Muscle tissue

A tissue that (a) causes movement by contracting (shortening), (b) holds body posture, and (c) helps generate body heat

- The muscle tissue contracts because the muscle cells in the tissue contract

- Muscle cells contract when they receive signals from motor neurons

- Muscle cells contain stacks of actin (thin) and myosin (thick) protein filaments

    √ The cell contracts by sliding the actin filaments inward, on top of the myosin filaments

- Muscles only generate force through contracting (never by getting longer)

Figs 4.2 and 10.10

There are three types of muscle tissue: skeletal, smooth, and cardiac

	Skeletal	Smooth	Cardiac
Location	Attached to bone (by tendons)	Hollow organ walls	Heart
Function:	Moves body parts by applying forces on bones	Moves substances through hollow organs by squeezing on the substance in the organ	Pumps blood by squeezing on blood in the heart
Voluntary:	Yes	No	No
Cell shape	Long, cigar-shaped	Short, pointed ends	Branched
Cell features	Striations Multiple nuclei	No striations	Striations Intercalated discs

Fig 10.2; Table 4.2

Smooth muscle

Involuntary muscle for movement of substances through hollow organs

Figs 10.2 and 10.23; Table 4.2

Cardiac muscle (heart muscle)

Involuntary muscle that propels blood through circulatory system

- Intercalated discs = Round structures at the ends of cardiac muscle cells that contain gap junctions (openings that join the cytoplasm of each cell to its neighbors)

Figs 10.2, 10.21, and 10.22; Table 4.2

Skeletal muscle

Voluntary muscle tissue that moves body parts

Fig 10.2; Table 4.2

Some generalizations about how skeletal muscles cause movement:

a) Each end of the skeletal muscle is attached to a bone by a tendon

b) Skeletal muscles cause movement at joints by pulling on the bones

- The muscle attaches (via tendons) to both bones of the joint, but one bone is more moveable than the other
- Origin = The muscle's attachment to the less movable bone
- Insertion = The muscle's attachment to the more movable bone

c) Contraction of the muscle pulls the insertion towards the origin

d) Movement at each joint is usually controlled by two muscles, attached to opposite sides of the bones

- One muscle moves the joint in one direction, the other muscle moves the joint in the opposite direction

Skeletal muscle organ structure

- Each muscle cell is wrapped in a sheath of dense connective tissue
- Fascicle = A bundle of muscle cells wrapped in a connective tissue sheath
- Each muscle organ is a bundle of fascicles wrapped in a fascia (the outermost connective tissue sheath)

√ The outermost sheath is continuous with muscle's tendons

Fig 10.3; Table 4.2

Skeletal muscle cell structure

- Sarcoplasmic reticulum = The endoplasmic reticulum (a network of membranous tubes) inside the muscle cell

    √ The sarcoplasmic reticulum contains a high concentration of calcium ions

- Sarcomere = A stack of myosin with stacks of actin (held by Z-discs) on its left and right sides

- Myofibril = A chain of sarcomeres

- Each muscle cell contains many myofibrils

- A bands = Dark striations caused by myosin stacks

- I band = Light striations caused by actin stacks

    √ Z line = a line in the middle of the I band caused by the Z-disc

    √ I bands get smaller when muscle contracts

Figs 10.3, 10.4, 10.5, and 10.10

Muscle cell contraction (brief overview)

- Muscle cells contract when they receive signals from motor neurons

  √ The contraction of the muscle cell is caused by the contraction of the sarcomeres inside the muscle cell

- Sarcomere contraction is caused by the myosin proteins pulling the actin proteins inward

- The myosin proteins have heads that bind to actin ("form a cross bridge" to actin) and then pull the actins inward (the "powerstroke")

  √ Actin proteins have binding sites for the myosin heads

  √ The myosin heads use ATP as their energy source

Figs 10.5, 10.8, 10.10, and 10.11

Motor unit

One motor neuron and all the muscle cells that it synapses with

- Each motor neuron has several collaterals at the end of its axon

- Each collateral synapses with a different muscle cell

- When the motor neuron has a nerve signal, all the muscles cells in the motor unit contract

The neuromuscular junction

The synapse between a motor neuron and a muscle cell

Figs 10.8 and 12.16

Relaxing (non-contracted) muscle cells

Actin proteins have binding sites for the myosin heads but the binding sites are blocked by tropomyosin protein when the muscle cell is relaxing (no nerve signal)

√ This prevents the myosins from pulling the actins inward when muscle is relaxing

√ The tropomyosin is held in place by troponin protein

Figs 10.5 and 10.9

Events during stimulation of muscle cells by motor neurons

- The motor neuron secretes the neurotransmitter acetylcholine into the neuromuscular junction

- The acetyelcholine receptors in the muscle cell membrane are chemical gated sodium channels open when they bind acetylcholine

  √ This causes a depolarization of the muscle cell

- The depolarization causes voltage gated calcium channels in the sarcoplasmic reticulum to open

  √ The calcium ion concentration in the cytoplasm increases

- Calcium ions (from the sarcoplasmic reticulum) cause contraction of the sarcomeres by removing troponin and tropomyosin

- The myosin heads can now bind the actin and pull it inward

  √ This makes the sarcomere contract

Figs 10.5, 10.6, 10.7, 10.8, and 10.11

ATP for muscle contraction

- Only enough ATP is stored in muscle cells for six seconds of contractions

- Creatine phosphate in muscle can quickly recharge ATP

  √ Only enough creatine phosphate for ≈ 20 seconds

- Aerobic respiration of glucose can recharge ATP continuously during rest, light exercise, or medium exercise

  √ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
  (glucose)

  √ This reaction recharges 32 ATP molecules per glucose

- Anaerobic respiration of glucose can recharge ATP during bursts of intense exercise (when there is insufficient O_2 for aerobic respiration)

  √ $C_6H_{12}O_6 \rightarrow 2\ C_3H_6O_3$
  (glucose) (lactic acid)

  √ This reaction recharges 2 ATP molecules per glucose

  √ The body soon increases breathing and heart rate to return to aerobic respiration

Fig 10.12

Muscle fatigue

The decrease in a muscle's force as it is being exercised

- The major causes of muscle fatigue are (1) depletion of the muscle's glycogen stores, and (2) increase in lactic acid in the muscle
    - √ Both of these are the results of anaerobic respiration

Muscles use a mixture of aerobic and anaerobic respiration to provide themselves with energy during exercise

- The lower the intensity of exercise, the more aerobic and the less anaerobic respiration is used, and the higher the intensity of exercise, the more anaerobic and the less aerobic respiration is used
- The intensity of exercise can be gauged by the person's % of $V_{02\ Max}$
    - √ $V_{02\ Max}$ = The person's maximum rate of oxygen consumption
    - √ The more intense the exercise, the higher the % of $V_{02\ Max}$
- The intensity of exercise can be gauged from the amount of lactic acid in the person's blood

Aerobic exercise

Exercise consisting of sustained activity at increased breathing and heart rate

• Increases endurance and cardiovascular health (but not muscle size)

Fig 10.18

Resistance training

Exercise consisting of intense contractions against large resistance

• Increases muscle size (more actin and myosin per muscle cell) and power

√ Does not increase endurance or cardiovascular health

Fig 10.19

The two major categories of skeletal muscle cells are slow twitch skeletal muscle cells and fast twitch skeletal muscle cells

Slow twitch skeletal muscle cells (red muscle cells, type I)

Muscle cells that have slow contractions but high endurance

• Used for slower repetitive movements (example: long distance run)

• They use mostly cellular aerobic respiration for generating ATP

Fast twitch skeletal muscle cells (white muscle cells, type IIX)

Muscle cells that have fast contractions but low endurance

• Used for fast explosive movements (example: sprinting, punching)

• They use mostly cellular anaerobic respiration for generating ATP

Graded contractions

A muscle's ability to generate different amounts of force (tension)

- The greater the number of cells within the muscle organ that contract, the greater the muscle force

    √ The number of cells that contract is controlled by how many motor units send signal to the muscle organ

- The higher the frequency of nerve signals to a muscle cell, the greater its force

    √ A twitch = The amount a muscle cell contracts caused one nerve signal

    √ A single twitch does **not** completely contract the sarcomeres, so one twitch does not generate the cell's maximum force

    √ The faster the rate of nerve signals, the more the sarcomeres contract, the more force the muscle cell produces

    – If signal rate is fast enough, the sarcomeres (and the muscle) become fully contracted and the muscle cell generates its maximum possible force (a state called tetanus)

Fig 10.16

Muscular development

- Newborns have all muscles and nerves but lack coordination skills
- Testosterone (male hormone) causes increased muscle size and strength
    - √ "Anabolic steroids" = synthetic testosterone drugs
- Muscles naturally atrophy (get smaller and weaker) if not exercised
- Aging muscles lose muscle cells, gain connective tissue

Fig 10.20

Degenerative muscular disorders

- Duchenne muscular dystrophy = A fatal degenerative muscle disease of children, usually boys
- Myasthenia gravis = An autoimmune muscle disease of adults