Chapter 5 – The Lipids: Triglycerides, Phospholipids, and Sterols

Learning Objectives
After completing Chapter 5, the student will be able to:

1. Describe the structure of a fatty acid and the effects of chain length and saturation on the properties of the fat.
2. Describe the triglyceride.
3. List and describe the three types of fatty acids found in foods.
4. Explain the structure of the omega-3 and -6 fatty acids.
5. Explain the roles of phospholipids and sterols in foods and in the body.
6. Trace the digestion of lipids including identification of enzymes needed and the role of bile.
7. Describe the absorption of lipids into the intestine and the formation of the chylomicron.
8. Describe the role of the liver in the production of lipoproteins.
9. Explain the health implications of LDL and HDL and the factors that raise or lower levels of these lipoproteins.
10. Identify the uses of triglyceride in the body.
11. Identify the essential fatty acids and their role in the formation of eicosanoids.
12. Discuss the role of fat in the development of heart disease, cancer, and obesity.
13. Explain the recommended dietary intakes for fat, saturated fat, essential fatty acids, and cholesterol.
14. Describe the diet recommendations for selection of a diet lower in total fat, saturated fat, trans fat, and cholesterol.

I. The Chemist’s View of Fatty Acids and Triglycerides

The class of nutrients known as lipids includes triglycerides (fats and oils), phospholipids, and sterols. Most are triglycerides with glycerol backbones and three fatty acids attached. Fatty acids vary in carbon chain lengths, degree of unsaturation, and number of double bonds. Saturation affects the physical characteristics of the fat and its storage properties. Trans-fatty acids, which are altered, have the same negative health effects as saturated fatty acids.

A. Fatty Acids

1. The Length of the Carbon Chain
   a. Long-chain fatty acids are found primarily in meat, fish, and vegetable oils.
   b. Medium- and short-chain fatty acids are found in dairy products.

2. The Degree of Unsaturation
   a. Saturated fatty acids carry the maximum possible number of hydrogen atoms. When most of the fatty acids are saturated it is called a saturated fat.
   b. Unsaturated fatty acids lack hydrogen atoms and have at least one double bond. The double bond is considered the point of unsaturation.
      1. Monounsaturated fatty acids lack two hydrogen atoms and have one double bond. When most of the fatty acids are monounsaturated it is called a monounsaturated fat.
      2. Polyunsaturated fatty acids (PUFA) lack four or more hydrogen atoms and have at least two or more double bonds. When most of the fatty acids are polyunsaturated it is called a polyunsaturated fat.
         a. Linoleic acid is an essential fatty acid.
         b. Linolenic acid is an essential fatty acid.

3. The Location of Double Bonds
   a. The omega number refers to the position of the first double bond.
   b. An omega-3 fatty acid has the location of the double bond in the third position. An example is linolenic acid.
   c. An omega-6 fatty acid has the location of the double bond in the sixth position. An example is linoleic acid.
   d. Omega-9 fatty acids tend to be monounsaturated. An example is oleic acid.

B. Triglycerides are lipids with three fatty acids attached to a glycerol.
C. Degree of Unsaturation Revisited
   1. Firmness
      a. Saturated fats are solid at room temperature.
      b. Polyunsaturated fats are liquid at room temperature.
      c. Shorter fatty acid chains are softer at room temperature than longer chains.
   2. Stability
      a. Saturated fat is more resistant to oxidation.
      b. Monounsaturated fat is slightly less susceptible to spoilage.
      c. Polyunsaturated fat spoils most readily.
      d. Protection from rancidity:
         1. Sealed in airtight containers away from light.
         2. Add antioxidants.
         3. Hydrogenation
   3. Hydrogenation
      a. Protects against oxidation, therefore prolonging shelf life.
      b. Alters texture.
   4. Trans-Fatty Acids
      a. Act like saturated fats in the body.
      b. Heart disease connection is being researched.
      c. Conjugated linoleic acid is a naturally occurring trans fat that may be beneficial to health. These acids are not included under trans fats on food labels.

II. The Chemist’s View of Phospholipids and Sterols
   Phospholipids and sterols have unique chemical structures that allow them to have unique roles in the body. Sterols have a multiple-ring structure.

A. Phospholipids
   1. Phospholipids in Foods
      a. Phospholipids contain glycerol, two fatty acids and a phosphate group with a molecule of choline.
      b. Used as emulsifiers in the food industry.
      c. A well-known phospholipid is lecithin.
      d. Food sources of lecithin include eggs, liver, soybeans, wheat germ, and peanuts.
   2. Roles of Phospholipids
      a. Enable transport of lipids across cell membranes.
      b. Emulsifiers
      c. Lecithin is made by the liver. Supplements increase energy intake and can cause GI symptoms.

B. Sterols – A well-known sterol is cholesterol.
   1. Sterols in Foods
      a. Found in plant and animal foods.
      b. Cholesterol is found in animal foods only—meat, eggs, fish, poultry, and dairy products (exogenous).
   2. Roles of Sterols
      a. Starting material for bile acids, sex hormones, adrenal hormones, and vitamin D.
      b. Structural component of cell membranes.
      c. Liver produces 800-1500 mg cholesterol per day (endogenous).
      d. Atherosclerosis is a disease that causes heart attacks. It occurs when cholesterol forms plaque deposits in the artery wall.

III. Digestion, Absorption, and Transport of Lipids
   Special arrangements are made in the digestion of lipids. This is due to the hydrophobic nature of lipids. Lipids tend to separate from the watery fluids of digestion. Digestive enzymes are hydrophilic, or water loving. Bile from the liver emulsifies lipids. Enzymes are then able to break down lipids to monoglycerides and fatty acids.
A. Lipid Digestion
1. In the mouth, the salivary glands release lingual lipase.
2. Muscle contractions in the stomach disperse fat into smaller droplets. Fat is exposed to gastric lipase enzyme.
3. In the Small Intestine
   a. Cholecystokinin (CCK) signals the gallbladder to release bile.
   b. Pancreatic and intestinal enzymes hydrolyze lipids to monoglycerides and fatty acids.
   c. Phospholipids are hydrolyzed.
   d. Sterols are absorbed as is.
4. Bile’s Routes
   a. Enterohepatic circulation – reabsorbed and recycled.
   b. Soluble fibers are effective in trapping some bile and excreting it from the body through the large intestine.
B. Lipid Absorption
1. Glycerol and short- and medium-chain fatty acids diffuse and are absorbed directly into the bloodstream.
2. Monoglycerides and long-chain fatty acids form micelles, are absorbed, and are reformed into new triglycerides. With protein they are transported by chylomicrons.
C. Lipid transport is made possible by a group of vehicles known as lipoproteins.

1. Chylomicrons
   a. Largest of the lipoproteins.
   b. Least dense.
   c. Get smaller as triglyceride portion is removed by the cells.
2. VLDL (Very-Low-Density Lipoproteins)
   a. Composed primarily of triglycerides.
   b. Made by the liver.
   c. Transport lipids to the tissues.
   d. Get smaller and more dense as triglyceride portion is removed.
3. LDL (Low-Density Lipoproteins)
   a. Composed primarily of cholesterol.
   b. Transport lipids to the tissues.
4. HDL (High-Density Lipoproteins)
   a. Transport cholesterol from the cells to the liver.
   b. Have anti-inflammatory properties.
5. Health Implications
   a. High LDL is associated with higher risk of heart attack and is known as “bad” cholesterol.
   b. High HDL seems to have a protective effect and is known as “good” cholesterol.
   c. Factors that lower LDL and raise HDL
      1. Weight control.
      2. Replace saturated fat with monounsaturated fat and polyunsaturated fat in the diet.
      3. Soluble fibers.
      4. Phytochemicals.
      5. Moderate alcohol consumption.
      6. Physical activity.
   d. Genes influence lipoprotein activity.

IV. Lipids in the Body
The triglycerides have important roles in the body. Essential fatty acids also play important roles. The body can store unlimited amounts of fat when fat is consumed in excess. The liver can also convert excess carbohydrate and protein to fat. The body needs carbohydrate to break down fat efficiently. Inefficient breakdown of fat forms ketone bodies.

A. Roles of Triglycerides
1. A source of energy for the cells.
2. Provide more energy than carbohydrates or proteins.
3. Can be stored to an unlimited capacity in adipose tissue.
4. Adipose tissue secretes hormones (adipokines).

B. Essential Fatty Acids — cannot be made by the body.
1. Linoleic Acid and the Omega-6 Family
   a. Can make arachidonic acid, which is a conditionally essential fatty acid.
   b. Supplied by vegetable oils and meats.
2. Linolenic Acid and the Omega-3 Family
   a. Must be supplied by food.
   b. Can make EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid), important for eyes, brain, and heart.
3. Eicosanoids
   a. Made from arachidonic acid and EPA.
   b. Like hormones but have different effects on different cells.
   c. Include prostaglandins, thromboxanes, and leukotrienes.

4. Fatty Acid Deficiencies
   a. Are rare in the U.S. and Canada.
   b. Occur in infants and children with fat-free or low-fat diets.

C. A Preview of Lipid Metabolism
1. Storing Fat as Fat
   a. Lipoprotein lipase (LPL) hydrolyzes triglycerides as they pass and directs the parts into the cells to be used for energy or storage.
2. Using Fat for Energy
   a. Hormone-sensitive lipase inside the adipose cells hydrolyzes triglycerides when needed for energy.
   b. During fasting the body metabolizes fat, but requires carbohydrate and protein for complete fat breakdown.
   c. Ketone bodies can be made from fat fragments.

V. Health Effects and Recommended Intakes of Lipids
   High intakes of saturated fat and trans fat and high blood LDL cholesterol are related to increased risk for heart disease. Omega-3 fatty acids in the diet appear to have a protective effect.

A. Health Effects of Lipids
1. Blood lipid profile
   a. Reveals concentrations of lipids in the blood
   b. Desirable levels
      1. Total cholesterol < 200 mg/dL
      2. LDL cholesterol < 100 mg/dL
      3. HDL cholesterol ≥ 60 mg/dL
      4. Triglycerides < 150 mg/dL
2. Heart Disease
   a. Elevated blood cholesterol is a risk factor for cardiovascular disease.
   b. Cholesterol accumulates in the arteries, restricts blood flow, and raises blood pressure.
   c. Saturated fat in the diet raises blood cholesterol.
3. Risks from Saturated Fats
   a. Saturated fat in the diet raises LDL cholesterol, which increases risk of heart disease.
   b. Food sources include whole milk, cream, butter, cheese, high-fat cuts of beef and pork, and coconut, palm, and palm kernel oils.
4. Risks from Trans Fats
   a. Trans-fatty acids in the diet increase LDL cholesterol and decrease HDL cholesterol.
   b. Food sources include deep-fried foods using vegetable shortening, cakes, cookies, doughnuts, pastry, crackers, snack chips, margarine, imitation cheese, and meat and dairy products.
   c. Debate over butter versus margarine.
5. Risks from Cholesterol
a. Dietary cholesterol has less effect on blood cholesterol than saturated fat and trans fat.

b. Food sources of cholesterol include egg yolks, milk products, meat, poultry, and shellfish.

6. Benefits from Monounsaturated Fats and Polyunsaturated Fats
   a. Replacing saturated fat and trans fat with monounsaturated fat and polyunsaturated fat is the most effective dietary strategy in preventing heart disease.
   b. Food sources of monounsaturated fat include olive, canola, and peanut oils and avocados.
   c. Food sources of polyunsaturated fat include vegetable oils (safflower, sesame, soy, corn, and sunflower), nuts, and seeds.

7. Benefits from Omega-3 Fats
   a. Beneficial effects in reducing risk of heart disease and stroke, supporting the immune system, and defending against inflammation.
   b. Food sources include vegetable oils (canola, soybean, and flaxseed), walnuts and flaxseeds, and fatty fish (mackerel, salmon, and sardines).
      1. Need to avoid fish with high levels of mercury.
      2. Eat more fish (2-3 oz. portions per week) and less meat.
      3. Bake, broil or grill the fish.
      4. Functional foods are being developed.
      5. Supplements are not the answer.

8. Omega-6 to Omega-3 Ratio
   a. Ideal ratio ranges from 5:1 to 10:1.
   b. Increasing omega-3 intake is most important.

9. Cancer
   a. Dietary fat has an association with risks for some types of cancer, but it is not as strong as the link to heart disease.
   b. Fat does not initiate cancer development but may be a promoter once cancer has developed.
   c. Some types of cancer have a stronger relationship to fat intake. Saturated fat from meat is implicated.

10. Obesity can be a consequence of high-fat, high-kcalorie diets in excess of energy needs.

B. Recommended Intakes of Fat

1. The DRI and the 2005 Dietary Guidelines recommend fat at 20%-35% of energy intake (400-700 kcalories of a 2,000-kcalorie diet).

2. FDA recommends 10% of energy intake from saturated, 30% of energy intake total fat.

3. 2005 Dietary Guidelines suggest choosing a diet low in saturated fat and cholesterol and moderate in total fat.

4. Daily Values
    a. 65 g fat based on 30% of 2000-kcal diet
    b. 20 g saturated fat based on 10% of 2000-kcal diet
    c. 300 mg cholesterol

5. USDA Food Guide considers saturated fats discretionary kcalories.

6. Too little fat can be detrimental to health.

C. From Guidelines to Groceries

1. Very lean and lean options of meats and meat alternates should be chosen.

2. Choose fat-free and low-fat milks and milk products.

3. Choose a wide variety of vegetables, fruits, and whole grains.

4. Avoid invisible fat from high-fat cheese and baked and fried foods.

5. Choose wisely from many available food products.

6. Fat Replacers
    a. Ingredients derived from carbohydrate, protein, or fat.

    b. Replace fat in foods.

    c. Artificial fats offer sensory and cooking qualities but no kcalories. Research on olestra supports its safety but it decreases the absorption of fat-soluble vitamins and may cause digestive distress in some consumers.

7. Read Food Labels
    a. Provide information on fat grams and % Daily Values.
b. % Daily Values are not the same as % of kcalories from fat.

VI. Highlight: High-Fat Foods—Friend or Foe?
There are many relationships between the kinds of fat in the diet and their roles in supporting or harming health. It is complex. Translating the research from general recommendations into specific recommendations is challenging.

A. Guidelines for Fat Intake
1. It is recommended that individuals replace “bad” fats with “good” fats.
2. Specific guidelines for reducing saturated fat, trans fat, and cholesterol.
3. Specific guidelines for increasing monounsaturated and polyunsaturated fat.

B. High-Fat Foods and Heart Health
1. Cook with Olive Oil
   a. Many health benefits.
   b. Still provides 9 kcal/gram.
2. Nibble on Nuts
   a. Many health benefits.
   b. Still a high-kcalorie food.
3. Feast on Fish
   b. Mercury caution for pregnant and lactating women and young children.

C. High-Fat Foods and Heart Disease
1. Limit Fatty Meats, Milk Products, and Tropical Oils
   a. Read food labels to determine those lowest in saturated fat.
   b. Choose leaner and lower-fat animal foods.
2. Limit Hydrogenated Foods
   a. Contain trans fats.
   b. Watch convenience foods.

D. The Mediterranean Diet
1. Links with good health but may not be the only factor.
2. Focus on whole grains, potatoes, and pasta, vegetables and legumes, low-fat cheeses, yogurt, fruits, some fish, other seafood, poultry, a few eggs, and little meat.

E. Conclusion
1. Saturated fat and trans fat are poor for heart health.
2. Unsaturated fat in moderation is good for heart health.
3. Food is a mixture of good and bad fat.
4. Manufacturers are complying with consumer requests.
5. Try Mediterranean eating habits.