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 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 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 ~7.35–7.45. Deviations disrupt enzyme function, protein structure, and cellular metabolism.
2. **Buffer Systems**
    - **Bicarbonate Buffer**: $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$.
    - Phosphate and protein buffers also contribute but bicarbonate is primary in blood plasma.
3. **Respiratory Mechanisms**
    - Adjusting ventilation changes blood CO_2 (respiratory acid).
    - Hyperventilation → Decreases CO_2 (alkalosis), Hypoventilation → Increases CO_2 (acidosis).
4. **Renal Mechanisms**
    - **Bicarbonate Reabsorption and H^+ Excretion**: Proximal tubule cells reabsorb most filtered HCO_3^-, secrete H^+.
    - **Distal Nephron and Collecting Duct**: Fine-tuning of acid-base via intercalated cells secreting H^+ or HCO_3^-.
    - Formation of **titratable acids** (e.g., phosphate) and **ammonium** (NH_4^+) aids in 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, 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_4)** and **Triiodothyronine (T_3)** 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^+ retention, K^+ 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)

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.