Chapter 9
Muscle Tissue

- Alternating contraction and relaxation of cells
- Chemical energy changed into mechanical energy

3 Types of Muscle Tissue

- Skeletal muscle
  - attaches to bone, skin or fascia
  - striated with light & dark bands visible with scope
  - voluntary control of contraction & relaxation
3 Types of Muscle Tissue

- Cardiac muscle
  - striated in appearance
  - involuntary control
  - autorhythmic because of built in pacemaker
3 Types of Muscle Tissue

- Smooth muscle
  - attached to hair follicles in skin
  - in walls of hollow organs -- blood vessels & GI
  - nonstriated in appearance
  - involuntary
Functions of Muscle Tissue

- Producing body movements
- Stabilizing body positions
- Regulating organ volumes
  - bands of smooth muscle called sphincters
- Movement of substances within the body
  - blood, lymph, urine, air, food and fluids, sperm
- Producing heat
  - involuntary contractions of skeletal muscle (shivering)

Properties of Muscle Tissue

- Excitability
  - respond to chemicals released from nerve cells
- Conductivity
  - ability to propagate electrical signals over membrane
- Contractility
  - ability to shorten and generate force
- Extensibility
  - ability to be stretched without damaging the tissue
- Elasticity
  - ability to return to original shape after being stretched

Skeletal Muscle -- Connective Tissue

- Superficial fascia is loose connective tissue & fat underlying the skin
- Deep fascia = dense irregular connective tissue around muscle
- Connective tissue components of the muscle include
  - epimysium = surrounds the whole muscle
  - perimysium = surrounds bundles (fascicles) of 10-100 muscle cells
  - endomysium = separates individual muscle cells
- All these connective tissue layers extend beyond the muscle belly to form the tendon
Nerve and Blood Supply

- Each skeletal muscle is supplied by a nerve, artery and two veins.
- Each motor neuron supplies multiple muscle cells (neuromuscular junction)
- Each muscle cell is supplied by one motor neuron terminal branch and is in contact with one or two capillaries.
  - nerve fibers & capillaries are found in the endomysium between individual cells

Fusion of Myoblasts into Muscle Fibers

- Every mature muscle cell developed from 100 myoblasts that fuse together in the fetus. (multinucleated)
- Mature muscle cells can not divide
- Muscle growth is a result of cellular enlargement & not cell division
- Satellite cells retain the ability to regenerate new cells.

Muscle Fiber or Myofibers

- Muscle cells are long, cylindrical & multinucleated
- Sarcolemma = muscle cell membrane
- Sarcoplasma filled with tiny threads called myofibrils & myoglobin (red-colored, oxygen-binding protein)
Transverse Tubules

- T (transverse) tubules are invaginations of the sarcolemma into the center of the cell
  - filled with extracellular fluid
  - carry muscle action potentials down into cell
- Mitochondria lie in rows throughout the cell
  - near the muscle proteins that use ATP during contraction

Myofibrils & Myofilaments

- Muscle fibers are filled with threads called myofibrils separated by SR (sarcoplasmic reticulum)
- Myofilaments (thick & thin filaments) are the contractile proteins of muscle

Sarcoplasmic Reticulum (SR)

- System of tubular sacs similar to smooth ER in nonmuscle cells
- Stores Ca+2 in a relaxed muscle
- Release of Ca+2 triggers muscle contraction
Atrophy and Hypertrophy

- **Atrophy**
  - wasting away of muscles
  - caused by disuse (disuse atrophy) or severing of the nerve supply (denervation atrophy)
  - the transition to connective tissue cannot be reversed

- **Hypertrophy**
  - increase in the diameter of muscle fibers
  - resulting from very forceful, repetitive muscular activity and an increase in myofibrils, SR & mitochondria

Filaments and the Sarcomere

- Thick and thin filaments overlap each other in a pattern that creates striations (light I bands and dark A bands)
- The I band region contains only thin filaments.
- They are arranged in compartments called sarcomeres, separated by Z discs.
- In the overlap region, six thin filaments surround each thick filament

Thick & Thin Myofilaments

- Supporting proteins (M line, titin and Z disc help anchor the thick and thin filaments in place)
Overlap of Thick & Thin Myofilaments within a Myofibril

Dark(A) & light(I) bands visible with an electron microscope

The Proteins of Muscle

- Myofibrils are built of 3 kinds of protein
  - contractile proteins
    - myosin and actin
  - regulatory proteins which turn contraction on & off
    - tropomyosin and troponin
  - structural proteins which provide proper alignment, elasticity and extensibility
    - titin, myomesin, nebulin and dystrophin

The Proteins of Muscle -- Myosin

- Thick filaments are composed of myosin
  - each molecule resembles two golf clubs twisted together
  - myosin heads (cross bridges) extend toward the thin filaments
- Held in place by the M line proteins.
The Proteins of Muscle -- Actin

- Thin filaments are made of actin, troponin, & tropomyosin
- The myosin-binding site on each actin molecule is covered by tropomyosin in relaxed muscle
- The thin filaments are held in place by Z lines. From one Z line to the next is a sarcomere.

The Proteins of Muscle -- Titin

- Titan anchors thick filament to the M line and the Z disc.
- The portion of the molecule between the Z disc and the end of the thick filament can stretch to 4 times its resting length and spring back unharmed.
- Role in recovery of the muscle from being stretched.

Other Structural Proteins

- The M line (myomesin) connects to titin and adjacent thick filaments.
- Nebulin, an inelastic protein helps align the thin filaments.
- Dystrophin links thin filaments to sarcolemma and transmits the tension generated to the tendon.
Sliding Filament Mechanism Of Contraction

- Myosin cross bridges pull on thin filaments
- Thin filaments slide inward
- Z Discs come toward each other
- Sarcomeres shorten. The muscle fiber shortens. The muscle shortens
- Notice: Thick & thin filaments do not change in length

How Does Contraction Begin?

- Nerve impulse reaches an axon terminal & synaptic vesicles release acetylcholine (ACh)
- ACh diffuses to receptors on the sarcolemma & Na+ channels open and Na+ rushes into the cell
- A muscle action potential spreads over sarcolemma and down into the transverse tubules
- SR releases Ca+2 into the sarcoplasm
- Ca+2 binds to troponin & causes troponin-tropomyosin complex to move & reveal myosin binding sites on actin—the contraction cycle begins

Excitation - Contraction Coupling

- All the steps that occur from the muscle action potential reaching the T tubule to contraction of the muscle fiber.
Steps in the Contraction Cycle

- Notice how the myosin head attaches and pulls on the thin filament with the energy released from ATP

Overview: From Start to Finish

- Nerve ending
- Neurotransmitter
- Muscle membrane
- Stored Ca+2
- ATP
- Muscle proteins

Rigor Mortis

- Rigor mortis is a state of muscular rigidity that begins 3-4 hours after death and lasts about 24 hours
- After death, Ca+2 ions leak out of the SR and allow myosin heads to bind to actin
- Since ATP synthesis has ceased, crossbridges cannot detach from actin until proteolytic enzymes begin to digest the decomposing cells.
Neuromuscular Junction (NMJ) or Synapse

- NMJ = myoneural junction
  - end of axon nears the surface of a muscle fiber at its motor end plate region (remain separated by synaptic cleft or gap)

Structures of NMJ Region

- Synaptic end bulbs are swellings of axon terminals
- End bulbs contain synaptic vesicles filled with acetylcholine (ACh)
- Motor end plate membrane contains 30 million ACh receptors.

Events Occurring After a Nerve Signal

- Arrival of nerve impulse at nerve terminal causes release of ACh from synaptic vesicles
- ACh binds to receptors on muscle motor end plate opening the gated ion channels so that Na⁺ can rush into the muscle cell
- Inside of muscle cell becomes more positive, triggering a muscle action potential that travels over the cell and down the T tubules
- The release of Ca²⁺ from the SR is triggered and the muscle cell will shorten & generate force
- Acetylcholinesterase breaks down the ACh attached to the receptors on the motor end plate so the muscle action potential will cease and the muscle cell will relax.
Pharmacology of the NMJ

- Botulinum toxin blocks release of neurotransmitter at the NMJ so muscle contraction can not occur
  - bacteria found in improperly canned food
  - death occurs from paralysis of the diaphragm
- Curare (plant poison from poison arrows)
  - causes muscle paralysis by blocking the ACh receptors
  - used to relax muscle during surgery
- Neostigmine (anticholinesterase agent)
  - blocks removal of ACh from receptors so strengthens weak muscle contractions of myasthenia gravis
  - also an antidote for curare after surgery is finished

The Motor Unit

- Motor unit = one somatic motor neuron & all the skeletal muscle cells (fibers) it stimulates
  - muscle fibers normally scattered throughout belly of muscle
  - One nerve cell supplies on average 150 muscle cells that all contract in unison.
- Total strength of a contraction depends on how many motor units are activated & how large the motor units are

Muscle Tone

- Involuntary contraction of a small number of motor units (alternately active and inactive in a constantly shifting pattern)
  - keeps muscles firm even though relaxed
  - does not produce movement
- Essential for maintaining posture (head upright)
- Important in maintaining blood pressure
  - tone of smooth muscles in walls of blood vessels
Isotonic and Isometric Contraction

- Isotonic contractions = a load is moved
  - concentric contraction = a muscle shortens to produce force and movement
  - eccentric contractions = a muscle lengths while maintaining force and movement
- Isometric contraction = no movement occurs
  - tension is generated without muscle shortening
  - maintaining posture & supports objects in a fixed position

Variations in Skeletal Muscle Fibers

- Myoglobin, mitochondria and capillaries
  - red muscle fibers
    - more myoglobin, an oxygen-storing reddish pigment
    - more capillaries and mitochondria
  - white muscle fibers
    - less myoglobin and less capillaries give fibers their pale color
- Contraction and relaxation speeds vary
  - how fast myosin ATPase hydrolyzes ATP
- Resistance to fatigue
  - different metabolic reactions used to generate ATP

Classification of Muscle Fibers

- Slow oxidative (slow-twitch)
  - red in color (lots of mitochondria, myoglobin & blood vessels)
  - prolonged, sustained contractions for maintaining posture
- Fast oxidative-glycolytic (fast-twitch A)
  - red in color (lots of mitochondria, myoglobin & blood vessels)
  - split ATP at very fast rate; used for walking and sprinting
- Fast glycolytic (fast-twitch B)
  - white in color (few mitochondria & BV, low myoglobin)
  - anaerobic movements for short duration; used for weightlifting
Fiber Types within a Whole Muscle

- Most muscles contain a mixture of all three fiber types
- Proportions vary with the usual action of the muscle
  - neck, back and leg muscles have a higher proportion of postural, slow oxidative fibers
  - shoulder and arm muscles have a higher proportion of fast glycolytic fibers
- All fibers of any one motor unit are same.
- Different fibers are recruited as needed.

Anabolic Steroids

- Similar to testosterone
- Increases muscle size, strength, and endurance
- Many very serious side effects
  - liver cancer
  - kidney damage
  - heart disease
  - mood swings
  - facial hair & voice deepening in females
  - atrophy of testicles & baldness in males

Anatomy of Cardiac Muscle

- Striated, short, quadrangular-shaped, branching fibers
- Single centrally located nucleus
- Cells connected by intercalated discs with gap junctions
- Same arrangement of thick & thin filaments as skeletal
Cardiac versus Skeletal Muscle

• More sarcoplasm and mitochondria
• Larger transverse tubules located at Z discs, rather than at A-I band junctions
• Less well-developed SR
• Limited intracellular Ca+2 reserves
  – more Ca+2 enters cell from extracellular fluid during contraction
• Prolonged delivery of Ca+2 to sarcoplasm, produces a contraction that last 10 -15 times longer than in skeletal muscle

Appearance of Cardiac Muscle

• Striated muscle containing thick & thin filaments
• T tubules located at Z discs & less SR

Physiology of Cardiac Muscle

• Autorhythmic cells
  – contract without stimulation
• Contracts 75 times per min & needs lots O2
• Larger mitochondria generate ATP aerobically
• Sustained contraction possible due to slow Ca+2 delivery
  – Ca+2 channels to the extracellular fluid stay open
Two Types of Smooth Muscle

- Visceral (single-unit)
  - in the walls of hollow viscera & small BV
  - autorhythmic
  - gap junctions cause fibers to contract in unison
- Multiunit
  - individual fibers with own motor neuron ending
  - found in large arteries, large airways, arrector pili muscles, iris & ciliary body

Microscopic Anatomy of Smooth Muscle

- Small, involuntary muscle cell -- tapering at ends
- Single, oval, centrally located nucleus
- Lack T tubules & have little SR for Ca++ storage

Microscopic Anatomy of Smooth Muscle

- Thick & thin myofilaments not orderly arranged so lacks sarcomeres
- Sliding of thick & thin filaments generates tension
- Transferred to intermediate filaments & dense bodies attached to sarcolemma
- Muscle fiber contracts and twists into a helix as it shortens -- relaxes by untwisting
Physiology of Smooth Muscle

- Contraction starts slowly & lasts longer
  - no transverse tubules & very little SR
  - Ca+2 must flows in from outside
- Calmodulin replaces troponin
  - Ca+2 binds to calmodulin turning on an enzyme (myosin light chain kinase) that phosphorylates the myosin head so that contraction can occur
  - enzyme works slowly, slowing contraction

Smooth Muscle Tone

- Ca+2 moves slowly out of the cell
  - delaying relaxation and providing for state of continued partial contraction
  - sustained long-term
- Useful for maintaining blood pressure or a steady pressure on the contents of GI tract

Regeneration of Muscle

- Skeletal muscle fibers cannot divide after 1st year
  - growth is enlargement of existing cells
  - repair
    - satellite cells & bone marrow produce some new cells
    - if not enough numbers—fibrosis occurs most often
- Cardiac muscle fibers cannot divide or regenerate
  - all healing is done by fibrosis (scar formation)
- Smooth muscle fibers (regeneration is possible)
  - cells can grow in size (hypertrophy)
  - some cells (uterus) can divide (hyperplasia)
  - new fibers can form from stem cells in BV walls
### Developmental Anatomy of the Muscular System

- Develops from mesoderm
- Somite formation
  - blocks of mesoderm give rise to vertebrae and skeletal muscles of the back
- Muscles of head & limbs develop from general mesoderm

### Aging and Muscle Tissue

- Skeletal muscle starts to be replaced by fat beginning at 30
  - “use it or lose it”
- Slowing of reflexes & decrease in maximal strength
- Change in fiber type to slow oxidative fibers may be due to lack of use or may be result of aging

### Myasthenia Gravis

- Progressive autoimmune disorder that blocks the ACh receptors at the neuromuscular junction
- The more receptors are damaged the weaker the muscle.
- More common in women 20 to 40 with possible line to thymus gland tumors
- Begins with double vision & swallowing difficulties & progresses to paralysis of respiratory muscles
- Treatment includes steroids that reduce antibodies that bind to ACh receptors and inhibitors of acetylcholinesterase
Muscular Dystrophies

- Inherited, muscle-destroying diseases
- Sarcolemma tears during muscle contraction
- Mutated gene is on X chromosome so problem is with males almost exclusively
- Appears by age 5 in males and by 12 may be unable to walk
- Degeneration of individual muscle fibers produces atrophy of the skeletal muscle
- Gene therapy is hoped for with the most common form = Duchenne muscular dystrophy

Abnormal Contractions

- Spasm = involuntary contraction of single muscle
- Cramp = a painful spasm
- Tic = involuntary twitching of muscles normally under voluntary control—eyelid or facial muscles
- Tremor = rhythmic, involuntary contraction of opposing muscle groups
- Fasciculation = involuntary, brief twitch of a motor unit visible under the skin