Nutrition
Lipids
Function of Lipids

In the diet, fats enhance flavor, mouthfeel, and prolong satiety through slower gastric emptying

- In the body, fat provides a concentrated source of energy; storage of fat (adipose tissue) provides an energy reserve, insulation, and shock protection

- Part of cell membrane structure

- Provides precursors for biologically important substances (e.g., essential fatty acids, cholesterol)
Function of Lipids

- **Storing Fat as Fat**
  - Provides twice the energy as carbohydrate and protein
  - Adipose tissue readily stores fat.
  - Lipoprotein lipase (LPL) hydrolyzes triglycerides from lipoproteins
    - Produces glycerol, fatty acid & monoglycerides
    - These enter the adipose cell and are reassembled into triglycerides
Adipose Cell

Newly imported triglycerides first form small droplets at the periphery of the cell, then merge with the large, central globule.

Large central globule of (pure) fat

Cell nucleus

Cytoplasma

As the central globule enlarges, the fat cell membrane expands to accommodate its swollen contents.

Lipids in the Body

• The liver can also convert excess carbohydrate and protein to fat.
• Fat needs carbohydrate to break down efficiently.
• Inefficient breakdown of fat forms ketone bodies.
Lipids in the Body

● Using Fat for Energy
  ● Hormone-sensitive lipase inside the adipose cells hydrolyzes triglycerides when needed for energy.
  ● Fat is metabolized during fasting, but fat requires carbohydrate and protein for complete breakdown.
  ● Ketone bodies can be made from fat fragments.
Methyl end

H—C—C—OH

H

H

Acid end

Fatty Acid
The Lipids

- Fatty Acid compared to a simple sugar
  - Both are composed of carbon, hydrogen and oxygen
  - Fatty acids have more carbon, less oxygen than sugars
  - Fatty acids can be various size molecules
    - Short chain fatty acids = less than 6 carbons
    - Medium chain fatty acids = 6-10 carbons
    - Long chain fatty acids – 12-24 carbons
  - There are three 6-carbon sugars important in human diets, i.e., glucose, fructose, galactose
The Lipids

• The Length of the Carbon Chain
  • Long-chain fatty acids (12-24 carbons) are found primarily in meat, fish, & vegetable oils.
  • Whether they are solid or liquid at room temperature depends on their degree of saturation (i.e., number of double bonds)
The Lipids

**The Length of the Carbon Chain**

- Medium (6-10 carbons) and short-chain fatty acids (fewer than 6 carbons) are found in dairy products and some tropical oils.
- Medium & short chain fatty acids tend to be liquid at room temperature regardless of saturation.
The Lipids

The Degree of Unsaturation

- **Saturated** fatty acids carry the maximum possible number of hydrogen atoms.
- **Unsaturated** fatty acids lack hydrogen atoms and have at least one double bond.
- The double bond is considered the point of unsaturation.
Firmness of the Fat

- Saturated fats are solid at room temperature.
- Polyunsaturated fats are liquid at room temperature.
- Shorter fatty acid chains are softer at room temperature than longer chains.
The Lipids

- **Stability**
  - Saturated fat is more resistant to oxidation.
  - Monounsaturated fat is slightly less susceptible to spoilage.
  - Polyunsaturated fat spoils most readily.
- **Protection from rancidity**
  - Sealed in airtight containers away from light
  - Add antioxidants
  - Hydrogenation
Fatty Acids

- Monounsaturated fatty acids
  - lack two hydrogen atoms
  - have one double bond.
- Polyunsaturated fatty acids (PUFA)
  - lack four or more hydrogen atoms
  - have at least two or more double bonds.
- When most of the fatty acids in a fat are monounsaturated it is called a monounsaturated fat
- When most are polyunsaturated it is called a polyunsaturated fat.
Stearic acid, an 18-carbon saturated fatty acid

Oleic acid, an 18-carbon monounsaturated fatty acid

Linoleic acid, an 18-carbon polyunsaturated fatty acid

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Composition of Dietary Fats

Animal fats and the tropical oils of coconut and palm are mostly **saturated** fatty acids.

- Coconut oil
- Butter
- Beef tallow
- Palm oil
- Lard

Some vegetable oils, such as olive and canola, are rich in **monounsaturated** fatty acids.

- Olive oil
- Canola oil
- Peanut oil

Many vegetable oils are rich in **polyunsaturated** fatty acids.

- Safflower oil
- Flaxseed oil
- Walnut oil
- Sunflower oil
- Corn oil
- Soybean oil
- Cottonseed oil

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Trans Fatty Acids (Synthetic Sources)

- Hydrogenation of liquid (unsaturated) fats
  - Protects against oxidation & prolongs shelf life
  - Alters texture of the fat (important in food processing, baking, etc)

- Trans-Fatty Acids
  - Created by partial hydrogenation of liquid fats
    - Fatty acids, artificially altered from cis to trans configuration
  - Act like saturated fats in the body
    - Increase LDL cholesterol in the body.
    - May decrease HDL cholesterol levels when they replace saturated fats in the diet
Hydrogenation of Fatty Acids

Polyunsaturated fatty acid  \[\rightarrow\]  Hydrogenated (saturated) fatty acid
A *cis*-fatty acid has its hydrogens on the same side of the double bond; *cis* molecules fold back into a U-like formation. Most naturally occurring unsaturated fatty acids in foods are *cis*.

A *trans*-fatty acid has its hydrogens on the opposite sides of the double bond; *trans* molecules are more linear. The *trans* form typically occurs in partially hydrogenated foods when hydrogen atoms shift around some double bonds and change the configuration from *cis* to *trans*.
Trans Fatty Acids - Natural (Ruminant) Sources

- A heterogeneous group of positional & geometric isomers of linoleic acid
- Found primarily in milk, milk products, meat and meat products of ruminants
  - Conjugated linoleic acid (CLA)
    - naturally occurring trans fat that may be beneficial to health.
  - Positive health effects attributed to CLA
    - mostly based on cell culture models & animal studies
The Location of Double Bonds

- The omega number refers to the position of the first double bond nearest the methyl end (CH$_3$) of the carbon chain.
- An omega-3 fatty acid has the location of the double bond in the third position, e.g., the essential fatty acid, linolenic acid.
- An omega-6 fatty acid has the location of the double bond in the sixth position, e.g., the essential fatty acid, linoleic acid.
Omega-3 and Omega-6 Fatty Acids

Linolenic acid, an omega-3 fatty acid

Linoleic acid, an omega-6 fatty acid
Essential Fatty Acids

- The human body cannot produce a carbon to carbon double bond before the 9th carbon in the fatty acid chain (Omega-9 fatty acid)
- Omega 3 fatty acid: double bond is in the number 3 carbon from the methyl end
- Omega 6 fatty acid: double bond is in the number 6 position from the methyl end
Essential Fatty Acids

- Alpha-linolenic Acid (ALA)
  - An omega-3 fatty acid
  - An essential fatty acid (i.e., cannot be synthesized by humans)
- Linoleic Acid (LA)
  - An omega-6 fatty acid
  - An essential fatty acid (i.e., cannot be synthesized by humans)
Long-Chain n-3 & n-6 Fatty Acids

- Eicosapentaenoic acid (EPA) & docosahexaenoic acid (DHA) can be synthesized from ALA but this synthesis may be insufficient under certain conditions. (Long chain n-3 fatty acids)
- Arachidonic acid (AA) can be synthesized from LA (Long chain n-6 fatty acids).
Omega 3 Fatty Acids

- Sources of linolenic acid are walnuts, flaxseed oil, soybean & canola oils
- Sources of EPA and DHA (long chain Omega 3 fatty acids) are fatty fish (e.g., herring, salmon, mackerel & tuna) & fish oils and algal oils
Omega -6 Fatty Acids

- Sources of Linoleic acid (LA) include vegetable oils, poultry fat, nuts & seeds
- Sources of Arachidonic acid (AA) (long chain Omega 6 fatty acids) include meats, poultry & eggs
Essential Fatty Acids (ALA & LA)

- Structural components of cell membranes
  - Incorporated into phospholipids
  - Affect cell membrane properties such as
    - Fluidity
    - Flexibility
    - Permeability
    - Activity of membrane-bound proteins

- Eicosanoids
  - Potent chemical messengers
  - Play critical roles in immune & inflammatory responses
Eicosanoids

- Omega-3 derived eicosanoids
  - Dilate blood vessels
  - Discourage blood clotting
  - Reduce inflammation

- Omega-6 derived eicosanoids
  - Increase cell proliferation
  - Constrict blood vessels
  - Promote inflammation
  - Promote blood clotting
Omega 3 Fatty Acids

- Clear benefits of long chain n-3 fatty acids have been shown for:
  - Reducing high blood pressure
  - Reducing elevated blood triglycerides
  - Reducing risks of mortality in people with a history of cardiovascular disease

- Benefits have been studied in other conditions but benefits are not as clearly established

- NIH, National Library of Medicine, 2010
Essential Fatty Acids

- N-3 fatty acids are required for normal conception, growth & development of an embryo
  - DHA (long-chain n-3 fatty acid) is found in high concentrations in the brain and retinal membrane and is assumed to play a critical role in both vision and cognitive function
DRI Recommended Intakes

- Not enough evidence to determine specific requirements
- AI based on highest median intakes of healthy US populations
- Linoleic Acid (Omega-6)
  - Men 19-50 years – 17 g/day
  - Women 19-50 years – 12 g/day
- Linolenic Acid (Omega-3)
  - Men– 1.6 g/day
  - Women– 1.1 g/day
Omega-6 and Omega-3 fatty acids compete for the same enzymes so an increase in the availability of one relative to the other can have an impact on what eicosanoids are more abundant.

- Western & U.S. diets tend to be much higher in Omega-6 fatty acids relative to Omega-3’s with ratios of 15:1 and higher.
- Expert sources differ as to what constitutes an appropriate ratio between Omega 6 and Omega 3 fatty acids.
2006: American Heart Association statement encouraged increased consumption of Omega-3 fatty acids by consuming 2 servings of fish, especially oily fish, each week.

Problems have also been noted in individuals who consume too much Omega-3 fatty acids.
Essential Fatty Acids (EFA’s)

- Fatty Acid Deficiencies
  - Are rare in U.S. and Canada
  - Occur in infants and children with fat-free or low-fat diets
The Lipids

- Triglycerides are lipids with three fatty acids attached to a glycerol.
- Most triglycerides contain a mixture of fatty acids
  - Saturated
  - Monounsaturated
  - Polyunsaturated
Phospholipids and Sterols

- Phospholipids and sterols have unique chemical structures that allow them to have unique roles in the body.
  - Phospholipids contain glycerol, two fatty acids and a phosphate group with a molecule of choline.
    - Their structure makes them soluble in both water and fat
  - Sterols have a multiple-ring structure.
Phospholipids

From glycerol

From phosphate

From 2 fatty acids

The plus charge on the N is balanced by a negative ion—usually chloride.

From choline
Phospholipids and Sterols

Roles of Phospholipids

- Enable transport of lipids across cell membranes (because they are soluble in both water & fat)
- Emulsifiers
Phospholipids of a Cell

Outside cell

- Watery fluid
- Glycerol heads
- Fatty acid tails

Inside cell

Watery fluid
Phospholipids and Sterols

Phospholipids in Foods

- Used as emulsifiers in food industry
- A well-known phospholipid is lecithin.
  - Food sources of lecithin include eggs, liver, soybeans, wheat germ and peanuts.
Phospholipids and Sterols

Sterols in Foods

- Found in plant and animal foods
- Cholesterol is found in animal foods only—meat, eggs, fish, poultry and dairy products (exogenous).
- Plant sterols are not absorbed in the GI tract and can prevent absorption of cholesterol as well.
Comparison of Cholesterol and Vitamin D
Sterols

- Roles of Cholesterol
  - Starting material for bile acids, sex & adrenal hormones, and vitamin D
  - Structural component of cell membranes
- Liver produces 800-1500 mg cholesterol per day (endogenous).
- Atherosclerosis is a disease that causes heart attacks. Elevated blood cholesterol levels are implicated in the development of atherosclerosis.
Health Implications of Lipids

- Transport of Lipids
  - LDL (Low-Density Lipoproteins)
    - Composed primarily of cholesterol
    - Transports lipids to the tissues
    - Removed from circulation by the liver
  - HDL (High-Density Lipoproteins)
    - Made by the liver to transport cholesterol from the cells back to the liver
    - Composed primarily of protein
Health Implications of Lipids

- High LDL is associated with higher risk of heart attack and is known as “bad” cholesterol.

- High HDL seems to have a protective effect and is known as “good” cholesterol.
Health Implications of Lipids

- Factors that lower LDL and/or raise HDL
  - Weight control
  - Replace saturated fat with monounsaturated fat and polyunsaturated fat in the diet
  - Limit intake of “trans” fats
  - Soluble fibers
  - Plant sterols
  - Moderate alcohol consumption
  - Physical activity

- Genes also influence lipoprotein activity.
Health Effects and Recommended Intakes of Lipids

- **Blood lipid profile**
  - Reveals concentrations of lipids in the blood
  - **Desirable levels**
    - Total cholesterol < 200 mg/dL
    - LDL cholesterol < 100 mg/dL
    - HDL cholesterol ≥ 60 mg/dL
    - Triglycerides < 150 mg/dL
Health Effects and Recommended Intakes of Lipids

- Heart Disease
  - Elevated blood cholesterol is a risk factor for cardiovascular disease.
  - Cholesterol accumulates in the arteries, restricts blood flow and raises blood pressure.
  - Saturated fat in the diet raises blood cholesterol.
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.
Health Effects and Recommended Intakes of Lipids

- **Risks from Saturated Fats**
  - Saturated fat in the diet raises LDL cholesterol, which increases risk of heart disease.
  - Food sources include
    - whole milk, cream, butter, cheese, high-fat cuts of beef and pork, and coconut, palm and palm kernel oils.
Sources of Saturated Fat

Note that fruits, grains, and vegetables are insignificant sources, unless saturated fats are intentionally added to them during preparation.
Health Effects and Recommended Intakes of Lipids

• Risks from *Trans* Fats (Synthetic Sources)
  • *Trans*-fatty acids in the diet increase LDL cholesterol and decrease HDL cholesterol.
  • Food sources include
    • deep-fried foods using vegetable shortening, cakes, cookies, doughnuts, pastry, crackers, snack chips, margarine, imitation cheese, and meat and dairy products.
  • Debate over butter versus margarine
Health Effects and Recommended Intakes of Lipids

- **Risks from Dietary Cholesterol**
  - Dietary cholesterol has less effect on blood cholesterol than saturated fat and *trans* fat.
  - Sources of cholesterol include **ANIMAL** Foods:
    - egg yolks, milk products, meat, poultry and shellfish.
Health Effects and Recommended Intakes of Lipids

- **Benefits from Monounsaturated Fats and Polyunsaturated Fats**
  - Replacing saturated fat and trans fat with monounsaturated fat and polyunsaturated fat is the most effective dietary strategy in preventing heart disease.
Health Effects and Recommended Intakes of Lipids

- Benefits from Monounsaturated Fats and Polyunsaturated Fats
  - Food sources of monounsaturated fat include:
    - olive, canola and peanut oil and avocados.
  - Food sources of polyunsaturated fat include:
    - vegetable oils (safflower, sesame, soy, corn and sunflower), nuts and seeds.
Health Effects and Recommended Intakes of Lipids

- **Benefits from Omega-3 Fats**
  - Beneficial effects in reducing risk of heart disease and stroke
  - Food sources include
    - vegetable oils (canola, soybean and flaxseed), walnuts and flaxseeds), and
    - fatty fish (mackerel, salmon, and sardines)
  - Need to avoid fish with high levels of mercury
Health Effects and Recommended Intakes of Lipids

- Balance Omega-6 and Omega-3 Intakes
  - Eat more fish (2 3-oz. portions per week) and less meat.
  - Bake, broil or grill the fish.
  - Functional foods are being developed.
    - Functional foods = foods that contain physiologically active compounds that provide health benefits beyond their nutrient contribution.
Health Effects and Recommended Intakes of Lipids

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

✓ Obesity can be a consequence of high-fat, high-kcalorie diets in excess of energy needs.
Health Effects and Recommended Intakes of Lipids

- Recommended Intakes of Fat
  - DRI
    - Acceptable Macronutrient Distribution Range (AMDR):
      - 20-35% of energy intake
Health Effects and Recommended Intakes of Lipids

- Dietary Guidelines for Americans 2010
  - Consume less than 10% of calories from saturated fat
  - Consume less than 300 mg per day of dietary cholesterol
  - Keep trans fatty acid consumption as low as possible
  - Reduce the intake of calories from solid fats
Cutting Fat Cuts Kcalories and Saturated Fat

Pork chop with fat (340 kcal, 19 g fat, 7 g saturated fat).

Potato with 1 tbs butter and 1 tbs sour cream (350 kcal, 14 g fat, 10 g saturated fat).

Whole milk, 1 c (150 kcal, 8 g fat, 5 g saturated fat).

Pork chop with fat trimmed off (230 kcal, 9 g fat, 3 g saturated fat).

Plain potato (200 kcal, <1 g fat, 0 g saturated fat).

Fat-free milk, 1 c (90 kcal, <1 g fat, <1 g saturated fat).

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Health Effects and Recommended Intakes of Lipids

Guidelines to Groceries
- Very lean and lean options of meats and meat alternates should be chosen.
- Choose fat-free and low-fat milks and milk products.
- Choose a wide variety of vegetables, fruits, and whole grains.
- Avoid invisible fat from high-fat cheese and baked and fried foods.
- Choose wisely from many available food products.
Potential Relationships among Dietary Saturated Fatty Acids, LDL Cholesterol, and Heart Disease Risk

- 1% increase in dietary saturated fatty acids
  → 2% increase in LDL cholesterol
  → 2% increase in heart disease risk
- 1% decrease in dietary saturated fatty acids
  → 2% decrease in LDL cholesterol
  → 2% decrease in heart disease risk

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