

17.6 What Food Substances Form the Basis of Human Nutrition?

The use of foods by organisms is termed **nutrition**. The ability of an organism to use a particular food material depends upon its chemical composition and upon the metabolic pathways available to the organism. In addition to essential fiber, food includes the macronutrients—protein, carbohydrate, and lipid—and the micronutrients—including vitamins and minerals.

Humans Require Protein

Humans must consume protein in order to make new proteins. Dietary protein is a rich source of nitrogen, and certain amino acids—the so-called **essential amino acids**—cannot be synthesized by humans (and various animals) and can be obtained only in the diet. The average adult in the United States consumes far more protein than required for synthesis of essential proteins. Excess dietary protein is then merely a source of metabolic energy. Some of the amino acids (termed **glucogenic**) can be converted into glucose, whereas others, the **ketogenic** amino acids, can be converted to fatty acids and/or keto acids. If fat and carbohydrate are already adequate for the energy needs of the individual, then both kinds of amino acids will be converted to triacylglycerol and stored in adipose tissue.

An individual's protein undergoes a constant process of degradation and resynthesis. Together with dietary protein, this recycled protein material participates in a nitrogen equilibrium, or **nitrogen balance**. A positive nitrogen balance occurs whenever there is a net increase in the organism's protein content, such as during periods of growth. A negative nitrogen balance exists when dietary intake of nitrogen is insufficient to meet the demands for new protein synthesis.

Carbohydrates Provide Metabolic Energy

The principal purpose of carbohydrate in the diet is production of metabolic energy. Simple sugars are metabolized in the glycolytic pathway (see Chapter 18). Complex carbohydrates are degraded into simple sugars, which then can enter the glycolytic pathway. Carbohydrates are also essential components of nucleotides, nucleic acids, glycoproteins, and glycolipids. Human metabolism can adapt to a wide range of dietary carbohydrate levels, but the brain requires glucose for fuel. When dietary carbohydrate consumption exceeds the energy needs of the individual, excess carbohydrate is converted to triacylglycerols and glycogen for long-term energy storage. On the other hand, when dietary carbohydrate intake is low, **ketone bodies** are formed from acetate units to provide metabolic fuel for the brain and other organs.

Lipids Are Essential, But in Moderation

Fatty acids and triacylglycerols can be used as fuel by many tissues in the human body, and phospholipids are essential components of all biological membranes. Even though the human body can tolerate a wide range of fat intake levels, there are disadvantages in either extreme. Excess dietary fat is stored as triacylglycerols in adipose tissue, but high levels of dietary fat can also increase the risk of atherosclerosis and heart disease. Moreover, high dietary fat levels are also correlated with increased risk for colon, breast, and prostate cancers. When dietary fat consumption is low, there is a risk of **essential fatty acid** deficiencies. As will be seen in Chapter 24, the human body cannot synthesize linoleic and linolenic acids, so these must be acquired in the diet. In addition, arachidonic acid can be synthesized in humans only from linoleic acid, so it too is classified as essential. The essential fatty acids are key components of biological membranes, and arachidonic acid is the precursor to prostaglandins, which mediate a variety of processes in the body.

A DEEPER LOOK

A Popular Fad Diet—Low Carbohydrates, High Protein, High Fat

Possibly the most serious nutrition problem in the United States is excessive food consumption, and many people have experimented with fad diets in the hope of losing excess weight. One of the most popular of the fad diets has been the high-protein, high-fat (low-carbohydrate) diet. The presumed rationale is tantalizing: Because the tricarboxylic acid (TCA) cycle (see Chapter 19) plays a key role in fat catabolism and because glucose is usually needed to replenish intermediates in the TCA cycle, if carbohydrates are restricted in the diet, dietary fat should merely be converted to ketone bodies and excreted. This so-called diet appears to work at first because a low-carbohydrate diet results in an initial water (and weight) loss. This occurs because glycogen reserves are de-

pleted by the diet and because about 3 grams of water of hydration are lost for every gram of glycogen.

However, the premise for such diets is erroneous for several reasons. First, ketone body excretion by the human body usually does not exceed 20 grams (400 kJ) per day. Second, amino acids can function effectively to replenish TCA cycle intermediates, making the reduced carbohydrate regimen irrelevant. Third, the typical fare in a high-protein, high-fat, low-carbohydrate diet is expensive but not very tasty, and it is thus difficult to maintain. Finally, a diet high in saturated and *trans* fatty acids is a high risk factor for atherosclerosis and coronary artery disease.

Fiber May Be Soluble or Insoluble

The components of food materials that cannot be broken down by human digestive enzymes are referred to as **dietary fiber**. There are several kinds of dietary fiber, each with its own chemical and biological properties. **Cellulose** and **hemicellulose** are insoluble fiber materials that stimulate regular function of the colon. They may play a role in reducing the risk of colon cancer. **Lignins**, another class of insoluble fibers, absorb organic molecules in the digestive system. Lignins bind cholesterol and clear it from the digestive system, reducing the risk of heart disease. Pectins and gums are water-soluble fiber materials that form viscous gel-like suspensions in the digestive system, slowing the rate of absorption of many nutrients, including carbohydrates, and lowering serum cholesterol in many cases. The insoluble fibers are prevalent in vegetable grains. Water-soluble fiber is a component of fruits, legumes, and oats.

SUMMARY

17.1 Is Metabolism Similar in Different Organisms? One of the great unifying principles of modern biology is that organisms show marked similarity in their major pathways of metabolism. Given the almost unlimited possibilities within organic chemistry, this generality would appear most unlikely. Yet it's true, and it provides strong evidence that all life has descended from a common ancestral form. All forms of nutrition and almost all metabolic pathways evolved in early prokaryotes prior to the appearance of eukaryotes 1 billion years ago. All organisms, even those that can synthesize their own glucose, are capable of glucose degradation and ATP synthesis via glycolysis. Other prominent pathways are also virtually ubiquitous among organisms.

17.2 What Can Be Learned from Metabolic Maps? Metabolism represents the sum of the chemical changes that convert nutrients, the "raw materials" necessary to sustain living organisms, into energy and the chemically complex finished products of cells. Metabolism consists of literally hundreds of enzymatic reactions organized into discrete pathways. Metabolic maps portray the principal reactions of the intermediary metabolism of carbohydrates, lipids, amino acids, and their derivatives. In such maps, arrows connect metabolites and represent the enzyme reactions that interconvert the metabolites. Alternative mappings of biochemical pathways have been proposed in a response to the emergence of genomic, transcriptomic, and proteomic perspectives on the complexity of biological systems.

17.3 How Do Anabolic and Catabolic Processes Form the Core of Metabolic Pathways? *Catabolism* involves the oxidative degradation of complex nutrient molecules (carbohydrates, lipids, and proteins) obtained

either from the environment or from cellular reserves. The breakdown of these molecules by catabolism leads to the formation of simpler molecules such as lactic acid, ethanol, carbon dioxide, urea, or ammonia. Catabolic reactions are usually exergonic, and often the chemical energy released is captured in the form of ATP. *Anabolism* is a synthetic process in which the varied and complex biomolecules (proteins, nucleic acids, polysaccharides, and lipids) are assembled from simpler precursors. Such biosynthesis involves the formation of new covalent bonds, and an input of chemical energy is necessary to drive such endergonic processes. The ATP generated by catabolism provides this energy. Furthermore, NADPH is an excellent donor of high-energy electrons for the reductive reactions of anabolism.

17.4 What Experiments Can Be Used to Elucidate Metabolic Pathways? An important tool for elucidating the steps in the pathway is the use of *metabolic inhibitors*. Adding an enzyme inhibitor to a cell-free extract causes an accumulation of intermediates in the pathway prior to the point of inhibition. Each inhibitor is specific for a particular site in the sequence of metabolic events. Genetics provides an approach to the identification of intermediate steps in metabolism that is somewhat analogous to inhibition. Mutation in a gene encoding an enzyme often results in an inability to synthesize the enzyme in an active form. Such a defect leads to a block in the metabolic pathway at the point where the enzyme acts, and the enzyme's substrate accumulates. Such genetic disorders are lethal if the end product of the pathway is essential or if the accumulated intermediates have toxic effects. In microorganisms, however, it is often possible to manipulate the growth medium so that essen-