CONTRACTION OF SMOOTH MUSCLE

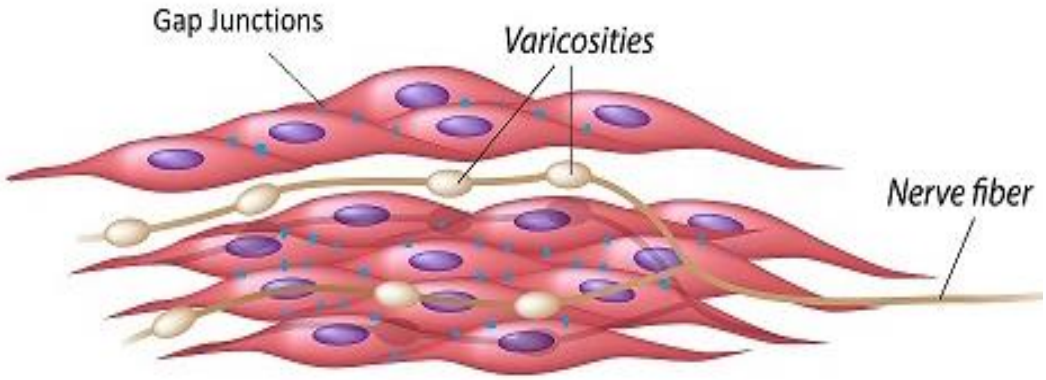
Many of the principles of contraction that apply to skeletal muscle also apply to smooth muscle. Most importantly, essentially the same attractive forces that occur between myosin and actin filaments in skeletal muscle also cause contraction in smooth muscle, but the internal physical arrangement of actin and myosin filaments in smooth muscle fibers is somewhat different from that of skeletal muscle.

Types of Smooth Muscle

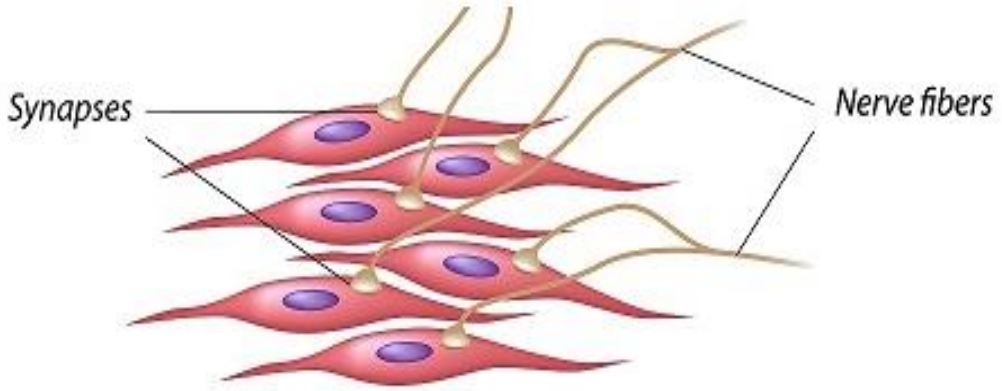
In general, smooth muscle can be divided into two major types:

1- Multi-unit smooth muscle. The most important characteristics of multi-unit smooth muscle fibers are that each fiber can contract independently of the others and the control is exerted mainly by nerve signals.

Examples include the smooth muscle fibers of the ciliary muscle of the eye, the iris of the eye, and the piloerector muscles that cause erection of the hairs when stimulated by the sympathetic nervous system.



2- Single-unit smooth muscle. This type is also called unitary smooth muscle, syncytial smooth muscle, and visceral smooth muscle. A mass of hundreds to millions of muscle fibers contract together as a single unit. The cell membranes of adjacent fibers are connected electrically by gap junctions, which permits action potentials to travel from one fiber to the next so that muscle fibers contract together. This type of muscle is found in the walls of the gastrointestinal tract, bile ducts, ureters, uterus, oviducts, and blood vessels.

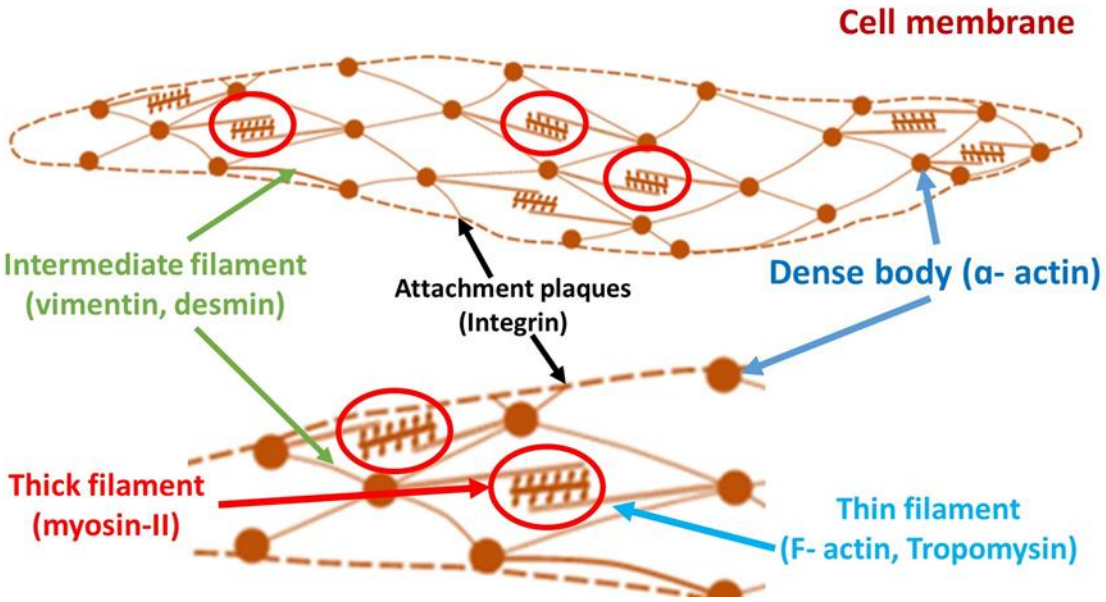


Physical Basis for Smooth Muscle Contraction

Actin filaments attach to dense bodies. Some of the dense bodies are dispersed inside the cell and held in place by a scaffold of structural proteins linking one dense body to another. Others are attached to the cell membrane and form bonds with dense bodies of adjacent cells, allowing the force of contraction to be transmitted from one cell to the next. Dense bodies therefore have similar function to Z disks in skeletal muscle.

• Myosin filaments are interspersed among actin filaments. The myosin filaments have a diameter that is more than twice as large as that of the actin filaments.

• Contractile units. The individual contractile units consist of actin filaments radiating from two dense bodies; these filaments overlap a single myosin filament that is located midway between the dense bodies.



Unlike Skeletal Muscle Contractions, Most Smooth Muscle Contractions Are Prolonged Tonic Ones That Sometimes Last Hours or Even Days. Both the physical and chemical characteristics of smooth muscle are different than those of skeletal muscle. Some of the differences are as follows:

• Slow cycling of the cross-bridges. The rapidity of cross-bridge cycling in smooth muscle (i.e., the rate of myosin cross-bridge attachment and release with actin) is much slower in smooth muscle than in skeletal muscle.

• Low energy requirement. Only 1/10 to 1/300 as much energy is required to sustain a contraction in smooth muscle compared with that of skeletal muscle.

• Slow onset of contraction and relaxation. A typical smooth muscle begins to contract 50 to 100 milliseconds after it is excited and has a total contraction time of 1 to 3 seconds, which is 30 times longer than in skeletal muscle.

• Increased maximum force of contraction. The maximum force of contraction of smooth muscle per unit of muscle cross section is often greater than that of skeletal muscle. This increased force of contraction is postulated to result from the prolonged period of attachment of the myosin cross-bridges to the actin filaments.

Smooth Muscle Can Shorten by a Higher Percentage of Its Length Than Can Skeletal Muscle. Skeletal muscle has a useful distance of contraction of only about one fourth to one third of its resting length, whereas smooth muscle can often contract more than two thirds of its stretched length.

The “Latch Mechanism” Facilitates Prolonged Holding Contractions. Once smooth muscle has developed full contraction, the degree of activation of the muscle can usually be reduced to far less than the initial level, yet the muscle can maintain its full force of contraction.

This is called the latch mechanism. The importance of the latch mechanism is that it can maintain prolonged tonic contraction in smooth muscle for hours with relatively little use of energy.

Regulation of Contraction by Calcium Ions

Calcium Ions Combine With Calmodulin to Cause Activation of Myosin Kinase and hosphorylation of the Myosin Head.

Smooth muscle does not contain troponin but instead has calmodulin, another calcium-binding regulatory protein. Although this protein reacts with calcium ions, it is different from troponin in

the manner in which it initiates the contraction; calmodulin does so by activating the myosin cross-bridges. Regulation of contraction is thus myosin based in smooth muscle,

rather than actin based, as it is in skeletal muscle. This activation and subsequent contraction occur in the following sequence:

1. The calcium ions bind with calmodulin; the calmodulin-calcium complex then joins with and activates myosin kinase, a phosphorylating enzyme.
2. One of the light chains of each myosin head, called the regulatory chain, becomes phosphorylated in response to the myosin kinase.
3. When the regulatory chain is phosphorylated, the head has the capability of binding with the actin filament, causing muscle contraction. When this myosin light chain is not phosphorylated, the attachment-detachment cycling of the head with the actin filament does not occur.

   Myosin Phosphatase Is Required for Cessation of Contraction. When the calcium ion concentration falls below a critical level, the aforementioned processes automatically reverse except for phosphorylation of the myosin head. Reversal of this step requires another enzyme, myosin phosphatase, which splits the phosphate from the regulatory light chain; the cycling then stops, and relaxation occurs.

NERVOUS AND HORMONAL CONTROL OF SMOOTH MUSCLE CONTRACTION

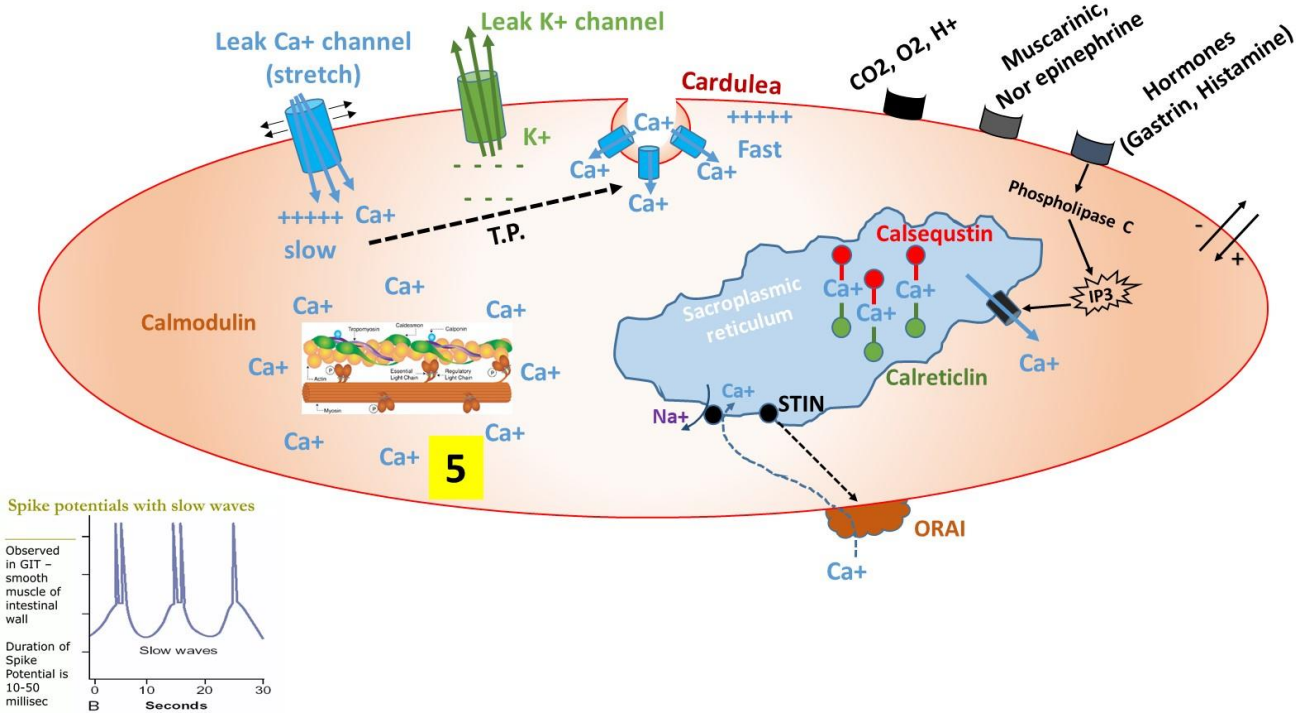
Neuromuscular Junctions of Smooth Muscle Neuromuscular Junctions of the Highly Structured Type Found on Skeletal Muscle Fibers Are Not Present in Smooth Muscle.

• Diffuse junctions. These are the sites of transmitter release. In most instances, the autonomic nerve fibers form so-called diffuse junctions that secrete their transmitter substance into the matrix coating of the smooth muscle; the transmitter substance then diffuses a short distance to the fibers.

• Varicosities on the axon terminals. The axons that innervate smooth muscle fibers do not have typical branching end feet of the type found in the motor end plate on skeletal muscle fibers. Instead, most of the fine terminal axons have multiple varicosities that are distributed along their axes. The varicosities contain vesicles loaded with transmitter substance.

• Contact junctions. In the multi-unit type of smooth muscle, the varicosities lie directly on the muscle fiber membrane. These so-called contact junctions have a function similar to that of the skeletal muscle neuromuscular junctions.

Acetylcholine and Norepinephrine Can Have Excitatory or Inhibitory Effects at the Smooth Muscle Neuromuscular Junction. Acetylcholine and norepinephrine are secreted by the autonomic neurons that innervate smooth muscle, but these substances are never both secreted by the same neurons. Acetylcholine is an excitatory transmitter substance for smooth muscle fibers in some organs but an inhibitory substance for smooth muscle in others. When acetylcholine excites a muscle fiber, norepinephrine ordinarily inhibits it, and vice versa.



Membrane Potentials and Action Potentials in Smooth Muscle

The resting membrane potential depends on the type of smooth muscle and the momentary condition of the muscle. It is usually about −50 to −60 millivolts, or about 30 millivolts less negative than in skeletal muscle.

Action Potentials Occur in Single-Unit Smooth Muscle, Such as Visceral Smooth Muscle, in a Manner Similar to That of Skeletal Muscle. The action potentials of visceral smooth muscle occur in two forms:

• Spike potentials. Typical spike action potentials occur in most types of single-unit smooth muscle. They can be elicited by electrical stimulation, stretch, or the action of hormones and

transmitter substances, or they may be the result of spontaneous generation in the muscle fiber itself.

• Action potentials with plateaus. The onset of this type of action potential is similar to that of the typical spike potential. However, repolarization is delayed for several hundred milliseconds. The plateau accounts for the prolonged periods of contraction that occur in the ureter, the uterus under some conditions, and some types of vascular smooth muscle.

Calcium Ions Are Required for Generating Smooth Muscle Action Potentials. Sodium participates little in generation of the action potential in most smooth muscle.

Instead, the movement of calcium ions to the interior of the fiber is mainly responsible for the action potential.

Slow-Wave Potentials in Single-Unit Smooth Muscle Can Lead to Generation of Action Potentials. Slow waves are slow oscillations in membrane potential. The slow wave itself is not an action potential.

• Cause of slow waves. Two possible causes of slow waves are (1) oscillations in sodium pump activity, which cause the membrane potential to become more negative when sodium is pumped rapidly and less negative when sodium is pumped slowly, and (2) the conductance of the ion channels, which may increase and decrease rhythmically.

• Importance of slow waves. Action potentials can be initiated when the potential of the slow wave rises above threshold (about −35 millivolts). The action potential spreads over the muscle mass, and contraction occurs. Slow waves themselves can cause muscle contractions in gastric smooth muscle.

Spontaneous Action Potentials Are Often Generated When Visceral (Single-Unit) Smooth Muscle Is Stretched.

Spontaneous action potentials result from a combination of the normal slow wave potentials in addition to a decrease in the negativity of the membrane potential caused by the stretch itself. This response to stretch allows the gut wall, when excessively stretched, to contract automatically, thereby resisting the stretch.

Effect of Local Tissue Factors and Hormones on Smooth Muscle Contraction Without Action Potentials

Smooth Muscle Relaxation in Blood Vessels Occurs in Response to Local Tissue Factors. This vasodilatory response is required for local control of blood flow.

Many Circulating Hormones in the Body Affect Smooth Muscle Contraction to Some Degree. A hormone causes contraction when the muscle cell membrane contains excitatory receptors for the respective hormone.

Conversely, the hormone causes relaxation if the membrane contains inhibitory receptors.