Skeletal muscle

About 40 percent of the body is skeletal muscle, and perhaps another 10 percent is smooth and cardiac muscle. Some of the same basic principles of contraction apply to all of these muscle types

PHYSIOLOGICAL ANATOMY OF SKELETAL MUSCLE

SKELETAL MUSCLE FIBER

Figures below show the organization of skeletal muscle demonstrating that all skeletal muscles are composed of numerous fibers ranging from 10 to 80 micrometers in diameter. Each of these fibers is made up of successively smaller subunits, and described in subsequent paragraphs.
In most skeletal muscles, each fiber extends the entire length of the muscle. Except for about 2 percent of the fibers, each fiber is usually innervated by only one nerve ending, located near the middle of the fiber

The Sarcolemma Is a Thin Membrane Enclosing a Skeletal Muscle Fiber.
The sarcolemma consists of a true cell membrane, called the *plasma membrane*, and an outer coat made up of a thin layer of polysaccharide material that contains numerous thin collagen fibrils. At each end of the muscle fiber, this surface layer of the sarcolemma fuses with a tendon fiber. The tendon fibers in turn collect into bundles to form the muscle tendons that then connect the muscles to the bones.

Myofibrils Are Composed of Actin and Myosin Filaments.

Each muscle fiber contains several hundred to several thousand *myofibrils* Each myofibril is composed of about 1500 adjacent *myosin filaments* and 3000 *actin filaments*, which are large polymerized protein molecules that are responsible for the actual muscle contraction. the thick filament is myosin and the thin filament is actin

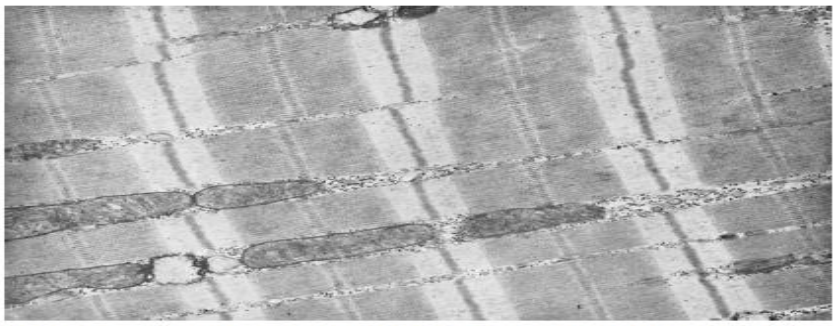


Figure 6-2. An electron micrograph of muscle myofibrils showing the detailed organization of actin and myosin filaments. Note the mitochondria lying between the myofibrils. *(From Fawcett DW: The Cell. Philadelphia: WB Saunders, 1981.)*

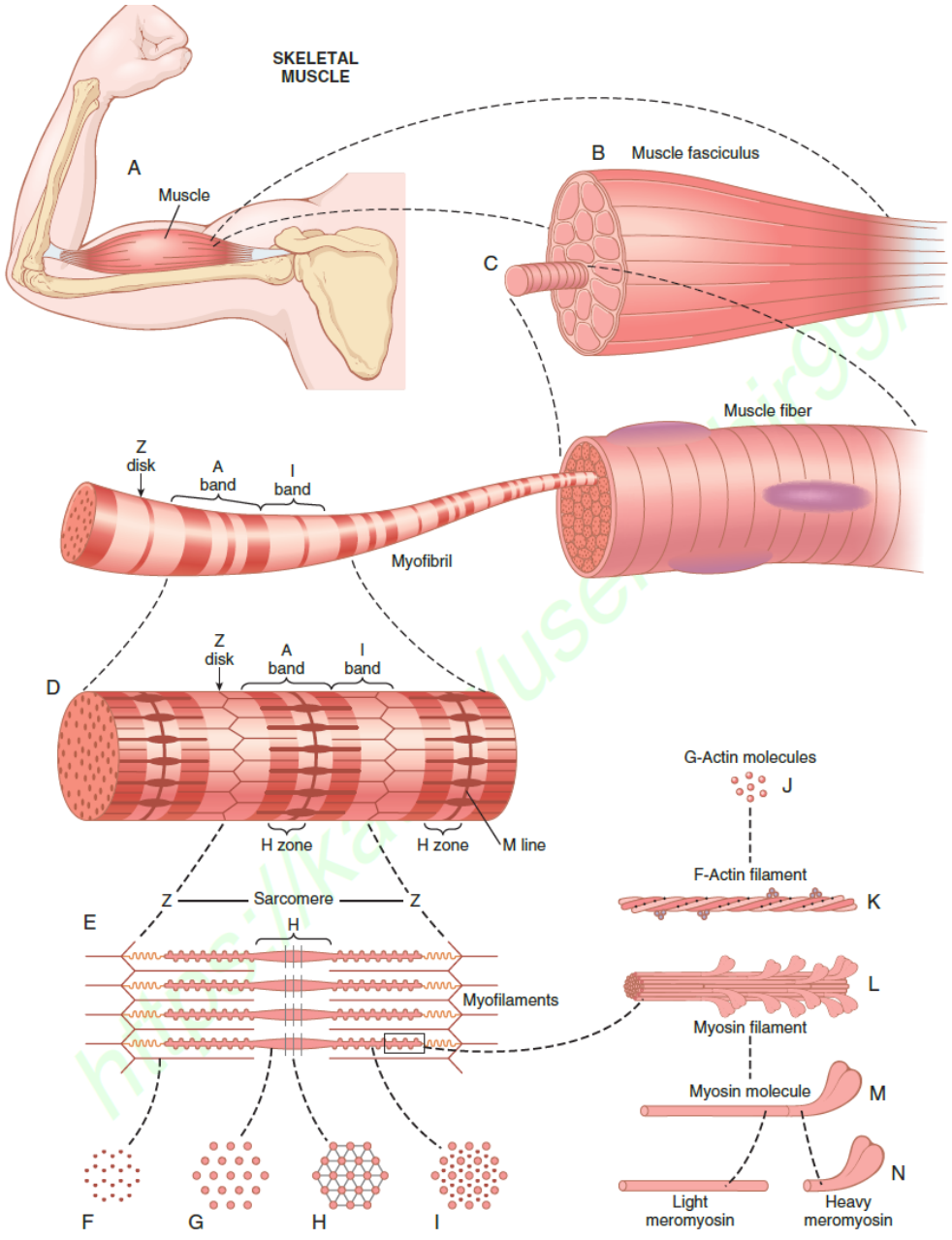


Figure 6-1. Organization of skeletal muscle, from the gross to the molecular level. *F, G, H,* and *I* are cross sections at the levels indicated.

the myosin and actin filaments partially interdigitate and thus cause the myofibrils to have alternate light and dark bands. The light bands contain only actin filaments and are called *I bands* because they are *isotropic* to polarized light. The dark bands contain myosin filaments, as well as the ends of the actin filaments where they overlap the myosin, and are called *A bands* because they are *anisotropic* to polarized light. Note also the small projections from the sides of the myosin filaments These projections are *cross-bridges.* It is the interaction between these cross-bridges and the actin filaments that causes contraction.

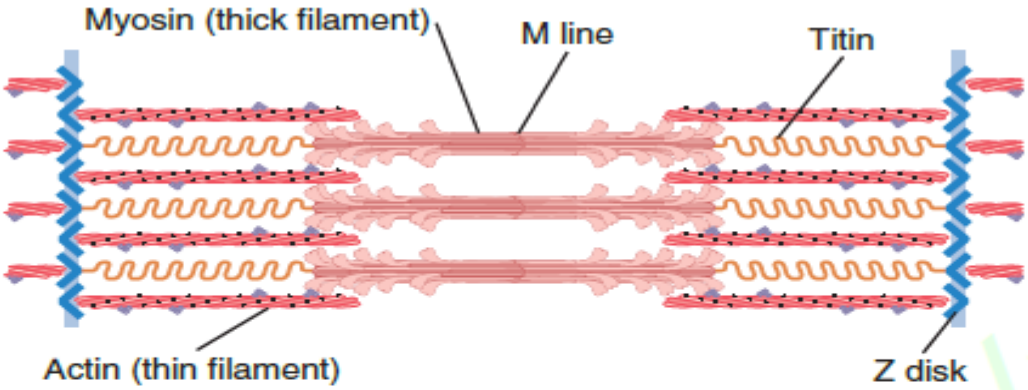


Figure 6-3. Organization of proteins in a sarcomere. Each titin molecule extends from the *Z disk* to the *M line*. Part of the titin molecule is closely associated with the myosin thick filament, whereas the rest of the molecule is springy and changes length as the sarcomere contracts and relaxes.

GENERAL MECHANISM OF MUSCLE CONTRACTION

The initiation and execution of muscle contraction occur in the following sequential steps.

1. An action potential travels along a motor nerve to its endings on muscle fibers.
2. At each ending, the nerve secretes a small amount of the neurotransmitter substance *acetylcholine.*
3. The acetylcholine acts on a local area of the muscle fiber membrane to open “acetylcholine-gated” cation channels through protein molecules floating in the membrane.
4. Opening of the acetylcholine-gated channels allows large quantities of sodium ions to diffuse to the interior of the muscle fiber membrane. This action causes a local depolarization that in

turn leads to opening of voltage-gated sodium channels, which initiates an action potential at the membrane.

5. The action potential travels along the muscle fiber membrane in the same way that action potentials travel along nerve fiber membranes.

6. The action potential depolarizes the muscle membrane, and much of the action potential electricity flows through the center of the muscle fiber. Here it causes the sarcoplasmic reticulum to release large quantities of calcium ions that have been stored within this reticulum.

7. The calcium ions initiate attractive forces between the actin and myosin filaments, causing them to slide alongside each other, which is the contractile process.

8. After a fraction of a second, the calcium ions are pumped back into the sarcoplasmic reticulum by a Ca++ membrane pump and remain stored in the reticulum until a new muscle action potential comes along; this removal of calcium ions from the myofibrils causes the muscle contraction to cease.

MOLECULAR MECHANISM OF MUSCLE CONTRACTION

Muscle Contraction Occurs by a Sliding Filament Mechanism. Figure below demonstrates the basic mechanism of muscle contraction. It shows the relaxed state of a sarcomere (top) and the contracted state (bottom). In the relaxed state, the ends of the actin filaments extending from two successive Z disks barely overlap one another. Conversely, in the contracted state, these actin filaments have been pulled inward among the myosin filaments, so their ends overlap one another to their maximum extent. Also, the Z disks have been pulled by the actin filaments up to the ends of the myosin filaments. Thus, muscle contraction occurs by a *sliding filament mechanism.*

This action is caused by forces generated by interaction of the cross-bridges from the myosin filaments with the actin filaments. Under resting conditions, these forces are inactive but when an action potential travels along the muscle fiber, this causes the sarcoplasmic reticulum to release large quantities of calcium ions that rapidly surround the

myofibrils. The calcium ions in turn activate the forces between the myosin and actin filaments.

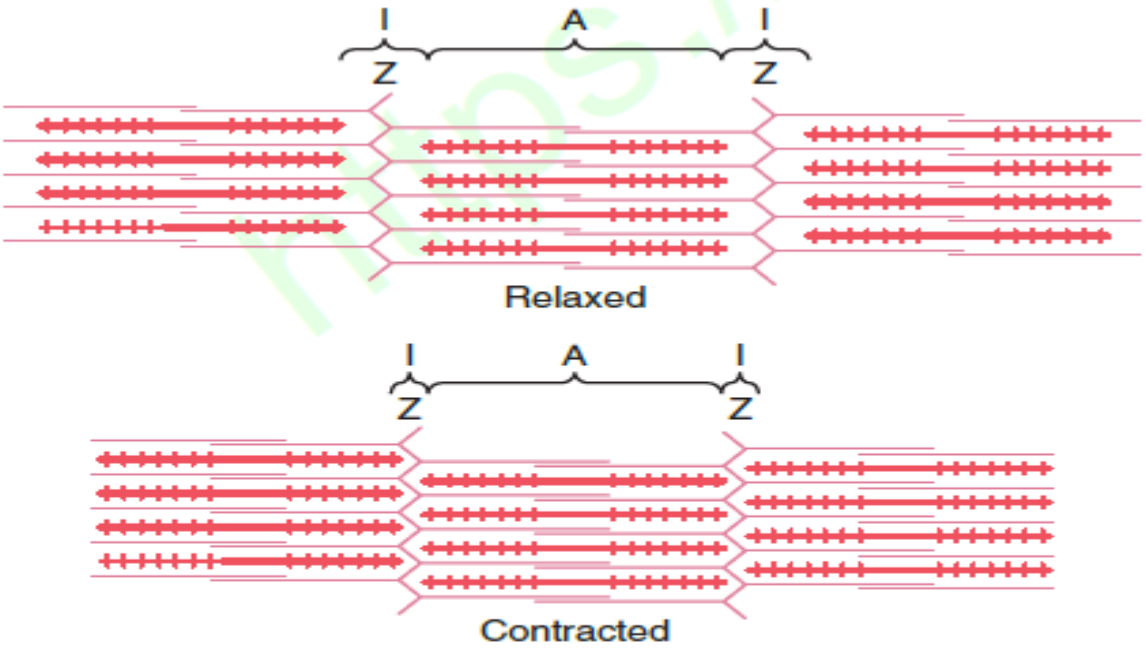


Figure 6-5. Relaxed and contracted states of a myofibril showing (*top*) sliding of the actin filaments (*pink*) into the spaces between the myosin filaments (*red*) and (*bottom*) pulling of the Z membranes toward each other.

TRANSMISSION OF IMPULSES FROM NERVE ENDINGS TO SKELETAL MUSCLE FIBERS: THE NEUROMUSCULAR JUNCTION

Skeletal muscle fibers are innervated by large, myelinated nerve fibers that originate from large motoneurons in the anterior horns of the spinal cord. each nerve fiber, after entering the muscle belly, normally branches and stimulates from three to several hundred skeletal muscle fibers. Each nerve ending makes a junction, called the *neuromuscular junction*, with the muscle fiber near its midpoint. The action potential initiated in the muscle fiber by the nerve signal travels in both directions toward the muscle fiber ends.

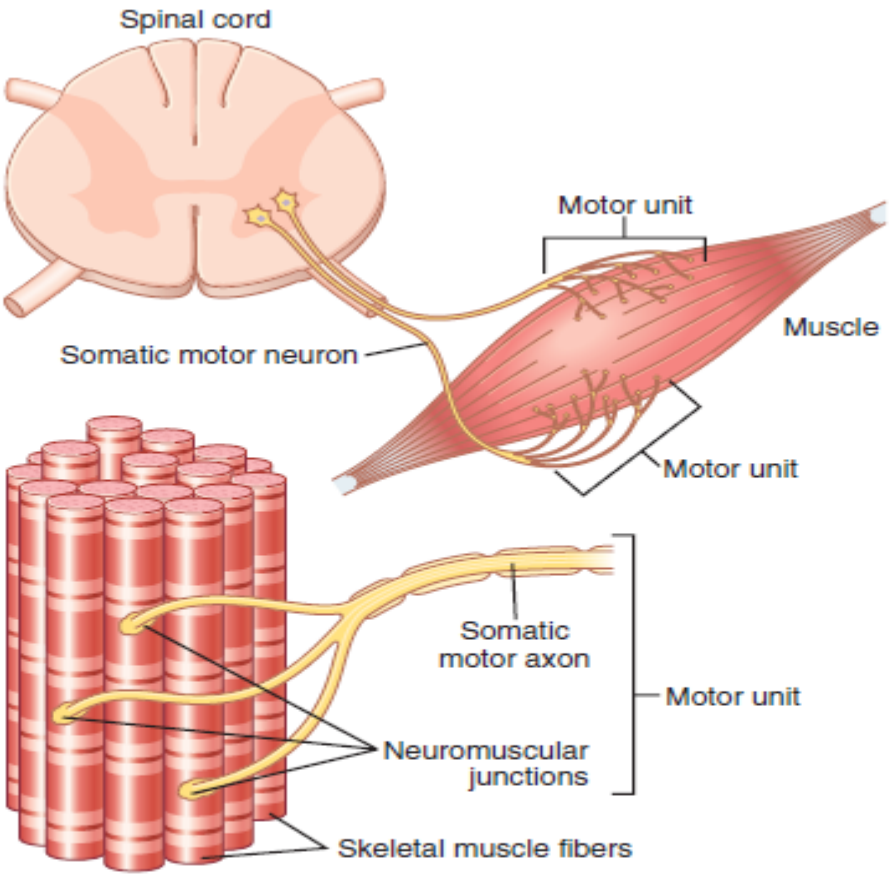
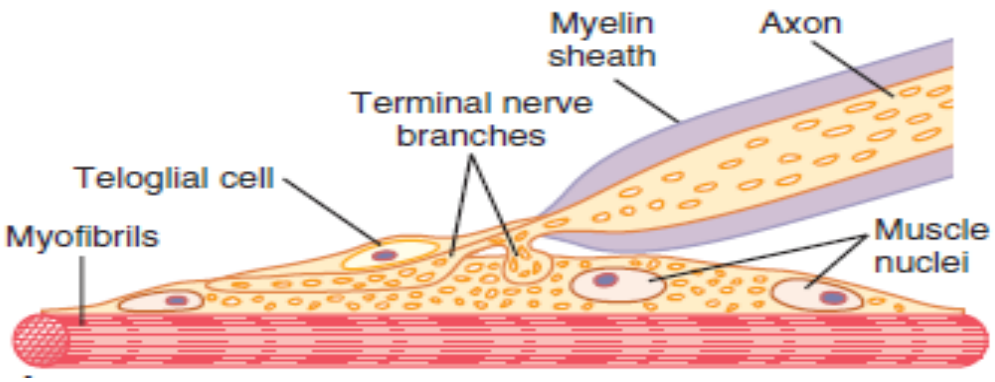


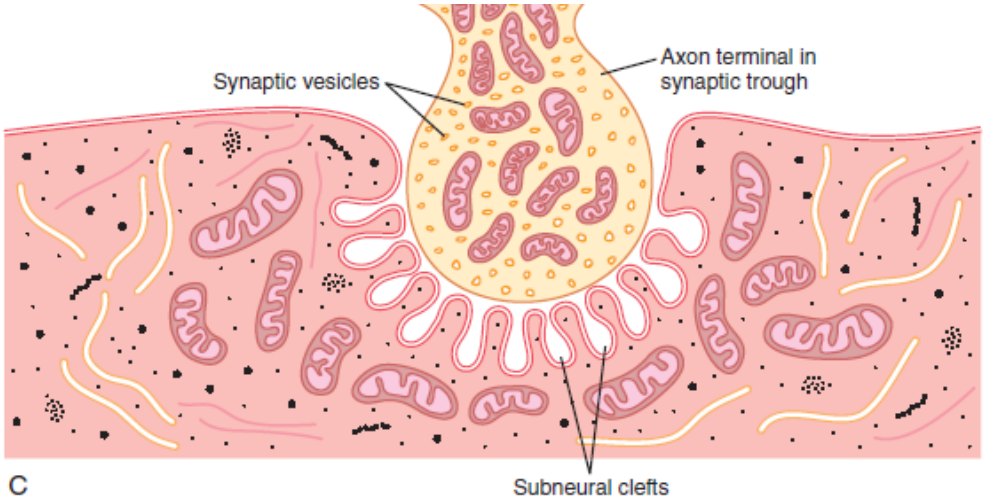
Figure 6-14. A motor unit consists of a motor neuron and the group of skeletal muscle fibers it innervates. A single motor axon may branch to innervate several muscle fibers that function together as a group. Although each muscle fiber is innervated by a single motor neuron, an entire muscle may receive input from hundreds of different motor neurons.

Figures below shows the neuromuscular junction from a large, myelinated nerve fiber to a skeletal muscle fiber. The nerve fiber forms a complex of *branching nerve terminals* that invaginate into the surface of the muscle fiber but lie outside the muscle fiber plasma membrane. The entire structure is called the *motor end plate.*



the space between the terminal and the fiber membrane is called the *synaptic space* or *synaptic cleft.* At the bottom of the trough are numerous smaller *folds* of the muscle membrane called *subneural clefts*, which greatly increase the surface area at which the synaptic transmitter can act.

In the axon terminal are many mitochondria that supply adenosine triphosphate (ATP), the energy source that is used for synthesis of an excitatory transmitter, *acetylcholine.* The acetylcholine in turn excites the muscle fiber membrane. Acetylcholine is synthesized in the cytoplasm of the terminal, but it is absorbed rapidly into many small *synaptic vesicles*. In the synaptic space are large quantities of the enzyme *acetylcholinesterase*, which destroys acetylcholine a few milliseconds after it has been released from the synaptic vesicles.



SECRETION OF ACETYLCHOLINE BY THE NERVE TERMINALS

When a nerve impulse reaches the neuromuscular junction, about 125 vesicles of acetylcholine are released from the terminals into the synaptic space. Some of the details of this mechanism can be seen in **Figure below**, which shows an expanded view of a synaptic space with the neural membrane above and the muscle membrane and its subneural clefts below.

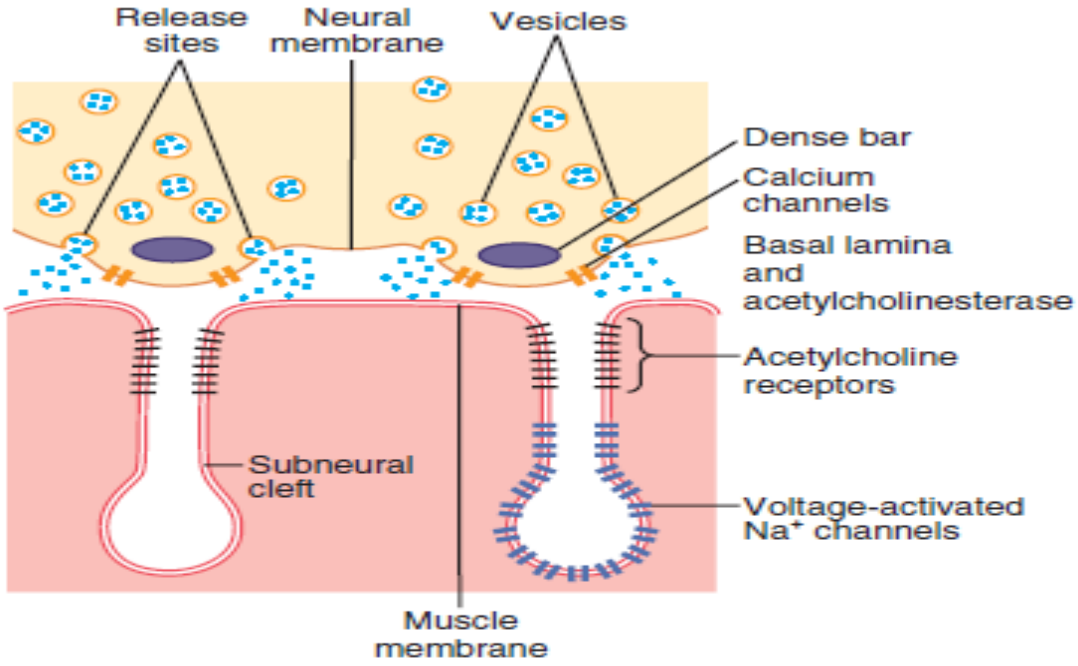


Figure 7-2. Release of acetylcholine from synaptic vesicles at the neural membrane of the neuromuscular junction. Note the proximity of the release sites in the neural membrane to the acetylcholine receptors in the muscle membrane, at the mouths of the subneural clefts.

On the inside surface of the neural membrane are linear *dense bars*, shown in cross section in **Figure 7-2**.at each side there are ca+ channel it activated when action potential occur and open and ca+ ion enter from synaptic apace to neural terminal and activate ca+ kinase that anchor Ach vesicles to the cytoskeletone presynatic terminal the vesicles then come to presynaptic membrane of active zone and release of its Ach to the synaptic space by process exocytosis.

On the muscle fiber membrane directly below dense bar near subneural cleft Ach receptor, called ***Ach gated ion channel*** ,Ach bind to this receptor and this attachment cause conformational change that open the channel this Ach gated channel passes Na+, K+ and Ca+ but it repel negative ion as Cl- due to negative charge of the channel as in figure below , the principal effect of opening the acetylcholine-gated channels is to allow large numbers of sodium ions to pour to the inside of the fiber, carrying with them large numbers of positive charges. This action creates a local positive potential change inside the muscle fiber membrane, called the *end plate potential.* In turn, this end plate

potential initiates an action potential that spreads along the muscle membrane and thus causes muscle contraction.

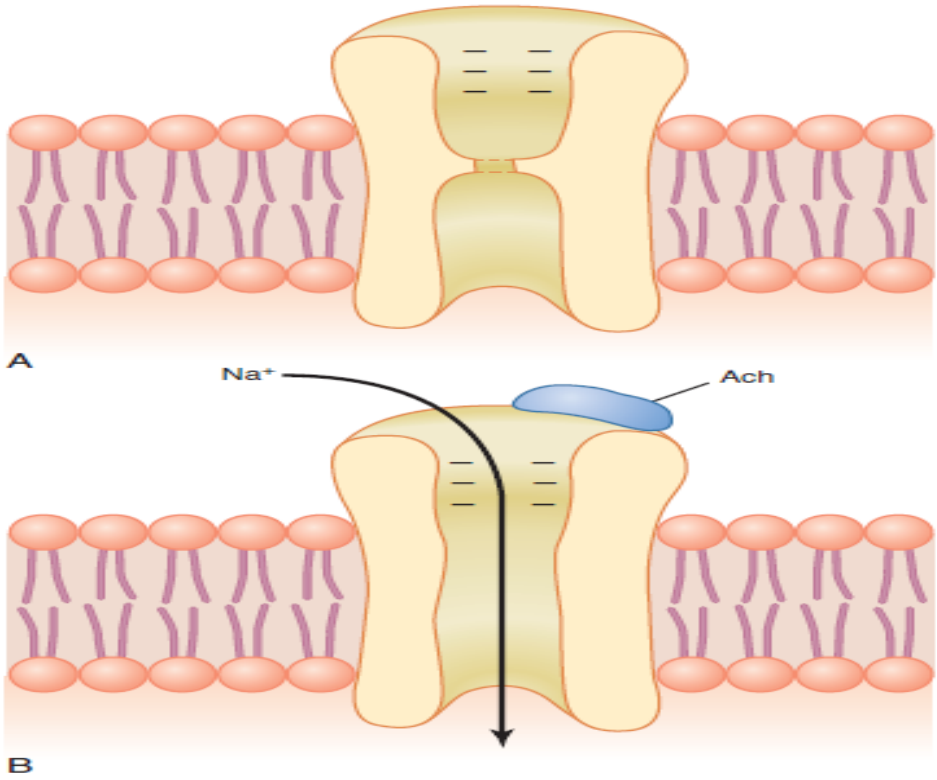


Figure 7-3. Acetylcholine-gated channel. **A,** Closed state. **B,** After acetylcholine *(Ach)* has become attached and a conformational change has opened the channel, allowing sodium ions to enter the muscle fiber and excite contraction. Note the negative charges at the channel mouth that prevent passage of negative ions such as chloride ions.

Destruction of the Released Acetylcholine by Acetylcholinesterase. The acetylcholine, once released into the synaptic space, continues to activate the acetylcholine receptors as long as the acetylcholine persists in the space. However, it is removed rapidly by two means: (1) Most of the acetylcholine is destroyed by the enzyme *acetylcholinesterase*, that fills the synaptic space between the presynaptic nerve terminal and the postsynaptic muscle membrane, and (2) a small amount of acetylcholine diffuses out of the synaptic space and is then no longer available to act on the muscle fiber membrane.