Muscle Cell Anatomy & Function

(mainly striated muscle tissue)

General Structure of Muscle Cells (skeletal)

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**
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)
various bands and zones
one set = sarcomere
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

sarcoplasm contains an abundance of:

glycogen (=animal starch) - a form of stored energy
myoglobin – a molecule that can store some O_2

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^{++} 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:

   ATP is needed for both attachment and release of each myosin head

Relaxation

1. When stimulus stops, Ca^{++} ions reenter SR

2. interaction between actin and myosin is blocked,

3. muscle cell relaxes

Muscle cells grow when exercised and shrink when not used

yet muscle cells can't divide to produce new cells

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

→ 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

when muscle cells are not used they shrink

eg. disuse atrophy, in cast for fracture

they can quickly regrow when exercise resumes

if atrophy becomes too advanced the fibers die and are not replaced
→ physical therapy

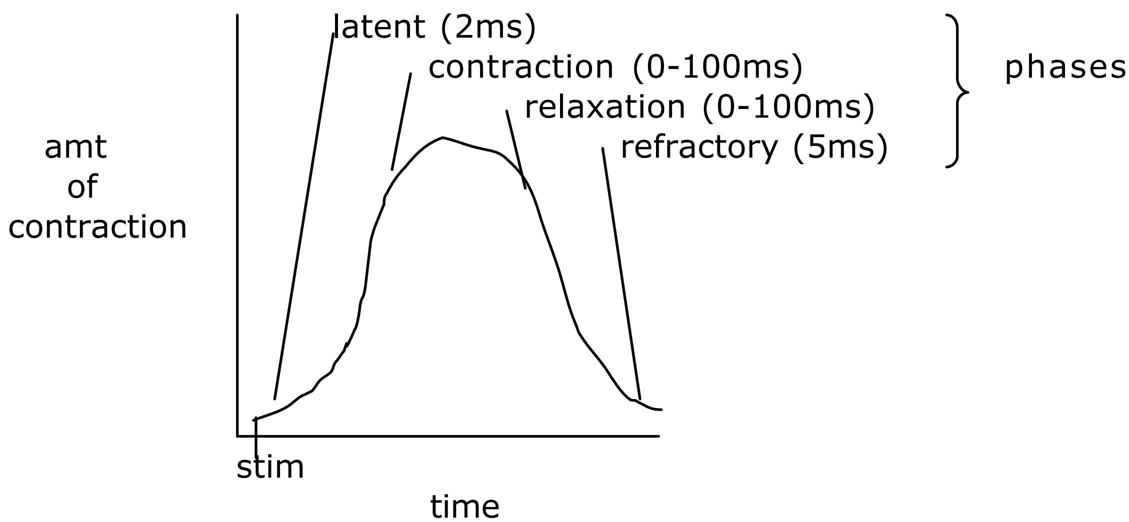
Muscle Organ Physiology

Kinds of Muscle Contractions

1. Twitch

the process of **muscle cell** 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 nervous
electrical

chemical
injury

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

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 organ 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

can experimentally generate other kinds of contractions:

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

Energy Requirements

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

but cells cannot store ATP
(only about 5 seconds worth)

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

glucose + O_2 → CO_2 + H_2O + ATP

Aerobic Respiration

main energy providing pathway of all cells including muscle cells

requires lots of **mitochondria**

requires lots of $\mathbf{O_2}$ (rich blood supply)

produces 38 ATP vs 2 ATP per glucose molecule

also produces carbon dioxide and water as final waste products:

CO_2 not as toxic as lactic acid (but does affect blood pH)
CO_2 is voided through the lungs
H_2O is a significant source of water in body fluids; ~250ml/day

→ 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))

Anaerobic Respiration

in first minute of muscle use 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)

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 O2 needed to
remove lactic acid, restore creatin phosphate, replace glycogen stores

all non aerobic sources of ATP during
muscle activity contribute to this debt

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