Muscle Organ Physiology

Kinds of Muscle Contractions

1. Twitch
   the process of *muscle cell* contraction just described = twitch

   single stimulus → single contraction

   
   ![Graph showing twitch contractions]

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

   eg. eye = .01 sec
   eg. gastrocnemius = .03 sec

   When muscle cell is stimulated 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 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

the *degree of contraction* depends on length of muscle organ and muscle fibers within:

muscle contract about 1/2 their resting length
→ longer muscles produce greater shortening but may be less powerful

the *strength* (force) of contraction of a muscle organ depends on:

1. # of motor units (muscle fibers) stimulated
2. relative size of muscle cells – how many myofibrils
   (exercise leads to muscle hypertrophy)
3. Nature of *“series elastic elements”* ~ noncontractile part of muscle; slack in system
4. Load
   heavier load produces stronger contraction
5. Degree of muscle stretch
   if overstretched, can’t contract → no overlap
6. Oxygen and nutrient availability, preexisting fatigue, etc

we 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 warm up 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

> requires lots of glucose

cell can store some **glycogen**

> this takes lots of oxygen

cell stores some O₂ on **myoglobin**

but

> complex series of reactions (~30 rxns)

glycolysis → Krebs Cycle → ETS

> Takes time (~1 min (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 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

e.g. 100 M dash:
~12 seconds of intense muscular activity
requires 6 liters of O2 (1.5 gal) for total aerobic energy production
but maximum the body can deliver in 12 sec is 1-2 liters
therefore, oxygen debt = 4.8 liters
requires rapid, deep breathing for several minutes after running

stored ATP, CP and anaerobic glycolysis can provide energy for strenuous activity for ~1 minute

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>ATP</th>
<th>Creatin Phosphate</th>
<th>Anaerobic Respiration</th>
<th>Aerobic Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>10</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>20</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>30</td>
<td>ATP</td>
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<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>40</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>50</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
<tr>
<td>≥60</td>
<td>ATP</td>
<td>ATP</td>
<td>ATP + lactic acid</td>
<td>ATP</td>
</tr>
</tbody>
</table>

within 30 minutes after exercise some lactic acid washes into blood
\(\rightarrow\) can be used by some body cells for energy

Kinds of Skeletal Muscle Fibers:

Skeletal muscle fibers are not all alike:

1. Red vs white fibers
   - red = high myoglobin content
   - more capillaries
   - more mitochondria
   - white = less myoglobin
   - fewer capillaries
   - fewer mitochondria

2. Also vary in speed of contraction
   - how fast they extract energy from ATP
   - fast twitch
   - slow twitch

3. Also vary in how quickly they fatigue
   - aerobic (oxidative) resistant to fatigue
   - anaerobic (glycolytic) very susceptible to fatigue

These variations result in three basic kinds of skeletal muscle fibers:

- slow oxidative (red)
- intermediate fibers (pink)
- fast glycolytic (white)

production
eg. liver, heart muscle, kidney cells
by then aerobic respiration is generating ATP for continued activity

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

most skeletal muscles consist of various combinations of these three types of fibers

skeletal muscle fibers of any one motor unit are all the same

the fiber composition of each muscle is at least partially genetically determined

different kinds of motor units may be recruited
eg. weak contr \(\rightarrow\) slow oxidative
    stronger \(\rightarrow\) fast glycolytic

different proportions in different muscle types
eg. more red - postural muscles, soles
    more white – biceps brachii, gastrocnemius, extrinsic eye muscles
**Muscle Fitness; Use & Disuse**

Various types of exercise can induce some changes in the proportion of different kinds of muscle fibers.

- **Nonathletic types** have 40-50% slow twitch fibers.
- **Endurance exercises** (running, swimming) changes proportion of fast glycolytic to slow oxidative.
- **Most cyclists** have 60% slow twitch fibers; Lance Armstrong has ~80% slow twitch fibers.

Muscle cells can’t generally divide to produce new cells:
- No new cells; change in myofibrils, capillaries, etc.
- We have fewer muscles cells as adults than we had as newborns.

Muscles must be used continuously to keep them in shape.

**Myofibrils**

<table>
<thead>
<tr>
<th>Proportion of slow and fast twitch fibers in Quadriceps Femoris of male athletes</th>
<th>Slow oxidative</th>
<th>Fast glycolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marathon runners</td>
<td>52%</td>
<td>18%</td>
</tr>
<tr>
<td>Swimmers</td>
<td>74%</td>
<td>26%</td>
</tr>
<tr>
<td>Average man</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>Sprinters &amp; jumpers</td>
<td>37%</td>
<td>63%</td>
</tr>
</tbody>
</table>

- When muscles begin to atrophy 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 bounce 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.

**Exercise & Disuse**

- 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.

They can quickly regrow when exercise resumes:
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- 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.
- Muscles must be used continuously to keep them in shape.
- With age or chronic disuse muscle cells degenerate and are replaced by connective tissue (fibrosis).

**Cranps 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.

Treatment: apply heat to tense/tight muscles; cold to sore/tender muscles.

**Fibrosis**

Skeletal muscle fibers degenerate and are replaced by fibrous connective tissue associated with aging, loss of strength.

**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.
- Increases isometric strength.
- Rise in body weight.
- Not sure if these changes result in better performance.
- Negative data: bloated faces, shrunken testes, infertility, liver damage.
alters blood cholesterol levels
1/3rd of users exhibit serious mental problems such as manic behaviors

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%
especially loose fast twitch fibers

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

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

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
  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  paralyis
=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 3%/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, 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
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
    negative data:
        bloated faces
        shriveled testes
        infertility
        liver damage
        alters blood cholesterol levels
        1/3 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 fit chances of heart attach increase during heavy exercise
    inactive people should not engage in strenuous exercise

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