Structure and Function of the Musculoskeletal System

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DEA 3250/6510

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.
➔Chrondrocytes - 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 increasing 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 (chrondrocytes) 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 1) – S fibers, fatigue resistant, red fibers, slow myosin, contraction times from 100-120 msecs.
- Fast twitch fibers (type II) – white fibers, fast myosin, contraction times from 40- 45 msecs., subdivided into:
  - FR fibers (type IIa) –aerobic, fatigue resistant
  - FF fibers (type IIx) – type IIb, anaerobic, fatigable
- Average person has 50% type 1, 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

- ➔ Myotendinal 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.