Anatomy and Physiology: Signals and the Endocrine System

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Overview of the Endocrine System

- **Two Major Control Systems:** The endocrine system is one of the body's two primary control systems, the other being the nervous system.
- **Fundamental Differences:Nervous System:** Uses both electrochemical (action potentials) and chemical signals (neurotransmitters). Neurotransmitters act locally across a synaptic cleft.
- **Endocrine System:** Operates on chemical signals only (hormones). Endocrine organs are not excitable tissue and do not produce action potentials.
- **Hormones vs. Neurotransmitters:Chemical Identity:** Can be chemically identical.
- **Release and Travel:Neurotransmitters:** Released by vesicles, travel a tiny distance across the synaptic cleft, and act on immediate cells. Do not travel throughout the body.
- **Hormones:** Released by glands into the bloodstream, broadcast throughout the body, reaching all cells with a blood supply.
- **Receptor-Mediated Action:** All chemical signals (neurotransmitters and hormones) require binding to a specific receptor for an effect to occur.

II. Mechanisms of Hormone Action

- **Receptor Location:** Receptors for hormones can be located in two main places:
- **Inside Cells (Intracellular Receptors):Steroid Hormones:** All steroid hormones are modified cholesterol molecules (lipids).
- **Mechanism:** Being lipids, they can directly pass through the phospholipid bilayer of the cell membrane and even the nuclear membrane.
- **Receptor Location:** Receptors are located in the cytoplasm or nucleoplasm.
- **Consequence of Binding:** Binding causes a shape change in the receptor protein, often leading to **direct gene activation**. This means a specific gene within the DNA is turned on, transcribed into mRNA, which then instructs ribosomes to build a new protein.

- **On the Cell Surface (Membrane-Bound Receptors):Amino Acid-Based Hormones:** The majority of hormones are amino acid-based (proteins or oligopeptides) and are not lipids.
- **Mechanism:** Cannot enter the cell due to their chemical nature. Receptors are embedded in the cell membrane.
- **Consequence of Binding:** Binding causes a shape change in the receptor protein, which activates a **second messenger system** inside the cell.
- **First Messenger:** The hormone itself. Its job is done once it binds to the receptor.
- **Second Messenger:** An intracellular signal molecule (e.g., cyclic AMP) that carries the message from the receptor into the cell, ultimately leading to a cellular effect.

III. Key Endocrine Glands and Their Hormones

- **Hypothalamus:**Part of the brain (nervous system).
- Interacts significantly with the pituitary gland, serving as a major interface between the nervous and endocrine systems.
- Produces hormones that control the anterior pituitary (releasing and inhibiting hormones) and neurohormones (ADH and oxytocin) that are stored and released by the posterior pituitary.
- **Pituitary Gland (Hypophysis):**Often called the "master gland" due to its control over many other glands.
- **Two Parts:Anterior Pituitary (Adenohypophysis):**True gland.
- Releases **releasing or inhibiting hormones** that control the secretion of hormones from other endocrine glands.
- Hormones: Growth Hormone (GH), Prolactin (PRL), Follicle-Stimulating Hormone (FSH), Luteinizing Hormone (LH), Thyrotropic Hormone (TH/TSH), Adrenocorticotropic Hormone (ACTH).
- **Posterior Pituitary (Neurohypophysis):**An extension of the brain, not a true gland.
- Composed of axon terminals of neurons originating in the hypothalamus (hypothalamic-hypophyseal tract).
- Releases **neurohormones** (released into the bloodstream, not synaptic clefts).
- Hormones:
- **Antidiuretic Hormone (ADH):** Promotes water reabsorption by kidneys, reducing urine volume to conserve water and increase blood pressure.
- **Oxytocin:** Involved in uterine contractions during childbirth (positive feedback) and milk ejection from mammary glands.
- **Thyroid Gland:**Located in the neck, wrapped around the thyroid cartilage. Butterfly-shaped.
- **Follicular Cells:** Produce **Thyroid Hormone (T3 and T4/Thyroxine)**.
- Structurally an amine, but functionally similar to steroids (hydrophobic, enters cells directly).
- Regulates basal metabolic rate.
- **Parafollicular Cells:** Produce **Calcitonin**.

- Decreases blood calcium levels if too high by promoting calcium uptake into bones (tells osteoblasts to build bone). Less important than PTH.
- **Parathyroid Glands:**Typically four small glands embedded in the posterior thyroid gland.
- Release **Parathyroid Hormone (PTH)**.
- **Crucial for Calcium Homeostasis:** Increases blood calcium levels if too low by stimulating osteoclasts to break down bone and release calcium into the blood. Essential for heart function and nerve/muscle signaling. Cannot live without.
- **Adrenal Glands:**Located on top of the kidneys (ad-renal: "on kidneys"). Functionally separate from kidneys.
- **Two Functionally Distinct Parts:Adrenal Medulla:**Inner part, stimulated by the nervous system (neural stimulus).
- Releases **epinephrine (adrenaline) and norepinephrine (noradrenaline)**.
- **Short-term stress response (fight-or-flight):** Increases heart rate, blood pressure, dilates bronchioles, converts liver glycogen to glucose.
- **Adrenal Cortex:**Outer part, stimulated by hormones (humoral stimulus).
- Releases **adrenocorticoids** (all are steroid hormones, therefore lipids, acting via intracellular receptors). Three layers:
- **Mineralocorticoids (e.g., Aldosterone):** Outer layer; control mineral (sodium and potassium) balance.
- **Glucocorticoids (e.g., Cortisol):** Middle layer; control glucose levels in blood, especially crucial for brain fuel.
- **Sex Hormones (Androgens, Estrogens):** Deepest layer; contribute to secondary sex characteristics.
- **Prolonged Stress Response:** Glucocorticoids are involved, sparing glucose for the brain by encouraging other body parts to use fats/proteins as fuel. Can suppress the immune system with chronic stress.
- **Pancreas:**Located in the hairpin loop of the duodenum.
- **Mixed Gland:** Both exocrine and endocrine functions.
- **Exocrine Function:** Produces digestive enzymes (pancreatic juice) released into the small intestine via ducts. (Not part of endocrine system).
- **Endocrine Function (Pancreatic Islets/Islets of Langerhans):** Collections of cells looking like "islands."
- **Alpha Cells:** Produce **Glucagon**.
- Raises blood glucose levels when too low (e.g., after fasting) by stimulating the liver to break down glycogen into glucose and release it into the blood.
- **Beta Cells:** Produce **Insulin**.
- Lowers blood glucose levels when too high (e.g., after a meal) by allowing body cells (excluding the brain) to take in glucose from the blood.
- **Antagonistic Effects:** Insulin and glucagon work oppositely to maintain blood glucose homeostasis. The brain does NOT require insulin for glucose uptake.
- **Thymus:**Located in the mediastinum (middle part of the thorax).
- Large in newborns, shrinks with age.
- Important for **T-cell (T-lymphocyte) maturation**, crucial for immunity.

- Releases chemicals that aid in T-cell proper maturation.
- **Pineal Gland:**Part of the brain, cone-shaped.
- Releases **Melatonin**.
- Regulates **circadian rhythms** (daily rhythms), including sleep-wake cycles.
- **Gonads (Testes/Ovaries):**Primary sex organs, produce gametes.
- **Mixed Glands:** Both exocrine and endocrine.
- **Testes (Male):** Produce **Testosterone** (endocrine) and sperm (exocrine).
- **Ovaries (Female):** Produce **Estrogen and Progesterone** (endocrine) and eggs (exocrine).
- Sex hormones are also produced by the adrenal cortex, meaning both sexes produce all types of sex hormones, though in varying amounts depending on the primary source.

IV. Stimuli for Hormone Release

- **Humoral Stimulus:** Release triggered by changes in blood levels of certain ions or nutrients (e.g., Parathyroid hormone release due to low blood calcium, insulin/glucagon release due to blood glucose levels).
- **Neural Stimulus:** Release triggered by nerve impulses (e.g., Adrenal medulla releasing epinephrine/norepinephrine in response to sympathetic nervous system stimulation).
- **Hormonal Stimulus:** Release triggered by other hormones (e.g., Anterior pituitary hormones stimulating other glands, hypothalamus releasing hormones stimulating the anterior pituitary).

V. Additional Concepts

- **Feedback Mechanisms:** Oxytocin and childbirth (positive feedback). Most endocrine regulation involves negative feedback.
- **Renin-Angiotensin-Aldosterone System (RAAS):** Complex multi-organ system (kidneys, liver, lungs, adrenal cortex) involved in regulating blood pressure and volume.
- Decreased blood volume/pressure sensed by kidneys, releasing **Renin**.
- Renin converts **Angiotensinogen** (from liver) to **Angiotensin I**.
- **ACE** (Angiotensin Converting Enzyme, from lungs) converts Angiotensin I to **Angiotensin II**.
- Angiotensin II causes vasoconstriction (increases blood pressure) and stimulates aldosterone release (mineralocorticoid from adrenal cortex) to promote sodium/water reabsorption.
- **Atrial Natriuretic Peptide (ANP):** Released by heart atria in response to high blood volume/pressure; promotes sodium and water excretion by kidneys, lowering blood pressure. Antagonistic to RAAS.

Quiz: The Endocrine System

Instructions: Answer each question in 2-3 sentences.

1. Describe the fundamental difference in the nature of signals used by the nervous system versus the endocrine system.
2. Explain how steroid hormones exert their effects on target cells, including where their receptors are located.
3. Contrast the mechanism of action of amino acid-based hormones with that of steroid hormones, specifically mentioning the role of a "second messenger."
4. Identify the two parts of the pituitary gland and briefly state whether each part is a true gland or an extension of the brain.
5. What are neurohormones? Provide two examples of neurohormones and the part of the pituitary gland from which they are released.
6. Describe the primary function of Parathyroid Hormone (PTH) and explain its importance for human survival.
7. Distinguish between the short-term and prolonged stress responses, including the key hormones and the specific parts of the adrenal gland involved in each.
8. Explain the antagonistic relationship between insulin and glucagon in regulating blood glucose levels.
9. Why is the thymus gland particularly large in infants and children compared to adults, and what is its main role?
10. Name two locations in the body where sex hormones are produced.

Quiz Answer Key

1. The nervous system uses both electrochemical signals (action potentials) and chemical signals (neurotransmitters), which typically act locally across synaptic clefts. In contrast, the endocrine system operates exclusively on chemical signals called hormones, which are released into the bloodstream and broadcast throughout the entire body to reach target cells.
2. Steroid hormones are lipids, allowing them to pass directly through the cell membrane and even the nuclear membrane. Their receptors are located inside the cell, either in the cytoplasm or nucleoplasm. Upon binding, the hormone-receptor complex often directly activates a specific gene, leading to the synthesis of a new protein.
3. Amino acid-based hormones cannot enter the cell, so their receptors are located on the cell surface (membrane-bound). When the hormone binds, it causes a shape change in the receptor, activating a "second messenger system" inside the cell. The second messenger then carries out the intracellular effects that the hormone initiated.
4. The two parts of the pituitary gland are the anterior pituitary (adenohypophysis) and the posterior pituitary (neurohypophysis). The anterior pituitary is a true glandular tissue, while the posterior pituitary is an extension of the brain, composed of neuron axon terminals.

5. Neurohormones are chemical signals released by neurons directly into the bloodstream, rather than into a synaptic cleft. Two examples are Antidiuretic Hormone (ADH) and Oxytocin, both released from the posterior pituitary gland.
6. Parathyroid Hormone (PTH) primarily functions to increase blood calcium levels when they fall below normal. It achieves this by stimulating osteoclasts to break down bone, releasing calcium into the blood. This function is vital because calcium is essential for critical processes like heart contraction and nerve signaling, making PTH crucial for survival.
7. The short-term stress response involves the adrenal medulla releasing epinephrine and norepinephrine, triggered by neural stimulation, leading to immediate "fight-or-flight" effects. The prolonged stress response involves the adrenal cortex releasing glucocorticoids, stimulated by hormonal pathways originating from the hypothalamus and anterior pituitary, which primarily help conserve glucose for the brain but can suppress the immune system with chronic activation.
8. Insulin and glucagon have antagonistic effects on blood glucose levels. Insulin, released by beta cells, lowers high blood glucose by promoting glucose uptake into body cells (except the brain). Glucagon, released by alpha cells, raises low blood glucose by stimulating the liver to convert stored glycogen back into glucose and release it into the bloodstream.
9. The thymus gland is particularly large in infants and children because it plays a critical role in the maturation of T-lymphocytes (T-cells), a type of white blood cell essential for the proper development of the immune system. As a person ages and the immune system matures, the thymus gradually shrinks.
10. Sex hormones are primarily produced in the gonads (testes in males and ovaries in females). Additionally, the adrenal cortex also produces sex hormones, contributing to the overall levels in both sexes.

Essay Format Questions

1. Compare and contrast the nervous system and the endocrine system as control systems of the body. Discuss their distinct modes of signaling, speed of response, duration of effects, and the ways in which they interact.
2. Describe in detail the two major mechanisms by which hormones exert their effects on target cells. Include specific examples of hormones for each mechanism and explain the molecular events that occur from hormone binding to the final cellular response.
3. Explain the intricate relationship between the hypothalamus and the pituitary gland. Detail the specific hormones released by the anterior and posterior pituitary, their target glands/tissues, and their primary functions.
4. Discuss the concept of homeostasis as it relates to calcium and glucose regulation. Describe the roles of the specific endocrine glands and hormones involved in maintaining the proper balance of each, highlighting any antagonistic relationships.

5. Analyze the body's stress response, differentiating between the short-term and prolonged mechanisms. Identify the endocrine glands and specific hormones involved in each, outline their physiological effects, and discuss the potential health implications of chronic stress.

Glossary of Key Terms

- **Action Potentials:** Electrochemical signals used by the nervous system for rapid, localized communication.
- **Adenohypophysis:** Another name for the anterior pituitary gland, referring to its glandular nature.
- **Adrenal Glands:** Endocrine glands located on top of the kidneys, composed of a cortex and medulla, involved in stress response and electrolyte balance.
- **Adrenal Cortex:** The outer part of the adrenal gland, producing steroid hormones (mineralocorticoids, glucocorticoids, sex hormones).
- **Adrenal Medulla:** The inner part of the adrenal gland, producing catecholamine hormones (epinephrine, norepinephrine) involved in short-term stress.
- **Adrenocorticotropic Hormone (ACTH):** Hormone from the anterior pituitary that stimulates the adrenal cortex.
- **Aldosterone:** A mineralocorticoid hormone from the adrenal cortex, regulating sodium and potassium balance.
- **Amino Acid-Based Hormones:** Hormones composed of amino acids (proteins or oligopeptides), typically hydrophilic, binding to cell surface receptors.
- **Angiotensin Converting Enzyme (ACE):** An enzyme (primarily from the lungs) that converts Angiotensin I to Angiotensin II, a potent vasoconstrictor.
- **Angiotensin I/II:** Peptides involved in the renin-angiotensin-aldosterone system, regulating blood pressure.
- **Angiotensinogen:** A plasma protein (prohormone) produced by the liver, converted to Angiotensin I by renin.
- **Antagonistic Hormones:** Hormones that have opposite effects on a physiological process (e.g., insulin and glucagon, PTH and calcitonin).
- **Antidiuretic Hormone (ADH):** A neurohormone from the posterior pituitary that promotes water reabsorption by the kidneys, reducing urine volume.
- **Atrial Natriuretic Peptide (ANP):** A peptide hormone released by the heart atria that promotes sodium and water excretion, lowering blood pressure.
- **Basal Metabolic Rate:** The rate at which the body uses energy while at rest to maintain vital functions. Regulated by thyroid hormones.
- **Beta Cells:** Endocrine cells in the pancreatic islets that produce insulin.
- **Calcitonin:** A hormone produced by the parafollicular cells of the thyroid gland, which lowers blood calcium levels.
- **Circadian Rhythms:** Biological processes that oscillate over approximately 24 hours, regulated by hormones like melatonin.

- **Corpus Luteum:** A temporary endocrine structure in the ovary formed after ovulation, involved in progesterone production.
- **Corticoid:** A general term for steroid hormones released from the adrenal cortex.
- **Cortisol:** A primary glucocorticoid hormone from the adrenal cortex, involved in glucose regulation and stress response.
- **Cyclic AMP (cAMP):** A common second messenger molecule involved in the intracellular signaling pathways of many amino acid-based hormones.
- **Diuresis:** The production of a high volume of dilute urine.
- **Direct Gene Activation:** The mechanism of action for steroid hormones, where the hormone-receptor complex directly influences gene transcription.
- **Ductless Gland:** A characteristic of endocrine glands, meaning they release their secretions (hormones) directly into the bloodstream without ducts.
- **Endocrine Gland:** A gland that releases its secretions (hormones) directly into the bloodstream.
- **Epinephrine (Adrenaline):** A stress hormone released by the adrenal medulla, involved in the "fight-or-flight" response.
- **Estrogen:** A female sex hormone produced primarily by the ovaries and also by the adrenal cortex.
- **Exocrine Gland:** A gland that releases its secretions through ducts onto a surface (e.g., sweat glands, digestive glands of the pancreas).
- **Fight-or-Flight Response:** The body's immediate physiological response to perceived threats, mediated by the sympathetic nervous system and adrenal medulla.
- **Follicle-Stimulating Hormone (FSH):** A gonadotropin from the anterior pituitary that stimulates follicle development in females and sperm production in males.
- **Follicular Cells:** Cells forming the walls of thyroid follicles, which produce thyroid hormone.
- **Glucagon:** A hormone produced by the alpha cells of the pancreatic islets, which raises blood glucose levels.
- **Glucocorticoids:** A class of steroid hormones from the adrenal cortex (e.g., cortisol) that regulate blood glucose levels and suppress inflammation.
- **Gonadotropins:** Hormones from the anterior pituitary (FSH and LH) that act on the gonads.
- **Gonads:** Primary sex organs (testes in males, ovaries in females) that produce gametes and sex hormones.
- **Growth Hormone (GH):** A hormone from the anterior pituitary that promotes overall body growth, especially of bones and muscles.
- **Humoral Stimulus:** A stimulus for hormone release triggered by changing blood levels of ions or nutrients.
- **Hydrophobic:** Water-fearing; describes lipids and certain hormones like thyroid hormone, allowing them to pass through cell membranes.
- **Hypothalamic-Hypophyseal Tract:** A bundle of axons connecting the hypothalamus to the posterior pituitary, along which neurohormones travel.
- **Hypothalamus:** A region of the brain that integrates the nervous and endocrine systems, controlling pituitary gland function.

- **Hypophysis:** Another name for the pituitary gland.
- **Insulin:** A hormone produced by the beta cells of the pancreatic islets, which lowers blood glucose levels.
- **Islets of Langerhans (Pancreatic Islets):** Clusters of endocrine cells within the pancreas that produce insulin and glucagon.
- **Ithmus:** A narrow strip of tissue connecting two larger parts, specifically referring to the connection between the two lobes of the thyroid gland.
- **Lactation:** The production and secretion of milk by the mammary glands.
- **Lian:** A general term for a particle that binds to a protein, causing a shape change.
- **Luteinizing Hormone (LH):** A gonadotropin from the anterior pituitary that triggers ovulation in females and testosterone production in males.
- **Melatonin:** A hormone produced by the pineal gland, regulating circadian rhythms and sleep-wake cycles.
- **Mineralocorticoids:** A class of steroid hormones from the adrenal cortex (e.g., aldosterone) that regulate mineral balance, particularly sodium and potassium.
- **Neurohormones:** Hormones produced by neurons and released into the bloodstream.
- **Neuromuscular Junction:** The synapse between a motor neuron and a muscle fiber.
- **Neurohypophysis:** Another name for the posterior pituitary gland, referring to its neuronal composition.
- **Neurotransmitters:** Chemical signals released by neurons across a synaptic cleft, acting locally.
- **Norepinephrine (Noradrenaline):** A stress hormone released by the adrenal medulla, similar to epinephrine.
- **Neural Stimulus:** A stimulus for hormone release triggered by nerve impulses.
- **Oligopeptides:** Short chains of amino acids, forming a class of amino acid-based hormones.
- **Osteoblasts:** Bone cells responsible for building new bone matrix, taking calcium from the blood.
- **Osteoclasts:** Bone cells responsible for breaking down bone matrix, releasing calcium into the blood.
- **Ovaries:** Female gonads, producing eggs, estrogen, and progesterone.
- **Oxytocin:** A neurohormone from the posterior pituitary involved in uterine contractions and milk ejection.
- **Pancreas:** A mixed gland with both exocrine (digestive enzymes) and endocrine (insulin, glucagon) functions.
- **Parafollicular Cells:** Cells in the thyroid gland (between follicles) that produce calcitonin.
- **Parathyroid Glands:** Small glands embedded in the thyroid, producing parathyroid hormone (PTH).
- **Parathyroid Hormone (PTH):** A hormone from the parathyroid glands that increases blood calcium levels.
- **Pineal Gland:** A small gland in the brain, producing melatonin.
- **Pituitary Gland:** A major endocrine gland (hypophysis) that secretes many hormones regulating other glands.

- **Progesterone:** A female sex hormone produced primarily by the ovaries, crucial for maintaining pregnancy.
- **Prolactin (PRL):** A hormone from the anterior pituitary that promotes milk production (lactation).
- **Receptor:** A protein molecule to which specific chemical signals (hormones, neurotransmitters) bind, initiating a cellular response.
- **Releasing/Inhibiting Hormones:** Hormones produced by the hypothalamus or anterior pituitary that control the release of other hormones from target glands.
- **Renin:** An enzyme released by the kidneys in response to low blood pressure/volume, initiating the renin-angiotensin-aldosterone system.
- **Second Messenger System:** An intracellular signaling pathway activated by the binding of an amino acid-based hormone to a cell surface receptor, involving intermediate molecules.
- **Sex Hormones:** Steroid hormones (androgens, estrogens, progesterone) influencing sexual development and reproduction, produced by gonads and adrenal cortex.
- **Steroid Hormones:** Lipid-soluble hormones derived from cholesterol, capable of passing directly through cell membranes to bind with intracellular receptors.
- **Synaptic Cleft:** The tiny gap between neurons or between a neuron and a target cell across which neurotransmitters diffuse.
- **T-cells (T-lymphocytes):** A type of white blood cell that matures in the thymus and plays a key role in cell-mediated immunity.
- **Testes:** Male gonads, producing sperm and testosterone.
- **Testosterone:** A male sex hormone produced primarily by the testes and also by the adrenal cortex.
- **Thymus:** A gland in the mediastinum important for T-cell maturation in immunity.
- **Thyroid Gland:** A large endocrine gland in the neck, producing thyroid hormones (T3, T4) and calcitonin.
- **Thyroid Hormone (T3/T4):** Hormones produced by the follicular cells of the thyroid gland, regulating metabolic rate.
- **Thyrotropic Hormone (TH) / Thyroid Stimulating Hormone (TSH):** Hormone from the anterior pituitary that stimulates the thyroid gland.
- **Tract:** A bundle of axons in the central nervous system (brain or spinal cord).