tioning, then, depends on the functioning of many other parts of the body. This fact illustrates a principle that is repeated often in this book. It can be simply stated: Each part of the body is one of many components in a large, interactive system. The normal function of one part depends on the normal function of the other parts.

Motor Unit

Before a skeletal muscle can contract and pull on a bone to move it, the muscle must first be stimulated by nerve impulses. Muscle cells are stimulated by a nerve fiber called a **motor neuron** (Figure 6-4). The point of contact between the nerve ending and the muscle fiber is called a **neuromuscular junction.** Specialized chemicals are released by the motor neuron in response to a nervous impulse. These chemicals then generate events within the muscle cell that result in contraction or shortening of the muscle cell. A single motor neuron, with the muscle cells it innervates, is called a **motor unit** (Figure 6-4).

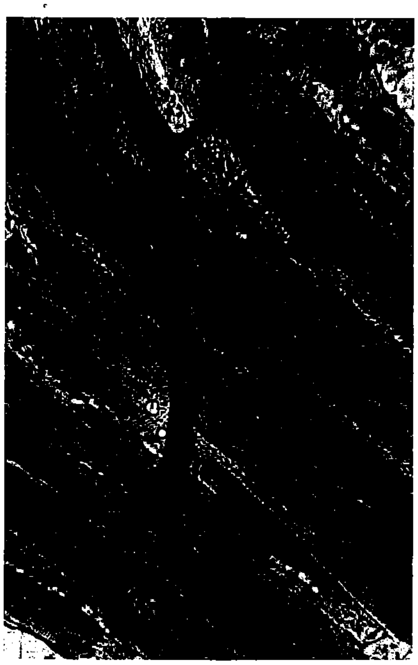
Muscle Stimulus

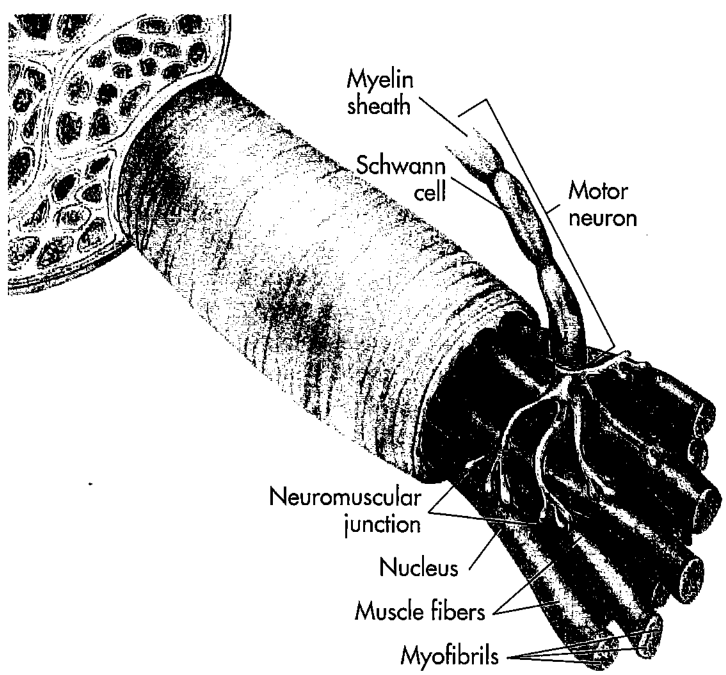
In a laboratory setting a single muscle fiber can be isolated and subjected to stimuli of varying intensities so that it can be studied. Such experiments show that a muscle fiber does not contract until an applied stimulus reaches a certain level of intensity. The minimal level of stimulation required to cause a fiber to contract is called the **threshold stimulus.**

When a muscle fiber is subjected to a threshold stimulus, it contracts completely. Because of this,

FIGURE 6-4

Motor neuron. A motor unit consists of one motor neuron and the muscle fibers supplied by its branches.





muscle cells are said to respond **"all or none."** However, a muscle is composed of many muscle cells that are controlled by different motor units and that have different threshold-stimulus levels. Although each fiber in a muscle such as the biceps brachii responds all or none when subjected to a threshold stimulus, the muscle as a whole does not. This fact has tremendous importance in everyday life. It allows you to pick up a 2-liter bottle of soda or a 20 kg weight because different numbers of motor units can be activated for different loads. Once activated, however, each fiber always responds all or none.

Types of Skeletal Muscle Contraction

In addition to the specialized tonic contraction of muscle that maintains muscle tone and posture, other types of contraction also occur. Additional types of muscle contraction include the following:

1. **Twitch contraction**
2. **Tetanic contraction**
3. **Isotonic contraction**
4. **Isometric contraction**

Twitch and Tetanic Contractions

A **twitch** is a quick, jerky response to a stimulus. Twitch contractions can be seen in isolated muscles during research, but they play a minimal role in normal muscle activity. To accomplish the coordinated and fluid muscular movements needed for most daily tasks, muscles must contract not in a jerky but in a smooth and sustained way.

A **tetanic contraction** is a more sustained and steady response than a twitch. It is produced by a series of stimuli bombarding the muscle in rapid succession. Contractions "melt" together to produce a sustained contraction or *tetanus.* About 30 stimuli per second, for example, evoke a tetanic contraction in certain types of skeletal muscle. Tetanic contraction is not necessarily a maximal contraction in which each muscle fiber responds at the same time. In most cases, only a few groups of muscle fibers undergo contractions at any time.

Isotonic Contraction

In most cases, isotonic contraction of muscle produces movement at a joint. With this type of contraction the muscle shortens, and the insertion end moves toward the point of origin (Figure 6-5, *A*). Walking, running, breathing, lifting, and twisting are examples of isotonic contraction.

Isometric Contraction

Contraction of a skeletal muscle does not always produce movement. Sometimes, it increases the tension within a muscle but does not shorten the muscle. When the muscle does not shorten and no movement results, it is called an *isometric contraction.* The word *isometric* comes from Greek words that mean "equal measure." In other words, a muscle's length during an isometric contraction and during relaxation is about equal. Although muscles do not shorten (and thus produce no movement) during isometric contractions, tension within them increases (Figure 6-5, *B*). Because of this, repeated isometric contractions make muscles grow larger and stronger. Pushing against a wall or other immovable object is a good example of isometric exercise. Although no movement occurs and the muscle does not shorten, its internal tension increases dramatically.

Effects of Exercise on Skeletal Muscles

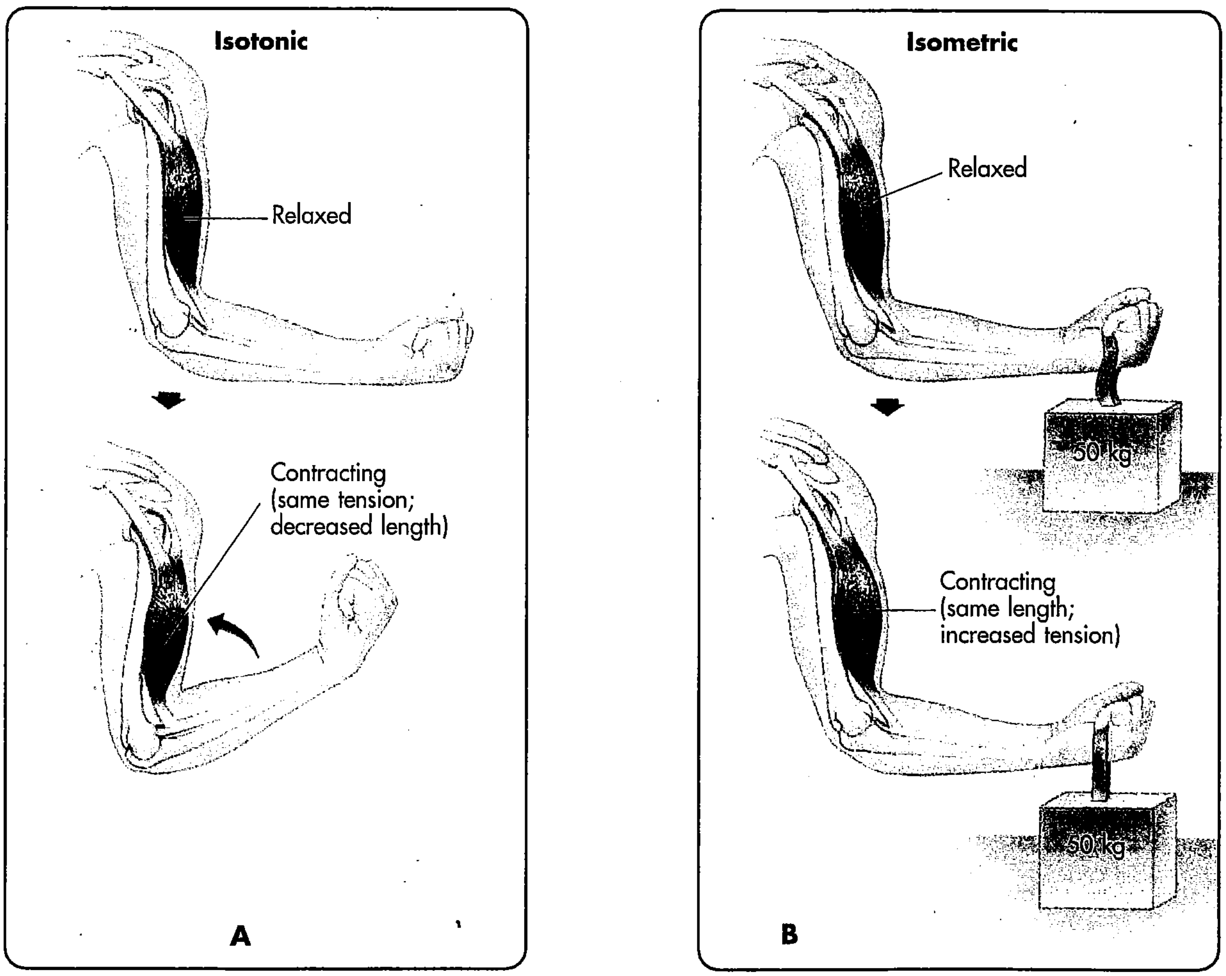
We know that exercise is good for us. Some of the benefits of regular, properly practiced exercise are greatly improved muscle tone, better posture, more efficient heart and lung function, less fatigue, and looking and feeling better.

Skeletal muscles undergo changes that correspond to the amount of work that they normally do. During prolonged inactivity, muscles usually shrink in mass, a condition called **disuse atrophy.** Exercise, on the other hand, may cause an increase in muscle size called **hypertrophy.**

Muscle hypertrophy can be enhanced by **strength training,** which involves contracting muscles against heavy resistance. Isometric exercises

FIGURE 6-5

Types of muscle contraction. A, In isotonic contraction the muscle shortens, producing movement. **B,** In isometric contraction the muscle pulls forcefully against a load but does not shorten.



and weight lifting are common strength-training activities. This type of training results in increased numbers of myofilaments in each muscle fiber. Although the number of muscle fibers stays the same, the increased number of myofilaments greatly increases the mass of the muscle.

Endurance training, often called **aerobic training,** does not usually result in muscle hypertrophy. Instead, this type of exercise program increases a muscle's ability to sustain moderate exercise over a long period. Aerobic activities such as running, bicycling, or other primarily isotonic movements increase the number of blood vessels in a muscle without significantly increasing its size. The increased blood flow allows a more efficient delivery of oxygen and glucose to muscle fibers during exercise. Aerobic training also causes an increase in the number of mitochondria in muscle fibers. This allows production of more ATP as a rapid energy source.