Chapter 18, Part 2
The Endocrine System

SECTION 18-3
The bilobed pituitary gland is an endocrine organ that releases nine peptide hormones

What you need to know for each hormone we cover:
1. Name (of hormone)
2. Source
3. Target
4. Effect on target
5. Regulatory control

Know at the level covered in these notes
Pituitary Gland

A.K.A. Hypophysis (“growth below”)
- Connected to hypothalamus by infundibulum
- Sits in sella turcica of sphenoid
- All 9 hormones found here are proteins or peptides
- All use cAMP as second messenger
- Two major parts:
  - Anterior pituitary = adenohypophysis
  - Posterior pituitary = neurohypophysis
Anterior Pituitary – Adenohypophysis

A.K.A. Adenohypophysis ("adeno-" = gland)

Pars distalis
- Most anterior and largest portion

Pars intermedia
- Narrow band adjacent to posterior pituitary

Pars tuberalis
- Area around infundibulum

The Hypophyseal Portal System

Figure 18-7

Useful for 253 blood-tracing assignment
Hypophyseal Portal System

Hypothalamic releasing hormones enter here
- Superior hypophyseal artery →
- Capillary bed in median eminence →
- Portal veins →
- Capillary bed in anterior pituitary →
- Hypophyseal veins →
[Back to heart]

Hypothalamic Control of Pituitary Secretion

**Releasing hormones**
- Stimulate synthesis and secretion of *one or more* hormones

**Inhibiting hormones**
- Opposite effects

A *tropic* hormone causes another gland to release its hormone.

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<table>
<thead>
<tr>
<th>Releasing hormone (RH)</th>
<th>Hormone 1 (from pituitary)</th>
<th>Endocrine target organ</th>
<th>Hormone 2 (from target organ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRH</td>
<td>TSH</td>
<td>Thyroid gland</td>
<td>Thyroid hormones</td>
</tr>
<tr>
<td>CRH</td>
<td>ACTH</td>
<td>Adrenal cortex</td>
<td>Glucocorticoids</td>
</tr>
<tr>
<td>GnRH</td>
<td>FSH</td>
<td>Testes</td>
<td>Inhibit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ovaries</td>
<td>Inhibit Inhibin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Estragens</td>
</tr>
<tr>
<td>LH</td>
<td>Testes</td>
<td>Ovaries</td>
<td>Androgens</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Progesterone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Estrogens</td>
</tr>
</tbody>
</table>

Table showing the hypothalamic releasing hormones that follow the typical pattern of regulation shown in Figure 18-8d above.
Example of Feedback Control (Figure 18-8a)

TRH (Thyrotropin releasing hormone)
- TRH from hypothalamus → anterior pituitary
- Anterior pituitary releases TSH (Thyroid stimulating hormone)
- TSH effects:
  a. Thyroid releases thyroid hormones (T₃, T₄)
  b. Negative feedback of T₃, T₄ on hypothalamus → ↓ TRH
  c. Negative feedback on anterior pituitary → ↓ TSH
Anterior Pituitary Hormones – 1

Thyroid stimulating hormone (TSH)
- a.k.a. thyrotropin
- Thyrotropin-releasing hormone causes secretion
- Target: thyroid gland
- Effect: target releases thyroid hormones

Adrenocorticotropic hormone (ACTH)
- a.k.a. corticotropin
- Corticotropin-releasing hormone (CRH) causes release
- Target: adrenal cortex (zona fasciculata)
- Effect: target releases glucocorticoids

Anterior Pituitary Hormones – 2

Gonadotropins (FSH, LH)
Gonadotropin-releasing hormone (GnRH) causes release of gonadotropins:
1. Follicle-stimulating hormone (FSH)
   - Target in female: ovarian follicles
     Stimulates follicle development, estrogen secretion
   - Target in male: Sertoli cells
     Stimulates sperm production
   - Both inhibited by inhibin
### Anterior Pituitary Hormones – 3

2. Luteinizing hormone (LH)  
   a.k.a. Lutropin in females and…  
   Interstitial cell-stimulating hormone in males  
   - **Target in female:** ovaries  
     Stimulates ovulation  
     Leads to formation of corpus *luteum* *(which secretes progesterone)*  
   - **Target in male:** interstitial cells of Leydig  
     Stimulates secretion of androgens  
     *(e.g. testosterone)*

### Anterior Pituitary Hormones – 4

**Prolactin**  
   a.k.a. mammotropin  
   - **Target in female:** mammary glands  
     Stimulates development and milk *production*  
     *(Estrogens, progesterone, glucocorticoids, pancreatic hormones also involved in this)*  
   - Stimulated by prolactin-releasing factor  
   - Inhibited by prolactin-inhibiting hormone *(dopamine)*  
     *(Milk *ejection* due to oxytocin)*
Anterior Pituitary Hormones – 5

Growth hormone (GH or hGH)
  a.k.a. somatotropin
  • Target: most cells
    (Especially skeletal muscle and cartilage)
  • Stimulates cell growth, protein synthesis
Has both direct and indirect effects

See slide #9

Anterior Pituitary Hormones – 6

A. Indirect effects of GH - acts via somatomedins
GH → liver; liver releases somatomedins
  (a.k.a. insulin-like growth factors)
Somatomedin (indirect) effects - Big picture:
  Make and save protein
    • (increase amino acid uptake, protein synthesis)
  Maintain blood [glucose] (for use by brain)
  Use lipids for energy source
  Especially important right after a meal
B. **Direct effects of GH**

Usually important when blood [glucose] and [amino acids] are **normal** (not high right after a meal)

1. **Adipose tissue**
   - Triglycerides → fatty acids
   - Use fat instead of glucose
   - **Glucose-sparing effect**

2. **Liver**:
   - Glycogen → glucose
   - **Diabetogenic effect**

**Both direct and indirect: save glucose for brain**

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### Anterior Pituitary Hormones Summary

**Source, hormone, target, effect(s) on target, control of secretion**

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Target</th>
<th>Hormonal Effect</th>
<th>Hypothalamic Regulatory Hormone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thyroid-stimulating hormone (TSH)</strong></td>
<td>Thyroid gland</td>
<td>Secretion of thyroid hormones</td>
<td>Thyrotropin-releasing hormone (TRH)</td>
</tr>
<tr>
<td><strong>Adrenocorticotropic hormone (ACTH)</strong></td>
<td>Adrenal cortex ( zona fasciculata)</td>
<td>Secretion of glucocorticoids (cortisol, corticosterone)</td>
<td>Corticotropin-releasing hormone (CRH)</td>
</tr>
<tr>
<td><strong>Gonadotropin</strong></td>
<td>Follicle cells of ovaries</td>
<td>Secretion of estrogen, follicle development</td>
<td>Gonadotropin-releasing hormone (GnRH)</td>
</tr>
<tr>
<td><strong>Follicle-stimulating hormone (FSH)</strong></td>
<td>Follicle cells of ovaries</td>
<td>Ovulation, formation of corpus luteum, secretion of progesterone</td>
<td>Gonadotropin-releasing hormone (GnRH)</td>
</tr>
<tr>
<td><strong>Luteinizing hormone (LH)</strong></td>
<td>Follicle cells of ovaries</td>
<td>Increased secretion of estrogen, progesterone</td>
<td>Gonadotropin-releasing hormone (GnRH)</td>
</tr>
<tr>
<td><strong>Prolactin (PRL)</strong></td>
<td>Mammary glands</td>
<td>Production of milk</td>
<td>Prolactin-releasing factor (PRLF)</td>
</tr>
<tr>
<td><strong>Growth hormone (GH)</strong></td>
<td>All cells</td>
<td>Growth, protein synthesis, lipid mobilization and catabolism</td>
<td>Growth hormone-releasing hormone (GHRH)</td>
</tr>
</tbody>
</table>

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### Posterior Pituitary Hormones – 1

1. Antidiuretic hormone (ADH)
   - a.k.a. arginine vasopressin (AVP)
   - Formed by supraoptic nuclei (hypothalamus)
   - Stored in Posterior pituitary
   - Stimuli for release:
     - $\uparrow$ Blood [osmotic], $\downarrow$ blood volume,
     - $\downarrow$ blood pressure
   - Targets: kidneys, blood vessels
   - Effects:
     - $\downarrow$ Water loss by kidneys
     - $\uparrow$ Vasoconstriction $\rightarrow$ $\uparrow$ blood pressure

### Posterior Pituitary Hormones – 2

2. Oxytocin (OT)
   - Stimulates smooth muscle contraction
   - Targets and effects:
     - Uterus
       - Contraction
     - Myoepithelial cells of mammary glands
       - Milk ejection
     - Male and female orgasm
       - Contraction of vas deferens, prostate
       - Contraction of uterus and vagina
SECTION 18-4
The thyroid gland lies inferior to the larynx and requires iodine for hormone synthesis
The Thyroid Gland - Histology

Note: follicles, follicular cells, parafollicular cells (C cells) capillaries

Thyroid Hormone Synthesis – 1

1a. Thyroglobulin (protein) synthesized

1b. Iodide (I\(^-\)) pumped from blood into follicular cell (TSH promotes this example of secondary active transport.)

2. Iodide diffuses to apical membrane

3 a. Thyroid peroxidase converts I\(^-\) to I\(^+\)

   b. One or two I\(^+\) attached to tyrosines in thyroglobulin molecule

      • Iodinated tyrosines pair up to make T\(_3\) and T\(_4\)

   c. Thyroglobulin enters colloid by exocytosis

   http://www.vivo.colostate.edu/hbooks/pathphys/endocrine/thyroid/synthesis.html
Thyroid Hormone Synthesis – 2

Release depends on TSH:
4. Thyroglobulin re-enters cell by endocytosis
5. Lysosomes digest thyroglobulin
   • Release thyroid hormones into cytoplasm
   • Release amino acids (recycled)
6. Hormones *diffuse* through cell membrane into blood
   • Most binds with thyroid-binding globulin (TBG)
   • Some transported by albumin or transthyretin
   • Free fraction is very small (<< 1%)

Thyroid Follicle Function

Figure 18-11a
Thyroid Hormone Function – 1

Most secreted hormone is T₄ (thyroxine), but T₃ is much more powerful

- T₄ converted to T₃ by liver, kidney, other tissues

Functions:
1. Bind cytoplasmic receptors
   - Stored here
2. Bind mitochondrial receptors
   - Increase ATP production
3. Bind nuclear receptors, activate genes
   - E.g. make new Na⁺/K⁺ ATPase pumps, increase ATP use and oxygen consumption

Thyroid Follicle Function – 2  

Figure 18-11b

The regulation of thyroid secretion.
Thyroid Gland – Parafollicular (C) cells

Parafollicular = “next to” a follicle; C = “clear” or “calcitonin”

- Stimulus for calcitonin secretion: ↑ blood [Ca^{2+}]
- Target: o’clasts, kidneys
- Effects:
  a) Inhibit o’clasts
  b) Stimulate Ca^{2+} secretion by kidneys
  c) i.e. decrease blood [Ca^{2+}]

Physiological significance unclear

SECTION 18-5
The four parathyroid glands, embedded in the posterior surface of the thyroid gland, secrete parathyroid hormone to elevate plasma Ca^{2+}
Parathyroid Glands

Discussed during BIOL& 251 – Bones
- 2 pairs embedded in posterior of thyroids
- Stimulus = ↓ blood [Ca^{2+}]
- Effects = ↑ blood [Ca^{2+}]
  a) Stimulate o’clasts
  b) Inhibit o’blasts (↓ bone formation)
  c) Stimulate Ca^{2+} reabsorption by kidneys
  d) Stimulate formation of calcitriol
Chapter 18, Part 2 – Endocrine system

Calcium Homeostasis – 1

Figure 18-13, top

Calcitonin effects

Thyroid gland produces calcitonin

Increased excretion of calcium by kidneys

Calcium deposition in bone

HOMEOSTASIS

Normal blood calcium levels (8.5–11 mg/dL)

HOMEOSTASIS RESTORED

Blood calcium levels decline

Rising levels of blood calcium

HOMEOSTASIS DISTURBED

Rising calcium levels in blood

Calcium Homeostasis – 2 – PTH

Figure 18-3, bottom

PTH effects

Parathyroid glands secrete parathyroid hormone (PTH)

HOMEOSTASIS

Normal blood calcium levels (8.5–11 mg/dL)

HOMEOSTASIS RESTORED

Blood calcium levels increase

Rising levels of blood calcium

HOMEOSTASIS DISTURBED

Falling calcium levels in blood

Increased reabsorption of calcium by kidneys

Calcium release from bone

Increased calcitriol production causes Ca^{2+} absorption by digestive system
**Thyroid and Parathyroid Hormone Summary**

**Section 18-6**

The suprarenal (adrenal) glands, consisting of a cortex and medulla, cap the superior borders of the kidneys and secrete several hormones

<table>
<thead>
<tr>
<th>Gland/Cells</th>
<th>Hormone</th>
<th>Target</th>
<th>Hormonal Effect</th>
<th>Regulatory Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>THYROID GLAND</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follicular epithelium</td>
<td>Thyroxine (T4)</td>
<td>Whole cells</td>
<td>Increases energy utilization, oxygen consumption, growth, and development</td>
<td>Stimulated by TSH from the anterior lobe of the pituitary gland</td>
</tr>
<tr>
<td>C cells</td>
<td>Calcitonin (CT)</td>
<td>Bone, kidneys</td>
<td>Decreases Ca²⁺ concentrations in body fluids</td>
<td>Stimulated by elevated plasma Ca²⁺ levels; actions opposed by PTH</td>
</tr>
<tr>
<td><strong>PARATHYROID GLANDS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parathyroid (chief cells)</td>
<td>Parathyroid hormone (PTH)</td>
<td>Bone, kidneys</td>
<td>Increases Ca²⁺ concentrations in body fluids</td>
<td>Stimulated by low blood Ca²⁺ levels; PTH effects enhanced by calcitonin and opposed by calcitonin</td>
</tr>
</tbody>
</table>
The Adrenal Glands

Figure 18-14

Adrenal Glands – Zona Glomerulosa

A. Zona glomerulosa
   • Secretes mineralcorticoids
   • Affect electrolyte (Na\(^+\), K\(^+\)) and water balance
     (These affect blood volume and pressure)
   • Principle hormone = **aldosterone**
     Acts on kidneys and other organs
     • Retain Na\(^+\) (and water)
   • Regulation of aldosterone release =
     1. Direct effects on z. glomerulosa cells
     2. Renin-angiotensin pathway
### Renin-Angiotensin Pathway – 1

**1. Stimuli for aldosterone release are:**

- **a.** Low blood Na\(^+\) (direct effect on z.g. cells)
- **b.** High blood K\(^+\) (direct effect on z.g. cells)
- **c.** Low blood volume (Renin-angiotensin pathway)
- **d.** Low blood pressure (Renin-angiotensin pathway)

**2. Renin (enzyme) released by JG cells in kidney**

**3. Renin acts on angiotensinogen in blood (from liver)**

   > Converts \( \text{angiotensinogen} \rightarrow \text{angiotensin I} \)

**Knowing the stimuli makes pathway easier to understand**

### Renin-Angiotensin Pathway – 2

**4. Angiotensin I → \text{angiotensin II}**

**5. Angiotensin II effects**

- **a.** Aldosterone release (and ADH release)
  - Retain Na\(^+\) reabsorption in kidney
  - *Water follows*
  - Blood volume and pressure restored
- **b.** Vasoconstriction
  - Increase blood pressure
- **c.** Thirst

**What was the original stimulus? How does each of these remove the original stimulus?**
Endocrine Functions of the Kidneys

Zona Fasciculata – 1
Secretes glucocorticoids in response to ACTH
- Controls glucose metabolism
- Responses to stress
Major glucocorticoids:
1. Cortisol (hydrocortisone) most abundant
2. Corticosterone
3. Cortisone
Zona Fasciculata – Glucocorticoids

Glucocorticoid effects:

Coping with stress:

- Spare glucose for use by the brain
- Use other fuels for energy

1. Release amino acids from skeletal muscle
   - Used by liver for:
     - Plasma protein synthesis
     - Gluconeogenesis
   - Use amino acids for ATP production

2. Release fatty acids from adipose tissue, use for ATP synthesis

3. Increase glucose and glycogen synthesis (liver)

4. Anti-inflammatory effects
   - Decrease mast cell activity
   - Increase sensitivity to vasoconstrictors
   - Stabilize lysosome membranes
   - Decrease capillary permeability
   - Decrease phagocyte activity
Adrenals – Zona Reticularis

Secretes gonadocorticoids
- Release stimulated by ACTH

Androgens released in both males and females
- Concentrations normally too low to be significant

In females, maybe:
- ↑ Muscle mass, RBC formation, sex drive
- Converted in tissues to estrogens
  (Important after menopause?)

Adrenal Hormones

Source, hormone, target, effect(s) on target, control of secretion

<table>
<thead>
<tr>
<th>The Adrenal Hormones</th>
<th>Region/Zone</th>
<th>Hormones</th>
<th>Primary Target</th>
<th>Hormonal Effects</th>
<th>Regulatory Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADRENAL CORTEX</td>
<td>Glomerulosa</td>
<td>Mineralocorticoids, primarily aldosterone</td>
<td>Kidneys</td>
<td>Increase renal reabsorption of Na⁺ and water (especially in the presence of ACTH), and accelerate urinary loss of K⁺</td>
<td>Stimulated by angiotensin II, elevated blood K⁺ or fall in blood Na⁺; inhibited by ANP and BNP</td>
</tr>
<tr>
<td>Zona fasciculata</td>
<td>Glucocorticoids (cortisol, hydrocortisone, cortisone)</td>
<td>Most cells</td>
<td>Increase rates of glucose and glycogen formation by the liver; release of amino acids from skeletal muscles, and lipids from adipose tissues; promote peripheral utilization of lipids; anti-inflammatory effects</td>
<td>Stimulated by ACTH from the anterior lobe of the pituitary gland</td>
<td></td>
</tr>
<tr>
<td>Zona reticularis</td>
<td>Androgens</td>
<td>Most cells</td>
<td>Adrenal androgens stimulate the development of pubic hair in boys and girls before puberty.</td>
<td>Androgen secretion is stimulated by ACTH.</td>
<td></td>
</tr>
<tr>
<td>ADRENAL MEDULLA</td>
<td>Epinephrine (E), norepinephrine (NE)</td>
<td>Most cells</td>
<td>Increases cardiac activity, blood pressure, glycogen breakdown, blood glucose levels; releases lipids by adipose tissue</td>
<td>Stimulated by sympathetic preganglionic fibers</td>
<td></td>
</tr>
</tbody>
</table>
Adrenal Medulla, Pineal Gland

Adrenal Medulla: See Chapter 16
Pineal Gland: Skip this section (18-7)

SECTION 18-8
The pancreas, located within the abdominopelvic cavity, is both an exocrine organ and endocrine organ
Recall that the pancreas is a heterocrine gland.

A heterocrine gland

Exocrine portion = acini cells
   Secrete digestive enzymes and bicarbonate

Endocrine portion = islets of Langerhans
   1. Alpha cells: glucagon
   2. Beta cells: insulin
   3. Delta cells: somatostatin (GH-IH)
   4. F cells: pancreatic polypeptide
Insulin

Stimulus for secretion = ↑ blood [glucose]

Effects cause ↓ blood [glucose]: (why useful?)

1. Increase glucose uptake by cells
   - Increased number of glucose transporters
2. Increased use of glucose for energy
   - More glucose available within cells
   - Second messengers activate enzymes in metabolic pathways
3. Increased glycogen formation (skeletal muscle and liver)
4. Increased amino acid uptake for protein synthesis
5. Increased triglyceride formation (adipose)

Insulin Decreases Blood [Glucose]

Figure 18-17, top
Glucagon

Stimulus = decreased blood [glucose]
Effects act to increase blood [glucose]

1. Glycogen → glucose (skeletal muscle, liver)
2. Triglycerides → fatty acids (adipose)
3. Gluconeogenesis (liver)
   - Make “new” glucose from amino acids

Insulin is the more physiologically-important hormone

Glucagon Increases Blood [Glucose]

Figure 18-17, bottom
Pancreatic Hormone Summary

| Source, hormone, target, effect(s) on target, control of secretion |
| --- | --- | --- | --- |
| **Table 18-5** | **Hormones Produced by the Pancreatic Islets** | **Hormonal Effect** | **Regulatory Control** |
| Structure/Cells | Hormone | Primary Targets | | |
| **PANCREATIC ISLETS** | | | | |
| Alpha cells | Glucagon | Liver, adipose tissue | Mobilizes blood reserve; promotes glucose synthesis and glycogen breakdown in liver, stimulates blood glucose concentrations | Stimulated by low blood glucose concentrations; inhibited by GH-IH from delta cells |
| Beta cells | Insulin | Most cells | Facilitates uptake of glucose by target cells; stimulates formation and storage of lipids and glycogen | Stimulated by high blood glucose concentrations, parasympathetic stimulation, and high levels of some amino acids; inhibited by GH-IH from delta cells and by sympathetic activation |
| Delta cells | GH-IH (somatostatin) | Other islet cells, digestive epithelium | Inhibits insulin and glucagon secretion; slows rates of nutrient absorption and enzyme secretion along digestive tract | Stimulated by protein-rich meal; mechanism unclear |
| F cells | Pancreatic polypeptide (PP) | Digestive organs | Inhibits gallbladder contraction; regulates production of pancreatic enzymes; influences rate of nutrient absorption by digestive tract | Stimulated by protein-rich meal and by parasympathetic stimulation |

* Cover next term in Digestion chapter

SECTION 18-9
Many organs have secondary endocrine functions

Hormones secreted by other organs will be covered in the appropriate chapters.

- Intestines
- Kidneys
- Thymus
- Gonads
- Adipose tissue
SECTION 18-10
Hormones interact to produce coordinated physiological responses

Terms Relating to Hormone Interactions

<table>
<thead>
<tr>
<th>Antagonistic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hormones have opposing effects on target organs</td>
</tr>
<tr>
<td>• E.g. PTH (↑ blood [Ca²⁺]), calcitonin (↓ blood [Ca²⁺])</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Synergistic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Effects add together → effects of both together are greater than the sum of the effects of either alone</td>
</tr>
<tr>
<td>• Both glucocorticoids and GH spare glucose for use by the brain. Effects are additive.</td>
</tr>
</tbody>
</table>
### Terms Relating to Hormone Interactions – 2

<table>
<thead>
<tr>
<th>Permissive effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• One hormone’s is required for <em>(permits)</em> the effects of a second hormone</td>
</tr>
<tr>
<td>• Epinephrine can only ↑ metabolic rate efficiently if thyroid hormone is also present</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrative effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Complementary effects of two or more hormones</td>
</tr>
<tr>
<td>• PTH and calcitonin regulate blood [Ca(^2+)]</td>
</tr>
<tr>
<td>• Insulin and glucagon regulate blood glucose</td>
</tr>
</tbody>
</table>