Muscular System

(smooth and cardiac muscles are not considered part of the Muscular System; they will be discussed as parts of other organ systems)

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

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

Muscles are under direct control of the CNS
skeletal muscles are innervated by motor neurons
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

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
range from extremely small to broad flat sheets
muscle organs each consists of several kinds of tissue:

1. fibrous connective tissue

2. Nervous Tissue

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   binding opens channels→ creates action potential

3. Muscle Tissue
close to half of body consists of striated (voluntary) 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 generally stop dividing at birth

but each cell can expand greatly in volume

development is affected by sex hormones

→ males’ muscles respond better than females’ to exercise

**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)

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 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
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

B. **Muscles that move the upper arm**
- Adduct/abduct
  - Adduct arm: 
    - Pectoralis major
  - Abduct arm: 
    - Latissimus dorsi
- Flex/extend
  - Flexors: 
    - Pectoralis major
  - Extensors: 
    - Triceps brachii

C. **Muscles that move forearm**
- Flex/extend
  - Flexors: 
    - Biceps brachii
  - Extensors: 
    - Brachioradialis
- Adduct/abduct
  - Adductors: 
    - Brachialis
  - Abductors: 
    - Biceps femoris

D. **Muscles that move wrist and fingers**
- Flexes wrist
  - Flexor carpi radialis
- Extends wrist
  - Extensor carpi radialis
- Flexes fingers
  - Flexor digitorum
- Extends fingers
  - Extensor digitorum

**Head and Trunk Muscles**

A. **Muscles of the head and neck**
- Sphincters:
  - Orbicularis oculi (close eye)
  - Orbicularis oris (close mouth)
- Chewing:
  - Closes jaw: 
    - Masseter
  - 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
  - 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 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, tropomyosin, troponymosin
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

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++ → prevents interaction between actin & myosin

with Ca++ → 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:
causes cross bridges of myosin filaments to rotate to
different angles and move thin filaments forward
ATP is needed for both attachment and release of each
myosin head
muscles shorten up to 60% (ave=35-50%)
one cycle results in ~1% shortening
so many cycles are involved

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
too many Mg ions or too few Ca$^{++}$ ions can prevent the release of ACh

**Botulism toxin** - blocks release of Ach
**paralysis**

**black widow toxin** - stimulates massive release of Ach
**intense cramping & spasms**

**nicotine** - mimics Ach
**prolonges hyperactivity**

**atropine, curare** - prevents Ach from binding to receptors
**paralysis**

**nerve gas** and related **organophosphates** inhibit cholinesterase muscle cant respond to continuing stimuli; especially of diaphragm, leads to respiratory failure

muscle cells grow when exercised and shrink when not used
- exercise stimulates increase in myofibrils
each muscle cell gets larger
when muscle cells are not used they shrink
e.g. disuse atrophy, in cast for fracture
ty they can quickly regrow when exercise resumes
but if atrophy becomes too advanced the fibers die and are not replaced
- physical therapy to prevent it
yet muscle cells can’t generally divide to produce new cells

**Muscle Organ Physiology**

**Kinds of Muscle Contractions**

1. **Twitch**
   - the process of **muscle cell** contraction just described = twitch
   - single stimulus $\rightarrow$ single contraction
   - length of time for twitch may vary depending on size of muscle cells (.01 - .1 sec) [10 – 100ms]
     - eg. eye = .01 sec
     - eg. gastrocnemious = .03 sec
   - 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

$\rightarrow$ we have fewer muscles cells as adults than we had as newborns

well exercised muscle cells also develop more mitochondria, more myoglobin and glycogen and a greater density of capillaries

skeletal muscles contract only if stimulated stimulus must be above **threshold**

greater stimulus $\neq$ greater contraction

**BUT:**
muscle cells rarely act alone
muscle organs operate on principle of **“graded strength”**

**Motor Units**
the **“functional unit”** of muscle system

**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

each muscle is composed of 1000’s of motor units

whole motor unit responds as **“all or none”**
muscle cells cannot “partially” contract
the fewer muscle cells/ motor unit $\rightarrow$ more precise movement the muscle can make

eg. eye: 10-23 fibers/axon
hand: few
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

2. **Treppe/Summation**
   muscles don’t begin at maximum efficiency
   staircase effect: get increased strength of contraction with repeated stimuli
due partly to rise in muscle temperature as it warms up
eg. athletes warmup exercise

3. **Tetanus**
   series of rapid stimuli cause sustained contraction of a muscle
   usually begins at 20-60 stimuli/second for most skeletal muscles
   useful muscle contractions typically consist of a mixture of twitches and tetanic contractions
twitch alone is rare
eg. twitch of eyelid or facial muscle
can continue to contract until they fatigue

4. **Isometric vs Isotonic contractions**
   when skeletal muscles contract but don’t cause movement = **isometric**
   contractions that produce movement = **isotonic**
tone = continued partial sustained contraction important for posture & as fixator muscles
typical skeletal movement involve combinations of isotonic and isometric contractions by various muscles within a group

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**Energy Requirements**

**Energy Requirements**
active muscle require large amounts of energy
→ large #'s of mitochondria
but cells cannot store ATP (only about 5 seconds worth)

**Aerobic Respiration**
the main energy producing process is **aerobic respiration**:  

\[
\text{glucose + O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{ATP}
\]
main energy providing pathway of all body cells including muscle cells
requires lots of **mitochondria**
requires lots of **O**\(_2\) (rich blood supply)
produces 38 ATP per glucose molecule
also produces carbon dioxide and water as final waste products:
→ requires lots of glucose
cell can store some **glycogen**

→ this takes lots of oxygen
cell stores some O\(_2\) on **myoglobin**
but
→ complex series of reactions (~30 rxns)
glycolysis→Krebs Cycle→ETS
→ Takes time (~1min (30-40 Seconds))

**What happens in the meantime??**

1. **Creatine Phosphate**
   can’t store ATP but muscle cells do have CP
   CP can make ATP in a single reaction
   → instant energy
   good for 10 – 15 seconds
   **but still not enough to last until mitochondria begin producing ATP**

2. **Anaerobic Respiration**
   and when muscles are being used near capacity, aerobic metabolism cannot supply adequate amounts of ATP
   glycolysis can make ATP without oxygen = **anaerobic respiration**
much quicker (fewer reactions)
doesn’t happen in mitochondria
much less efficient:
- makes only 2 ATP/glucose vs 38 ATPs/glucose molecule
produces large amounts of “toxic wastes”
  lactic acid → leads to fatigue
  a. lactic acid build up slows ATP production
  b. Fatigue: muscles can’t contract even though they are being stimulated; ATP supply is coming too slowly
  c. Fatigue is not same as complete lack of ATP
      Lack of ATP results in muscles locking up
          → writer’s cramp - temporary
          → rigor mortis – permanent: Calcium leaks out of SR, enough ATP to attach myosin heads but not enough to detach them (takes ~24 hrs to occur)
fatigue creates oxygen debt
  = the extra amount of O$_2$ needed to remove lactic acid, restore creatin phosphate, replace glycogen stores
stored ATP, CP and anaerobic glycolysis can provide

**Effects of Aging on Muscular System**

**energy for strenuous activity for ~ 1 minute**

**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

with continued aerobic activity muscle cells switch to using fatty acids instead of glucose to produce ATP

**the muscular system suffers fewer disorders than most other organ systems**

but it is particularly vulnerable to stress injuries

often exacerbated by overzealous exertion or improper warmup exercises

  → most athletic injuries can be prevented by proper conditioning

"no pain, no gain" is a dangerous creed

typical injuries are treated with **RICE**:

- **Rest** – prevents further injury
- **Ice** – helps reduce swelling
- **Compression** – with elastic, helps prevent fluid accumulation
- **Elevation** – promotes drainage

1. **Cramps and Spasms**

abnormal uncoordinated contractions of various muscle groups

especially in calf (back of lower leg), hamstrings (back of thigh) and quadriceps (front of thigh)

cause unsure; may be due to muscle fatigue, inadequate stretching before exercise, dehydration, electrolyte imbalance

by age 80 most have only half as much strength and endurance

  eg. a large percentage of 70 yr olds cannot lift 10 lb weights
  → major factor in falls, fractures, etc
as we age lean body mass is replaced with fat

  eg. young well conditioned male, muscle accounts for 90% of cs area of mid thigh; in 90 yr old woman only 30%
muscle fiber have fewer myofibrils; sarcomeres less organized, less ATP, glycogen, myoglobin, etc

  → fatigue more quickly

reduced circulation means muscles heal more slowly
motor units have fewer muscle fibers per neuron
less ACh is produced
treatment: apply heat to tense/tight muscles; cold to sore/tender muscles

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 exocytosis & release of Ach
     → paralysis
     = Botox: relieves crossed eyes and uncontrolled blinking, also relaxes muscles that cause facial wrinkles
   Tetanus toxin – interferes with inhibition of antagonists
     → all muscles contract
     black widow toxin – stimulates massive release of Ach
     → intense cramping & spasms
   nicotine - mimics Ach
     → prolongs hyperactivity
   atropine, curare - binds to and prevents Ach from binding to receptors → 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
   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

7. Muscular Dystrophy
   (muscle destroying diseases)
   some are fatal, others have little impact on life expectancy
   Duchénes: 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
   Physiological Cause: sarcolemma deteriorates
   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
   weight gain
   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

9. fibrodysplasia ossificans progressiva
   also called “statue disease”
   a disease that progressively turns muscles into bone tissue
   caused by a single mutation in gene: ACVR1

10. 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

10. Joubert Syndrome
    single gene mutation that disrupts prenatal development of a brain region that controls muscle coordination
    affected individuals are clumsy when walking or using their hands, have irregular breathing and eye movements. Patients with severe symptoms tend to die young.
    first described ~1970; affects 1 in 30,000 people

11. Heavy Exercise
    can trigger heart attacks in some;
    even in the fit, chances of heart attach increase during heavy exercise
    → inactive people should not engage in strenuous exercise