

## v. Excretory and Endocrine Systems

### v. Excretory and Endocrine Systems - Excretory products and their elimination from the body, acid-base regulation, Endocrine glands and Hormonal functions

## Excretory System: Excretory Products, Elimination, and Acid-Base Regulation

### Overview of Excretory Products

#### 1. Nitrogenous Wastes

- **Urea**: Primary waste product of protein metabolism in most mammals. Synthesized in the liver via the urea cycle; relatively less toxic, water-soluble.
- **Uric Acid**: Produced from purine catabolism. In humans, moderately soluble; higher levels can precipitate (gout).
- **Ammonia**: Highly toxic, excreted directly by many aquatic organisms; in humans, converted primarily to urea.

#### 2. Other Metabolic Byproducts

- **Creatinine**: Byproduct of muscle creatine phosphate breakdown, a measure of kidney filtration efficiency.
- **Bilirubin**: Heme breakdown product, processed by the liver and excreted into bile.

### Anatomy of the Human Excretory System

#### 1. Kidneys

- **Location**: Retroperitoneal organs in the abdomen, each containing ~1-1.5 million nephrons (functional units).
- **Gross Structure**: Cortex (outer region), medulla (inner region with renal pyramids), pelvis (collecting area leading to ureter).

#### 2. Nephron

- **Glomerulus**: A tuft of capillaries in Bowman's capsule. **Filtration** driven by hydrostatic pressure.
- **Tubules**: Proximal convoluted tubule (PCT), loop of Henle (descending and ascending limbs), distal convoluted tubule (DCT), and collecting duct.
- **Selective Processes**:
  - **Filtration**: Blood → Renal tubule (filtrate).
  - **Reabsorption**: Valuable solutes (glucose, amino acids, ions, water) returned to the bloodstream.
  - **Secretion**: Additional waste/toxins actively transported from peritubular capillaries into the tubule.
  - **Excretion**: Remaining fluid (urine) flows to renal pelvis → ureter → bladder → urethra.

#### 3. Associated Structures

- **Ureters**: Convey urine from kidneys to the urinary bladder.
- **Urinary Bladder**: Temporarily stores urine; lined with transitional epithelium.
- **Urethra**: Conducts urine out of the body (longer in males, shorter in females).

### Regulation of Kidney Function

#### 1. Glomerular Filtration Rate (GFR)

- Influenced by **renal blood flow, hydrostatic/osmotic pressures**, and structural integrity of glomerular capillaries.
- **Autoregulation** (myogenic and tubuloglomerular feedback in the juxtaglomerular apparatus) stabilizes GFR over a wide range of blood pressures.

#### 2. Hormonal Control

- **Renin-Angiotensin-Aldosterone System (RAAS)**:
  - Decreased blood volume/pressure → Renin release (juxtaglomerular cells) → Angiotensin II formation → Aldosterone release (adrenal cortex).
  - Effects: Increased  $\text{Na}^+$  and water reabsorption, vasoconstriction → raises blood pressure.
- **Antidiuretic Hormone (ADH, vasopressin)**: Released from posterior pituitary when plasma osmolality is

high or blood volume is low. Promotes water reabsorption in the collecting ducts by increasing aquaporin channels → concentrated urine.

- **Atrial Natriuretic Peptide (ANP):** Released by atria in response to stretch (high blood volume), reduces  $\text{Na}^+$  reabsorption, lowers blood pressure and volume.

### 3. Neural Regulation

- **Sympathetic Nervous System:** Can constrict afferent arteriole (reducing GFR) under stress or shock, redirecting blood flow to vital organs.

## Acid-Base Regulation

### 1. Importance of pH Homeostasis

- Normal arterial blood pH  $\sim 7.35\text{--}7.45$ . Deviations disrupt enzyme function, protein structure, and cellular metabolism.

### 2. Buffer Systems

- **Bicarbonate Buffer:**  $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$ .
- Phosphate and protein buffers also contribute but bicarbonate is primary in blood plasma.

### 3. Respiratory Mechanisms

- Adjusting ventilation changes blood  $\text{CO}_2$  (respiratory acid).
- Hyperventilation → Decreases  $\text{CO}_2$  (alkalosis), Hypoventilation → Increases  $\text{CO}_2$  (acidosis).

### 4. Renal Mechanisms

- **Bicarbonate Reabsorption and  $\text{H}^+$  Excretion:** Proximal tubule cells reabsorb most filtered  $\text{HCO}_3^-$ , secrete  $\text{H}^+$ .
- **Distal Nephron and Collecting Duct:** Fine-tuning of acid-base via intercalated cells secreting  $\text{H}^+$  or  $\text{HCO}_3^-$ .
- Formation of **titratable acids** (e.g., phosphate) and **ammonium** ( $\text{NH}_4^+$ ) aids in  $\text{H}^+$  excretion.

### 5. Disorders

- **Metabolic Acidosis:** Excess acid or loss of bicarbonate (e.g., diabetic ketoacidosis).
- **Metabolic Alkalosis:** Excess base or loss of acid (e.g., vomiting).
- Compensatory responses involve both respiration and kidney adjustments.

## Endocrine System: Endocrine Glands and Hormonal Functions

### General Principles of Endocrine Signaling

#### 1. Hormones

- Chemical messengers secreted by endocrine glands into the bloodstream, acting on distant target cells via specific receptors.
- Categories: **Peptide/Protein Hormones, Steroid Hormones, Amino Acid Derivatives** (e.g., catecholamines, thyroid hormones).

#### 2. Feedback Regulation

- **Negative Feedback:** Most common; elevated hormone levels or end-product signals inhibit further hormone release (e.g., hypothalamic-pituitary axes).
- **Positive Feedback:** Rare; hormone action amplifies production (e.g., oxytocin during childbirth).

#### 3. Receptor Mechanisms

- **Cell Surface Receptors:** Peptide/protein hormones and catecholamines (e.g., GPCRs, tyrosine kinase receptors). Trigger second messenger cascades (cAMP,  $\text{IP}_3$ /DAG).
- **Intracellular Receptors:** Steroid, thyroid hormones diffuse into cells, bind cytoplasmic or nuclear receptors, directly modulate gene transcription.

### Major Endocrine Glands and Hormones

#### 1. Hypothalamus and Pituitary Gland

- **Hypothalamus:** Secretes releasing/inhibiting hormones (TRH, CRH, GnRH, GHRH, somatostatin, etc.) that act on the anterior pituitary. Produces oxytocin and ADH (stored in posterior pituitary).
- **Anterior Pituitary:**
  - TSH (Thyroid-Stimulating Hormone) → Thyroid gland.

- ACTH (Adrenocorticotropic Hormone) → Adrenal cortex.
- LH, FSH (Luteinizing Hormone, Follicle-Stimulating Hormone) → Gonads.
- GH (Growth Hormone) → Growth, metabolism.
- PRL (Prolactin) → Lactation.
- **Posterior Pituitary:** Stores and releases ADH (water reabsorption in kidneys) and Oxytocin (uterine contractions, milk ejection).

## 2. Thyroid Gland

- Produces **Thyroxine (T<sub>4</sub>)** and **Triiodothyronine (T<sub>3</sub>)** under TSH control. Influence basal metabolic rate, growth, and development.
- **Calcitonin:** Lowers blood calcium levels by inhibiting osteoclasts, increasing calcium deposition in bones.

## 3. Parathyroid Glands

- **PTH (Parathyroid Hormone):** Raises blood calcium by stimulating osteoclast activity, enhancing renal reabsorption of calcium, and activating vitamin D (increasing intestinal calcium absorption).

## 4. Adrenal Glands

- **Adrenal Cortex:**
  - **Glucocorticoids (Cortisol):** Stress response, gluconeogenesis, anti-inflammatory effects.
  - **Mineralocorticoids (Aldosterone):** Na<sup>+</sup> retention, K<sup>+</sup> excretion, blood pressure regulation.
  - **Androgens:** Minor source of sex steroids.
- **Adrenal Medulla:** Secretes **Epinephrine** and **Norepinephrine** (catecholamines), augmenting sympathetic "fight or flight" responses.

## 5. Pancreas (Endocrine Portion)

- **Islets of Langerhans:**
  - **β-cells** produce **Insulin** → lowers blood glucose by facilitating cellular uptake, glycogenesis, lipogenesis.
  - **α-cells** produce **Glucagon** → raises blood glucose (glycogenolysis, gluconeogenesis).
  - **δ-cells** produce **Somatostatin** → inhibits insulin and glucagon release, modulates digestion.

## 6. Gonads (Testes and Ovaries)

- **Testes:** Produce **Testosterone** under LH stimulation; essential for spermatogenesis, male secondary sexual characteristics.
- **Ovaries:** Produce **Estrogen** and **Progesterone**; regulate menstrual cycle, female secondary sexual characteristics, pregnancy maintenance.

## 7. Pineal Gland

- Secretes **Melatonin**, regulating circadian rhythms and sleep-wake cycles. Influenced by light exposure.

## Hormonal Functions and Integration

1. **Metabolic Regulation**
  - **Insulin** and **Glucagon** coordinate glucose homeostasis.
  - **Cortisol** modulates metabolism under stress, affecting protein and lipid catabolism.
2. **Calcium-Phosphate Homeostasis**
  - **PTH, Calcitonin, Vitamin D** interplay to maintain serum calcium levels, impacting bone density and neuromuscular excitability.
3. **Reproductive Function**
  - **FSH, LH, Estrogen, Testosterone, Progesterone** orchestrate gametogenesis, sexual development, and reproductive cycles.
4. **Growth and Development**
  - **GH, Thyroid Hormones, Insulin, IGFs (Insulin-like Growth Factors)** coordinate tissue growth, cellular differentiation.
5. **Stress Response**
  - Acute (adrenal medulla catecholamines) vs. chronic (cortisol) stress adaptations, impacting cardiovascular and metabolic states.

## Concluding Remarks

The **excretory system**, centered on the **kidneys**, fulfills critical roles in **removing metabolic wastes** and **regulating acid-base balance**, fluid volume, and electrolyte composition. Intricate **hormonal** signals (e.g., RAAS, ADH, ANP)

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integrate with **neural** inputs to modulate renal function in response to physiological demands.

Meanwhile, the **endocrine system**—via **ductless glands** releasing hormones into the bloodstream—maintains **systemic homeostasis**, orchestrating metabolism, growth, reproduction, and stress responses. Negative feedback loops, receptor specificity, and tightly regulated release mechanisms ensure a delicate balance across these networks. Dysregulation can lead to pathologies, ranging from **kidney failure** and **acid-base imbalances** to **diabetes mellitus, thyroid disorders, and adrenal insufficiencies**.

Understanding these **hormonal and renal regulatory axes** underpins therapeutic strategies for a myriad of conditions, highlighting the interconnectedness of excretory and endocrine systems in sustaining optimal human health.