

Structure and Function of the Musculoskeletal System

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Functions of the Musculoskeletal System

- Support and protect the body and its organs.
- Provide motion.

Musculoskeletal System:

Major substructures

- Tendons.
- Ligaments.
- Fascia.
- Cartilage.
- Bone.
- Muscle.
- Joints - allow motion between body segments.

Connective Tissues

- Cells.
- Extracellular matrix:
 - Fibers:
 - ◆ Collagen
 - ◆ Elastin
 - Ground substance.

Connective Tissue Cells

- Fibroblasts - cells producing the matrix for skin, tendons and ligaments.
- Chondrocytes - cells producing the matrix for cartilage.
- Osteocytes - cells producing the matrix for bone.

Connective Tissue Matrix

→ Collagen fibers:

- Type I - tendons, ligaments, bone, skin.
- Type II - cartilage.
- Type III - blood vessel walls.

→ Mechanical properties depend on fiber types and fiber arrangements.

Tendons

Ligaments

Fascia

Mechanical Properties of Fibers

→ Stress - force on a fiber e.g. weight.

→ Strain - % stretching of fibers.

→ Elastic limit - point at which the elasticity of the fiber is lost.

→ Failure - point at which the fiber breaks.

Collagen

- Collagen molecule - a triple helix of three extended protein chains wrapped around one another.
- Numerous rodlike collagen molecules cross-link together to form unextendable collagen fibrils.
- Collagen fibrils are striped because of the regular repeating arrangement of the collagen molecules within the fibril.

Collagen fibers

→ Strength of collagen is 50% strength of bone.

→ Under tension, collagen fibers first elongate slightly and then become increasingly stiff until failure.

→ Collagen fibrils have the tensile strength of steel.

Elastic Fibers

→ Elastin - polypeptide chains cross-linked together to form rubberlike, elastic fibers.

→ Elastin molecule uncoils when the fiber is stretched and spontaneously recoils when the stretching force is relaxed.

Elastic fibers

→ Weak and brittle fibers.

→ At low loads they strain greatly and can increase ~200% in length before failure.

Tendon structure

→ Tendon

→ Tendon sheath:

- Synovium - lubricant producing tissue.
- Synovial fluid - lubricant fluid.

Tendons and Ligaments

→ At certain points, ligaments surround parts of the tendon sheath to act as:

- Pulleys – retinaculae that keep tendons attached to joints when muscles contract
- Tendon guides – retinaculae that restrict lateral tendon movement

→ Ligament attachments allow tendons to work around corners, as in the fingers and toes.

Tendons

→ Tendons connect muscle to bone to create movement.

Collagen in Tendons

→ Tendons comprise parallel bundles of collagen fibers, with few elastic fibers and ground substance.

Finger Movement

Tendon and Muscle

- Muscle fiber wrapped in endomysium
- Fibers bundled into fascicles (up to 200 fibers) wrapped in perimysium
- Fasciculi bundled together and interspersed with blood vessels and nerves in muscle and wrapped in epimysium
- Epimysium and perimysium tissues taper at each end to form tendons

Cartilage: 3 types

- Hyaline cartilage
 - Solid matrix, cells (chondrocytes) densely clustered
 - present in the growth plates at the end of bones and on the articular surfaces of joints. Also present in the respiratory tract (e.g. trachea).
- Fibrocartilage
 - solid matrix, cells widely interspersed among collagen fibers
 - present in intervertebral discs,
- Elastic cartilage
 - solid matrix, cells in small groups between many elastic fibers
 - present in ears, nose, epiglottis etc.

Bone

- Adult human skeleton has 206 bones.
- Babies born with ~ 300 bones but fusion occurs as a child develops.
- 99% of bodies calcium is in bone.
- 80% of bone tissue by weight is minerals.
- Longest bone (femur)
- Smallest bone (stapes)
- Males have slightly thicker and longer legs and arms
- Females have a wider pelvis and a larger pelvic cavity

Bone groups

- Axial skeleton (80 bones)
 - skull (29 bones)
 - thorax (25 bones)
 - vertebrae (33 bones)
 - Auditory ossicles
 - Hyoid bone
- Appendicular skeleton (126 bones)
 - pectoral girdle (4 bones)
 - upper extremity (60 bones)
 - lower extremity (60 bones)
 - and pelvic girdle (2 bones)

Long bones

- Round bones comprising:
 - diaphysis - shaft
 - epiphyses - 2 expanded ends

Bone Structure and Growth

- Ossification - processes of bone formation.
 - Osteoblasts - cells that form the bone matrix. They transform into
 - Osteocytes - cells isolated inside the mineralized bone matrix.
 - Osteoclasts - cells important to bone remodeling.

Types of Bone

- Cancellous (spongy) bone - less dense bone tissue found at the epiphyses of the long bones and in axial bones, such as the skull. 30-90% porosity.
- Cortical (compact) bone - tissue with high proportion of bone. 5-30% porosity.

Anisotropy

- All bone is anisotropic (i.e. its mechanical property changes when loads are applied in different directions).

Bone: Mechanical properties

- Most important properties are strength and stiffness of bone.
- Fractures occur when the bone is loaded to failure.
- Compression fractures are commonest in cancellous bone (e.g. fractured skull)
- Bending and torsional fractures are commonest in cortical bone (e.g. broken tibia).

Speed of loading to fracture.

Human Muscles

- Muscular system is 50% of total human body weight.
- >600 skeletal muscles, which enables the human body to move and stand erect.
- Skeletal muscles are arranged in overlapping intricate layers:
 - Superficial muscles
 - Deep muscles

Skeletal muscle

- Skeletal muscle is striated (striped), and excludes cardiac and smooth muscle.
- Skeletal muscle is under voluntary control.
- Each muscle is a separate organ.
- Each muscle is attached to bone by tendons that cross one or more joints.
- Generally, skeletal muscles generate moments about joints.

Muscle fibers

- Long, cylindrical cells containing multiple nuclei.
- Most of the fiber volume is occupied by the contractile elements - myofibrils.
- Myofibrils show a banding pattern (transverse striation) of thick myofilaments (myosin) and thin ones (actin).
- The contractile unit of the myofibril is called the sarcomere.

Structure of Skeletal Muscle

- Skeletal muscle is covered by a fascia called the epimysium.
- The epimysium penetrates and subdivides the muscle into muscle fiber bundles called the fascicles (fasciculi).
- Each fascicle is covered by connective tissue called the perimysium.
- Each individual muscle fiber is covered by connective tissue called the endomysium.

- Connective tissue provides pathways for nerves and blood vessels + contributes to the mechanical properties of the muscle.

Skeletal Muscle Structure

- Actin & Myosin filamentary protein molecules form the sarcomeres, and these bundle to form myofibrils, which bundle to form muscle fibers.
- Longest fibers ~30 cm long, 0.05-0.15 mm wide, and contain several thousand nuclei.

Motor Units

- Motor unit - group of muscle fibers innervated by branches of the same efferent neuron.
- Functional unit of the muscle.
- Motor units are small in muscles requiring precise control (e.g. eye muscles), and large in coarse acting muscles (e.g. gastrocnemius muscle).
- Motor units work in an “all-or-none” way.
- Progressive contraction occurs because of recruitment of motor units.

Sarcomere

Sarcomere and Contraction

Muscle Action

- Actin & Myosin filamentary protein molecules interact to create movement.
- The Myosin head firmly attaches to the Actin filament.
- When the Myosin head swivels it pulls the Actin filament forward.
- Many Myosin head swiveling simultaneously, or nearly so, pull the entire thin actin myofilament.

Muscle fibers

- Slow twitch fibers (type I) – S fibers, fatigue resistant, red fibers, slow myosin, contraction times from 100-120 msec.
- Fast twitch fibers (type II) – white fibers, fast myosin, contraction times from 40- 45 msec., subdivided into:
 - FR fibers (type IIa) –aerobic, fatigue resistant
 - FF fibers (type IIx) – type IIb, anaerobic, fatigable
- Average person has 50% type I, 25% type IIa, 25% type IIx
- Elite distance runners have more type I fibers
- Elite sprinters have more type IIx fibers
- Exercise can convert type I and IIx fibers to type IIa fibers

Muscles and Aging

- Loss of muscle mass begins around age 25 years
- By age 50 there is a 10% loss of skeletal muscle mass
- By age 80 there is a 50% loss of skeletal muscle mass
- Most loss is loss of muscle fibers and fast fibers atrophy at a higher rate than slow fibers
- In aged muscle up to 30% of fibers have morphed into something between a fast and slow fiber

- Muscle fibers are never regained
- Muscle bulk can be increased with weight training and this thickens the muscle fibers

Muscle Junctions

- Myotendinous junction - area where tendon fibers insert into muscle connective tissue and also into bone matrix (Sharpey's fibers).
- Neuromuscular junction - motor endplate where nerve fibers connect with myofibrils. In leg muscle one neuron innervates several hundred to >1000 muscle fibers. In finger muscles one neuron innervates one to a few muscle fibers.

Musculotendinous Unit

- Skeletal muscles anchor to the skeleton via either a:
 - Tendon – narrow cord of connective tissue
 - Aponeurosis – broad band of connective tissue

Skeletal Muscle Innervation

- Nerves (neurons) connect from the brain and spinal cord to muscles.
- Efferent nerves carry motor instructions for contraction to the muscles.
- Afferent nerves carry sensory information to the brain.
 - Proprioceptive feedback - muscle tone.
 - Kinesthetic feedback - muscle + joint status.
- Mixed nerves carry a mix of both sensory and motor neurons (e.g. median nerve).

Properties of Skeletal Muscle

- Isometric (static, eccentric) contraction – when the muscle force is less than the external load the muscles contract to change muscle tone without changing length. This increases postural stability.
- Isotonic (dynamic, concentric) contraction - when muscle force is greater than the external load the muscle contracts in length. This produces movement at joints.
- Static contraction is prone to rapid fatigue.
- Dynamic contraction increases blood flow through muscles which slows fatigue.

Muscle Organization at Joints

- Agonist muscle - the muscle directly engaged in contraction (e.g. in flexing the elbow the biceps brachii is the agonist).
- Antagonist - the opposing muscle in relaxation (e.g. in flexing the elbow the triceps is the antagonist).

Joints

- A joint is the union of 2 or more bones. 3 types of joint are found in the body.
 - Synovial joint (diarthrodial joint) - no tissue between the articular surfaces. Most of the body joints are this type.
 - Fibrous joint - fibrous tissue bridge between bones (e.g. skull).
 - Cartilagenous joint - cartilage bridge between bones (e.g. intervertebral disc in spine).

Structure of a Synovial Joint

- Joint capsule - fibrous capsule around the joint.
- Synovial membrane - membrane lining the joint capsule and surrounding the synovial cavity. This tissue secretes the lubricating synovial fluid.
- Synovial cavity (joint cavity) - cavity containing synovial fluid + bone ends
- Articular cartilage (hyaline cartilage) - cartilage covering articular surfaces of the bone ends.

Joint degeneration

- Cartilage does not have a good capillary blood supply.
- Cartilage has a poor ability to repair and regenerate itself.
- With age, overuse and/or disease, such as arthritis, the articular cartilage degenerates and bone ends make more direct contact, causing inflammation and pain.

Intervertebral Disc Structure

- Nucleus pulposus - incompressible watery gel contained within an elastic sac.
- Annulus fibrosis - fibrocartilage lamellae arranged in layers around the nucleus. Fiber orientation varies from layer to layer.
- End plates - hyaline cartilage end plates protect each end of the disc.
- Motion segment - 2 vertebrae either side + intervertebral disc.

Bone and Muscle Loss in Space

- In space, astronauts will experience a deterioration in their musculoskeletal system:
 - 1 to 2 % loss of bone mass each month.
 - Up to 20% loss of skeletal muscle mass within 2 weeks if the astronaut does not exercise:
 - ◆ Visiting astronauts (< 2 weeks) exercise 30 minutes/day
 - ◆ Space station astronauts exercise 2 hours/day.