Exercise Physiology

Energy, Nutrition, and Human performance

WILLIAMD. MCARDLE
FRANKI. KATCH
VICTORL. KATCH

Preface

IN *Exercise Physiology: Energy, Nutrition, and Human Performance,* we have attempted to integrate basic concepts and relevant up-to-date scientific information to provide the foundation for understanding exercise. Our main theme is that exercise performance is largely determined by one's capacity to generate energy. This in turn is intimately related to the food nutrients consumed in the diet and the metabolic and physiologic systems of energy delivery and energy utilization. The textbook represents a holistic approach to the multidimensional study of exercise physiology, physical fitness, and health-related fitness aspects. The information is drawn from the research literature in physical education, physiology, metabolism, and health and nutrition. There are seven main sections with 29 chapters, each intimately related to the central theme.

Section I discusses food nutrients and optimal nutrition for exercise performance. Section II deals with the energy for physical activity including energy metabolism as it relates specifically to various modes of exercise. The next section is concerned with the physiologic systems involved in energy delivery and energy utilization, emphasizing pulmonary ventilation, circulation, and neuromuscular integration. In Section IV, the discussion moves to applied physiology where topics related to training, conditioning, and ergogenic aids are discussed with emphasis on the development of muscular strength and anaerobic and aerobic power. Section V deals with the environmental aspects of exercise that include diving, altitude, and thermal stress. Section VI is a particularly important section that focuses on the latest information concerning body composition, obesity, and exercise and weight control. The concluding section presents the role of exercise as it relates to cardiovascular health and aging. These topics are relevant to the emerging areas of adult fitness and cardiac prevention and rehabilitation programs.

Throughout this book, we have tried to balance our discussions between theoretical foundations and practical applications. Our aim is to provide a comprehensive teaching text that not only answers important questions but provides the underlying reasons and rationale. Because many students enter exercise physiology with only minimal science background, the material assumes no previous specialization in topic areas. However, we have tried to develop the basic introductory material into the complete picture required by the exercise specialist. This should make the text attractive to both undergraduate and graduate students as well as students in "special topics" courses dealing with exercise and weight control, environmental physiology, nutrition and sport, and physical conditioning.

We believe the field of exercise physiology is at the dawn of a new era. Recent advances in microscopic and biochemical techniques, aided by computerized technology, are opening up new frontiers in subcellular architecture, function, and adaptation to exercise and training. A cross-discipline thrust will hopefully begin to unravel the many unanswered secrets relating to the elite performer, as well as to a large segment of the population that is increasing its appreciation for involvement in sport and exercise. We have been particularly impressed by the public's keen awareness and enthusiasm, as well as thirst for knowledge about the role exercise can play in shaping one's lifestyle. We also share the commitment as scientists and educators to continually strive to challenge our students to achieve at their own level of excellence in the scientific, academic, and business communities. Not too many years ago, few were trained with a comprehensive background in exercise science. The knowledge explosion had not yet fully matured, and the leadership role for the conduct and implementation of exercise and training programs was entrusted to a handful of professionals struggling to maintain a high degree of respectability within our field.

It took a concerted effort, but now the academic domain of physical education has achieved distinction, especially within the broad spectrum of subdisciplines in the exercise sciences. Men like Clarke, Cureton, Dill, Henry, Hitchcock, Karpovitch, McCloy, Sargent, and Steinhaus were the early pioneers who provided the initial spark and lay the foundation for what is now called exercise physiology. We all must strive to spread their contagious enthusiasm for the systematic study of human exercise performance, and not let that commitment erode as we join in harmony with colleagues in medicine, physiology, psychology, and nutrition to further our understanding of the science of exercise.

Many colleagues in physical education and other disciplines have had a significant impact on our lives. To J. Ball, A.R. Behnke, J.A. Faulkner, D. Fleming, G.F. Foglia, F.M. 'Doc" Henry, H.J. Montoye, E.D. Michael, and G.Q. Rich, III, we would like to say "thank you" for the privilege of your close association as scientists, teachers, and friends. Appreciation is extended to G. Brooks, University of California at Berkeley; Robert Girandola, University of Southern California, P. Ribisl, Wake-Forest University; W. Osness, University of Kansas; J. Magel, Queens College; M. Svboda, Portland State University; and A. Weltman, University of Colorado, for their instructive comments and helpful suggestions during the preparation of the manuscript. We also wish to acknowledge our many undergraduate and graduate students who endured, notably S.S., G.B., R.G., P.F., K.C., A.W., G.L., N.W., M.T., N.G., D.G., J.C., and D.D. Finally, to J. Spahr, T. Colaiezzi, and E. Wickland at Lea & Febiger, our sincere appreciation for coping above and beyond the call of duty.

Sound Beach, New York
Amherst, Massachusetts
Ann Arbor, Michigan

WILLIAM D. MCARDLE
FRANK I. KATCH
VICTOR L. KATCH

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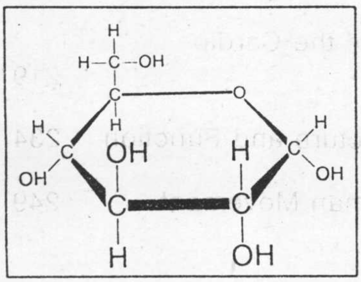

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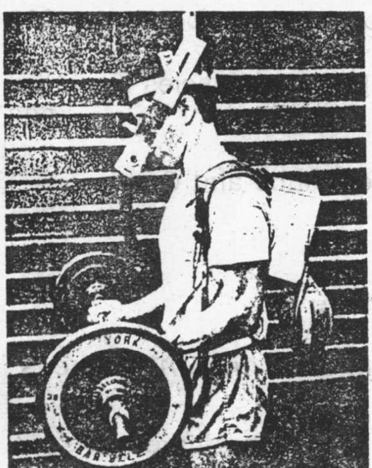

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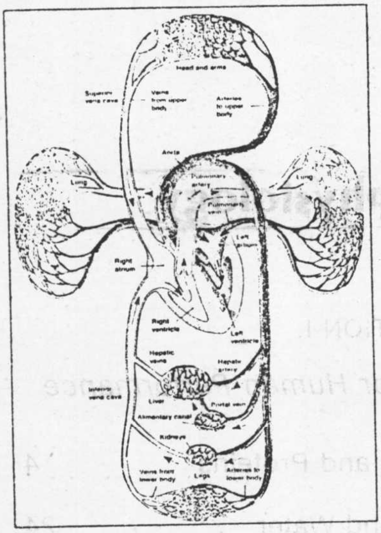

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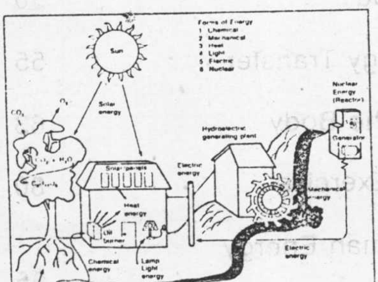

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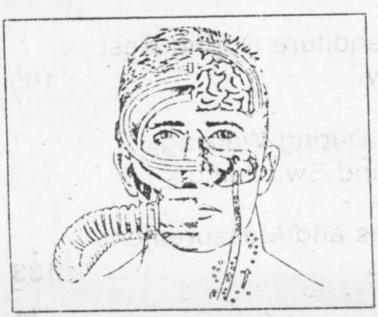

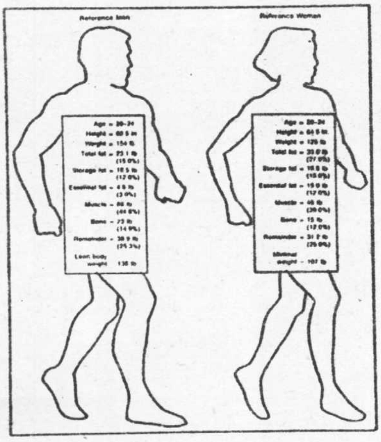

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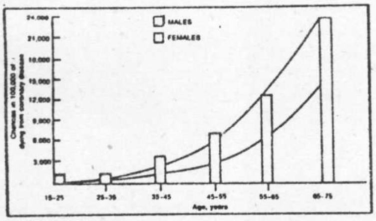

Exercise Physiology

Energy, Nutrition, and Human Performance

WILLIAM D. McARDLE
Professor, Department of Health and Physical Education
Queens College of The City University of New York
Flushing, New York

FRANK I. KATCH
Chairman, Department of Exercise Science
University of Massachusetts
Amherst, Massachusetts

VICTOR L. KATCH
Professor, Department of Physical Education
Associate Professor, Department of Pediatric Cardiology
School of Medicine
University of Michigan
Ann Arbor, Michigan

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SECTION I

Nutrition: The Base for Human Performance

In a textbook dealing with the physiology of human performance, it is uncommon to find a section devoted to the basics of human nutrition. We feel, however, that this topic is of such importance that it should serve as the starting point for this book.

Proper nutrition forms the foundation for physical performance; it provides both the fuel for biologic work and the chemicals for extracting and utilizing the potential energy contained within this fuel. Food also provides the essential elements for the synthesis of new tissue and the repair of existing cells.

Some may argue that adequate nutrition for exercise can easily be achieved through the intake of a well-balanced diet and that it therefore is of little consequence in the study of exercise performance. We maintain, however, that the study of exercise, especially when viewed within the framework of energy capacities, must be based on an understanding of the sources of food energy and the role of nutrients in the process of energy release. With this perspective, it becomes possible for the exercise specialist to appreciate the importance of "adequate" nutrition and to evaluate critically the validity of claims concerning nutrient supplements and special dietary modifications for enhancing physical performance. Because various food nutrients provide energy and regulate physiologic processes associated with exercise, it is tempting to link dietary modification to improvement in athletic performance. Too often individuals spend considerable time and "energy" striving for the optimum in exercise performance, only to fall short due to inadequate, counterproductive, and sometimes harmful nutritional practices.

In the chapters that follow, we will look at the six broad classifications of nutrients: carbohydrate, fat, protein, vitamins, minerals, and water. We will attempt to answer the following questions: What are they? Where are they found? What are their functions? What specific role do they play in physical activity?

Carbohydrates, Fats, and Proteins

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The carbohydrate, fat, and protein nutrients consumed daily provide the necessary energy to maintain body functions both at rest and during various forms of physical activity. Aside from their role as biologic fuel, these nutrients (called macronutrients by nutritionists) also play an important part in maintaining the structural and functional integrity of the organism. In this chapter, each of these nutrients is discussed in terms of general structure, function, and source in specific foods in the diet. Emphasis is placed on their importance in sustaining physiologic function during moderate and more strenuous physical activity.

BASIC STRUCTURE OF NUTRIENTS

All biologic systems are composed of cells that engage in similar activities required to maintain the integrity and life of the cell. Although different cells possess specialized functions that necessitate special structures, the basic life-sustaining processes among all cells are similar. Cells with diverse functions also have similar chemical compositions. All cells are composed of essentially the same chemicals, differing only in the proportion and arrangement of these chemicals.

Atoms: Nature's Building Blocks

Of the 103 different types of atoms or elements, hydrogen, nitrogen, oxygen, and carbon play the *major* role in the chemical composition of nutrients and comprise the structural units for most biologically active substances in the body. Hydrogen, with its relatively low atomic weight, accounts for 10% of the body weight and 63% of all the atoms in the body; carbon, for 18% of the body weight and 9% of all the atoms; nitrogen makes up 3% of the body weight and only 1% of the total number of atoms in the body; and the relatively "heavy" oxygen atom accounts for 65% of body weight yet only 26% of the total number of atoms.

Molecules are formed from the union of two or more atoms. The specific atoms as well as the arrangement of these atoms give the molecule its properties. Glucose is glucose because of the arrangement of 24 atoms of three different kinds within its molecule. *Chemical bonding,* e.g., between atoms of hydrogen and oxygen in the water molecule, involves a common sharing of electrons between atoms. *It is this force of attraction created between the positive and negative charges of atoms that forms the basis for bonding and provides the "cement" that keeps the atoms and molecules within a substance from readily coming apart.* When these forces are altered due to the removal, transfer, or exchange of certain electrons, energy is provided to power all cellular functions. When two or more molecules are chemically bound, a larger aggregate of matter or a *substance* is formed. This substance may take the form of a gas, liquid, or a solid, depending on the force of interaction between molecules.

Carbon: The Versatile Element

All of the nutrients except water and minerals contain carbon. In fact, almost all of the biologic substances within the body are composed of compounds containing carbon. Carbon atoms have an almost unlimited ability to share chemical bonds with other carbon atoms and with atoms of other elements to form large carbon chain molecules.

Fats and carbohydrates are formed from specific linkages of carbon atoms with atoms of hydrogen and oxygen. With the addition of nitrogen and certain mineral substances, a protein molecule is formed. These atoms of carbon, hydrogen, oxygen, and nitrogen are the *organic* building blocks from which the nutrients are made.

PART 1

Carbohydrates

THE NATURE OF CARBOHYDRATES

Atoms of carbon, hydrogen, and oxygen combine to form carbohydrate compounds. The basic chemical structure of a simple sugar molecule consists of a chain of from 3 to 7 carbon atoms with the hydrogen and oxygen atoms attached singly. The most typical sugar, *glucose*, is illustrated in Figure 1-1. The glucose molecule consists of 6 carbon, 12 hydrogen, and 6 oxygen atoms ($C_6H_{12}O_6$). Each of the carbon atoms has four bonding sites that can link to other atoms, including carbon atoms. Carbon atoms not linked to other carbons are "free" to hold hydrogen (which has only one bond site itself), oxygen (which has two bond sites), or an oxygen–hydrogen combination, termed a hydroxyl (OH).

Fructose and *galactose* are two other simple sugars that have the same chemical formula as glucose, with a slightly different carbon-to-hydrogen-to-oxygen linkage. This alteration in atomic arrangement makes fructose, galactose, and glucose different substances.

KINDS AND SOURCES OF CARBOHYDRATES

The interaction of carbon dioxide in the atmosphere with water, solar energy, and the catalyst chlorophyll provides the necessary ingredients for plants to synthesize carbohydrates. In this process, oxygen is released into the atmosphere to be used by animals in the process of energy metabolism. The total process by which the energy from sunlight is harnessed by green plants in the production of carbohydrates is known as *photosynthesis*. This process of energy transfer is discussed more fully in Chapter 5.

There are three kinds of carbohydrates: *monosaccharides, oliosaccharides,* and *polysaccharides*. Each form of carbohydrate is distinguished by the number of simple sugars in combination within the molecule.

Monosaccharides

The monosaccharides or simple sugars, glucose, fructose, and galactose, were described previously. Glucose, also called dextrose or blood sugar, is formed as a natural sugar in food or is produced in the body as a result of digestion of more complicated carbohydrates.

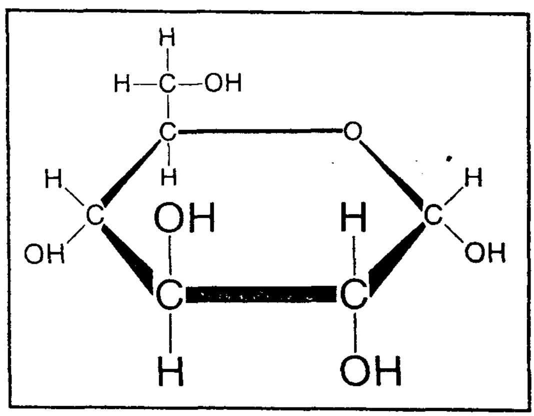

FIG. 1-1. *Three-dimensional structure of the simple sugar molecule glucose. The molecule resembles a hexagonal plate to which H and O atoms are attached.*

Fructose or fruit sugar is present in large amounts in natural form in fruits and honey and is the sweetest of the simple sugars. Galactose is not found in foods; rather, it must be produced from milk sugar in the mammary glands of lactating animals. In the body, both fructose and galactose are easily converted to glucose for energy metabolism.

Oligosaccharides

The major types of oligosaccharides are the *disaccharides* or double sugars, which are formed from the combination of two monosaccharide molecules. In the structure of each of the disaccharides, glucose is one of the simple sugars. The three principal disaccharides are:

Sucrose = glucose + fructose
Lactose = glucose + galactose
Maltose = glucose + glucose

Sucrose is the most common dietary disaccharide and contributes up to 25% of the total quantity of ingested carbohydrate in the United States. It occurs naturally in most foods containing carbohydrates, especially in beet and cane sugar, brown sugar, sorghum, maple syrup, and honey.

Lactose is found in natural form only in milk and is often called milk sugar. It is the least sweet of the disaccharides. Lactose can be artificially processed and is often found in carbohydrate-rich, high-calorie liquid meals.

Maltose occurs in malt products and in germinating cereals. It is considered a negligible carbohydrate in terms of its contribution to the carbohydrate content of the average person's diet.

Polysaccharides

Three or more simple sugar molecules form a polysaccharide. In fact, as many as 300 to 500 monosaccharide molecules can be linked to form a polysaccharide. There are generally two classifications of polysaccharides, plant and animal.

PLANT POLYSACCHARIDES. Two common forms of plant polysaccharides are *starch* and *cellulose*.

Starch is the most familiar form of plant polysaccharide. It is found in seeds, corn, and in the various grains from which bread, cereal, spaghetti, and pastries are made. Large amounts are also present in peas, beans, potatoes, and roots, where it serves as an energy store for future use by plants. Starch granules of different sizes are encased within the cellulose walls of the plant cell. Potato starch granules, for example, are relatively large, whereas the starch granules within rice are small. Plant starch is still the most important dietary source of carbohydrate in the American diet, accounting for approximately 50% of the total carbohydrate intake. It is interesting to note, however, that starch intake has decreased about 30% since the turn of the century, whereas the consumption of more simple sugars such as sucrose has correspondingly increased from 31% to about 50%.

Cellulose is another form of plant polysaccharide. It makes up the fibrous or structural part of plants and is present in leaves, stems, roots, seeds, and fruit coverings. Since cellulose is resistive to human digestive enzymes, its major function is to give "bulk" to the food residues in the small intestines. This bulk in the diet probably aids in gastrointestinal functioning and may reduce the probability of contracting colon cancer later in life.[9]

ANIMAL POLYSACCHARIDES. *Glycogen* is the polysaccharide synthesized and stored in the tissues of animals. Glycogen molecules are usually large and range in size from a few hundred to thousands of glucose molecules linked together, much like the links in a chain of sausages. In well-nourished humans, approximately 375 to 475 grams (g)* of carbohydrate are stored in the body. Of this, approximately 275 g are muscle glycogen, 100 to 120 g are liver glycogen, and only 15 to 20 g are present as blood glucose.

There are several factors that determine the rate and quantity of either glycogen synthesis or breakdown. During exercise, the carbohydrate stored as muscle glycogen is used as a source of energy for the specific muscle in which it is stored. In the liver, in contrast, glycogen is reconverted to glucose and transported in the blood for eventual use by the working

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*(Scientific measurement is generally presented in terms of the metric system. Appendix A shows the relationship between metric units and English units that are relevant to the material presented in this book. Also presented are some common expressions of work, energy, and power.)

muscles. The term *glycogenolysis* is used to describe this reconversion process, which provides a rapid supply of glucose for muscular contraction during all forms of work. When glycogen is depleted via dietary restriction or exercise, glucose synthesis from the structural components of the other nutrients, especially proteins, tends to increase. This process is termed *gluconeogenesis.* Hormones, especially insulin, play an important part in the regulation of liver and muscle glycogen stores by controlling the level of circulating blood sugar.

Because comparatively little glycogen is stored in the body, the quantity of liver and muscle glycogen can be modified considerably through the diet. For example, a 24-hour fast results in a large reduction in liver and muscle glycogen reserves. On the other hand, maintaining a carbohydrate-rich diet for several days enhances the body's carbohydrate stores to a level almost twice that obtained with a normal, well-balanced diet.[3] The effect of enhanced carbohydrate storage on exercise performance is discussed in a later section of this chapter.

RECOMMENDED INTAKE OF CARBOHYDRATES

Almost all foods contain some carbohydrates, even if only trace amounts. Figure 1-2 illustrates the carbohydrate content of selected foods. Cereals, cookies, candies, breads, and cakes are rich carbohydrate sources. Because the values are based on carbohydrate percentage in relation to the total weight, including water content, fruits and vegetables appear to be less valuable sources of carbohydrates. However, the dried portion of these foods is almost pure carbohydrate.

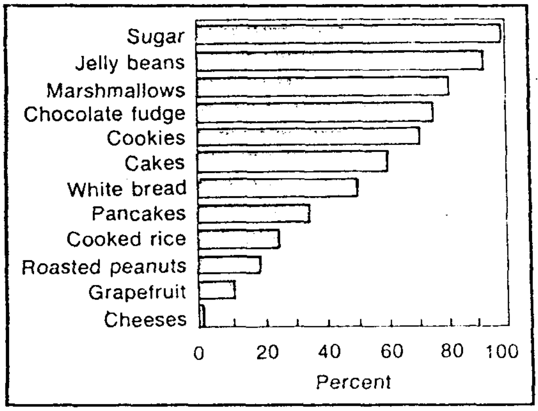

FIG. 1-2. *Percentage of carbohydrates in commonly served foods. (Adapted from Handbook No. 8: Composition of Foods. Washington, D.C., United States Department of Agriculture, 1963.)*

The typical American diet consists of approximately 40% to 50% of the total calories as carbohydrate. For a sedentary 70-kilogram (kg) person, for example, this amounts to approximately 147 g of carbohydrate per day. For active people and those involved in exercise training, about 50% to 55% of the daily caloric intake should be in the form of carbohydrates.[15]

The main dietary carbohydrate source is generally fruits and vegetables. This in no way, however, represents the "state of affairs" for all individuals. A recent dietary survey of 16 moderately overweight females at the University of Michigan revealed that their daily carbohydrate intake of 375 g accounted for 53% of their total caloric intake. Fruits and vegetables represented only 20% of the carbohydrate intake, whereas cereals, bread, and especially sweets accounted for approximately 80%. Perhaps these findings should not be surprising because it has been estimated that the average American consumes more than 100 pounds (lb) of table sugar each year!

Evidence is increasing to support the contention that an excessive quantity of sucrose in the diet is a main *cause* of tooth decay. In addition, in an as yet unexplained way, excessive dietary sugar is believed to be involved in a variety of other disease processes, most notably diabetes and coronary heart disease.

ROLE OF CARBOHYDRATES IN THE BODY

Carbohydrates serve several important functions related to exercise performance.

Energy Source

The main function of carbohydrate is to serve as an energy fuel for the body. The energy derived from the breakdown of carbohydrate is ultimately used to power muscular contraction as well as all other forms of biologic work.

Carbohydrates must be broken down during digestion to a simple 6-carbon sugar before they can be absorbed by the blood and used by the body. It is important that adequate amounts of carbohydrates are ingested routinely to maintain the body's relatively limited glycogen stores. If too few carbohydrates are ingested, glucose is then obtained from glycogen breakdown and the carbohydrate reserves become depleted. In contrast, following a meal, there may be excess carbohydrates that will be readily converted to muscle and liver glycogen. Once the capacity of the cell for glycogen storage is reached, the excess sugars are converted and stored as fat. This helps explain how body fat increases when excess calories in the form of carbohydrates are consumed. This process occurs even if the diet is low in fat.

Protein Sparing

Carbohydrates also provide a "protein sparing" effect. Under normal conditions, protein serves a vital role in the maintenance, repair, and growth of body tissues, and to a considerably lesser degree, as a nutrient source of energy. However, when carbohydrate reserves are reduced, metabolic pathways exist for the synthesis of glucose from protein. This process, termed gluconeogenesis, provides a metabolic option for augmenting carbohydrate availability in the face of depleted glycogen stores. We will point out shortly how this becomes increasingly important in prolonged endurance exercise. However, the price that is paid is a temporary reduction in the body's protein stores, especially muscle protein. Adequate intake and utilization of carbohydrates aid in the maintenance of tissue protein.

Metabolic Primer

Another function of carbohydrates is to serve as a "primer" for fat metabolism. Certain food fragments from the breakdown of carbohydrate must be available to facilitate the metabolism of fat. If insufficient carbohydrate metabolism exists, either through limitation in the transport of glucose into the cell, which occurs in diabetes, or depletion in glycogen through improper diet or prolonged exercise, the body begins to mobilize fat to a greater extent than it can utilize. The result is incomplete fat metabolism and the accumulation of acid by-products called *ketone bodies*. This situation can possibly lead to a harmful increase in the acidity of the body fluids, a condition called acidosis—or more specifically with regard to fat breakdown, *ketosis*. More is said of the role of carbohydrate as a primer for fat metabolism in Chapter 6.

Fuel for the Central Nervous System

Carbohydrate is essential for the proper functioning of the central nervous system. The brain uses blood glucose almost exclusively as a fuel and essentially has no stored supply of this nutrient. The symptoms of a modest reduction in blood glucose (*hypoglycemia*) include feelings of weakness, hunger, and dizziness. This condition impairs exercise performance and may partially explain the fatigue associated with prolonged exercise. Sustained and profound low blood sugar can cause irreversible brain damage. Because of the specific role played by glucose in generating energy for use by nerve tissue, blood sugar is regulated within narrow limits.

CARBOHYDRATE BALANCE IN EXERCISE

With the use of biochemical and biopsy techniques, it has been possible to study the contributions of various nutrients to the energy demands of physical activity. The biopsy technique permits the sampling of specific muscles with little interruption in exercise. Thus, through serial sampling of the same muscle in the same person, the role of intramuscular nutrients can be carefully evaluated during exercise.

Intense Exercise

Stored muscle glycogen and blood-borne glucose are the prime contributors of energy during high-intensity exercise. Blood glucose, for example, may supply 30% to 40% of the total energy of exercising muscles.[11] As illustrated in Figure 1-3, during the initial stage of exercise, the uptake of circulating blood glucose by the muscles increases sharply and continues to increase as exercise progresses. By the fortieth minute of exercise, the glucose uptake has risen to between 7 and 20 times the uptake at rest, depending on the intensity of the exercise. The increase in the percentage contribution of carbohydrate during intense exercise is explained largely by the fact that it is the *only* nutrient that provides energy when the oxygen supplied to the muscles is insufficient in relation to the oxygen needs. The specifics of this role in energy release are explained in Chapter 6.

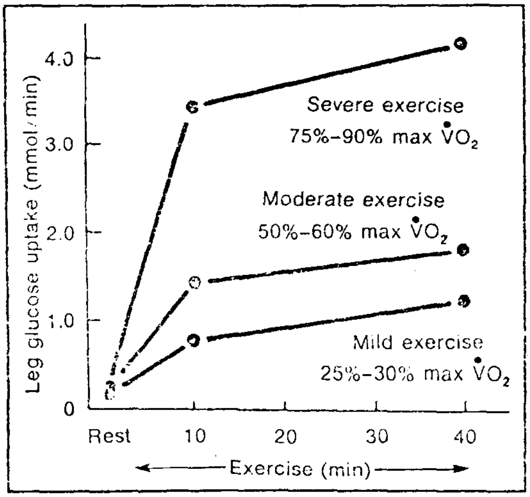

FIG. 1-3. *Relationship between blood glucose uptake by the leg muscles and exercise duration and intensity. Here intensity is expressed as a percent of one's maximum capacity to consume oxygen or max $\dot{V}o_2$. As exercise continues, blood-borne glucose becomes an increasingly important source of energy. If exercise continues for 10 to 40 minutes, glucose uptake by muscle rises to 7 to 20 times basal level, depending on the exercise intensity. This glucose metabolism can account for 30 to 40 percent of the total oxygen consumed by muscle. (Reprinted by permission from Felig, P., and Wahren, J.: Fuel homeostasis in exercise. Seminar in Medicine of the Beth Israel Hospital, Boston.* N. Engl. J. Med., 293:*1078, 1975.)*

Moderate and Prolonged Exercise

The specific nutrient fuel for muscular contraction depends not only on exercise intensity but also on the duration of the activity and, to some degree, on the diet of the individual.[6] During continuous moderate exercise, energy is derived mainly from the breakdown of the body's stores of fat and carbohydrate. In the early stages of such submaximal exercise, about 40% to 50% of the energy requirement is supplied by the glycogen stored in the liver and exercising muscles. Glucose output from the liver rises 3 to 5 times above resting values. As exercise continues and the glycogen stores become reduced, however, an increasingly greater percentage of energy is supplied through the metabolism of fat.[17]

Fatigue occurs if exercise is performed to the point where the glycogen in the liver and specific muscles becomes severely lowered, even though sufficient oxygen is available to the muscles and the potential energy from stored fat remains almost unlimited. Because enzymes are not present to allow for glycogen transfer between muscles, the relatively inactive muscles maintain their glycogen content. It is unclear why the depletion of muscle glycogen coincides with the point of fatigue in prolonged submaximal exercise. The function of carbohydrate as a "primer" in fat metabolism may provide part of the answer.

EFFECT OF DIET ON MUSCLE GLYCOGEN STORES. Figure 1-4 shows the results of one experiment in which the initial muscle glycogen stores were varied in 9 subjects through dietary manipulation.[3] In one condition, the normal caloric intake was maintained for 3 days but the major quantity of calories was supplied in the form of fat. In the second condition, the 3-day diet was normal and contained the recommended daily percentages of carbohydrate, fat, and protein. In the third diet, 82% of the calories were provided in the form of carbohydrates. The glycogen content of the *quadriceps femoris* muscle of the leg, determined by needle biopsy, averaged 0.63, 1.75, and 3.75 g of glycogen per 100 g wet muscle as a result of the high-fat, normal, and high-carbohydrate diets, respectively.

Endurance capacity on the bicycle ergometer varied considerably depending upon the diet

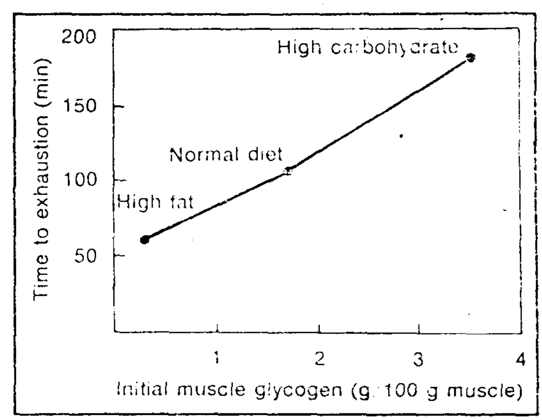

FIG. 1-4. *Effects of a mixed diet, a low-carbohydrate diet, and a high-carbohydrate diet on the glycogen content of the quadriceps femoris and the duration of exercise on a bicycle ergometer. These data clearly show that the higher the initial level of muscle glycogen, the greater is the endurance for submaximal exercise. (From Bergstrom, J. et al.: Diet, muscle glycogen and physical performance. Acta Physiol. Scand., 71:140, 1967.)*

each person consumed during the 3 days prior to the exercise test. With the normal diet, moderate exercise could be tolerated for an average of 114 minutes, whereas endurance averaged only 57 minutes with the high-fat diet. The endurance capacity of subjects fed the high-carbohydrate diet was more than three times greater than when the same subjects consumed the high-fat diet. Such results clearly demonstrate the importance of muscle glycogen for prolonged exercise lasting more than an hour, and emphasize the important role of nutrition in establishing the appropriate energy reserves.

A diet deficient in carbohydrates rapidly depletes muscle and liver glycogen and subsequently affects performance in intense short-term exercise as well as in prolonged, submaximal endurance activities. These observations are important not only for athletes but also for individuals who have modified their diet so that the normal recommended percentage of carbohydrates has become reduced. Reliance on starvation diets or on other potentially harmful diets such as high-fat, low-carbohydrate diets, "liquid-protein" diets, or water diets is counterproductive for weight control, exercise performance, optimal nutrition, and good health. Such low carbohydrate diets make it extremely difficult from the standpoint of energy supply to participate in vigorous physical activity or training.

ADMINISTRATION OF ORAL GLUCOSE. It is noteworthy that the exercise period can be extended if a solution of glucose and water is ingested at the point of fatigue from prolonged submaximal exercise.[7] This occurs even though for all practical purposes the muscles' "fuel tank" reads empty and continued energy metabolism is severely limited. In all likelihood, the additional sugar absorbed from the intestinal tract helps maintain the appropriate blood sugar level. This, in turn, supports the nutrient requirements of the central nervous system and working muscles and may forestall liver glycogen depletion during prolonged severe exertion.[8] The "sugar drink" usually recommended is an isotonic 5% glucose, fructose, or sucrose solution that can be made by adding 50 g of table sugar to one liter of water.[4] To be most effective, the fluid should be consumed at frequent intervals throughout the endurance activity.

Of considerable importance with regard to sugar drinks is the negative effect of glucose on water absorption from the digestive tract. Even a small amount of glucose significantly retards the movement of water out of the stomach. This could be deleterious during prolonged exercise in the heat, when adequate intake *and* absorption of fluid is of prime importance to the health and safety of the athlete.

SUMMARY

1. Atoms are the basic building blocks of all matter, and they combine to form molecules. Most cells are composed of the same chemicals, differing only in proportion and arrangement.

2. Carbon, hydrogen, oxygen, and nitrogen are the primary structural units of most of the biologically active substances in the body. Specific combinations of carbon with oxygen and hydrogen form carbohydrates and fats, whereas other combinations with the addition of nitrogen and minerals make proteins.

3. Simple sugars consist of a chain of from 3 to 7 carbon atoms with hydrogen and oxygen in the ratio of 2 to 1. Glucose, the most common simple sugar, contains a 6-carbon chain as $C_6H_{12}O_6$.

4. There are three kinds of carbohydrates: monosaccharides (simple sugars like glucose and fructose); oliosaccharides (disaccharides like sucrose, lactose, and maltose); and polysaccharides that contain three or more simple sugars to form starch, cellulose, and glycogen.

5. *Glycogenolysis* refers to the process of reconverting glycogen to glucose, whereas *gluconeogenesis* refers to the process of glucose synthesis, especially from protein sources.

6. Americans typically consume 40% to 50% of their total calories as carbohydrates. This is generally in the form of fruits, grains, and vegetables, although greater sugar intake in the form of sweets (simple sugars) is common and possibly harmful.

7. Carbohydrates serve (1) as a major source of energy, (2) to spare the breakdown of proteins, (3) as a metabolic primer for fat metabolism, and (4) as the fuel for the central nervous system.

8. Muscle glycogen and blood glucose are the primary fuels during intense exercise. The body's glycogen stores also serve an important

role in energy balance in sustained moderate exercise such as marathon running and distance swimming.

9. Sugar drinks may enhance exercise performance by maintaining blood sugar levels and perhaps delaying liver and muscle glycogen depletion. These drinks, however, have been shown to retard the movement of liquid out of the stomach, which ultimately may upset the body's fluid balance.

PART 2

Fats

THE NATURE OF FATS

A molecule of fat possesses the same structural elements as the carbohydrate molecule except that the linking of the specific atoms is markedly different. Specifically, the ratio of hydrogen to oxygen is considerably higher in the fat compound. For example, the common fat *stearin* has the formula $C_{57}H_{110}O_6$.

KINDS AND SOURCES OF FATS

According to common classification, fats can be placed into one of three main groups: *simple fats, compound fats,* and *derived fats.* Fats can be found in both plants and animals, are generally greasy to the touch, and are insoluble in water.

Simple Fats

The simple fats are often called *"neutral fats"* and consist primarily of *triglycerides.* Triglycerides, the most plentiful fat in the body, constitute the major storage form of fat (more than 99% of the body fat is in the form of triglycerides). A triglyceride molecule consists of two different clusters of atoms. One cluster is *glycerol,* a 3-carbon molecule. Glycerol in itself is not a fat because it is readily soluble in water. Attached to the glycerol molecule are three clusters of carbon-chained atoms termed *fatty acid.* Figure 1-5 shows the structure of glycerol and a typical 18-carbon fatty acid.

When glycerol and fatty acids are joined in the synthesis of the triglyceride molecule, three molecules of water are formed. Conversely, during *hydrolysis,* when the fat molecule is cleaved into its constituents, three molecules of water are added at the point where the fat molecule is split. The basic structures of the two kinds of fatty acid molecules, *saturated* and *unsaturated,* are shown in Figure 1-6.

SATURATED FATTY ACIDS. A *saturated* fatty acid contains only single bonds between carbon

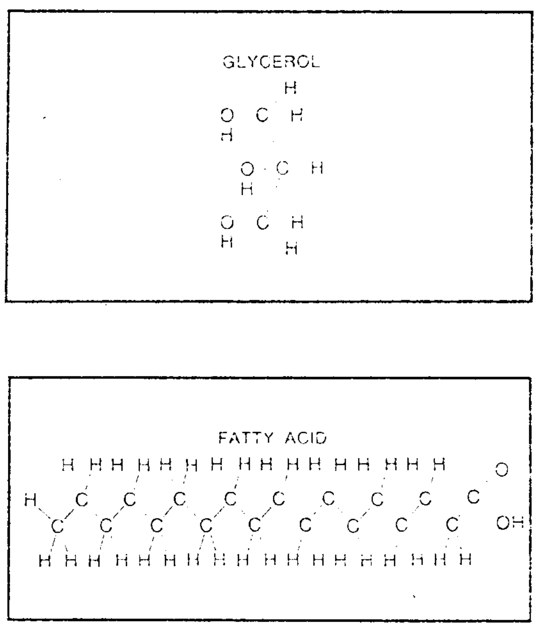

FIG. 1-5. *Chemical structure of a glycerol molecule and a fatty acid molecule. From* Nutrition, Weight Control, and Exercise *by Frank I. Katch and William D. McArdle. Copyright (c) 1977 by Houghton Mifflin Company. Reprinted by permission of the publisher.*