Part II, Muscle: Mechanisms of Contraction and Neural Control, Chapter 12

Outline of class notes

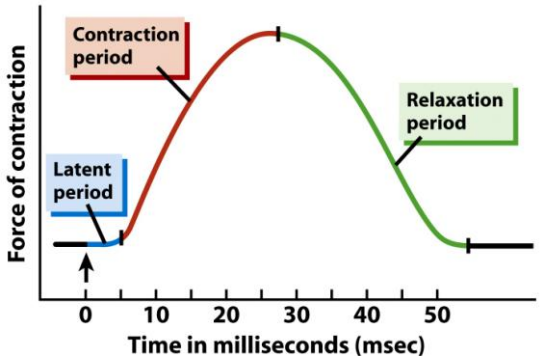
Objectives:

After studying part II of this chapter you should be able to:

1. Discuss how contractile force is regulated
2. Describe the difference between a twitch, wave summation, tetany, and treppe in muscle contraction.
3. Describe the difference between isometric and isotonic contractions.
4. Discuss the length tension relationship of skeletal muscle.
5. Describe the energy requirements of skeletal muscle and the creatine phosphate system.
6. What is meant by oxygen dept?
7. Describe the differences between skeletal muscle fiber types.
8. Explain the process of muscle fatigue.
9. Discuss the causes of muscle hypertrophy and muscle atrophy.
10. Discuss the characteristics of smooth and cardiac muscles and emphasize their differences in excitation-contraction coupling.
11. Discuss the Clinical Applications from the study guide and assigned Applications to Health.

Twitch

- **Twitch:** A single rapid contraction and relaxation of a muscle fiber or group of muscle fibers. Due to a single action potential of the motor neuron.
- Twitch tracing includes three distinct phases:
  - **Latent phase:** Interval from stimulus application until the muscle begins to shorten.
  - **Contraction phase**:
  - **Relaxation phase**:



Teppe

- **Treppe**: A “staircase” increase in tension production after repeated simulation, even though the muscle is allowed to relax between twitches.
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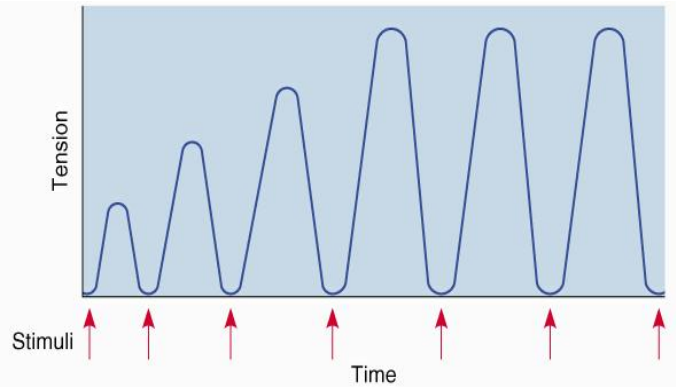
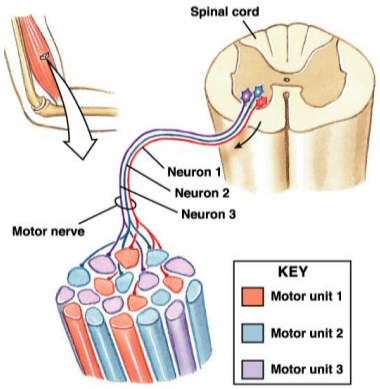
- Reason: Gradual increase in sarcoplasmic [Ca2+] because the ion pumps in the sarcoplasmic reticulum are unable to recapture all the calcium between stimulations so a portion of the Ca2+ is already there in the sarcoplasm for the next contraction



Regulation of Contractile Force

- The force of a contraction is increased in two ways:
  1. **Motor Unit Recruitment (Summation):**



- Recruitment is one factor responsible for producing smooth movements.
- Smaller motor units are activated first then larger units are activated as you need more strength.

2. **Wave Summation**: Increasing the frequency of stimulation of muscle fibers. Can be in the form of **incomplete** or **complete tetany.**
   - **Frequency** refers to the number of times a motor neuron is

   - **Incomplete (Unfused) tetanus**: Muscle fibers are stimulated at a rate where they don't completely relax before the next stimulus.
     - Have partial relaxation between twitches.
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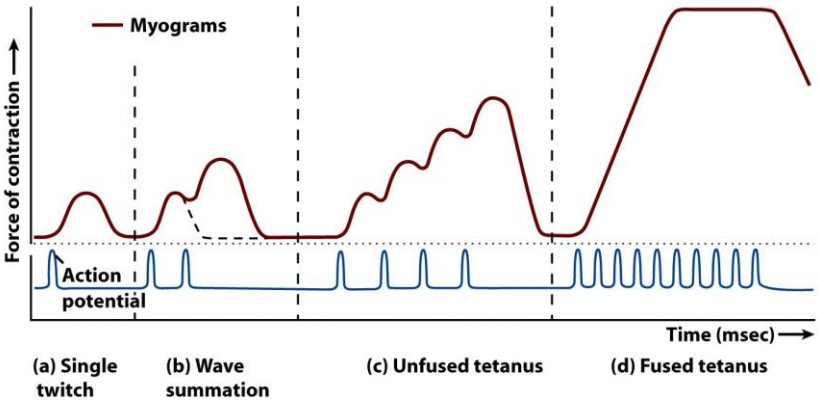
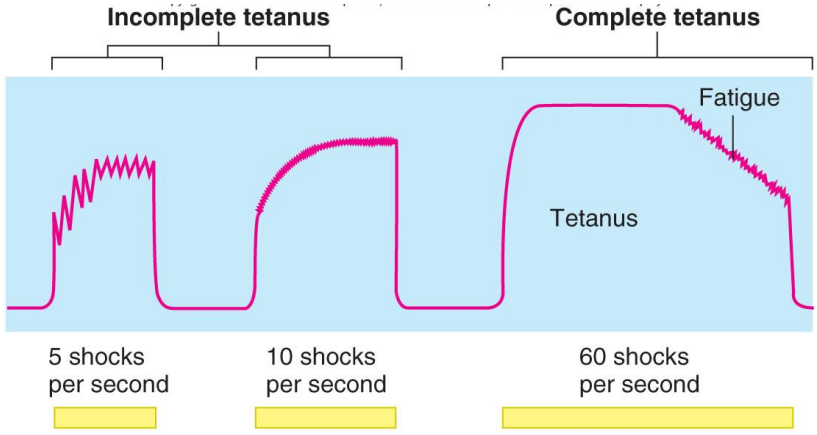
   - **Complete (Fused) tetanus**: High rate of stimulation where the muscle fibers do not relax between stimuli.





Physiology of Wave Summation

- Because the muscle is already partially contracted and more calcium is being released into the cytosol to replace that being reclaimed by the sarcoplasmic reticulum, muscle tension produced during the second contractions causes more shortening than the first.

Types of Contractions

- Contractions can be classified as isometric or isotonic:
  1. **Isometric** (Iso= same, metr=measure)
     - Contraction in which there is no appreciable shortening of the muscle.
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       - Example: Pushing on a brick wall
  2. **Isotonic** (Iso=same, ton=tension)
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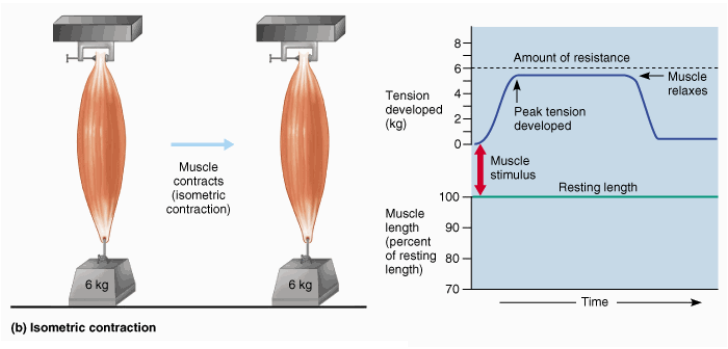
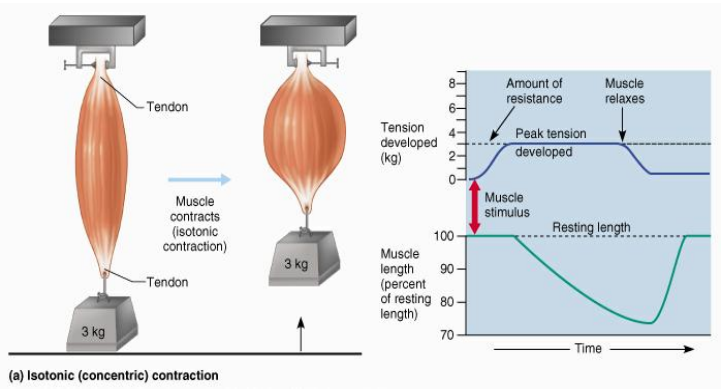
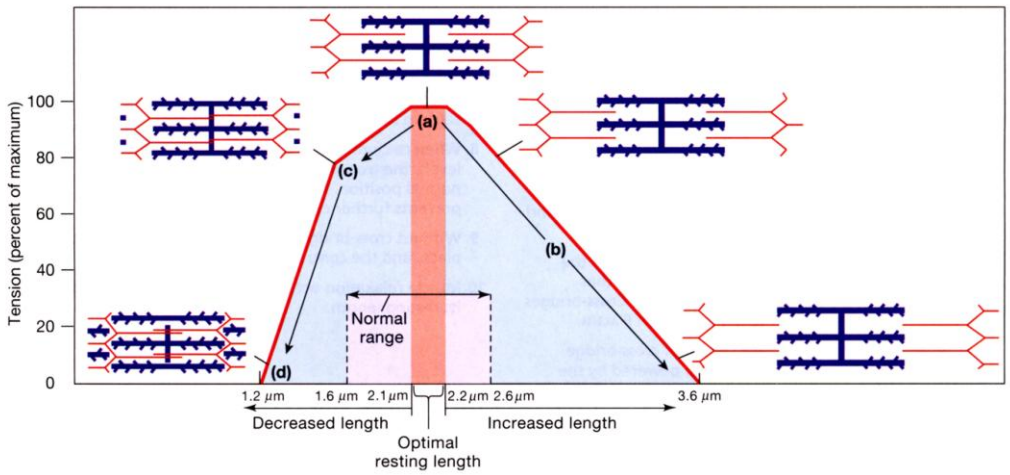
     - The force of contraction remains constant throughout the shortening process
       - Example: Picking up something that you can lift through the complete motion such as curling your physiology text book





Length-Tension Relationship

- **Maximum muscle tension**:
  - When a muscle is stretched to the point that there is no overlap of **actin** with **myosin**, no cross bridges can attach to the thin filament and the muscle cannot contract.
  - When the muscle is shortened to about 60% of its resting length, the Z lines abut the thick filaments so that further contraction cannot occur



Muscle Tone

- **Muscle Tone**:
  - Due to spinal reflexes that alternate activity of the motor units within particular muscle resulting in a slightly contracted state.
  - Their contractions do not produce enough tension to cause movement, but they do tense and firm the muscle.
  - The identity of the motor units involved changes constantly.

Muscle Metabolism and ATP

- ATP is necessary for muscle contraction.
  - Used to detach cross bridges, operate the Ca2+ pump in the SR, and return Na+ and K+ levels via the sodium/potassium pump.
- ATP is supplied to muscles from three sources:

1. **Aerobic Respiration**
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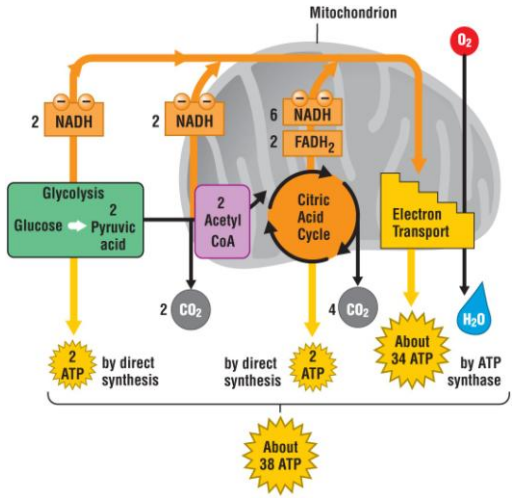
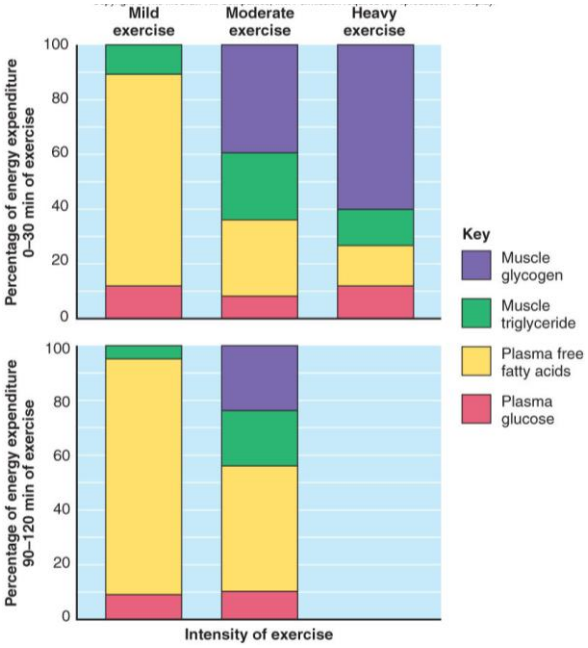
2. **Anerobic Respiration**
   - ATP production without oxygen – glycolysis, which produces lactic acid
3. **Creatine phosphate**
   - Direct phosphorylation of ADP by creatine phosphate



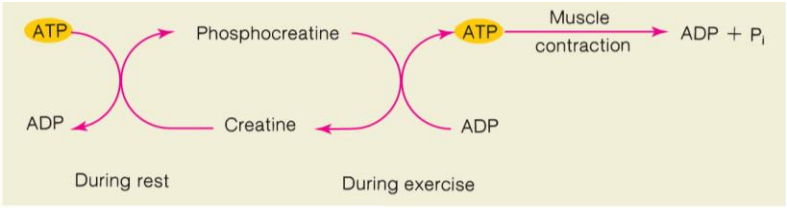
Energy Requirements of Skeletal Muscle

- **At rest/light exercise**: Most ATP from the aerobic respiration of fatty acids.
- **Moderate exercise**: ATP derived equally from fatty acids and glucose (muscle glycogen stores and plasma glucose)
- **Heavy exercise**:



Creatine Phosphate System

- Quick way to replenish ATP during the initial phase of heavy exercise while the metabolic pathways adjust to the suddenly higher demand for ATP.
  - **Creatine phosphate** adds a high energy phosphate group to ADP forming ATP.
  - Creatine-P + ADP ⟶ Creatine Kinase ⟶ Creatine + ATP
  - Phosphoylation of creatine by ATP restores levels of creatine phosphate.
  - Creatine phosphate system provides for maximum muscle power for about 15 seconds – a little longer for less vigorous activity.
    - Dominates in events such as the 100m dash or lifting weights.



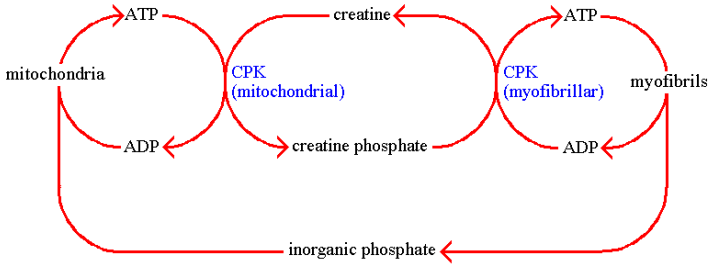
- **Creatine**: Produced by the liver and kidneys and

  - **Creatine** dietary supplements can increase muscle phosphocreatine by 15% – 40%
    - Found to increase muscle mass, strength, and performance of high-intensity exercise.
    - High doses can damage liver and kidneys.

- **Creatine phosphokinase (CPK or CK)**: Enzyme that catalyzes the transfer of phosphate between creatine and ATP.

  Creatine-P + ADP ⟶ Creatine Kinase ⟶ Creatine + ATP

- Enzyme exists in different forms (**isoenzmes**) depending on the tissue that it is found
  - Heart muscle, skeletal muscle, and



- **Damaged tissue leaks CPK into the blood stream** and can be used pinpoint the source of the damaged tissue.
  - **CPK-1** : found in the brain and lungs and increases due to a stroke or convulsions
  - **CPK-2**: found in the
  - **CPK-3** :found mostly in skeletal muscle and increases do to muscle trauma and muscular dystrophy

Oxygen Debt

- **Oxygen dept:** The amount of oxygen needed (heavy breathing) to restore normal conditions after exercise has stopped. Represents the difference between the amount of oxygen needed for totally aerobic muscle activity and the amount actually used.
- **Restoration includes:**
  - Replenish the oxygen withdrawn from **myoglobin** in muscle and hemoglobin in blood cells.
  - Aerobic metabolism to make ATP which is used to:
    - Replenish the Creatine phosphate (phosphagen) system
    - Power the Na+/K+ pump so as to restore resting ionic conditions within the cell.
    - Replenish the glycogen stores.
    -

Muscle Fiber Types

- Three main types based on their contraction speed and major pathways for forming ATP: Type I (slow oxidative), IIa (fast oxidative), and IIb (fast glycolytic).
  - **Speed of Contraction**: Slow and fast fibers are based on how fast their **myosin ATPases** split ATP resulting filaments sliding over each other.
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  - **Major pathways for forming ATP**: **Oxidiative fibers** rely mostly on aerobic pathways; **glycolytic fibers** rely more on anaerobic glycolysis

Slow Oxidative Fibers (Type I or Slow Twitch)

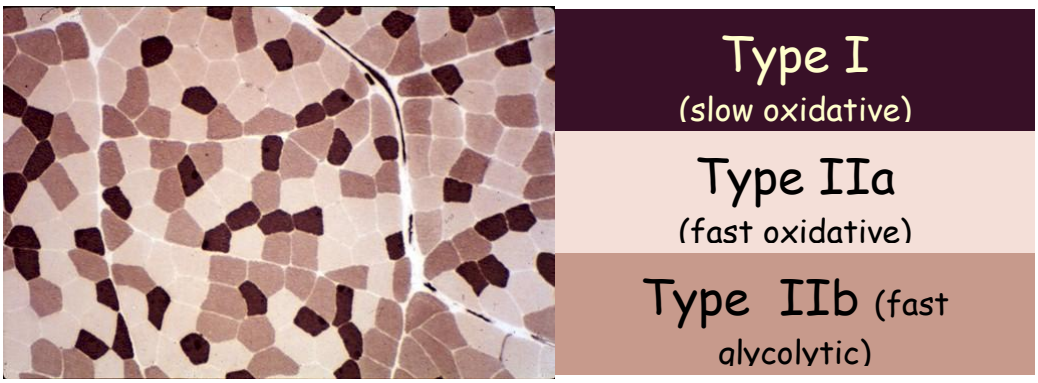
- **Slow twitch (red) fibers**: Specialized for endurance; high fatigue resistance –
- Contract slowly because its myosin ATPases splits ATP at a slow rate.
- Depends on **oxygen** for **aerobic** pathways to make ATP
- Abundant capillaries, mitochondria, and high myoglobin content which gives the muscle cells a **red color** thus called red fibers
  - **Myoglobin:** Pigment in muscle specialized for oxygen delivery
- Example: soleus muscle

Fast Oxidative Fibers (Type IIa or Intermediate)

- **Intermediate twitch fiber**:
  - Example: Gastrocnemius muscle – used in sprint or long-distance race.
- Moderate capillary supply and myoglobin content – contract quickly but need a good supply of oxygen.

Fast Twitch Fibers

- **Fast twitch:** Split ATP at a rapid rate and thus have a fast contraction velocity after stimulation, but fatigue rapidly.
- Contain densely packed myofibrils, large glycogen reserves, and relatively few mitochondria and myoglobin.
- Anaerobic metabolism – does not rely on oxygen for ATP production.
- Best suited for short term, power activities such as



White vs Dark Meat

- Chicken's breast is composed mainly of fast-twitch fibers giving the characteristic white meat appearance.
  - Relatively little blood supply and less myoglobin than dark meat
  - Muscles adapted to contract rapidly for

- Chicken's leg muscles are composed of slow-twitch fibers - meat is dark.
  - Muscles adapted for endurance – running
  - Darker appearance is partly due to a richer blood supply and presence of myoglobin.
  - **Myoglobin** is an oxygen-carrying pigment of muscle tissue – it stores oxygen temporarily until the muscle needs it.

Muscle Fatigue

- **Muscle fatigue:** The inability of the muscle to contract forcefully after long periods of activity. Results from:
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  - Depletion of ATP, glycogen, and/or creatine phosphate
  - Reduced release of Ca2+ ions from sarcoplasmic reticulum.
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  - Failure of nerve impulses to release enough acetylcholine.
  - Depletion of intracellular K+ and accumulation of extracellular K+

Cardiac Muscle

- Located in the walls of the heart (myocardium)
- Contract spontaneously and display a rhythmic beat.
  - Specialized cardiac cells called **pacemaker cells** set the heart rate
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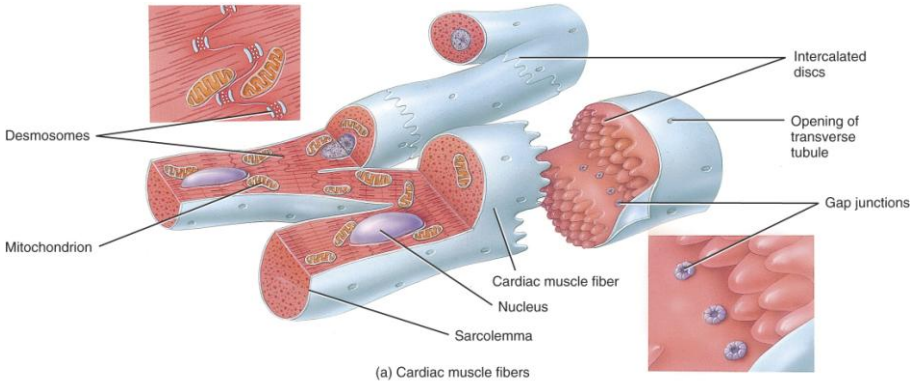
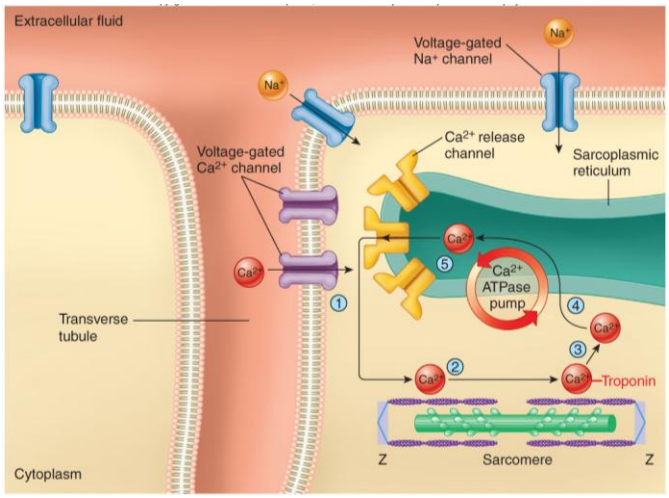
- Myocardium behaves as a single functional unit because cells are electrically joined by gap junctions.



Excitation-Contraction Coupling in Cardiac Muscle

- Unlike skeletal muscle, in cardiac cells the voltage-gated Ca2+ channels in the plasma membrane and the Ca2+ release channels in the sarcoplasmic reticulum do not directly interact.
- In cardiac cells, the Ca2+ that enters the cytoplasm through the voltage-gated Ca2+ channels in the transverse tubules stimulate the opening of the Ca2+ release channels of the sarcoplasmic reticulum.
- This process is known as

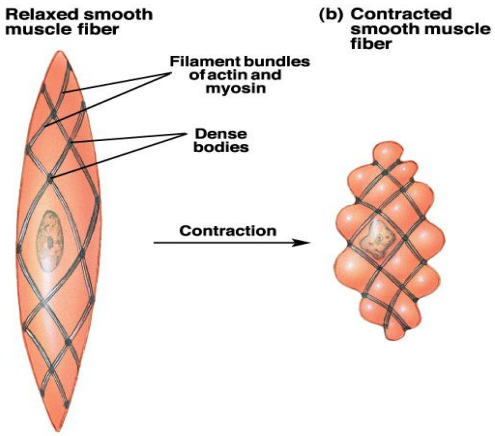


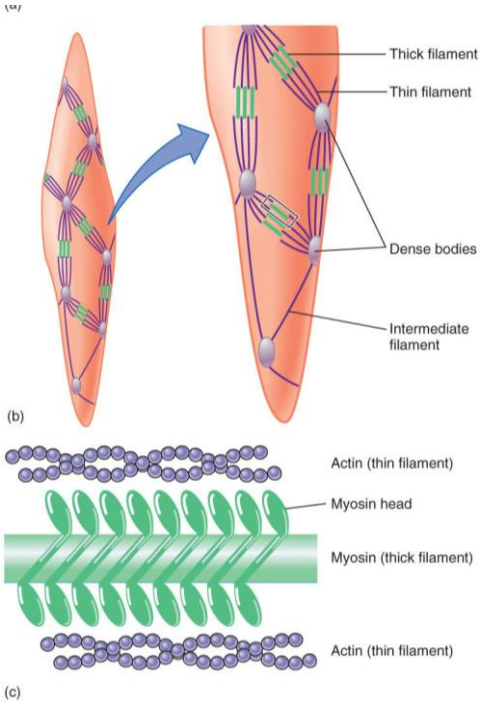
Smooth Muscle

- Contain myosin and actin filaments, but not organized into sarcomeres
  - Are attached to peripheral and cytoplasmic structures called **dense bodies**.
- Occurs within most visceral organs and surrounds the blood vessels, bronchi, and various ducts.
  - Rings of smooth muscle, called sphincters, regulate movement along internal passageways.

Excitation-Contraction Coupling in Smooth Muscles

- The **sarcoplasmic reticulum is less developed** than that of skeletal and cardiac muscle and releases little Ca2+.
- Extracellular Ca2+ diffusing into the smooth muscle cell through its plasma membrane is responsible for sustained contractions.
- Ca2+ enters through **voltage-regulated Ca2+ channels** in the plasma membrane.





- Smooth muscle cells do not contain **troponin** and the **tropomyosin** present does not block actin's cross-bridge binding site. What, then, prevents actin and myosin from binding and how is crossbridge activity switched on in the excited state? Answer: **Myosin light chains**.
- As Ca2+ enters through voltage gated Ca2+ channels and binds to a protein called **calmodulin** instead of <u>troponin, which is not present in smooth muscle</u>.
- **Calmodulin-Ca2+** complex activates **myosin light-chain kinase (MLCK)**, an enzyme that catalyzes the phosphorylation of **myosin light chains**.
- Smooth muscle myosin heads can interact with actin only when the myosin light chain is phosphylated.
    - Note: the phosphate on the myosin light chain is in addition to the phosphate on the myosin head ATPase site.
- The Phosphate on the light chain induces a chemical change in myosin and permits the myosin head to bind with actin so that the cross-bridge cycling can begin and produce a contraction.
- **Relaxation** follows the closing of the Ca2+ channels and lowering of cytoplasmic Ca2+ concentrations by the action of **Ca2+ - ATPase active transport pumps**.

Poorly developed Sacoplasmic Reticulum