Excitation and Contraction of Smooth Muscle

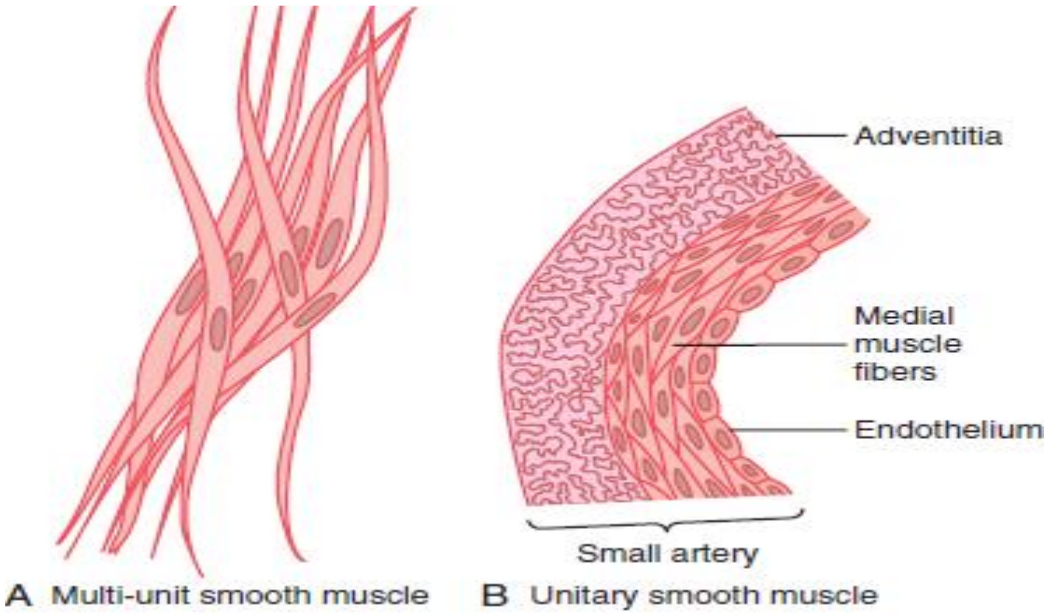
which is composed of far smaller fibers that are usually 1 to 5 micrometers in diameter and only 20 to 500 micrometers in length. In contrast, skeletal muscle fibers are as much as 30 times greater in diameter and hundreds of times as long. Many of the same principles of contraction apply to smooth muscle as to skeletal muscle. Most important, essentially the same attractive forces between myosin and actin filaments cause contraction in smooth muscle as in skeletal muscle, but the internal physical arrangement of smooth muscle fibers is different.

The smooth muscle of each organ is distinctive from that of most other organs in several ways: (1) physical dimensions, (2) organization into bundles or sheets, (3) response to different types of stimuli, (4) characteristics of innervation, and (5) function. Yet, for the sake of simplicity, smooth muscle can generally be divided into two major types, *multi-unit smooth muscle* and *unitary* (or *single-unit*) *smooth muscle*

Multi-Unit Smooth Muscle. Multi-unit smooth muscle is composed of discrete, separate smooth muscle fibers. Each fiber operates independently of the others and often is innervated by a single nerve ending, as occurs for skeletal muscle fibers. Further, the outer surfaces of these fibers, like those of skeletal muscle fibers, are covered by a thin layer of basement membrane–like substance

Important characteristics of multi-unit smooth muscle fibers are that each fiber can contract independently of the others, and their control is exerted mainly by nerve signals. In contrast, a major share of control of unitary smooth muscle is exerted by non-nervous stimuli. Some examples of multi-unit smooth muscle are the ciliary muscle of the eye, the iris muscle of the eye, and the piloerector muscles that cause erection of the hairs when stimulated by the sympathetic nervous system.

Unitary Smooth Muscle. Unitary smooth muscle is also called *visceral smooth muscle.* The term "unitary" is confusing because it does not mean single muscle fibers. Instead, it means a mass of hundreds to thousands of smooth muscle fibers that contract together as a single unit. The fibers usually are arranged in sheets or bundles, and their cell membranes are adherent to one another at multiple points so that force generated in one muscle fiber can be transmitted to the next. In addition, the cell membranes are joined by many *gap junctions* through which ions can flow freely from one muscle cell to the next so that action potentials, or simple ion flow without action potentials, can travel from one fiber to the next and cause the muscle fibers to contract together. *visceral smooth muscle* because it is found in the walls of most viscera of the body, including the gastrointestinal tract, bile ducts, ureters, uterus, and many blood vessels.



CONTRACTILE MECHANISM IN SMOOTH MUSCLE

Smooth muscle contains both *actin* and *myosin filaments,* having chemical characteristics similar to those of the actin and myosin filaments in skeletal muscle. actin and myosin filaments derived from smooth muscle interact with each other in much the same way that they do in skeletal muscle. Further, the contractile process is activated by calcium ions, and adenosine triphosphate (ATP) is degraded to adenosine diphosphate (ADP) to provide the energy for contraction.

Smooth muscle does not have the same striated arrangement of actin and myosin filaments as is found in skeletal muscle. large numbers of actin filaments attached to *dense bodies.* Some of these bodies are attached to the cell membrane, and others are dispersed inside the cell. Some of the membrane-dense bodies of adjacent cells are bonded together by intercellular protein bridges. It is mainly through these bonds that the force of contraction is transmitted from one cell to the next.

postulated structure of an individual contractile unit within a smooth muscle cell, showing large numbers of actin filaments radiating from two dense bodies; the ends of these filaments overlap a myosin filament located midway between the dense bodies. This contractile unit is similar to the contractile unit of skeletal muscle, but without the regularity of the skeletal muscle structure; in fact, the dense bodies of smooth muscle serve the same role as the Z disks in skeletal muscle.

Another difference is that most of the myosin filaments have “sidepolar” cross-bridges arranged so that the bridges on one side hinge in one direction and those on the other side hinge in the opposite direction. This configuration allows the myosin to pull an actin filament in one direction on one side while simultaneously pulling another actin filament in the opposite direction on the other side. The value of this organization is that it allows smooth muscle cells to contract as much as 80 percent of their length instead of being limited to less than 30 percent, as occurs in skeletal muscle.

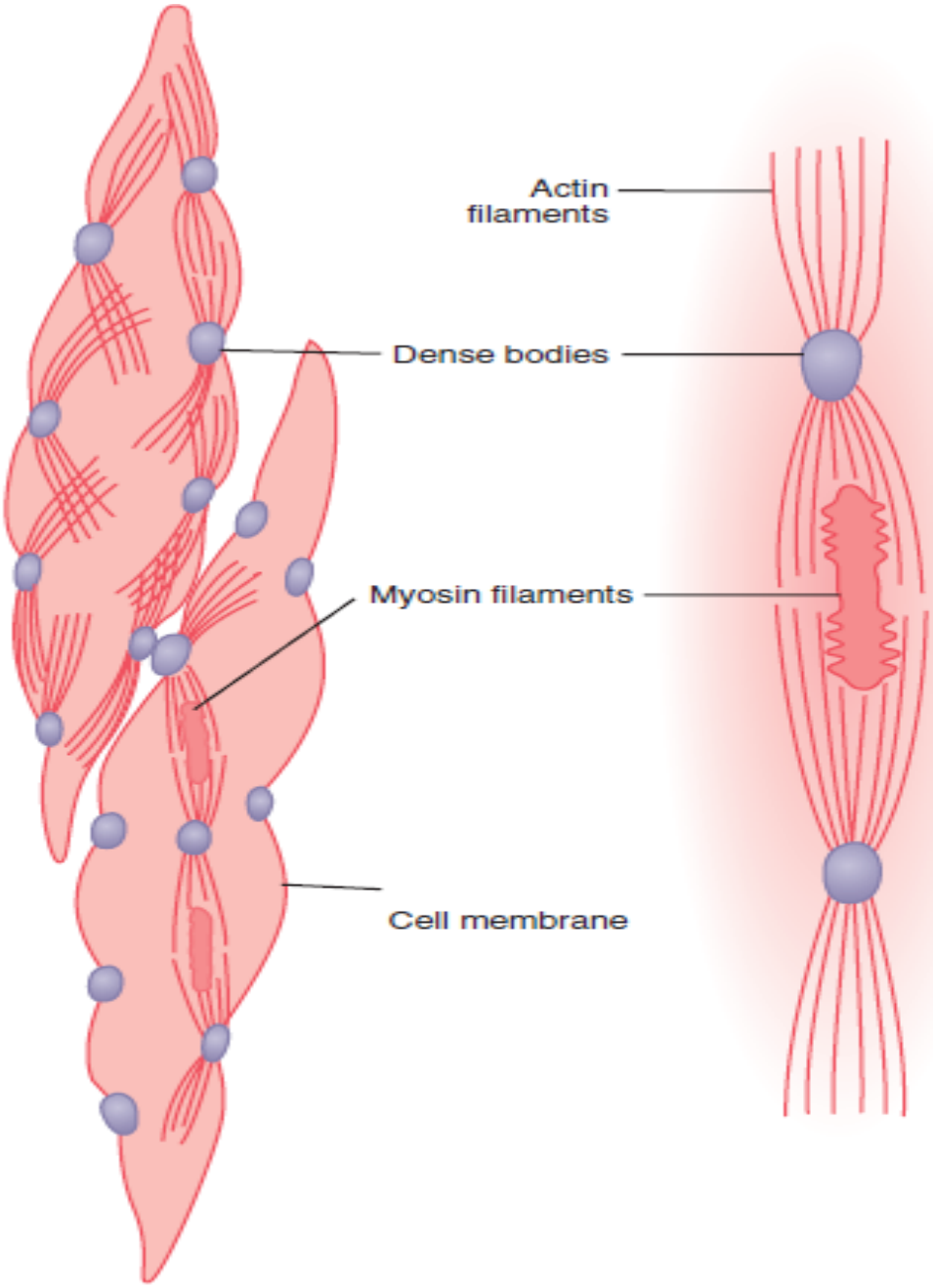


Figure 8-2. Physical structure of smooth muscle. The fiber on the upper left shows actin filaments radiating from dense bodies. The fiber on the lower left and at right demonstrate the relation of myosin filaments to actin filaments.

Comparison of Smooth Muscle Contraction and Skeletal Muscle Contraction

Although most skeletal muscles contract and relax rapidly, most smooth muscle contraction is prolonged tonic contraction, sometimes lasting hours or even days. Therefore, it is to be expected that both the physical

and the chemical characteristics of smooth muscle versus skeletal muscle contraction would differ

1. Slow Cycling of the Myosin Cross-Bridges

Mean the attachment of myosin to actin and forming cross-bridge and then release from actin this cycle is slow in smooth muscle than skeletal muscle 1/10 to 1/300 as in skeletal muscle

2. Low Energy Requirement to Sustain Smooth Muscle Contraction. Only 1/10 to 1/300 as much energy is required to sustain the same tension of contraction in smooth muscle as in skeletal muscle.

3. **Slowness of Onset of Contraction and Relaxation of the Total Smooth Muscle Tissue.** A typical smooth muscle tissue begins to contract 50 to 100 milliseconds after it is excited, reaches full contraction about 0.5 second later, and then declines in contractile force in another 1 to 2 seconds, giving a total contraction time of 1 to 3 seconds. This is about 30 times as long as a single contraction of an average skeletal muscle fiber.

4. **The Maximum Force of Contraction Is Often Greater in Smooth Muscle Than in Skeletal Muscle.** Despite the relatively few myosin filaments in smooth muscle, and despite the slow cycling time of the cross-bridges, the maximum force of contraction of smooth muscle is often greater than that of skeletal muscle—as great as 4 to 6 kg/ cm2 cross-sectional area for smooth muscle, in comparison with 3 to 4 kilograms for skeletal muscle

Physiologic Anatomy of Smooth Muscle Neuromuscular Junctions.

Neuromuscular junctions of the highly structured type found on skeletal muscle fibers do not occur in smooth muscle. Instead, the *autonomic nerve fibers* that innervate smooth muscle generally branch diffusely on top of a sheet of muscle fibers. In most instances, these fibers do not make direct contact with the smooth muscle fiber cell membranes but instead form *diffuse junctions* that secrete their transmitter substance into the matrix coating of the smooth muscle. most of the fine terminal axons have multiple *varicosities* distributed along their axes. In the

varicosities are vesicles similar to those in the skeletal muscle end plate that contain transmitter substance. But in contrast to the vesicles of skeletal muscle junctions, which always contain acetylcholine, the vesicles of the autonomic nerve fiber endings contain *acetylcholine* in some fibers and *norepinephrine* in others, and occasionally other substances as well. The most important transmitter substances secreted by the autonomic nerves innervating smooth muscle are *acetylcholine* and *norepinephrine,* but they are never secreted by the same nerve fibers. Acetylcholine is an excitatory transmitter substance for smooth muscle fibers in some organs but an inhibitory transmitter for smooth muscle in other organs. When acetylcholine excites a muscle fiber, norepinephrine ordinarily inhibits it. Conversely, when acetylcholine inhibits a fiber, norepinephrine usually excites it.

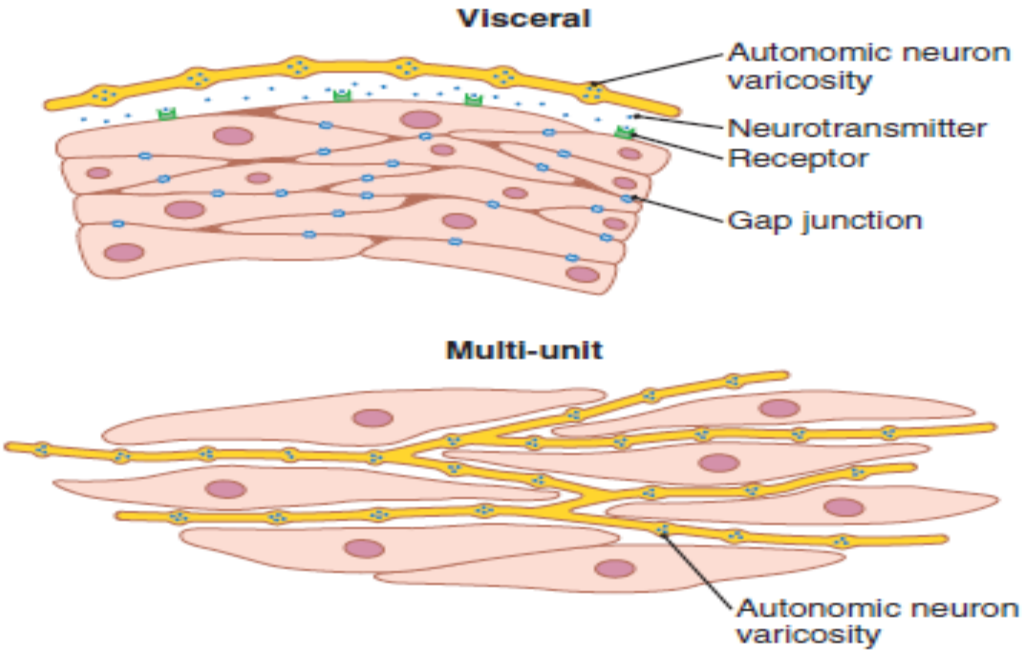


Figure 8-6. Innervation of smooth muscle by autonomic nerve fibers that branch diffusely and secrete neurotransmitter from multiple varicosities. Unitary (visceral) smooth muscle cells are connected by gap junctions so that depolarization can rapidly spread from one cell to another, permitting the muscle cells to contract as a single unit. In multiunit smooth muscle, each cell is stimulated independently by a neurotransmitter released from closely associated autonomic nerve varicosities.