

General Information Muscles

A. Muscle tissue - specialized tissue that generates force

1. *about 40-50% of body weight*

B. Myology - study of muscles

C. Characteristics of muscle tissue

1. ***excitability - ability to receive & respond to stimuli***
 - a. stimulus - internal or external changes that are strong enough to imitate an impulse (action potential)
2. ***contractility - ability to generate force to shorten & thicken to do work***
3. ***extensibility - ability to be stretched***
4. ***elasticity - ability to regain shape***

D. Functions

1. ***motion (both reflex & voluntary)***
 - a. includes heart beating, etc.
2. ***posture maintenance - by contraction of skeletal muscles***
3. ***heat production***
 - a. up to 85% of body heat!

E. Types

1. ***skeletal muscle tissue***
 - a. striated
 - b. voluntary
 - c. mainly attached to bones & moving parts of body, but also skin, other muscles, deep fascia
2. ***Cardiac muscle tissue***
 - a. striated
 - b. involuntary
 - c. built in controls (involuntary nerves & hormones)

3. **Smooth muscle tissue**

- a. helps with maintenance of internal environment
- b. in walls of blood vessels, stomach & intestines; also in hair follicles
- c. non-striated
- d. involuntary with built in controls

II. **Skeletal Muscle Tissue**

A. **Connective Tissue Components**

1. ***fascia - sheet or band of fibrous, connective tissue under skin or around muscles & organs***
2. ***superficial fascia - subcutaneous layer***
 - a. storage of waste & fat
 - b. insulation
 - c. mechanical protection
 - d. pathway for nerves & vessels
3. ***deep fascia - lines body wall & holds muscles together***
 - a. allows
 - v free movement, support for blood vessels, filler & origins
4. ***other coverings - fibrous connective with collagen, etc.***
 - a. epimysium - wraps entire muscle
 - b. perimysium - wraps fasciculi [bundles of muscle fibers (cells)]
 - c. endomysium - surrounds fibers
5. ***tendons - cords***
6. ***aponeurosis - sheets***
7. ***tendon sheaths (synovial)***

B. **Nerve & Blood Supply**

1. well innervated & vascularized

- a. artery & vein for each nerve
- b. capillaries within endomysium
 - v each fiber is close to 10 or more caps.
- c. each fiber makes contact with synaptic end bulb of a nerve cell

C. Histology

1. muscle fibers (= myofibers) cellular units of muscles

- a. parallel cells
- b. 10-100 um in diameter
- c. up to 30 cm in length!

2. muscle fiber construction

- a. sarcolemma - membrane sheath
- b. sarcoplasm - cytoplasm
- c. multinucleate - syncytial tissue
- d. sarcoplasmic reticulum - like smooth ER
 - v terminal cisterns
 - v transverse tubules (T-tubules)
 - extensions of sarcolemma
 - v triad - one T-tubule & adjacent cisterns
- e. myofibrils
 - v cylindrical structures 1-2 um in diameter in fiber
 - v longitudinal
 - v made of myofilaments
 - thin - 6nm
 - thick - 16nm
- f. sarcomeres - compartments of myofibrils

- v z-lines - dense zones on ends
 - v A (anisotropic) band - length of thick myofilaments
 - v I (isotropic) band - thin myo only
 - v H zone - area in "A" with only thick myofilaments
 - v M-line - transverse threads that connect middle parts of adjacent thick myofilaments
- g. thin myofilament structure
- v anchored at z lines
 - v made of actin
 - double helix of actins
 - each has myosin binding sites
 - o connects to cross-bridge on myosin
 - v tropomyosin - protein in strands next to actin helices
 - v troponin - regular intervals
 - troponin I - actin binding site
 - troponin C - Ca binder
 - troponin T - tropomyosin binder
 - v tropomyosin - troponin complex
 - important in contraction physiology
- h. myosin - like golf club shape
- v in parallel with heads out
 - v heads - cross-bridges
 - have actin-binding sites
 - have ATP-binding sites

3. Contraction

- a. Sliding filament Theory
- v myosin cross-bridges pull on thin myofilaments v slide them toward H-zone
 - v sarcomere shortens but not filaments
- b. Neuromuscular Junction

- v neuron delivers stimulus
- v axon - up to 91 cm long
- v bundle forms nerve
- v motor neuron - neuron to muscle
- v detailed structure
 - telodendria - branched end of axon
 - motor end plate - sarcolemma next to axon
 - neuromuscular junction (= myoneural junction)
 - synaptic end bulbs - expanded telodendria
 - ⊕ synaptic vesicles - contain neurotransmitters
- v synaptic trough - invaginated area of sarcolemma
 - synaptic cleft - space between bulb & trough
 - subneural clefts - folds of trough
 - o increase receptor area
- v acetylcholine ACH
 - released at cleft when nerve action potential arrives
 - alters Na^+ & K^+ ions ultimately results in muscle action potential
 - # leads to muscle contraction

4. motor unit

- a. motor neuron with all muscle fibers it stimulates
 - v 150 fibers/neuron average
- b. range 2000/fiber in gastrocnemius to 10/fibers in extrinsic eye muscles
- c. recruitment
 - v way of resting some while maintaining tension in muscle

D. Physiology of Contraction

1. Conditions prior to contraction

- a. Ca^{2+} ions low in sarcoplasm but high in sarcoplasmic reticulum
- b. ATP conc. high including attachments to ATP-binding sites of myosin cross-bridges

- c. myosin cross bridges blocked from actin by tropomyosin-troponin complex on actin & by ATP bound to myosin cross-bridges

2. **Initiation of Contraction**

- a. nerve action potential arrives at synaptic end bulb
 - v causes release of a little Ca^{2+} ions to synaptic end bulb
 - v this causes release of acetylcholine from vesicles into synaptic cleft
- b. (ACH) binds with receptor sites on sarcolemma of muscle fiber
 - v causes membrane proteins (acetylcholine-gated ion channels) to open & allow rapid influx at cations (esp. Na^+)
- c. muscle action potential results
- d. muscle action potential travels along sarcolemma & through transverse tubules
- e. action potential causes sarcoplasmic reticulum to release Ca^{2+} ions into sarcoplasm around micro filaments
 - v through calcium release channels
- f. Ca^{2+} combines with troponin C & causes structural change
- g. moves troponin & tropomyosin to side
- h. exposes myosin-binding sites on actin!
- i. ATP on myosin splits ($\text{ADP} + \text{P}$) & energy causes myosin cross-bridges to bind to actin

3. **Contraction**

- a. $\text{ADP} + \text{P}$ release from myosin & myosin changes orientation
- b. myosin cross bridge moves toward H zone (=power stroke)
- c. actin thin filaments slide past thick myofilaments
- d. ATP combines again & causes repeat
- e. Z lines are pulled closer
 - v up to 50% of distance of sarcomere

4. **Relaxation**

- a. acetylcholine digested by acetylcholinesterase
- b. Ca^{2+} actively transported into sarco. reticulum
- c. troponin-tropomyosin complex reattached to actin

- d. ATP breaks myosin cross-bridge/actin bonds

5. Note: rigor mortis due to lack of ATP

E. Energy for Contraction & Relaxation

1. Existing ATP

- a. $\text{ATP} \rightarrow \text{ADP} + \text{P}$
- b. enough to last only 5-6 seconds of vigorous exercise

2. Phosphagen System

- a. kicks in after existing ATP is depleted
- b. phosphocreatine
 - v high energy molecule found in muscle tissue
 - v 2-3 x's conc of ATP
 - v process:
 - phosphocreatine \rightarrow creatine + phosphate + energy
 - energy + ADP + P \rightarrow ATP
- c. ca. 15 sec./max for short bursts (e.g. 100m dash)

3. Glycogen - Lactic Acid System

- a. kicks in after phosphagen system
- b. glycogen converted to glucose
- d. requires Ca^{2+} & calmodulin, etc.
- a. glycolysis releases 2 ATP/glucose
- b. pyruvic acid converted to lactic acid so glycolysis can continue in absence of O_2
- c. ca. 30-40 sec. of max muscle activity (e.g. 400-m dash)

4. Aerobic System

- a. Pyruvic acid enters mitochondria
- b. process (Krebs cycle & electron transport chain) $\text{pyruvic acid} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{energy (34 ATP)}$
- c. also - metabolism of lipids, amino acids, etc.
- d. sustained activity

F. All-or-none Principle - threshold stimulus --> total contraction only for ind. fibers.

G. Kinds of Contractions

1. *Twitch contraction*

- a. follows threshold stimulus
- b. rapid, jerky contraction
- c. myogram of frog muscle
 - v latent period
 - 10 millisecon.
 - released from SR
 - v contraction period
 - 50 millisecon
 - cross-bridge act.
 - v relaxation period
 - active transport. of Ca^{2+} etc.
- d. refractory period
 - v time required for muscle to be able to respond to stimulus
 - 5 millisecon in skeletal
 - 300 millisecon in cardiac

2. *Other muscle fiber contraction patterns*

- a. wave summation
 - v stimulus received before full relaxation
- b. tetanus
 - v allows smooth sustained contractions

3. treppe

- * strength is more in subsequent contractions
- * "warmup" phenomenon is due to this

4. isotonic vs. isometric type contractions

- * isotonic - shortening occurs

* isometric - tension constant but no shortening

H. Muscle Tension

1. related to such things as

- a. freq. of stimulus
- b. # of fibers contracting
- c. contractile & elastic elements
- d. length of myofibers

* highest tension at max. thin filament & thick filament overlap

* none at 175% +

I. Muscle Tone

1. state of sustained partial contraction
2. maintains posture, etc.
3. tension monitored by muscle spindles
4. disorders

a. hypotonia

* flaccid muscles symptoms

* can result from inactivity,

* nervous disorders, etc

* flaccid paralysis

b. hypertonia

* spasticity & rigidity

* spastic paralysis

* due to nervous disorders, etc.

c. muscle atrophy vs. hypertrophy

J. Types of Skeletal Muscle Fibers

1. Color - red vs. white

a. red - has more myoglobins (an O₂ storing pigment)

* smaller diameter

- * more mitochondria & capillaries

b. white - less myoglobin

- * more SR

2. Velocity of Contraction

a. Type I - slow twitch

- * red fibers

- * slow but steady ATP splitting

- * resistant to fatigue

- * common in postural muscles

b. Type IIB - fast twitch (glycolytic)

- * white but

- * lots of glycogen

- * can do anaerobic met.

- * can split ATP rapidly/contr. fast

- * fatigue easily

- * common in arm

c. Type IIA - fast twitch (oxidative)

- * rare in humans

- * characteristics of both type I & IIB

III. Cardiac

A. General Structure

1. one centrally-located nucleus per fiber
2. more sarcoplasm & mitochondria larger & more numerous
3. action/myosin arrangement similar but not in discrete myofibrils
4. SR is well-developed and t-tubules a little different (due to lack of discrete myofibrils)
5. myofibers branch & interconnect within networks
6. two distinct networks, atrial and ventricular, separated from each other by connective tissue insulation

- a. intercalated discs exist between cardiac fibers in the same network
- b. disc areas have high concentrations of desmosomes "welds" that help hold the fiber together and gap junctions that conduct muscle action potentials from one fiber to the next without stopping

B. Physiology

1. rhythmic contractions; requires large amounts of O₂ and ATP.
2. autorhythmicity (intrinsic stimulation) in three types of highly specialized cells in "conduction system"
 - a. Sinuatrial (SA) node cells
 - Extracellular Ca⁺⁺ influx instead of Na⁺ results in depolarization of the sarcolemma
 - Cycles at about 70-80 times/minute
 - b. Atrioventricular (AV) node cells
 - Is not directly connected to SA node
 - Cycles at about 50 times/minute
 - Is stimulated by atrial myocardium due to faster cycle of SA node
 - c. Purkinje fibers
 - Reach papillary muscles before rest of lower ventricles
 - Communicates with lower ventricles earlier than sides of ventricles
 - Cycle at a lower rate than nodes
3. contractions 10-15X longer due to slower moving action potentials and prolonged Ca⁺⁺ delivery to filaments
4. long refractory period
5. regulatory stimulation and inhibition of heart occurs via the autonomic nervous system, specifically from the medulla oblongata; mostly communicate to the SA & AV nodes but also to the myocardium of the ventricles
 - cardioacceleratory center (sympathetic nervous system)
 - cardioinhibitory center (parasympathetic nervous system via the vagus nerve)
 - these centers modify the base rate of the heart and can influence the force of contraction

- these centers receive regulatory input from the hypothalamus of the brain which, among many other things, monitors homeostasis in the body

IV. Smooth Muscle

A. General Structure

1. fibers *5-10um x 30-200um long

- * shorter than skeletal
- * tapered
- * single nucleus
- * thick & thin myofilaments but no sarcomeres
 - # 10-15 thin/1 thick (2:1 in skeletal)
- * intermediate filaments anchor to dense bodies

2. Dense bodies - serve similar purpose as Z lines

- * bundles of intermediate fibers attach to dense bodies
 - # thick & thin filaments transmit force to inter fibers

3. Caveolae

- * serve purpose like T-tubules of skeletal muscle

4. Types

- * visceral (single-unit) muscle tissue
 - # small arteries; veins & hollow viscera
 - # have conducting gap junctions
 - # waves of contractions
- * multiunit smooth muscle tissue
 - # individual fibers have own motor units
 - # walls of large arteries, airways to lungs arrector pili, intrinsic eye muscles (in iris)

B. Physiology

1. duration of contraction/relaxation 5-500x's that of skeletal muscle fibers

- # no T-tubules
- # have different Ca⁺⁺ binding mechanism

Ca^{2+} move more slowly out of SR

allows long-term tone (e.g. in stomach, urinary bladder, blood vessels)

V. Regeneration of Muscle Tissue

A. Satellite Cells Skeletal Muscle

1. replace on individual basis skeletal muscle cells
 - * dormant until needed
 - * not sufficient to compensate for significant damage
2. cannot divide after ca. 1st year
3. healing by fibrous scar tissue

B. Cardiac

1. no mitotic ability
2. no satellite cells
3. healing by scar tissue only

C. Smooth

1. some (e.g. in uterus) can divide
2. can arise from stem cells (pericytes)
3. higher but still limited power of regeneration

VI. Homeostasis

A. Oxygen Debt

1. oxygen needed to
 - * metabolize lactic acid
 - * replenish ATP, phosphocreatine & glycogen
 - * oxygenize hemoglobin & myoglobin
 - * replace air in lungs & fluids with fresh air
2. Maximal O_2 Uptake
 - * max rate during aerobic catabolism of pyruvic acids
 - * affected by sex (male>female), age (max at 20), size (max at large body size), training
 - * rate affects needed for lactic acid production & oxygen debt

B. Muscle Fatigue

1. affected by pH, glycogen stores, etc.

C. Heat Production

1. 85% released as heat
2. initial (contraction & relaxation) v. recovery (ATP restoration)

D. Aging

1. at about 30 years of age muscle loss begins
 - * fat levels in muscles increase

E. Disorders

1. Fibrosis

- * connective tissue hypertrophy

2. Fibromyalgia

- * non articular rheumatic disorders

pain, tenderness & stiffness of muscles & soft tissues (fibrous connective components)

3. Muscular Dystrophies

- * degeneration of muscle fibers

Duchenne (DMD)

--> gene ID'ed

http://www.msco.edu/~bstewart/bstewart/classes/anatomy/muscle_tissues.htm