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**

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**

speech, facial expression, hand gestures, body language, writing

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

the shapes of muscle organs ranges 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 several layers of sheaths around individual cells and the whole organ and extends to the periosteum of each bone

very tough and strong yet flexible, very elastic

→mostly made of collagen fibers

→ very strong, rarely separated from bone or muscle

arranged in overlapping layers:
surrounding whole organ = **epimysium**
surrounding fascicles = **perimysium**
surrounding individual cells = **endomysium**

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 ~1/4th total blood supply at rest (~1.25 liter of blood/min)

during heavy exercise they can use >3/4th 's of all blood pumped by the heart (up to 11.6 liters/min)

these layers extends beyond the muscle cells and attaches each muscle organ to bone or to other muscles

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

broad sheet = **aponeurosis**

tendons are continuous with periosteum of bones

tendons are often surrounded by **tendon sheath** of synovial membrane

→fluid lubricates tendons to reduce friction

also are synovial sacs = **bursae**

scattered between some tendons and muscles

wherever there is lots of friction and tension

2. Nervous Tissue

all skeletal muscles are under direct control of the CNS

skeletal muscles will not contract without stimulation

skeletal muscles are innervated by **motor neurons** (voluntary)

each motor neuron branches into 200 or so **synaptic knobs**

each synaptic knob synapses with a single muscle cell

each neuron typically innervates a few dozed to a few hundret muscle cells

the connection between a neuron and a muscle cell = **neuromuscular junction**

at **motor end plate**

it's not a direct connection

there is a gap, or **synapse**, between the neuron and the muscle cell

3. Muscle Tissue

close to half of body consists of muscle tissue

consists of elongated muscle cells,

spindle shaped, up to 1 ft long, striated, voluntary

= **muscle fibers**

able to contract about half their length for movement

Some Basic Principles of Voluntary Muscle Function

1. Bones act as levers, articulations as pivots

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 working as a group

= **functional groups**

prime mover

synergists

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)

origin and insertion
(sternocleidomastoid)

number of origins
(biceps, triceps)

shape
(deltoid, trapezius)

action
(flexors, extensors)

Examples of Human Muscle Groups:

Muscles of the Appendages

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

A. Muscles that move the pectoral girdle

levate/depress
levates & depresses scapula — trapezius

B. Muscles that move the upper arm

adduct/abduct
abduct — deltoid
adduct — pectoralis major

flex/extend
flex — pectoralis major
extend — latissimus dorsi

C. Muscles that move forearm

flex/extend
flex — biceps brachii
extend — triceps brachii

D. Muscles that move the hand

flex/extend
flex — on ventral surface of forearm
extend — on dorsal surface of forearm

E. Muscles that move thigh

abduct/adduct
abduct — tensor fascia latae
adduct — adductor longus
flex/extend
flex — rectus femoris
extend — gluteus maximus

F. Muscles that move lower leg

flex/extend
flex — biceps femoris
extend — rectus femoris

G. Muscles that move foot

dorsiflexion/plantarflexion
dorsiflexion — tibialis anterior
plantarflexion — gastrocnemius

Head and Trunk Muscles

A. Muscles of the head and neck

sphincters: orbicularis oculi (close eye)
orbicularis oris (close mouth)

chewing: closes jaw — masseter

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 for contraction

can shorten substantially when stimulated

most muscle 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

eg calf muscles can support 1 ton

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

lots of **mitochondria**
for energy generation

some cell structures have taken on new functions:

cell membrane = **sarcolemma**

Muscular Dystrophy

a group of muscle destroying diseases
→ **sarcolemma** deteriorates

some types are inherited (sex linked) others may occur spontaneously

some are fatal usually by the age of 20 yrs
others have little impact on life expectancy

Symptoms: muscle stiffness, difficulty relaxing muscles, muscle weakness,

difficulty walking, drooping eyelids,

progresive muscle wasting progresses from extremities upward

biotech trying to replace gene that makes missing protein

cytoplasm = **sarcoplasm**
ER = **sarcoplasmic reticulum**

T tubules

tubes that open to cell surface and 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** → mainly actin

Muscle Cell Contraction & Relaxation:

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

Relaxation

1. ACh is rapidly broken down by ACh esterase
   → stops generation of muscle action potential
2. When stimulus stops, Ca^{++} ions reenter SR
3. Troponin moves back in to block interaction of actin and myosin, muscle cell relaxes

other controls of muscle cell contractions

the **nerve impulse** is the ultimate control of whether a muscle cell contracts or not

→ most cases of paralysis are not due to defective muscles but to muscles not receiving an impulse to contract

conditions at the **synapse** can also affect whether a cell contract or not

eg. too few **Ca^{++} ions** in body fluids can prevent the release of ACh

eg. **Botulism toxin** - blocks release of Ach →paralysis

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

eg. **nicotine** - mimics Ach →prolonges hyperactivity

eg. **black widow toxin** – stimulates massive release of Ach →causes intense cramping & spasms

Myasthenia Gravis (Heavy weakness)

autoimmune disease that mostly affects women, 20-50 yrs old

immune system attacks **ACh receptors**

shortage of ACh receptors prevents fibers from contracting

causes weakness of skeletal muscles,

damage leads to easy fatigue and weakness on exertion

often, eyes are affected with drooping eyelids and double vission

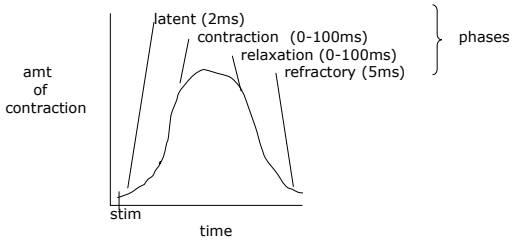
difficulty swallowing or speaking are comon

Muscle Organ Physiology

Twitch

The kind of contraction just described is referred to as a **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

stimulus must be above **threshold**

greater stimulus ≠ 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

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

Tetanus

another kind of muscle contraction is **tetanus**

series of rapid stimuli cause sustained contraction of a muscle

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**

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

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**:

$$glucose + O_2 \rightarrow CO_2 + H_2O + ATP$$

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

→ 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 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)

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

muscle cells can use various substrates for aerobic respiration:

glucose

first from glycogen inside cell then from blood

fatty acids

sometimes amino acids

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

Muscle Fittness; Use & Disuse

<u>Kinds of Skeletal Muscle Fibers:</u>

Skeletal muscle fibers are not all alike:

two of the main types are: **red** & **white** fibers

red = high myoglobin content
more capillaries
more mitochondria
fewer myofibrils
most energy from aerobic respiration
resistant to fatigue

white = less myoglobin
fewer capillaries
fewer mitochondria
lots more myofibrils
energy mainly from anaerobic respiration
short bursts of strength but fatiques easily

most of our muscle organs consist of a combination of these two kinds of fibers

there are different proportions in different kinds of muscles:

eg. more red fibers in postural muscles

eg. more white in biceps brachii, gastrocnemius

various types of exercise can induce changes in the proportion of the 2 kinds of muscle fibers

nonathletic types have ~44% red fibers, 55% white

endurance exercises (running, swimming) increases proportion of red fiber

eg. marathon runners up to 82% red, 18% white

eg. most cyclists have 60% red; 40% white

(Lance Armstrong has ~ 80% red fibers)

strength exercises (weight lifting) increase size and strength of white fibers

eg. sprinters & jumpers ~37% red and 63% white fibers

<u>Muscle Fittness</u>

muscle cells can't generally divide to produce new cells

muscle cells stop dividing at birth (# fixed at birth)

→ we have fewer muscles cells as adults than we had as newborns

but muscle cells can grow greatly in size when exercised

→ exercise stimulates increase in myofibrils, each muscle cell gets larger

well exercised muscle cells also develop more mitochondria, more myoglobin

and glycogen and a greater density of capillaries

also, greater muscle use adds more nuclei to a muscle fiber

muscle cell development is also affected by sex hormones

→ males' muscles respond better than females' to exercise

Steroid abuse

normally testosterone promotes bone development and muscle mass

many athletes believe megadoses improve performance

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

muscles must be used continuously to keep them in shape

when muscle cells are not used they get smaller

the actual fibers get smaller but the nuclei remain

recent (2010) experiments have found that the many nuclei in skeletal muscle fibers act as a type of muscle memory that allows muscles to bounch back more quickly when retrained

those extra nuclei help muscles to recover much more quickly after a period of disuse

→ finding suggests that exercise early in life may help fend off frailness in elderly if they remain active

they can quickly regrow when exercise resumes

with age or chronic disuse muscle cells die and are replaced by connective tissue (**fibrosis**)

→ "use it or lose it"

eg. lack of stimulation or immobilization (splint or cast) muscle cell mass can decrease 5%/day down to 25% loss

→ physical therapy helps to prevent it

can also stimulate muscles electrically to reduce atrophy

must also be careful of exercising too intensely:

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

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 muscle injuries are treated with **RICE**:

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

Disorders of the Muscular System

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. 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

4. 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

5. **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

6. **fibrodysplasia ossificans progressiva**

also called "statue disease"

a disease that progressively turns muscles into bone tissue

caused by a single mutation in gene: ACVR1

7. **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