Ch. 8 Contraction and Excitation of Smooth Muscle

- Smooth Muscle
  - Smaller fiber – usually 1 ~5 micrometers in diameter
  - 20 ~ 500 micrometers in length
  - Same principles of muscle contraction as skeletal muscles
  - But differ in internal physical arrangement of smooth muscle fibers
- Smooth muscles are distinctive in several ways
  (1) physical dimensions
  (2) organization into bundles or sheets
  (3) response to different types of stimuli
  (4) characteristics of innervation
  (5) function

Types of smooth muscle

- Fig. 8-1
- Two major types: multi-unit vs. single unit smooth muscle
- **Multi-unit smooth muscles**
  - Each fiber contract independently
  - Their control is exerted mainly by nerve signals
  - Almost none spontaneous contractions
- **Unitary smooth muscle**
  - Not a single fiber: “unitary” is confusing because it does not mean single muscle fibers
  - A mass of hundreds to thousands of smooth muscle fibers that contract together as a single unit
  - Major share of control of unitary smooth muscle is exerted by non-nervous stimuli.
  - 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
  - Muscle fibers contract together as a single unit
  - Cell membranes are joined by many ***gap junctions***
  - **Gap junctions**: ions can flow freely from one cell to the next so that action potentials or ion flow can travel from one fiber to the next and cause the muscle fibers to contract together

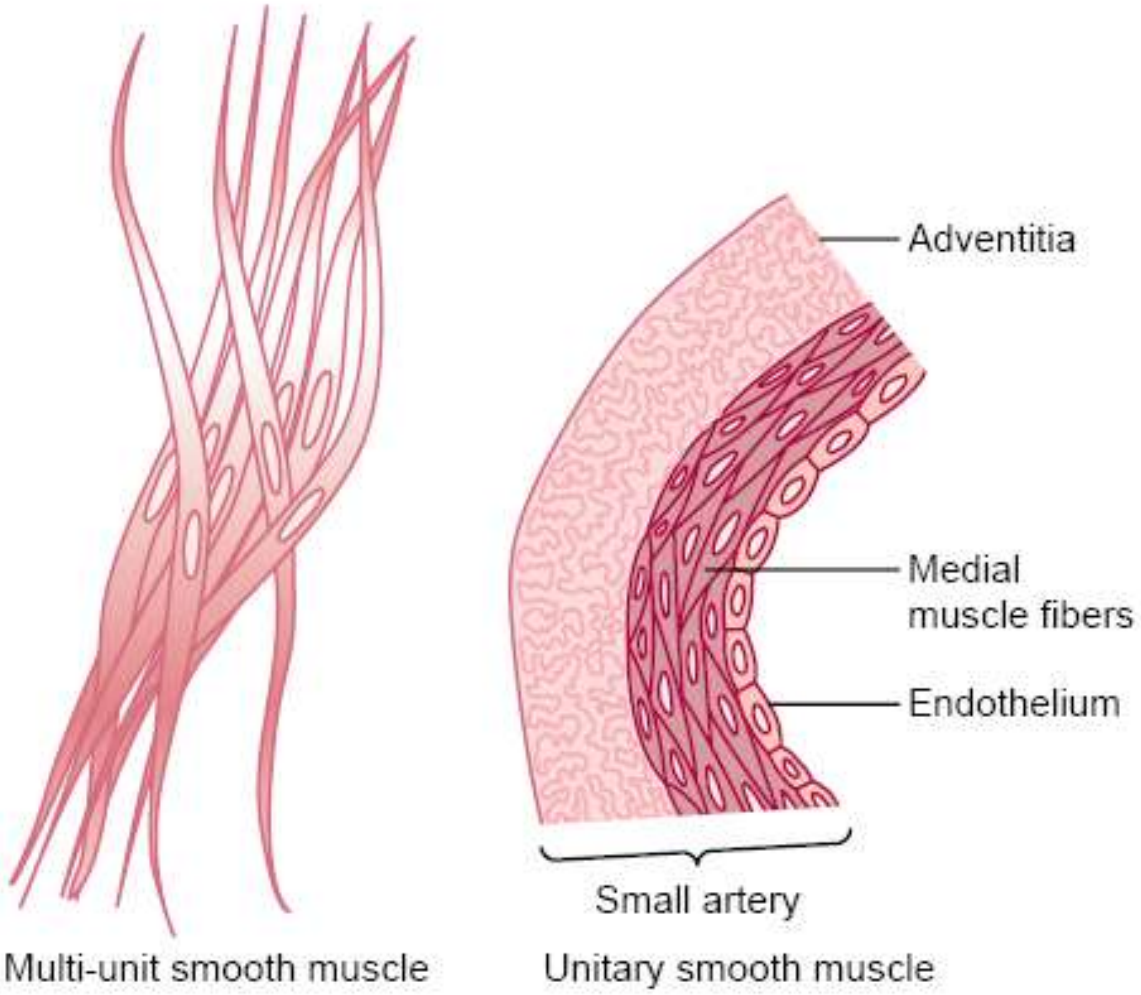


Figure 8–1

Multi-unit *(A)* and unitary *(B)* smooth muscle.

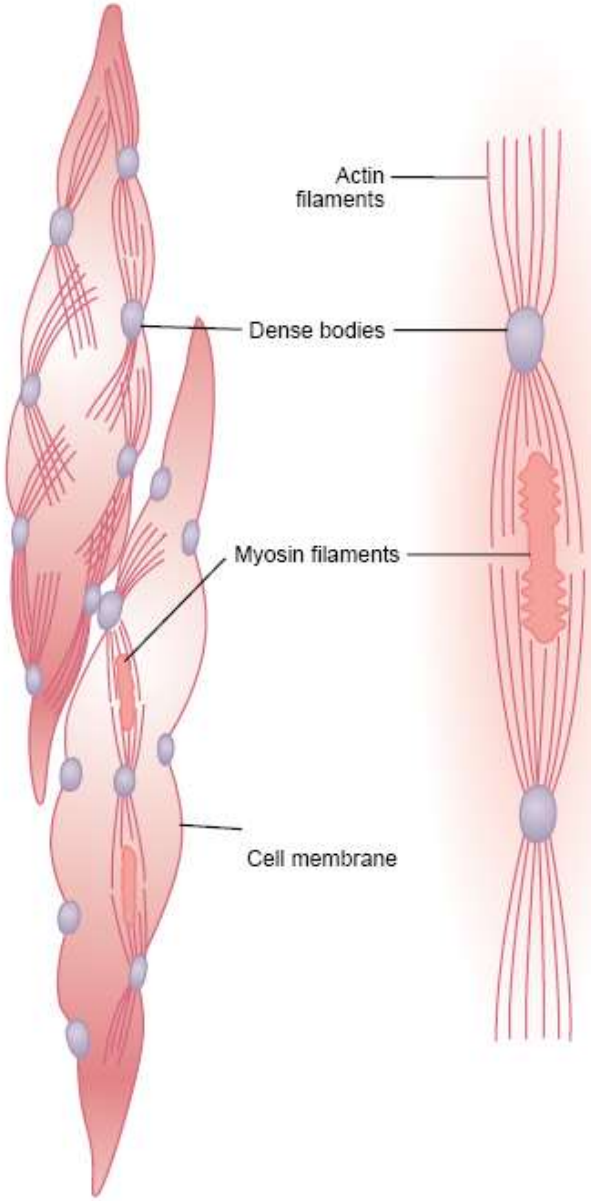
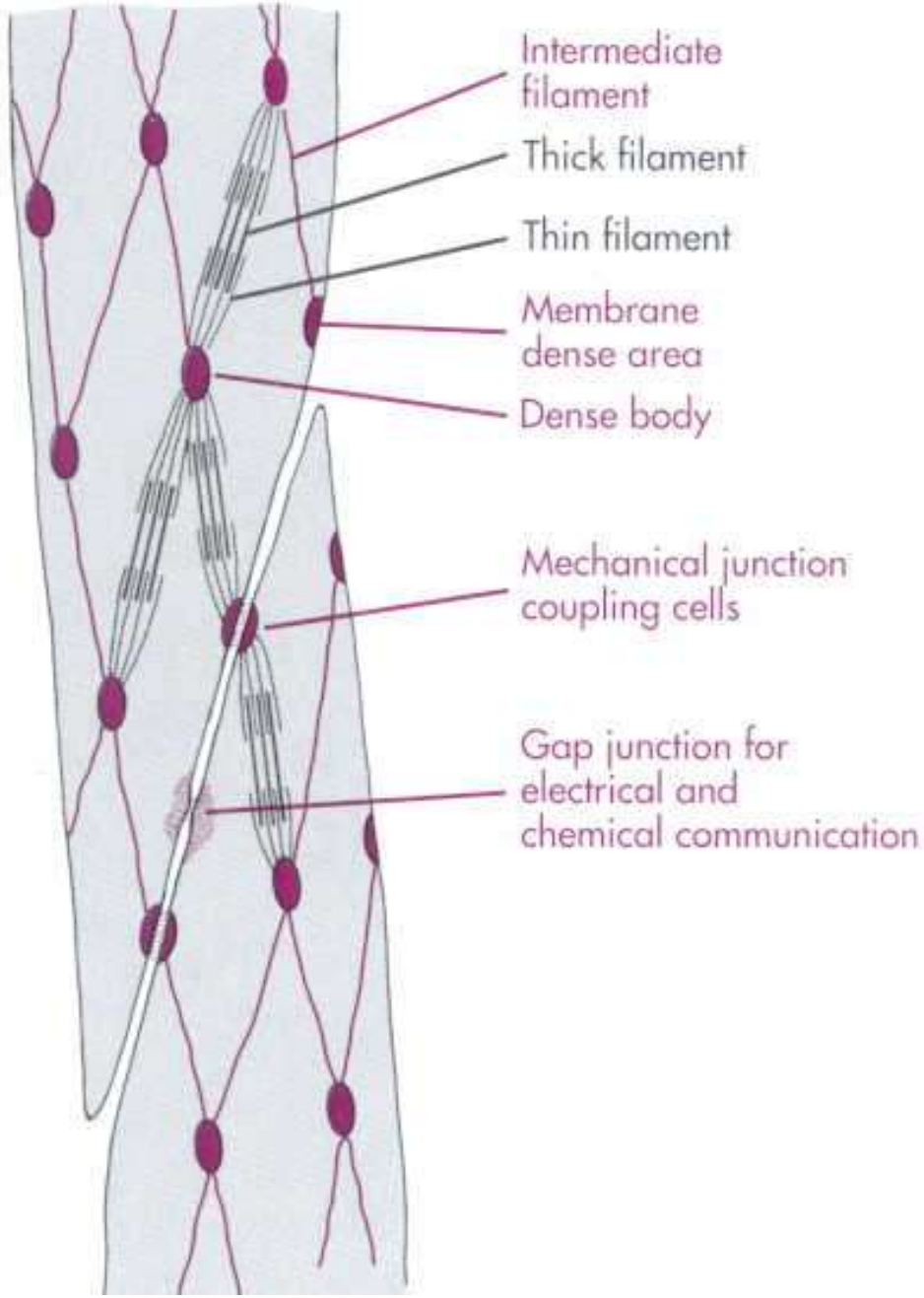


Figure 8–2

Physical structure of smooth muscle. The upper left-hand fiber shows actin filaments radiating from dense bodies. The lower left-hand fiber and the right-hand diagram demonstrate the relation of myosin filaments to actin filaments.


Intermediate filament
Thick filament
Thin filament
Membrane dense area
Dense body
Mechanical junction coupling cells
Gap junction for electrical and chemical communication

Contractile Mechanism in Smooth Muscle

- Chemical basis for smooth
  - Actin and myosin filaments, but no troponin complex
  - Note major differences between skeletal and smooth muscles in terms of the followings.
    - Physical organization
    - Excitation-contraction coupling
    - Control of the contractile processing by calcium ions
    - Duration of contraction
    - Amount of energy for contraction
- Physical basis for smooth muscle contraction
  - No striated arrangement like skeletal muscles
  - See Fig. 8-2
  - Actin filaments connected to **dense bodies**
  - **Sidepolar cross-bridges** so that the bridges on one side hinge in one direction, but the other side in the opposite direction. This structure allows contraction over 80% of their length (only up to 30% for skeletal muscles)

Smooth vs. Skeletal Muscles

Smooth Muscle

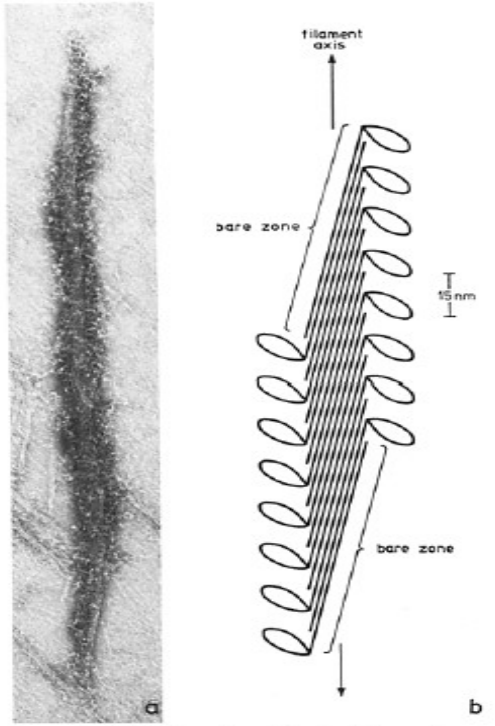


FIGURE 2 (*a*) 1.7-μm long side-polar filament formed from purified myosin at 0.3 M KCl, pH 6. × 86,000. (*b*) Schematic diagram of side-polar filament for comparison with Fig. 2*a*. Only two-dimensional details of those features thought to be fundamental to the side-polar mode of assembly are shown. The real structure is thicker than the single layer of myosin molecules shown, but the full three-dimensional packing of the myosin molecules is not yet understood. (For example, parallel interactions may also be present, generating the 15-nm cross-bridge repeat, and the antiparallel interactions may not occur in the plane of the page.) For the sake of clarity, certain aspects of the structure have been exaggerated. The myosin tails have arbitrarily been drawn to overlap almost completely. The specific interactions actually involved remain to be determined.

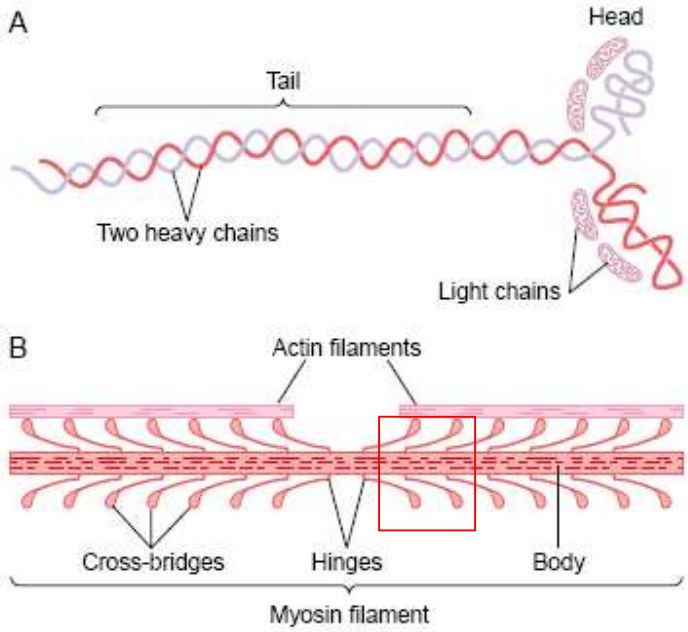


Figure 6–5

A, Myosin molecule. *B*, Combination of many myosin molecules to form a myosin filament. Also shown are thousands of myosin *cross-bridges* and interaction between the *heads* of the cross-bridges with adjacent actin filaments.

Skeletal Muscles

Comparison of Smooth Muscle Contraction with Skeletal Muscle Contraction

- Most skeletal muscles contact and relax rapidly
- Smooth muscle contraction is prolonged, lasting hours or even days.
- Some physical and chemical characteristics are different between smooth vs. skeletal muscles.

1. Slow cycling of the myosin cross-bridges

- Attachment to actin and release from actin is much slower. As little as 1/10 to 1/300 the frequency
- Yet the fraction of time that the cross-bridges remain attached to the actin is greater in smooth muscle
- Slow cycling is that the cross-bridge heads have far less ATPase activity than in skeletal muscle, so that degradation of the ATP that energizes the movements of the cross-bridge heads is greatly reduced, with corresponding slowing of the rate of cycling.

2. **Energy required 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
- Due to the slow attachment and detachment cycling of the cross-bridges and because only one molecule of ATP is required for each cycle, regardless of its duration.
- Explains tension (tonic muscle contraction for energy saving) in intestines, urinary bladder, gallbladder

3. **Slowness of onset of contraction and relaxation of smooth muscle**

- Total contraction time of 1 to 3 seconds
- 30 times as long as a single contraction of a skeletal muscle
- Slow onset of contraction of smooth muscle, as well as its prolonged contraction, is caused by Slow attachment and detachment
- Initiation of contraction due to calcium is much slower too

4. **Force of smooth muscle contraction**

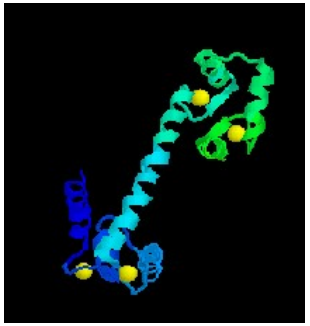
- Despite the relatively few myosin filaments in smooth muscle, and despite the slow cycling time of the cross-bridges,,,
- Max. force of contraction of smooth muscle is greater than that of skeletal muscle, as great as 4 to 6 kg/cm2 in comparison to 3 to 4 kg for skeletal muscle
- This great force results from the prolonged attachment of the myosin cross-bridges to actin

5. **Latch mechanism**

- After full contraction, actin-myosin continue to be attached (latched) continuously generating tension without using ATP (a very low affinity for ATP)
- This mechanism is called the latch mechanism and saves the smooth muscle cell a great deal of ATP

Regulation of Contraction by Calcium Ions

- For skeletal muscle, calcium ions initiate contraction
- Smooth muscle has no troponine
- Combination of calcium ions with calmodulin in smooth muscle
- Calmodulin: a special protein that reacts with four calcium ions.
- Three steps for activation and contraction by calmoduline
  1. Calcium ions bind with calmodulin
  2. Calmodulin-calcium combination then joins with and activates myosin kinase, a phosphrelating enzyme
  3. One of the light chains of each myosin head becomes phosphrelated by myosin kinase. Myosin head binds with actin filament, causing muscle contraction.
  4. Cessation of contraction – role of myosin phosphatase. Calcium concentration falls low, reverse phosphorylation due to myosin phosphatase, then cessation of contraction.



calmodulin

Neuromuscular Junctions of Smooth Muscle

- No neuromuscular junctions of the highly structured type in smooth muscle, unlike skeletal muscles
- Instead autonomic nerve fibers innervate smooth muscles as in Fig. 8-3.
- Autonomic nerve fiber endings contain acetylcholine (also norepinephrine) vesicles.
  - 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.
- Via diffuse junctions, secrete transmitters into matrix (no direct contact with smooth muscle fibers)

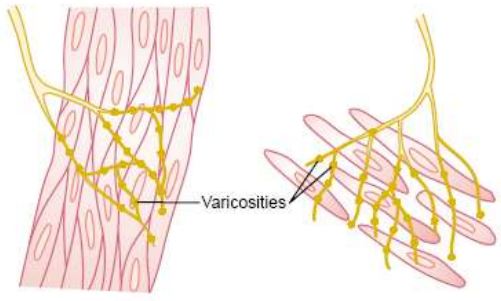


Figure 8–3

Innervation of smooth muscle.

Membrane Potentials and Action Potentials in Smooth Muscle

- In smooth muscle, the membrane potential is about 30mV less negative (-50 ~-60 millivolts)
- Action potentials of smooth muscles in two forms

  (1) Spike potentials in Fig. 8-4 A

  - Duration 10 ~50 msec.

  (2) Action potentials with plateaus in Fig. 8-4 C

  - Repolarization is delayed for several hundred to 1sec.
  - Explains prolonged contraction in smooth muscles.

- Smooth muscle membrane has far more voltage-gated calcium(Ca+) channels and few voltage-gated Na+ channels.
- Na+ participates little in generation of action potentials
- Flow of Ca+ ions into cells mainly responsible for action potential (same + ions).
- But Ca+ channels open more slowly than Na+ channels, also open much longer => explain prolonged plateau action potentials.
- Fig. 8-4 B. Some smooth muscles are self-excitatory. That is action potentials arise without external stimuli. This is associated with slow wave rhythm of membrane potential. Slow waves are called pacemaker waves.

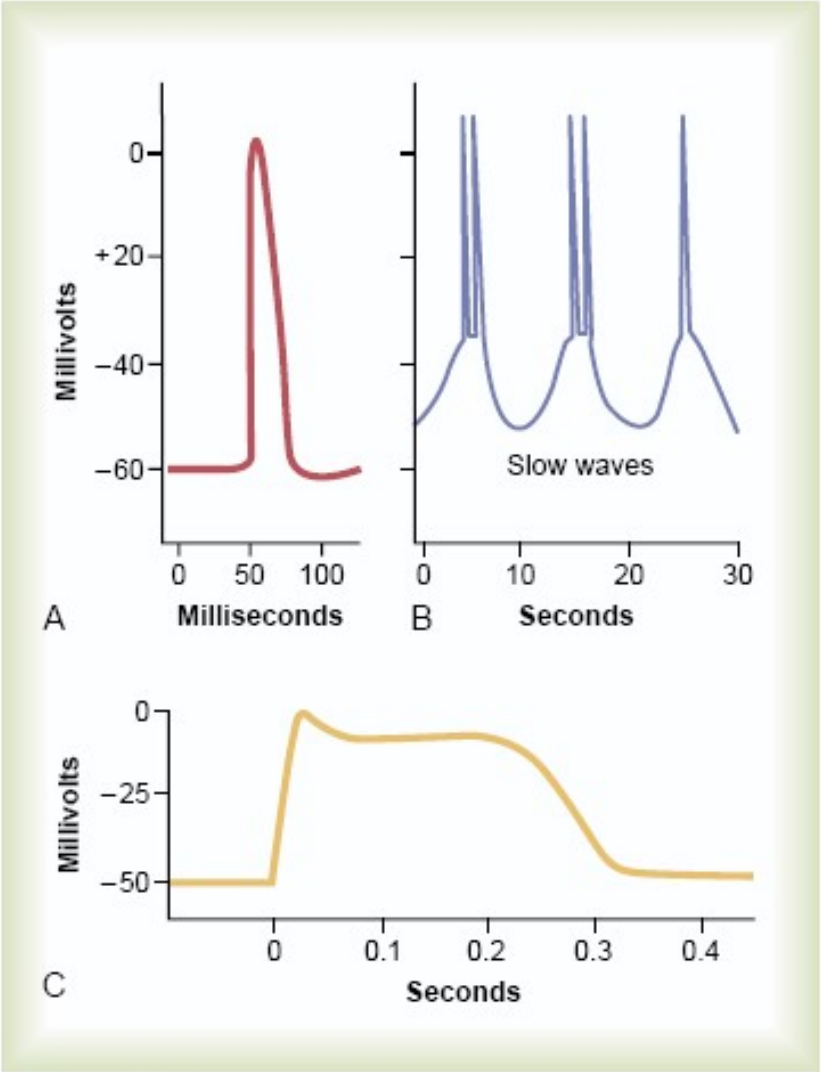


Figure 8–4

A, Typical smooth muscle action potential (spike potential) elicited by an external stimulus. *B*, Repetitive spike potentials, elicited by slow rhythmical electrical waves that occur spontaneously in the smooth muscle of the intestinal wall. *C*, Action potential with a plateau, recorded from a smooth muscle fiber of the uterus.

https://www.youtube.com/watch?v=qEVRoKuoj4U&ab_channel=ByteSizeMed