There are three types of muscle in the human body. The most abundant type is called *skeletal muscle* because virtually all these muscles are attached to the bones of the skeletal system. Skeletal muscle makes up the more than 600 muscles in the body, most of which are close to the surface of the body, between the integumentary system and the bones (Fig. 8.1). Many muscles bulge when they contract; therefore, they are visible and can be felt as firm lumps under the skin. This chapter is concerned mainly with skeletal muscle.

*Cardiac muscle* is found exclusively in the heart (Chap. 4). *Visceral muscle*, or *smooth muscle*, is found within organs in many body systems.

**MAIN FUNCTIONS FOR HOMEOSTASIS**

The muscle system performs three functions that help maintain homeostasis: movement, support, and heat production.

**Movement**

The movement produced by muscles allows a person to carry out the last step in negative feedback systems: making an adjustment to a change in conditions. Movement is used to get away from impending danger (e.g., fire, falling objects), escape from unfavorable conditions (e.g., intense sunlight), and eliminate wastes and unwanted materials (e.g., carbon dioxide, splinters).

Movement is also important in taking positive actions. It allows a person to move toward, obtain, and use items and conditions that promote the welfare of the body and quality of life. These needs include basic physical needs (e.g., food, water, shelter) and other needs (e.g., social interactions, recreational activities). Movement allows people to rearrange their environment and construct and repair useful and decorative artifacts to suit human requirements and desires.

**Support**

The muscle system provides support when muscle contractions prevent the movement of a part of the body. Support maintains proper positional conditions of parts of the body so that they function well. For example, muscle contractions can maintain an upright posture. This activity includes holding the bones in place and
FIGURE 8.1 Skeletal muscles in the muscle system.

preventing the protrusion of the organs in the lower trunk. With proper posture, circulation is improved because blood vessels are open rather than pinched shut, and respiration is assisted because the lungs have room to inflate easily. Holding the head up positions the eyes for viewing the surrounding environment.

Heat Production

Heat production is essential for maintaining a proper and fairly stable body temperature because most people live in environments that are cooler than normal body temperature. Therefore, the body is always losing heat to the environment, just as any warm object or substance, such as warm food, loses heat and becomes cool. However, if the body is allowed to become cool, this will make the rate of its chemical reactions too slow to sustain life functions (e.g., heartbeat, respiration, brain activities) and perform effective negative feedback responses. Therefore, to prevent cooling of the body, the amount of heat loss must be balanced by an equal amount of heat production.

Heat is produced by many chemical reactions in the body, but the muscle system is the main heat producer. One reason for this is that the muscle system is one of the largest systems, usually accounting for one-third or more of body mass. Second, the muscle system is one of the most active systems in the body. When a person is awake but resting, this activity involves steady muscle contractions (muscle tone) that help maintain posture. This system is especially active and produces much more heat when a person is forcefully contracting muscles during vigorous exercise. Still, the muscle system performs many chemical reactions even when the muscles are relaxed; this is why a sleeping person remains warm.

AGE CHANGES VERSUS OTHER CHANGES

The functioning of the muscle system depends on the nervous, circulatory, and respiratory systems. As a result, many age-related changes in this system derive from age-related changes in the other systems, which vary greatly among individuals. Furthermore, alterations in exercise received by muscles quickly and dramatically affect the
muscle system. Though there is an average age-related decline in exercise, changes in the total amount of exercise of the body and of each muscle vary greatly both from time to time and from one person to another. Two consequences of these variables are that they add to the age-related increase in heterogeneity among people and make it quite difficult to identify true age changes in the muscle system. Therefore, in this chapter the causes of each age-related change will be noted.

**MUSCLE CELLS**

The muscles are composed primarily of muscle cells, which perform the three functions of the muscle system. Other materials in each muscle include nerve cells, collagen and elastin fibers, fat, and blood vessels (Fig. 8.2).

**Structure and Functioning**

The main activity of muscle cells is **contraction**, which produces both the force needed for movement and support and most of the heat derived from the muscle system. Muscle cells have many specializations that permit them to perform contraction.

Muscle cells are very long and thin, reaching lengths of up to several centimeters. Usually, these cells are as long as the muscle in which they are contained. Because of their shape, muscle cells are also called **muscle fibers** (Fig. 8.2).

**Cell Membrane (Sarcolemma)** The muscle cell membrane (sarcolemma) is modified in three ways (Fig. 8.3). First, the spot on the membrane that receives stimulatory messages from a somatic motor neuron is highly convoluted. This modified area (motor end plate) apparently provides more surface area and receptor molecules to receive and respond to molecules of acetylcholine from the somatic motor neuron. Second, the cell membrane can carry messages in the form of action potentials, just as axons do. Third, the membrane has many penetrating indentations (T tubules), which deliver action potentials deep within the cell.

**Myoglobin, Oxygen, and Energy** The muscle cell cytoplasm (sarcoplasm) contains a protein called **myoglobin**, which is found only in muscle cells and causes muscles to appear red in color. Myoglobin attracts oxygen from the blood into the muscle cells and stores oxygen. As soon as a muscle cell uses some of the oxygen, its myoglobin quickly attracts more (Fig. 8.4).

The muscle cell uses the oxygen to obtain energy from sugar and other nutrient molecules. As long as the cell has enough oxygen, it can obtain much energy from nutrients while producing only carbon dioxide (CO₂) and water as waste products. The CO₂ and water are easily removed from the cell and can be eliminated from the body by the respiratory and urinary systems, respectively.

When a person engages in vigorous activity, the amount of oxygen required to produce the energy needed by a muscle cell often rises above the supply of oxygen to the cell. The cell can continue to work because some energy can be obtained by breaking nutrients down partially. One of the main waste products from this process is **lactic acid** (Fig. 8.4), which tends to accumulate in muscle cells and causes them to become acidic. A result of lactic acid accumulation is weakening of the muscle cell's contractions. The affected person experiences fatigue in the forms of muscle weakness and muscle pain. The person also feels out of breath.

If activity decreases, the circulatory and respiratory systems can again deliver oxygen to the muscle cell faster than oxygen is consumed. The extra oxygen is used to complete the breakdown of lactic acid into CO₂ and water; this not only eliminates the lactic acid but also makes a large
FIGURE 8.3 Components of a muscle cell.

MUSCLE FIBER
- Myofibrils
- Actin and myosin myofilaments

Sarcoplasm
Sarcolemma
T tubule
Motor neuron axon
Motor end plate
Sarcolemma
T tubule
Sarcoplasmic reticulum

Amount of energy available to the muscle cell. The affected person’s sensation of fatigue subsides and he or she may claim, “I have caught my breath.” The oxygen used to eliminate the lactic acid produced by vigorous exercise is called the oxygen debt.

Much of what has just been said is also true of cardiac muscle cells. For example, when cardiac or skeletal muscle cells accumulate lactic acid, they become weak. However, unlike cardiac muscle cells, skeletal muscle cells are rarely seriously injured or killed by lactic acid. These cells can continue to work with lactic acid present as long as the acid concentration does not become too severe. Still, exceedingly high levels of lactic acid will prevent skeletal muscle cells from contracting.

Contraction The membranes of the endoplasmic reticulum within muscle cells are arranged in the form of lacy tubes that extend over the length of the cell (Fig. 8.3). These membranes are called sarcoplasmic reticulum and regulate the movement of calcium ions needed for contraction.

The region in the cell surrounded by each tube of sarcoplasmic reticulum contains an array of tiny fibers called myofilaments. Clusters of thick myofilaments alternate with clusters of thin myofilaments (Fig. 8.5). The alternating clusters overlap to form units called sarcomeres, which extend from one end of the cell to the other like links in a chain. Each chain of sarcomeres is surrounded by sarcoplasmic reticulum and is called a myofibril.

When the cell is stimulated and action potentials pass over the sarcolemma, the sarcoplasmic reticulum releases calcium, which causes the thick myofilaments to pull on the thin myofilaments and slide farther among them. The pulling and sliding cause the muscle cell to become shorter; contraction has occurred. The contraction applies a pulling force to the bone or other structure to which the muscle is attached, and the structure is either moved or held in place.

Recall that energy for contraction comes from the breakdown of nutrient molecules. Only some of the energy released from these molecules is converted into movement of the myofilaments; the remainder is converted into heat. This is why muscles produce so much heat when they contract.

Types of Muscle Cells The proportions of muscle cell components are different among muscle cells, so the cells have different characteristics. Type I fibers contract more slowly and can work longer...
before becoming fatigued. *Type IIA fibers* contract more quickly and resist becoming fatigued, also. *Type IIB fibers* contract quickly, but they become fatigued quickly. *Type IIC fibers* are intermediate between Type IIA and Type IIB. Type IIA and Type IIB fibers are most important for fast and powerful movements. Different muscles have different combinations of these types of muscle cells, and the combinations change gradually during adulthood.

### Age Changes in Muscle Cells

#### Internal Components

As muscle cells age, the convolutions in the motor end plate decrease and the sarcolemma becomes smoother. The resulting decrease in surface area diminishes the ability of the muscle cell to be stimulated by the motor neuron. Other changes in the sarcolemma cause the action potentials that lead to contraction to become weaker, slower, and more irregular. Because of the changes in the action potentials, the cell takes longer to begin to contract and is less able to recover from one contraction and prepare for the next. Age-related slowing of calcium release and retrieval by the sarcoplasmic reticulum contribute to these effects.

The large-scale results of these cellular age changes include a longer time to respond when a person wants to move suddenly and a diminished ability to perform rapidly repeated movements such as playing fast music on a piano. Muscle composed of aging cells also has a weaker maximum strength when used for activities requiring rapid and very strong contractions, such as grasping a handrail to stop a fall.

Another change in aging muscle cells is a decrease in the substances used to supply energy for contraction (ATP, creatine phosphate, glycogen). Much of this change seems to be caused by a decrease in exercise rather than by aging. Lack of exercise also seems to cause most of the decrease in the enzymes that extract energy from nutrients. There is even a decrease in the number and size of mitochondria, which perform most of the energy extraction. Many remaining mitochondria have been damaged, so they are less efficient and produce more free radicals (*FRs). Some muscle cells seem to accumulate damaged mitochondria and become sources of *FR damage to surrounding cells. All these changes leave the cells with less energy, especially for tasks requiring a prolonged effort.

The final substantive change inside muscle cells is a decrease in the number of sarcomeres within the myofibrils. This tends to cause the cells and the muscles they compose to become shorter and have a reduced distance through which they can move. The affected person experiences stiffness and diminished freedom of movement. The loss of sarcomeres also reduces the strength of the cells and muscles.

#### Cell Thickness

Since muscle cells that get little exercise lose parts of their internal components, they decrease in thickness. This shrinkage is prevalent among the elderly because of the general reduction in physical activity as people age. Regularly exercised muscles show little change in cell thickness until age 70 or beyond. Even then, there is only a slight thinning of cells in muscles that receive plenty of exercise. Therefore, reduction in exercise rather than aging is the main cause of muscle cell thinning and much of the consequent decrease in muscle thickness and strength that usually accompanies advancing age.

#### Cell Number

Most of the decrease in the thickness of muscles with aging is caused by the death
of muscle cells. Up to half the muscle cells in a muscle may be lost by late old age. This loss occurs in exercised muscles and in muscles receiving little use. Lost muscle cells are not replaced by new ones because except in very unusual circumstances, adult muscle cells cannot form new muscle cells.

Type II fibers become thinner and are lost faster than Type I fibers. The ratios of loss are different for different muscles. Some muscles may lose Type II fibers more than twice as fast as they lose Type I fibers. Type IIB fibers are lost faster than Type IIA fibers. Some of the loss of Type II fibers may be from conversion to Type I fibers. Most age-related decreases in strength and speed result from thinning and loss of Type II fibers.

In muscles receiving much regular strenuous exercise, the space left by the lost cells may be largely filled by the remaining cells. This occurs because muscle cells pulling against heavy loads on a regular basis adapt by synthesizing more internal components. The additional components increase the thickness and strength of these cells, which encroach on the vacant areas. As a result, the decline in thickness and strength of exercised muscles is slow.

Aging muscles that receive little strenuous exercise have the spaces left by lost cells filled with fibrous tissue and fat. Such muscles become thinner and considerably weaker as time passes.

Cell Repair Though muscle cells are unable to reproduce, they can repair themselves after an injury. One common cause of injury is contracting against a load much heavier than that normally encountered by muscle cells. This type of injury can be sustained when a person who normally lifts objects weighing less than 30 pounds tries to support a 60-pound object.

A muscle containing muscle cells injured by an excessive force, such as lifting a heavy object, is weakened and causes the sensations of muscle soreness and stiffness. If the muscle is rested, the injured muscle cells will repair themselves within a few days and the soreness and stiffness will subside. As was mentioned above, the cells will adapt to the heavy demands previously placed on them by becoming thicker and stronger. They will then be more resistant to injury caused by excessive loads. For muscle cells receiving regular strenuous exercise, the ability to repair injury and recover from such weakness and soreness is not altered by aging.

It is uncertain whether muscle cells that receive little exercise can repair themselves as quickly as exercised muscle cells do. Still, muscle cells in exercised or unused muscles retain the ability to adapt to heavier loads by manufacturing internal components. Thus, the thickness and strength of muscles can be increased by strenuous exercise regardless of age. However, muscle cells in older individuals make the compensatory increase in thickness more slowly.

NERVE-MUSCLE INTERACTION

Motor Units

Recall from Chap. 6 that skeletal muscle cells are stimulated to contract by nerve cells called somatic motor neurons. The axon from each motor neuron branches as it passes through its muscle. Some motor neurons have only a few branches, while others have several hundred.

Each branch from a motor neuron axon ends on a muscle cell, and each muscle cell receives a branch from only one motor neuron (Fig. 8.6). Thus, the muscle cells in a muscle are organized into groups, with all the cells in each group being controlled by one motor neuron. The combination of one motor neuron and all the muscle cells it controls is the functional unit of the muscle and is called a motor unit.

When an impulse travels down a motor neuron, it passes along every branch of its axon. Therefore, every muscle cell in the motor unit is stimulated to contract; it is not possible to cause only some of these cells to contract.

The strength of each contraction is determined by which motor units and how many motor units are activated at a given time. Since more varied combinations of numbers of muscle cells can be selected in muscles with small motor units, a person has more control over the amount of strength provided by each contraction in such muscles. It is more difficult to select precise levels of strength from muscles with large motor units because the muscle cells contract in larger groups. The difference in the degree of control is similar to the difference between the ability to pay an exact amount when one has many one dollar bills and small
Changes in Motor Units

Since motor units change in many ways as people get older, the functioning of a muscle also changes. Some of these changes and their consequences were described in Chap. 6.

One change is an exponential decrease in the number of motor neurons. The loss may reach 50 percent by age 60. This is the main reason for the decrease in the number of muscle cells because a muscle cell degenerates and dies if it does not receive stimulation from a motor neuron. As more motor neurons and their muscle cells are lost, the maximum strength of contraction the muscle can produce diminishes.

Fortunately, many surviving motor neurons produce additional axon branches that connect to the orphaned muscle cells. These adopted muscle cells survive and function. This compensatory process helps slow the decline in the strength of the muscle. Note, however, that the size of the remaining motor units increases. This means that there is a decrease in control of the strength of each contraction. This may be one reason people have a reduced ability for fine movements as age increases. Also, Type II fibers are often “adopted” by motor neurons from Type I fibers. This alteration speeds up the conversion of Type II fibers to Type I fibers.

A second age change is a slowing in the passage of impulses to muscle cells. There is a variable amount of slowing among the motor neurons controlling a muscle. As mentioned in Chap. 6, three alterations in the overall contraction of the muscle result. First, it takes longer for the muscle to reach its peak strength of contraction. Second, the peak amount of strength is lower. Third, the entire contraction takes more time. These alterations further reduce the maximum amount of strength a muscle can produce and make it more difficult to perform very quick movements.

Another change in motor neurons is a decrease in the frequency with which impulses are sent to the muscle. Normally, a motor neuron sends a volley of impulses in rapid succession so that the muscle cells contract rapidly. A rapid series of contractions—*incomplete tetany*—provides a fairly smooth and strong contraction that can be maintained for a long time. Since age changes in muscle cell action potentials decrease the frequency at which muscle cells can contract, reducing the frequency of neuron impulses may be compensatory. Sending impulses faster than the muscle cells can respond would be wasteful of neuron energy and neurotransmitter materials.

Other Nerve-Muscle Interactions

Several other changes in the nervous system alter the operation of muscles as people age. Recall from Chap. 6 that age changes in sensory neurons, synapses used by reflex pathways, and other areas of the central nervous system involved in controlling voluntary movements all affect adversely the ability of the muscle system to maintain homeostasis and the quality of life.

**BLOOD FLOW IN MUSCLES**

Muscle cells depend on the circulatory system to supply oxygen, nutrients, and other needed materials and to remove wastes. Service of muscle cells diminishes somewhat even when no disease of the circulatory system is present. Exactly how much of this decrease is due to age changes and how much is due to a reduction in exercise is not known.

Reasons for the reduced ability of the circulatory system to meet the needs of muscle cells
include the decrease in the density of capillaries among muscle cells and age changes in capillary structure. These changes may contribute to the decline in the maximum rate of working and the faster onset of muscle fatigue as people advance in age. These and other age changes in and diseases of the circulatory system that can affect the muscle system were discussed in Chap. 4.

CHANGES IN MUSCLE MASS

The many changes at the cellular and microscopic levels in the muscle system combine to reduce the thickness of each muscle and therefore the total amount of muscle mass. Serious loss of muscle mass is called sarcopenia. On the average, sarcopenia begins during the third decade. The rate of loss is low at first, but the rate increases with age, rising quickly after age 50. Muscle mass may decrease as much as 50 percent by age 80. This increasingly rapid loss seems to be due primarily to the decline in physical activity that usually accompanies advancing age. Most of the loss of muscle mass and thickness is due to the loss of muscle cells rather than to thinning of the cells.

Effects of Mass on Strength

The decline in muscle mass produces several effects, one of which is a decline in muscle strength. This loss of strength is related to the total thickness of a muscle since the amount of strength per unit of cross-sectional area of muscle cells remains fairly stable regardless of age. However, the reduction in muscle strength that accompanies aging is only partially due to thinning of the muscles. Other important factors include changes in muscle cell structure and functioning and increases in fat and fibrous material among the muscle cells. Changes in factors outside the muscle system (e.g., nervous system, joints, motivation) also play an important role in the decline in strength with age.

In general, strength peaks during the third decade and declines little during the fourth decade. Age-related decrease in strength becomes more rapid and significant during the fifth decade. The decline in strength becomes faster as age increases after that. However, the decline in muscle strength varies considerably from person to person and from muscle to muscle. There is variation with respect to the age at which a substantial reduction in strength can first be detected and the rate at which strength declines afterward. Muscles used for quick strong contractions show a greater decline in strength than do muscles used to maintain posture or perform other actions requiring long-lasting mild contractions.

It seems that the most important reason for heterogeneity in loss of strength is the increased variability in the amount of strenuous exercise performed regularly by each person and each muscle. For example, individuals whose daily routines include gripping objects or tools lose grip strength slowly, but these individuals may have a fairly rapid loss of leg strength if their activities include little use of the legs.

The amount of strength lost over a period of years may impair an individual’s ability to carry out ordinary activities such as shopping, gardening, cleaning, climbing stairs, and breathing heavily during exertion. It becomes increasingly difficult to continue in certain lines of employment, such as those requiring lifting or moving heavy loads. It may be necessary to forsake strenuous recreational activities such as sailing. Still, many aging individuals can tolerate declining strength by using methods requiring less brute strength, substituting power tools and appliances for muscle power, and enlisting aid from others.

The unevenness in loss of strength among different muscles creates an additional problem in the form of reduced coordination. This occurs because the balance in strength among the muscles used to perform an action is altered. An important effect of dwindling strength and decline in coordination is an increase in the risk of falling. Reduced and unbalanced muscle strength also modifies posture. Detrimental outcomes from deteriorating posture may include biological effects (e.g., restricted ability to inhale, impingement of bones on nerves), social and psychological effects of altered appearance, and economic effects from the need to obtain different clothing or furniture.

Other Effects

The reduction in muscle mass accompanying aging can have effects other than changes in strength. A change in body proportions can have social, psychological, and economic consequences for the reasons noted above related to altered posture. Another effect is the need to modify one's
diet. With less muscle mass, there is a decrease in the basal metabolic rate and a consequent decrease in the amount of calories needed per day. Though the diet consumed by most aging people should contain fewer calories, it should be richer in protein to maintain the remaining muscle mass while preventing an undesirable gain in weight. The declining metabolic rate, along with a relative decrease in the proportion of body mass composed of lean muscle, also necessitates adjustments in the doses of medications.

MUSCLE SYSTEM PERFORMANCE

Reaction Time and Speed of Movement

All the changes in the muscle system already mentioned, combined with aging in the nervous, circulatory, respiratory, and skeletal systems, lead to other noticeable alterations in the actions produced by muscles. One is an increase in the time needed to begin a voluntary motion in response to a stimulus (reaction time). For example, it takes longer for a driver to move his or her foot from the gas pedal to the brake when a traffic signal turns red. Most of the increase in reaction time is caused by slowing of the processing of impulses in the central nervous system.

Note that by definition, reaction time ends when the person begins to move. The time from the beginning of a motion to the end of that motion also increases with age. This second alteration, a decrease in the speed of movement, is caused by decreasing muscle strength.

Both the increase in reaction time and the decrease in speed of movement make the performance of rapid movements difficult. As can be seen in the example of driving, these changes increase certain risks. There is also an increased risk of falling. The probability of sustaining greater injury from a fall also rises because it takes longer to grasp a handrail or piece of furniture or to change body position to break or cushion the fall.

Longer reaction times and slower movements also make it more difficult to perform rapidly repeated movements such as those used in playing fast music or dancing. The effects of these changes become greater when individuals attempt more complex or less familiar movements. As with declining strength, changes in reaction time and speed of movement occur faster as age increases.

Skill

A third aspect of muscle activity that changes with age is skill in performing tasks. Though changes in reaction time and speed of movement have profound adverse effects on a person’s skill in performing novel activities, they have much less of an impact on activities that have been performed routinely for many years. Skill in well-practiced actions can even improve with age if repetition of the movements involved continues.

Practice also reduces the frequency of errors in performing an intended movement and selecting sequences of movements to complete complicated tasks. New strategies are formulated, and the efficiency of energy use improves with practice. Therefore, experienced older individuals may perform better than do younger individuals in activities requiring both strength and speed.

Stamina

The advantage of experience can be overshadowed by a gradual drop in stamina. Stamina may be defined as the ability to perform vigorous activity continuously for more than a few seconds. The effect of dwindling stamina on overall muscle system performance is proportionately greater than is the effect of the age-related decrease in speed of movement. Stamina declines faster as age increases.

The decrease in stamina is manifested in four ways. First, there is a decline in the maximum rate at which vigorous activities can be performed. For example, the maximum speed at which a bicycle can be ridden diminishes. Second, the length of time such activities can be performed without stopping to rest becomes shorter. This decrease in endurance is evident whether a person is working as fast as possible or at a rate somewhat lower than the maximum rate. As will be explained below, important causes of the reduction in endurance include a more rapid accumulation of lactic acid in muscles and a faster and more intense onset of discomfort at a given rate of vigorous activity.

The third indication of reduced stamina is a lengthening of the time needed to recover after ending an activity such as running. For example, it may take longer for respiration and heart rate to return to resting values. One reason for the increase in recovery time is the faster accumulation...
of lactic acid caused in part by a decline in the efficiency of movement. Another factor is a slowing in the rate at which the heat produced by muscle contraction is released from the body.

The fourth indication of dwindling stamina is a rise in muscle stiffness and soreness experienced hours or days after a vigorous activity has ended. Lactic acid buildup also seems to be a main reason for this indication.

The decline in the maximum rate of performing physical activity has been studied intensively. Therefore, this age-related change will be discussed in detail below.

\`V_{O_2}\text{max} \quad \text{The maximum rate at which a person can use muscles to perform an activity is commonly determined by measuring the rate at which that person uses oxygen while engaging in an activity at the fastest rate possible. The maximum rate of working is expressed as the \`V_{O_2}\text{max. A person's \`V_{O_2}\text{max is the amount of oxygen used per kilogram of body weight per minute while a person is exercising at the fastest rate attainable. Exercises commonly used for determining \`V_{O_2}\text{max include riding a stationary exercise bike and walking or running on a treadmill. \`V_{O_2}\text{max is also called aeroblic capacity.}}}

\`V_{O_2}\text{max declines with age. The decline begins at about age 20 for men and about age 35 for women. These are average values, however. As with many other age-related changes, there is great variability among individuals of the same age in regard to actual \`V_{O_2}\text{max values and the rate of decline in \`V_{O_2}\text{max values.}}}

A main reason for differences in the levels and rates of change of \`V_{O_2}\text{max is variation in the amount of exercise a person gets. For example, the \`V_{O_2}\text{max for people who have a rather sedentary lifestyle drops about twice as fast as does the \`V_{O_2}\text{max of individuals whose jobs, home lives, and recreational activities include large amounts of physical activity. Also, \`V_{O_2}\text{max begins to decline faster when a person's activity decreases. By contrast, when a person's participation in regular vigorous exercise increases, the decline may be delayed and become slower or even be temporarily reversed. Still, some reduction in \`V_{O_2}\text{max eventually occurs in all people, including individuals who engage in highly demanding physical activities throughout life. When vigorous physical training continues, \`V_{O_2}\text{max declines 5 percent per decade.}}}

Much of the decline in \`V_{O_2}\text{max is due to the age-related decrease in total muscle mass combined with a relative increase in the proportion of body fat. The rate of oxygen consumption of each kilogram of muscle may be the same despite age.}

Many other factors seem to contribute to the decline in \`V_{O_2}\text{max. One factor is a reduction in the ability of muscles to extract oxygen from blood. Other factors include changes and diseases that limit the functioning of the circulatory, respiratory, and skeletal systems. A person may be affected by more than one factor, and many people are affected by most or all of them. Therefore, it is extremely difficult to identify how much of the decline in \`V_{O_2}\text{max is due to aging of the muscle system rather than to other factors.}}

\textbf{Consequences of Lowered \`V_{O_2}\text{max} } \quad \text{Since \`V_{O_2}\text{max is an indicator of the maximum rate at which a person can perform activities, a small decline means a drop in the maximum rate at which a person can run, climb stairs, and carry out other vigorous activities. Individuals with lowered values tend to stop physical activities sooner because of the discomfort such activities induce. As \`V_{O_2}\text{max decreases further, limitations in less demanding activities, such as walking briskly, become evident. When very low values are reached, individuals may have trouble walking slowly or even getting up from a chair or bed.}

Since a substantial decline in \`V_{O_2}\text{max adversely affects the performance of all types of physical activity, it can reduce a person's effectiveness and participation in occupational, recreational, and social activities. When \`V_{O_2}\text{max becomes very low, the performance of ordinary daily activities needed to maintain a person becomes difficult or impossible. Examples include shopping, dressing, and bathing. Serious losses in the sense of independence and other negative psychological consequences often develop. Undesirable alterations in one area can cause detrimental effects in other areas, leading to a synergistic spiral of decline.}

As mentioned previously, the decline in \`V_{O_2}\text{max can be slowed or even reversed when an adult of any age begins a program of exercise or includes vigorous activity in his or her daily life. Individuals with relatively high \`V_{O_2}\text{max values need to engage in activities with high intensity}
and frequency to derive beneficial alterations in \( \text{VO}_2\text{max} \). People whose \( \text{VO}_2\text{max} \) is fairly low can slow the decline or increase this parameter with less strenuous activities. For many, substituting muscle power for convenience can achieve real gains. For example, parking farther from stores and walking to reach them or climbing stairs rather than using an elevator can significantly increase a person’s amount of exercise.

**STAYING PHYSICALLY ACTIVE**

Many age-related changes in the muscle system are caused or greatly increased by a decrease in physical activity. Conversely, many of these adverse changes can be greatly slowed or even negated by continuing to engage in regular exercise. It is also possible to delay, slow, reduce, or prevent many undesirable changes and diseases in other body systems by living a physically active lifestyle. In general and within reasonable limits, the more exercise a person gets, the greater the benefits.

**Specific Effects**

Many effects from maintaining a high level of physical activity are listed in Table 8.1.

**Muscle Mass** Besides retaining the strength to perform both heavy and ordinary tasks, maintaining muscle mass helps stabilize body proportions.

It also reduces detrimental changes in the ability of the hormone insulin to regulate blood sugar and certain metabolic activities in the body (Chap. 14). The effects of ongoing exercise on the nervous system help slow both the increase in reaction time and the decline in speed of movement.

\( \text{VO}_2\text{max} \) The impact of ongoing exercise on slowing the decline in \( \text{VO}_2\text{max} \) is so great that very active elderly people have values equal to or greater than those of sedentary individuals of about age 30. However, no amount of exercise can completely stop the decrease in \( \text{VO}_2\text{max} \) as age increases. Therefore, younger people who exercise will have values greater than those of older individuals who get in the same amount of exercise.

**Overview**

In considering the beneficial effects of years of physical activity, it is important to realize that these benefits are obtained only by persons who continue to lead active lives. People who are very active or athletic during youth but then become sedentary for many years lose most of the benefit they acquired in their previously active lives.

Getting regular exercise throughout life has been shown to increase life expectancy, possibly because exercise reduces the risks of certain causes of death. Exercise has not been shown to increase maximum longevity. Finally, exercise undoubtedly improves the quality of life. Long-

<table>
<thead>
<tr>
<th>TABLE 8.1 EFFECTS OF MAINTAINING A HIGH LEVEL OF PHYSICAL ACTIVITY THROUGHOUT LIFE</th>
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<tbody>
<tr>
<td><strong>Muscle system</strong></td>
</tr>
<tr>
<td>Slower decline in energy molecules (ATP, creatine phosphate, glycogen), oxidative enzymes, muscle cell thickness, number of muscle cells, muscle thickness, muscle mass, muscle strength, blood supply, speed of movement, stamina, endurance, ( \text{VO}_2\text{max} )</td>
</tr>
<tr>
<td>Slower increase in fat and fibers, reaction time, recovery time, development of muscle soreness</td>
</tr>
<tr>
<td><strong>Nervous system</strong></td>
</tr>
<tr>
<td>Slower decline in processing impulses by the CNS</td>
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<td>Slower increase in variations in speed of motor neuron impulses</td>
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<tr>
<td><strong>Circulatory system</strong></td>
</tr>
<tr>
<td>Maintenance of lower levels of LDLs and higher HDL/cholesterol and HDL/LDL ratios</td>
</tr>
<tr>
<td>Decreased risk of high blood pressure, atherosclerosis, heart attack, stroke</td>
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<tr>
<td><strong>Skeletal system</strong></td>
</tr>
<tr>
<td>Slower decline in bone minerals</td>
</tr>
<tr>
<td>Decreased risk of fractures and osteoporosis</td>
</tr>
</tbody>
</table>
term exercise enables an individual to participate more fully and with greater pleasure in many more life activities. Years of regular exercise also markedly reduce the risk of developing many disabling diseases. Those who exercise and still develop a disease are often less affected.

**STARTING OR INCREASING EXERCISE**

Clearly, elderly individuals who have been involved in vigorous physical activity throughout their lives benefit from such a lifestyle. Young people who adopt active lifestyles can expect to reap the same benefits when they become elderly. Furthermore, people of any age who have lived sedentary lives and begin to get exercise and those who have been getting only low or moderate amounts of exercise for many years and increase their exercise can improve their well-being. We will now examine outcomes in older people who begin vigorous exercise or substantially increase their level of physical activity.

**Effects**

Many effects on older people who begin or increase physical activity are listed in Table 8.2.

**Circulatory System** The rise in maximum cardiac output is evident within a few days to weeks of initiating an exercise program. The more intense the exercise program, the sooner a significant increase in maximum cardiac output appears. This rise begins to be reversed within days of ending the exercise program. The final maximum cardiac output of those leaving an exercise program will be about the same as that which existed when the exercise program began. Altering blood lipoprotein levels requires a decrease in body fat along with the effects of the exercise.

**Respiratory System** There is disagreement about whether increasing exercise increases respiratory volumes and speed of airflow, but long-term participation in exercise programs slows the decline in respiratory functioning. Therefore, in the long

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**Table 8.2: Effects of Starting or Increasing Exercise**

<table>
<thead>
<tr>
<th>System</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Circulatory system</strong></td>
<td>Increases cardiac output, cardiac efficiency, HDL/cholesterol and HDL/LDL ratios, blood vessel diameter, muscle capillaries</td>
</tr>
<tr>
<td></td>
<td>SLOWS decline in heart functioning</td>
</tr>
<tr>
<td></td>
<td>Decreases resting blood pressure, blood pressure during exercise, heartbeat abnormalities</td>
</tr>
<tr>
<td><strong>Respiratory system</strong></td>
<td>Increases clearance of mucus and respiratory efficiency</td>
</tr>
<tr>
<td></td>
<td>SLOWS decline in respiratory functioning and closing of airways</td>
</tr>
<tr>
<td><strong>Nervous system</strong></td>
<td>Increases formation of new axon branches to orphaned muscle cells, speed of impulse processing by the CNS, balance, short-term memory, sleep, mental abilities (possibly)</td>
</tr>
<tr>
<td></td>
<td>DECREASES variability in speed of action potentials in motor neurons and risk of falling</td>
</tr>
<tr>
<td><strong>Muscle system</strong></td>
<td>Increases oxidative enzymes, stored glycogen, capillary numbers, blood flow, uptake of oxygen from blood, cell thickness, muscle strength, muscle mass, speed of movement, stamina, endurance, Vo2max</td>
</tr>
<tr>
<td></td>
<td>SLOWs decline in efficiency of movement and increase in recovery time</td>
</tr>
<tr>
<td><strong>Skeletal system</strong></td>
<td>Increases ease of movement, range of movement, joint flexibility</td>
</tr>
<tr>
<td></td>
<td>SLOWs bone demineralization</td>
</tr>
<tr>
<td></td>
<td>DECREASEs risk of falling and sustaining fractures</td>
</tr>
<tr>
<td><strong>Endocrine system</strong></td>
<td>Increases glucose tolerance and sensitivity to insulin</td>
</tr>
<tr>
<td></td>
<td>SLOWs decline in growth hormone</td>
</tr>
</tbody>
</table>
run elderly individuals who exercise will eventually have better respiratory system functioning than they will if they remain sedentary.

The respiratory system changes caused by a proper exercise program are of special importance to persons who have chronic obstructive pulmonary diseases (COPDs) such as chronic bronchitis and emphysema.

**Nervous System** The mechanisms by which strenuous exercise increases strength in older people are different from those in younger people. At younger ages the increase in strength from training with heavy weights is caused almost exclusively by thickening of the muscle cells rather than alterations in the nervous system. Perhaps the change in mechanisms for increasing strength is a way the aging body partially compensates for a decreased ability of the muscle cells to adapt to lifting or moving heavy loads.

**Muscle System** The gain in strength achieved by older individuals is proportionately the same as that which younger adults attain with the same type of exercise. For example, consider an older person who has had little exercise for many years and a younger adult who has had the same level of activity. The older person will not be as strong as the younger adult because the older adult has been losing strength for a longer period. If both individuals begin an exercise program designed to double the strength of an adult, both will end the program with twice the strength they had when they started. Of course, since the younger person was stronger at the start of the program, he or she will be the stronger person at the end. However, an older person who participates in such a program can become stronger than a younger adult who remains sedentary.

Older individuals whose exercise is not strenuous enough to cause an increase in strength still benefit because they at least have a slower decline in strength. Therefore, after long-term involvement in physical activity these individuals will be stronger than they would have been if they had remained sedentary. They will also have retained more total muscle mass. Keeping a high muscle mass helps the functioning of insulin.

Alterations in \( V_{\text{O}_2 \text{max}} \) caused by increased exercise are similar in three ways to exercise-induced changes in strength. First, the increase in \( V_{\text{O}_2 \text{max}} \) attained by an older person is proportionately the same as that achieved by a younger adult who starts with the same capability and participates in the same exercise program. Second, elderly people who increase their physical activity enough can develop values that are greater than those of much younger adults who remain sedentary. Third, elderly people whose increase in exercise is not enough to produce an increase in \( V_{\text{O}_2 \text{max}} \) will still benefit because even small increases in physical activity slow the decline in \( V_{\text{O}_2 \text{max}} \). Therefore, these individuals will eventually have a greater \( V_{\text{O}_2 \text{max}} \) than they would have had if they had remained sedentary.

There is an important difference between the effects of exercise on alterations in conditions such as blood lipoproteins, body composition, percent body fat, functioning of insulin, and strength and the effects on alterations in \( V_{\text{O}_2 \text{max}} \). Though vigorous activity is needed to effect substantial changes in the first five parameters, for very sedentary older people even low levels of easy activities such as walking can substantially increase \( V_{\text{O}_2 \text{max}} \). The resulting improvements can restore the ability of very sedentary elderly individuals with extremely low \( V_{\text{O}_2 \text{max}} \) values to perform the ordinary activities of daily living.

All the exercise-induced alterations in the nervous and muscle systems just described combine to produce several other benefits in the elderly. These benefits include the perception that less effort is needed to perform demanding tasks; improved mood and sense of well-being; improved social interactions; and increased independence.

**Skeletal System** Aging of the skeletal system raises the risk of sustaining fractures by causing demineralization of bones and reducing the ease of movement and range of motion of joints. Some forms of the joint disease called arthritis exaggerate these changes.

No one knows the best exercise program for slowing or reversing bone demineralization caused by aging or osteoporosis; different programs may be effective for different individuals. Also, different individuals can tolerate different amounts and types of exercise. The causes of these differences include physical condition, presence of diseases, lifestyle, and motivation.

The possible benefits of slowing bone demineralization and deterioration of joint functioning through a large increase in strenuous or vigorous physical activity must be weighed against the
added risk of injury. Some more common problems include; increased risk of fracture of the bones in the spinal column caused by lifting or holding heavy loads; increased risk of fracturing hip, leg, or arm bones by falling; traumatic injury to the bones, muscles, ligaments, and tendons in the lower legs from walking or running on hard surfaces or with improper footwear; and injury to the joints from excessive movements or forces, including impact forces.

**Endocrine System**  Exercise leading to a decrease in body fat significantly improves glucose tolerance and insulin sensitivity in elderly people who have a reduced glucose tolerance or non-insulin-dependent diabetes mellitus (NIDDM). Individuals who improve their glucose tolerance and insulin sensitivity have a substantially reduced risk of developing the complications associated with diabetes.

These beneficial effects of exercise begin to develop within days or even hours after a person increases the level of vigorous physical activity. Improvement increases as body fat decreases. However, the beneficial effects of the exercise begin to dwindle within a few days of ending involvement in the exercise program. Therefore, to sustain the benefits of exercise, a person with reduced glucose tolerance or NIDDM must engage in the exercise at least once every three days.

By contrast, individuals with type I (insulin-dependent) diabetes mellitus (IDDM) have very unstable blood sugar levels. Therefore, the amount of exercise they get must be carefully monitored and adjusted according to factors such as the severity of the disease, diet, and insulin treatments.

**Other Effects**  The effects of increasing exercise mentioned up to this point are related to specific body systems, but elderly people who increase their exercise seem to benefit in many other ways. These other benefits include helping to maintain normal body weight by improving nutrition and using more calories; increasing independence by generally slowing the onset of disability and physical limitations; and helping to enhance psychological health by improving mood and sense of well-being while reducing boredom, anxiety, and stress.

The physical and psychological effects of exercising also increase older individuals' ability to remain productive and economically self-sufficient. Their social situation is bolstered by the additional social interactions obtained through exercise programs and through an enhanced ability to participate in other activities in the community. Therefore, while increasing exercise has not been shown to lengthen life, it dramatically improves the quality of life for older individuals.

**EXERCISE RECOMMENDATIONS**

Having reviewed how exercise benefits the elderly, we will now consider information and suggestions that have been found important in achieving these benefits.

First, as with other mechanisms that maintain homeostasis, adjustments made in body systems to each form of exercise represent attempts to minimize or prevent disturbances in internal conditions. Furthermore, adjustments and improvements made by the body are specific to the demands placed on it. For example, if conditions in leg muscles are significantly disturbed by lifting heavy loads, those muscles will become stronger and therefore will be less affected when the loads are lifted a few days later. By contrast, if conditions in leg muscles are disturbed by an activity involving many repeated actions that do not require much strength, such as walking briskly for a long distance, the adjustments in the body will increase stamina for walking but will have little effect on muscle strength.

**Set Goals**

The first step in preparing to increase exercise is to establish specific goals. Then activities can be selected that will cause the body to make the adjustments needed to achieve those goals. For example, if an increase in the range of motion of the arms is desired, activities requiring movement of the arms over wide angles can be selected. If increasing the grip strength of the hands is a goal, activities using strong grasping should be undertaken. As more goals are identified, a greater number and variety of exercises or activities must be employed.

In a more general way, if exercise is being used to improve the functioning of the circulatory and respiratory systems, a number of activities demanding faster blood flow and increased respi-
ration can produce the desired results. Examples include walking or riding a bicycle at a fast pace, running, and swimming.

**Evaluate and Individualize**

When one is deciding on exercises, attention must be paid to the condition of the person who is participating in the exercises. Careful attention to an elderly person’s physical condition is particularly important because of the higher incidence of disease and the increased heterogeneity among older people. At this point, a qualified professional should perform a physical examination and evaluation of the participant and the information obtained should be used to determine the appropriateness of the anticipated activities. At least one follow-up examination and evaluation should be performed several days or a few weeks after the individual has taken up the new level of activity. Data from the first and later examinations and evaluations should be used to determine what changes are occurring because of the increased exercise and to suggest improvements in the activities.

**Plan a Program**

Once appropriate activities have been selected and the condition of the participant has been ascertained, decisions about the intensity and the length of exercise can be made. The time allotted for exercise should include time for warming up and cooling down. The frequency with which the activity will be performed can also be established. A healthy person should exercise at least 30 minutes each session, with sessions occurring at least every three days.

Generally, starting in with a fairly low level of intensity and a short duration of activity is best, especially for very sedentary or frail individuals, who can achieve substantial benefits from relatively low levels of exercise. Also, such individuals are more likely to sustain injuries or other adverse effects from a sudden increase in physical activity. Beginning with low levels of exercise also helps prevent negative attitudes by minimizing the discomfort caused by an increase in exercise.

Consideration might also be given to the number of weeks or months during which the participant expects to perform the activity. Exercise programs lasting only a few weeks produce little benefit, while those lasting several months or longer yield significantly better results. Longer-lasting programs are especially important for older people since the rate of improvement caused by exercise decreases with age. Sustained participation in the exercise program is aided by using positive feedback and other motivational strategies, such as combining exercise sessions with social activities. Since the exercise program should last for an extended time, it is important to provide for proper nutrition.

As the exercise program continues, the intensity or duration of each exercise or the frequency with which it is performed each week should be increased gradually so that the participant continues to improve. If the exercise is not increased, the participant’s level of physical fitness will soon stabilize, and boredom may become a problem if there is no variation. Furthermore, the psychological benefits of exercise become most apparent once a high intensity and greater frequency have been achieved.

**Minimize Problems**

Although the benefits are directly proportional to the intensity, duration, and frequency of exercise, care must be taken not to exceed reasonable limits. As levels of exercise increase, so do the risks of overheating, being physically injured, and developing complications from existing diseases.

Very strenuous activities present a special danger to those with atherosclerosis because people tend to hold their breath while pulling or pushing with great force. Blood pressure rises to a very high level during such maneuvers, placing a great burden on the heart and arteries. A heart attack, a stroke, or damage to the retina or vitreous humor can result. When the straining ends, there is a sudden drop in blood pressure, placing additional burdens on the heart and sometimes causing dizziness, fainting, and falling. These problems can be largely avoided by minimizing exercises requiring great strength and maximizing activities involving free movement of parts of the body.

**Consider Alternatives**

When one is discussing exercise, focusing in on activities whose primary purpose is exercise is easy (e.g., aerobics, weight lifting, jogging). Using such activities and the many available exer-
Exercise machines and devices provide means of carefully regulating the amount of exercise obtained and measuring physical status and improvements in physical fitness.

While some individuals enjoy such purposeful exercise, others find it unpleasant, expensive, or unavailable. These individuals can still obtain plenty of beneficial exercise through activities with other primary purposes. Examples include recreational activities such as dancing, sports, and hiking and activities related to occupations requiring physical work. Activities performed in caring for one’s home and family, such as gardening and mowing a lawn, shopping, and doing laundry, can provide opportunities to get healthful exercise. Choosing to walk or climb stairs rather than riding can add substantially to the amount of beneficial exercise obtained.

Achieving the benefits of increasing exercise often involves nothing more than substituting muscle power for motor power. What may be needed first, however, is replacement of the notion that using minimal physical effort means living well with the realization that only through regular physical exercise can an older person achieve “the good life.”

**DRIVING MOTOR VEHICLES**

Driving accidents increase in numbers and in rates as the age of the drivers increase. For example, elderly drivers have twice as many accidents per mile compared with younger drivers. Elder drivers who have accidents are more likely to sustain serious or fatal injury than are younger drivers. At the same time, the number and proportion of elder drivers are increasing, and they will continue to increase at faster rates for the next few decades. By 2024, drivers over age 64 will make up 25 percent of all drivers.

Potential accident situations often require making quick and coordinated responses in new situations. Therefore, elder drivers can be very safe drivers until they meet surprising or complicated situations that demand quick reactions in unfamiliar situations. Examples of problematic situations for elders are intersections. In such demanding situations, age changes in muscle strength, speed, reaction time, and coordination contribute to an age-related decrease in driving ability. Age changes and age-related abnormalities in other body systems also contribute to reduced driving ability. These changes and abnormalities are described in other chapters.

Neurological parameters that change very little with normal aging include implicit memory of driving skills and making automatic coordinated responses. Other age-related changes that do not have a major impact on driving ability in elders include modest decrements in vision and in hearing. The small effects on driving safety among elders from decrements in vision and in hearing may be due to elders avoiding driving at times and conditions where these decrements are important (e.g., nighttime, bad weather, heavy traffic, high speeds, time pressures). In general, overall cognitive ability has little to do with driving skills until cognitive abilities become severely reduced. Therefore, people in early stages of dementia can still be good drivers.

Important neurological factors that limit driving ability for elders include age-related decreases in avoiding distraction; changing attention quickly; responding quickly in unfamiliar situations; noticing, accurately identifying and responding to sudden changes in the visual field; noticing and responding to a novel change in the environment; and distinguishing between important and unimportant items in the visual field.

Driving is very important to elders for many reasons including mobility; independence; a sense of self-efficacy; and a sense of self-worth. Loss of driving often causes major psychological, social, and economic problems for elders. Demands to provide alternative means of transportation increase (e.g., family, friends, community groups, private companies, governmental agencies).

Recommendations that can accommodate these diverse factors include providing reliable, practical and regular tests for evaluating elder drivers; providing education and training to maintain or improve elders’ driving skills and safety; and developing alternative transportation for elders as they give up or lose their driving privileges.