I. Endocrine System
   a. The nervous and endocrine systems together control all body functions.
   b. Instead of using neurotransmitters released into a synapse, the endocrine system uses hormones released into the bloodstream, which travel to virtually every cell in the body.
      i. secrete: to synthesize & release a physiologically substance.
   c. The study of and diagnosis and treatment of conditions of the endocrine system is known as endocrinology.
   d. Neuroendocrine system: the nervous system and the endocrine system working together.
      i. Sometimes the nervous system will stimulate or inhibit the glands of the endocrine system, influencing hormone release.
   e. The nervous system reacts and gets results within milliseconds, some hormones take several seconds, minutes, or even hours to see a result.

II. Glands
   a. Two types of glands exist in the body
      i. Exocrine Glands: secrete substances into ducts that carry the secretions into body cavities, lumens of an organ, or the outer surface of the body.
         1. Lumen: the inner side of an organ (i.e. the inside of the esophagus is a lumen)
         2. Include sweat glands, sebaceous glands, mucous glands, and digestive glands.
      ii. Endocrine Glands: secrete their substances into the interstitial fluid of surrounding the cells, which then diffuse into capillary blood vessels and is carried away by the blood.
         1. Endocrine Glands: pituitary gland, thyroid, parathyroid, adrenal, and pineal glands.
         2. There are some tissues and organs of the body that are not exclusively endocrine glands, but do secrete hormones.
            a. Hypothalamus, thymus, pancreas, ovaries, testes, kidneys, stomach, liver, small intestine, skin, heart, adipose tissue (fat), and placenta.

III. Hormone Activity
   a. Hormones only need small concentrations to have powerful effects on the body.
   b. Some cells respond to hormones differently because of hormone receptors.
   c. Hormone receptors are constantly breaking down and being synthesized.
   d. Target Cell: the cell that is targeted by a hormone released into the bloodstream.
   e. Hormone Receptors: binding site on a target cell for hormones.
      i. Hormones are specific in the cell or organ they stimulate because only that cell or organ has receptors for that specific hormone.
      ii. I.e. Thyroid Stimulating Hormone (TSH) binds to receptors on the thyroid gland. It does not bind to the ovaries or any other organ because they do not have TSH Receptors.
   f. Down-Regulation: When a hormone is present in excess, the number of receptors on the target cell decreased to decrease sensitivity to the hormone.
   g. Up-Regulation: When a hormone is deficient, the number of receptors on the target cell increases to increase sensitivity.

IV. Circulating and Local Hormones
   a. Circulating Hormones: hormones that enter the blood stream and target a distant cell or organ.
      i. Aka: endocrines
   b. Local Hormones: Hormones that do not enter the bloodstream and act locally.
      i. Paracrines: Local hormones that are secreted act on neighboring cells
ii. **Autocrines:** Local hormones that act on the same cells that secreted them
c. Local hormones are usually used and inactivity quickly
d. Circulating hormones are allowed to linger in the bloodstream for a few minutes up to
   possibly hours.
   i. Circulating hormones are eventually inactivated by the liver and excreted
      by the kidneys. Therefore, liver or kidney failure can lead to excessive hormone
      build up in the blood.

V. **Chemical Classes of Hormones**
a. Two Chemical Classes of Hormones based on their solubility in lipid (fat).
b. **Lipid-Soluble Hormones:** hormones that dissolve in lipid.
   i. **Steroid Hormones:** derived from cholesterol
   ii. **Two Thyroid Hormones:** synthesized from tyrosine.
      1. T3 and T4 are the two lipid-soluble thyroid hormones.
   iii. **Nitric Oxide:** a gas that is both a hormone and a neurotransmitter.
c. **Water Soluble Hormones:** hormones that dissolve in water
   i. **Amine Hormones:** synthesized from amino acids
      1. Epinephrine, norepinephrine, dopamine: from tyrosine
      2. Histamine: from histidine
   ii. **Peptide and Protein Hormones:** TSH
   iii. **Eicosanoid Hormones:** derived from arachadonic acid
      1. Prostaglandins and Leukotrienes

VI. **Hormone Transport in Blood**
a. Most water-soluble hormones travel freely in the blood plasma.
b. Most lipid-soluble hormones bind to transport proteins to carry them through the
   blood.
c. Transport proteins have three functions:
   i. Improve transportability of lipid soluble hormones by making them
      temporarily water-soluble.
   ii. Slow the passage of small hormone molecules through the filtering system
      in the kidneys, slowing the rate of hormone loss in the urine.
   iii. Provide a ready-reserve of hormones present in the blood.
d. **Free Fraction:** this is the amount of a specific hormone that is not bound to any
   transport proteins (up to 10%).
   i. It is this free fraction of hormone that diffuses out of the capillaries and
      binds to receptors to create a reaction.
   ii. As these hormone molecules leave the blood and bind to receptors,
      transport proteins release hormone molecules to restore the free fraction.

VII. **Mechanism of Hormone Action**
a. The response elicited by a hormone depends on the hormone as well as the target cell.
b. Different target cells react differently to the same hormone.
   i. I.e. insulin will cause the liver to synthesize glycogen (stored glucose) and
      at the same time cause adipose cells to synthesize triglycerides (a form of fat).

VIII. **Action of a lipid-soluble hormone**
a. Lipid-soluble hormones bind to receptor sites within the target cell.
b. Mechanism:
   i. The lipid-soluble hormone molecule diffuses through the blood, interstitial
      fluid, and through the cell’s lipid bilayer into the cell.
   ii. If the cell is a target cell, the hormone molecule will bind to and activate
      the receptor within the cell. The activated receptor turns specific DNA genes on
      or off (aka “alters gene expression”) within the cell’s nucleus..
iii. As the DNA is transcribed, new messenger RNA (mRNA) forms, leaves the nucleus and enters the cytosol, where it directs synthesis of new proteins (usually enzymes) on the ribosomes.

iv. The new proteins alter the cell’s activity and cause the typical physiological responses of that hormone.

IX. Action of a Water-Soluble Hormone

a. Water-soluble hormone molecules cannot diffuse through the lipid-bilayer to attach to the receptor sites inside the target cell.

b. Water-soluble hormone molecules must bind to receptor sites on the extra-cellular surface of the plasma membrane.

c. The receptor then stimulates the release of an enzyme inside the cell that can stimulate hormone responses.
   i. Because of this mechanism, it is called a Second Messenger System.
   ii. The water soluble hormone molecule is the 1st Messenger and the internal enzyme is the 2nd Messenger.
   iii. A common 2nd messenger is known as cyclic AMP (cAMP) activated by the enzyme adenylyl cyclase, which is attached to the inner surface of the plasma membrane.

d. Mechanism of water soluble hormonal action:
   i. The water-soluble hormone molecule (1st messenger) diffuses from the blood, into the interstitial fluid and then binds to the receptor site on the surface of the plasma membrane. This activates a G-Protein inside the cell, which in turn, activates adenylyl cyclase.
   ii. Adenylyl Cyclase then converts ATP into cAMP inside the cell.
   iii. cAMP (2nd messenger) activates enzymes called protein kinases (enzymes that add phosphate groups to cellular proteins).
   iv. The protein kinases add phosphate groups (or phosphorylate) one or several other enzymes. Phosphorylation can turn on or off different enzymes.
      1. The result could be regulation of other enzymes, secretion, protein synthesis, and/or changes in the permeability of the plasma membrane.
   v. Enzymes activated by phosphorylation catalyze reactions that produce the physiological responses associated with the particular hormone involved.

e. After a brief period of time, an enzyme called phosphodiesterase inactivates cAMP and turns off the response unless new hormone molecules continue to bind to the plasma membrane.

X. Control of Hormone Secretion

a. Most hormones are released in short bursts with little or no secretion between bursts.

b. When more hormone release is needed, the bursts are more frequent and when less hormone is needed, the bursts are less frequent.

c. Hormone secretion is regulated in 3 ways:
   i. Nervous stimulation
      1. i.e. nervous stimulation to the adrenal gland stimulates the release of epinephrine
   ii. Chemical changes in the blood
      1. decreased Ca++ levels in the blood stimulate the release of parathyroid hormone
   iii. Other hormones
      1. a hormone from the anterior pituitary gland stimulates the release of cortisol (another hormone) from the adrenal gland.

d. Hyposcretion: inadequate release of a hormone

e. Hypersecretion: excessive release of a hormone.

ENDOCRINE GLANDS AND THEIR HORMONES

History: The first hormone ever discovered was called Secretin. It was discovered by Bayliss & Starling in 1902.
A. Secretin is secreted by the duodenum of the small intestine in response to low duodenal pH (high acid) from the presence of gastric juice & chyme (partially digested food). It’s function is to increase pH by stimulating the release of bicarbonate.

B. Tropic Hormones: some hormones are called ‘tropic hormones’ or ‘tropins’ which means that hormone specifically targets another endocrine gland either stimulating it to or inhibiting it from secreting a hormone of it’s own.
   a. i.e. Thyrotropin (aka thyroid stimulating hormone) is secreted by the anterior pituitary gland and targets the thyroid gland stimulating it to secrete thyroid hormones.

XI. Hypothalamus and Pituitary Gland: all pituitary and hypothalamic hormones fall into the peptide and protein hormones category.
   a. The hypothalamus is known as the integrating center between the nervous system and the endocrine system. It not only serves as a portion of the CNS, but it is also a powerful endocrine gland.
      i. The hypothalamus receives input from the limbic system, cerebral cortex, thalamus, reticular activating system of the brain, the internal organs and the retina.
      ii. The hypothalamus controls the ANS and regulates body temperature, thirst, hunger, sexual behavior, and defensive reactions (i.e. fear and rage).
      iii. The hypothalamus synthesizes 8 different hormones. 6 of the hormones synthesized by the hypothalamus are secreted into the infundibulum (bypassing the general blood circulation) and target the anterior pituitary gland directly, stimulating it to secrete its own hormones.
      iv. 2 hypothalamic hormones, oxytocin and antidiuretic hormone are produced by the hypothalamus but stored in axon terminals that extend into the posterior pituitary gland awaiting release when necessary.
      v. The other 7 hypothalamic hormones are inhibiting and releasing hormones specifically designed to stimulate or inhibit the anterior pituitary gland to or from secreting its hormones:
         vi. Growth Hormone Releasing Hormone (GHRH) stimulates the anterior pituitary gland to secrete human growth hormone.
         vii. Growth Hormone Inhibiting Hormone (GHIH) inhibits the anterior pituitary gland from secreting human growth hormone.
         viii. Thyrotropin Releasing Hormone (TRH): stimulates the anterior pituitary gland to secrete Thyrotropin (aka Thyroid Stimulating Hormone).
         ix. Gonadotropin Releasing Hormone (GnRH): stimulates the anterior pituitary gland to secrete follicle stimulating hormone and leutenizing hormone (aka the gonadotropins)
         x. Prolactin Inhibiting Hormone (PIH): inhibits the anterior pituitary gland from secreting prolactin.
         xi. Corticotropin Releasing Hormone (CRH): Stimulates the anterior pituitary gland to secrete Adrenocorticotropin Hormone (ACTH)
   b. The Pituitary Gland has 2 anatomically and functionally separate portions.
      i. Anterior Pituitary: adenohypophysis
      ii. Posterior Pituitary: Neurohypophysis

XII. The Anterior Pituitary Gland
   a. The hormones secreted by the pituitary are influenced by releasing hormones and inhibiting hormones, which are released by the hypothalamus.
   b. The hypothalamus releases these hormones into a portal system that links it directly to the anterior pituitary gland via the infundibulum without having to go the heart first.
      i. This results in quick stimulation of the pituitary without the hormone being diluted in the general blood circulation.
c. The Anterior Pituitary gland then responds appropriately to the hypothalamic hormones and if necessary, releases hormones into the general circulation for distribution throughout the body.

d. The Anterior Pituitary Gland secretes 6 major hormones:
   i. **Human Growth Hormone (hGH or somatotropin):** stimulates several tissues to produce insulin-like growth factors, which stimulate general body growth and regulate aspects of metabolism.
   ii. **Thyroid-Stimulating Hormone (TSH or thyrotropin):** controls secretions and other activities of the thyroid gland.
   iii. **Follicle-Stimulating Hormone (FSH) AND Luteinizing Hormone (LH):** both act on the gonads. They stimulate secretion of estrogens and progesterone as well as the maturation of oocytes in the ovaries. They also stimulate the secretion of testosterone and sperm production in the testes.
   iv. **Prolactin (PRL):** initiates milk production in the mammary glands.
   v. **Adrenocorticotropin (ACTH):** stimulates the adrenal gland to secrete glucocorticoids

e. The secretion of Anterior pituitary hormones is regulated in two ways:
   i. Neurosecretory cells of the hypothalamus release 5 stimulating and 2 inhibiting hormones.
   ii. A negative feedback system adjusts secretions of hormones based on how much hormone is already present in the system
      1. i.e. if there is enough circulating levels of testosterone in the blood, the pituitary gland will not release anymore FSH and LH in an attempt to avoid having too much testosterone in the blood.

f. **Human Growth Hormone (hGH) and Insulin-like Growth Factors (IGFs)**
   i. hGH is the most abundant of the Anterior pituitary hormones.
   ii. hGH works indirectly on cells and tissues by stimulating them to produce small protein hormones called insulin-like growth factors (IGFs).
   iii. IGFs cause cells to multiply and grow
   iv. In children & teens, hGH increases the growth rate of the skeleton and skeletal muscles
   v. In adults, hGH helps maintain muscle & bone mass, promote healing of injuries and tissue repair, and liberate glucose from liver stores into the bloodstream.
   vi. The anterior pituitary releases bursts of hGH every few hours, especially during sleep
   vii. Which is why most tissue repair occurs during sleep
   viii. hGH is regulated by the hypothalamus via a hormone called growth hormone releasing hormone (GHRH) and growth hormone inhibiting hormone (GHIH).
   ix. Low blood glucose (or sugar) stimulates the hypothalamus to secrete GHRH to the anterior pituitary gland, and in turn the anterior pituitary releases hGH into the bloodstream.
   x. High blood glucose levels stimulate the hypothalamus to release GHIH to the anterior pituitary, and in turn inhibits the release of hGH by the anterior pituitary gland.
   xi. Other stimuli that promote hGH secretion:
      1. Decreased fatty acids and increased amino acids in the blood
      2. Deep sleep
      3. Increased sympathetic activity
   xii. Other stimuli that inhibit hGH secretion
      1. Increased fatty acids and decreased amino acids in the blood
      2. REM sleep
      3. Emotional deprivation
      4. Obesity
5. Low levels of thyroid hormones
6. hGH itself

g. **Thyroid Stimulating Hormone (TSH)**
   i. Stimulates the secretion of T3 and T4 hormone.
   ii. Controlled by **Thyrotropin Releasing Hormone (TRH)** released by the hypothalamus.
   iii. Low levels of T3 and TSH as well as a low metabolic rate stimulate the release of TRH from the hypothalamus to the anterior pituitary.

h. **Follicle Stimulating Hormone (FSH)**
   i. Female: FSH is transported from the anterior pituitary to the ovaries, where it stimulates the production of follicles each month to support an oocyte (beginning of an egg). Also stimulates the secretion of estrogens.
   ii. Male: FSH stimulates sperm production in the testes.
   iii. The hypothalamus stimulates the release of FSH with **Gonadotropin Releasing Hormone (GnRH)**. The presence of FSH, estrogen, and/or testosterone inhibit the release of GnRH and FSH via a negative feedback system.

i. **Luteinizing Hormone**
   i. Females: Along with FSH, stimulates the release of estrogens resulting in the release of a secondary oocyte (future ovum) in the process of ovulation.
      1. Also stimulates the formation of a corpus luteum in the ovary (the structure formed after ovulation) and the release of progesterone.
      2. Estrogen and progesterone prepare the uterus for implantation of a fertilized ovum and prepare the mammary glands for milk production.
   ii. Males: LH promotes secretion of testosterone
   iii. LH is also controlled by GnRH from the hypothalamus.

j. **Prolactin**
   i. Initiates and maintains the mammary glands for milk production.
      1. Helped by Oxytocin
   ii. Inhibited by **Prolactin Inhibiting Hormone (PIH)** from the hypothalamus.
      1. PIH is dopamine
      2. Does not require a releasing hormone
   iv. Unknown purpose in males, however hypersecretion of prolacin can cause erectile dysfunction and/or impotence.

k. **Adrenocorticotropic hormone (ACTH)**
   i. ACTH stimulates the secretion of glucocorticoids (mainly cortisol) from the cortex of the adrenal glands.
      1. Glucocorticoids responsible for metabolism and resistance to stress
   ii. Stimulated by **Corticotropin Releasing Hormone (CRH)** from the hypothalamus.

XIII. **Posterior Pituitary Gland**
a. The posterior pituitary gland does not synthesize hormones
b. However, it does store and release 2 hormones that are synthesized by the hypothalamus.
   i. **Oxytocin**
      1. During delivery of a baby, oxytocin targets the uterus and enhances contraction of smooth muscle cells in the uterine wall.
      2. After delivery of a baby, oxytocin stimulates milk ejection (aka letdown) from the mammary glands in response to a suckling infant.
   ii. **Antidiuretic Hormone (ADH or vasopressin)**
      1. ADH is produced and secreted by the hypothalamus, however it is stored in synaptic vesicles that extend into the posterior pituitary gland.
      2. 3 functions
         a. ADH causes the kidneys to return more water to the blood, thus decreasing urine volume and increasing blood volume and water retention
b. Decreases water loss from sweating  
c. Constricts arterioles causing an increase in blood pressure  

3. The absence of ADH would increase urine production by 10 times.  
a. Important hormone for fluid balance  

4. Regulation of ADH  
a. A decrease in blood pressure (or an increase blood osmotic pressure, discussed later) caused by dehydration, diarrhea, or loss of blood, will cause the hypothalamus to stimulate the production and release of ADH.  
b. ADH causes water retention in the kidneys and sweat glands, as well as vasoconstriction, thus increasing the blood volume and pressure.  
c. An increase in blood pressure will inhibit the hypothalamus from releasing ADH.  

5. ADH is also influenced in other ways:  
a. ADH secretion is increased by pain, stress, trauma, anxiety, acetylcholine, nicotine, morphine, tranquilizers, and some anesthetics.  
b. ADH secretion is inhibited by alcohol. Hence, the increased urine output associated with alcohol and the dehydration associated with the thirst and headache of a hangover.

XIV. The Thyroid Gland  
a. Inferior to the larynx on both sides of the trachea.  
b. Two Thyroid Hormones produced  
   i. Thyroxin (T4) & triiodothyronine (T3)  
      a. T3=3 Iodine, T4=4 iodine.  
c. Some cells within the thyroid follicles are known to produce a hormone called calcitonin for calcium regulation.  
d. The thyroid stores about a 100-day supply of T3 & T4 as regulated by TSH.  
e. Thyroid hormones have three functions:  
   i. Regulate oxygen and basal metabolic rate  
   ii. Regulate cellular metabolism  
   iii. Regulate growth and development  
f. Basal Metabolic Rate (BMR) is defined as the rate of oxygen consumption at rest after an overnight fast.  
   i. Otherwise: how much energy you spend at rest to keep your body alive.  
   ii. The thyroid hormones stimulate the conversion of oxygen to ATP (energy), protein synthesis, and the use of glucose and lipid for energy. A bi-product of this is heat.  
      1. Therefore, the thyroid hormones play a major role in temperature regulation.  
      2. The production of heat as a response to the thyroid hormones is known as the calorigenic effect of the thyroid hormones.  
   iii. Hypothyroidism, a decrease in the function of the thyroid, results in obesity and intolerance to cold.  
   iv. Hyperthyroidism, an increase in thyroid activity, results in an inability to gain weight, sweating, exopthalmos (protruding eyes), and intolerance to heat.  
g. Calcitonin: promotes the uptake of calcium into the bones and inhibits the liberation of calcium in the bones (bone resorption). Resulting in increased bone density and decreases blood calcium.  
   i. Stimulated by a higher than normal blood calcium level.  

XV. Parathyroid Glands  
a. Attached to the posterior surface of the lateral lobes of the thyroid gland  
b. Parathyroid hormone increases the number and activity of osteoclasts.
i. The result is increased bone resorption, releasing calcium from the bones into the blood.
ii. Result from PTH is decreased bone density and increased blood calcium.
iii. Also stimulates the kidneys to release calcitrol, which stimulates the absorption of calcium from foods in the digestive tract helping to increase the blood calcium level.
iv. Stimulation by a lower than normal blood calcium level.

XVI. Adrenal Glands (aka suprarenal glands)

a. Located superior to each kidney
b. Adrenal Cortex: the outer portion of the gland
c. Adrenal Medulla: inner portion of the gland
d. Adrenal Cortex produces and secretes mineralocorticoids (affect homeostasis of minerals), glucocorticoids (affect glucose homeostasis) and weak androgens (steroid hormones with masculinizing effects)
e. Mineralocorticoids
i. Aldosterone: increases the body’s reabsorption of sodium (Na+) into the blood.
   1. Leads to the reabsorption of chlorine (Cl\(^-\)), bicarbonate (HCO\(_3\)\(^-\)), and water molecules.
   2. Also leads to the excretion of potassium (K\(^+\)) and hydrogen ions (H\(^+\)) from the blood
ii. The combination of H\(^+\) (acid) and HCO\(_3\)\(^-\) (base) removal and reabsorption protect the body from acidosis and keep the blood’s pH above 7.35.
f. Glucocorticoids
i. Regulate metabolism and resistance to stress
ii. Stimulated by: Corticotropin Releasing Hormone from the hypothalamus stimulates the anterior pituitary to release Adrenocorticotropin hormone, which stimulates the adrenal cortex to release glucocorticoids.
iii. Cortisol (hydrocortisone), corticosterone, and cortisone
1. Cortisol is responsible for 95% of glucocorticoids activity
iv. Effects on the body:
   1. Breakdown of proteins into amino acids for metabolic enzyme production (produce the chemicals needed to increase metabolism)
   2. Formation of glucose from proteins or lactic acid.
      a. The formation of glucose from a source other than glycogen or another storage or monosaccharide form of glucose is known as gluconeogenesis.
   3. Lipolysis: breakdown of triglycerides (a storage form of fatty acids) into free fatty acids in the blood from adipose tissue.
   4. Resistance to Stress: additional glucose provides tissues with a ready supply of ATP to combat stresses such as exercise, fasting, fright, temperature extremes, bleeding, high altitude, infections, surgery, trauma, and disease.
   5. Anti-inflammatory effects: inhibit the cells participating in inflammatory responses, such as histamine-producing mast cells.
      a. Also decrease the permeability of capillaries so fluid cannot leave and swell the tissues, depress phagocytosis, and slow the release of destructive enzymes.
      b. Cortisone is frequently used as a drug for its anti-inflammatory effects, however, it slows connective tissue repair and wound healing. Also can cause severe disturbances in high doses and bone density loss with prolonged use.
   6. Depression of immune responses: given to organ donor recipients to decrease the risk of rejection.
g. Androgens: contribute sex drive and estrogen production in females.
h. **Adrenal Medulla** produces epinephrine and norepinephrine, which mimic the same responses brought on by the sympathetic nervous system.
   i. Increase blood pressure, blood flow to the skeletal muscles, heart, liver, and adipose tissue, dilate airways to the lungs, and increase blood levels of glucose and fatty acids.

XVII. **Pancreas**
   a. Located posterior and slightly inferior to the stomach
   b. Both an endocrine and exocrine gland
   c. Contains endocrine tissue called the **Islets of Langerhans or pancreatic islets**
   d. Each islet has 4 different types of cells
      i. Alpha cells: secrete glucagons
      ii. Beta Cells: secrete insulin
      iii. Delta Cells: secrete somatostatin (identical to GHIH from the hypothalamus)
      iv. F Cells: secrete pancreatic polypeptide
   e. **Glucagon**: released in response to low blood sugar by the Alpha Cells. Stimulate the liver cells to convert glycogen (stored glucose) into glucose (process known as **glycogenolysis**). The liver releases the glucose into the blood to raise blood sugar.
   f. **Insulin**: released in response to high blood sugar by the beta cells of the islets. Stimulates the cells to absorb glucose (especially skeletal muscle), speeds the conversion of glucose by the liver into glycogen (glycogenesis) and by adipose tissue into fat cells (lipogenesis) for storage.

XVIII. **Ovaries & Testes**
   a. Ovaries: produce several steroid hormones
      i. **Estrogen & Progesterone** work with LH & FSH to regulate the menstrual cycle, maintain pregnancy, and prepare for lactation.
         1. also establish and maintain feminine secondary sex characteristics, such as breast and wide hips.
   b. Ovaries also produce **inhibin**, inhibits the production of FSH and **relaxin**, which increases the flexibility of the pubic symphysis during pregnancy in animals (but not in humans) and helps dilate the cervix for labor and delivery. In humans, estrogen takes on this role.
   c. Testes produce **testosterone**, which regulates sperm production and the development and maintenance of masculine secondary sex characteristics such as a beard and a deep voice.

XIX. **Pineal Gland**
   a. Secretes melatonin, which regulates sleepiness. More melatonin is produced in darkness than in light due to stimulation to the retina creating impulses reaching the suprachiasmatic nucleus of the hypothalamus.
   b. In bright light norepinephrine released by sympathetic fibers inhibits the release of melatonin and thus results in a lack of sleepiness.
   c. Therefore, the release of melatonin is governed by the circadian (daily) dark-light cycle.
   d. This process is established in infancy and the pineal gland does not have much known function in adults.