# Lecture 11
# BIEN 500- Chaps 06-08 (Guyton and Hall, 13th edition)

Topic: Muscle

(Some content adapted from Dr. Alan Chiu)

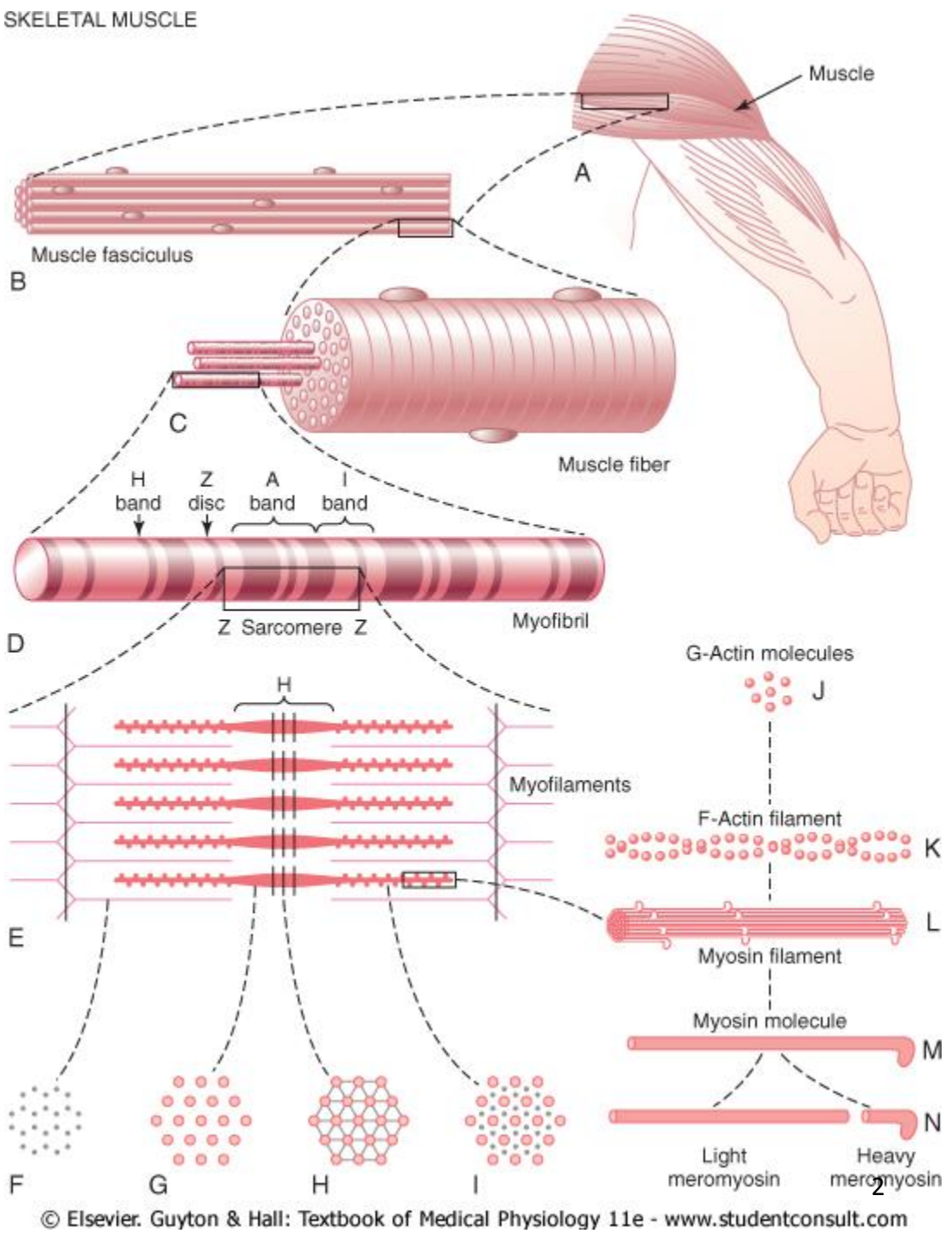
# BIEN500 – Chapter 06

- Structure and function of muscles
- General mechanism of contraction
- Sliding filament theory
- Length tension relation
- Muscular energy demand
- Difference between skeletal, cardiac, smooth

# Contraction of 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.
- Figure 6-1 shows the organization of skeletal muscle, demonstrating that all skeletal muscles are composed of numerous fibers.
- Each of these fibers is made up of successively smaller subunits

# Structure and functions of muscles



# Physiology of the skeletal muscle fiber

- In most skeletal muscles, each fiber extends the entire length of the muscle. 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.
- At each end of the muscle fiber, this surface layer of the sarcolemma fuses with tendon fibers, which then in turn collect into bundles to form the muscle tendons that then connect the muscles to the bone.

- Three major muscle tissue
  - Skeletal – moves body by pulling on bones
  - Cardiac – pushes blood through circulatory system
  - Smooth – controls the digestive track and diameters of small arteries

# Functions of skeletal muscle

- Produce skeletal movement
- Maintain posture and body position
- Support soft tissues
- Guard entrances and exits
- Maintain body temperature

# Animation

- Home > Muscular System > Anatomy Review: Skeletal Muscle Tissue

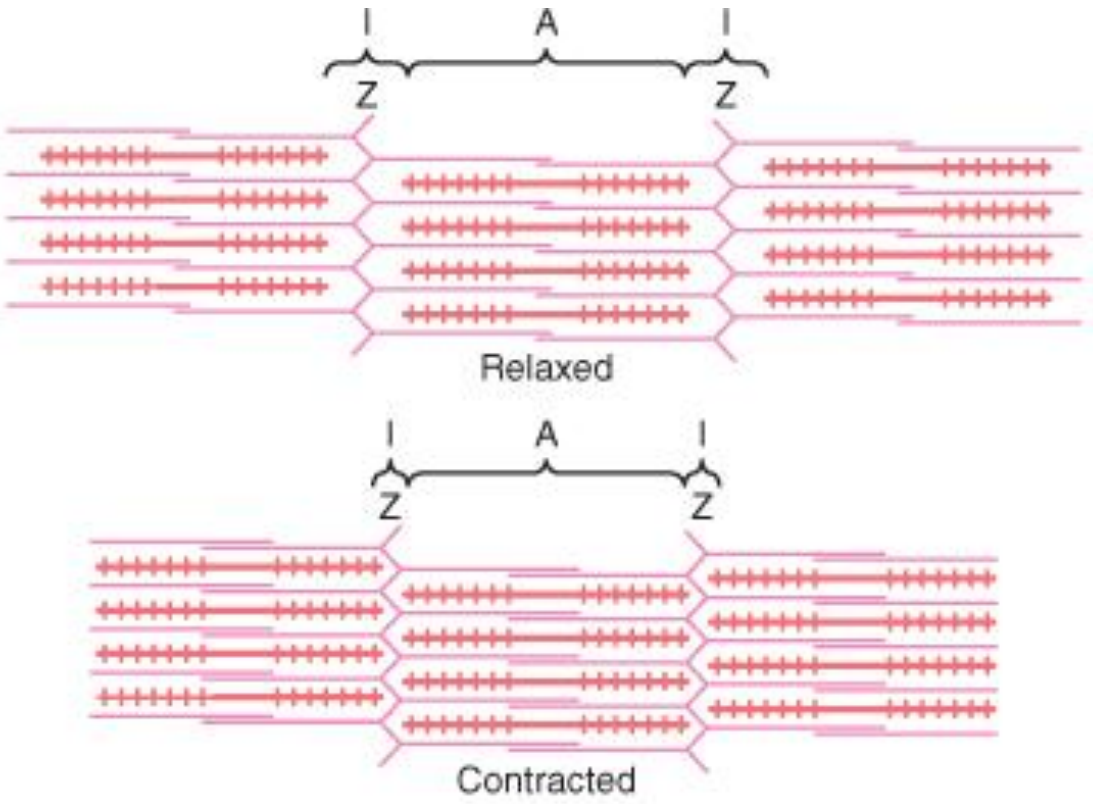
# Gross anatomy of muscle

- Sarcolemma – cell membrane
- Transverse Tubules – conduct signal of contract throughout interior of cell
- Myofibrils – responsible for skeletal muscle fiber contraction
- Sacroplasmic reticulum – release calcium ion to control muscle contraction

# General mechanism of contraction

- AP arrives along motor nerve to muscle fiber
- Nerve secretes Ach
- Ach activates Ach-channel
- Large amount of Na influx to muscle fiber
- Initiates AP in muscle
- AP travels along muscle fiber
- SR release large amount of Ca
- Ca cause myosin filaments to slide

# Sliding Filament Theory



# Animation

- Home > Muscular System > Sliding Filament Theory

# Protein make-up of the skeletal muscle

- Titin filamentous molecules keep the myosin and actin filaments in place.
- The side-by-side relationship between the myosin and actin filaments is maintained by a large number of filamentous molecules of a protein called titin.
- Each titin molecule has a molecular weight of about 3 million, which makes it one of the largest protein molecules in the body.
- Also, because it is filamentous, it is very springy.

# Sarcoplasm is the intracellular fluid between the myofibrils

- The spaces between the myofibrils of each muscle fiber are filled with intracellular fluid called sarcoplasm, containing large quantities of potassium, magnesium, and phosphate, plus multiple protein enzymes.
- Also present are tremendous numbers of mitochondria that lie parallel to the myofibrils, providing energy in the form of ATP.

# Sarcoplasmic reticulum is specialized endoplasmic reticulum of skeletal muscle

- Also in the sarcoplasm surrounding the myofibrils of each muscle fiber is an extensive reticulum, called the sarcoplasmic reticulum.
- This reticulum has a special organization that is extremely important in regulating calcium storage, release, and reuptake and therefore muscle contraction.
- The rapidly contracting types of muscle fibers have especially extensive sarcoplasmic reticula.

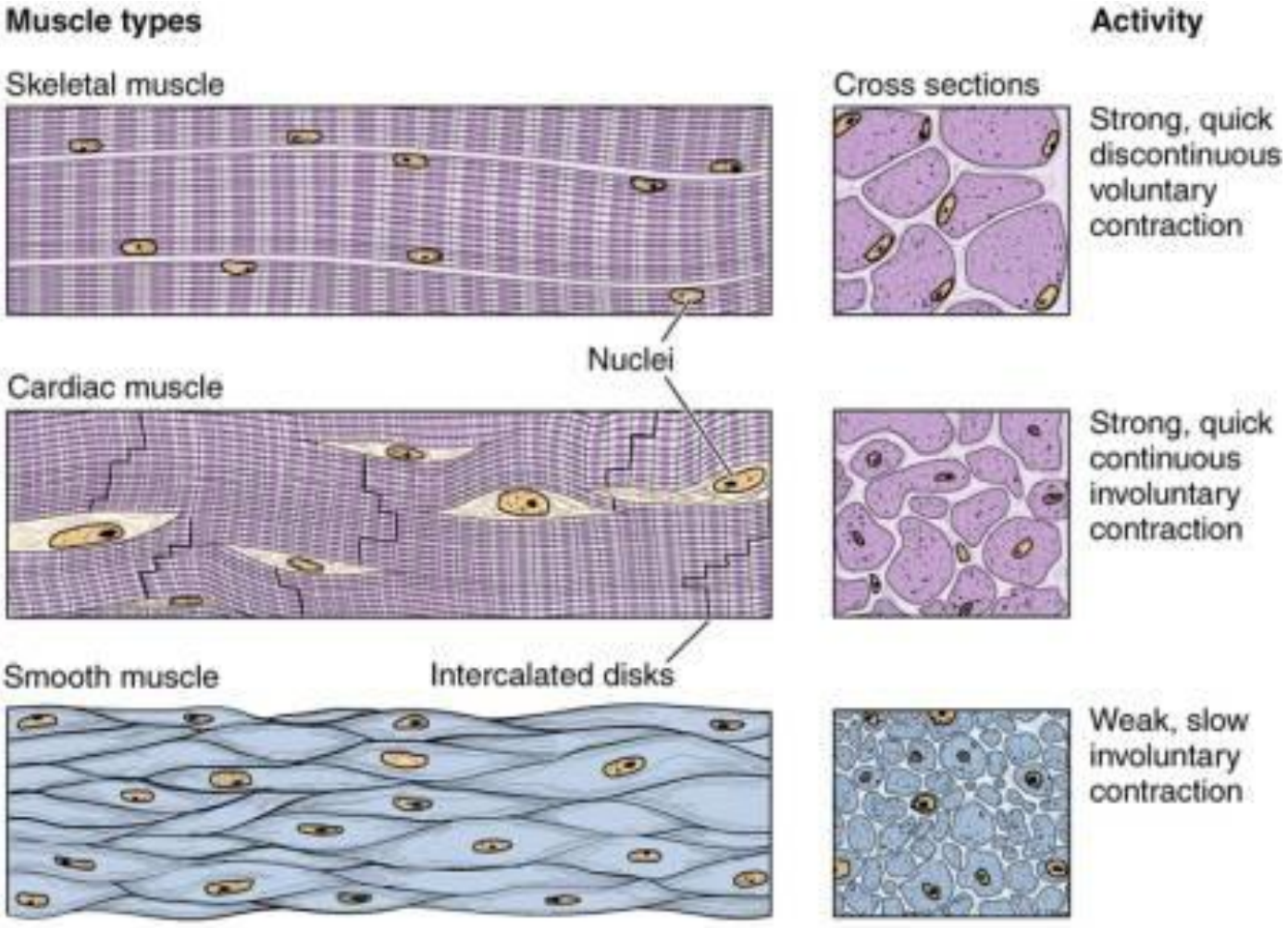
# Energy Demand

- A single muscle fiber may contain 15 billion thick filaments.
- When that muscle fiber is actively contracting, each thick filament breaks down roughly 2500 ATP molecules per second.
- Because even a small skeletal muscle contains thousands of muscle fibers, the ATP demands of a contracting skeletal muscle are enormous.
- In practical terms, the demand for ATP in a contracting muscle fiber is so high that it would be impossible to have all the necessary energy available as ATP before the contraction begins.
- Instead, a resting muscle fiber contains only enough ATP and other high-energy compounds to sustain a contraction until additional ATP can be generated.
- Throughout the rest of the contraction, the muscle fiber will generate ATP at roughly the same rate as it is used.

# Muscle fatigue

- A skeletal muscle fiber is said to be fatigued when it can no longer contract despite continued neural stimulation.
- The cause of muscle fatigue varies with the level of muscle activity. After short peak levels of activity, such as running a 100-meter dash, fatigue may result from the exhaustion of ATP and Creatine Phosphate reserves or from the drop in pH that accompanies the buildup of lactic acid.
- After prolonged exertion, such as running a marathon, fatigue may involve physical damage to the sarcoplasmic reticulum that interferes with the regulation of intracellular Ca2+ concentrations.
- Muscle fatigue is cumulative.

# Difference between muscle types

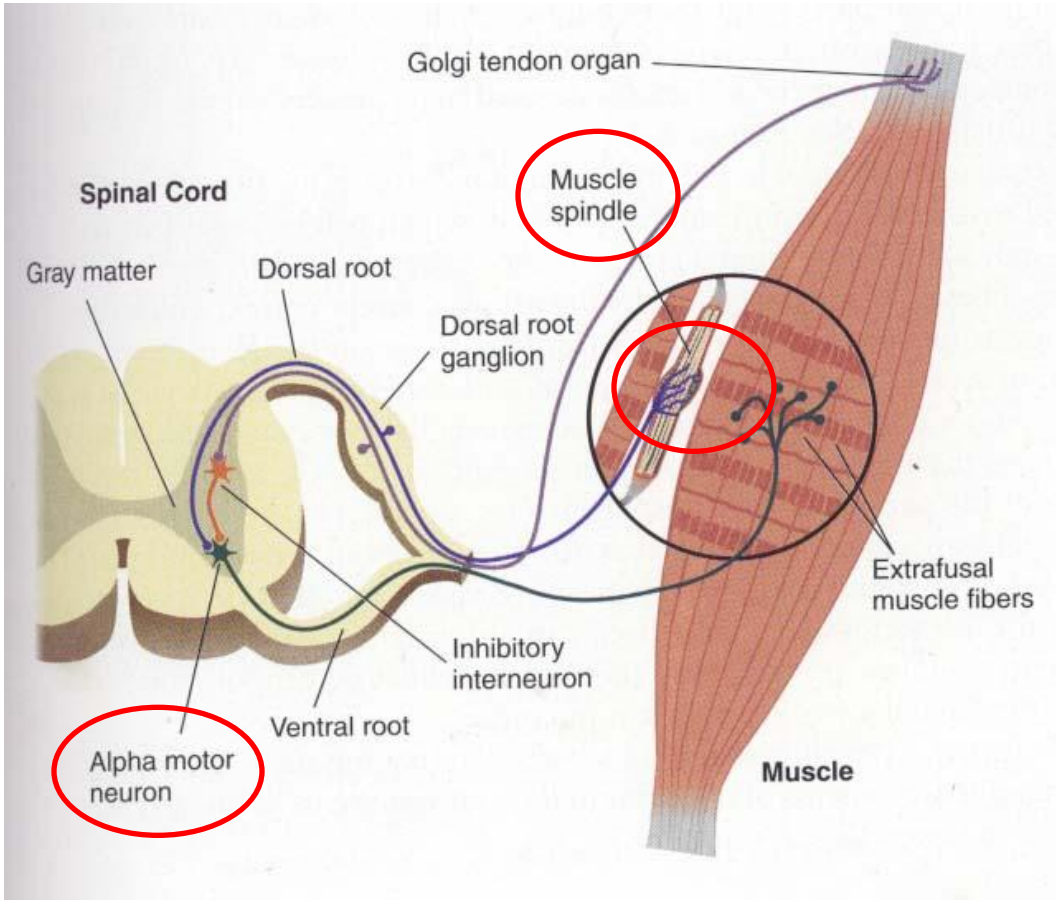


# BIEN500 – Chapter 07

- Neuromuscular system
- Synapse between a neuron & muscle
- How the nervous system varies muscle force
- Neuromuscular diseases
- Smooth Muscles

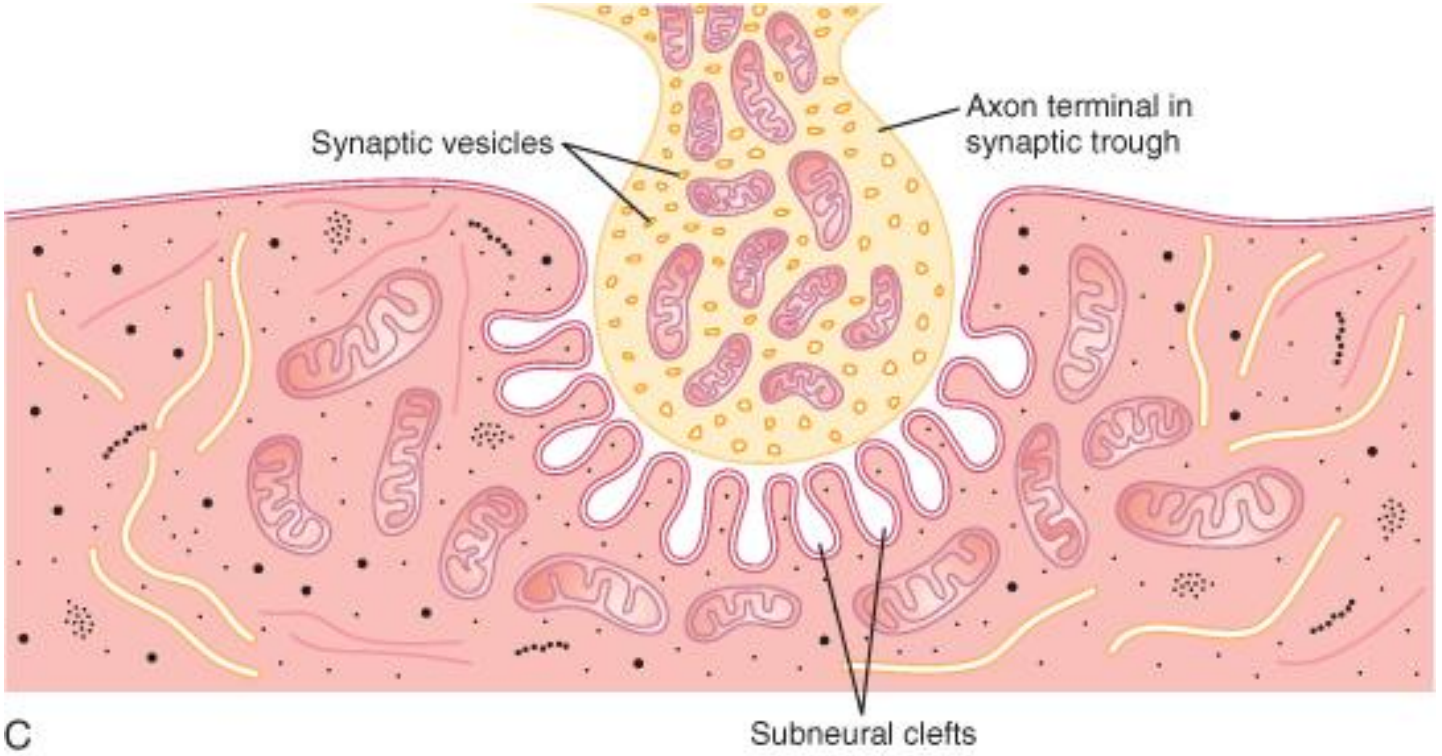
# Neuromuscular system

- A single motor neuron and the muscle fibers it innervates constitute a motor unit
- Each muscle fiber is usually innervated by only one motor neuron although each motor neuron innervates a number of skeletal muscle fibers
- The number of muscle fibers innervated by one motor neuron is called the innervation ratio.
- Although the innervation ratio varies considerably from one muscle to another, it is roughly proportional to the size of the muscle. [eye 10, hand 100, gas 2000]



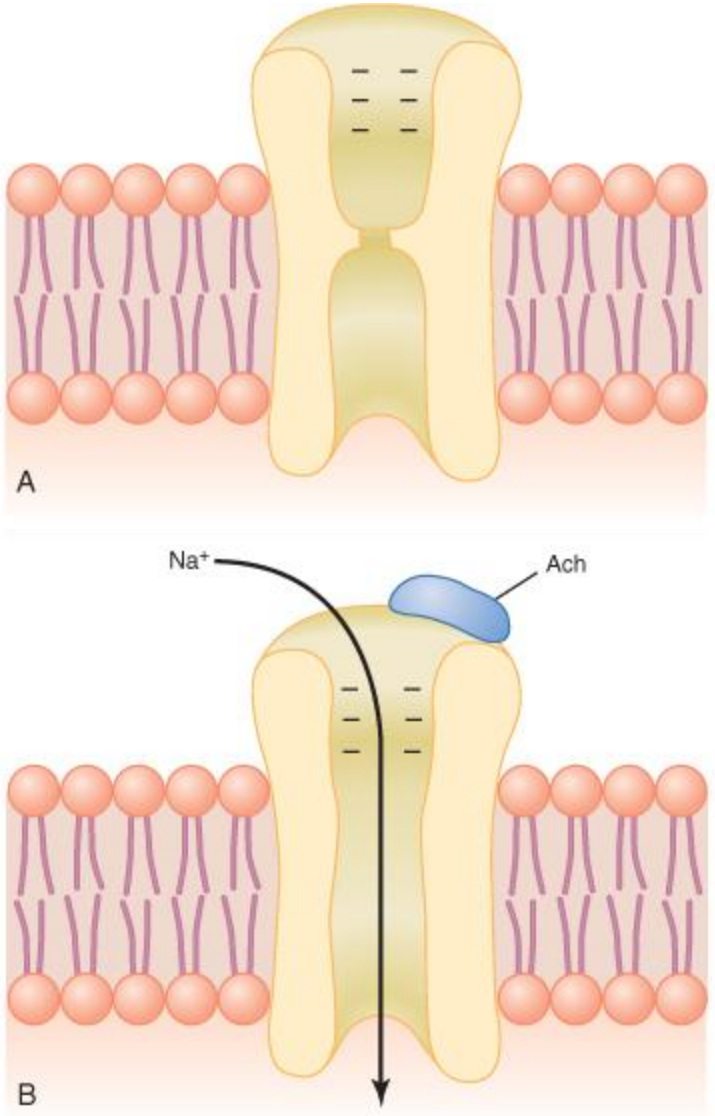
# Neuromuscular synaptic junction

- Electron electrographic appearance of axon terminal and muscle fiber membrane.



# Synapse between a Neuron & Muscle

- Acetylocholine (Ach) as a major neurotransmitter.

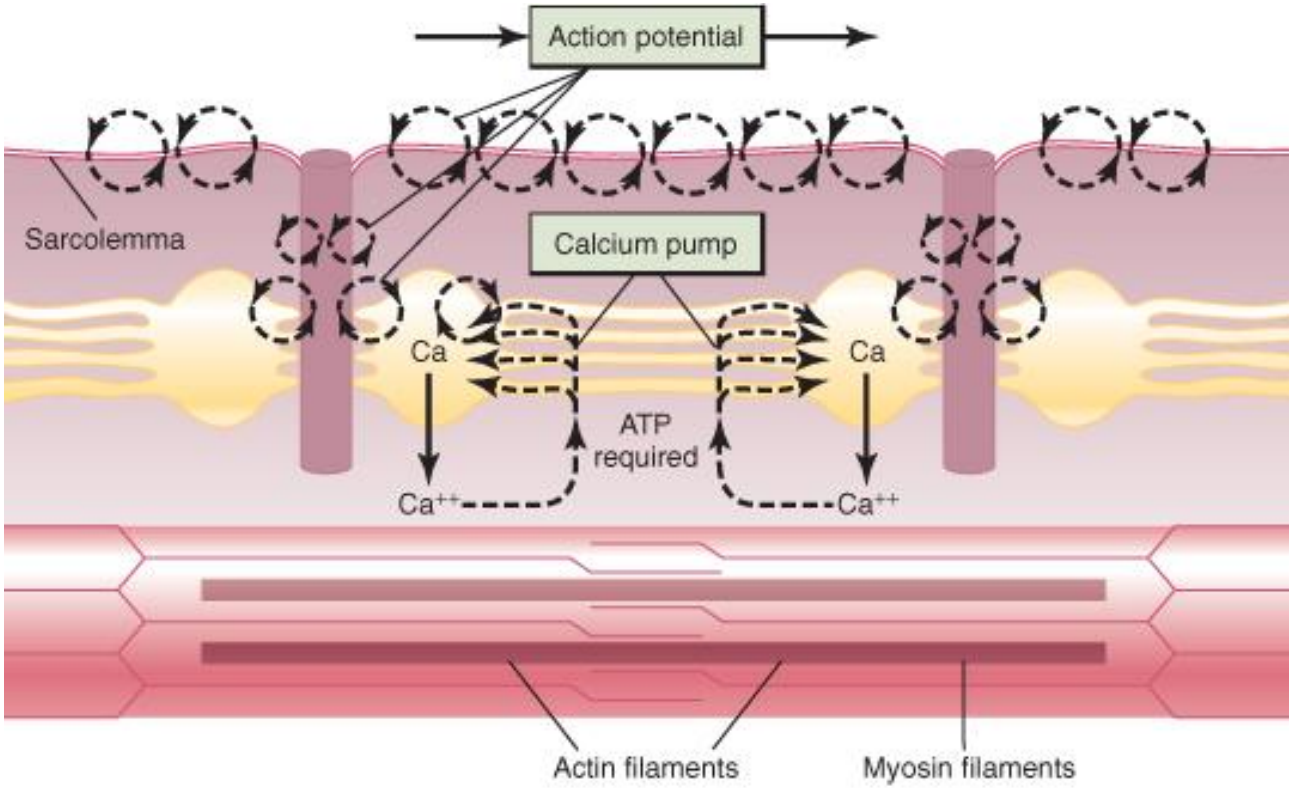


# Cascade of steps for synapse (1)

- A Neural action potential is generated in a motor neuron by the spatial and temporal summation of incoming action potentials on the dendrites from neighboring neurons.
- These action potentials travel at a characteristic velocity of approximately 100 m/s and end up at the motor end-plate.
- Action potentials cause secretion of the neurotransmitter acetylcholine (ACh) from small synaptic vesicles that pack Ach into the space beneath the end-plate (synaptic cleft).
- ACh binds to the receptors in the muscle fiber membrane.
- This causes chemically gated Ca2+ channels to open and this way initiate the muscle action potential (MUAP) that travels along the muscle fiber in both directions at characteristic speed of the order of 5 m/s.

# Cascade of steps for synapse (2)

- As MUAP propagates down the length of muscle fiber, MUAP increases permeability of the sarcoplasmic reticulum which contains Ca2+ which is then released into the sarcoplasm.

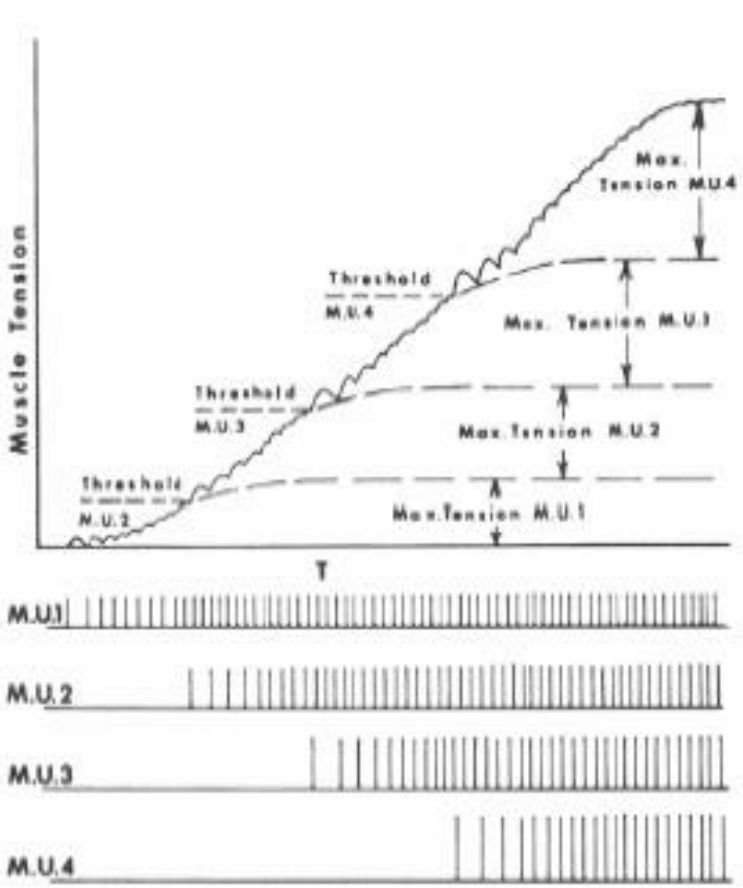


# Cascade of steps for synapse (3)

- Here Ca2+ binds to the protein troponin which is located at the thin actin myofilaments.
- Troponin inhibits the binding of myosin cross-bridges to specific receptor sites on the actin filaments.
- With inhibition removed, myosin is free to bind to actin which causes two myofilaments to slide relative to each other and a force is generated.

# Nervous system varies muscle force

- changes in motor cortex output recruits (or de-recruits) motor units.
- Threshold-based
- Smaller motor units get recruited first followed by larger ones.
- Frequency



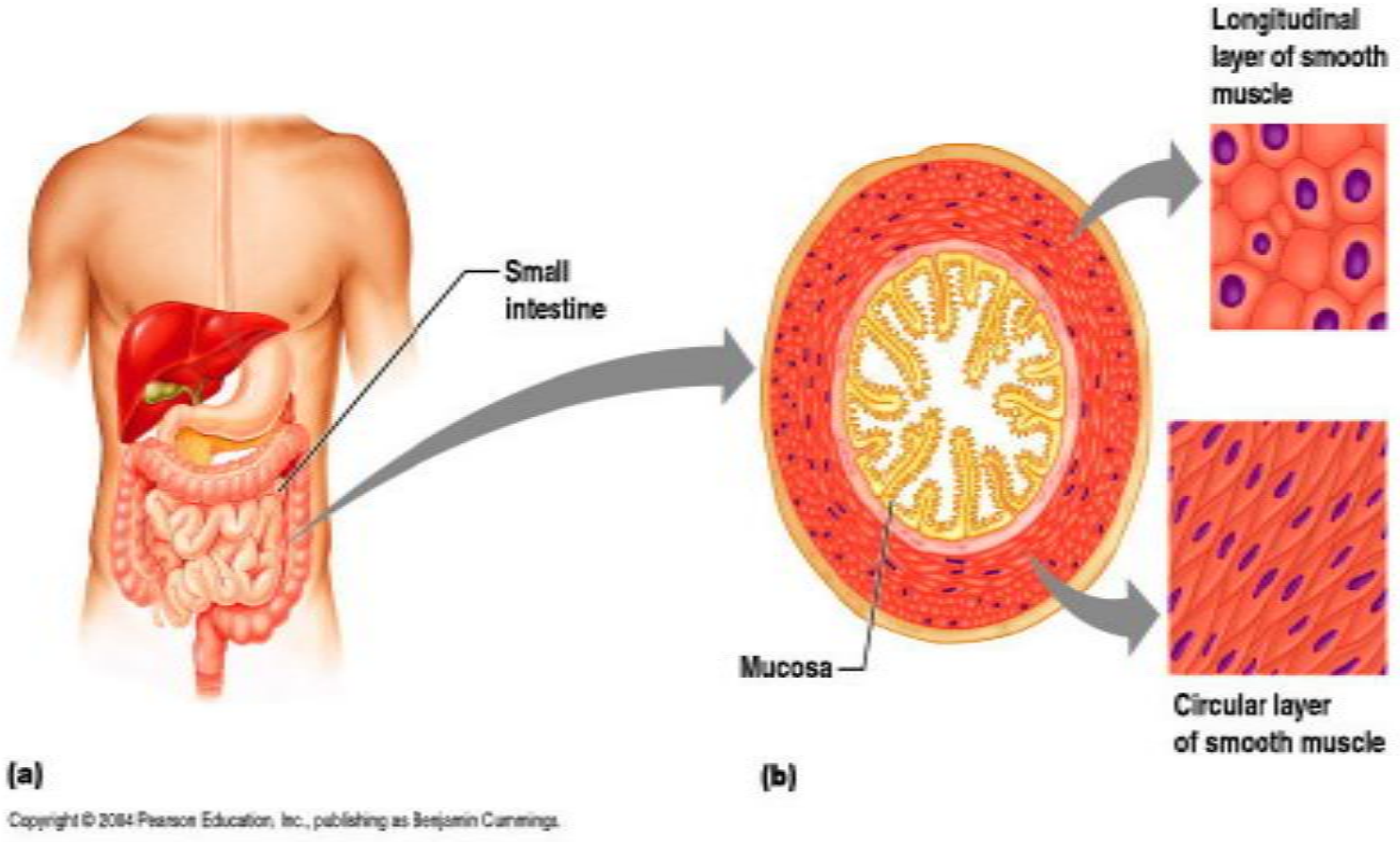
# BIEN500 – Chapter 08

- Smooth muscle
- Single versus multi-unit
- Microscopic anatomy
- Contraction
- Regulation

# Smooth muscle

- Composed of spindle-shaped fibers with a diameter of 2-10 μm and lengths of several hundred μm
- Lack the coarse connective tissue sheaths of skeletal muscle, but have fine endomysium
- Organized into two layers (longitudinal and circular) of closely apposed fibers
- Found in walls of hollow organs (except the heart)
- Have essentially the same contractile mechanisms as skeletal muscle

# Smooth muscle in the small intestine



# Types of smooth muscle: single unit

- The cells of single-unit smooth muscle, commonly called visceral muscle:
  - Contract rhythmically as a unit
  - Are electrically coupled to one another via gap junctions
  - Often exhibit spontaneous action potentials
  - Are arranged in opposing sheets and exhibit stress relaxation response

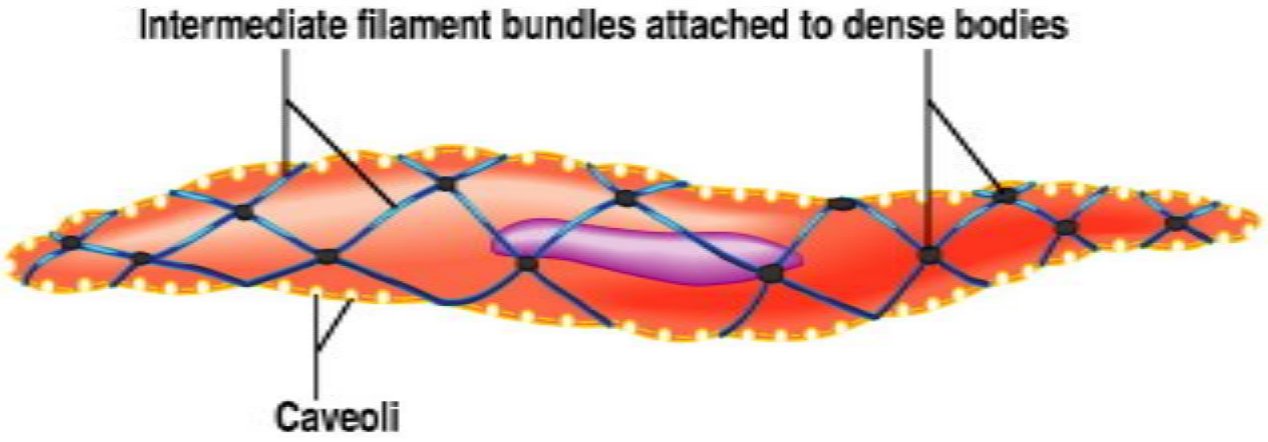
# Types of smooth muscle: multiunit

- Multiunit smooth muscles are found:
  - In large airways to the lungs
  - In large arteries
  - In arrector pili muscles
  - Attached to hair follicles
  - In the internal eye muscles

# Microscopic anatomy

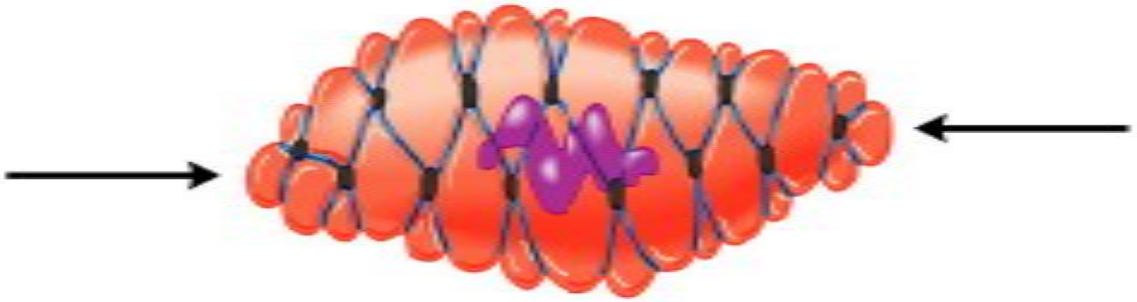
- SR is less developed than in skeletal muscle and lacks a specific pattern
- T tubules are absent
- Plasma membranes have pouch like infoldings called caveoli
- Ca2+ is sequestered in the extra cellular space near the caveoli, allowing rapid influx when channels are opened
- There are no visible striations and no sarcomeres
- Thin and thick filaments are present
- Ratio of thick to thin filaments is much lower than in skeletal muscle
- Thick filaments have heads along their entire length
- There is no troponin complex
- Thick and thin filaments are arranged diagonally, causing smooth muscle to contract in a corkscrew manner
- Noncontractile intermediate filament bundles attach to dense bodies (analogous to Z discs) at regular intervals

# Microscopic anatomy




**(a) Relaxed smooth muscle cell**





**(b) Contracted smooth muscle cell**

# Contraction

1. Wave of depolarization along membrane from the neuromuscular junction or adjacent cells.
2. Calcium is released from caveolae and endoplasmic reticulum
3. Calcium binds to calmodulin
4. Calcium-calmodulin complex activates and unfolds myosin light chain kinase
5. ATP is used to phosphorylate myosin light chain kinase (this is unique to smooth muscle).
6. Phosphorylated light chain kinase is activated so it can bind actin.
7. Works like an ATPase to bind actin and move along the F actin chain.

# Regulation

- Smooth muscle can either receive innervation via the autonomic nervous system, or hormones through the blood system can regulate them.
- Some muscle responds to both types of regulation.
- Innervation involves nerve endings forming synapses with smooth muscle cells. They are usually in the form of swellings of axons which contain synaptic vesicles (norepinephrine or acetylcholine are two neurotransmitters).
- An example of hormonal control would be found in the uterus, which is under the influence of oxytocin. This would be active particularly during labor and delivery.