Chapter 25: NUTRITION, METABOLISM, and TEMPERATURE REGULATION

I. THE NUTRIENTS

A. Carbohydrates: Starches and sugars
   1. Monosaccharides: Glucose, fructose, galactose, and others
   2. Disaccharides
      a. Sucrose (glucose + fructose)  b. Maltose (glucose + glucose)
      c. Lactose (glucose + galactose)
   3. Polysaccharides (Complex carbohydrates)
      a. Starch (many glucose molecules)
      b. Glycogen (“animal starch”)
      c. Cellulose (indigestible plant material)
   4. Functions

B. Lipids: Def:
   1. Neutral fats (triglycerides)
      a. Components: Fatty acids and glycerol
      b. Functions:
   2. Cholesterol: Complex lipid-soluble, stable molecule
      Functions:
3. **Phospholipids:** Two fatty acids bound with phosphorus

   Functions:

4. **Essential fatty acids:** Polyunsaturated lipid chains obtainable through the diet

   a. Linoleic acid (omega 6)

   Sources:

   b. Alpha-Linolenic acid (omega 3)

   Sources:

   Related fish oils (EPA; DHA)

   c. Functions

C. **Proteins**

1. Def.: Long chains of amino acids in a specific order

2. Amino acids

   a. Essential: Must be obtained in the diet

   b. Nonessential: Can be synthesized by the body

3. Complete proteins: foods which contain all essential amino acids

4. Functions of body proteins
D. Vitamins (Table 25.2)

1. Def.: Large, complex organic molecules needed by body cells but not synthesized by cells

2. Sources:

3. Functions: Many serve as co-factors necessary to enzyme function

4. Fat-soluble vitamins

5. Water-soluble vitamins

   Antioxidant vitamins

E. Minerals (Table 25.3)

1. Def.: Inorganic elements needed by body cells

2. Major minerals (components of bone)
   a. Calcium
   b. Phosphorus
   c. Magnesium

3. Trace minerals
   a. Iron      b. Zinc
   c. Iodine    d. Copper
   e. Sodium    f. Sulfur
   g. Chlorine  h. Selenium, etc.

4. Functions: Co-factors of enzymes; water balance; resting and action potentials
II. METABOLISM

A. Def: The study of chemical reactions involved in:

1. Producing and storing energy
2. Synthesizing compounds
3. Regulating these

B. Anabolism

1. Def.: Reactions that build up large molecules from smaller ones
2. Functions: Synthesis of cellular structures; energy storage
3. Ex.: 

C. Catabolism:

1. Def: Reactions that break down large molecules into smaller ones
2. Functions: Recycling of worn-out materials; release of energy by cells
3. Ex.: 

D. Coupled reactions (Fig. 25.3)

1. Def: Using energy released from catabolic reactions to drive anabolic reactions
2. Ex: \[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]
   a. If "uncoupled," all energy \( \rightarrow \) ______________.
   b. If coupled to anabolic reaction:
      c. Glucose + \( \text{O}_2 \)
         
         ATP
         \[ \text{CO}_2 + \text{H}_2\text{O} \] ADP + P
E. Glucose catabolism in cells to generate ATP (Fig. 25.4)

Overall scheme: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$

**glucose** **respiration** **waste** **"metabolic water"**

1. **Glycolysis**
   a. **Def:** Enzymatic catabolism of glucose, in cytoplasm, without $\text{O}_2$, yielding 2 3-carbon pyruvic acids + 2 ATP + energy-rich H’s
   b. If no $\text{O}_2$ is available, the 2 pyruvic acids + H’s $\rightarrow$ 2 lactic acids
      Where?

2. **Acetyl-CoA formation (only if $\text{O}_2$ is available)**
   a. Each pyruvic acid (3 carbons) loses a $\text{CO}_2$ and energy-rich H’s, forming acetyl, which is carried by Coenzyme A (CoA)
      $2\text{ acetyl CoA} + \text{CO}_2 + 2\text{ H}$
   b. Two 2-carbon acetyl CoA enters citric acid cycle (Krebs cycle)
   c. Location: Mitochondria

3. **Citric acid cycle (Krebs cycle)**
   a. **Def:** Enzymatic breakdown of the products of glycolysis, using $\text{O}_2$ (aerobic), in which all carbon appears as $\text{CO}_2$, and energy-rich H’s are released. Two molecules of ATP are released per glucose.
   b. Intermediate compounds synthesized during the reactions are regenerated as catabolism is completed, hence a "cycle."
   c. Location: Mitochondria
4. Electron transport chain

   a. Energy-rich H's (with electrons) from glycolysis, acetyl-CoA formation, and citric acid cycle move down a "staircase" of enzymes, causing a series of reactions which release large amounts of energy

   b. Location: on inner membrane of mitochondria

   c. O₂ is final H acceptor, ---> H₂O₂ (hydrogen peroxide) ---> H₂O

\[
C₆H₁₂O₆ + 6O₂ ---> 6CO₂ + 6H₂O
\]

   d. Source of energy-rich H's (per glucose):

      i. Glycolysis
      ii. Acetyl CoA formation
      iii. Citric acid cycle (Krebs cycle)

   e. Electron transport chain generates 34 ATP/glucose

C. Final summary per glucose

1. Carbon:  2 lost per glucose as 2 CO₂’s during acetyl CoA formation
            + 4  lost as 4 CO₂’s in Krebs cycle
            6  total lost = 6 per glucose

2. Hydrogens:  4 from glycolysis
               4 from acetyl CoA formation
               16 from Krebs cycle: (4 from glucose metabolites; 12 from 6H₂O)
               24 total

3. ATP:  2 Glycolysis
         2 Krebs cycle
         + 34 Electron transport chain
         38 Total
III. EVENTS OF THE ABSORPTIVE STATE (Fig. 25.15)

A. Def.: Time after meals when absorbed food molecules provide fuel

1. Metabolic goals:
   a. 
   b. 
   c. 

2. Hormonal control:
   a. Source
   b. Stimulus

B. Glucose: The “blood sugar” and a preferred fuel

1. Fructose and galactose are converted to glucose by ____________

2. Glucose enters cells by facilitated diffusion. Requires ______________
   a. This carrier depends on _____________
   b. Exceptions:

3. Effect on blood glucose (B.G.) when glucose enters cells?

C. Glucose storage

1. Glycogenesis: Def.:
   a. 20% glycogen is stored in liver, 80% in skeletal muscle
   b. Function:
   c. Increased by ____________
D. Lipid uptake (p. 910-911 [915-916]) (Fig. 24.31 [24.30])

1. Very low density lipoproteins (VLDLs) and low density lipoproteins (LDLs) transport cholesterol from liver to adipose tissue or tissues

2. High density lipoproteins (HDLs) transport triglycerides and fats and cholesterol from tissues to liver for recycling or disposal

E. Lipogenesis

1. Excess glucose or amino acids are converted to saturated fatty acids
   a. Fatty acids + glycerol ---->

2. Increased by

F. Protein usage

1. Dietary proteins ---> amino acids ---> tissue proteins

2. Transamination: Transferring an amino group (-NH₂) from an amino acid to a ketoacid to synthesize nonessential amino acids

3. Energy use if excess in diet:
   a. Oxidative deamination (removal of - NH₂ from an amino acid) --->
      "ketoacids" (remains of amino acid once - NH₂ is removed)
   b. Ketoacids enter the citric acid cycle
   c. In liver: -NH₂ (amino group) is converted to _______________

   Why?

G. Maintaining the absorptive state
IV. POSTABSORPTIVE (FASTING) STATE (Fig. 25.16)

A. Def.: Time when previously stored nutrients are used as fuel

B. Metabolic goal: Maintain blood glucose 70-110 mg/100 ml blood.
   1. Why?
   2. Central role of the liver
      a. Glycogenolysis: Def:
         Releases glucose from liver into blood; ________ blood glucose
      b. Gluconeogenesis: glucose synthesis from amino acids, lactic acid, or glycerol; ________ blood glucose

3. Switch to fat catabolism: Lipolysis
   a. Gluconeogenesis: Liver transforms glycerol to glucose
   b. Beta Oxidation: The breakdown of fatty acids into many acetylts which can enter the citric acid cycle. One fatty acid yields about 10 acetylts.
      Where? Result?
   c. Ketogenesis: Liver transforms acetylts to ketone bodies
      Two acetylts form 1 ketone body. Ketone bodies are released by the liver into the blood, and are taken up by cells, which split them back into 2 acetylts and use them in the citric acid cycle.

4. Phases of starvation
   a. Switch to fat metabolism (glucose sparing)
   b. Brain gradually gains ability to use ketone bodies
   c. Catabolism of body proteins for energy
C. Hormonal control of postabsorptive state (Fig. 18.18, lower half)

1. Insulin levels ______, causing lipo______________.

2. Glucagon (alpha cells of pancreas)
   Function: Signals __________________________ by liver, ____ B.G.

3. Epinephrine and norepinephrine (adrenal medulla)
   Function: Signal__________________________ by liver, ____ B.G.
   and also stimulate lipo______________.

4. Cortisol (adrenal cortex)
   Function: Signals liver to undergo ____________________,
   causing lipolysis and protein ____________________, ____ B.G.

5. Growth hormone (anterior pituitary)
   Function: Opposes cortisol by inhibiting protein ____________

D. Regulation of blood glucose during exercise (Fig. 18.19)

1. Hormones are in absorptive or postabsorptive secretion patterns?

2. Blood glucose levels ________.

F. Hypoglycemia (Low blood glucose)

1. Symptoms relating to brain function:

2. Symptoms relating to compensation:

3. "Reactive" hypoglycemia

G. Read in Chapter 18: “Hormonal Regulation of Nutrients” (p. 632-636 [638]).
V. DIABETES MELLITUS (p. 630, 631 [636], Chapter 18)

A. Insulin-dependent diabetes (IDDM; Type I): Loss of insulin
   1. Insulin levels:
   2. Cause:
   3. Occurrence:

B. Non-insulin dependent diabetes (NIDDM; Type II): Receptor unresponsiveness to insulin: “Insulin resistance”
   1. Insulin levels:
   2. Causes:
   3. Occurrence:

C. Symptoms relating to decreased movement of glucose into cells
   1. Elevated blood glucose
   2. Glucosuria (glucose in the urine)
   3. Polyuria (excessive urination)
   4. Thirst

D. Symptoms relating to altered lipid metabolism
   1. Weight loss (IDDM)
   2. Weight gain (NIDDM)
   3. Acidosis ---> diabetic coma
   4. Ketone bodies ---> acetone breath
   5. Atherosclerosis, blindness, gangrene
VI. METABOLIC RATE

A. Def.: Body's total energy use/time

B. Basal metabolic rate (BMR):
   1. Body's total energy use during
      a. Awake
      b. Resting (no skeletal muscle effort)
      c. Postabsorptive (not digesting food)
      d. Thermoneutral (neither sweating nor shivering)

   2. Summary: Minimal (basal) energy use while awake
      a. Organismal energy use:
      
         b. Cellular energy use:

C. Measuring BMR
   1. Direct: Measure heat produced/unit of time
   2. Indirect: Measure O₂ used/time
   3. Units: kcal energy/meter² surface area/hour

D. Factors affecting BMR
   1. BMR ______ with body size
   2. BMR ______ with age
   3. BMR is greater in ________
   4. Thyroxine ______ BMR
   5. Fever ______ BMR
   6. Severe dieting ______ BMR
   7. Pregnancy ______ BMR
   8. Lactation ______ BMR
   9. Regular exercise ______ BMR
E. Factors affecting overall (non-basal) energy expenditure (Metabolic Rate)

1. Exercise ______ MR  2. Sympathetic stimulation ___ MR
5. “Thermic effect of food”: Digesting food ______ MR

Which food type produces highest thermic effect? ________________

F. Caloric value of foods

1. Lipids 9 kcal/g
2. Protein 4 kcal/g
3. Carbohydrates 4 kcal/g
4. Alcohol 7 kcal/g

G. Weight gain or loss

1. 3,500 kcal excess ---> 1 pound weight gain
2. 3,500 kcal deficit ---> 1 pound weight loss
VII. THERMOREGULATION

A. Homeotherms ("warmblooded") vs. Poikilotherms ("cold-blooded")

1. Source of heat:
2. Metabolic rate:
3. Insulation:

B. Heat exchange (Fig. 25.17)

1. Radiation: Infrared rays to cooler object

   Ex.:

2. Convection: Heat transfer object to moving air

   "Wind-chill index" (Air temp + _________________________)

3. Conduction: Heat transfer from warmer to cooler object

   Ex.:

4. Evaporation: Heat loss as water changes from liquid to gas

   a. Changing water to water vapor requires 580 cal/g of heat

   b. Heat is taken from wet surface, leaving surface _____________

   c. High relative humidity ________ evaporation rate

   d. Heat index (Air temp + ________________________________)

   e. Can evaporation decrease body temperature below environmental temperature?
C. Increasing heat loss

1. Behavioral - preferred
   a. Move to cool area  
   b. _______ insulation  
   c. _______ surface area  
   d. _______ activity  

2. Physiological
   a. Sweat --- but sweating ______ energy expenditure  
   b. Vaso________________________ skin  
   c. _______ BMR (long term) How?

D. Increasing heat gain

1. Behavioral
   a. Move to warmth  
   b. _______ insulation  
   c. _______ surface area  
   d. _______ activity  

2. Physiological
   a. Vaso________________________ skin  
   b. Shiver  
   c. Piloerection  
   d. _______ BMR (long term)  

E. Hypothalamic control of body temperature (Fig. 25.18)

1. Sensory inputs from skin and blood signal hypothalamus  
2. Hypothalamus stimulates response of sweat glands, blood vessels, etc.

F. Read “Clinical Focus,” p. 953 [957]: Heat exhaustion, heat stroke, and fever