Muscular System

The Muscular System consists of about 700 muscle organs that are typically attached to bones across a joint to produce all voluntary movements.

The design and integration of our muscles is the result of millions of years of evolutionary pressures:

eg. new analyses (2004) indicate that the anatomy and physiology of humans became adapted toward distance running and spear throwing about 2 M years ago.

running was perhaps an adaptation for hunting → running prey to exhaustion.

A well-conditioned human can run 5 miles or more as good as wild dogs, zebras, antelopes and wildebeasts.

It would also allow us to compete with dogs and hyenas for widely dispersed carcasses.

eg. humans are the only primates who can launch a spear or rock overhand with speed, force, and precision.

All other primates throw underarm with poor aim.

General Functions of Muscular System:

1. movement
   voluntary – skeletal muscles

2. Control of Body Openings and Passages
   ring-like sphincter muscles around eyelids, pupils, mouth, urethra, anus
   usually also associated with involuntary internal sphincters eg. anal, urethral sphincters

3. Posture & Stability
   sustained partial contractions
   at any moment most of our muscles are probably at least partially contracted.

   resists gravity, prevents unwanted movements.

4. Communication
   facial expression, hand gestures, body language, writing, speech.

5. Control of Body Temperature
   muscles comprise 40-50% of body mass
   metabolism requires lots of energy (ATP) for movement
   ~25% = energy of movement
   ~75% = heat energy

   Skeletal muscles generate up to 85% of our body heat.

Muscle Organs:

Almost 700 muscle organs in body

Each limb is operated by over 50 muscles not including many stabilizer muscles.

Muscle organs range from extremely small to broad flat sheets.

Muscle organs consist of several kinds of tissue:

1. fibrous connective tissue
2. nervous tissue
3. muscle tissue

1. Fibrous Connective Tissue
   Fascia (=sheets of fibrous connective tissue) are found between the skin and muscles and surrounding muscle tissue.
   Superficial fascia lies beneath the skin.
   Deep fascia below this is part of muscle organ.

   Forms continuous sheath (series elastic components) of tissue from endomysium to bone matrix.

   Arranged in overlapping layers:

   - individual cells = endomysium
   - fascicles = perimysium
   - whole organ = epimysium

   Epimysium also called deep fascia as distinct from superficial fascia of skin.

   Very tough and strong yet flexible, very elastic collagen fibers mostly.

   Very strong, rarely separated from bone or muscle.

   Extends beyond muscle and attaches muscle to bone or to other muscles.

   (between each end is body of muscle)

   Tough strap = tendon (=sinews)

   Broad sheet = aponeurosis.

   Tendons are continuous with periosteum of bones.

   Elastic recoil of tendons increases power of muscle (eg. kangaroos and jumping animals).

   Tendons are often surrounded by tendon sheath of synovial membrane.

   Fluid lubricates tendons to reduce friction.

   Also are synovial sacs = bursae.
2. Nervous Tissue

Almost all muscles in the body are under direct or indirect control of the CNS, esp skeletal muscles.

Skeletal muscles are innervated by **somatic motor neurons** (voluntary).

Skeletal muscles will not contract without stimulation.

Each motor neuron branches into 200 or so **synaptic knobs** (within a **motor end plate**).

Each muscle cell in innervated by only one motor neuron.

Each neuron typically innervates ~200 muscle cells.

Connection between neuron and muscle cell = **neuromuscular junction**

At **motor end plate**

Not a direct connection, synapse or gap.

**Neurotransmitter**, Acetylcholine, is released.

NT crosses synapse to trigger contraction (30-40 M ACh receptors/motor end plate)

Binding opens channels → creates action potential.

3. Muscle Tissue

Close to half of body consists of muscle tissue.

Elongated cells, spindle shaped, up to 1 ft long = muscle fibers.

Very little matrix, instead embedded in framework of fibrous connective tissue.

Highly **contractile** and **elastic**.

Muscle cells stop dividing at birth (# fixed at birth).

But each cell can expand greatly in volume.

Development is affected by sex hormones.

→ Males’ muscles respond better than females’ to exercise.

There are three kinds of muscle tissue:

1. **striated**: most abundant, voluntary

   Most attached to two or more bones across a joint.

   All organs of the **muscular system** are made of striated muscle tissues.

2. **smooth**: internal organs; arranged in two or more layers eg circular and longitudinal

   Produce several kinds of movements:

   - **eg. peristalsis** = slow wavelike contractions that are used to push materials down a “tube” within the body.

   - **eg. segmentation** = a mixing motion made by smooth muscle lining the digestive tract.

   - **eg. sphincters** = involuntary (reflex) control over various internal body openings.

3. **cardiac**: heart only

   Main movement is:

   - **systole/diastole** = coordinated contraction and relaxation of the chambers of the heart.

Blood Supply to Muscles

Our voluntary muscles have a rich blood supply to bring needed oxygen and energy molecules to the cells.

**Endomysium** is full of capillaries that reach every muscle fiber.

All skeletal muscles receive ~1.25 liter of blood/min at rest (~1/4th total blood supply).

During heavy exercise they can use up to 11.6 liters/min (>3/4th’s of all blood)

Increased demand for oxygen and glucose.

Muscle Compartments

Muscles of the limbs are arranged into tightly packed “compartments.”

Fascia surround and enclose the muscles, nerves and blood vessels within each compartment.

If the blood vessels within a compartment are damaged blood and tissue fluid accumulate.

→ Fascia prevent swelling and relief of pressure.

→ Blood vessels and nerves are compressed and obstructed.

If pressure persists for >2-4 hrs nerves begin to die.
Some Basic Principles of Voluntary Muscle Function

1. **Bones act as levers and pivots** (fulcrums)
   
   - Most skeletal muscles are arranged in bundles with ends attached to two different bones.
   - Muscles pull across joints to produce movement.
   - Each muscle must attach to at least two **different** bones on opposite sides of an articulation:
     
     - **Origin** – proximal, less mobile point of attachment.
     - **Body** – most muscle fibers grouped here.
     - **Insertion** – distal and more mobile point of attachment.

   *Usually the body of the muscle that moves a part does not lie over the part it moves.*

   **Intramuscular Injections**: muscles with thick bellies commonly used when drug must be absorbed more slowly or is given in large doses.

   - Eg. deltoid, gluteus medius, vastus lateralis.

2. **Muscles can only pull not push**
   
   - Any movement requires coordination of several muscles.
   - Eg. opposing pairs.
   - Eg. functional groups.
     
     - **Prime mover**
     - **Synergist** (including fixators).
     - **Antagonists**.

3. **Kinds of body movements**:
   
   - The synovial joints of the body each allow specific kinds of voluntary movements, such as:
     
     - **Flexion/extension** = decrease vs increase angle (Inc. hyperextension beyond anatomical position).
     - **Supination/pronation** = rotate outward vs inward.
     - **Adduction/abduction** = toward vs away from median.
     - **Levator/depressor** = produces upward vs downward movement.
     - **Rotation/circumduction** = pivot vs describe cone.
     - **Eversion/inversion** = turns sole outward vs inward.
     - **Dorsiflexion/plantarflexion** = toes up vs toes down.
       
       - Flexes foot vs extends foot at ankle joint.

   Other kinds of muscle movements:

   - **Tensor** = makes body part more rigid.
   - **Sphincter** = decreases size of opening (orbicularis); voluntary or smooth muscles.

4. **Skeletal muscle are named in several ways**:
   
   - **Direction of muscle fibers** (rectus, transverse, oblique).
   - **Location** (temporalis, orbicularis oris).
   - **Size** (maximus, minimus).
Examples of Human Muscle Groups:

Muscles of the Appendages

A. Muscles that move the pectoral girdle
   - levate/depress
     - levates & depresses scapula: trapezius
     - depresses scapula: latissimus dorsi
     - several movements of scapula: pectoralis major

B. Muscles that move the upper arm
   - adduct/abduct
     - adduct arm: deltoid
     - pectoralis major
     - latissimus dorsi
   - flex/extend
     - flexors: pectoralis major
     - latissimus dorsi
   - extensors: triceps brachii

C. Muscles that move forearm
   - flex/extend
     - flexors: biceps brachii
     - brachialis
     - brachioradialis
   - extensor: triceps brachii

D. Muscles that move wrist and fingers
   - flexes wrist
     - flexor carpi radialis
     - flexor carpi ulnaris
   - extends wrist
     - extensor carpi radialis
     - extensor carpi ulnaris

E. Muscles that move thigh
   - abduct/adduct
     - thigh: tensor fascia latae
     - adductor longus
     - adductor magnus
     - gracilis
   - flex/extend
     - flexors: sartorius
     - rectus femoris
     - tensor fascia latae
     - extensors: gluteus maximus
     - biceps femoris
     - semitendinosus
     - semimembranosus

F. Muscles that move lower leg
   - flexors: biceps femoris
     - semitendinosus
     - semimembranosus
     - sartorius
   - extensors: rectus femoris
     - vastus lateralis
     - vastus medialis

G. Muscles that move foot
   - dorsiflex/plantarflex
     - dorsiflexors: tibialis anterior
     - plantarflexors: gastrocnemius
     - soleus

Head and Trunk Muscles

A. Muscles of the head and neck
   - sphincters:
     - orbicularis oculi (close eye)
     - orbicularis oris (close mouth)
   - chewing:
     - closes jaw: masseter
     - temporalis
     - orbicularis oris
     - opens jaw: platysma
   - facial expression:
     - frontalis (raise eyebrows)
     - orbicularis oculi (squint)
     - orbicularis oris (purse lips, pout, kiss)
   - extrinsic eye muscles: 3 pairs for each eye for voluntary eye movements
   - head movement:
     - sternocleidomastoid (flexes head, turns head)
     - trapezius (extends head)

B. Breathing Muscles
   - inspiration:
     - contract diaphragm
     - external intercostals (elevates rib cage)
   - expiration:
     - relax diaphragm
     - internal intercostals (depresses rib cage)

C. Muscles of the Abdominal Wall
   - layers:
     - external oblique
     - internal oblique
     - transversus abdominis
     - rectus abdominis (linea alba)
   - Hernia
     - occurs because of weakness in body wall may cause rupture
     - visceral organs protrude through opening
     - wall is weak because of spaces between bundles of muscle fibers
     - undue pressure on abdominal viscera may force a portion of parietal peritoneum and intestine through these weak spots
     - eg. heavy lifting can create up to 1,500 lbs pressure/sq " in abdominal cavity (~100x's normal pressure)
     - most common at inguinal area, also diaphragm & naval
     - women rarely get inguinal hernias
**Muscle Cell Anatomy & Function**
(mainly striated muscle tissue)

**General Properties of Skeletal Muscle Cells**
muscle cells are highly specialized to have several distinctive properties:

- **excitability (responsiveness)**
  respond with electrical changes = impulse

- **conductivity**
  electrical signal travels throughout the muscle cell
  - since muscle cells are not myelinated the impulse travels much slower than on nerve cell
  - T-tubule system helps to get impulse into cell and around the myofibrils

- **contractility**
  can shorten substantially when stimulated
  - most cells can shorten to almost half their length
  - all cells contract to some degree, but muscle cells are much stronger and contract much more efficiently
    - e.g. calf muscles can support 1 ton

- **extensibility**
  some can stretch up to 3 times their normal length
  - elasticity can recoil when not being stretched

**General Structure of Skeletal Muscle Cells**
several nuclei (skeletal muscle)
skeletal muscles are formed when embryonic cells fuse together
some of these embryonic cells remain in the adult and can replace damaged muscle fibers to some degree (= satellite cells)
lots of mitochondria for energy generation
some cell structures have taken on new functions:
  - cell membrane = sarcolemma
  - cytoplasm = sarcoplasm
  - ER = sarcoplasmic reticulum

**T tubules**
tube or tunnel-like infoldings of sarcolemma open to cell surface extend into muscle cell surround sarcoplasmic reticulum

**Myofibrils**
most of muscle cell is filled with myofibrils regularly overlapping filaments (in striated mm) surrounded by SR SR in turn surrounded by T-Tubules
myofibrils consists of packets of:

a. **thick filaments → myosin**
  - each filament consists of several 100 molecules of myosin
  - each myosin molecule is shaped like a golf club with heads directed outward

b. **thin filaments → actin, troponin, tropomyosin**
  - one type of actin (G-actin) contains active sites
  - when myofibrils are relaxed, tropomyosin blocks these active sites
  - each tropomyosin has a calcium binding troponin molecule attached to it

c. **elastic filaments → titin (= connectin)**
  - springy protein run through core of thick filaments
  - help keep thick and thin filaments aligned with each other
  - help cell recoil to resting length when stretched

[myosin and actin = contractile proteins
tropomyosin and troponin = regulatory proteins]

the proteins actin and myosin are found in all cells function in cell motility, cell division and transport of materials throughout the cell
myofilaments are arranged into sarcomeres
Muscle Cell Contraction:

1. nerve impulse arrives at neuromuscular junction
2. ACh is released and diffuses across synapse
3. binds to receptor on sarcolemma and initiates an impulse
4. impulse travels across sarcolemma and into T tubules
5. impulse triggers release of Ca\(^{++}\) from SR
6. Ca\(^{++}\) binds to troponin which moves tropomyosin away from actin binding sites
   - acts as a switch:
     - without Ca\(^{++}\) \(\rightarrow\) prevents interaction between actin & myosin
     - with Ca\(^{++}\) \(\rightarrow\) allows interaction
7. Myosin binds with actin in ratchet-like mechanism pulls thin filaments toward thick filaments
8. Thick & thin filaments telescope into each other causing shortening of muscle fibers = contraction
   - requires lots of ATP:

Relaxation

1. ACh is rapidly broken down by ACh esterase
   - stops generation of muscle action potential
   - Cholinesterase inhibitors in some pesticides bind to AchE and prevent it from degrading
     - causes spastic paralysis = a state of continual contraction
     - may affect diaphragm and cause suffocation
2. When stimulus stops, Ca\(^{++}\) ions reenter SR
   - keeps [Ca\(^{++}\)] 10,000 lower in sarcoplasm than in SR
3. Troponin moves back in to block interaction of actin and myosin, muscle cell relaxes

Muscular Dystrophy (muscle destroying diseases)

Physiological Cause: sarcolemma deteriorates
some are fatal, others have little impact on life expectancy
Duchenes: sex linked recessive trait; usually inherited but can occur spontaneously
Symptoms: muscle stiffness, difficulty relaxing muscles, muscle weakness, difficulty walking, drooping eyelids, progressive muscle wasting progresses from extremities upward
most die by 20 yrs old
biotech trying to replace gene that makes missing protein

Myasthenia Gravis (‘Heavy weakness’)

weakness of skeletal muscles,
esp face and neck muscles:
  - drooping eyelids
  - difficulty talking and swallowing

Autoimmune disease: immune system attacks ACh receptors
shortage of ACh receptors prevents fibers from contracting mostly women, 20-50 yrs old
damage leads to easy fatigue and weakness on exertion often, eyes are affected with drooping eyelids and double vision
difficulty swallowing or speaking are common