

Metabolism
(Chapter 25)
Lecture Materials
for
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Primary Sources for figures and content:

Marieb, E. N. Human Anatomy & Physiology 6th ed. San Francisco: Pearson Benjamin Cummings, 2004.

Martini, F. H. Fundamentals of Anatomy & Physiology 6th ed. San Francisco: Pearson Benjamin Cummings, 2004.

Metabolism

Digestion + Absorption by GI →

monomers (building blocks) for ATP
or biomolecule synthesis

Metabolism = sum of all chemical
reactions in body

1. **Catabolism**: breakdown of organics
 - A. **Hydrolysis**: large molecules into monomers
 - B. **Cellular Respiration**: oxidation of monomers in mitochondria
40% of energy → ATP
60% of energy → heat

2. **Anabolism**: synthesis of new organics
 - cell maintenance and repair
 - growth
 - formation of secretions
 - nutrient reserves

*Catabolism supplies ATP and monomers to drive anabolism

Carbohydrate Metabolism

1. Carbohydrate Catabolism

Carbs easiest to catabolize for energy,
always used first

Cellular Respiration: oxidizes glucose +
oxygen → carbon dioxide + water and
generates ATP
(go to handout)

2. Carbohydrate Anabolism

All carbohydrates and lactic acid can be
converted to glucose

Gluconeogenesis = synthesis of glucose
from a non-carbohydrate precursor,
e.g. glycerol, amino acids

3. Functions of Glucose

- stored as glycogen
- used to generate ATP
- to create other carbohydrates (cell membranes receptors, nucleic acids)

Lipid Metabolism

1. Lipid Catabolism

- Triglycerides most common
- Lipolysis:

Triglyceride \rightarrow glycerol + 3 fatty acids

A. Glycerol: \rightarrow pyruvic acid \rightarrow Citric Acid Cycle, generates 18 ATP

B. Fatty Acids: undergo β -oxidation to become 2 carbon acetyl \rightarrow Citric Acid Cycle, each 2-C fragment generates 17 ATP

*Carbon for carbon, lipids have 1.5X the energy of carbohydrates but are more difficult to use

- lipolysis common to hepatocytes, cardiac muscle, skeletal muscle for ATP synthesis
- not possible in neurons
- not water soluble, difficult for enzymes to access
- lipolysis requires oxygen for ATP synthesis, no fermentation

2. Lipid Anabolism

A. Lipogenesis: triglycerides synthesized from cellular respiration intermediates:

- glycerol from glycolysis products
- fatty acids from Acetyl Co A

B. Cholesterol Synthesis: from any saturated fat molecule

C. Essential Fatty Acids: must be ingested in diet, no synthesis:

1. linolenic acid = Omega 3 fatty acid

2. linoleic acid = Omega 6 fatty acid

Both used to synthesize arachidonic acid, to synthesize eicosanoids (leukotrienes and prostaglandins), for cell signaling

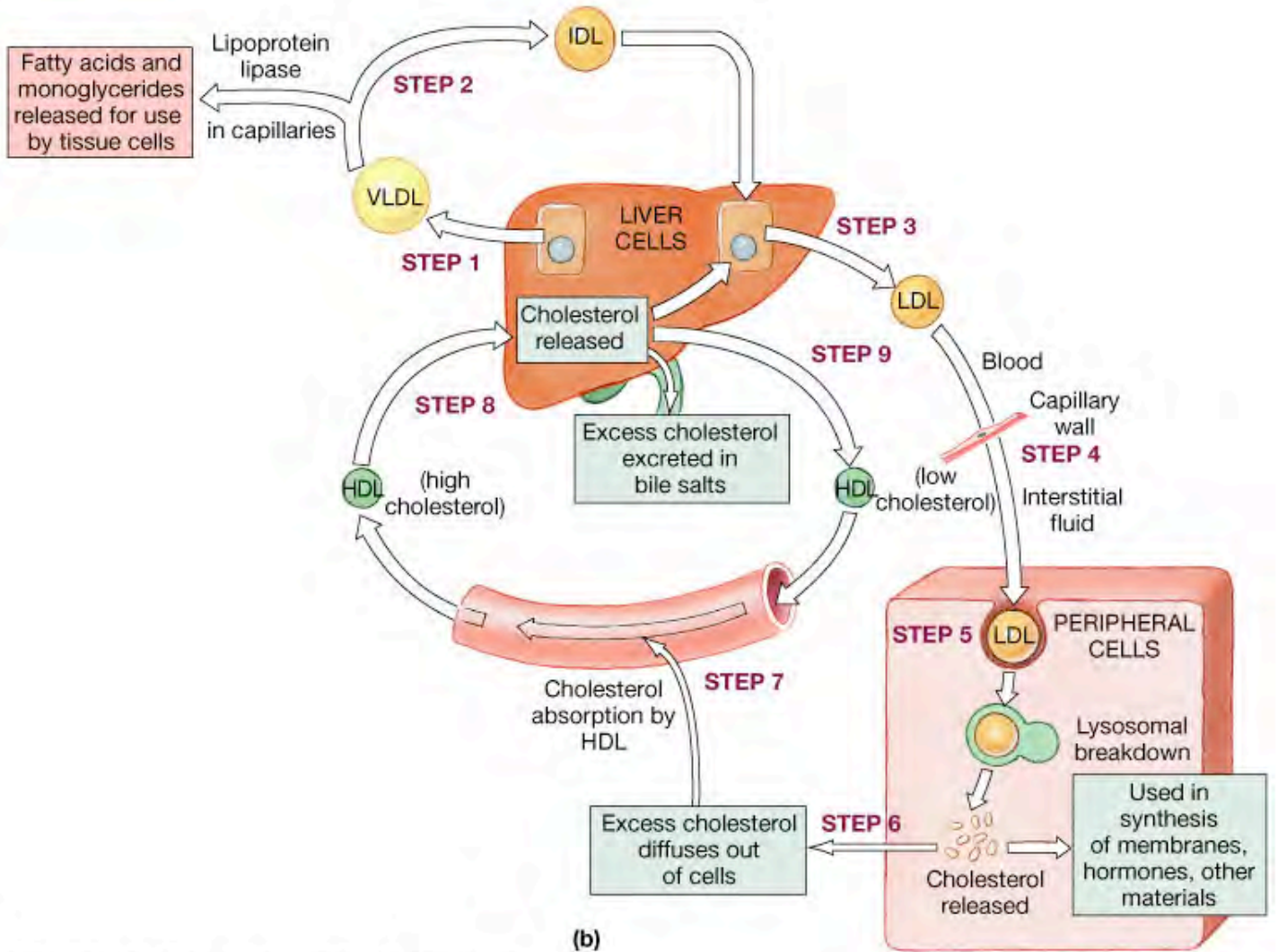
3. Functions of Lipids

- catabolism to generate ATP (triglycerides)
- cell membranes (phospholipids, glycolipids, cholesterol)
- myelin sheaths on axons
- bile salts
- steroid hormones
- cell signaling molecules
- energy reserve, 80% of total (triglycerides)
- insulation and protection

4. Lipid Transport

- free fatty acids bound to albumins in blood
- others bound to proteins to form lipoproteins: soluble, bind specific receptors
- Five classes of lipoproteins based on size and composition:
 - High protein content = high density
 - High lipid content = low density
 - (go to handout)

Lipoprotein distribution (handout)



(b)

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Cholesterol and Health

HDLs > 60mg/ml, with LDLs < 160mg/ml
>240mg/ml LDLs need immediate
medication or risk cardiovascular
disease and heart attack

Diet rich in saturated fats (animal) →
Triggers synthesis of cholesterol and
blocks excretion / conversion by liver

Diet rich in non-hydrogenated unsaturated
fats (plant) → enhance excretion and
conversion to bile salts

Protein Metabolism

- amino acids usually recycled to new proteins
- when carbs and lipids lacking or amino acids in excess, can be catabolized for ATP or stored as fat

1. Amino Acid Catabolism

- deamination: amino group removed, requires vitamin B6
- generates ammonia, toxic, converted by liver to urea, excreted in urine
- carbon chain → Citric Acid Cycle for ATP
- different amino acids produce different amounts of ATP, some not used at all
- catabolism difficult, inefficient and toxic, last resort for energy, “protein starvation”

2. Amino Acid Anabolism

A. Essential Amino Acids

- 8 for adults, 10 for children
- must be ingested, no synthesis

B. Synthesis

- 12 can be synthesized using carbon backbone from other amino acids
- amination = addition of amino group

(fun fact: you will synthesize 500-1000 pounds of protein in your lifetime!)

Phenylketonuria = lack enzyme to convert phenylalanine to tyrosine, tyrosine needed for melanin, deaminated phenylalanine levels rise → neurotoxic

3. Functions of Proteins

- cell structural components
- enzymes
- hormones

Nucleic Acid Metabolism

- nucleotides usually recycled for new nucleic acids
- DNA never catabolized for energy
- RNA only under extreme conditions:
- nucleotide hydrolyzed to pentose sugar, nitrogenous base, and phosphate

- sugar → glycolysis for ATP
- Pyrimidine bases (C, U) → acetyl → Citric Acid Cycle for ATP
- Purine bases (A, G) → deaminated, excreted as uric acid, not used for ATP

Gout = crystals of uric acid in joints, pain and swelling

Metabolic Interactions
(handout)

Patterns of Metabolic Activity
(handout)

Balanced Diet provides:

1. Substrates for energy (ATP) production
2. Complete proteins (all essential a.a.)
3. Essential lipids
4. Nitrogen (needed for a.a. and nucleotides)
5. Minerals = inorganic ions (Ca^{++} , Na^+ , etc.)
 - regulation of osmotic conc.
 - physiological processes
 - cofactors for enzymes
 - form compounds
6. Vitamins = organic cofactors
 - tissue maintenance
 - coenzymes
 - antioxidants
 - hormone and neurotransmitter synthesis

Gut bacteria synthesize K, B5, biotin

Skin synthesizes D3

All others from diet:

Fat soluble (A, D, E, K) stored in fat, too much can cause toxicity

Water soluble (B, C, niacin, folacin, biotin), either used or excreted by kidney

Bioenergetics

- study of acquisition and use of energy by organisms
- measure food energy in Calories
- 1C = 1kcal = amount of energy needed to raise temp of 1 kg H₂O 1 °C
- lipids → 9.46 C/g
- carbs → 4.18 C/g
- protein → 4.32 C/g

Metabolic Rate = sum of all catabolic and anabolic reaction energy needs in body

Basal Metabolic Rate (BMR) = minimal energy cost of living to maintain homeostasis

BMR measured 12hr post food, 25°C room
Average → 70 C/hr, 1680 C/day
(Increased during healing or pregnancy)

Guestimate:

weight in kg X 1.0 for males
X 0.9 female = BMR C/hr

If one consumes more Calories than needed,
excess is stored as triglycerides
Not enough, weight loss of triglycerides and
muscle protein

Body Mass Index (BMI)

$$\text{BMI} = \frac{\text{weight in lb} \times 705}{(\text{height in inches})^2}$$

BMI < 18 = underweight

18-25 = normal

25-30 = overweight

> 30 = obese (1:3 Americans)

obese = 20% + over ideal body weight

Ob Mouse Studies:

Leptin k/o mouse = obese

Leptin release by adipocytes to trigger
satiating in brain

5% of obese people have mutation in leptin
gene or leptin receptor

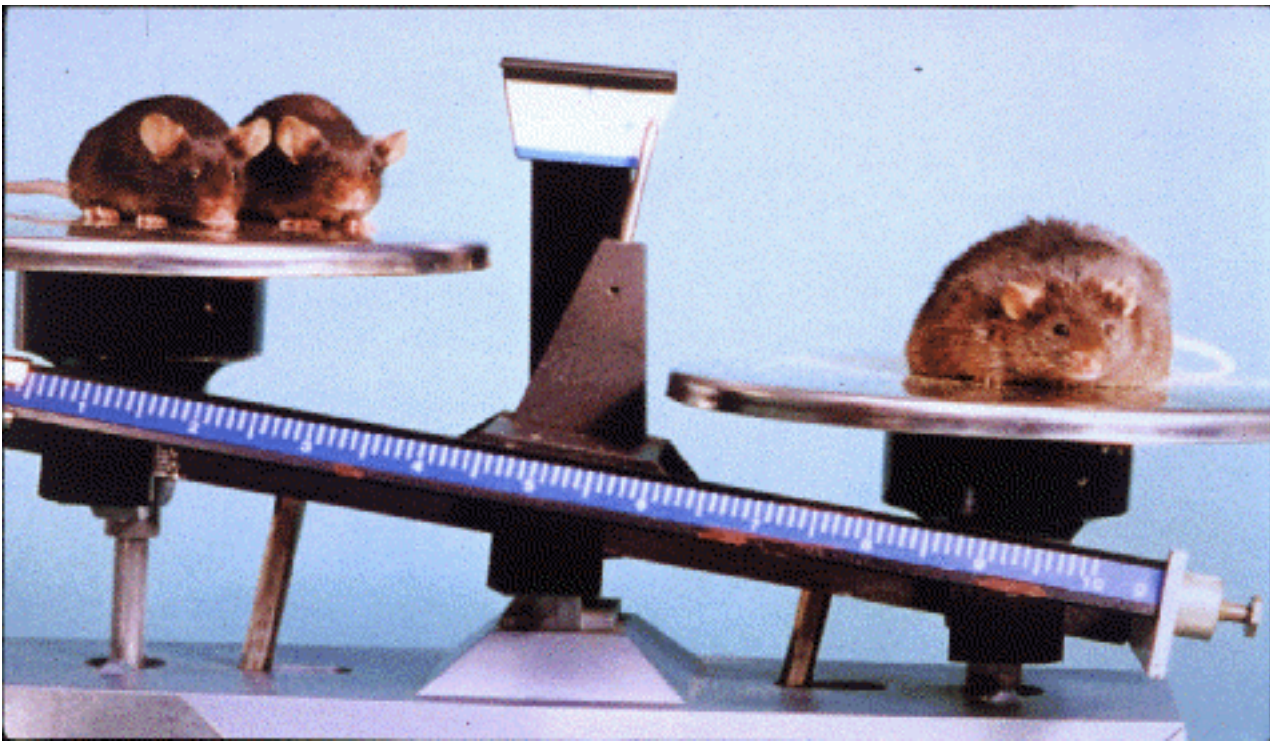
Fat cells

Leptin

Hypothalamus

Stop Eating

Ob knock-out Mouse



Thermoregulation

Body temp: 97–104°F, for enzymes to function

Heat: byproduct of metabolism

110°F = dead, must lose heat

Heat transfer methods:

1. Radiation: infrared waves, ~50%
2. Conduction: direct heat transfer: low%
3. Convection: warm air rises away from skin, cold air gets heated, ~15%
4. Evaporation: water changes to gas vapor using heat energy, ~20%, constant 10% loss due to insensible perspiration

Heat regulation controlled by anterior hypothalamus:

- receptors in skin and brain detect temp change
- hypothalamus responds via ANS stimulation

Too hot: trigger heat loss

1. peripheral vasodilation
(↑ radiation, convection)
2. sensible perspiration (↑ evaporation)
3. ↑ respiration depth (↑ evaporation)

Pyrexia = elevated temp, if too high → heat stroke, cooling mechanisms shut down → death

Too cold: trigger heat retention and generation

1. constrict cutaneous vessels
(↓ radiation, convection)
Frost bite: if flow restricted for too long, tissues die
2. nonshivering thermogenesis: hormones ↑ metabolic rate (60% of catabolism = heat)
3. shivering thermogenesis: muscle contraction
(↑ muscle metabolism ↑ heat)

Hypothermia = low temperature, slow metabolism, confusion

Fever: triggered by pyrogens, resets thermostat, triggers heat generation to elevate body temp. Up to 104°F OK, 106°F → dysfunctional, 110°F → dead

Heat and Surface Area:

Volume to surface area ratio affects heat loss and BMR

↑ area ↓ volume = ↑ heat loss, ↑ BMR
(thin people, children)

Infants / small children have brown fat for heat generation (adipose with mitochondria):
aerobic respiration produces 60% heat,
40% ATP

Age Related Changes:

1. ↑ non-insulin dependent diabetes (cells ignore insulin and won't use glucose)
2. ↑ glucose in blood can cause permanent protein changes by binding: cataracts, glaucoma, capillary blockage→necrosis
3. ↓ metabolic rate
4. ↑ malnutrition due to ↓ appetite