# 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



   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

range from extremely small to broad flat sheets

muscle organs each consists of several kinds of tissue:

1. **fibrous connective tissue**



2. **nervous tissue**
3. **muscle tissue**

**1. Fibrous Connective Tissue**

forms continuous sheath from muscle to bone

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

tough strap = **tendon** (=sinews)

broad sheet = **aponeurosis**

tendons are continuous with periosteum of bones

**2. Nervous Tissue**



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

**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 ($\sim 1/4^{th}$ total blood supply)

during heavy exercise they can use up to 11.6 liters/min



($>3/4^{th}$ '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 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 can be named accordcing to:

**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)



# 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**

| | |
|---|---|
| abduct arm | deltoid |
| adduct arm | pectoralis major<br>latissimus dorsi |

**flex/extend**

| | |
|---|---|
| flexors | pectoralis major |
| extensors | latissimus dorsi |

### C. Muscles that move forearm

**flex/extend**

| | |
|---|---|
| flexors | biceps brachii<br>brachialis<br>brachioradialis |
| extensor | triceps brachii |

### D. Muscles that move wrist and fingers

| | |
|---|---|
| **flexes wrist** | flexor carpi radialis<br>flexor carpi ulnaris |
| **extends wrist** | extensor carpi radialis<br>extensor carpi ulnaris |
| **flexes fingers** | flexor digitorum |
| **extends fingers** | extensor digitorum |



### E. Muscles that move thigh

**abduct/adduct**

| | |
|---|---|
| abduct thigh | tensor fascia latae |
| adduct thigh | adductor longus<br>adductor magnus<br>gracilis |

**flex/extend**

| | |
|---|---|
| flexors | sartorius<br>rectus femoris<br>tensor fascia latae |
| extensors | gluteus maximus<br>biceps femoris<br>semitendinosus<br>semimembranosus |

### F. Muscles that move lower leg

| | |
|---|---|
| **flexors** | biceps femoris<br>semitendinosus<br>semimembranosus<br>sartorius |
| **extensors** | rectus femoris<br>vastus lateralis<br>vastus medialis |

### G. Muscles that move foot

**dorsiflex/plantarflex**

| | |
|---|---|
| dorsiflexors | tibialis anterior |
| plantarflexors | gastrocnemius<br>soleus |



## Head and Trunk Muscles

### A. Muscles of the head and neck

| | |
|---|---|
| **sphincters:** | orbicularis oculi (close eye)<br>orbicularis oris (close mouth) |
| **chewing:** | closes jaw: masseter, temporalis, orbicularis oris<br>opens jaw: platysma |
| **facial expression:** | frontalis (raise eyebrows)<br>orbicularis oculi (squint)<br>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)<br>trapezius (extends head) |

### B. Breathing Muscles

| | |
|---|---|
| **inspiration** | contract diaphragm<br>external intercostals (elevates rib cage) |
| **expiration** | relax diaphragm<br>internal intercostals (depresses rib cage) |

### C. Muscles of the Abdominal Wall

| | |
|---|---|
| **layers** | external oblique<br>internal oblique<br>transversus abdominis<br>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, 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

## 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 foreward

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

eg. disuse atrophy, in cast for fracture

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



→ 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



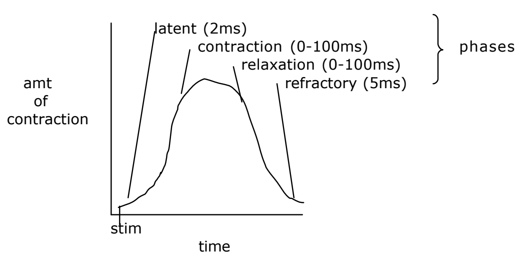
# Muscle Organ Physiology

## Kinds of Muscle Contractions

**1. Twitch**

the process of **<u>muscle cell</u>** contraction just described = twitch

single stimulus → 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



skeletal muscles contract only if stimulated

stimulus must be above **threshold**

greater stimulus ≠ greater contraction

**<u>BUT:</u>**

muscle *cells* rarely act alone

muscle ***organs*** operate on principle of **"graded strength"**

**<u>Motor Units</u>**

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
→ 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 |

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



# Energy Requirements

<u>**Energy Requirements**</u>

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**:

glucose + $O_2$ → $CO_2$ + $H_2O$ + 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**

<u>but</u>
→ 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 ATP's/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



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



# Effects of Aging on Muscular System

strength and muscle mass peak in 20's

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



# Disorders of the Muscular System

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**:

**R**est – prevents further injury
**I**ce – helps reduce swelling
**C**ompression – with elastic, helps prevent fluid accumulation
**E**levation – promotes drainage

**1. Cramps and Spasms**

abnormal uncoordinated contractions of various muscle groups

especialy 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 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 →prolonges 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

Duchenes: sex linked recessive trait; usually inherited but can occur spontaneously

Symptoms: muscle stiffness, difficulty relaxing muscles, muscle weakness, difficulty walking, drooping eyelids, progresive 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



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 vission

difficulty swallowing or speaking are comon

## 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