Is Fish Really 

Brain Food?

DIETARY LIPIDS CAN PROFOUNDLY AFFECT OUR RISK 
OF DEVELOPING DEMENTIA LATER IN LIFE.
The Lipids

LEARNING OBJECTIVES

- Identify the four major categories of dietary lipids (Infographic 5.1)
- Describe the structural differences between saturated, monounsaturated, and polyunsaturated fats (Infographic 5.2)
- Identify the types of foods that are rich in monounsaturated fat, polyunsaturated fat, and saturated fat (Infographic 5.3)
- Name two roles of phospholipids in the body (Infographic 5.4)
- Describe the process of lipid digestion, and explain how emulsification assists in the process (Infographic 5.5)
- List the four major lipoproteins, and describe their functions in the transport of lipids (Infographic 5.6 and Infographic 5.7)
- Identify the two essential fatty acids, their primary structural difference, and food sources of each in the diet (Infographic 5.8 and Infographic 5.9)
- Describe sources of saturated fat in the U.S. diet (Infographic 5.10)
- Describe the Acceptable Macronutrient Distribution Range for lipids and how to use a Nutrition Facts Panel to evaluate a food’s fat content (Infographic 5.11)

In generations past, it was not uncommon for a mother to insist that her children line up each morning to take cod liver oil because of health benefits believed to be bestowed by the ill-tasting spoonful. Turns out, mother may have been right. Cod liver oil is rich in healthy fats called omega-3 fatty acids. Many cold-water, oily fish are rich in these fats. Remarkably, one of these fats, docosahexaenoic acid (DHA), is also found abundantly in the human brain.
Particularly dependent on DHA is an area of the brain just behind the forehead (called the prefrontal cortex) that is the site of cognitive (mental) processing, which includes learning, memory, prioritizing, problem solving, sustained focus, as well as behavioral and social development. These higher-level brain functions are crucial to our survival and quality of life. In fact, adequate levels of DHA are critical to our brain development in the womb and during infancy.

During the last third of pregnancy, DHA is rapidly accumulating in the fetal brain as it is incorporated into brain structures in this period of accelerated brain growth. An adequate supply of DHA is therefore essential to support brain development in the fetus. To meet this demand, the DHA levels in blood delivered to the fetus via the umbilical cord are double that in the mother’s circulation, and they steadily rise as her pregnancy advances.

After birth, high levels of DHA in human milk may continue to optimally support the growth and development of the infant’s brain. A number of studies have found that breastfeeding is associated with increased intelligence as the infant ages. One study found that by age 2 infants who had been exclusively breastfed for at least three months showed a substantial increase in brain growth compared to those who had been fed formula—resulting in improved cognition as these children grew older. Some studies have found that the cognitive benefits of breastfeeding may persist into adolescence and early adulthood.

In addition to DHA being critical during fetal and infant development, adequate intakes appear to be important throughout our lives. What happens to our fully developed adult brain when the DHA content in our diet is too low? In animal studies, low DHA adversely affects cognition, vision, attention, and behavior. In humans, low DHA levels in adults are associated with poorer cognitive functions and some psychiatric disorders.

These findings seem to point to DHA as vital for both the developing and adult brain, but could DHA be as essential for the aging brain? If so, does DHA have a potential role in reducing the risk of Alzheimer’s disease (AD), the common form of dementia (loss of memory and other cognitive functions) in elderly individuals?

Martha Clare Morris, PhD, an expert in the study of the connection between nutrition and disease in human populations (a nutritional epidemiologist), became intrigued by these questions in the early 2000s. Since then, Morris and a team of researchers working out of Rush University in Chicago have been searching for answers by studying various dietary fats and their effects on the aging brain.

Cod liver oil supplements, a source of DHA, were commonly given to children in the 1930s to prevent rickets, a bone disorder that is discussed in Chapter 7.
DIETARY FAT

Found in plant and animal foods, dietary fat, or what we commonly call fat, is an essential component of a healthy diet. Fats are a concentrated source of energy, providing 9 kilocalories (kcal) per gram, typically accounting for one-third or more of our total calorie intake, and are significantly more energy dense than carbohydrates and protein, each providing only 4 kcal per gram. When selected and consumed in appropriate proportions, fat confers some important health benefits, as some fats are essential nutrients. Dietary fats are also required for the efficient absorption and transport of fat-soluble vitamins (A, D, E, and K) and phytochemicals. Fat consumption contributes to satiety (the sensation of feeling full) in part by slowing gastric emptying, which keeps food in the stomach a little longer. This causes foods to be digested and absorbed over longer periods, which can improve blood glucose control following the ingestion of high-carbohydrate foods when fats are included. (Refer to Spotlight A.)

Fat is stored in our body primarily in adipose tissue (body fat), which is made up largely of adipocytes, or fat cells. Having adequate fat stores is important as adipose tissue cushions, protects, and insulates the kidneys, heart, and other organs and serves as a storage site for fat-soluble vitamins. Furthermore, inadequate stores of fat can reduce fertility in both men and women.

For some, high-fat diets can make it difficult to control body weight. Fats increase the palatability (taste and flavor) of food and contribute to texture and aroma. Many popular foods get most of their calories from fat, and with their taste appeal and caloric density, it can be easy for some of us to eat too much. Any excess fat above overall calorie need is efficiently deposited as fat in the body, making high-fat, energy-dense diets one reason some people tend to overeat and gain weight.

OVERVIEW OF THE LIPIDS

Scientists have long known that fats are a subclass of lipids, a group of compounds made up of carbon, hydrogen, and a small amount of oxygen that generally can’t mix or dissolve in water (they are water insoluble). Lipids play important roles in the body. As a major component of cell membranes, lipids give those structures flexibility and integrity, and various lipids are required for the synthesis of some hormones and hormonelike substances.

Lipids are diverse in structure and function. We will discuss the four most common lipid classes: fatty acids, triglycerides, sterols (such as cholesterol), and phospholipids (such as lecithin). Although some use the term lipid interchangeably with fat, the word fat, more precisely, refers to triglycerides, which make up 95% of all lipids in our foods and 99% of the stored fat in our bodies. (INFOGRAPHIC 5.1)

Fatty Acids

Fatty acids are a type of lipid with multiple functions. They are metabolized to provide energy, they regulate rates of gene expression,
Dietary fats come from plant and animal sources. Dietary fats contain 9 kcal per gram and contribute to the taste and texture of foods.

**THE LIPIDS**

**METHYL GROUP**
a group of three hydrogen atoms bonded to a carbon atom found at the opposite end (the “omega” end) of the fatty acid chain from the carboxyl group.

**CARBOXYLIC ACID GROUP**
the acid group found at one end of the fatty acid chain.

**SATURATED FATTY ACIDS**
a fatty acid molecule with no double bonds between the carbon molecules; all carbon binding sites not already bound to another carbon are saturated with hydrogen.

**UNSATURATED FATTY ACIDS**
a fatty acid with fewer than the maximum possible number of hydrogen atoms attached to the carbon chain.

**MONOUNSATURATED FATTY ACIDS**
a fatty acid with only one double bond between carbons in the carbon chain.

**POLYUNSATURATED FATTY ACIDS**
a fatty acid with two or more double bonds between carbons in the carbon chain.

and they are the starting material used to synthesize several hormonelike compounds in the body. They are also the primary components of two other types of lipids, triglycerides and phospholipids. Fatty acids consist of a linked chain of carbon atoms with remaining bonds containing only hydrogen atoms (a hydrocarbon chain). A methyl group is at one end of the fatty acid chain (three hydrogens bonded to a carbon atom—also called the “omega” end of the fatty acid), and a carboxylic acid group is attached to the other end.

Fatty acids differ in length, so they are categorized by the length of their hydrocarbon chains, as well as in their degree of saturation (how many carbon atoms have their available bonds filled with hydrogen atoms). Short-chain fatty acids have fewer than 6 carbons; medium-chain fatty acids have 6–12 carbons, and long-chain fatty acids have more than 12 carbons. Both properties—length of hydrocarbon chains and degree of saturation—determine the function of a fatty acid in the body and its role in health and disease.

**Saturated fatty acids**, with carbon atoms having every available bond filled with hydrogen atoms, are relatively solid at room temperature. They are typically highest (as a percentage of total fat) in animal products (such as meats and dairy), but they are also abundant in some vegetable oils (such as coconut oil, palm kernel oil, palm oil, and cocoa butter). The rest of the fatty acids are unsaturated, with less hydrogen and one or more double bonds (or point of unsaturation) between carbon atoms. Because of this configuration, unsaturated fatty acids are generally liquid at room temperature. Unsaturated fats are found most abundantly in plant foods, such as seeds, nuts, grains, and most vegetable oils. Fatty acids with one point of unsaturation are called monounsaturated fatty acids (abundant in olive and canola oils and nuts); those with more than one point of unsaturation are called polyunsaturated fatty acids (abundant in corn, safflower, sunflower, sesame, and soybean oils). The arrangement of the hydrogen atoms on either side of double bonds can be in an either “cis” or “trans” orientation, which has important health implications, as will be discussed later in the chapter. **(INFOGRAPHIC 5.2)**
INFOGRAPHIC 5.2 The Structure of Triglycerides and Fatty Acids

Food fats, or triglycerides, are a mixture of many different fatty acids. The balance of the different fatty acids determines the physical property of the food fat at room temperature.

TRIGLYCERIDES: Compounds made up of a glycerol molecule and three fatty acids.

FATTY ACIDS: Vary in degree of saturation and chain length.

<table>
<thead>
<tr>
<th>Fatty Acid Type</th>
<th>Solid or Liquid at Room Temperature?</th>
<th>Food Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated Fatty Acid</td>
<td>Solid</td>
<td>Solid</td>
</tr>
<tr>
<td>Methyl, or omega, end</td>
<td>Each carbon has 4 bonds</td>
<td>Solid</td>
</tr>
<tr>
<td>Carboxylic acid end</td>
<td></td>
<td>Solid</td>
</tr>
<tr>
<td>Shorthand notation for fatty acid (every bend represents a carbon and 2 hydrogen atoms).</td>
<td></td>
<td>Solid</td>
</tr>
<tr>
<td>Monounsaturated Fatty Acid</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>A carbon-carbon double bond</td>
<td>Hydrogen atoms ‘missing’</td>
<td>Liquid</td>
</tr>
<tr>
<td>replaces the missing C-H bonds and each carbon still has 4 bonds.</td>
<td></td>
<td>Liquid</td>
</tr>
<tr>
<td>Polyunsaturated Fatty Acid</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Polysaturated fatty acids contain more than one carbon-carbon double bond.</td>
<td></td>
<td>Liquid</td>
</tr>
<tr>
<td>Cis and Trans Fatty Acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In a ‘cis’ arrangement, both hydrogens are on the same side of the double bond.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In a ‘trans’ arrangement, hydrogen atoms are attached on the opposite sides of the double bond.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most unsaturated fatty acids found in nature are in the cis configuration; however, small amounts of trans fatty acids naturally occur in dairy and beef. The addition of artificial trans fats during food manufacturing or processing was recently banned by the FDA.

How are trans fatty acids both similar to and different from saturated and unsaturated fatty acids?

Photo credits: Eli Ensor (top 3 photos), Africa Studio/Shutterstock (bottom photo—main), orinocoArt/Shutterstock (bottom photo—butter)
The most discussed sterol is cholesterol. A molecule with varied functions, cholesterol is a critical component of our cell membranes and is needed as a precursor (a compound that is used to synthesize another compound) for the synthesis of bile acids, vitamin D, and steroid hormones (such as estrogen and testosterone), but it does not provide any energy.

Cholesterol is synthesized in nearly every tissue in the body but in particularly large quantities by the liver. Approximately 75% of the cholesterol in blood is made in our body, which provides all the cholesterol needed for body functions. Although a dietary source of cholesterol is not required, we consume cholesterol in animal foods such as meats and dairy products. Indeed, the presence of cholesterol in cell membranes is one distinguishing characteristic between plant and animal cells; thus dietary cholesterol is found only in foods of animal origin.

Early research by Morris and her colleagues focused on the effects of dietary fats on risk of AD in study participants 65 and older with no signs of disease when the study began. After study participants were followed for almost four years, Morris concluded that a diet high in saturated and trans fats may accelerate cognitive decline and increase risk of AD and that a diet rich in monounsaturated and polyunsaturated fat appears to exert protective effects on the brain associated with a reduced risk of AD. Ten years later in 2014, Morris and her team published a review of data from laboratory, animal, and epidemiological studies on the effects of dietary fat on dementia and AD that confirmed their earlier findings.

Epidemiological studies conducted by other researchers also have demonstrated the risk of saturated fats on cognitive function. According to Morris, the data point to a clear connection between higher saturated fat intake and greater cognitive decline.

**Triglycerides**

Triglycerides are the most abundant type of dietary lipid, providing a large portion of total food energy, and they are required for the efficient transport of certain fat-soluble vitamins (vitamin A, D, E, and K) through the body. A triglyceride is made up of three fatty acid chains bound to one glycerol, a small three-carbon molecule that makes up the glycerol backbone of each triglyceride. The fatty acid chains form the “tails” of the triglyceride. All triglycerides are composed of a mix of short-chain, medium-chain, and long-chain fatty acids. They seldom contain exclusively one type of fatty acid.

Because triglycerides consist of three fatty acids, they can provide essential fatty acids, the fatty acids our bodies need but cannot synthesize in sufficient amounts. Essential fatty acids must be obtained through our diet. (INFOGRAPHIC 5.3)

**Sterols**

Chemically, sterols are complex lipids of four interconnected carbon rings with a hydrocarbon side chain.

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*Stay Tuned*

Fat-soluble vitamins are covered in more detail in Chapter 7.

*Stay Tuned*

For more on the effect of cholesterol and other dietary fats on blood cholesterol levels, see Spotlight B.

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*A cholesterol-rich egg bacon cheeseburger.*

Dietary sources of cholesterol are not needed; the body produces most of the cholesterol it requires in sufficient amounts.
synthesize other types of sterols (and the closely related stanols), but these types are poorly absorbed by the body and can actually interfere with and lower cholesterol absorption. For this reason, some spreads and other food products are fortified with plant sterols or stanols to help lower cholesterol levels in the body.
As with heart disease, growing evidence links high levels of cholesterol in the blood to the development of AD and other forms of dementia. In fact, several studies in midlife participants showed that those with higher levels of total cholesterol had an increased risk of developing dementia later in life compared to those with normal or low blood cholesterol levels.

Animal studies offer further clues to the connection between cholesterol and AD. In these studies, a diet high in saturated fat and cholesterol has been shown to cause brain inflammation and lesions and impair memory. Another finding indicates that increased cholesterol accelerates the buildup of a sticky protein called amyloid beta, a characteristic of AD. Amyloid beta can assemble into cell pores or channels to accumulate into clumps in those cells, which travel to the brain and disrupt its function.

Phospholipids are a primary component of cell membranes and are required for the transport of other lipids in the blood. The hydrophilic (having an affinity for water) and the hydrophobic (tending to repel water) structure of phospholipids is key to their function.

Because the body can produce phospholipids, they are not considered an essential nutrient. Most phospholipids are similar to triglycerides in structure in that they have a glycerol backbone, but they differ in that they have two rather than three attached fatty acids. Attached to the third position is a phosphate group and one of several water-soluble “headgroups.” Together the glycerol backbone, the phosphate, and the headgroup create a hydrophilic (water-soluble) head on the phospholipid, whereas the fatty acid “tails” at the other end are soluble in lipids but hydrophobic (not soluble in water). In the membranes of our cells, phospholipids assemble into a lipid bilayer (two parallel sheets), with the fatty acids of each sheet facing each other in the internal portion of membranes and the hydrophilic heads facing outward and in contact with water in and around our cells. (INFOGRAPHIC 5.4)

INFOGRAPHIC 5.4 Phospholipids Are a Critical Component of Cell Membranes  They also play a central role in transporting lipids throughout the body. Despite their importance, they are not essential nutrients, as we are able to synthesize all that we need.

Why do the fatty acid “tails” face each other within the cell membrane?
Functioning as a semipermeable barrier to the external cell environment, the lipid bilayer controls the molecules that enter and exit the internal cell.

This two-sided structural arrangement of phospholipids—one end water-soluble and the other end fat-soluble—allows phospholipids to suspend fat in water. The fat-soluble tails of phospholipids will surround small fat droplets, leaving the water-soluble head of the phospholipid facing outward toward the water. Placing such a hydrophilic coating around the lipid droplets allows them to remain stably dispersed (mixed) in the watery environment.

An example of a phospholipid is lecithin. In addition to being the most abundant phospholipid in our body, lecithin is also frequently added to food products, such as salad dressings, as an emulsifier because of its ability to keep water and lipids from separating.

As discussed previously, blood lipids can also affect risk of AD, and a complete cholesterol test—also called a lipid panel—determines the amount of lipids circulating in blood. As Morris explains, a diet high in saturated fat and low in unsaturated fats increases total blood cholesterol, which can be harmful to our health, increasing the risk of not only dementia but also heart disease.

\[ \text{\textbf{LIPID DIGESTION AND ABSORPTION}} \]

To carry out their functions in the body, most dietary lipids must be digested first. As introduced in Chapter 3, a small amount of fat digestion takes place in the mouth and stomach (via enzymes called lipases), but most occurs in the small intestine. However, because lipids are not water soluble, and therefore cannot mix with water, the fat tends to clump together in the small intestine’s watery environment. The body’s solution to that problem is \textit{emulsification}.

Emulsification aids digestion by breaking up large fat globules into much smaller droplets so that fat-digesting enzymes can operate efficiently. Bile acids produced in the liver from cholesterol (and stored in the gallbladder) make emulsification possible. The molecular makeup of bile acids features a water-soluble and fat-soluble “face.” These two-faced molecules surround small lipid droplets so that the lipids remain suspended in water instead of clumping together.

\textit{Lipases}, produced by the pancreas and released into the small intestine, can now readily access the triglycerides suspended in these droplets and digest them into monoglycerides and free fatty acids. The products of triglyceride digestion, along with bile acids and other fat-soluble dietary substances, form structures called micelles that deliver dietary lipids to the surface of mucosal cells of the small intestine. Micelles then release the dietary lipids, which are absorbed by the mucosal cells. Once inside mucosal cells, fatty acids and monoglycerides (which, as their name implies, contain only one fatty acid chain) are reassembled into triglycerides. (\textbf{INFOGRAPHIC 5.5})

\textbf{LECI\textsc{H}I\textsc{N}}

the most abundant phospholipid in the body; frequently added to food products, such as salad dressings, as an emulsifier

\textbf{EMULSIFICATION}

a process that allows lipids—fats—to form stable mixtures with water

\textbf{LIP\textsc{A}SE}

enzymes that remove fatty acids from the glycerol backbone of triglycerides
Lipid Digestion and Absorption

The majority of the lipids in our diet are in the form of triglycerides, which must be digested before they can be absorbed. Most triglyceride digestion occurs in the small intestine by pancreatic lipase, with the assistance of bile acids produced by the liver.

**INFOGRAPHIC 5.5**

**EMULSIFICATION ASSISTS THE DIGESTION OF LIPIDS**

1. Bile acids produced in the liver attach to lipid globules.
2. Triglycerides
3. Pancreatic lipase digests the triglycerides to monoglycerides and free fatty acids.
4. Digested lipids and bile acids are packaged into micelles for delivery through digestive fluids to the surface of mucosal cells.
5. Lipids leave the micelle and are absorbed by transporters on the surface of mucosal cells.
6. Lipids are repackaged by the cell into a chylomicron, which moves out of the cell into a lymph vessel.

**EMULSIFICATION ASSISTS THE DIGESTION OF LIPIDS**

- **Fat-soluble side:** Lipid
- **Water-soluble side:** Bile acids

- **Lipid:** Triglycerides
- **Pancreatic lipase:** Monoglycerides and free fatty acids
- **Micelle:** Fat-soluble side
- **Mucosal cell:** Water-soluble side
- **Chylomicron:** Lipids
- **Lymph:** Cholesterol

**Questions:** Why might someone who has had his or her gallbladder surgically removed need to avoid consuming excess fat?
LIPOPROTEIN TRANSPORT
Because most lipids are not soluble in water, they cannot dissolve in the watery environment of the bloodstream and require carriers for transport in it. Lipoproteins are protein-containing spherical particles that act as the primary carriers of lipids in blood. In the mucosal cells of the small intestine, triglycerides, other lipids, and hydrophobic substances of dietary origin are incorporated into a type of lipoprotein called a chylomicron. (Refer to Infographic 5.5.) Unlike other lipoproteins, however, chylomicrons are too large to enter blood immediately after their formation, so they first enter the lymphatic system, which then delivers them into the bloodstream.

Lipoproteins are classified by their density, which is determined by the relative ratios of triglycerides, cholesterol, and proteins present. This classification scheme also separates them by their functions. Chylomicrons (the largest and least-dense particles) and very low-density lipoproteins (VLDLs) are similar in that they both transport primarily triglycerides to adipose tissue and cardiac and skeletal muscles. They differ, however, in their site of origin. (INFOGRAPHIC 5.6)

Chylomicrons originate in the small intestine and carry essentially all lipids consumed through the lymphatic system. Very low-density lipoproteins (VLDLs) are responsible for transporting primarily triglycerides from the liver to adipose tissue, cardiac muscle, and skeletal muscles.

INFOGRAPHIC 5.6   Lipoprotein Structure and Function. Lipoproteins consist of a lipid “cargo” core of triglycerides and cholesterol surrounded by a single layer of phospholipids containing both cholesterol and proteins.

Because the water-soluble heads of the phospholipids are facing outward, the lipoprotein can be transported through the watery environment of the lymph and blood.

Chylomicron
Transports dietary fats and cholesterol from intestines to muscle and adipose tissue.

VLDL
Carries mainly triglycerides from liver to muscle and adipose tissue.

LDL
VLDL is converted to LDL, which primarily carries cholesterol to all cells in the body.

HDL
Picks up cholesterol from the body cells and returns them to the liver.

Approximate percent composition of the lipid cargo for each lipoprotein

Which lipoprotein transports fat and cholesterol from dietary sources?
THE LIPIDS

LOW-DENSITY LIPOPROTEIN (LDL)  
a lipoprotein responsible for transporting primarily cholesterol from the liver through the bloodstream to the tissues

HIGH-DENSITY LIPOPROTEIN (HDL)  
a lipoprotein responsible for transporting cholesterol from the bloodstream and tissues back to the liver

ESSENTIAL FATTY ACIDS  
linolenic acid (omega-3, for example) and linoleic acid (omega-6), which are required in the diet because they cannot be synthesized by the human body

ALPHA-LINOLENIC ACID (LINOLENIC ACID)  
an omega-3 polyunsaturated essential fatty acid found in walnuts, flax seeds, soy, canola oil, and chia seeds; modified in the body to produce eicosapentaenoic acid and docosahexaenoic acid

LINOLEIC ACID  
an omega-6 polyunsaturated essential fatty acid found in seeds and vegetable oils

OMEGA-3 FATTY ACIDS  
polyunsaturated fatty acids that have the first double bond at the third carbon molecule from the methyl end of the chain, associated with a decreased risk of cardiovascular disease and improved brain function

OMEGA-6 FATTY ACIDS  
polyunsaturated fatty acids that have the first double bond at the sixth carbon molecule from the methyl end of the chain. Eicosanoids  

Eicosanoids  
hormonelike signaling molecules synthesized from arachidonic acid and eicosapentaenoic acid

in our diet (shown in Infographic 5.5), whereas VLDLs originate from the liver and carry lipids that have been synthesized there, as well as lipids the liver has removed from blood. As chylomicrons and VLDLs enter the capillaries of adipose tissue and skeletal and cardiac muscle, their triglycerides are broken down to glycerol and fatty acids by the enzyme lipoprotein lipase (LPL) that is present in the capillaries of these tissues. As chylomicrons and VLDLs are depleted of their triglycerides, they are transformed into smaller "remnant" lipoproteins, which increase the proportion of their lipid cargo that is cholesterol. (Refer to Infographic 5.6.) The triglyceride-depleted chylomicrons are referred to as chylomicron remnants, and VLDLs are transformed into cholesterol-rich low-density lipoproteins (LDLs). LDLs are the primary carrier of cholesterol in the blood, transporting cholesterol to essentially all cells. They are often referred to as "bad" cholesterol, as elevated levels are associated with an increase in the risk of heart disease. (INFOLGRAPHIC 5.7)

In contrast, high-density lipoproteins (HDLs) often are referred to as "good" cholesterol. Rather than delivering cholesterol around the body, HDLs pick up as much excess cholesterol as they can from cells throughout the body and return it to the liver, which then uses the cholesterol to make bile acids, excretes it directly into bile, or recycles it. This action explains why high levels of HDL cholesterol are typically associated with a lower risk for heart disease. The commonly held view of cholesterol as being either "good" or "bad," however, is potentially misleading. Cholesterol is necessary for numerous essential functions throughout the body, and because most cells in the body receive cholesterol transported by LDLs, even LDLs are necessary. However, when the LDL cholesterol level rises too high and the HDL cholesterol level drops too low, it is this ratio—meaning the amount of each relative to each other—of lipoproteins (HDL to LDL) that is "bad" because high LDL cholesterol increases the risk of cardiovascular disease. (Refer to Infographic 5.7.) Clinical laboratory tests that monitor blood lipid levels typically measure amounts and types of lipids present in lipoproteins in blood and provide an indication of risk of heart disease.

ESSENTIAL FATTY ACIDS  
The human body needs fatty acids. Most are easily supplied in sufficient amounts through our diet, and if not, we can make them from excess carbohydrates and proteins. Two fatty acids are considered essential fatty acids because they cannot be synthesized by humans and must be supplied through the diet. These are alpha-linolenic acid (commonly called linolenic acid, for short) and linoleic acid. Both linolenic acid and linoleic acid are long-chain polyunsaturated fatty acids with 18 carbon molecules. (INFOLGRAPHIC 5.8)

Linoleic acid is an omega-3 fatty acid—omega-6 fatty acid, so called because the first double bond of the carbon chain is placed in the sixth position, counting from the omega end of the fatty acid. It is needed for normal growth and for synthesis of important hormonelike compounds called eicosanoids. (Refer to Infographic 5.8.) By far, linoleic acid is the most abundant polyunsaturated fatty acid in our diet. The primary sources are cooking oils, salad dressings, nuts, and seeds.

One of the most important functions of essential fatty acids is to provide parent compounds to produce the hormonelike eicosanoids. These compounds are released during injury and stress and regulate blood pressure, inflammation, body temperature, and even pain. Aspirin and similar pain medicines work by blocking the synthesis of prostaglandins, which are one class of eicosanoids. This reduction in prostaglandin synthesis has the effect of not only reducing pain, inflammation, and fever but also
Lipoproteins Circulate Lipids Throughout the Body

Each lipoprotein serves as a vehicle that carries lipids through the watery environment of the bloodstream.

**LIPID TRANSPORT BY CHYLOMICRONS**

- Dietary lipids (primarily triglycerides) are packaged into chylomicrons by mucosal cells in the small intestine.
- In adipose and muscle tissues, chylomicrons are depleted of triglycerides as they are broken down to fatty acids and glycerol by the enzyme lipoprotein lipase (LPL). In the process, chylomicrons are transformed into the much smaller chylomicron remnants.
- Chylomicron remnants are taken up by the liver.

**LIPID TRANSPORT BY VLDL**

- VLDLs (very low-density lipoproteins) are produced in the liver and transport lipids (mainly triglycerides made in the liver) to adipose tissue and muscle.
- As triglycerides are broken down and removed from VLDL by LPL, they eventually become cholesterol-rich LDLs (low-density lipoproteins).
- Virtually all cells in the body take up LDLs from blood when they need cholesterol.

**LIPID TRANSPORT BY HDL**

- HDLs (high-density lipoproteins) are produced in the liver and small intestine. Initially, they contain very little lipid.
- As HDLs circulate throughout the body, they pick up excess cholesterol from cells.
- HDLs return cholesterol to the liver where it can be used to make bile acids or be excreted in bile fluid.

**Question:** Which lipoprotein picks up excess cholesterol from cells and delivers it to the liver for use or excretion?
Linolenic and linoleic acids are two essential fatty acids. The 18-carbon essential fatty acids can each be lengthened into 20-carbon fatty acids, which are used to synthesize hormonelike eicosanoids.

**Essential Fatty Acids**

- **Omega-3 Fatty Acid (Linolenic acid)**
  - Methyl or omega end
  - Omega carbon

- **Omega-6 Fatty Acid (Linoleic acid)**
  - Carboxylic acid end

**Eicosanoid Synthesis**

Essential fatty acids are precursors for the synthesis of hormonelike eicosanoids (such as prostaglandins).

- **18 carbons**
  - Linoleic acid
  - Arachidonic acid
  - Increase clotting and inflammation

- **20 carbons**
  - Omega-6 fatty acids
  - Omega-3 fatty acids

- **+2 carbons**
  - Linolenic acid
  - Eicosapentaenoic acid
  - Decrease clotting and inflammation

- **-2 carbons**
  - Eicosapentaenoic acid
  - Docosahexaenoic acid

**Eicosapentaenoic Acid (EPA)**

A 20-carbon omega-3 fatty acid that can be produced in the body by the metabolism of the essential fatty acid alpha-linolenic acid or provided in the diet by oily fish.

Because linolenic acid converted to eicosapentaenoic acid (EPA) inefficiently we make less than adequate quantities of EPA derived eicosanoids when dietary intake of EPA is low.

Limited amounts of EPA are converted to DHA in our body by adding 2 carbons.

In contrast, DHA can readily be converted to EPA in our body by removing 2 carbons.

Seek these types of fats. Omega-3 fatty acids are found in fatty fish, such as salmon, and in some oils, such as canola oil.

Reducing blood clotting. Two polyunsaturated fatty acids that are directly used for eicosanoid synthesis are arachidonic acid and *eicosapentaenoic acid (EPA)*, which are 20-carbon fatty acids made from linoleic and linolenic acids, respectively.

The effect of an eicosanoid on body functions depends on the fatty acid from which it is made. Blood clotting and inflammation is promoted when there is excess production of eicosanoids from arachidonic acid (an omega-6 fatty acid), compared with those produced from EPA (an omega-3 fatty acid).
Essential Fatty Acids

Blood clotting and inflammation are decreased when the production of eicosanoids from EPA increases. Because of these opposing effects, it is desirable to have a proper balance of omega-6 and omega-3 fatty acids in the diet. Although neither EPA nor the longer 22-carbon DHA (docosahexaenoic acid) are essential fatty acids—in fact, DHA can be made from EPA—we do not effectively convert linolenic acid to EPA or DHA. We can more efficiently boost EPA and DHA concentrations in our body by regularly eating fish, particularly fatty fish like salmon, albacore tuna, trout, and sardines, which are excellent sources of these fatty acids. (INFOGRAPHIC 5.9)

INFOGRAPHIC 5.9 Dietary Sources of Essential Fatty Acids

The diets of most individuals living in the United States provide too little omega-3 fatty acids. When possible, choose foods and cooking oils that will increase your intake of these fatty acids.

**FOOD SOURCES OF ESSENTIAL FATTY ACIDS**

<table>
<thead>
<tr>
<th>Food Source</th>
<th>Saturated</th>
<th>Monounsaturated</th>
<th>Polyunsaturated</th>
<th>Omega-6</th>
<th>Omega-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaxseed oil</td>
<td>10</td>
<td>19</td>
<td>15</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Tuna (Albacore)</td>
<td>29</td>
<td>29</td>
<td>4</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Salmon (Chinook)</td>
<td>28</td>
<td>50</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walnuts</td>
<td>10</td>
<td>14</td>
<td>61</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Canola oil</td>
<td>8</td>
<td>64</td>
<td>19</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Soybean oil</td>
<td>16</td>
<td>24</td>
<td>53</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>11</td>
<td>20</td>
<td>69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Almonds</td>
<td>8</td>
<td>66</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olive oil</td>
<td>14</td>
<td>75</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>37</td>
<td>47</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground beef</td>
<td>10</td>
<td>53</td>
<td>2</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Butter</td>
<td>68</td>
<td>28</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coconut</td>
<td>94</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What are two foods/oils that are high in omega-6 fatty acids and provide a reasonable, good source of omega-3 fatty acids?
Because fish is the primary source of DHA and EPA in the American diet, Morris and her team conducted a study that evaluated the effects of fish consumption and total intake of omega-3 fatty acids on risk of developing AD. For the study, about 800 elderly individuals were followed for four years. The results of this study showed an impressive 60% reduction in AD among those who consumed even one fish meal a week compared to those who ate fish less frequently or never. Other studies have also shown that increased fish consumption is linked to a reduced risk of AD. Total intake of omega-3 fatty acids and DHA were associated with lower risk of AD, although no specific protective benefit with EPA alone was found.

Another research group studied the effects of DHA levels in blood on risk of developing AD and other forms of dementia. After a nine-year follow-up period, they found that patients with the highest levels of blood DHA showed nearly a 50% lower risk of developing dementia. Of note, levels of EPA in blood were not shown to affect dementia risk.

It appears then that DHA plays a key role in protecting the brain from damage and in decreasing AD risk. Morris notes that of all the lipids, DHA is most important for AD. DHA appears to reduce risk via several mechanisms, most notably by producing beneficial compounds that reduce inflammation in the brain and protect it from damage that may contribute to the cause of the disease.

Additional research will help elucidate the specific mechanisms of DHA in slowing cognitive decline. Most current knowledge is based on animal studies. According to Morris, DHA added to animal models has been shown to increase enzymes that protect the brain from damage, reduce brain inflammation, and improve nerve function while decreasing brain damage due to restricted blood supply. It is the hope of Morris and others in her field that further study in humans will confirm that DHA has the potential to reduce risk of AD and other forms of dementia.

**TRANS FATS**

Most people who eat a Western diet—such as North Americans and many Europeans—consume plenty of fat, just not necessarily the right kinds. Until recently, too much of the fat we consumed had undergone a process of hydrogenation, which makes unsaturated fats more solid and stable by chemically adding hydrogen to each carbon atom, flanking a double bond on the fatty acid chain to make them more saturated. This renders them harder at room temperature and more resistant to becoming rancid (oxidation and/or decomposition that can occur in unsaturated fats, resulting in an unpleasant taste and smell).

One outcome of partial hydrogenation, however, is that the structure of some of the unsaturated fatty acids is converted from their natural cis configuration to another configuration known as trans. These trans fatty acids raise levels of LDL cholesterol and lower levels of HDL cholesterol in blood, thereby increasing the risk of heart disease more than any other type of fat. As little as 1% of total calories from trans fats can increase the risk of heart disease, stroke, or sudden death from these conditions and other causes. Given the risks of trans fats, the U.S. Food and Drug Administration banned added trans fats (partial hydrogenated oils) from foods except in special circumstances. This ban went into effect on June 18, 2018, with Canada banning its use on September 15, 2018. Although a small amount of trans fat is naturally present in dairy products and beef, most of the trans fat we consumed prior to the ban had come from the partially hydrogenated oils used to extend the shelf life of processed foods or to increase the melting point of vegetable oils. Do not be alarmed, however, if you see fully hydrogenated oils in the list of ingredients, as all double bonds have been eliminated in full hydrogenation and consequently no trans fats are produced.

**CURRENT FAT INTAKE AND RECOMMENDATIONS**

Our understanding of the role of fat in the diet is constantly changing. The dietary recommendations for fat intake have changed...
Current Fat Intake and Recommendations

over the years as new scientific evidence and population studies are released and research continues to evolve. The changing and sometimes conflicting messages about dietary fats can create confusion about what to believe and what foods to buy.

Since the early 1980s, in response to health messages and consumer demand, the marketplace has produced and promoted reduced-fat foods, including commercially formulated versions of typically higher-fat products, which have a smaller percentage of calories from fat (and often saturated fat). But the total amount of fat that Americans consume has not decreased because we simply eat more food (and calories) than we did before. Today, approximately one-third of the calories that American men and women consume come from fat. Surveys suggest that we are eating less fat from some sources, such as meat and dairy (opting for low-fat milk, for instance), but getting more fat in our diets from other sources, such as high-fat snack foods and baked goods.

Within our overall fat intake, it is recommended that we emphasize unsaturated fats over saturated fats when choosing foods and added fats. (INFGRAPHIC 5.10)

To promote health and reduce the risk of chronic disease, the Acceptable Macronutrient Distribution Range (AMDR) for total fat has been set at 20–35% of our total calories. (INFOGRAPHIC 5.11)

Morris and her colleagues examined the effects of two well-known diets on AD risk. Both the Mediterranean diet and DASH (Dietary Approaches to Stop Hypertension) diet have been shown to reduce cardiovascular disease, obesity, and diabetes—all conditions that are also associated with cognitive decline. Their study found that elderly individuals whose dietary patterns

INFGRAPHIC 5.10  Sources of Saturated Fat in the U.S. Population

- Burgers and sandwiches account for 19% of the saturated fats in the diets of people age 2 and older.


Percent Saturated Fat Contribution to Diet
The AMDR for total fat is 20–35% of total calories, and most of those calories should come from unsaturated fats.

What's Your Strategy for Choosing Healthier Fats?
In an attempt to eat healthier, people too often purchase low- or reduced-fat foods that are often high in refined carbohydrates and added sugars or saturated fats. Try a different strategy—replace harmful fats with those that are beneficial. As you work to reduce your consumption of harmful fats, food labels can help guide your choices.

Ingredients:
Enriched Wheat Flour, Sugar, Semi-Sweet Chocolate Chips (Sugar, Chocolate, Milkfat, Cocoa Butter, Soy Lecithin), White Chips (Sugar, Fractionated Palm Kernel Oil, Milk, Nonfat Milk, Fully-Hydrogenated Palm Oil, Soy Lecithin, Natural Flavor), Vegetable Oil (Palm Oil, Canola Oil), Water, 2% or Less of Corn Syrup Solids, Eggs, Molasses, Salt, Baking Soda, Sodium Aluminum Phosphate, Natural Flavor, Vanilla Extract.

% OF CALORIES FROM FAT: Look beyond the grams of total fat, and determine the percentage of total calories that are provided by fat. To do this, multiply fat grams by 9 to determine the number of kcals from fat (4.5 x 9 = 40.5 kcals), divide fat calories by total calories, and multiply by 100. (40.5 ÷ 90) × 100 = 45% of calories from fat. That’s above the upper end of the AMDR range of 35% for fat.

UNHEALTHY SATURATED AND TRANS FATS: Even when total fat is low, unhealthy fats may be high. Half of the fat in this product is from saturated fats. Note that the %DV for saturated fats is much higher than for total fat.

TRANS FAT: The adding of artificial trans fats to foods was banned by the FDA in July 2018, so this value will generally be zero, unless the food has large amounts of beef or lamb meat with naturally occurring trans fats.

CHECK FOR SOURCES OF SATURATED FAT: Fully hydrogenated and tropical oils (coconut, palm, and palm kernel oils) are sources of saturated fat.

What parts of a Nutrition Facts panel can help you reduce your intake of saturated fat? How can it help you identify unsaturated fat content? How can a food label help you understand whether a food product is within the AMDR range for fat?
Current Fat Intake and Recommendations

most closely resembled these diets experienced a much slower decline in cognitive function over a period of 10 years. Morris and her team then devised a new approach that incorporated specific foods from these two diets with other foods demonstrated to have cognitive benefits, in what they called the MIND (Mediterranean-DASH Intervention for Neurodegenerative Delay) Diet.

The MIND diet includes green leafy vegetables, berries, beans, nuts, whole grains, poultry, and fish. The MIND diet also limits the intake of red meats, cheese, and butter and reduces saturated fat by substituting olive oil in place of butter and margarine. To assess the effect of diet on the risk of AD, the Morris-led team devised a scoring method to determine how closely individuals’ diets resembled the MIND diet. They examined the diets of about 900 individuals over about a five-year period and found that elderly individuals whose diets either highly or moderately adhered to the MIND diet were significantly less likely to be diagnosed with AD.

More recently, the ability of the MIND diet to preserve cognitive function was examined in approximately 6000 elderly adults. This study found that seniors whose diets were closely aligned with the MIND diet were 35% less likely to exhibit poor cognitive performance and that those whose diets only moderately aligned with the MIND diet were 24% less likely to demonstrate poor cognitive performance. Similarly, another recent study found that among more than 7000 elderly women, those whose diets best resembled the MIND diet had a 34% lower risk of developing AD after an average follow-up period of about 13 years.

Although the results of these studies are quite promising, intervention trials that prescribe the MIND diet to study participants and compare their risk of AD to those who follow a control diet must be performed to verify a cause-and-effect relationship between this diet and risk of AD. Other intervention studies have demonstrated that both a Mediterranean diet and the DASH diet reduce the development of AD.

What is known to date about the connection between diet and AD seems promising: Certain dietary fats, perhaps most significantly DHA, which is readily available in seafood, are integral to brain development and protection throughout a person’s life. Fish in particular, Morris asserts, is “brain food.”

STAY TUNED
For more on the Mediterranean and DASH diets, as well as the role of plant-based diets in reducing risk of certain diseases, see Spotlight C.
CHAPTER 5 BRING IT HOME

Choosing added or cooking fats

Do you spread butter or margarine on your toast in the morning? At a restaurant, do you dip your bread in olive oil or spread butter on it? Do you add butter or margarine to your baked potato? When you prepare a meal, what type of fat do you use to sauté vegetables? Using the food labels provided here, answer the questions about these commonly used fats.

Consider

1. To moderate saturated fat intake, which of the dietary fats (butter, canola oil, coconut oil, and so forth) would you use sparingly?

2. Of these dietary fats, why is butter the only source of dietary cholesterol?

3. At a restaurant, you have the option of spreading butter on your bread or dipping your bread in a seasoned olive oil. Which would you choose? Why?

4. You observe a friend preparing a pasta dish using a large amount of olive oil. Your friend says, “This stuff is great for you!” How might you respond? (Hint: Note the % Daily Value for total fat on the label for olive oil.)

TAKE IT FURTHER

Despite its high concentration of saturated fat, coconut oil has been advertised as a healthy fat and promoted on television for multiple benefits. Explore some of the science behind the claims for coconut oil by searching “coconut oil” at www.pubmed.gov. After reading two or three abstracts about the role of coconut oil in health, do you believe the evidence is sufficient to recommend the use of coconut oil as a cooking fat on a regular basis? What might you tell a friend who asks, “Is coconut oil healthy?”
Lipids make up a group of structurally diverse compounds composed of carbon, hydrogen, and a small amount of oxygen that are insoluble in water.

Among their varied functions in the body, lipids serve as a component of cell membranes, as protection and insulation of internal organs in nutrient transport, and as precursors for hormones.

The four classes of lipids are fatty acids, triglycerides, sterols, and phospholipids.

Fatty acids are the primary components of triglycerides and phospholipids. Dependent upon the number of hydrogen atoms filling their carbon bonds, fatty acids are either saturated or unsaturated with one or more double bonds determining their function in the body as well as their role in health and disease.

Triglycerides, commonly referred to as fat, are the primary storage form of lipid in our bodies and the primary source of lipid in our diet, providing a concentrated energy source, essential fatty acids, and carriers of fat-soluble vitamins.

Cholesterol is a sterol synthesized primarily by the liver in amounts sufficient to meet our needs, but it is also consumed through foods of animal origin.

Most lipid digestion occurs in the small intestine facilitated by bile acids, the process of emulsification, and the action of lipases.

Protein-rich lipoproteins transport lipids in the bloodstream and include chylomicrons, very low-density lipoproteins (VLDLs), low-density lipoproteins (LDLs), and high-density lipoproteins (HDLs). Lipoproteins are classified according to their density and their function; they differ in which lipids they carry to which body parts.

The essential fatty acids include alpha-linolenic acid (an omega-3 fatty acid) and linoleic acid (an omega-6 fatty acid), which are required for the synthesis of longer-chain fatty acids and, in turn, the production of eicosanoid.

Depending on the type and amount in the diet, fat can have positive and negative health effects.

The current recommended fat intake is 20–35% of total calories.

Although some trans fatty acids (trans fats) are naturally occurring, they can be produced through partial hydrogenation of polyunsaturated fats, but consumption of trans fats increases the risk of heart disease more than any other type of fat. The FDA banned added trans fats in 2018.
NEED TO KNOW

Review Questions

1. Characteristics of lipids include all of the following, EXCEPT that they:
   a. are structurally similar compounds with specific functions.
   b. are composed of carbon, hydrogen, and oxygen.
   c. include triglycerides, phospholipids, and sterols.
   d. are generally insoluble in water.

2. Dietary fat contributes to satiety by:
   a. adding to the effect of high-carbohydrate foods in raising blood glucose levels.
   b. increasing the rate at which food passes through the GI tract.
   c. prolonging the time food stays in the stomach.
   d. producing bulk to fill the stomach.

3. All of the following are true in regards to adipose tissue, EXCEPT that:
   a. it is composed primarily of adipocytes.
   b. excess is associated with improved fertility.
   c. it is a storage site for energy.
   d. it provides insulation for the body’s organs.
   e. it is a storage site for fat-soluble vitamins.

4. Structurally, fatty acids:
   a. consist of carbon chains of similar lengths.
   b. differ in their degree of saturation.
   c. are composed of carbon rings with a hydrocarbon side chain.
   d. have a hydrogen and an oxygen attached to each carbon.

5. A serving of cookies has 7 grams of fat. How many calories from fat would these cookies provide?
   a. 7 calories
e. 70 calories
   b. 28 calories
   c. 49 calories
   d. 63 calories
   e. 63 calories

6. Cholesterol is a sterol that:
   a. must be consumed in the diet to meet the body’s needs.
   b. provides 9 calories per gram.

7. Emulsification of fats in the small intestine requires the presence of:
   a. bile acids.
   b. hydrochloric acid.
   c. lipases.
   d. cholesterol.
   e. insulin.

8. Low-density lipoproteins (LDLs):
   a. transport cholesterol from the body’s tissues back to the liver.
   b. transport cholesterol to essentially all cells in the body.
   c. lower the risk of heart disease as their levels increase.
   d. aid in the digestion of lipids in the small intestine.
   e. are derived from chylomicrons as triglycerides are removed.

9. Linoleic acid and linolenic acid:
   a. can be synthesized from phospholipids in the body.
   b. are both classified as omega-3 fatty acids.
   c. must be consumed through the diet to meet the body’s needs.
   d. are both saturated fatty acids.
   e. are both trans fatty acids.

10. Omega-3 fatty acids:
    a. can be synthesized in the body in sufficient amounts to meet our needs.
    b. consumed in the United States in proportionally higher amounts than omega-6 fatty acids.
    c. are supplied in the U.S. diet primarily through vegetable oils.
    d. provide a source of linoleic acid.
    e. provide a source of alpha-linolenic acid.
11. All of the following are true statements regarding trans fatty acids, EXCEPT:
   a. trans fatty acids are produced by complete hydrogenation of unsaturated fatty acids.
   b. trans fatty acids are present in small amounts in meats and full-fat dairy foods.
   c. trans fatty acids can increase LDL cholesterol levels.
   d. adding trans fatty acids to foods was banned by the FDA in 2018.

12. What is the AMDR for total calories from dietary fat for adults?
   a. 5–20%
   b. 10–25%
   c. 15–30%
   d. 20–35%
   e. 25–40%