Lecture 9a

Muscle structure

Topics

- Smooth, skeletal, and cardiac muscle tissues
- Structure and function of skeletal muscle cells.
- Sarcomeres structure and contraction
- Actin-myosin interaction and sliding filament theory

Muscle Similarities

- Muscle types: skeletal, cardiac, smooth
- Skeletal and smooth muscle cells are elongated and are called muscle fibers
- Muscle contraction depends on two kinds of myofilaments – actin and myosin
- Muscle terminology is similar
  - Sarcolemma – muscle plasma membrane
  - Sarcoplasm – cytoplasm of a muscle cell
  - Prefixes – myo, mys, and sarco all refer to muscle

Classification of Muscle Cells

- Striated (muscle cells with a banded appearance) or nonstriated (not banded)
- Muscle cells can have a single nucleus or be multinucleate
- Muscle cells can be controlled voluntarily (consciously) or involuntarily (automatically)

Skeletal Muscle

- Striated, “voluntary”, and multinucleated
- Cells can be very long
- Contracts rapidly but tires easily
- Is extremely adaptable and can exert forces ranging from a fraction of an ounce to over 70 pounds
- **Satellite cells**: Like a muscle “stem cell,” can divide to become new skeletal muscle cells (adult skeletal muscle cells do not divide).

Cardiac Muscle Cells

- Occurs only in the heart
- Is striated, not voluntary, uni- or bi- nucleate
- Contracts at a fairly steady rate set by the heart’s pacemaker cells
- Cells are called cardiac myocytes
- Form branching networks connected at intercalated disks
- Neural controls allow the heart to respond to changes in bodily needs

Limited capacity for repair

Smooth Muscle Cells

- Nonstriated, involuntary, and have a single nucleus
- Smooth muscle cells are small and tapered
- can divide and regenerate
- Found in walls of hollow organs and blood vessels
- Contract alone or under nervous system control
- Smooth muscle helps maintain blood pressure, and squeezes or propels substances (i.e., food, feces) through organs

Functional Characteristics of Muscle Tissue

- Excitability, or irritability – the ability to receive and respond to stimuli
- Contractility – the ability to shorten forcibly
- Extensibility – the ability to be stretched or extended
- Elasticity – the ability to recoil and resume the original resting length

Characteristics of Skeletal, Cardiac, and Smooth Muscle

TABLE 10–4 A Comparison of Skeletal, Cardiac, and Smooth Muscle Tissues

Property	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Fiber dimensions (diameter × length)	100 μm × up to 30 cm	10–20 μm × 50–100 μm	5–10 μm × 30–200 μm
Nuclei	Multiple, near sarcolemma	Generally single, centrally located	Single, centrally located
Filament organization	In sarcomeres along myofibrils	In sarcomeres along myofibrils	Scattered throughout sarcoplasm
SR	Terminal cisternae in triads at zones of overlap	SR tubules contact T tubules at Z lines	Dispersed throughout sarcoplasm, no T tubules
Control mechanism	Neural, at single neuromuscular junction	Automaticity (pacemaker cells)	Automaticity (pacesetter cells), neural or hormonal control
Ca^{2+} source	Release from SR	Extracellular fluid and release from SR	Extracellular fluid and release from SR
Contraction	Rapid onset; may be tetanized; rapid fatigue	Slower onset; cannot be tetanized; resistant to fatigue	Slow onset; may be tetanized; resistant to fatigue
Energy source	Aerobic metabolism at moderate levels of activity; glycolysis	Aerobic metabolism, usually lipid or carbohydrate substrates	Primarily aerobic metabolism (anaerobic during peak activity)

Table 10-4

The Muscular System

- Includes only skeletal muscles
  - attached to the skeletal system
  - allow us to move
- Muscle tissue (muscle cells or fibers)
- Connective tissues
- Nerves
- Blood vessels

Functions of Skeletal Muscles

1. Produce skeletal movement
2. Maintain body posture
3. Support soft tissues
4. Stabilize joints
5. Guard body openings
6. Generate heat

Skeletal Muscle

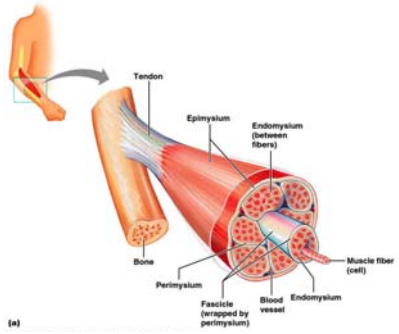
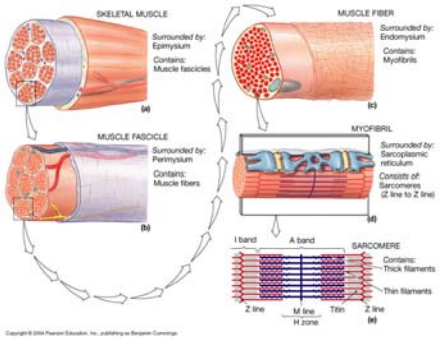


Figure 9.2a

Organization of Connective Tissues

- Muscles have 3 layers of connective tissues:
  - –Epimysium – an overcoat of dense regular and irregular connective tissue that surrounds the entire muscle; Separates muscle from surrounding tissues
  - –Perimysium – fibrous connective tissue that surrounds groups of muscle fibers called fascicles; Contains blood vessel and nerve supply to fascicles
  - –Endomysium – fine sheath of connective tissue composed of collagen and reticular fibers surrounding each muscle cell/fiber; Contains capillaries and nerve fibers contacting muscle cells; Contains satellite cells (stem cells) that repair damage

Levels of organization



Level 1: Skeletal Muscle

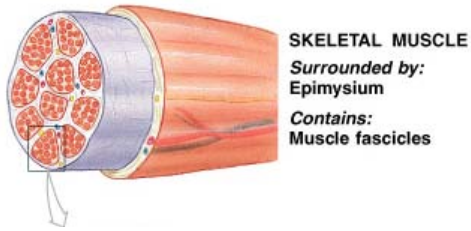


Figure 10-6 (1 of 5)

Level 2: Muscle Fascicle

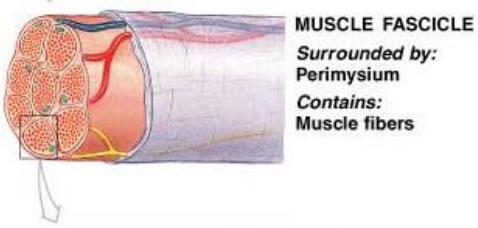


Figure 10-6 (2 of 5)

Level 3: Muscle Cell (Fiber)

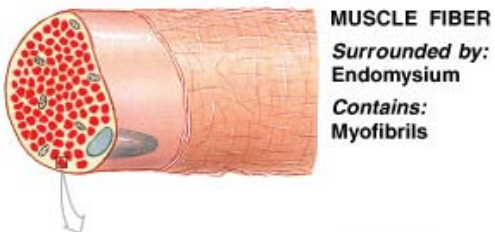


Figure 10-6 (3 of 5)

Level 4: Myofibril

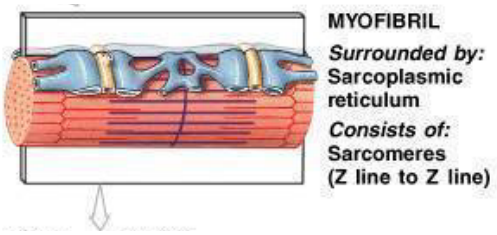
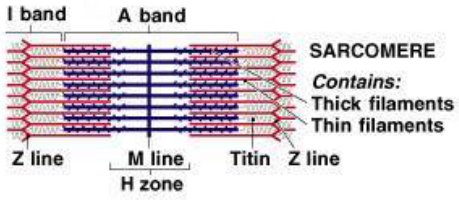


Figure 10-6 (4 of 5)

Level 5: Sarcomere



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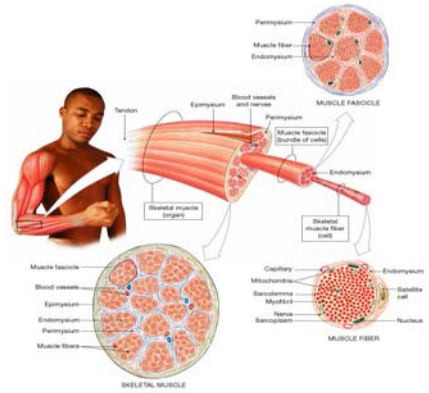


Summary – muscle orgnaization

- Epimysium surrounds muscle (which are bundles of fascicles)
- Perimysium surrounds fascicles (which are bundles are fibers/cells)
- Endomysium surrounds muscle fibers (which are filled with myofibrils)
- Myofibrils are long cylinders of sarcomeres
- Sarcomeres contract to shorten muscles. (Made up of myofilaments)

Muscle Attachments

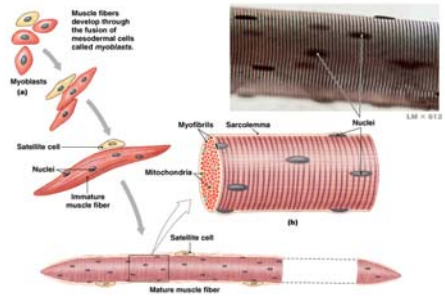
- Direct – epimysium of the muscle is fused to the periosteum of a bone
- Indirectly – connective tissue wrappings (endomysium, perimysium, and epimysium) come together at ends of muscles and extend beyond it as a tendon (bundle) or aponeurosis (sheet)

Innervation and Vascularization

- Nerves
  - Skeletal muscles are voluntary muscles, controlled by nerves of the somatic nervous system
- Muscles have extensive vascular systems:
  - supply large amounts of oxygen and nutrients
  - carry away wastes

Formation of Skeletal Muscle Fibers

- Skeletal muscle cells are called fibers
- Myoblasts join to form muscle fibers



igure 10-2

Skeletal Muscle Fibers

- Are very long cylindrical cell with hundreds of nuclei just beneath the sarcolemma
- Each cell is a syncytium produced by fusion of embryonic mesodermal cells (myoblasts)
- Fibers are 10 to 100 μm in diameter, and up to hundreds of centimeters long

Organization of Skeletal Muscle Fibers

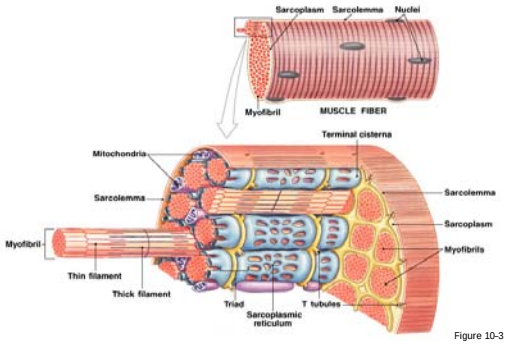
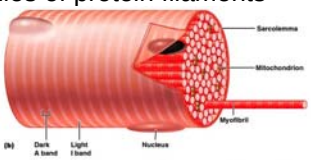


Figure 10-3

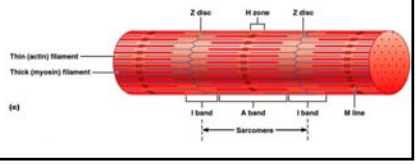
Myofibrils

- Myofibrils are densely packed, rodlike contractile elements
- Make up most of the muscle cell volume
- Made up sarcomeres, which are themselves bundles of protein filaments (myofilaments)



Sarcomeres

- The smallest contractile unit of a muscle
- The region of a myofibril between two successive Z discs
- Composed of myofilaments made up of contractile proteins
- The repeating pattern of myofibrils notice the presence of a repeating portion known as a **sarcomere**



Myofilaments

- Myofibrils and sarcomeres consist of **thick** and *thin* myofilaments
- These filaments are responsible for the striations of muscle, which are alternating **dark** and *light* bands
- Myofilaments are responsible for muscle contraction
  - Thin filaments:
    - made of the protein actin
  - Thick filaments:
    - made of the protein myosin

Sarcomeres

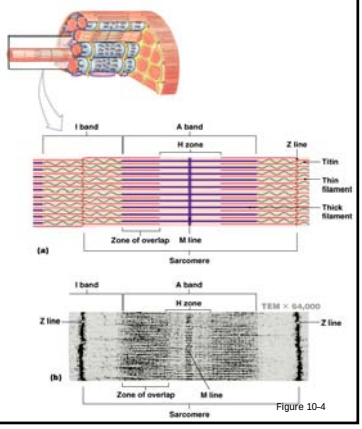
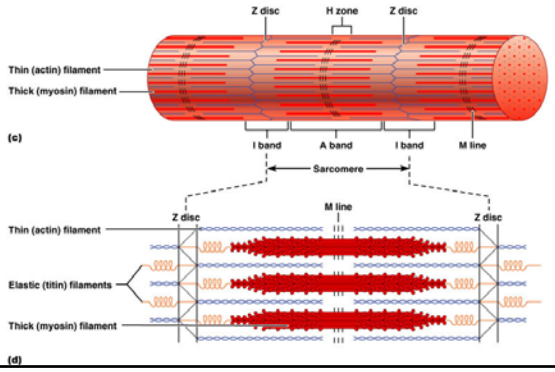


Figure 10-4

Sarcomeres

- The contractile units of muscle
- Structural units of myofibrils (that is, myofibrils are made up of many sarcomeres postioned end to end)
- Form visible striated patterns within myofibrils:
  - alternating dark, thick filaments (A bands) and light, thin filaments (I bands)

Sarcomere



M Lines and Z Lines

- M line:
  - the center of the A band
  - at midline of sarcomere
- Z lines/discs:
  - the centers of the I bands
  - at 2 ends of sarcomere (like z is at the end of the alphabet)
  - coin-shaped sheet of proteins (connectins) that anchors the thin filaments and connects myofibrils to one another

Zone of Overlap

- The densest, darkest area on a light micrograph
- Where thick and thin filaments overlap

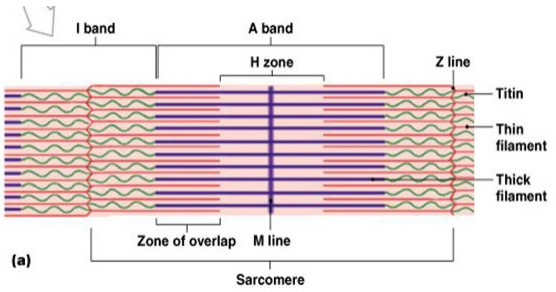
The H Zone

- The area around the M line
- Has only thick filaments but no thin filaments

Titin

- Strands of protein that reach from tips of thick filaments to the Z line
- Stabilize the filaments

Sarcomere



Sarcomere Structure

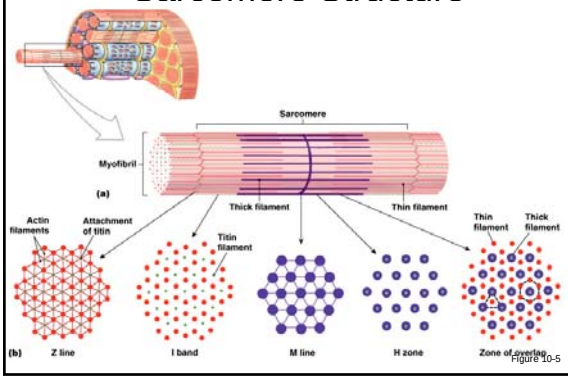


Figure 10-5

Special names for skeletal muscle cell structures

- Sarcolemma: plasma membrane
- Sarcoplasm: cytoplasm
- Sarcoplasmic reticulum (like smooth ER)

New to skeletal muscle cells:

- Transverse tubules (T tubules) are extensions of the sarcolemma that join with the SR at specialized regions

The Sarcolemma

- The cell membrane of a muscle cell
- Surrounds the sarcoplasm (cytoplasm of muscle fiber)
- Muscle contractions are started by a change in transmembrane potential (electrical charge on either side of the membrane)

Action potential

- A rapid, transitory reversal of the transmembrane potential that propagates quickly along the length of an electrically excitable cell.
- Huh? Basically, a portion of a cell goes from negative to positive charge very quickly and this spreads from one part of the cell to the next to the next and so on.

Transverse Tubules (T tubules)

- T tubules are continuous with the sarcolemma and have the same properties
- They conduct action potentials to the deepest regions of the muscle
- These impulses signal for the release of Ca^{2+} from adjacent terminal cisternae
- Allow entire muscle fiber to contract simultaneously

Zone of overlap and T tubules

- Transverse tubules encircle the sarcomere near zones of overlap (why?)
- Ca^{2+} released by SR causes thin and thick filaments to interact

Sarcoplasmic Reticulum

- An elaborate membranous structure that runs longitudinally, surrounding each myofibril
- Similar in structure to smooth endoplasmic reticulum
- Helps transmit action potential to myofibril
- Forms chambers (terminal cisternae) attached to T tubules that release calcium during muscle contraction

Terminal Cisternae

- Concentrate Ca^{2+} inside (*via* ion pumps)
- When stimulated by an action potential, they release Ca^{2+} into sarcomeres to begin muscle contraction

A Triad

- Structure formed by 1 T tubule and 2 terminal cisternae (thickenings of the SR)
- T tubules and SR provide tightly linked signals for muscle contraction
- T tubule proteins act as voltage sensors
- SR has receptors that regulate Ca^{2+} release from the terminal cisternae

Organization of Skeletal Muscle Fibers

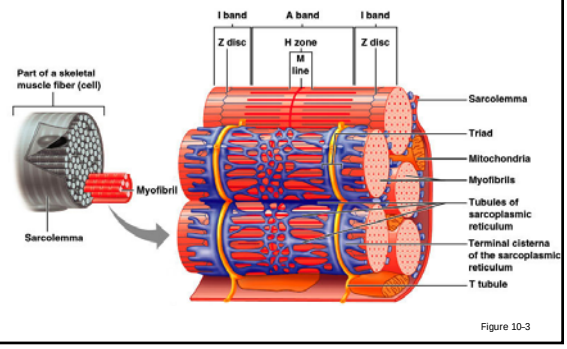
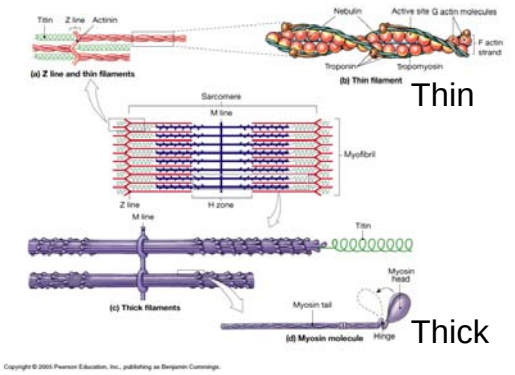


Figure 10-3

Muscle Contraction

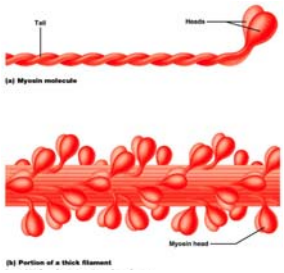
- Is caused by interactions of thick and thin filaments
- Structures of protein molecules detemine interactions

Thin and thick filaments



Myofilaments: Thick Filaments

- Composed of the protein myosin (approximately 500)
- Each myosin molecule has a rod-like tail and two globular heads
  - Tails – two interwoven, heavy polypeptide chains, bound together, pointing towards the M line
  - Heads – two smaller, light polypeptide chains that reach out and grab onto actin



The Myosin Molecule

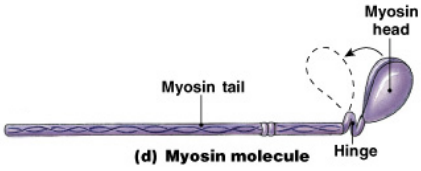
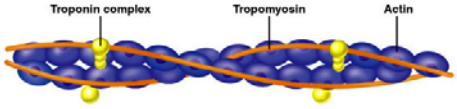


Figure 10-7d

Myofilaments: Thin Filaments

- Thin filaments are chiefly composed of the protein actin held together by nebulin
- The subunits contain the active sites to which myosin heads attach during contraction
- Tropomyosin strands block active sites
- Troponin holds tropomyosin and actin together (at rest)



Arrangement of the Filaments in a Sarcomere

- Longitudinal section within one sarcomere

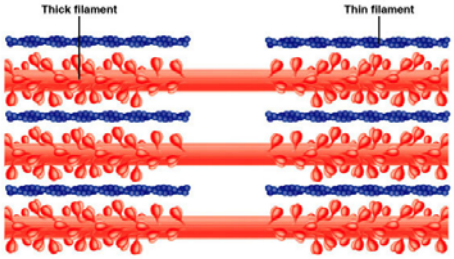
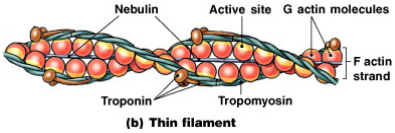


Figure 9.4d

Troponin and Tropomyosin

- Troponin binds tropomyosin to actin
  - consists of three subunits
    - TnI: binds to actin
    - TnT: bonds to tropomyosin
    - TnC: binds calcium
  - controlled by Ca^{2+}, kind of like the "lock" and Ca^{2+} is the "key"



Initiating Contraction

- Ca^{2+} binds to receptor on troponin molecule
- Troponin–tropomyosin complex changes shape, moves troponin out of the way
- Exposes the active site of each actin molecule (bead)

Myosin Action

- During contraction, myosin heads:
  - interact with actin filaments, forming cross-bridges
  - **pivot**, producing motion

It is the pivoting of myosin heads that causes muscle contraction and therefore all movements

Sliding Filaments

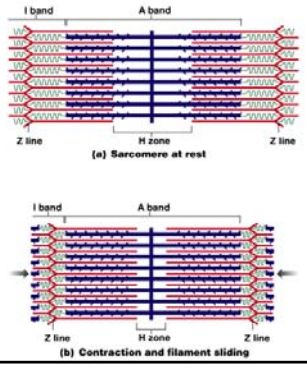
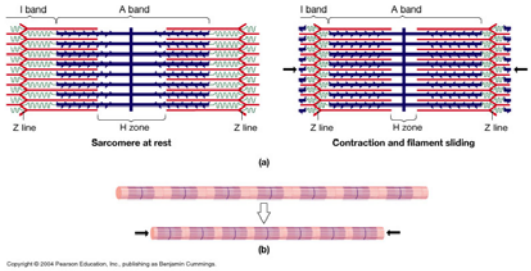


Figure 10-8

Notice that during contraction, the sarcomere shortens.



Sliding Filament Model of Contraction

- Thin filaments slide past the thick ones so that the actin and myosin filaments overlap to a greater degree
- In the relaxed state, thin and thick filaments overlap only slightly
- Upon stimulation, myosin heads bind to actin and sliding begins
- Myosin heads pull the actin thin filaments closer together, sliding them in between the thick filaments
- As this event occurs throughout the sarcomeres, the muscle shortens
  - Z lines move closer together
  - width of A band stays the same
  - width of the I band and the H zone both shrink

Movie

- contraction

Summary

- Smooth. Skeletal, and cardiac muscle tissues
- Structure and function of skeletal muscle cells.
- Sarcomere structure and contraction
- Actin-myosin interaction and sliding filament theory