19.1 Overview of Bone and Cartilage

- The **skeleton** provides attachment sites for the muscles.
  - Muscle contraction makes bones move
  - Allows walking, playing sports, holding a book

- The **musculoskeletal system** includes the bones and muscles.
  - Bone and connective tissue make up the skeleton
  - Muscular tissue makes up the muscles

Organization of Bone and Associated Tissues

- Bones classified by their shape
  - Long, short, flat
- Long bones (ex: arm or leg)
  - Enclosed by periosteum
    - Made of tough, fibrous connective tissue
    - Continuous with ligaments
    - Contains blood vessels that service bone
  - Epiphyses – expanded end of a long bone
  - Diaphysis – shaft between the epiphyses
    - **Joint** forms between the diaphysis of two long bones
Structure of Bone and Associated Tissues

- The primary connective tissues of the skeleton are bone, cartilage, and dense fibrous connective tissue.
- All connective tissues contain cells separated by a matrix containing fibers.
- Bone is strong because the matrix contains collagen and mineral salts.

Bone

- **Compact bone** is highly organized
  - Composed of **osteons** – tubular units
  - **Osteocytes** (bone cells) lie in lacunae
    - Lacunae are arranged in concentric circles around a central canal.
    - **Central canals** contain blood vessels, lymphatic vessels, and nerves.
    - **Canaliculi** connect lacunae with each other and the central canal.

- **Spongy bone** has an unorganized appearance.
  - Osteocytes are found in trabeculae.
    - Numerous thin plates surrounded by unequal spaces
    - Plates follow lines of stress so spongy bone is strong

- **Spaces filled with red bone marrow**
  - Red bone marrow produces blood cells.
  - In infants, red marrow is present in cavities of all bones.
  - Mit is found in a more limited number of bones in adults.
Figure 19.1

Hyaline cartilage

matrix

cells in lacunae

50 µm

Figure 19.1

Compact bone

osteocyte in lacuna

concentric lamellae

central canal

osteon

100 µm

Figure 19.1
Cartilage

• Cartilage
  – Not as strong as bone but more flexible
  – Gel-like matrix with many collagen and elastic fibers
  – Cells lie within lacunae which are irregularly grouped
  – No blood vessels

Cartilage

• Three types of cartilage
  – Hyaline – firm and somewhat flexible
    • Ends of long bones, nose, ends of ribs, larynx, trachea
  – Fibrocartilage - stronger, thick collagen fibers, can withstand both pressure and tension
    • Intervertebral disks, knees
  – Elastic - most flexible, elastin fibers
    • Ear flaps and epiglottis

Dense Fibrous Connective Tissue

• Dense fibrous connective tissue
  – Rows of fibroblasts separated by bundles of collagen fibers
  – Forms flared sides of the nose
  – Ligaments - connect bone to bone
  – Tendons - connect muscle to bone
Bone Development and Growth

- Most bones of the human skeleton first appear as hyaline cartilage
  - Skull bones are the exception
- **Endochondral ossification** replaces cartilage with bone.
  - Hyaline cartilage “template” forms first
  - Cartilage is gradually replaced by bone
  - Cartilage breaks down in center of a long bone, and periosteum develops

Bone Development and Growth

- **Endochondral Ossification**
  - **Osteoblasts** invade and produce spongy bone in what is called the primary ossification center.
  - Other osteoblasts then produce compact bone beneath the periosteum.
  - **Osteoclasts** break down spongy bone and create the medullary cavity.

Bone Development and Growth

- **Endochondral Ossification**
  - The ends of developing bones continue to grow.
  - Secondary ossification centers appear.
    - Spongy bone forms and does not break down.
  - **Growth plates** remains between primary ossification center and each secondary center.
  - Limbs keep increasing in length as long as the growth plates are present.
  - Eventually, growth plates ossify and the bone stops growing.
Remodeling of Bones

- Adult bone is continually broken down and built up.
- Osteoclasts break down bone matrix and release calcium to blood.
- Osteoblasts pick up calcium from blood and deposit it in new bone matrix.
  - Get trapped in matrix and become osteocytes within lacunae
- Remodeling can change bone thickness.
  - Affected by hormones and physical use

Remodeling of Bones

- Healing a fractured bone occurs in three phases.
  1. **Reactive phase** – inflammatory response
  2. **Reparative phase** – generation of bone callus, which is a temporary connective tissue bridge that is gradually replaced
  3. **Remodeling phase** – osteoclasts and osteoblasts gradually replace temporary bone with compact bone

Figure 19.2
Figure 19.2

a. cartilaginous model developing periosteum

b. compact bone developing

c. primary ossification center

Figure 19.2

a. cartilaginous model developing periosteum blood vessel

b. compact bone developing

c. primary ossification center medullary cavity

d. secondary ossification center
19.2 Bones of the Skeleton

- Functions of the skeleton pertain to particular bones
  - Supports body
  - Protects soft body parts
  - Produces blood cells
  - Stores mineral and fat
  - With muscles, permits flexible body movement
Classification of the Bones

- There are approximately 206 bones classified based on two divisions of the skeleton.
  - **Axial skeleton**
    - Midline of body
  - **Appendicular skeleton**
    - Bones of limbs and the limb girdles

Classification of the Bones

- Further classified by shape
  - **Long** - bones of limbs
  - **Short** – cube-shaped bones of digits
  - **Flat** - skull
  - **Irregular** - like vertebrae and facial bones
  - **Round** - like the patella
    - All bones have depressions and protruberances (processes) for attachment of muscles, openings for nerves and/or blood vessels

The Skeleton

Figure 19.3
The Axial Skeleton
The Skull

• The **skull**
  – Formed by cranium (braincase) and facial bones
• The **cranium**
  – Protects the brain
  – Not completely ossified in infants
    • Fontanels usually close by the age of 24 months by the process of intramembranous ossification
• The **sinuses**
  • Air spaces lined by mucous membranes
  • Reduce weight of skull
  • Give resonant sound to voice

---

The Axial Skeleton
The Skull

• The **Cranium**
  – Bones named for the lobes of the brain
    • Frontal - forms forehead
    • Parietal - sides of braincase
    • Temporal - below parietales, has external auditory canal
    • Occipital - base of the skull; foramen magnum for passage of spinal cord
  – Foramen magnum – spinal cord connects to brain stem
  – Sphenoid bone - floor of cranium, part of orbits
  – Ethmoid bone - forms part of orbits and nasal septum

---

Figure 19.4a
The Axial Skeleton

The Skull

- **Facial Bones**
  - **Mandible** - lower jaw; only movable bone of the skull
  - **Maxillae** - upper jaw; also forms anterior hard palate
  - **Zygomatic bones** - cheekbones
  - **Nasal bones** - bridge of nose
  - **Lacrimal bones** - contain the nasolacrimal canals
  - Temporal and facial bones - also bones of the cranium which contribute to the face
The Axial Skeleton
Hyoid bone

- Hyoid bone
  - Only bone in the body which does not articulate with another bone
  - Attached to the larynx via membrane, and to the temporals by muscles and ligaments
  - Anchors the tongue and attaches muscles associated with swallowing
Figure 19.5c

Figure 19.5

The Axial Skeleton

Vertebral Column

- Vertebral column
  - 33 vertebrae
  - Four normal curvatures
    - Abnormal curvatures
      - Scoliosis - abnormal lateral (sideways) curvature
      - Kyphosis - hunchback
      - Lordosis - swayback
  - Spinal cord passes through the vertebral canal
  - Spinal nerves exit through intervertebral foramina
  - Spinous processes serve as attachment sites for muscles
The Axial Skeleton
Vertebral Column

- **Types of vertebrae**
  - 7 cervical vertebrae — first 2 are specialized
    - Atlas — “yes” motion
    - Axis — “no” motion
  - 12 thoracic vertebrae — articular facets to articulate with the ribs; prominent spinous processes
  - 5 lumbar vertebrae — large bodies and thick processes
  - 5 sacral vertebrae — fused to form the sacrum
  - 3-5 coccyx — fused to form “tailbone”

The Axial Skeleton
Vertebral Column

- **Intervertebral disks**
  - Occur between the vertebrae as a padding
  - Composed of fibrocartilage
  - Help absorb shock and prevent vertebrae from grinding against one another
  - Can herniate and rupture as they weaken with age
    - Puts pressure on the spinal cord

The Vertebral Column

Figure 19.6
Rib Cage

- **Rib cage** (thoracic cage)
  - Part of axial skeleton
  - Composed of thoracic vertebrae, ribs and associated cartilages, and sternum
  - Both protective and flexible
    - Protects the heart and lungs
    - Flexible during inspiration and expiration

The Axial Skeleton

The Ribs

- Ribs – 12 pairs
  - Each originates at a thoracic vertebra and proceeds to anterior thoracic wall
  - “True ribs” - 7 upper pairs which articulate directly with sternum by means of a costal cartilage
  - “False ribs” - next 3 pairs which first join in a common cartilage and then to the sternum
  - “Floating ribs” - last 2 pairs which do not articulate with the sternum at all

The Axial Skeleton

The Sternum

- **Sternum** or breastbone
  - Along with the ribs, helps protect heart and lungs
  - Formed when three bones fuse during fetal development
    - **Manubrium** - articulates with clavicle and first rib pair
    - **Body** - point of junction between manubrium and body of sternum - identifies second pair of ribs
      - Allows counting of ribs to determine apex of heart
    - **Xiphoid** - serves as attachment site for diaphragm
The Appendicular Skeleton
• Consists of bones within the pectoral and pelvic girdles and their attached limbs
  – The pectoral girdles and upper limbs are specialized for flexibility
  – The pelvic girdle and lower limbs are specialized for strength

Appendicular Skeleton
The Pectoral Girdles and Upper Limbs
• Pectoral Girdle (shoulder girdle)
  – Clavicle
    • Articulates with sternum and acromion process of scapula
  – Scapula
    • Glenoid cavity articulates with humerus
      – Rotator cuff
    • Coracoid process - point of arm and chest muscle attachment

Appendicular Skeleton
The Pectoral Girdles and Upper Limbs
• Upper limb
  – Humerus - Upper arm bone
  – Radius - bone of forearm
  – Ulna - bone of forearm
• Hand
  – Carpal bones – eight bones of the wrist
  – Metacarpals - five bones that form the palm
  – Phalanges - bones of the digits
Appendicular Skeleton
The Pelvic Girdle and Lower Limb

• Pelvic Girdle
  – Composed of two coxal bones (hipbones) each composed of three fused bones
    • Ilium - largest of the three
    • Ischium - has posterior spine called ischial spine
    • Pubis - fused with opposite side at pubic symphysis
  – Pelvis includes pelvic girdle, sacrum, and coccyx
    • Protects internal organs, bears weight of body, serves as point of attachment for lower limbs

• Lower limb
  – Femur - largest bone
  – Tibia - weight bearing bone of lower leg
  – Patella - kneecap
  – Fibula - smaller bone on lateral side of tibia
  – Tarsals - ankle bones
    • Calcaneus - heel bone
  – Metatarsals - instep of foot
  – Phalanges - digits
Appendicular Skeleton

Joints
• Bones are joined at joints, classified as
  – **Fibrous** – immovable
    • **Sutures** between cranial bones
  – **Cartilaginous** – slightly movable
    • Connected by hyaline cartilage
      – Ribs / sternum
    • Connected by fibrocartilage
      – Intervertebral discs
  – **Synovial** – freely movable
    • Produce _synovial fluid_

Appendicular Skeleton

Joints
• **Synovial Joints** – freely movable
  – Two bones are separated by a cavity.
  – Ligaments hold the two bones in place and form a joint capsule.
  – Tendons help to stabilize the joint.
  – The joint capsule is lined by a _synovial membrane_ which produces _synovial fluid_ (lubricant).
Appendicular Skeleton Joints

- Major synovial joints include the:
  - Shoulder, elbow, hip and knee
  - The knee:
    - Has menisci made of hyaline cartilage in addition to articular cartilage
    - Provides added stability and acts as shock absorbers
    - Includes thirteen fluid-filled sacs called bursae, which ease friction between tendons and ligaments
      - Bursitis is inflammation of the bursae

Appendicular Skeleton Joints

- Types of Synovial Joints
  - **Hinge joint** - permits movement in one direction only
    - Ex: knee
  - **Pivot joint** - permits only rotational movement
    - Ex: joint between radius and ulna
  - **Ball and socket joint** - permits movement in all planes
    - Ex: hip joint
19.3 Skeletal Muscles

- Three types of muscle tissue
  - Smooth
  - Cardiac
  - Skeletal
- Skeletal muscle makes up the greatest percentage of muscle tissue in the body
  - Voluntary because its contraction is controlled consciously to stimulate by the nervous system

Skeletal Muscles Work in Pairs

- Skeletal muscles are voluntary
- They are covered by layers of connective tissue called fascia.
  - Extend beyond muscle to form tendon
- Tendons attach skeletal muscles to bones.
- When a muscle contracts, one bone remains stationary, the other moves
  - Origin of a muscle is on the stationary bone
  - Insertion of a muscle is on the bone that moves

Movements of Synovial Joints

<table>
<thead>
<tr>
<th>Type</th>
<th>Example</th>
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<tbody>
<tr>
<td>Flexion</td>
<td>Forearm toward the arm</td>
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<tr>
<td>Extension</td>
<td>Forearm away from the body</td>
</tr>
<tr>
<td>Abduction</td>
<td>Arms sideways, away from body</td>
</tr>
<tr>
<td>Adduction</td>
<td>Arms back to the body</td>
</tr>
<tr>
<td>Rotation</td>
<td>Head to move &quot;in&quot;</td>
</tr>
</tbody>
</table>
Major Skeletal Muscles

- 650 human skeletal muscles
- Named based on the following characteristics:
  - Size - “maximus” - largest
    - ex: Gluteus maximus
  - Shape – include trapazoid (trapezius),
    - ex: latissimus (wide)
    - ex: Deltoid has shape (triangle) of the Greek letter
  - Location –
    - ex: frontalis overlies the frontal bone
    - ex: pectoralis (chest)

- Direction of muscle fibers - “rectus” means straight
  - ex: rectus abdominis
- Number of attachments - “biceps” means two
  - ex: biceps brachii
- Action – movement caused by muscle
  - ex: extensor digitorum extends the digits
19.3 Skeletal Muscles

Figure 19.12
### TABLE 15.2 Major Human Reactions (Pg. 15.12a: Amater View)

<table>
<thead>
<tr>
<th>Name</th>
<th>Action</th>
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</thead>
<tbody>
<tr>
<td>Emotional stress</td>
<td>centered</td>
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<tr>
<td>Motor output</td>
<td>surrounded</td>
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<tr>
<td>Sensory output</td>
<td>centered</td>
</tr>
<tr>
<td>Temperature change</td>
<td>centered</td>
</tr>
<tr>
<td>Pressure change</td>
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<td>Ocular pressure</td>
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### TABLE 15.2 Major Human Reactions (Pg. 15.12d: Amater View)

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<td>Ocular pressure</td>
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</table>
### TABLE 19.3 Major Human Muscles (Fig. 19.12b: Posterior View)

<table>
<thead>
<tr>
<th>Name</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td></td>
</tr>
<tr>
<td>Occipitofrontalis</td>
<td>Moves head and neck forward</td>
</tr>
<tr>
<td>Sternocleidomastoid</td>
<td>Torsion</td>
</tr>
<tr>
<td>Temporalis</td>
<td>Everts lateral to side, flexes neck and head</td>
</tr>
<tr>
<td>Upperlimb and trunk</td>
<td></td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>Extends and adducts arm (flexes/abducts arm)</td>
</tr>
<tr>
<td>Deltoideus</td>
<td>Able to adduct from raised arm to free</td>
</tr>
<tr>
<td>Intertascible US</td>
<td>Breats on arm</td>
</tr>
<tr>
<td>Trapezius</td>
<td>Everts scapula</td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>Everts scapula</td>
</tr>
<tr>
<td>Anterior deltoid</td>
<td>Everts arm</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>Everts humerus</td>
</tr>
<tr>
<td>Gastrocneumus</td>
<td>Everts foot</td>
</tr>
<tr>
<td>Backs and lower limb</td>
<td></td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>Abducts thigh</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Extends thigh back (forms buttock)</td>
</tr>
<tr>
<td>Hamstring group</td>
<td>Flexes leg and extends thigh</td>
</tr>
<tr>
<td>Gastrocneumus</td>
<td>Plantar: flexes foot (tip-toe)</td>
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</table>
19.4 Mechanism of Muscle Fiber Contraction

- Muscle Fiber
  - A cell containing typical cellular components which have been given special names
    - Sarcolemma – plasma membrane
    - Sarcoplasmic reticulum – endoplasmic reticulum
    - Sarcoplasm – cytoplasm
  - Unique structures
    - T (Transverse) tubules – penetrate into the cell so that they come in contact with expanded portions of the sarcoplasmic reticulum

- Sarcolemma

- Sarcoplasmic reticulum
  - Expanded portion stores Ca\(^{2+}\), essential for contraction
  - Encases hundreds or thousands of myofibrils, the contractile portion of muscle cells (fibers)
  - Other organelles such as mitochondria are located in the sarcoplasm between myofibrils
    - Sarcoplasm also contains glycogen, to provide energy for muscle contraction

Figure 19.13
Skeletal Muscle Fiber Structure and Function

Figure 19.13

6000x

bundle of muscle fibers
A muscle contains bundles of muscle fibers, and a muscle fiber has many myofibrils.

myofibrils
skeletal muscle fiber sarcolemma mitochondrion calcium storage sites sarcoplasm

nucleus

cross-bridge myosin

Sarcomeres are relaxed. H zone

T tubule sarcoplasmic reticulum nucleus

Figure 19.13

one sarcomere

Figure 19.13

one myofibril

Figure 19.13

A myofibril has many sarcomeres.

actin Z line Z line

Figure 19.13

myosin cross-bridge

calcium storage sites

one sarcomere

Figure 19.13

Z line A band I band

Figure 19.13

mitochondrion

6000x

bundle of muscle fibers
Myofibrils and Sarcomeres

• Myofibrils are cylindrical and run the length of the muscle fiber.
• Striated appearance is due to arrangement of contractile filaments.
  – Unit of contraction - **sarcomere**
  – Extends from Z line to Z line
  – Contains two types of contractile proteins
    • Actin - thin filament
    • Myosin - thick filament

<table>
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<tr>
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<th>Function</th>
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<td>Sarcomere</td>
<td>Striated appearance is due to arrangement of contractile filaments.</td>
</tr>
<tr>
<td>Myofibrils</td>
<td>Myofibrils are cylindrical and run the length of the muscle fiber.</td>
</tr>
<tr>
<td>T-tubule</td>
<td>Increase of the sarcomeres that extends into the muscle fiber and connects to the sarcolemma, which contains sarcolemmal Na⁺/Ca²⁺ exchanger.</td>
</tr>
<tr>
<td>Sarcoplasmic reticulum</td>
<td>The smooth ER of a muscle fiber that stores Ca²⁺ ion in the extracellular space.</td>
</tr>
<tr>
<td>Myofilament</td>
<td>A bundle of myofilaments that contract.</td>
</tr>
</tbody>
</table>

Myofibrils and Sarcomeres

• Myofibrils
  – I band - light colored band of sarcomere, contains only actin
  – A band - has overlapping actin and myosin
  – H band - contains only myosin
Myofilaments

- **Thick filaments** – only myosin
  - Each myosin molecule is shaped like a golf club.
  - The straight portion ends in a double globular head or cross-bridge.
  - Cross-bridges occur on each side of a sarcomere but not in the middle.
- **Thin filaments** – primarily actin
  - Consists of two intertwining actin filaments
  - Tropomyosin and troponin are associated proteins.

---

Myofilaments

- **Sliding filament model**
  - When muscles are stimulated, impulses travel down a T tubule.
  - Calcium is released from the sarcoplasmic reticulum.
  - Calcium triggers muscle fiber contraction as sarcomeres within the myofibrils shorten.
  - Actin (thin) slides past myosin (thick) filaments.
    - I band shortens, H band may disappear
    - Myosin filaments do the work.
    - Break down ATP and form cross-bridges

---

Skeletal Muscle Contraction

- One motor neuron can synapse with few or many muscle fibers in a muscle.
- Each axon has branches that end in an axon terminal near muscle fiber sarcolemma.
- The gap between axon terminal and sarcolemma is a **Neuromuscular junction**.
  - Axon terminals contain synaptic vesicles filled with acetylcholine (ACh).
  - When the nerve impulse reaches the end of an axon, ACh is released into the synaptic cleft.
  - ACh diffuses across the cleft and binds to receptors in the sarcolemma.
a. One motor axon causes several muscle fibers to contract.

A neuromuscular junction is the juxtaposition of an axon terminal and the sarcolemma of a muscle fiber.
The release of a neurotransmitter (ACh) causes receptors to open and Na\(^+\) to enter a muscle fiber.

Neuromuscular Junction

The Molecular Mechanism of Contraction

- Two other proteins associated with actin filaments
  - *Tropomyosin* threads wind around an actin filament.
  - *Troponin* is located at intervals along the filaments.
- When Ca\(^{2+}\) is released it binds to troponin.
  - Causes tropomyosin threads to shift position.
The Molecular Mechanism of Contraction

- Globular heads of myosin have ATP binding sites.
  - ATPase splits ATP to ADP and \( \text{P} \)
  - Heads now bind to sites on actin and form cross-bridges
  - ADP and \( \text{P} \) are released from myosin and the cross-bridges change positions - power stroke
  - This causes the actin filaments to slide (contraction)
- Relaxation occurs when impulses stop and \( \text{Ca}^{2+} \) is actively transported into the sarcoplasmic reticulum.
The Molecular Mechanism of Contraction

Figure 19.15

Energy for Muscle Contraction

- ATP previously produced before strenuous exercise lasts only a few seconds
- Muscles acquire new ATP in three ways
  - Creatine phosphate (anaerobic) breakdown
    - Used first before O₂ enters mitochondria
  - Cell respiration (aerobic)
    - Occurs only as O₂ is available
  - Fermentation (anaerobic)
    - When O₂ is not delivered to meet demands of vigorously contracting muscle
Creatine Phosphate Breakdown

- Creatine phosphate is a high-energy compound that builds up in resting muscle.
  - Fastest way to make ATP available for muscle cells
  - Provides energy for about 8 seconds of intense activity
  - Creatine phosphate is rebuilt by transferring a phosphate group from ATP to creatine

Cellular Respiration

- Provides most of energy for muscle contraction
- Muscle cell uses glucose from glycogen and fatty acids from fat in cell respiration pathway
- Occurs in mitochondria and requires oxygen
- Muscle cell has myoglobin - has higher affinity for O₂ than hemoglobin
  - Allows temporary storage of oxygen

Cellular Respiration

- End products
  - Carbon dioxide removed by lungs
  - Water removed by bloodstream
  - Heat generated as a by-product and used to keep body warm
Fermentation

- Supplies ATP without oxygen
- Breaks glucose down to lactate (lactic acid)
- Lactic acid builds up and makes cytoplasm more acidic
  - If fermentation continues for more than 2-3 minutes, cramping and fatigue occur from lack of ATP to pump calcium back into sarcoplasmic reticulum

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ADP + ATP + glucose → lactate
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Oxygen Debt

- Debt occurs when a muscle uses creatine phosphate or fermentation to supply its energy needs.
- Ability to use oxygen debt is important because blood glucose can be spared and used by the brain.
- Repaying an oxygen debt requires two actions.
  - Replenish creatine phosphate supplies
  - Dispose of lactate
    - Metabolized in mitochondria or sent to the liver to reconstruct glycogen

19.5 Whole Muscle Contraction

- Isolated muscle fiber
  - Muscle fiber isolated in the laboratory, provided with ATP plus various salts, and observed via microscope
    - A single muscle fiber contracts completely along its length in response to a stimulus - all or none law
- Whole muscle
  - Muscle is stimulated electrically, and observed via myogram
    - Shows various degrees of contraction
    - A myogram is a visible pattern of contraction recorded in the laboratory
    - Muscle twitch is the response of a muscle to a single threshold stimulus
19.5 Whole Muscle Contraction

• The myogram has three stages.
  – **Latent Period**: from stimulus to onset of contraction
  – **Contraction Period**: while muscle is shortening
  – **Relaxation Period**: when muscle returns to resting length

• In the Laboratory
  – Whole Muscle Contraction
    • Unlike a single fiber, the whole muscle exhibits degrees of contraction.
    • A twitch can vary in height (strength) depending on degree of stimulation.
      – Stronger stimulation causes more fibers to contract
    • During a rapid series of stimuli, whole muscle can react to the next stimulus without relaxing completely from previous one.

• In the Laboratory
  – Summation
    • Increased muscle contraction until a maximum sustained contraction (tetanus) is reached
      • Myogram no longer show individual twitches
      • Twitches are fused together
      • Tetanus continues until muscle fatigues from depletion of energy reserves
Stimulus
relaxation
period
contraction
period
latent
period
Force
Stimulus

Figure 19.16

summation tetanus fatigue

Stimuli
Time

Figure 19.16

Physiology of Skeletal Muscle Contraction
19.5 Whole Muscle Contraction

• In the Body
  – A **motor unit** is a nerve fiber together with all the muscle fibers it innervates.
  – As the intensity of nervous stimulation increases, more motor units are activated.
  – Some muscle fibers are contracting while others are relaxing.
  – Even when muscles appear to be at rest, some fibers are always contracting (**muscle tone**).

Athletics and Muscle Contraction

• **Exercise and Size of Muscles**
  – Muscles not used decrease in size (atrophy).
  – If stimulation is not restored, muscle fibers are gradually replaced by fat and fibrous tissue.
  – Forceful activity over a prolonged period causes muscle to increase in size.
    • Hypertrophy occurs only if muscle contracts to at least 75% of maximum tension.
    • An increase in the number of myofibrils within fibers causes hypertrophy.

Athletics and Muscle Contraction

• **Slow-Twitch and Fast-Twitch Muscle Fibers**
  – Different types of metabolism
  – **Slow-twitch fibers** (tend to aerobic)
    • Have steadier “tug” and more endurance
    • Produce most energy aerobically
    • Have many mitochondria and are dark in color from myoglobin
    • Have low maximum tension which develops slowly
    • Have substantial reserves of glycogen and fat
    • Ex: Long-distance running, biking, jogging
Athletics and Muscle Contraction

- **Slow-Twitch and Fast-Twitch Muscle Fibers**
  - **Fast-twitch fibers** (tend to be anaerobic)
    - Develop maximum strength in a burst
    - Motor units contain many fibers
    - Fibers are light in color due to fewer mitochondria and little to no myoglobin
    - Dependence on anaerobic energy leaves them vulnerable to accumulation of lactic acid and fatigue
    - Ex: Sprinting, weight lifting, swing a golf club

- **Slow-twitch muscle fiber**
  - is aerobic
  - has steady power
  - has endurance

- **Fast-twitch muscle fiber**
  - is anaerobic
  - has explosive power
  - fatigues easily

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19.6 Disorders of the Musculoskeletal System
Disorders of the Skeleton and Joints

- Fractured Bones
  - Greenstick fractures
  - Stress fractures
  - Compound fractures
  - Comminuted fractures

Figure 19.18 Comminuted Fracture
Disorders of the Skeleton and Joints

- Disorders of the Skeletons and Joints
  - **Osteoporosis**
    - Bones lose mass and mineral content
    - Leads to an increase risk of fractures

Disorders of the Skeleton and Joints

- **Arthritis**
  - **Osteoarthritis**
    - Degenerative joint disease (cartilage)
  - **Rheumatoid arthritis**
    - Autoimmune disease
    - Joints and other tissues are attacked

Disorders of the Muscles

- Disorders of the Muscles
  - **Fibromyalgia**
    - Severe pain in neck, shoulders, back, and hips
    - Chronic fatigue
    - May be due to low levels of serotonin or other neurotransmitters involved with pain perception
Disorders of the Muscles

• **Muscular dystrophies (MD)**
  – Genetic diseases
  – Vary greatly in severity
  – Most common form is Duchenne muscular dystrophy
    ▪ Results from abnormal gene coding for dystrophin
    ▪ Affects mainly boys, because it is an X-linked disorder