Al-Mustaqbal University

College of Health and Medical Techniques

Medical Laboratories Techniques Departments

Biochemistry Lectures for 2nd Year Students

(2 Credit Hrs. Theory + 2 Credit Hrs. Practice / Week = 3 Credit Unit
Academic Year: 2024 - 2025

Course Organizers:

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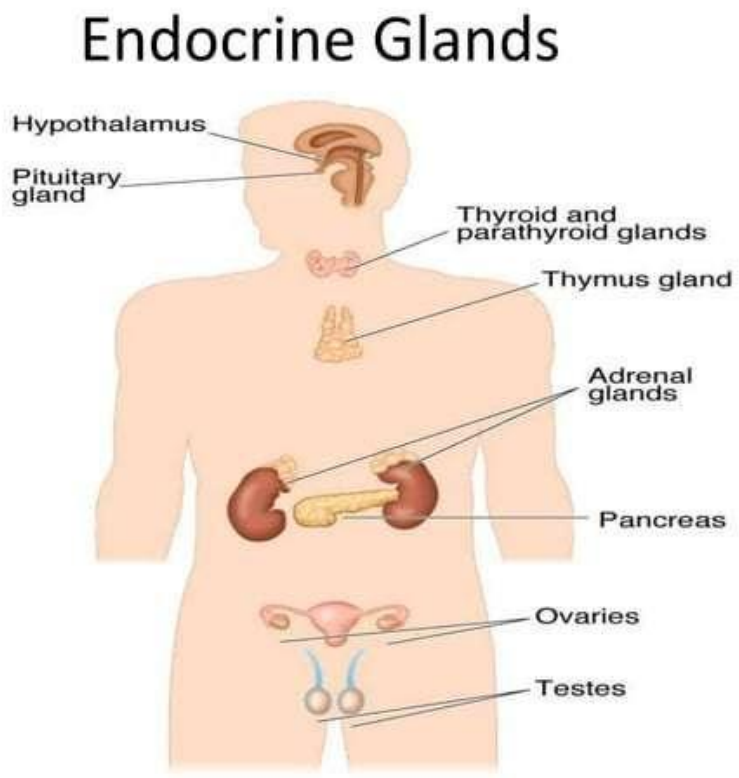
Second Semester

Lecture No. 1 and 2

Date: Jan., 19th , 2025

Biochemistry of Hormones:

Hormones, Receptors, Target Cells and Regulation:



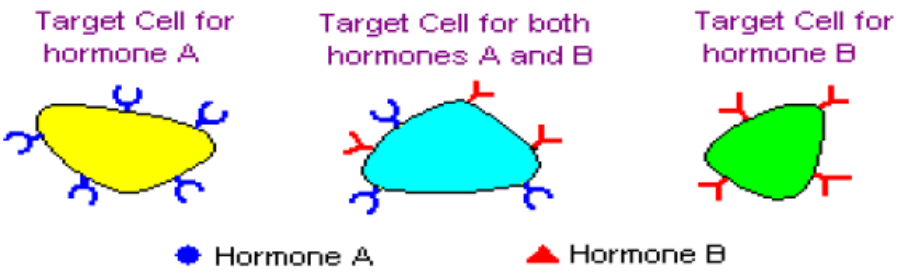
The endocrine system is one of the two coordinating and integrating systems of the body. It acts through chemical messengers - hormones – carried in the circulation.

Two systems control all physiologic processes:

1. The nervous system exerts point-to-point control through nerves, similar to sending messages by conventional telephone. Nervous control is electrical in nature and fast.
2. The endocrine system broadcasts its hormonal messages to essentially all cells by secretion into blood and extracellular fluid. Like a radio broadcast, it requires a receiver to get the message - in the case of endocrine messages, cells must bear a receptor for the hormone being broadcast in order to respond.

Receptors and Target Cells

A given hormone usually affects only a limited number of cells, which are called target cells. A target cell responds to a hormone because it bears receptors for the hormone.

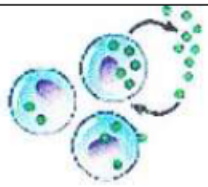
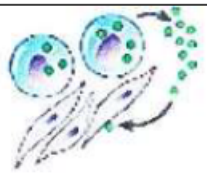
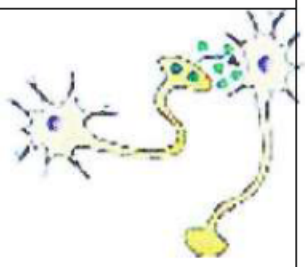


Hormone receptors are found either exposed on the surface of the cell or within the cell, depending on the type of hormone. In very basic terms, binding of hormone to receptor triggers a cascade of reactions within the cell that affects function. Hormone receptors have two essential qualities:

1. The receptor must be able to recognize a unique binding site within the hormone in order to discriminate between the hormone and all other proteins.
2. The receptor must be able to transmit the information gained from binding to the hormone into a cellular response.

Hormones may be secreted into blood and affect cells at distant sites. Some hormones known to act and affect neighboring cells or even have effects on the same cells that secreted the hormone. Three actions are defined:

1. Endocrine action: the hormone is distributed in blood and binds to distant target cells.
2. Paracrine action: the hormone acts locally by diffusing from its source to target cells in the neighborhood.
3. Autocrine action: the hormone acts on the same cell that produced it.

Types of hormones			
Chemical messengers			
Intracellular chemical signal	Description	Example	
Autocrine	Secreted by cells in a local area and influences the activity of the same cell from which it was secreted	Prostaglandins	
Paracrine	Produced by a wide variety of tissues and secreted into tissue spaces; has a localized effect on adjacent cells	Histamine, Prostaglandins	
Hormone	Secreted into the blood by specialized cells; travels by the blood to target tissues	Thyroxine, Insulin	
Neurohormone	Produced by neurons and functions like hormones	Oxytocin, Antidiuretic hormone	
Neurotransmitter	Produced by neurones and secreted into extracellular spaces by nerve terminals; travels short distances, influences postsynaptic cells or effector cells.	Acetylcholine, norepinephrine	

Hormones:

Hormones are the chemical messenger produced in small amount by endocrine glands, secreted into blood stream to control metabolism and biological activities in target cell or organs. Characteristics or properties of hormone Low molecular weight Small soluble organic molecules Rate of diffusion is very high and are readily oxidized but the effect does not remain constant. It is effective in low concentration, travels in blood, it has its target site different from where it is produce and is specific to a particular target.

Classification of hormone Hormones: are classified

A. On the basis of chemical nature

B. On the basis of mechanism of hormone action

- Group I hormone
- Group II hormone.

A. On the basis of chemical nature

1. Peptides and proteins
2. Amino acid derivatives
3. Steroids
4. Fatty acid derivatives - Eicosanoids

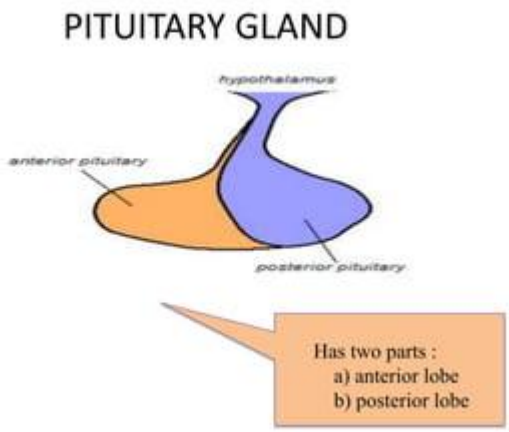
1. Peptides and Proteins Hormones

Peptide and protein hormones are products of translation. Peptide hormones are synthesized in endoplasmic reticulum, transferred to the Golgi and packaged into secretory vesicles for export. They can be secreted by one of two pathways:

Regulated secretion: The cell stores hormone in secretory granules and releases them in "bursts" when stimulated. This is the most commonly used pathway and allows cells to secrete a large amount of hormone over a short period of time.

Constitutive secretion: The cell does not store hormone, but secretes it from secretory vesicles as it is synthesized.

Most peptide hormones circulate unbound to other proteins, but exceptions exist; for example, insulin-like growth factor-1 binds to one of several binding proteins. In general, the half-life of circulating peptide hormones is only a few minutes. Several important peptide hormones are secreted from the pituitary gland they include:



A. T**he anterior pituitary secretes:**

1. Luteinizing hormone and follicle stimulating hormone, which act on the gonads (ovaries and testis).
2. prolactin, which acts on the lactating mammary gland,
3. adrenocorticotropic hormone (ACTH), which acts on the adrenal cortex to regulate the secretion of glucocorticoids, and mineralocorticoids.
4. growth hormone, which acts on bone, muscle and liver.

B. The posterior pituitary gland secretes:

1. antidiuretic hormone, also called vasopressin.
2. Oxytocin

Peptide hormones are produced by many different organs and tissues, however, including:

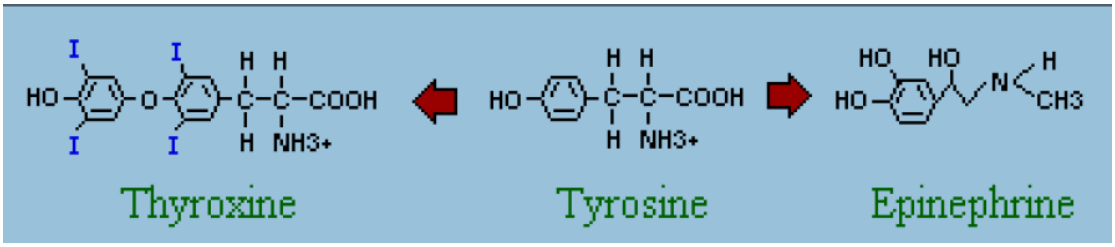
1. the heart (atrial-natriuretic peptide (ANP) or atrial natriuretic factor (ANF)
2. pancreas (insulin and somatostatin).
3. the gastrointestinal tract cholecystokinin, gastrin.
4. fat stores (leptin).

2. Amino acid derivatives

There are two groups of hormones derived from the amino acid tyrosine:

1. Thyroid hormones are basically a "double" tyrosine with the critical incorporation of 3 or 4 iodine atoms.
2. Catecholamines include epinephrine and norepinephrine, which are

used as both hormones and neurotransmitters



Two other amino acids are used for synthesis of hormones:

1. Tryptophan is the precursor to serotonin and the pineal hormone

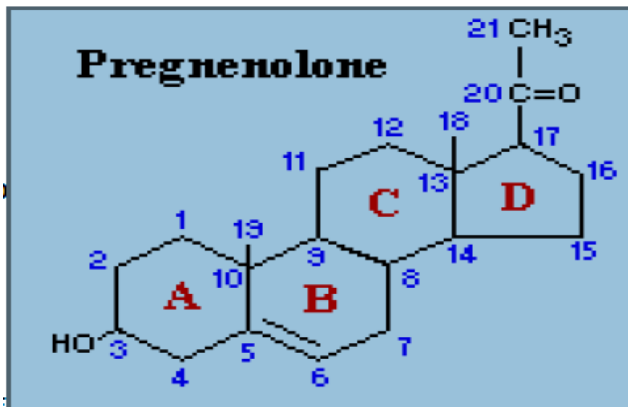
melatonin

2. Glutamic acid is converted to histamine

3. Steroids

Steroids are lipids and, more specifically, derivatives of cholesterol.

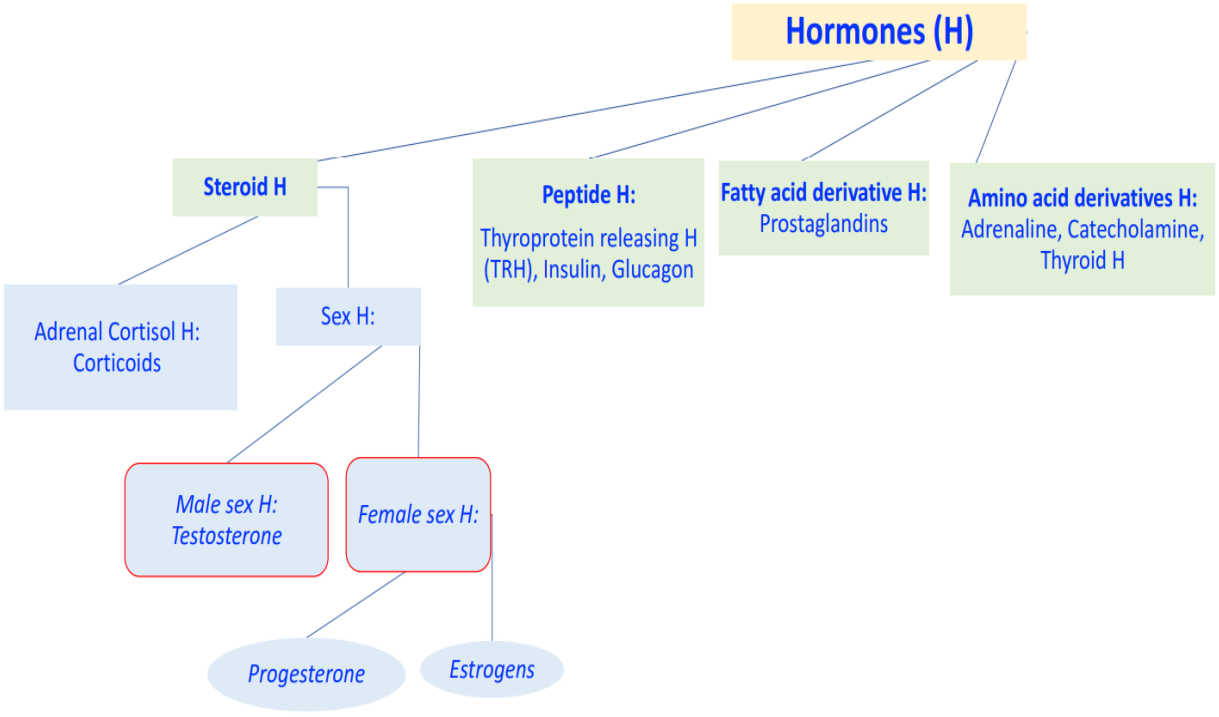
Examples include the sex steroids such as testosterone and adrenal steroids such as cortisol. The first and rate-limiting step in the synthesis of all steroid hormones is conversion of cholesterol to pregnenolone.Newly synthesized steroid hormones are rapidly secreted from the cell, with little if any storage. Increases in secretion reflect accelerated rates of synthesis. Following secretion, all steroids bind to some extent to plasma proteins.



4. **Fatty Acid Derivatives - Eicosanoids**

Eicosanoids are a large group of molecules derived from polyunsaturated fatty acids. The principal groups of hormones of this class are prostaglandins, prostacyclin, leukotrienes and thromboxane. Arachidonic acid is the most abundant precursor for these hormones. Stores of arachidonic acid are present in lipids membrane and released through the

action of various lipases. A great variety of cells produce prostaglandins, including those of the liver, kidneys, heart, lungs, thymus gland, pancreas, brain, and reproductive organs. In contrast to hormones, prostaglandins usually act locally, affecting only adjacent cells or the very cell that secreted it.



B. **On the basis of mechanism of hormone action**

1. Group I hormone (lipophilic hormone): These hormones are lipophilic in nature. They are mostly derivatives of cholesterol. These hormones bind to intracellular receptors Example: Steroid hormones, Estrogen, androgen, glucocorticoids, cholecalciferol, thyroxine etc .

Group II hormones (water soluble hormone): These hormones bind to cell surface receptors and stimulates the release of certain molecules (secondary messengers) to perform biochemical functions.

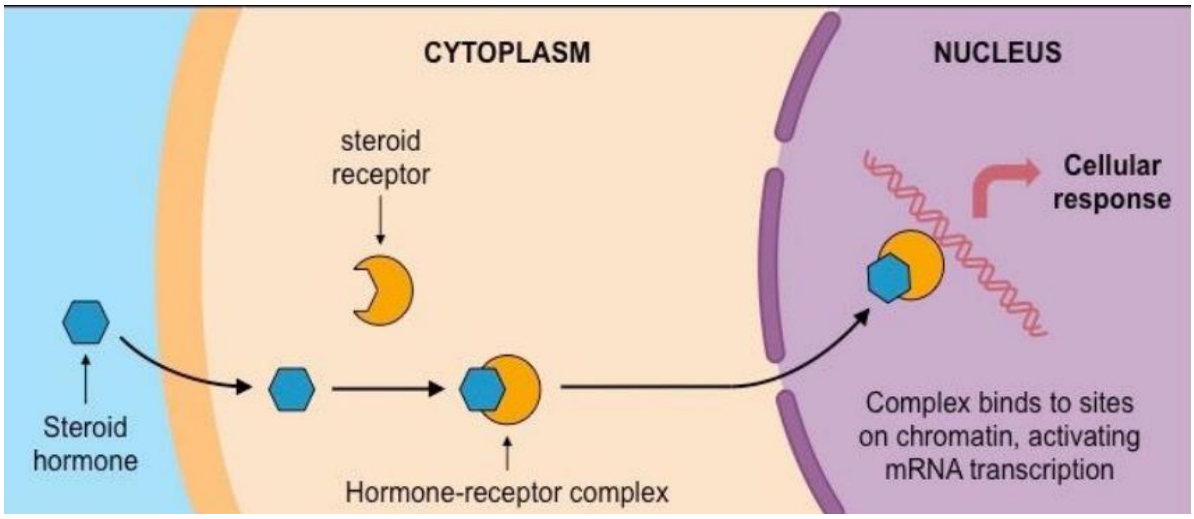
On the basis of secondary messengers group II hormones are of 3 types;

1. Secondary messenger is cAMP: eg. Adrenocorticotropic hormone, FSH, LH, PTH, ADH, calcitonin, glucagon.
2. Secondary messenger is phosphatidylinositol/calcium or both: eg. Acetylcholine, vasopressin, cholecystokinin, gastrin, gonadotropin releasing hormone, thyrotropin releasing hormone, Insulin, chorionic somatomammotropin, epidermal growth factors, fibroblast growth factors, GH, Prolactin.
3. Secondary messenger is cGMP: Atrial natriuretic peptide (ANP)

The different types of hormones will have different mechanisms of action due to their distinct chemical properties.

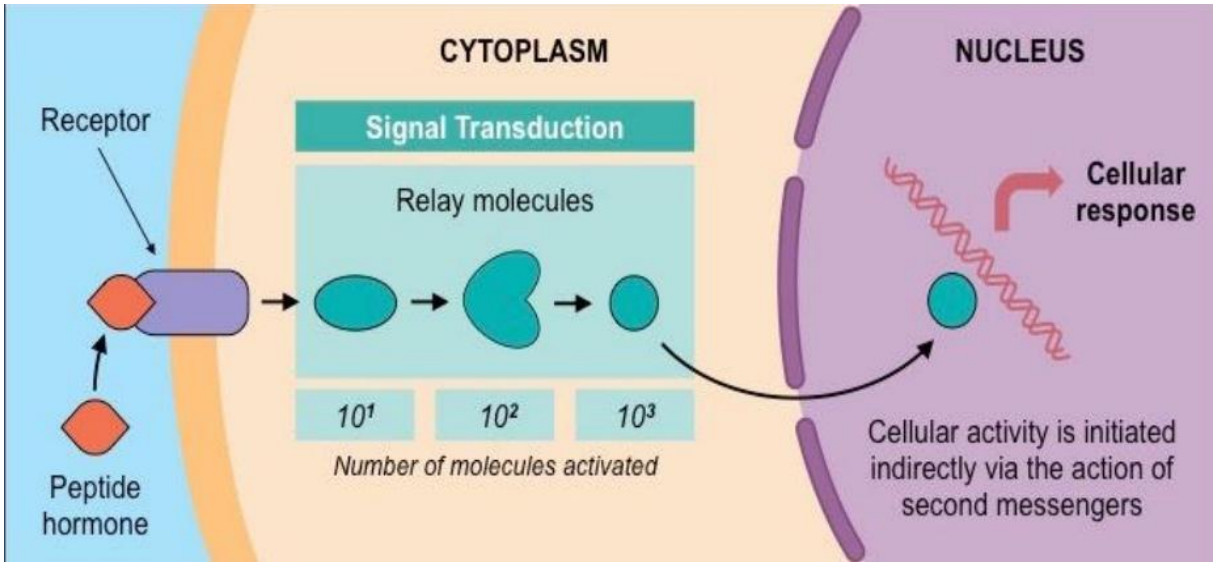
Group I (Steroid Hormones)

Steroid hormones are lipophilic (fat-loving) – meaning they can freely diffuse across the plasma membrane of a cell They bind to receptors in either the cytoplasm or nucleus of the target cell, to form an active receptor hormone complex This activated complex will move into the nucleus and bind directly to DNA, acting as a transcription factor for gene expression Examples of steroid hormones include those produced by the gonads (i.e. estrogen, progesterone and testosterone)



Group 2 (Peptide Hormones):

Peptide hormones are hydrophilic and lipophobic , they cannot freely cross the plasma membrane. They bind to receptors on the surface of the cell, which are typically coupled to internally anchored proteins (e.g. G proteins) The receptor complex activates a series of intracellular molecules called second messengers, which initiate cell activity. This process is called signal transduction, because the external signal (hormone) is transduced via internal intermediaries Examples of second messengers include cyclic AMP (cAMP), calcium ions (Ca2+), nitric oxide (NO) and protein kinases. The use of second messengers enables the amplification of the initial signal (as more molecules are activated) Peptide hormones include insulin, glucagon, leptin, ADH and oxytocin.



Amine Hormones

Amine hormones are derived from the amino acid tyrosine and include adrenaline, thyroxin and triiodothyronine Amine hormones do not all share identical properties and have properties common to both peptide and steroid hormones.

	Peptide	Steroid	Amino acid derivative
Synthesis	Synthesised as **prohormones**, requiring further processing (e.g. cleavage) to activate	Synthesised in a series of reactions from **cholesterol**	Synthesised from the amino acid **tyrosine**
Storage	Stored in vesicles (regulatory secretion)	Released immediately (constitutive secretion)	Stored before release (storage mechanism varies)
Solubility	Most are polar and water soluble, can travel freely in the blood	Generally non-polar and require carrier proteins to travel in blood	Some are polar (adrenaline), others must be protein-bound
Receptors	Bind receptors on cell membrane and transduce signal via the use of second messenger systems	Bind to intracellular receptors to change gene expression directly	Adrenaline acts on membrane receptors, while thyroid hormones act directly on nuclear receptors
Effects	Often fast onset transient changes in protein activity, though gene expression changes can occur	Alterations in gene expression; slower onset but longer duration than peptide hormones	Adrenaline functions like peptides, thyroid hormones function in a similar manner to steroids
Examples	Insulin, glucagon, prolactin, ACTH, gastrin parathyroid hormone	Cortisol, aldosterone, estrogen, progesterone, testosterone	Adrenaline, thyroxin, triiodothyronine

Feedback Control of Hormone Production

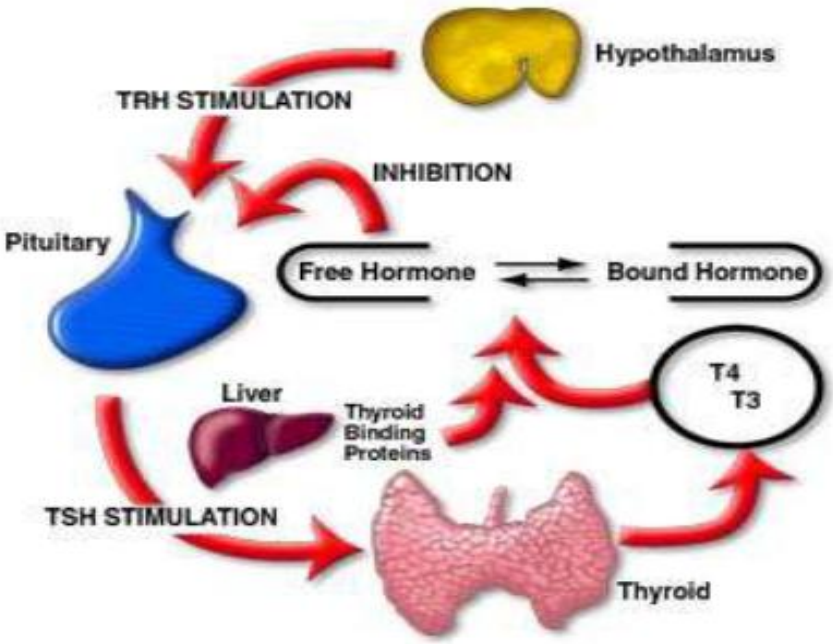
Feedback circuits are at the root of most control mechanisms in physiology, and are particularly prominent(obvious) in the endocrine system. Instances of positive feedback certainly occur, but negative feedback is much more common.

Feedback loops are used extensively to regulate secretion of hormones in the hypothalamic-pituitary axis. An important example of a negative feedback loop is seen in control of thyroid hormone secretion. The thyroid hormones thyroxine and triiodothyronine ("T4 and T3") are synthesized and secreted by thyroid glands and affect metabolism throughout the body. The basic mechanisms for control in this system are:

1. Neurons in the hypothalamus secrete thyroid releasing hormone (TRH), which stimulates cells in the anterior pituitary to secrete thyroid-stimulating hormone (TSH).
2. TSH binds to receptors on epithelial cells in the thyroid gland, stimulating synthesis and secretion of thyroid hormones, which affect probably all cells in the body.
3. When blood concentrations of thyroid hormones increase above a certain threshold, TRH-secreting neurons in the hypothalamus are inhibited and stop secreting TRH.

This is an example of "negative feedback".

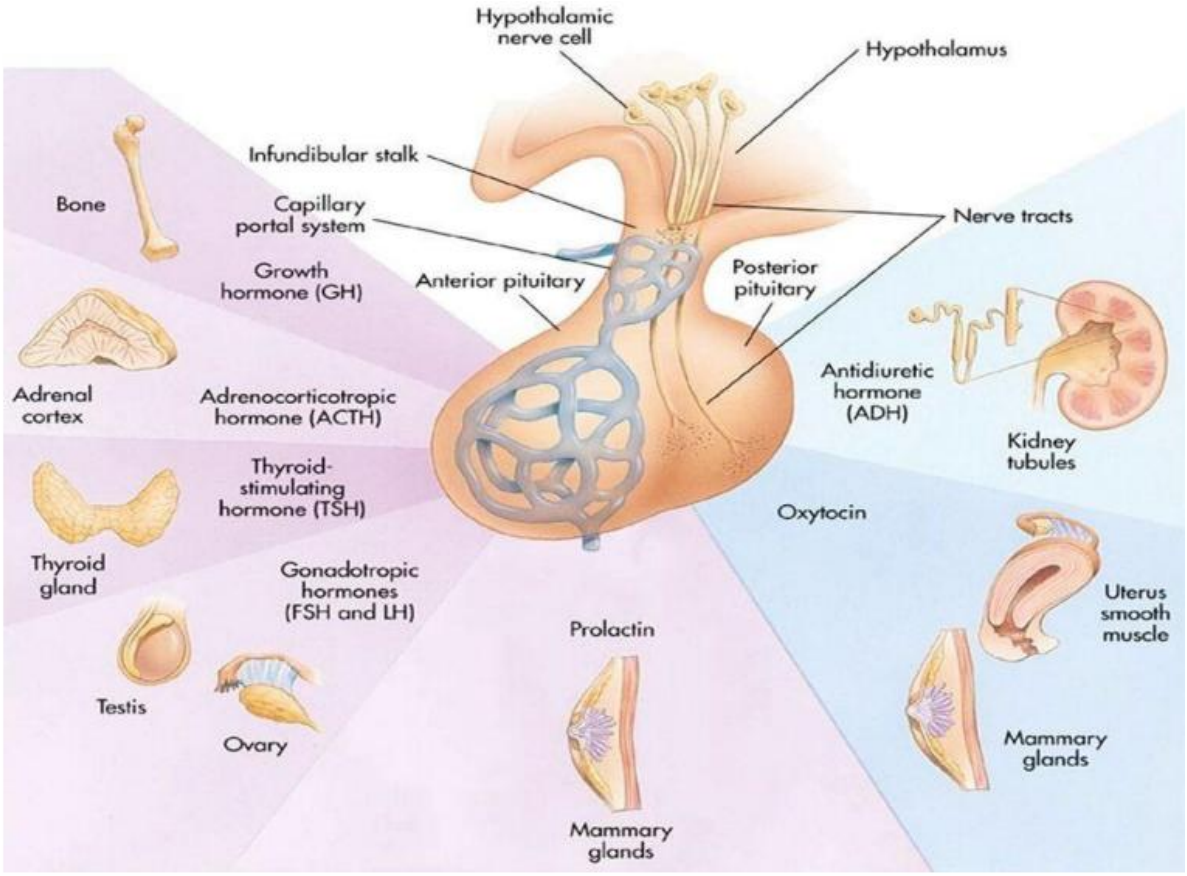
Inhibition of TRH secretion leads to shut-off of TSH secretion, which leads to shut-off of thyroid hormone secretion. As thyroid hormone levels decay below the threshold, negative feedback is relieved, TRH secretion starts again, leading to TSH secretion.



Hypothalamus – pituitary hormones

Hypothalamus – pituitary hormones Two lobes of pituitary gland. Anterior lobe is adenohyophysis. Posterior lobe is neurohypophysis which is an outgrowth of the hypothalamus. There is only vascular connection via hypophyseal portal veins which carry releasing and inhibiting hormones secreted by hypothalamus to anterior pituitary gland in order to regulate the activity of secretory cells in anterior pituitary. Anterior pituitary hormones

Anterior pituitary is referred to as the Master gland. It secretes six hormones as well as a number of other active molecules. Four of these hormones are the tropic hormones which regulate secretory activity of other endocrine glands: a. TSH—thyroid-stimulating hormone b. ACTH—adrenocorticotropic hormone c. FSH—follicle-stimulating hormone d. LH—lutenizing hormone The other two hormones have neuroendocrine targets which are: a. PRL—Prolactin b. GH—growth hormone Growth hormone (GH) GH stimulates most cells in the body to grow and divide but the major targets are bones and muscles. GH is anabolic hormone which promotes metabolism. Regulation of GH secretion is by hypothalamic hormones (negative feedback) where it is stimulated by somatocrinin (GHRH growth hormone releasing hormone) and inhibited by somatostatin (GHIH growth hormone inhibiting hormone). Abnormalities of GH secretion Adolescent hypersecretion: gigantism (excessive proportional growth) Adult hypersecretion: acromegaly (tissues grow disproportionately) Adult hyposecretion: little effect but Adolescent hyposecretion results in pituitary dwarfism Prolaction It stimulates milk production. Its secretion is controlled by PRH and PIH (serotonin and dopamine). The levels of prolactin parallel those of estrogen.



Thyroid-stimulating hormone (TSH)

TSH stimulates normal growth and activity of thyroid gland. It is controlled by hypothalamic TRH (thyrotropin releasing hormone). Thyroid hormones signal hypothalamus and anterior pituitary to stop TRH and TSH respectively. GHIH also inhibits TRH.

Hyposecretion of TSH:

- In childhood: Cretinism -

-In adulthood: Myxedema

Hypersecretion of TSH:

- Grave's disease

Adrenocorticotropic hormone (ACTH)

ACTH stimulates adrenal cortex to release corticosteroid hormones. There is a feedback inhibition where rising glucocorticoids inhibit CRH secretion.

Hypersecretion of ACTH: - Cushing syndrome

Hyposecretion of ACTH: - Hypoadrenalism.

Gonadotropins

FSH and LH They regulate gonads. FSH stimulates gamete production. LH promotes production of gonadal hormones. FSH and LH work in concert to cause follicle to mature. In females; LH causes egg to be extruded from follicle. In males; LH stimulates interstitial cells of the testes to produce testosterone. LH and FSH release is controlled by the hypothalamic GnRH (gonadotropinreleasing hormone). Negative feedback inhibition regulates FSH and LH release (testosterone, estrogen, inhibin) Hypersecretion of gonadotropins:

1- Hypersecretion of FSH: Kleinfelter's syndrome

2- Hypersecretion of LH: Turner syndrome Posterior pituitary hormones

ADH (antidiuretic hormone)

It prevents urine production. Hypothalamus has osmoreceptors and ADH is released from hypothalamus in response to increased solute concentration. ADH causes kidney tubules to reabsorb more water. At high doses, causes vasoconstriction (increases systolic blood pressure).

Hypersecretion of ADH: - Syndrome of inappropriate antidiuretic hormone (SIADH)

Hyposecretion of ADH: - Diabetes insipidus

Oxytocin (OXT): It stimulates smooth muscle contraction. The number of its receptors increases during pregnancy. Afferent impulses as uterus stretches during pregnancy signals release of oxytocin during late stages of pregnancy resulting in hormonal trigger for milk ejection (positive feedback mechanism)

Hypersecretion of Oxytocin (OXT): - Prostatic hyperplasia

Hyposecretion of Oxytocin (OXT): - Depression.

Hormones from other endocrine glands:

Thyroid hormones (TH): T3 and T4 Follicle cells produce thyroglobin and lumen stores colloid (thyroglobin in association with iodine). T2, T3 and T4 are iodinated thyroglobins. The metabolically active hormones are thyroxine (T4) and triiodothyronine (T3). Thyroxine (T4) is produced by thyroid gland while triiodothyronine (T3) is formed at target tissue when T4 is converted into T3. They increase metabolism in most tissues by stimulating glucose oxidation. They increase adrenergic receptors in blood vessels and regulates tissue growth and development. Thyroid disorders: - Hypothyroidism - Hypothyroidism in infants (Cretinism)

Hyperthyroidism (thyrotoxicosis)

Adrenocortical hormones Adrenal glands

represent two endocrine glands; adrenal medulla and cortex. They are involved in response to stressful conditions. Adrenal cortex secretes corticosteroids which are synthesized from cholesterol. Corticosteroids are: mineralocorticoids, glucocorticoids and gonadocorticoids.

A. Mineralocorticoids: They regulate electrolyte concentrations in extracellular fluid. Aldosterone is the most abundant mineralocorticoid. It reduces excretion of sodium from the body and stimulates reabsorption of sodium in the distal tubule of kidney.

Hypersecretion of aldosterone: - Primary aldosteronism (due to adrenal tumors).

Hyposecretion of aldosterone: - Addison’s disease

B. Glucocorticoids: They influence metabolism and mediate response to stress. They are: cortisol (hydroctisone), cortisone and corticosterone. Only cortisol is secreted in significant amounts. If there is no stress: cortisol inhibit CRH and ACTH. In stress: Sympathetic nervous system triggers CRH release.

Hypersecretion of cortisol: - Cushing syndrome

Hyposecretion of cortisol: - Addison's disease

C. Gonadocorticoids (Sex hormones): Primarily androgens: androstenedione converted to testosterone and dihydrotestosterone with small amounts of estrogens. Adrenal cortex secretes very small amounts of sex hormones with possible role in onset of puberty.

Adrenal medulla It is composed of chromaffin cells which secrete epinephrine and norepinephrine. This is the initial response to stress mediated by sympathetic NS. Activation of adrenal medulla and associated release of catecholamines (EPI and NE) prolongs sympathetic response resulting in elevated BP and HR, mobilization of glucose and shunt blood from GIT.

Hyposecretion of adrenal medulla: No significant effect

Hypersecretion of adrenal medulla: - Tumor of chromaffin cells called pheochromocytoma (uncontrolled sympathetic system activity)

Pancreatic hormones Pancreas: is both endocrine and exocrine organ. Exocrine secretions are the pancreatic juice enzymes to the pancreatic duct. Endocrine secretions are insulin, glucagon, somatostatin and pancretic peptide (PP). Beta cells of pancreas produce insulin which is hypoglycemic hormone. Alpha cells produce glucagon.

Hypersecretion of insulin: - Hyperinsulinism: (hypoglycemia) Hyposecretion of insulin: - Diabetes mellitus (DM) is hyposecretion or hypoactivity of insulin: (hypoglycemia)

Hypersecretion of glucagon: - Hyperglucagonemia: Glucagonoma syndrome (hypoglycemia) Hyposecretion of glucagon: - glucagon deficiency (hyperglycemia)

Gonad Hormones:

Testosterone: It is formed by the interstitial cells of Leydig which lie in adult testes. In general, testosterone is responsible for the distinguishing characteristics of the masculine body. It affects the distribution of body hair. It also decreases the growth of hair on the top of the head. It causes typical adult masculine voice. It increases the thickness of the skin over the entire body. It increases the ruggedness of the subcutaneous tissues (acne). It increases musculature. Testosterone also increases the total quantity of bone matrix and causes calcium retention. It greatly increases the strength of the bony skeleton for load-bearing. It can increase basal metabolic rate. It also increases the number of RBC per cubic millimeter. Estrogen & progesterone They are secreted by ovaries in response to FSH and LH. Estrogen regulates mestrual cycle. Progesterone functions mainly to prepare the uterus for pregnancy and the breasts for lactation. Disturbances in testosterone, estrogen or progesterone results in disturbance in sexual function and mood.

Estrogen & progesterone They are secreted by ovaries in response to FSH and LH. Estrogen regulates menstrual cycle. Progesterone functions mainly to prepare the uterus for pregnancy and the breasts for lactation. Disturbances in testosterone, estrogen or progesterone results in disturbance in sexual function and mood.

Summarized hormones' properties

Hormone	secreted by	targets at	results in	hyper-secretion	hypo-secretion	What stimulates its release?	What inhibits its release?
Growth hormone (GH)	Anterior pituitary	Bone, muscle, all body cells	Growth, division	1- In adolescence, causes gigantism 2- In adulthood, causes acromegaly	Dwarfism	Hypothalamic hormone somatocrinin (growth hormone releasing hormone GHRH)	Hypothalamic hormone somatostatin (growth hormone inhibiting hormone GHIH)
Prolactin PRL	Anterior pituitary	Breast	Production of milk	hyperprolactinemia	Rare	Prolactin releasing factors (VIP, serotonin)	Prolactin inhibitory factors (dopamine)
Thyroid-stimulating hormone (TSH)	Anterior pituitary	Thyroid gland	Stimulates growth and activity of thyroid (production of thyroxin: T3 and T4)	1- In childhood: cretinism 2- In adulthood: myxedema	Graves disease	Hypothalamic thyrotropin releasing hormone (TRH)	Thyroid hormones (T3, T4), (also somatostatin inhibits TRH)
Adreno-cortico-tropic-hormone (ACTH)	Anterior pituitary	Adrenal cortex	stimulates secretion of glucocorticoid steroid hormones from adrenal cortex	Cushing syndrome	Adrenal insufficiency (hypoadrenalism)	Hypothalamic corticotropin-releasing-hormone (CRH)	Adrenal cortical cortisol inhibits CRH and ACTH
Gonadotropins: Follicle-stimulating hormone (FSH) and (luteinizing hormone (LH)	Anterior pituitary		FSH: Stimulates gamete production LH: Promotes production of gonadal hormones	Hyper-gonadotrophic-hypo-gonadism (Klinefelter's syndrome in men and Turner syndrome in female)	hypogonadotrophic-hypogonadism (Kallman's syndrome)	Hypothalamic gonadotropin-releasing-hormone (GnRH)	Gonadal testosterone, estrogen, progesterone, inhibin
Antidiuretic hormone (ADH)	Posterior pituitary	Renal tubules	Water reabsorption	Syndrome of inappropriate antidiuretic hormone (SIADH)	Diabetes insipidus	Hyperosmolarity (high Na^+ concentration)	Hypo-osmolarity, alcohol ingestion

Oxytocin (OXT)	Posterior pituitary	Breast, uterus	Milk secretion, childbirth	Prostatic hyperplasia	Depression	Milk ejection, childbirth are also stimuli (positive feedback)	Catecholamines , stress
Calcitonin	Thyroid gland: Para-follicular cells	Bone, kidney tubules	Decreases blood Ca^{++} concentration	Hypocalcemia	Hypercalcemia	High blood Ca^{++}	Low blood Ca^{++}
Thyroxin (T4) and T3	Thyroid gland: Follicle cells	Many body cells	Regulation of metabolism and growth	Thyrotoxicosis (hyper-thyroidism)	Hypothyroidism	TSH	Lack of TSH
Para-thormone PTH	Para-thyroid glands (chief cells)	Bone, kidney tubules, intestine	Increases blood Ca^{++} concentration	Hyper-para-thyroidism	Hypo-para-thyroidism (very rare)	Low blood Ca^{++}	High blood Ca^{++}
Aldosterone (steroids)	Adrenal cortex: Zona glomerulosa	Kidney tubules, colon	Increases blood Na^{+} and decreases K^{+} concentration	Primary hyper-aldosteronism	Addison's disease	ACTH, Angiotensin-II, hyperkalemia (high blood K^{+}) , hyponatremia (low blood Na+) and low blood pressure	Lack of angiotensin-II, hypokalemia (low blood K^{+}) , hypernatremia (high blood Na+) and high blood pressure
Gluco-corticoids: Cortisol (steroids)	Adrenal cortex: Zona fasciculata	Many body organs	Regulation of glucose metabolism and immune, mtabolic, developmental, arousal and cognition effects and body fluid homeostasis	Cushing syndrome	Adrenal insufficiency (Addison's disease	ACTH, Stress	Lack of ACTH
Epinephrine and nor epinephrine	Adrenal medulla	Heart, blood vessels & others	Increases heart rate, blood pressure, blood glucose, break down of fat...	Pheochromocytoma (tumor of adrenal medulla), hypertension	No known effects	Increased sympathetic activity, stress.	Lower sympathetic activity

Insulin	Pancreas: Beta cells	Muscle, fat and liver cells	Decreases blood glucose, enhances glucose absorption into muscle and fat cells, inhibits breakdown of glycogen, promotes oxidation of glucose for ATP production, synthesis and storage of glycogen, conversion of glucose to fat	Hyperinsulinism, hypoglycemia (low blood glucose)	Diabetes mellitus, ketoacidosis	High blood glucose	Low blood glucose
Glucagon	Pancreas: alpha cells	Muscle, fat and liver cells	Breakdown of glycogen to glucose (glycogeno-lysis), synthesis of glucose from lactic acid, fatty acids and amino acids (gluco-neogenesis), Release of glucose from liver	Hyper-glucagonemia (Glucagonoma Syndrome)	Glucagon deficiency	Low blood glucose	High blood glucose
Testosterone	Testes: Leydig cells	Male genitalia, muscle, skin, bone marrow and other tissues	Spermatogenesis, secondary male sexual characteristics, erythropoiesis ...	Infertility and (in female): Hirsutism, deep voice, vrilism, heavy muscularity, acne...	Lack of male characteristics, mood disturbance	Luteinizing hormone (LH)	Lack of luteinizing hormone
Estrogen	Ovaries: Granulosa and corpus luteum	Female genitalia, breasts, uterus, skin, and others	Menstrual cycle, secondary female characteristics	Menstrual disturbances, mood disturbance, ...	Menstrual disturbances, mood disturbance,	Luteinizing hormone (LH)	Lack of luteinizing hormone
Progesterone	Ovaries: Corpus luteum	Uterus, breasts	Prepare the uterus for fertilization and breasts for milk production	Increased risk for developing breast cancer.	Disturbed menstruation, miscarriage	Luteinizing hormone (LH), human chorionic gonadotrophin HCG	Lack of luteinizing hormone or HCG