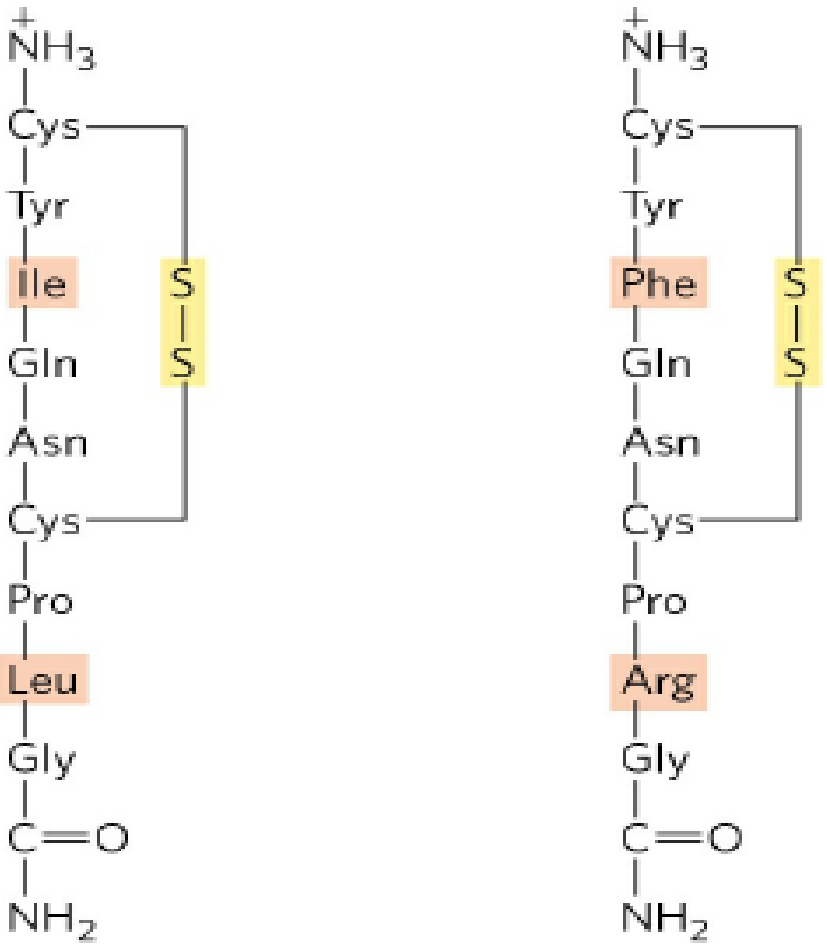
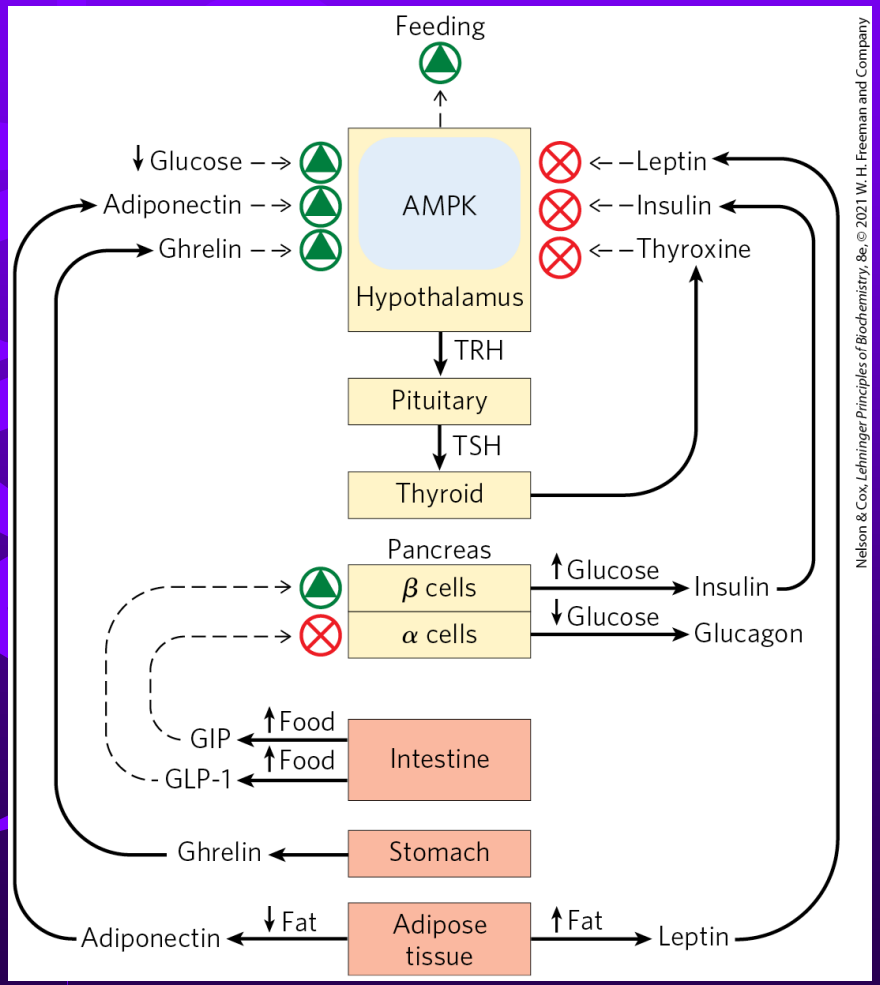


FIGURE 23-10 Two hormones of the posterior pituitary gland. The carboxyl-terminal residue of both peptides is glycinamide, —NH—CH_2—$CONH_2$ (as noted in Fig. 23-2, amidation of the carboxyl terminus is common in short peptide hormones). These two hormones, identical in all but two residues (shaded light red), have very different biological effects. Oxytocin acts on the smooth muscle of the uterus and mammary glands, causing uterine contractions during labor and promoting milk release during lactation. Vasopressin (also called antidiuretic hormone) increases water reabsorption in the kidney and promotes the constriction of blood vessels, thereby increasing blood pressure.

"Bottom-Up" Hormonal Systems Send Signals Back to the Brain and to Other Tissues

- some hormones are produced in the digestive tract, muscle, and adipose tissue and communicate the current metabolic state to the hypothalamus



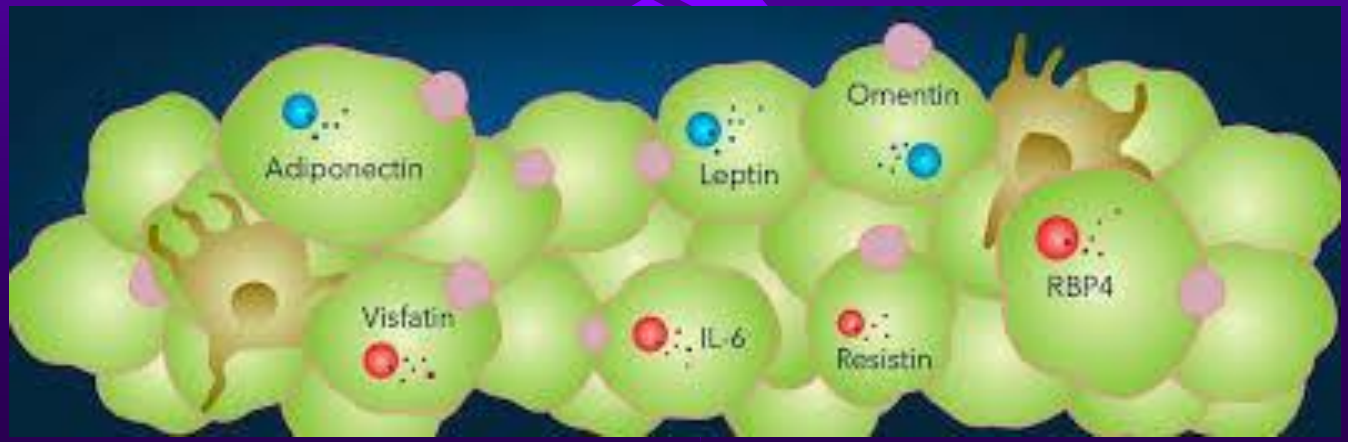
Peptide Hormones That Act on Feeding Behavior and Fuel Selection in Mammals

Table 23-2 Some Peptide Hormones That Act on Feeding Behavior and Fuel Selection in Mammals

Hormone	Production site(s)	Target tissue(s)	Action(s)
Insulin	Pancreatic β cells	Muscle, adipose, liver	Stimulates glucose uptake and synthesis of glycogen and fat
Glucagon	Pancreatic α cells	Liver, adipose	Stimulates gluconeogenesis and glucose release to blood
Leptin	Adipose tissue	Hypothalamus	Reduces hunger
Adiponectin	Adipose tissue	Muscle, liver, others	Stimulates catabolism and feeding behavior
Ghrelin	Stomach, intestine	Brain	Signals hunger
Incretins: GLP-1, GIP	Intestine	Pancreas	Stimulate insulin release
NPY	Hypothalamus, adrenals	Brain, autonomic nervous system	Stimulates feeding behavior
$PYY_{3–36}$	Intestine	Brain	Signals satiety
Irisin	Muscle (after exercise)	Adipose	Turns white adipose tissue to beige

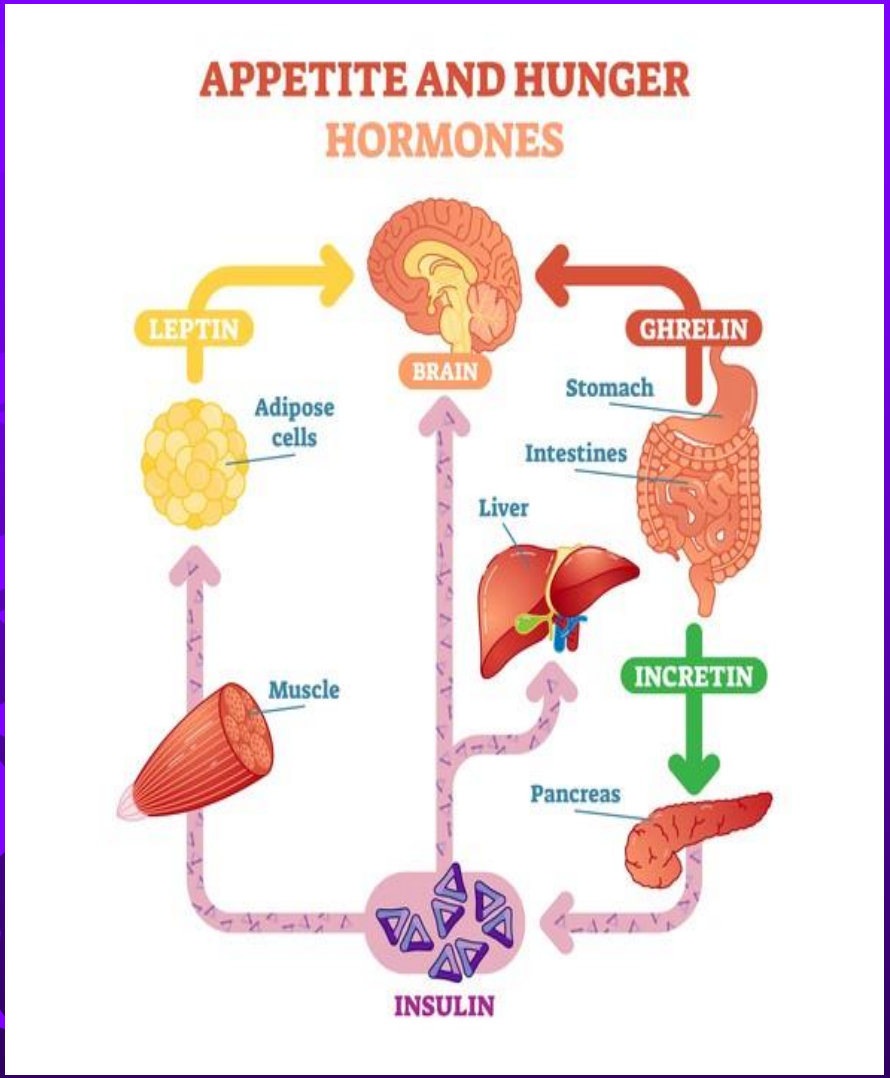
Adipokines

- **adipokines** = peptide hormones produced in adipose tissue that signal the adequacy of fat reserves
- **leptin** = an adipokine released when adipose tissue is well-filled with triacylglycerols
  - acts in the brain to inhibit feeding
- **adiponectin** = an adipokine released when adipose tissue is depleted of fat reserves
  - acts in the brain to stimulate feeding



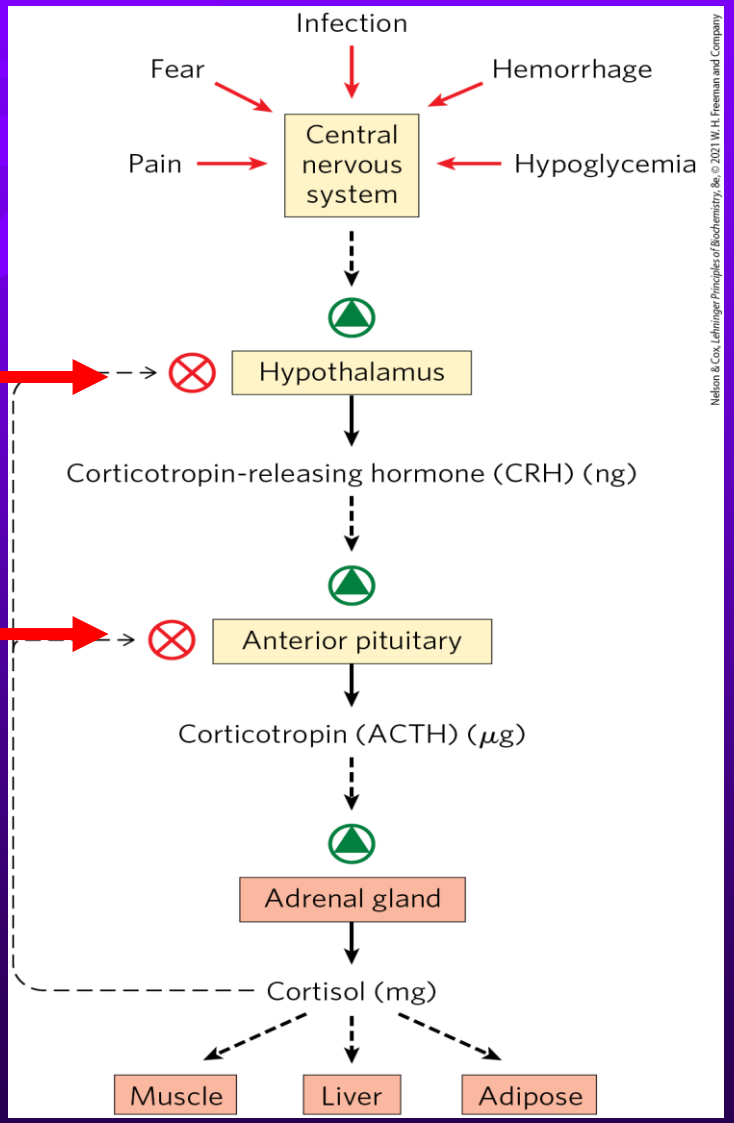
Gastrointestinal hormones

- **ghrelin** = produced in the gastrointestinal tract when the stomach is empty
  - acts in the hypothalamus to stimulate feeding
- **incretins** = peptide hormones produced in the gut after ingestion of a meal
  - acts in the pancreas to increase insulin secretion and decreases glucagon secretion
- **peptide YY (PYY3–36)** = a hormone produced in the intestine signals satiety in the brain (hypothalamus)



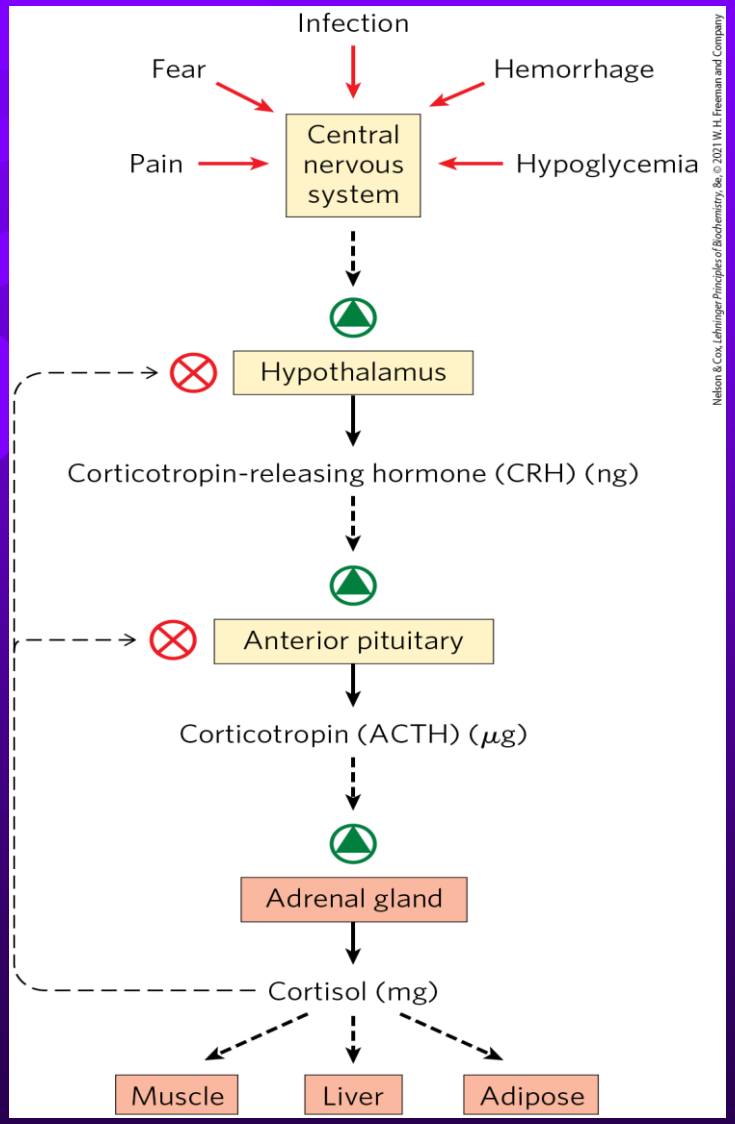
13. Top-Down Hormone Release and negative feedback

- at each level of a hormonal cascade, feedback inhibition of earlier steps is possible



14. Hormonal Cascades Result in Large Signal Amplifications

- at each level in the cascade, a small signal elicits a larger response
- the cortisol hormone cascade has an overall amplification of at least a millionfold: initial signal to the hypothalamus⟶ release of CRH (**ng**) ⟶ release of corticotropin (**µg**) ⟶ release of cortisol (**mg**)



14. Hormonal Cascades Result in Large Signal Amplifications

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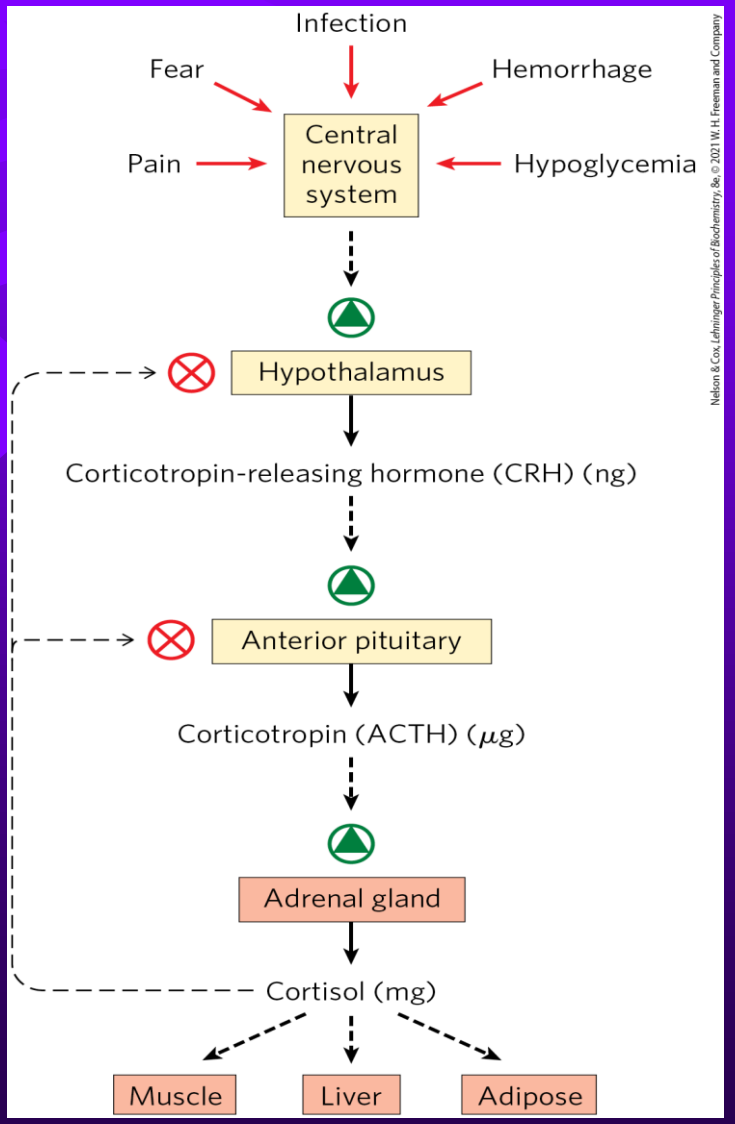
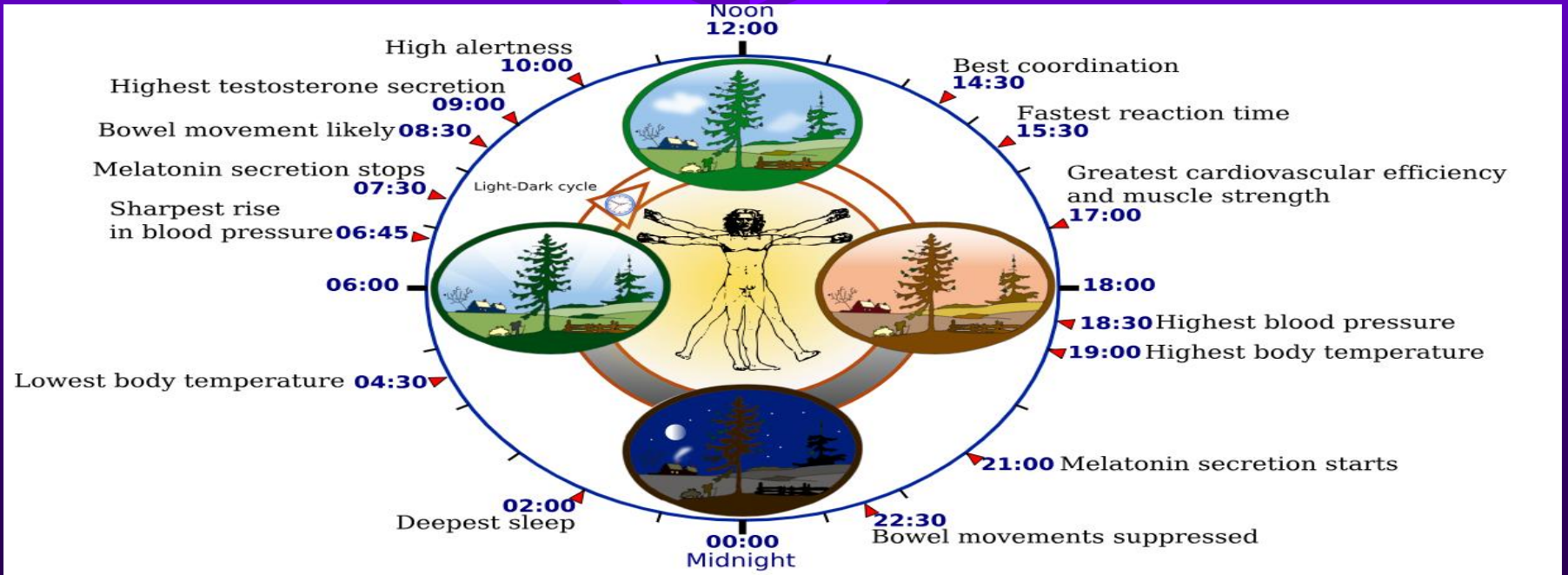
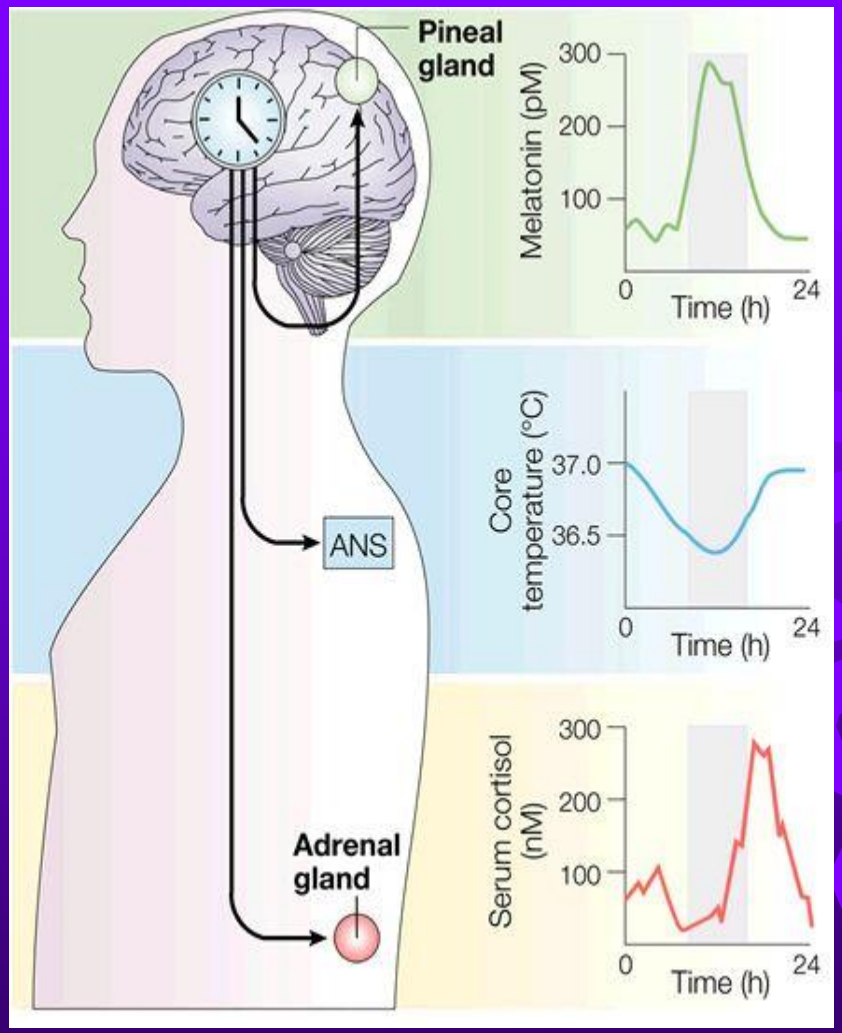


15. Several hormones were shown to have daily oscillations

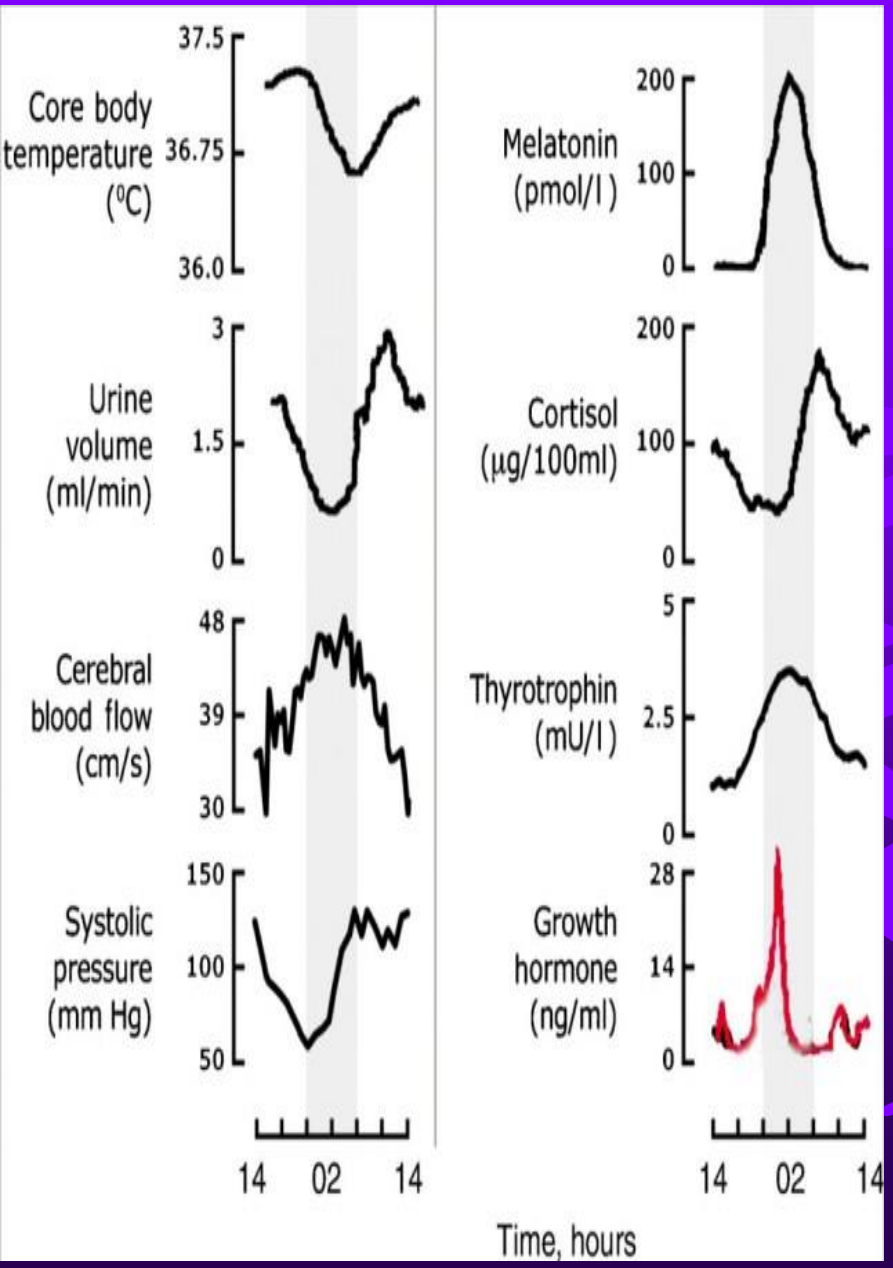
- Circadian rhythms are changes that follow a 24-hour cycle. These natural processes respond primarily to light and dark and affect animals, plants, and microbes.
- Circadian rhythms allow organisms to anticipate and prepare for precise and regular environmental changes.
- Chronobiology is the study of circadian rhythms





The classic phase markers for measuring the timing of a mammal's circadian rhythm are:

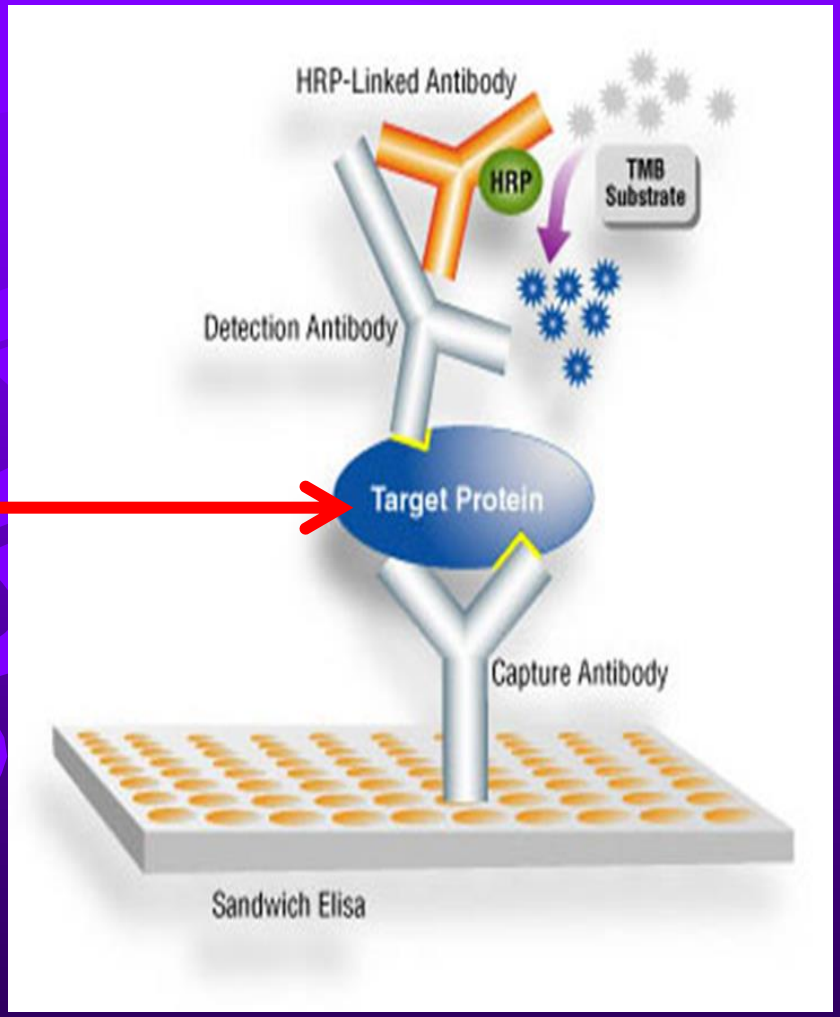
- melatonin secreted by the pineal gland
- core body temperature minimum
- plasma level of cortisol



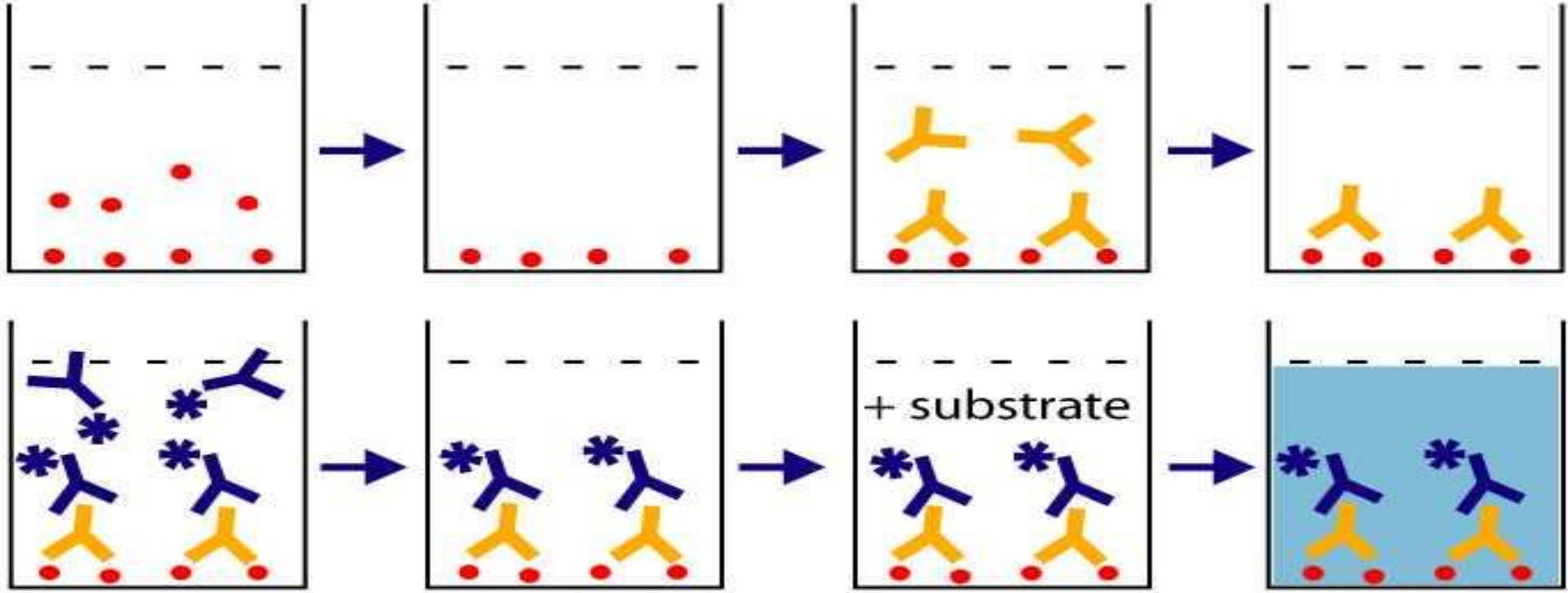
- **Melatonin** increases soon after the onset of darkness, peaks in the middle of the night, between 2 and 4 a.m.
- **Cortisol** has a circadian rhythm, with levels peaking in the morning between 08.00 and 09.00 (before the individual wakes up)
- **Testosterone** levels peak between 0530 and 0800 h, with trough levels occurring approximately 12 h later.
- **Growth hormone** (GH) secretion is characterized by a pulsatile, circadian rhythm, with the highest concentrations at night hours.

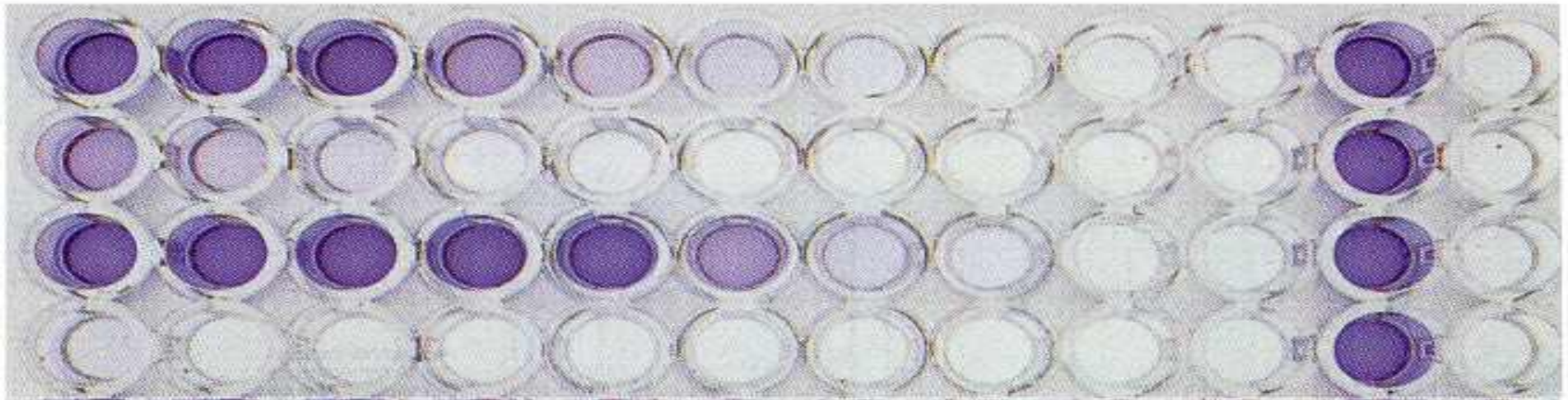
16. How can we measure hormones in the blood?

- Most hormones are present in the circulating blood in extremely low concentrations, some as low as one millionth of a microgram (one picogram) per mL.
- Because hormones circulate in low quantities in blood, their accurate measurement requires sensitive assays.
- The major assay in use is the immunoassay (IA), which relies on the antigen-antibody reaction. IA are easy to use, cheaper, faster and suitable for processing a large volume of samples.



ELISA





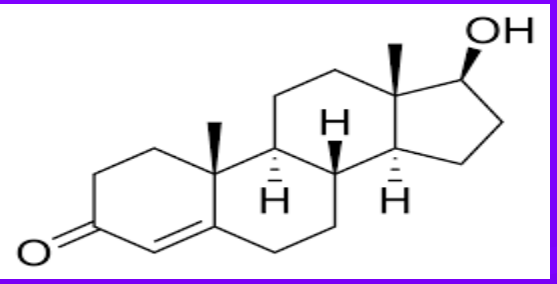

Substrate
100 ml
Sample Dilue
250 ml
MicroGeneSys, Inc.
Stopping
100 m

SUMMARY

- Hormones are chemical messengers secreted by certain tissues into the blood or interstitial fluid, serving to regulate the activity of other cells or tissues.
- Hormones are chemically diverse with a wide range of biological roles peptide hormones are synthesized as proteins on ribosomes then cleaved proteolytically to form the active peptide.
- Hormones may be classified by 1) the way they get from their point of release to their target tissue (endocrine-paracrine-autocrine); 2) their chemical structure and 3) their modes/mechanism of action.
- Peptide, catecholamine, and eicosanoid hormones bind to specific receptors in the plasma membrane of target cells, altering the level of an intracellular second messenger, without entering the cell.

- **Steroid, vitamin D, retinoid, and thyroid hormones** enter target cells and alter gene expression by interacting with specific nuclear receptors
- Some **important hormonal properties** are the following:
  1) Close **connection** with Central Nervous System (CNS);
  2) **Autoregulation** and feedback mechanisms;
  3) Hormonal Cascades Result in **Large Signal Amplifications**;
  4) Several hormones were shown to have daily oscillations (**circadian rhythm**)
- Hormones are regulated by a **top-down hierarchy** of interactions between the brain and endocrine glands: nerve impulses stimulate the hypothalamus to send specific hormones to the pituitary gland, thus stimulating (or inhibiting) the release of tropic hormones. The anterior pituitary hormones in turn stimulate other endocrine glands (thyroid, adrenals, pancreas) to secrete their characteristic hormones, which in turn stimulate specific target tissues.

- Some hormones act in **bottom-up** signaling: adipose tissue muscle and the gastrointestinal tract release peptide hormones that act on other tissues or in the central nervous system.
- Because hormones circulate in **very low quantities in blood**, their accurate measurement requires **sensitive assays**. **Immunoassays**, which relie on the antigen-antibody reaction, are practical and sensitive techniques for detecting and quantifying hormones.



Clinical problem #2

A 22-year-old infertile man receives intramuscular testosterone. How does testosterone work/act?

1) It binds to cell membrane receptors
2) It acts directly without receptors in the cell nucleus
3) It is a water-soluble hormone
4) It needs a second messenger to enhance the signal
5) It binds to specific nuclear receptors of steroid hormones, which alter gene expression and are responsible for androgenic actions

LEARNING OBJECTIVES-Students should be able to answer the following questions OR to:

- What are hormones? •What are hormonal functions and effects on humans?
- What are endocrine glands?
- What are the differences between endocrine and exocrine glands?
- Which system coordinates metabolism in mammals?
- What is a neurotransmitter?
- How can hormones be classified?
- How can hormones be classified based on their chemical structure?
- How can hormones be classified based on their molecular mode of action?
- How do hormones act through cellular receptors?
- What are the differences between water soluble and water insoluble hormones?
- Explain and interpret the main hormonal properties.
- How do autoregulation and feedback mechanism function?
- What are the neuroendocrine origins of hormone signals?
- What are hormonal cascades?
- What is a circadian rhythm? Provide examples.
- How do we measure hormones in the blood?

Multiple choice questions-SAMPLE

1. **Which of the following hormones is NOT derived from cholesterol?**

A. Cortisol

B. Insulin

C. Calcitriol

D. Progesterone

E. Estradiol

2. **Which of the following hormones binds to nuclear receptors?**

A. Thyroxine

B. Melatonin

C. Adrenaline

D. Dopamine

E. Parathormone

Study material

- 1) slides
- 2) Nelson DL, Cox MM. Lehninger Principles of Biochemistry. 8th edition. NY 2021: chapter 23.1: pages: 842-847

Thank you very much for your attention!!!