## Muscle Overview
- The three types of muscle tissue are skeletal, cardiac, and smooth
- These types differ in structure, location, function, and means of activation
- Skeletal and smooth muscle cells are elongated and are called muscle fibers
- Muscle contraction depends on two kinds of myofilaments – actin and myosin

## Muscle Similarities
- Muscle terminology is similar
  - Sarcolemma – muscle plasma membrane
  - Sarcoplasm – cytoplasm of a muscle cell
  - Prefixes – myo, mys, and sarco all refer to muscle

## Skeletal Muscle Tissue
- In skeletal muscles that attach to and cover the bony skeleton
- Has obvious (visible) stripes called striations
- Is controlled voluntarily (i.e., by conscious control)
- Contracts rapidly but tires easily
- Is responsible for overall body motility
- Is extremely adaptable and can exert forces ranging from a fraction of an ounce to over 70 pounds

## Cardiac Muscle Tissue
- Occurs only in the heart
- Is striated like skeletal muscle but is not voluntary
- Contracts at a fairly steady rate set by the heart’s pacemaker
- Neural controls allow the heart to respond to changes in bodily needs

## Smooth Muscle Tissue
- Found in the walls of hollow visceral organs, such as the stomach, urinary bladder, and respiratory passages
- Forces food and other substances through internal body channels
- It is not striated and is involuntary
**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

**Muscle Function**
- **Skeletal muscles**: responsible for all locomotion
- **Cardiac muscle**: responsible for coursing the blood through the body
- **Smooth muscle**: helps maintain blood pressure, and squeezes or propels substances (i.e., food, feces) through organs
- Muscles maintain posture, stabilize joints, and generate heat

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**Structure and Organization of Skeletal Muscle**

**Table 9.1a**

<table>
<thead>
<tr>
<th>Structure and Organizational Levels of Skeletal Muscle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure and Organizational Level</td>
<td>Connective Tissue Sheaths</td>
</tr>
<tr>
<td>Endomysium</td>
<td>Connective tissue composed of reticular fibers surrounding each muscle fiber</td>
</tr>
<tr>
<td>Perimysium</td>
<td>Connective tissue that surrounds groups of muscle fibers called fascicles</td>
</tr>
<tr>
<td>Epimysium</td>
<td>An overcoat of dense regular connective tissue that surrounds the entire muscle</td>
</tr>
</tbody>
</table>

**Table 9.1b**

<table>
<thead>
<tr>
<th>Structure and Organizational Levels of Skeletal Muscle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular Tissue</td>
<td>Cardiac Tissue</td>
</tr>
<tr>
<td>Muscle fibers</td>
<td>Muscle fibers</td>
</tr>
<tr>
<td>Myofilaments</td>
<td>Myofilaments</td>
</tr>
<tr>
<td>Intermyofibrillar</td>
<td>Intermyofibrillar</td>
</tr>
</tbody>
</table>

---

**Skeletal Muscle**
- Each muscle is a discrete organ composed of muscle tissue, blood vessels, nerve fibers, and connective tissue
- The three connective tissue sheaths are:
  - Endomysium – fine sheath of connective tissue composed of reticular fibers surrounding each muscle fiber
  - Perimysium – fibrous connective tissue that surrounds groups of muscle fibers called fascicles
  - Epimysium – an overcoat of dense regular connective tissue that surrounds the entire muscle

---

**Figure 9.2a**

**Figure 9.2b**

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**Figure 9.2c**
Skeletal Muscle: Nerve and Blood Supply
- Each muscle is served by one nerve, an artery, and one or more veins
- Each skeletal muscle fiber is supplied with a nerve ending that controls contraction
- Contracting fibers require continuous delivery of oxygen and nutrients via arteries
- Wastes must be removed via veins

Skeletal Muscle: Attachments
- Most skeletal muscles span joints and are attached to bone in at least two places
- When muscles contract the movable bone, the muscle’s insertion moves toward the immovable bone, the muscle’s origin
- Muscles attach:
  - Directly – epimysium of the muscle is fused to the periosteum of a bone
  - Indirectly – connective tissue wrappings extend beyond the muscle as a tendon or aponeurosis

Microscopic Anatomy of a Skeletal Muscle Fiber
- Each fiber is a long, cylindrical cell with multiple nuclei just beneath the sarcolemma
- Each cell is a syncytium produced by fusion of embryonic cells
- Sarcoplasm has numerous glycosomes and a unique oxygen-binding protein called myoglobin
- Fibers contain the usual organelles, myofibrils, sarcoplasmic reticulum, and T tubules

Myofibrils
- Myofibrils are densely packed, rodlike contractile elements
- They make up most of the muscle volume
- The arrangement of myofibrils within a fiber is such that a perfectly aligned repeating series of dark A bands and light I bands is evident

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
  - Myofilaments are of two types – thick and thin
Sarcomeres

Myofilaments: Banding Pattern
- Thick filaments – extend the entire length of an A band
- Thin filaments – extend across the I band and partway into the A band
- Z-disc – coin-shaped sheet of proteins (connectins) that anchors the thin filaments and connects myofibrils to one another

Myofilaments: Banding Pattern
- Thin filaments do not overlap thick filaments in the lighter H zone
- M lines appear darker due to the presence of the protein desmin

Ultrastructure of Myofilaments: Thick Filaments
- Thick filaments are composed of the protein myosin
- Each myosin molecule has a rod-like tail and two globular heads
  - Tails – two interwoven, heavy polypeptide chains
  - Heads – two smaller, light polypeptide chains called cross bridges

Ultrastructure of Myofilaments: Thick Filament
- Myosin molecules
Ultrastructure of Myofilaments: Thin Filaments

- Thin filaments are chiefly composed of the protein actin.
- Each actin molecule is a helical polymer of globular subunits called G actin.
- The subunits contain the active sites to which myosin heads attach during contraction.
- Tropomyosin and troponin are regulatory subunits bound to actin.

Arrangement of the Filaments in a Sarcomere

- Longitudinal section within one sarcomere.

Sarcoplasmic Reticulum (SR)

- SR is an elaborate, smooth endoplasmic reticulum that mostly runs longitudinally and surrounds each myofibril.
- Paired terminal cisternae form perpendicular cross channels.
- Functions in the regulation of intracellular calcium levels.
**T Tubules**
- T tubules are continuous with the sarcolemma
- They conduct impulses to the deepest regions of the muscle
- These impulses signal for the release of Ca\(^{2+}\) from adjacent terminal cisternae

**Triad Relationships**
- T tubules and SR provide tightly linked signals for muscle contraction
- A double zipper of integral membrane proteins protrudes into the intermembrane space
- T tubule proteins act as voltage sensors
- SR foot proteins are receptors that regulate Ca\(^{2+}\) release from the SR cisternae

**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

**Sliding Filament Model of Contraction**
- Each myosin head binds and detaches several times during contraction, acting like a ratchet to generate tension and propel the thin filaments to the center of the sarcomere
- As this event occurs throughout the sarcomeres, the muscle shortens

**Skeletal Muscle Contraction**
- In order to contract, a skeletal muscle must:
  - Be stimulated by a nerve ending
  - Propagate an electrical current, or action potential, along its sarcolemma
  - Have a rise in intracellular Ca\(^{2+}\) levels, the final trigger for contraction
  - Linking the electrical signal to the contraction is excitation-contraction coupling

**Nerve Stimulus of Skeletal Muscle**
- Skeletal muscles are stimulated by motor neurons of the somatic nervous system
- Axons of these neurons travel in nerves to muscle cells
- Axons of motor neurons branch profusely as they enter muscles
- Each axonal branch forms a neuromuscular junction with a single muscle fiber
Neuromuscular Junction

- The neuromuscular junction is formed from:
  - Axonal endings, which have small membranous sacs (synaptic vesicles) that contain the neurotransmitter acetylcholine (ACh)
  - The motor end plate of a muscle, which is a specific part of the sarcolemma that contains ACh receptors and helps form the neuromuscular junction
  - Though exceedingly close, axonal ends and muscle fibers are always separated by a space called the synaptic cleft

Neuromuscular Junction

- When a nerve impulse reaches the end of an axon at the neuromuscular junction:
  - Voltage-regulated calcium channels open and allow Ca^{2+} to enter the axon
  - Ca^{2+} inside the axon terminal causes axonal vesicles to fuse with the axonal membrane

Neuromuscular Junction

- This fusion releases ACh into the synaptic cleft via exocytosis
  - ACh diffuses across the synaptic cleft to ACh receptors on the sarcolemma
  - Binding of ACh to its receptors initiates an action potential in the muscle

Destruction of Acetylcholine

- ACh bound to ACh receptors is quickly destroyed by the enzyme acetylcholinesterase
- This destruction prevents continued muscle fiber contraction in the absence of additional stimuli

Action Potential

- A transient depolarization event that includes polarity reversal of a sarcolemma (or nerve cell membrane) and the propagation of an action potential along the membrane
**Role of Acetylcholine (Ach)**

- ACh binds its receptors at the motor end plate
- Binding opens chemically (ligand) gated channels
- Na⁺ and K⁺ diffuse out and the interior of the sarcolemma becomes less negative
- This event is called depolarization

**Depolarization**

- Initially, this is a local electrical event called end plate potential
- Later, it ignites an action potential that spreads in all directions across the sarcolemma

**Excitation-Contraction Coupling**

- Once generated, the action potential:
  - Is propagated along the sarcolemma
  - Travels down the T tubules
  - Triggers Ca²⁺ release from terminal cisternae
  - Ca²⁺ binds to troponin and causes:
    - The blocking action of tropomyosin to cease
    - Actin active binding sites to be exposed

**Excitation-Contraction Coupling**

- Myosin cross bridges alternately attach and detach
- Thin filaments move toward the center of the sarcomere
- Hydrolysis of ATP powers this cycling process
- Ca²⁺ is removed into the SR, tropomyosin blockage is restored, and the muscle fiber relaxes

**Excitation-Contraction (EC) Coupling**

1. Action potential generated and propagated along sarcomere to T-tubules
2. Action potential triggers Ca²⁺ release
3. Ca²⁺ bind to troponin; blocking action of tropomyosin released
4. contraction via crossbridge formation; ATP hydrolysis
5. Removal of Ca²⁺ by active transport
6. tropomyosin blockage restored; contraction ends
Role of Ionic Calcium (Ca\(^{2+}\)) in the Contraction Mechanism

- At low intracellular Ca\(^{2+}\) concentration:
  - Tropomyosin blocks the binding sites on actin.
  - Myosin cross bridges cannot attach to binding sites on actin.
  - The relaxed state of the muscle is enforced.

Role of Ionic Calcium (Ca\(^{2+}\)) in the Contraction Mechanism

- At higher intracellular Ca\(^{2+}\) concentrations:
  - Additional calcium binds to troponin (inactive troponin binds two Ca\(^{2+}\)).
  - Calcium-activated troponin binds an additional two Ca\(^{2+}\) at a separate regulatory site.

Role of Ionic Calcium (Ca\(^{2+}\)) in the Contraction Mechanism

- Calcium-activated troponin undergoes a conformational change.
  - This change moves tropomyosin away from actin’s binding sites.

Role of Ionic Calcium (Ca\(^{2+}\)) in the Contraction Mechanism

- Myosin head can now bind and cycle.
  - This permits contraction (sliding of the thin filaments by the myosin cross bridges) to begin.

Sequential Events of Contraction

- Cross bridge formation – myosin cross bridge attaches to actin filament.
- Working (power) stroke – myosin head pivots and pulls actin filament toward M line.
- Cross bridge detachment – ATP attaches to myosin head and the cross bridge detaches.
- “Cocking” of the myosin head – energy from hydrolysis of ATP cocks the myosin head into the high-energy state.
Contraction of Skeletal Muscle Fibers
- **Contraction** – refers to the activation of myosin’s cross bridges (force-generating sites)
- Shortening occurs when the tension generated by the cross bridge exceeds forces opposing shortening
- Contraction ends when cross bridges become inactive, the tension generated declines, and relaxation is induced

Contraction of Skeletal Muscle (Organ Level)
- Contraction of muscle fibers (cells) and muscles (organs) is similar
- The two types of muscle contractions are:
  - **Isometric contraction** – increasing muscle tension (muscle does not shorten during contraction)
  - **Isotonic contraction** – decreasing muscle length (muscle shortens during contraction)

Motor Unit: The Nerve-Muscle Functional Unit
- A motor unit is a motor neuron and all the muscle fibers it supplies
- The number of muscle fibers per motor unit can vary from four to several hundred
- Muscles that control fine movements (fingers, eyes) have small motor units

Motor Unit: The Nerve-Muscle Functional Unit
- Large weight-bearing muscles (thighs, hips) have large motor units
- Muscle fibers from a motor unit are spread throughout the muscle; therefore, contraction of a single motor unit causes weak contraction of the entire muscle

Motor Unit: The Nerve-Muscle Functional Unit
- Figure 9.13a

Motor Unit: The Nerve-Muscle Functional Unit
- Figure 9.13b

Muscle Twitch
- A muscle twitch is the response of a muscle to a single, brief threshold stimulus
- There are three phases to a muscle twitch
  - Latent period
  - Period of contraction
  - Period of relaxation
Phases of a Muscle Twitch

- Latent period – first few msec after stimulus; EC coupling taking place
- Period of contraction – cross bridges form; muscle shortens
- Period of relaxation – Ca\(^2+\) reabsorbed; muscle tension goes to zero

Muscle Twitch Comparisons

Graded Muscle Responses

- Graded muscle responses are:
  - Variations in the degree of muscle contraction
  - Required for proper control of skeletal movement
- Responses are graded by:
  - Changing the frequency of stimulation
  - Changing the strength of the stimulus

Muscle Response to Varying Stimuli

- A single stimulus results in a single contractile response – a muscle twitch
  - Frequently delivered stimuli (muscle does not have time to completely relax) increases contractile force – wave summation

Muscle Response to Varying Stimuli

- More rapidly delivered stimuli result in incomplete tetanus
- If stimuli are given quickly enough, complete tetanus results

Muscle Response: Stimulation Strength

- Threshold stimulus – the stimulus strength at which the first observable muscle contraction occurs
  - Beyond threshold, muscle contracts more vigorously as stimulus strength is increased
  - Force of contraction is precisely controlled by multiple motor unit summation
  - This phenomenon, called recruitment, brings more and more muscle fibers into play
Stimulus Intensity and Muscle Tension

Figure 9.16

Size Principle

Figure 9.17

Treppe: The Staircase Effect

- Staircase – increased contraction in response to multiple stimuli of the same strength
- Contractions increase because:
  - There is increasing availability of Ca\textsuperscript{2+} in the sarcoplasm
  - Muscle enzyme systems become more efficient because heat is increased as muscle contracts

Muscle Tone

- Muscle tone:
  - Is the constant, slightly contracted state of all muscles, which does not produce active movements
  - Keeps the muscles firm, healthy, and ready to respond to stimulus
  - Spinal reflexes account for muscle tone by:
    - Activating one motor unit and then another
    - Responding to activation of stretch receptors in muscles and tendons

Isotonic Contractions

- In isotonic contractions, the muscle changes in length (decreasing the angle of the joint) and moves the load
- The two types of isotonic contractions are concentric and eccentric
  - Concentric contractions – the muscle shortens and does work
  - Eccentric contractions – the muscle contracts as it lengthens
Isotonic Contractions

- Tension increases to the muscle’s capacity, but the muscle neither shortens nor lengthens
- Occurs if the load is greater than the tension the muscle is able to develop

Isometric Contractions

- ATP is the only source used directly for contractile activity
- As soon as available stores of ATP are hydrolyzed (4-6 seconds), they are regenerated by:
  - The interaction of ADP with creatine phosphate (CP)
  - Anaerobic glycolysis
  - Aerobic respiration

Muscle Metabolism: Energy for Contraction

- When muscle contractile activity reaches 70% of maximum:
  - Bulging muscles compress blood vessels
  - Oxygen delivery is impaired
  - Pyruvic acid is converted into lactic acid
### Muscle Metabolism: Anaerobic Glycolysis
- The lactic acid:
  - Diffuses into the bloodstream
  - Is picked up and used as fuel by the liver, kidneys, and heart
  - Is converted back into pyruvic acid by the liver

### Muscle Fatigue
- Muscle fatigue – the muscle is in a state of physiological inability to contract
- Muscle fatigue occurs when:
  - ATP production fails to keep pace with ATP use
  - There is a relative deficit of ATP, causing contractures
  - Lactic acid accumulates in the muscle
  - Ionic imbalances are present

### Muscle Fatigue
- Intense exercise produces rapid muscle fatigue (with rapid recovery)
- Na⁺-K⁺ pumps cannot restore ionic balances quickly enough
- Low-intensity exercise produces slow-developing fatigue
- SR is damaged and Ca²⁺ regulation is disrupted

### Oxygen Debt
- Vigorous exercise causes dramatic changes in muscle chemistry
- For a muscle to return to a resting state:
  - Oxygen reserves must be replenished
  - Lactic acid must be converted to pyruvic acid
  - Glycogen stores must be replaced
  - ATP and CP reserves must be resynthesized
  - Oxygen debt – the extra amount of O₂ needed for the above restorative processes

### Heat Production During Muscle Activity
- Only 40% of the energy released in muscle activity is useful as work
- The remaining 60% is given off as heat
- Dangerous heat levels are prevented by radiation of heat from the skin and sweating

### Force of Muscle Contraction
- The force of contraction is affected by:
  - The number of muscle fibers contracting – the more motor fibers in a muscle, the stronger the contraction
  - The relative size of the muscle – the bulkier the muscle, the greater its strength
  - Degree of muscle stretch – muscles contract strongest when muscle fibers are 80-120% of their normal resting length
**Muscle Fiber Type: Functional Characteristics**

- Speed of contraction – determined by speed in which ATPases split ATP
  - The two types of fibers are slow and fast
- ATP-forming pathways
  - Oxidative fibers – use aerobic pathways
  - Glycolytic fibers – use anaerobic glycolysis
- These two criteria define three categories – slow oxidative fibers, fast oxidative fibers, and fast glycolytic fibers

**Muscle Fiber Type: Speed of Contraction**

- Slow oxidative fibers contract slowly, have slow acting myosin ATPases, and are fatigue resistant
- Fast oxidative fibers contract quickly, have fast myosin ATPases, and have moderate resistance to fatigue
- Fast glycolytic fibers contract quickly, have fast myosin ATPases, and are easily fatigued

**Load and Contraction**

- Light load
- Intermediate load
- Heavy load
Effects of Aerobic Exercise
- Aerobic exercise results in an increase of:
  - Muscle capillaries
  - Number of mitochondria
  - Myoglobin synthesis

Effects of Resistance Exercise
- Resistance exercise (typically anaerobic) results in:
  - Muscle hypertrophy
  - Increased mitochondria, myofilaments, and glycogen stores

The Overload Principle
- Forcing a muscle to work promotes increased muscular strength
- Muscles adapt to increased demands
- Muscles must be overloaded to produce further gains

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

Peristalsis
- When the longitudinal layer contracts, the organ dilates and contracts
- When the circular layer contracts, the organ elongates
- Peristalsis – alternating contractions and relaxations of smooth muscles that mix and squeeze substances through the lumen of hollow organs
Innervation of Smooth Muscle

- Smooth muscle lacks neuromuscular junctions
- Innervating nerves have bulbous swellings called varicosities
- Varicosities release neurotransmitters into wide synaptic clefts called diffuse junctions

Microscopic Anatomy of Smooth Muscle

- SR is less developed than in skeletal muscle and lacks a specific pattern
- T tubules are absent
- Plasma membranes have pouchlike infoldings called caveoli

Ca²⁺ is sequestered in the extracellular 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

Proportion and Organization of Myofilaments in Smooth Muscle

- 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
Proportion and Organization of Myofilaments in Smooth Muscle

Intermediate filament bundles attached to dense bodies
Cavole

(a) Relaxed smooth muscle cell
(b) Contracted smooth muscle cell

Contraction of Smooth Muscle

- Whole sheets of smooth muscle exhibit slow, synchronized contraction
- They contract in unison, reflecting their electrical coupling with gap junctions
- Action potentials are transmitted from cell to cell

Contraction Mechanism

- Actin and myosin interact according to the sliding filament mechanism
- The final trigger for contractions is a rise in intracellular Ca$^{2+}$
- Ca$^{2+}$ is released from the SR and from the extracellular space
- Ca$^{2+}$ interacts with calmodulin and myosin light chain kinase to activate myosin

Contraction of Smooth Muscle

- Some smooth muscle cells:
  - Act as pacemakers and set the contractile pace for whole sheets of muscle
  - Are self-excitatory and depolarize without external stimuli

Role of Calcium Ion

- Ca$^{2+}$ binds to calmodulin and activates it
- Activated calmodulin activates the kinase enzyme
- Activated kinase transfers phosphate from ATP to myosin cross bridges
- Phosphorylated cross bridges interact with actin to produce shortening
- Smooth muscle relaxes when intracellular Ca$^{2+}$ levels drop

Special Features of Smooth Muscle Contraction

- Unique characteristics of smooth muscle include:
  - Smooth muscle tone
  - Slow, prolonged contractile activity
  - Low energy requirements
  - Response to stretch
Response to Stretch

- Smooth muscle exhibits a phenomenon called stress-relaxation response in which:
  - Smooth muscle responds to stretch only briefly, and then adapts to its new length
  - The new length, however, retains its ability to contract
  - This enables organs such as the stomach and bladder to temporarily store contents

Hyperplasia

- Certain smooth muscles can divide and increase their numbers by undergoing hyperplasia
  - This is shown by estrogen’s effect on the uterus
    - At puberty, estrogen stimulates the synthesis of more smooth muscle, causing the uterus to grow to adult size
    - During pregnancy, estrogen stimulates uterine growth to accommodate the increasing size of the growing fetus

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

| Table 9.3.1: Comparison of Skeletal, Cardiac, and Smooth Muscle

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Skeletal</th>
<th>Cardiac</th>
<th>Smooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body location</td>
<td>Attached to bones or joints</td>
<td>Wall of heart</td>
<td>Single-unit muscle in walls of hollow internal organs (e.g., blood vessels, digestive tracts, respiratory tract)</td>
</tr>
<tr>
<td>Muscle fiber shape</td>
<td>Single, long, cylindrical</td>
<td>Single fibers, a-muscle fibers with oxidative metabolism</td>
<td>Single fibers, innervated by motor units</td>
</tr>
<tr>
<td>Vascularization</td>
<td>None</td>
<td>Arteries</td>
<td>Arteries, veins, capillaries</td>
</tr>
<tr>
<td>Branching pattern</td>
<td>None</td>
<td>Branched arteries</td>
<td>No branching</td>
</tr>
<tr>
<td>Motor unit</td>
<td>None</td>
<td>Motor units</td>
<td>Motor units, anastomosis</td>
</tr>
</tbody>
</table>

Table 9.3.1
Muscular Dystrophy

- Duchenne muscular dystrophy (DMD)
  - Inherited, sex-linked disease carried by females and expressed in males (1/3300)
  - Diagnosed between the ages of 2-10
  - Victims become clumsy and fall frequently as their muscles fail

- Muscular dystrophy – group of inherited muscle-destroying diseases where muscles enlarge due to fat and connective tissue deposits, but muscle fibers atrophy
  - Progresses from the extremities upward, and victims die of respiratory failure in their 20s
  - Caused by a lack of the cytoplasmic protein dystrophin
  - There is no cure, but myoblast transfer therapy shows promise
Developmental Aspects

- Muscle tissue develops from embryonic mesoderm called myoblasts
- Multinucleated skeletal muscles form by fusion of myoblasts
- The growth factor agrin stimulates the clustering of ACh receptors at newly forming motor end plates

Developmental Aspects

- As muscles are brought under the control of the somatic nervous system, the numbers of fast and slow fibers are also determined
- Cardiac and smooth muscle myoblasts do not fuse but develop gap junctions at an early embryonic stage

Developmental Aspects: Regeneration

- Cardiac and skeletal muscle become amitotic, but can lengthen and thicken
- Myoblastlike satellite cells show very limited regenerative ability
- Cardiac cells lack satellite cells
- Smooth muscle has good regenerative ability

Developmental Aspects: After Birth

- Muscular development reflects neuromuscular coordination
- Development occurs head-to-toe, and proximal-to-distal
- Peak natural neural control of muscles is achieved by midadolescence
- Athletics and training can improve neuromuscular control

Developmental Aspects: Male and Female

- There is a biological basis for greater strength in men than in women
- Women’s skeletal muscle makes up 36% of their body mass
- Men’s skeletal muscle makes up 42% of their body mass

Developmental Aspects: Male and Female

- These differences are due primarily to the male sex hormone testosterone
- With more muscle mass, men are generally stronger than women
- Body strength per unit muscle mass, however, is the same in both sexes
**Developmental Aspects: Age Related**

- With age, connective tissue increases and muscle fibers decrease
- Muscles become stringier and more sinewy
- By age 80, 50% of muscle mass is lost (sarcopenia)

**Developmental Aspects: Age Related**

- Regular exercise reverses sarcopenia
- Aging of the cardiovascular system affects every organ in the body
- Atherosclerosis may block distal arteries, leading to intermittent claudication and causing severe pain in leg muscles