Functions of Hormones

1. Help Regulate:
   a. Chemical composition and volume of internal environment
   b. Metabolism and energy balance
   c. Contraction of smooth and cardiac muscle fibers
   d. Glandular secretions
   e. Some immune activities

2. Control growth and development

3. Regulate operation of reproductive systems

4. Help establish circadian rhythms
Hormones

• The Chemistry of Hormones

  – Amino Acid Based – formed by decarboxylating certain amino acids, examples:
    – Catecholamines – all derived from tyrosine
      • Epinephrine
      • Norepinephrine
      • Dopamine
    – Histamine – made from histidine
    – Serotonin and Melatonin – synthesized from tryptophan
    – Thyroxine
    – Peptide Hormones and Protein Hormones – amino acid polymers, examples
      • ADH, oxytocin, insulin
Hormones

- Steroids - derived from cholesterol, lipid soluble
  - Some gonadal
  - Adrenocortical Hormones

- Ecosanoid Hormones – made from arachidonic acid, lipid soluble
  - Prostaglandins – acts as a local hormone with diverse functions
  - Leukotrienes – function in inflammatory response
Hormones

• Mechanisms of Hormone Action
  
  – Hormones

  • Work on certain cells referred to as target cells

  • Alter cell function
    
    – Changes plasma membrane’s permeability
    
    – Stimulates synthesis of proteins (Functions of proteins)
    
    – Activates or deactivates enzymes
    
    – Induces secretory activity
    
    – Stimulates mitosis
Hormones

- Amino Acid-Based Hormones and Second Messenger Systems

- **Cyclic AMP**
Hormones

- The PIP-Calcium Signal Mechanism

First messenger
Hormone

Inactive G protein
Active G protein

Phospholipase

DAG
Second messenger

Effector

GDP
GTP

Relay

Protein kinase C

Protein kinase C

Catecholamines
TRH
ADH
LHRH
Oxytocin

Endoplasmic reticulum

Calcium

Third messenger

Ca^{2+}-calmodulin

Responses of target cell

Cytoplasm
Hormones

- Steroid Hormones and Direct Gene Activation
Hormones

- **Target Cell Specificity**

- **Up-Regulation**

- **Down Regulation**
Hormones

- **Half-Life and Duration of Hormone Activity**
  - Carried in blood in two ways
    - As free chemicals
    - Bound to plasma protein carrier molecules
  - Levels in blood determined by
    - Rate of release
    - Rate of inactivation or removal
Hormones

• Interaction of Hormones at Target Cells
  - Permissive Effect – require previous or simultaneous exposure to two or more hormones
  - Synergistic – two hormones act together in a greater or more extensive than the sum of each
  - Antagonistic – hormones that have opposite effects
Hormones

- Control of Hormone Release

- Nervous System Modulation
Major Endocrine Organs

- Pituitary Gland (Hypophysis)
Major Endocrine Organs

• Anterior Pituitary (Adenohypophyseal) Hormones
  
  – Growth Hormone (GH) or Somatotropin

  • Stimulates the uptake of amino acids and their conversion into proteins along with stimulating the breakdown of fats and glycogen

  • Stimulate the production of somatomedins by the liver that participate in bone and cartilage growth

  • Is secreted in response to increased blood amino acids, low blood glucose, or stress

  • Regulated by GHRH and GHIH or somatostatin
Major Endocrine Organs

(a) A 22-year old man with pituitary gigantism shown beside his identical twin

(b) Acromegaly (excess hGH during adulthood)
Major Endocrine Organs

- Thyroid-Stimulating Hormone (TSH) also called Thyrotropin – results in the release of thyroid hormones (more on this hormone when we discuss the thyroid gland)

- Adrenocorticotropic Hormone (ACTH) – stimulates the secretion of hormones from the adrenal cortex (more on this when we talk about the adrenal glands)

- Gonadotropins – promote growth and functioning of the gonads, release is stimulated by GnRH
  - Follicle-Stimulating Hormone (FSH)
  - Luteinizing Hormone (LH)
Major Endocrine Organs

- Prolactin – stimulates milk production in lactating females, secretion affected by PRH and PIH (dopamine)

• Posterior Pituitary Gland (Neurohypophysis) and Hypothalamic Hormones

  - Oxytocin –

    • Stimulates smooth muscle cells of the uterus, the result of stretching of uterus
    • Stimulates the ejection of milk from the breasts upon suckling on the nipples
Major Endocrine Organs

- Antidiuretic Hormone (ADH) or Vasopressin
  
  • Causes the kidneys to reabsorb more water (produce less urine)

  • Raises blood pressure by constricting blood vessels when present in high concentrations

  • Decreases production of perspiration
Thyroid Gland

- Anatomy and Location

- Hyoid bone
- Thyroid cartilage
- Epiglottis
- Internal carotid artery
- External carotid artery
- Superior thyroid artery
- Common carotid artery
- Isthmus of thyroid gland
- Inferior thyroid artery
- Trachea
- Brachiocephalic artery
- Aorta
- Left subclavian artery
- Left lateral lobe of thyroid gland

- Colloid-filled follicles
- Follicle cells
- Parafollicular cell
Thyroid Gland

- Thyroid Hormone – really two hormones
  
  - Thyroxine ($T_4$) - major thyroid hormone
  
  - Triiodothyronine ($T_3$)
  
  - Has wide effects, target cells most cells of the body except thyroid gland, adult brain, spleen, testes, and uterus
# Thyroid Gland

<table>
<thead>
<tr>
<th>Process or System Affected</th>
<th>Normal Physiological Effects</th>
<th>Effects of Hyposecretion</th>
<th>Effects of Hypersecretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal metabolic rate (BMR)/temperature regulation</td>
<td>Promotes normal oxygen use and BMR; calorigenesis; enhances effects of sympathetic nervous system</td>
<td>BMR below normal; decreased body temperature and cold intolerance; decreased appetite; weight gain; reduced sensitivity to catecholamines</td>
<td>BMR above normal; increased body temperature and heat intolerance; increased appetite; weight loss; increased sensitivity to catecholamines may lead to high blood pressure</td>
</tr>
<tr>
<td>Carbohydrate/lipid/protein metabolism</td>
<td>Promotes glucose catabolism, mobilizes fats; essential for protein synthesis; enhances liver's synthesis of cholesterol</td>
<td>Decreased glucose metabolism; elevated cholesterol/triglyceride levels in blood; decreased protein synthesis; edema</td>
<td>Enhanced catabolism of glucose, proteins, and fats; weight loss; loss of muscle mass</td>
</tr>
<tr>
<td>Nervous system</td>
<td>Promotes normal development of nervous system in fetus and infant; promotes normal adult nervous system function</td>
<td>In infant, slowed/deficient brain development, retardation; in adult, mental dulling, depression, paresthesias, memory impairment, hypoactive reflexes</td>
<td>Irritability, restlessness, insomnia, exophthalmos, personality changes</td>
</tr>
<tr>
<td>Cardiovascular system</td>
<td>Promotes normal functioning of the heart</td>
<td>Decreased efficiency of pumping action of the heart; low heart rate and blood pressure</td>
<td>Rapid heart rate and possible palpitations; high blood pressure; if prolonged, heart failure</td>
</tr>
<tr>
<td>Muscular system</td>
<td>Promotes normal muscular development, and function</td>
<td>Sluggish muscle action; muscle cramps; myalgia</td>
<td>Muscle atrophy and weakness</td>
</tr>
<tr>
<td>Skeletal system</td>
<td>Promotes normal growth and maturation of the skeleton</td>
<td>In child, growth retardation, skeletal stunting and retention of child’s body proportions; in adult, joint pain</td>
<td>In child, excessive skeletal growth initially, followed by early epiphyseal closure and short stature; in adult, demineralization of skeleton</td>
</tr>
<tr>
<td>Gastrointestinal system</td>
<td>Promotes normal GI motility and tone; increases secretion of digestive juices</td>
<td>Depressed GI motility, tone, and secretory activity; constipation</td>
<td>Excessive GI motility; diarrhea; loss of appetite</td>
</tr>
<tr>
<td>Reproductive system</td>
<td>Promotes normal female reproductive ability and lactation</td>
<td>Depressed ovarian function; sterility; depressed lactation</td>
<td>In females, depressed ovarian function; in males, impotence</td>
</tr>
<tr>
<td>Integumentary system</td>
<td>Promotes normal hydration and secretory activity of skin</td>
<td>Skin pale, thick, and dry; facial edema; hair coarse and thick</td>
<td>Skin flushed, thin, and moist; hair fine and soft; nails soft and thin</td>
</tr>
</tbody>
</table>
Thyroid Gland

- Hormone Synthesis

1. Thyroglobulin is synthesized and discharged into the follicle lumen.
2a. Trapping (active uptake) of iodide (I⁻).
2b. Oxidation of iodine.
3. Iodine enters follicle lumen where it is attached to tyrosine in colloid, forming DIT and MIT.
4. Iodinated tyrosines are linked together to form T₃ and T₄.
5. Thyroglobulin colloid is endocytosed and combined with lysosomes.
6. Lysosomal enzymes cleave T₄ and T₃ from thyroglobulin colloid and hormones diffuse from follicle cell into bloodstream.
Thyroid Gland

– Transport and Regulation

• Combine with plasma proteins – *thyroxine-binding globins* (TBG’s)

• $T_3$ the most cellularly active form

• Regulation

  – TRH

  – TSH
Goiter

Exophthalmia
Thyroid Gland

- Calcitonin
  - Produced by parafollicular or C cells
  - Lowers blood levels of calcium
    - Inhibits osteoclast activity
    - Stimulates boney matrix formation
  - Regulated by blood levels of calcium
Parathyroid Glands

(a) Diagram showing the location of the parathyroid glands in relation to the pharynx, thyroid gland, esophagus, and trachea.

(b) Microscopic image showing the chief cells and oxyphil cells.
1. High level of Ca\(^{2+}\) in blood stimulates thyroid gland parafollicular cells to release CALCITRIOL.

2. CALCITRIOL promotes deposition of blood Ca\(^{2+}\) into bone matrix, which increases bone Ca\(^{2+}\) level.

3. CALCITONIN promotes deposition of blood Ca\(^{2+}\) into bone matrix, which decreases blood Ca\(^{2+}\) level.

4. Low level of Ca\(^{2+}\) in blood stimulates parathyroid gland principal cells to release PARATHYROID HORMONE (PTH).

5. PTH promotes release of Ca\(^{2+}\) from bone matrix into blood and retards loss of Ca\(^{2+}\) in urine, which increases blood Ca\(^{2+}\) level.

6. PTH also stimulates the kidneys to release PARATHYROID HORMONE (PTH).

7. CALCITONIN promotes deposition of blood Ca\(^{2+}\) into bone matrix, which decreases blood Ca\(^{2+}\) level.

8. CALCITRIOL stimulates increased absorption of Ca\(^{2+}\) from foods in the gastrointestinal tract, which increases blood Ca\(^{2+}\) level.
Hyperparathyroidism

Calcification of cornea

Pseudoclubbing of fingers
Parathyroid Glands

- Parathyroid Hormone (PTH)
  - Very important in regulation of calcium
  - Effects three body systems

Key:
- $\cdot \cdot$ = Ca$^{2+}$ ions
- $\text{PTH}$ molecules

Hypocalcemia (low blood calcium) stimulates parathyroid glands

Rising Ca$^{2+}$ in blood inhibits PTH release

PTH release from parathyroid glands

PTH: Activates osteoclasts; calcium and phosphate ions released into blood

Intestine: Increases calcium absorption from food

Kidney: Promotes activation of vitamin D and increases calcium reabsorption

Bloodstream
Adrenal (Suprarenal) Glands

- Adrenal gland
  - Medulla
  - Cortex

- Kidney

(a) Capsule
   - Zona glomerulosa
   - Zona fasciculata
   - Zona reticularis
   - Adrenal medulla

(b)
Adrenal Glands

• Adrenal Cortical Hormones (corticosteroids)
  – Mineralcorticoids (aldosterone)
    • Secreted by cells of zona glomerulosa
    • Actions:
      – kidneys to conserve sodium
      – rids the body of excess potassium and hydrogen ions
Adrenal Glands

- Glucocorticoids (cortisol)
  
  • Secreted by cells of zona fasiculata

  • Actions:
    
    - Breakdown of proteins and fats
    - Increases glucose synthesis from amino acids
    - Decreases inflammation
    - Needed for the development of some tissues

  • Regulated by ACTH, which is regulated by CRH from the hypothalamus during times of stress or low blood sugar
Cushing’s Syndrome
(Hypercortisolism)
Adrenal Glands

- Gonadocorticotropicins – mainly androgens
  
  • Secreted by zona reticularis
  
  • Actions:
    
    - Males – little if any
    
    - Females
      
      • Stimulates axillary and pubic hair
      • Stimulates sex drive
Adrenal Glands

- Adrenal Medullary Hormones
  - Epinephrine (80%) and norepinephrine (20%)
    - Epinephrine
      - Increases blood levels of glucose
      - Increases heart rate and force of contractions
      - Vasoconstriction in skin and viscera
      - Vasodilation in skeletal muscles and heart
    - Norepinephrine
      - Stimulates heart muscle
      - Vasoconstriction of most peripheral blood vessels
  - Release of these hormones mediated by the sympathetic division of ANS during times of stress
**Short-term stress response**
1. Increased heart rate
2. Increased blood pressure
3. Liver converts glycogen to glucose and releases glucose to blood
4. Dilation of bronchioles
5. Changes in blood flow patterns leading to increased alertness, decreased digestive system activity, and reduced urine output
6. Increased metabolic rate

**Long-term stress response**
1. Retention of sodium and water by kidneys
2. Increased blood volume and blood pressure
3. Proteins and fats converted to glucose or broken down for energy
4. Increased blood sugar
5. Suppression of immune system
Pancreas

• Glucagon
  
  – Target tissue

  • Mostly the liver

  – Action

  • Causes the breakdown of glycogen and fats for use as an energy source
Pancreas

• Insulin
  
  – Target tissues
  
  • Liver
  • Adipose
  • Muscle
  • Satiety center in the hypothalamus
  
  – Actions
  
  • Increases cell’s uptake of glucose and amino acids
    
    – Glucose is used for energy or stored as glycogen
    
    – Amino acids are used for energy converted to proteins
The diagram illustrates the relationship between insulin and glucagon in regulating blood sugar levels.

1. **Glucose in the Liver**
   - The liver stores glucose as glycogen and releases it when needed.
   - When blood sugar is low, the liver releases glucose into the bloodstream.
   - When blood sugar is high, the liver stores excess glucose as glycogen.

2. **Insulin and Glucagon**
   - **Insulin** is released by the pancreas when blood sugar levels are high.
     - It promotes glucose uptake into tissue cells, stimulating glycogen formation in the liver.
     - It lowers blood sugar levels.
   - **Glucagon** is released by the pancreas when blood sugar levels are low.
     - It promotes glycogen breakdown in the liver, stimulating glucose release.
     - It raises blood sugar levels.

3. **High Blood Sugar**
   - When blood sugar levels are high, the pancreas releases insulin.
   - Insulin promotes glucose uptake into tissue cells, stimulating glycogen formation.
   - As a result, blood sugar levels decrease.

4. **Low Blood Sugar**
   - When blood sugar levels are low, the pancreas releases glucagon.
   - Glucagon promotes glycogen breakdown in the liver, stimulating glucose release.
   - As a result, blood sugar levels increase.

5. **Promotion of Release**
   - Insulin promotes release of glucagon from the pancreas when blood sugar levels are low.
   - Glucagon promotes release of insulin from the pancreas when blood sugar levels are high.

This diagram effectively illustrates the feedback mechanism between insulin and glucagon in maintaining a stable blood sugar level.
Pancreas

• Diabetes Mellitus (DM)
  – Hyposcretion or hypoactivity of insulin
  – Can be two types
    • Type I, Insulin Dependent Diabetes Mellitus (IDDM), or juvenile diabetes
    • Type II, Non-Insulin Dependent Diabetes Mellitus (NIDDM), or adult onset diabetes
<table>
<thead>
<tr>
<th>Organs/tissue involved</th>
<th>Organ/tissue responses to insulin deficiency</th>
<th>Resulting condition of:</th>
<th>Signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Blood</td>
<td>Urine</td>
</tr>
<tr>
<td></td>
<td>Decreased glucose uptake and utilization</td>
<td>Hyperglycemia</td>
<td>Glycosuria</td>
</tr>
<tr>
<td></td>
<td>Glycogenolysis</td>
<td>Osmotic diuresis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protein catabolism and gluconeogenesis</td>
<td>Lipidemia</td>
<td>Ketonuria</td>
</tr>
<tr>
<td></td>
<td>Lipolysis and ketogenesis</td>
<td>and ketoacidosis</td>
<td>Loss of Na⁺, K⁺;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>electrolyte and acid-base imbalances</td>
</tr>
</tbody>
</table>

= Muscle  = Adipose tissue  = Liver
**Pineal Gland**

- Secretes melatonin

- Receives info from the retina concerning amount of light (secretes melatonin in the dark)
  - In other animals effects mating behaviors
  - In humans
    - May influence puberty (melatonin appears to have an antigonadotropin effect)
    - Involved in the biological clock
Thymus Gland

• Produce hormones important in the development of T cells – more in a bit
## Other Hormone-Producing Structures

<table>
<thead>
<tr>
<th>Source</th>
<th>Hormone</th>
<th>Chemical Composition</th>
<th>Trigger</th>
<th>Target Organ and Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI tract mucosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Stomach</td>
<td>Gastrin</td>
<td>Peptide</td>
<td>Secreted in response to food</td>
<td>Stomach: stimulates glands to release hydrochloric acid (HCl)</td>
</tr>
<tr>
<td>• Stomach</td>
<td>Serotonin</td>
<td>Amine</td>
<td>Secreted in response to food</td>
<td>Stomach: causes contraction of stomach muscle</td>
</tr>
<tr>
<td>• Duodenum of small intestine</td>
<td>Intestinal gastrin</td>
<td>Peptide</td>
<td>Secreted in response to food, especially fats</td>
<td>Stomach: inhibits HCl secretion and gastrointestinal tract mobility</td>
</tr>
<tr>
<td>• Duodenum</td>
<td>Secretin</td>
<td>Peptide</td>
<td>Secreted in response to food</td>
<td>Pancreas and liver: stimulates release of bicarbonate-rich juice; stomach: inhibits secretory activity</td>
</tr>
<tr>
<td>• Duodenum</td>
<td>Cholecystokinin (CCK)</td>
<td>Peptide</td>
<td>Secreted in response to food</td>
<td>Pancreas: stimulates release of enzyme-rich juice; gallbladder: stimulates expulsion of stored bile; sphincter of Oddi: causes sphincter to relax, allowing bile and pancreatic juice to enter duodenum</td>
</tr>
<tr>
<td>Kidney</td>
<td>Erythropoietin (EPO)</td>
<td>Glycoprotein</td>
<td>Erythropoietin secreted in response to hypoxia</td>
<td>Bone marrow: stimulates production of red blood cells</td>
</tr>
<tr>
<td>Skin (epidermal cells)</td>
<td>Cholecalciferol</td>
<td>Steroid</td>
<td>Cholecalciferol activated by the kidneys to active vitamin D$_3$ [1,25(OH)$_2$D$_3$] and released in response to parathyroid hormone</td>
<td>Intestine: stimulates active transport of dietary calcium across intestinal cell membranes</td>
</tr>
<tr>
<td>Heart (atria)</td>
<td>Atrial natriuretic peptide</td>
<td>Peptide</td>
<td>Secreted in response to stretching of atria (by rising blood pressure)</td>
<td>Kidney: inhibits sodium ion reabsorption and renin release; adrenal cortex: inhibits secretion of aldosterone; decreases blood pressure</td>
</tr>
<tr>
<td>Adipose tissue</td>
<td>Leptin</td>
<td>Peptide</td>
<td>Secreted in response to fatty foods</td>
<td>Brain: suppresses appetite; increases energy expenditure</td>
</tr>
<tr>
<td>Adipose tissue</td>
<td>Resistin</td>
<td>Peptide</td>
<td>Same as leptin</td>
<td>Fat, muscle, liver: antagonizes insulin's action on fat, muscle, and liver cells</td>
</tr>
</tbody>
</table>