Chapter 21 The Endocrine System: Regulation of Energy Metabolism and Growth

- **Chapter Outline**
  - An Overview of Whole-Body Metabolism
  - Energy Intake, Utilization, and Storage
  - Energy Balance
  - Energy Metabolism During the Absorptive And Postabsorptive States
  - Regulation of Absorptive and Postabsorptive Metabolism
  - Thermoregulation
  - Hormonal Regulation of Growth
  - Thyroid Hormones
  - Glucocorticoids

21.1 Overview of Whole-Body Metabolism

- Catabolism = Breakdown large molecules to small molecules
- Anabolism = Small molecules used in generating energy and in synthesis of large molecules

21.2 Energy Intake, Utilization, and Storage

- Following intake, nutrients can be
  - Catabolized for energy
  - Used as substrates for new molecules synthesized in cells
  - Stored for energy (glycogen and fat)
- **Preferred Energy Substrates**
  - Brain: ______________
  - Resting skeleton muscle and liver: ______________
  - Heart: ______________

21.3 Energy Balance

- **Energy Balance**
  - Energy input = energy output
  - Energy input = energy content of consumed nutrients
  - Energy output = Heat (60%) + Work (40%)
- **Positive balance**
  - Energy intake > energy output
  - Store excess energy
- **Negative balance**
  - Energy intake < energy output
  - Consume stored energy
- **Energy balance is regulated by endocrine system**
- **Metabolic Rate** is the energy expended per unit time
  - Increases with increases in activity
  -Varies among genders, age, body surface, stress and environmental temperature
- **Basal Metabolic Rate**
Basal metabolic rate (BMR) = rate of energy expenditure of a person awake, resting, lying down, and fasted for 12 hours
- Represents minimum energy expenditure necessary to maintain body functions
- Depends on age, sex, body surface area, activity level, stress and thyroid hormone levels
- Hyperthyroids have high BMR
- Hypothyroids have low BMR

21.4 Energy Metabolism during the Absorptive and Postabsorptive States
- **Absorptive State**: 3–4 hours following meal
  - Nutrients in bloodstream plentiful from absorption
- **Postabsorptive State**: Between meals
  - Break down and mobilize stored energy
- **Energy Metabolism during Absorptive State**
  - Positive energy balance
  - Glucose = primary energy source for cell
  - Primarily anabolic
  - Excess nutrients taken up will be stored
  - Absorptive State Reactions (Figure 21.3)
- **Energy Metabolism during Postabsorptive State**
  - Negative energy balance
  - Glucose spared for nervous system
  - Other tissues use fatty acids or other sources for energy
  - Primarily catabolic state: stored nutrients broken down and mobilized
  - Postabsorptive State Reactions (Figure 21.4)

21.5 Regulation of Absorptive and Postabsorptive Metabolism
- **Hormonal regulation**
- **_________** = hormone of absorptive state
- Glucagon = hormone of postabsorptive state
- Other less important regulators
  - Epinephrine
  - Sympathetic nervous system
  - Glucocorticoids (under stress)
- **Insulin**
  - Signals related to feeding and absorption of nutrients stimulate its secretion
  - Promote absorptive state
  - Anabolic hormone
    - Promotes synthesis of energy storage molecules such as glycogen and triglycerides
    - Promotes glucose use for energy
    - Increase glucose uptake by cells
    - Decreases catabolism
- **Actions of Insulin (Figure 21.5)**
  - **Glucagon**
    - Catabolic hormone
    - Promotes breakdown of energy storage molecules (glycogenolysis and lipolysis)
    - Promotes glucose sparing for nervous system by diverting body cells to utilizing other sources of energy
    - Gluconeogenesis (-neo = new)
    - Promote postabsorptive state
  - **Actions of Glucagon (Figure 21.7)**
  - **Negative Feedback Regulation of Blood Glucose Levels**
    - Blood glucose levels are maintained primarily by actions of insulin and glucagon
    - Normal blood glucose = 70–100 mg/dL
    - Hyperglycemia = glucose > 140 mg/dL
    - Hypoglycemia = glucose < 60 mg/dL
  - **Glucose Regulation via Insulin (Figure 21.8 a)**
  - **Actions of Glucose on Insulin Secretion (Figure 21.6)**
  - **Glucose Regulation via Glucagon (Figure 21.8 b)**
  - **Diabetes Mellitus**
    - Characterized by chronic high blood glucose levels (hyperglycemia)
    - Type I (insulin dependent diabetes mellitus or IDDM) is due to insufficient insulin secretion
    - Type II (insulin independent diabetes mellitus or NIDDM) is due to lack of effect of insulin
  - **Effects of Epinephrine and Sympathetic Nervous Activity**
    - Indirectly promote postabsorptive state
    - Directly affect body metabolism such as fight-or-flight responses.

### 21.6 Thermoregulation
- Temperature balance
- Mechanisms of heat transfer
- Regulation of body temperature
- Fever
- **Temperature Balance**
  - Core body temperature
  - Humans: 37° C (98.6° F)
  - Hypothermia = decrease in body temperature (below 95 F or 35 C).
  - Hyperthermia = increase in body temperature
    - Above 41° C is dangerous
    - Above 43° C is deadly
- **Heat Transfer Mechanisms**
  - Radiation—thermal energy through electromagnetic waves
  - Conduction—thermal energy through contact
o Evaporation: Insensible water loss and sweating
o Convection—heat transfer by movement of fluid or air

**Regulation of Body Temperature**

o Receptors = thermoreceptors
  - Central: found in CNS (hypothalamus)
  - Peripheral: found in PNS (mainly skin)

o Effectors: Sweat glands, muscles skeletal muscles smooth muscle of cutaneous blood vessels

o Integrating center
  - Thermoregulatory center in hypothalamus

o Signals
  - Nerve impulses via neurons
  - Chemicals mainly via hormones

**Events of Thermoregulation (Figure 21.10)**

**Heat Generation: Cold Environment**

o Below thermoneutral zone (<25°)
  - Vasoconstriction alone cannot maintain proper core body temperature

o Heat-generating mechanisms
  - Shivering thermogenesis
  - Nonshivering thermogenesis

**Fever**

o Rise in core body temperature
o Accompanies infection
o White blood cells secrete pyrogens
o Body temperature set point increases
o Fever enhances immune responses

**21.7 Hormonal Regulation of Growth**

**Body growth usually refers to the increase of height.**

**Processes of Growth**

o Increase number of cells (hyperplasia)
o Increase size of some cells (hypertrophy)

o Increase bone length and thickness

**Human Growth Curve (Figure 21.12)**

**Body Growth**

o During childhood is regulated by hormones such as
  - growth hormone
  - Somatomedins (insulin-like growth factors)

o Genetic make up
o Disease and stress

**Actions of Growth Hormone**

o Promote growth
o Hypertrophy and hyperplasia
o Lean muscle mass
- Metabolic actions supporting growth
  - Inhibit glucose uptake into adipose tissue and skeletal muscle
  - Stimulate lipolysis and gluconeogenesis
  - Increase uptake of amino acids into cells
  - GH has some direct effects, but most through insulin-like growth factors (IGFs)

- **Somatomedins (Insulin-like Growth Factors: IGFs)**
  - IGFs are peptide molecules
  - GH stimulates IGF release from liver and other cells
  - IGFs have direct effect on target cells as hormone and paracrine

- **Factors Affecting Growth Hormone Secretion**
  - GHRH and GHIH (somatostatin)
  - Factors increasing GHRH release
    - Decreases in glucose or in fatty acids
    - Increases in amino acids
    - Sleep (not well understood)
    - Exercise or stress (response to ↓ glucose and fatty acids)
    - Circadian rhythm (↑ during the night ↓ during the day)

- **Actions of Growth Hormone (Figure 21/13)**

- **Bone Review**
  - Bone = calcium phosphate crystals (hydroxyapatite) osteoid
  - Bone
    - Is an important reservoir for calcium.
    - Decrease in plasma calcium level stimulates the release of calcium from bone
    - Elongates in childhood
    - Can heal and adapt to the life style of a person by increasing or decreasing the strength

- **Cells in Bone (Figure 21.14)**
  - Osteoblasts = bone ____________
  - Osteoclasts = bone breakers (resorption)
  - Osteocytes = bone maintainer
  - Gap junction allows communication between cells and exchange materials

- **Formation of Bone**
  - Osteoblasts lay down osteoid (organic matter)
  - Calcification (depositing of calcium phosphate)
  - Osteoblast becomes immobilized then becomes osteocyte
  - Osteocyte maintains surrounding osteoid

- **Resorption of Bone**
  - Osteoclasts secrete acid and enzymes
    - Acid dissolves calcium phosphate crystals
    - Enzymes degrade osteoid
- Calcium and phosphate released into blood

**Bone Growth**
- **Increase in width**
  - Osteoblasts lay down new bone on outer surface
  - Companied by resorption of bone in inner surface of cavity by osteoclasts.
  - Minimizes weight gain
- **Increase in length**
  - Osteoblasts lay down new bone at epiphyseal plates

**Structure of a Long Bone**
- **Epiphyseal Plate**
  - Site of growth in length of bone
  - Epiphyseal plate closure
  - Happens at puberty
  - Affected by sex hormones
  - No further increase in length possible

**Long Bone Growth**
- Chondrocytes produce new cartilage in epiphyseal plate
- Epiphyseal plate widens causing bone to lengthen
- Chondrocytes die
- Osteoblasts replace chondrocytes and lay down bone
- **Elongation of a Long Bone (Figure 21.16)**

**Effects of Abnormal Growth Hormone Secretion**
- Dwarfism = Decreased GH secretion in children
- Gigantism = Increased GH secretion in children
- Acromegaly= Increased GH secretion in adults

**Other Hormones That Affect Growth**
- ________hormones is required for synthesis of GH and permissive for GH actions
- ________is required for secretion of IGF-1 and is permissive for GH actions
- Sex Hormones
  - Little role in childhood growth
  - Important for pubertal growth spurt
  - Actively promote growth during puberty
- Glucocorticoids: Inhibit growth

**21.8 Thyroid Hormones**
- Synthesis and secretion of thyroid hormones

**Thyroglobulin in Thyroid Hormone Synthesis**
- Thyroglobulin = protein
- Precursor for thyroid hormones
- Contains tyrosine residues
- Located in colloid

**Iodide in Thyroid Hormone Synthesis**
• Iodide = I− = ionized form of iodine
• Actively transported from blood into colloid
• Added to thyroglobulin to form thyroid hormones

• Synthesis and Secretion of Thyroid Hormones (Figure 21.17)

• Thyroid Hormones
  • ____ (also called thyroxine): Most abundant form produced and less active.
    ▪ Provides long loop negative feedback
  • T3: Not as much made; more active at target tissue
  • Activation at target tissue: T4 converted to T3

• Secretion of Thyroid Hormones (Figure 21.18)

• Actions of Thyroid Hormones
  • Raise BMR and MR
  • Generate heat = calorigenic effect
  • Permissive to growth hormone therefore promote the normal growth and development of body function and the synthesis of beta adrenergic receptors
  • Mobilize energy

• Diseases of the Thyroid
  • Over secrete thyroid hormones = hyperthyroidism
  • Characterized weight loss, heat intolerance, irritability, high BMR
  • People with inadequate T4 & T3 levels are hypothyroidism
  • Have low BMR, weight gain, lethargy, cold intolerance
  • Myxedema = puffy face, hands, feet
  • During fetal development hypothyroidism can cause cretenism (severe mental retardation)

21.9 Glucocorticoids and Actions

• Glucocorticoids
  • Are steroids secreted by the adrenal cortex
  • Mobilize energy during post-absorptive stage
  • Are also required for growth hormone secretion in synergy with thyroid hormone
  • Reduce inflammation at high concentration
  • Are important in body’s response to stress

• Role of Cortisol in Stress Response
  • Cortisol = hormone of stress
  • Mobilizes energy stores
  • Suppresses immune response

• Secretion of Cortisol (Figure 21.19)

• General Adaptation Syndrome
  • Stereotypical response to stress: Increase the followings: cortisol secretion; sympathetic activity epinephrine secretion ADH release; angiotensin II production
  • Response—fight or flight: Mobilize energy stores and maintain blood pressure

• Effects of Abnormal Glucocorticoid Secretion
- Cushing’s syndrome: hypersecretion of cortisol; hyperglycemia and protein depletion → wasting away of tissue
- Addison’s disease: hyposecretion of cortisol; hypoglycemia; poor tolerance for stress
- Cause usually affects aldosterone as well: excess sodium retention and potassium secretion causes arrhythmias