Muscular System

General Functions:
1. movement
   voluntary – skeletal muscles
   involuntary – internal organs, heart
2. Posture
   sustained partial contractions
3. Heat Generation
   muscles comprise 40% of body mass
   metabolism requires lots of energy (ATP)
   for movement
   \(~25\% = \text{energy of movement}\)
   \(~75\% = \text{heat energy}\)

Muscle Organs:
almost 700 muscle organs in body
  range from extremely small
  to broad flat sheets

as organs each consists of several kinds of tissue:
1. fibrous connective tissue
2. nervous tissue
3. muscle tissue

1. Fibrous Connective Tissue
   superficial fascia beneath skin
   deep fascia below this is part of muscle organs
   continuous sheath of tissue enclosing
   individual cells = endomysium
   fascicles = perimysium
   whole organ = epimysium
   very tough and strong yet flexible
   collagen fibers mostly
   extends beyond muscle and attaches muscle to
   bone or to other muscles
   tough strap = tendon
   broad sheet = aponeurosis
   tendons are continuous with periosteum of bones
   very strong, rarely broken (instead are torn from bone)
   tendons are often surrounded by tendon sheath
   of synovial membrane
   fluid lubricates tendons to reduce friction
   also are synovial sacs = bursae
   scattered between tendons and muscles
   wherever there is lots of friction and tension
2. Nervous Tissue
skeletal muscles are innervated by
somatic motor neurons (voluntary)
will not contract without stimulation
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
all cells contract to some degree, but muscle cells
are much stronger and contract much more efficiently
→ calf muscles can support 1 ton
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
three types of muscle tissue:
striated: most abundant, voluntary
smooth: internal organs
cardiac: heart

Muscle Cell Anatomy (striated muscle tissue)
some cell structures have taken on new functions:
cell membrane = sarcolemma
cytoplasm = sarcoplasm
ER = sarcoplasmic reticulum

several nuclei (skeletal muscle)

lots of mitochondria

T tubules – tunnel-like infoldings of sarcolemma
**Myofibrils**

- regularly overlapping filaments (in striated mm)
- various bands and zones
- one set = sarcomere

**thick filaments** → myosin (200 molecules/filament)
**thin filaments** → actin, troponin, tropomyosin

**Muscle Cell Contraction:**

1. nerve impulse arrives at neuromuscular junction
2. ACh is released and diffuses across synapse and initiates an impulse
3. impulse travels across sarcolemma and into T tubules and triggers release of Ca++ from SR
4. Ca++ acts as a switch:
   - without Ca++ → prevents interaction between actin & myosin
   - with Ca++ → allows interaction
5. Myosin binds with actin in ratchet-like mechanism pulls thin filaments toward thick filaments
6. Thick & thin filaments telescope into each other causing shortening of muscle fibers
   - contraction
   - requires lots of ATP:
     ATP is needed for both attachment and release of each myosin head

**Muscle Organ Physiology**

When muscle cell is stimulate by a neuron it is an

**“all or none”** contraction
→ completely contracted or completely relaxed

size of stimulus doesn’t matter

skeletal muscles contract only if stimulated
- nervous
- electrical
- chemical
- injury
**Twitch**

single stimulus $\rightarrow$ single contraction

- **latent** (2ms)
- **contraction** (0-100ms)
- **relaxation** (0-100ms)
- **refractory** (5ms)

**stimulus must be above threshold**

greater stimulus $\neq$ greater contraction

length of time for twitch may vary depending on size of muscle (.01 - .1 sec) [10 – 100ms]

eg. eye = .01 sec

gastrocnemius = .03 sec

muscle **organs** operate on principle of

"**graded strength**"

based on functional unit of muscle system

= **motor unit**

each muscle is composed of 1000’s of motor units

**motor unit** = individual motor neuron and all muscle cells that it innervates

the axon of a motor neuron usually branches on entering a muscle bundle and a single axon may innervate a few to 100’s of muscle fibers at same time

the fewer muscle cells/motor unit $\rightarrow$ more precise movement the muscle can make

eg. eye: 10-23 fibers/axon
hand: few
abdominal wall: many
gross movements > 500 fibers/axon
gastrocnemius ~1000/axon

whole motor unit responds as “all or none”
muscle cells cannot “partially” contract

each motor unit may have a different threshold

different sized motor units in a muscle organ
to get stronger contraction, more motor units are recruited

>intensity of stimulus
  >motor units are activated
    > greater strength (force) or degree of contraction

each muscle organ can respond with appropriate degree and strength of contraction

can experimentally generate other kinds of contractions:

1. Treppe/Summation
   staircase effect: get increased strength of contraction with repeated stimuli
   muscles don’t begin at maximum efficiency
   eg. athletes warmup exercise

2. Tetanus
   series of rapid stimuli cause sustained contraction of a muscle
   this is normal way muscles work in body, twitch is rare
   eg. twitch of eyelid or facial muscle
tetanic contractions are much more common
can continue to contract until they fatigue
tone = continued partial sustained contraction
  important for posture & as fixator muscles
when skeletal muscles contract but don’t cause movement = isometric
contractions that produce movement = isotonic

typical skeletal movement involve combinations of
isotonic and isometric contractions by various muscles within a group
Some Basic Principles of Muscle Function

1. **Muscles can only pull not push**
   - any movement requires coordination of several muscles (muscle groups)
   - eg. opposing pairs
   - eg. prime mover, synergist (including fixators), antagonists

2. **Bones act as levers and fulcrums;**
   - 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
     - **insertion** – distal and more mobile point of attachment

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

3. **Skeletal muscle are named in several ways:**
   - direction of muscle fibers
     - (rectus, transverse, oblique)
   - location
     - (temporalis, orbicularis oris)
   - size
     - (maximus, minimus)
   - origin and insertion
     - (sternocleidomastoid)
   - number of origins
     - (biceps, triceps)
   - shape
     - (deltoid, trapezius)
   - action
     - (flexors, extensors)

4. **Kinds of body movements:**
   - **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
tensor
   = makes body part more rigid
sphincter
   = decreases size of opening
   (orbicularis)

Examples of Human Muscle Groups:

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 digastric

facial expression:
   frontalis (raise eyebrows)
   orbicularis oculi (squint)
   orbicularis oris (purse lips, pout, kiss)
   platysma

extrinsic eye muscles

head movement
   sternocleidomastoid (flexes neck, turns head)
   trapezius (extends neck)

B. Muscles that move the pectoral girdle

levate/depress
   trapezius
   latissimus dorsi
C. Muscles that move the upper arm

**adduct/abduct**
- abduct arm: deltoid
- adduct arm: pectoralis major, latissimus dorsi

**flex/extend**
- flexors: pectoralis major
- extensors: latissimus dorsi

**rotate**

D. Muscles that move forearm

**flex/extend**
- flexors: biceps brachii, brachialis, brachioradialis
- extensor: triceps brachii

**rotate**

E. Muscles that move wrist and fingers

**flexes wrist**
- flexor carpi radialis
- flexor carpi ulnaris

**extends wrist**
- extensor carpi radialis
- extensor carpi ulnaris

**flexes fingers**
- flexor digitorum

**extends fingers**
- extensor digitorum

F. Muscles that move rib cage

**elevates rib cage**
- external intercostals (inspiration)

**depresses rib cage**
- internal intercostals (expiration)

**breathing**
- diaphragm

G. Muscles of the Abdominal Wall

**layers**
- external oblique
- internal oblique
- transversus abdominis
- rectus abdominis (linea alba)
H. Muscles that move thigh

**abduct/adduct**
- abduct thigh: gluteus medius, minimus, tensor fascia latae
- adduct thigh: adductor longus, adductor magnus, gracilis

**flex/extend**
- flexors: sartorius, rectus femoris, tensor fascia latae
- extensors: gluteus maximus, biceps femoris, semitendinosus, semimembranosus

**rotate**

I. Muscles that move lower leg

**flexors**
- biceps femoris, semitendinosus, semimembranosus, sartorius

**extensors**
- rectus femoris, vastus lateralis, vastus medialis

J. Muscles that move foot

**evert/invert**

**dorsiflex/plantarflex**
- dorsiflexors: tibialis anterior
- plantarflexors: gastrocnemius, soleus
Muscle Cell Physiology

Energy Requirements

active muscle require large amounts of energy
→ large #'s of mitochondria

the main energy producing process is

**aerobic respiration:**

\[ \text{glucose} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{ATP} \]

→ requires lots of glucose
cell can store some **glycogen**

→ this takes lots of oxygen
cell stores some O2 on **myoglobin**

Creatine Phosphate

can’t store ATP but muscle cells do have CP
CP can make ATP in a single reaction
→ instant energy

Anaerobic Respiration

sometimes your muscles need more ATP or quicker than O2 can be delivered
glycolysis can make ATP without oxygen
= **anaerobic respiration**
much quicker (fewer reactions)
much less efficient:
makes only 2 ATP/glucose
produces large amounts of “toxic wastes”

**lactic acid** → leads to **fatigue**
fatigue creates **oxygen debt**
= the extra amount of O2 needed to
  remove lactic acid, restore creatin phosphate, replace glycogen stores

Aerobic Respiration

requires mitochondria (lots of mitochondria)

main energy providing pathway of all cells including muscle cells

requires lots of O2 (myoglobin, rich blood supply)
produces 38 ATP vs 2 ATP per glucose molecule

**as long as cell has enough oxygen it will make ATP aerobically**

good for extended activity that is not too strenuous
eg. walking, jogging

if oxygen is not available it shifts to anaerobic respiration

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**Other Kinds of Muscle Tissues**

previous discussion was mainly concerned with skeletal muscle tissue

skeletal muscles are voluntary muscles and can contract very rapidly and strongly

also have smooth and cardiac muscle tissue; both are involuntary

we are generally unaware of our involuntary muscles

only come to our attention as:
  - pounding heart when excited, scared or very active
  - rumbling stomach
  - abdominal cramps
  - etc

**Smooth Muscle Tissue**

shorter than skeletal muscle cells

mechanism of contraction is similar to skeletal muscle cells

called smooth muscle because myofibrils
  - are not arranged in such a fixed overlapping pattern

  - thick and thin filaments are of varying lengths
  - not organized into sarcomeres

  - ratio of thick to thin filaments is 10-15:1 vs 2:1 in skeletal muscle cells

  - produce weaker contractions
allows smooth muscle cells to stretch to much greater extent than skeletal cells and still be able to contract eg. bladder, uterus

close, and relax much more slowly

not as strong of a contraction

don’t need as much energy
    only need ~1% of energy required by skeletal muscle cells

but since don’t need as much energy, generally don’t fatigue
    → can maintain a contraction much longer than skeletal muscles can

    **eg. sphincters**
        usually remain contracted to close off various openings; esophagus, anus, stomach, etc

like skeletal muscle fibers they are innervated by nerve cells

**Cardiac Muscle Tissue**

a unique type of contractile tissue found only in the heart

many of its characteristics are intermediate between striated and smooth muscles

    has striations like skeletal muscle: same myofibril arrangement
        → can contract more strongly than smooth muscle
        → can contract more quickly than smooth muscle
        → requires more energy

    has a single nucleus and is self stimulating like smooth muscle
        → doesn’t need direct innervation of every cell

also has unique features:

    **branches** that merge with other cells
    **intercalated discs** between cells instead of tapering to point these are **gap junctions**
→ direct connections between cells
eg. all cardiac muscle cells of atria are interconnected and all cardiac muscle cells of ventricles are interconnected
→ atria contract as a unit
→ ventricles contract as a unit

are self stimulating
  cells contract and relax rhythmically and continuously even without a nervous connection
  \(~ 75 \text{ bpm}\)
innervation just allows control of heart beat:
  speeds up or slows down as needed

cardiac muscle cells are more active than smooth muscle cells yet cannot fatigue or you would die

**Disorders of the Muscular System**

1. **Convulsions and Spasms**
   abnormal uncoordinated contractions of various muscle groups
2. **Fibrillation** (cardiac muscle)
   asynchronous contraction of individual cardiac muscle cells
3. **Poisons and Toxins**
   mainly affect Ach at NM jcts and in brain where it is used as a NT
   **Botulism toxin** – blocks release of Ach
   \(\rightarrow \text{paralysis}\)
   **Tetanus toxin** – interferes with inhibition of antagonists
   \(\rightarrow \text{all muscles contract}\)
   **black widow toxin** – stimulates massive release of Ach
   \(\rightarrow \text{intense cramping & spasms}\)
   **nicotine**
   - mimics Ach
   \(\rightarrow \text{prolonges hyperactivity}\)
   **atropine, curare**
   - prevents Ach from binding to receptors
   \(\rightarrow \text{paralysis}\)
4. **Disuse Atrophy:**
   lack of stimulation or immobilization (splint, cast)
   muscle cell mass can decrease 5%/day down to 25% loss
   muscle tissue replaced by connective tissue (fibrosis)
   can stimulate muscles electrically to reduce atrophy
5. **Fibrosis**
   skeletal muscle fibers degenerate and are replaced by fibrous connective tissue
associated with aging
loss of strength

6. **Hernia**
occurs because of weakness in body wall may
cause rupture
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
most common at inguinal area

7. **Muscular Dystrophy**
(muscle destroying diseases)
Duchenes: sex linked recessive trait
sarcolemma deteriorates
progresses from extremities upward
most die by 20 yrs old
biotech trying to replace gene that makes
missing protein

8. **Myasthenia Gravis** (Heavy weakness)
weakness of skeletal muscles,
esp face and neck muscles:
drooping eyelids
difficulty talking and swallowing
shortage of Ach receptors → autoimmune disease
prevents fibers from contracting
mostly women, 20-50 yrs old

9. **Steroid abuse**
normally testosterone promotes bone development and muscle
mass

??could megadoses help body builders??

by 2000 nearly 1 in 10 young men have tried steroids
take high doses (to 200mg/d) during heavy resistance training
positive data:
increases isometric strength
rise in body weight
not sure if these changes result in better PERFORMANCE
negative data:
bloated faces
shriveled testes
infertility
liver damage
alters blood cholesterol levels
1/3rd of users exhibit serious mental problems such as
manic behaviors