Muscle Physiology

Part Two

Lecture Outline

- Muscle Function
- Muscle Characteristics
- Muscle Tissue Types
- Skeletal Muscle
  - General Functions of Skeletal Muscle
  - Functional Anatomy
  - Physiology
  - Energetics & Fatigue
  - Contraction Strength
  - Skeletal Muscle Types
  - Adaptive Responses
- Cardiac Muscle Physiology
- Smooth Muscle Physiology

Skeletal Muscle
Energetics & Fatigue

- ATP use is required for
  - maintenance of resting membrane potentials
    - Na^+/K^+ ATPase
  - exocytosis of ACh at the NMJ
    - Possibly kinesin ATPase
  - moving myosin heads back to “energized” state
    - myosin ATPase
  - return of Ca^{2+} into sarcoplasmic reticulum
    - Ca^{2+} ATPase

Skeletal Muscle
Energetics & Fatigue

- Sources of ATP for muscle action
  - Free ATP
    - Only have enough stores for about 5-6 seconds of intense activity
  - Phosphagen System
    - Transfer of high energy phosphate from creatine phosphate to ADP to make ATP

      C~P + ADP $\longleftrightarrow$ C + **ATP**

    - enough for approximately another 10-15 seconds of highly intense muscle action

Skeletal Muscle
Energetics & Fatigue

- Sources of ATP for muscle action cont…
  - Glycolysis (Glycogen-Lactic Acid System)
    - Glycogenolysis converts glycogen to glucose
    - Glucose is split into 2 pyruvate molecules with a net result of 2 ATP, if oxygen is present,
      - pyruvate is converted to acetyl coenzyme A,
    - If oxygen is not present,
      - pyruvate is converted to lactic acid
        - » Contributes to lactic acid accumulation in the muscle tissue
    - Provides enough ATP for an additional 30-40 seconds of intense activity

Skeletal Muscle
Energetics & Fatigue

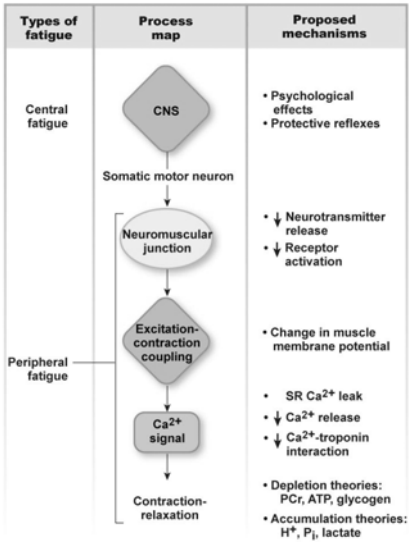
- Sources of ATP for muscle action cont…
  - Aerobic Respiration
    - Citric Acid Cycle + Electron Transport Chain
      - Highly efficient production of 30 – 32 molecules of ATP (net)
      - Long term… as long as oxygen and fuel are present

There are three sources of ATP for aerobic muscle to use: *carbohydrates, fats, and amino acid proteins*. Carbohydrates metabolize the most efficiently and are therefore used first. If carbohydrates are not available, your body metabolizes fat and amino acid proteins. All three of these reactions are called Aerobic Glycolysis because they use glucose and oxygen:

1. Carbohydrate Metabolism: Glucose + 0_2 → 36ATP + $C0_2$ + H_20
2. Fat Metabolism: Fatty Acid + 0_2 → 130 ATP + $C0_2$ + H_20
3. Amino Acid Protein Metabolism: Amino Acids + 0_2 → 15 ATP + $C0_2$ + H_20

Skeletal Muscle
Energetics & Fatigue

- What causes muscle to fatigue?



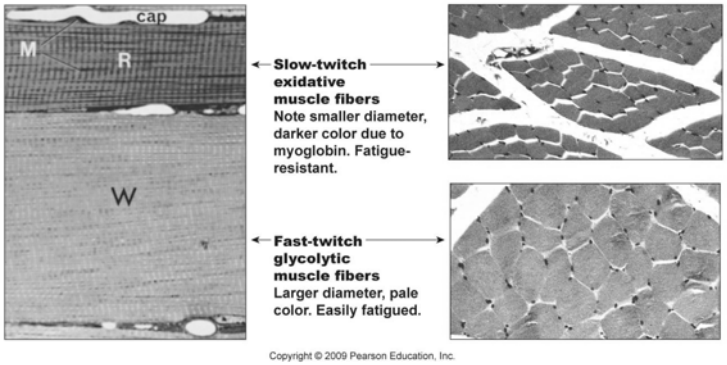
Skeletal Muscle
Types

- All skeletal muscle is skeletal muscle?
  - Yes but there are varieties
    - Oxidative vs. Glycolytic
      - ratio is dependent on genetics
      - Glycolytic muscles
        - » 3 types (Type IIa, IIb, IIx)
        - » Fast contraction action
        - » Generally paler in color due to lower amounts of myoglobin and vascularity
        - » utilize anaerobic pathways for energy
        - » not use for long term endurance activities
      - Oxidative
        - » Use aerobic processes
        - » Long term endurance activities
        - » Highly vascular, more myoglobin

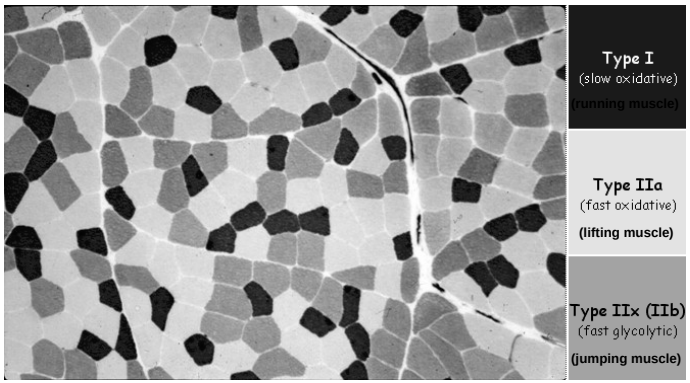
Skeletal Muscle
Types

Fiber Type	Type I fibers	Type II a fibers	Type II x fibers	Type II b fibers
contraction time	slow	moderately fast	fast	very fast
size of motor neuron	small	medium	large	very large
resistance to fatigue	high	fairly high	intermediate	low
activity used for	aerobic	long-term anaerobic	short-term anaerobic	short-term anaerobic
maximum duration of use	hours	<30 minutes	<5 minutes	<1 minute
power produced	low	medium	high	very high
mitochondrial density	high	high	medium	low
capillary density	high	intermediate	low	low
oxidative capacity	high	high	intermediate	low
glycolytic capacity	low	high	high	high
major storage fuel	Triglycerides	CP, glycogen	CP, glycogen	CP, glycogen

Skeletal Muscle
Types



Skeletal Muscle
Types

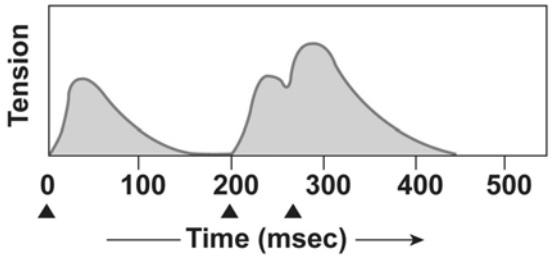


Skeletal Muscle
Strength of Contraction

- The response of skeletal muscle to an action potential in a motor neuron is the **twitch** of the muscle.
- Single twitches may not generate enough force to “get the job done
- What happens when resistance is greater than the force of contraction?
  - Isometric contraction
- How then can a stronger contraction be created in muscle tissue?

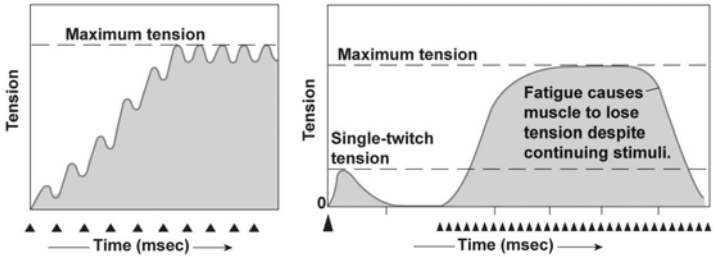
Skeletal Muscle
Strength of Contraction

1. Increase the frequency of action potentials
   – Called summation, as the twitches add together



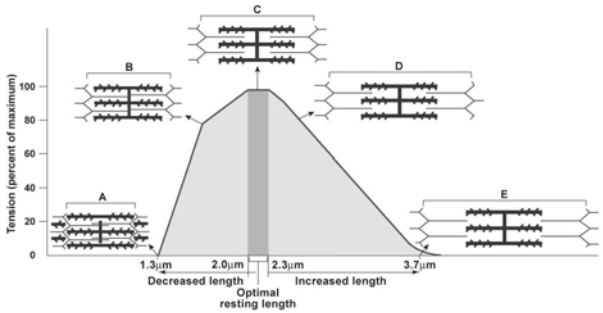
Skeletal Muscle
Strength of Contraction

1. Summation can lead to tetanus
   • unfused and fused depending on frequency of action potentials



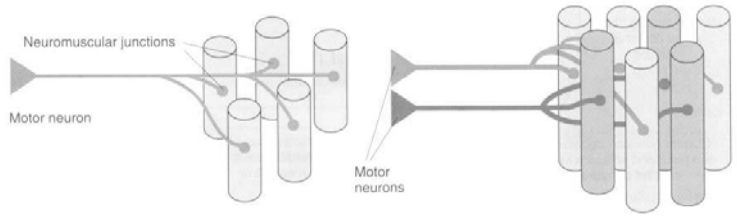
Skeletal Muscle
Strength of Contraction

2. alter the length of the muscle prior to contraction
   – Optimal overlap of myosin and actin allows for the generation of a stronger contraction



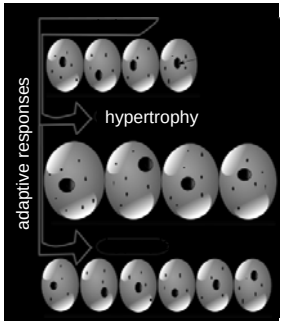
Skeletal Muscle
Strength of Contraction

3. Increase the number of functional motor units
   – Motor unit is a motor neuron and the muscle fibers it innervates
   – Recruitment is adding additional motor units to increase strength



Skeletal Muscle
Strength of Contraction

4. Muscle hypertrophy
   - this is an adaptive response to stressing the muscle and causes an increase in the size of muscle cells
   - may be the result of myofibril enlargement or increase in sarcoplasmic volume
5. Muscle hyperplasia
   - increase in muscle due to formation of new muscle cells
   - theories vary as to how



Skeletal Muscle
Adaptive Response

Overview	Growth In Muscle Fibers Below			
Repetition Range	**Type I**	**Type IIA**	**Type IIB (& IIx)**	**Strength Gains**
1-2 repetitions	Very Low	Low	Low	Excellent
3-5 repetitions	Very Low	Low	Decent to Good	Excellent
6-8 repetitions	Very Low	Good	Excellent	Good
9-12 repetitions	Low	Excellent	Very Good	Good Within Rep R.
13-15 repetitions	Decent	Very Good	Decent to Good	Endurance
16-25 repetitions	Very Good	Diminishing	Low	Endurance
25-50 repetitions	Excellent	Low	Very Low	Endurance

Table taken from: http://www.criticalbench.com/muscle-fiber-type.htm

Cardiac Muscle
General Features

- Shares features with both skeletal and smooth muscle
  - Like skeletal
    - Striated
    - sarcomere structure
  - Unlike skeletal
    - Muscle fibers shorter
    - may be branched
    - have single nucleus
    - T-tubules are larger, less frequent and over the z-discs
  - Like smooth
    - Electrically linked to one another; some exhibit pacemaker potentials
    - under sympathetic and parasympathetic control as well as hormone control

Cardiac Muscle
Physiology

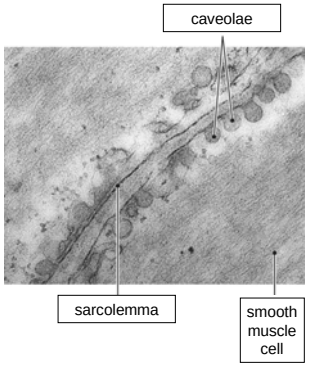
- Adaptations for continued contractions
  - Increased vascularity
  - Increased mitochondria
  - Increased levels of myoglobin
  - Adaptation to prevent summation
    - Influx of Ca^{2+} from ECF through L-type Ca^{2+} channels causing a CICR (Calcium Induced Calcium Release) from the sarcoplasmic reticulum sustains the depolarized state which increases the refractory period...
    - More on this later

Smooth Muscle

- Functional Characteristics
  - Variations in smooth muscle physiology allow for different autonomic tissues to have different characteristics
    - Vascular smooth muscle
    - Respiratory smooth muscle
    - Digestive wall smooth muscle
    - Urinary smooth muscle
    - Reproductive smooth muscle
    - Ocular smooth muscle

Smooth Muscle

- Functional Characteristics
  - Sarcolemma contains caveolae which contain
    - Receptors
      - prostacyclin, endothelin, serotonin, muscarinic receptors, adrenergic receptors
    - g proteins
    - Secondary messenger generators
      - Adenylyl cyclase
      - Phospholipase C
    - ion channels
      - L-type Ca^{2+} channels & K^{+} channels,
    - protein kinases



Smooth Muscle

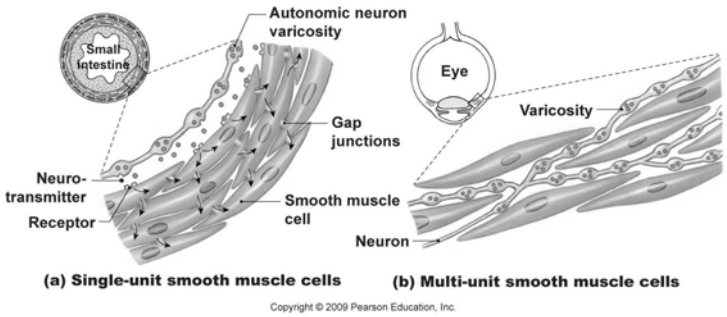
- Functional Characteristics
  - Contraction is controlled by
    - Acetylcholine
    - Norepinephrine
    - Nitric Oxide
  - Electrical properties and action vary
    - May depolarize without contraction
    - May hyperpolarize
    - May contract without a change in membrane potential
  - This results in smooth muscle having many operating parameters and “integrates” the different responses

Smooth Muscle

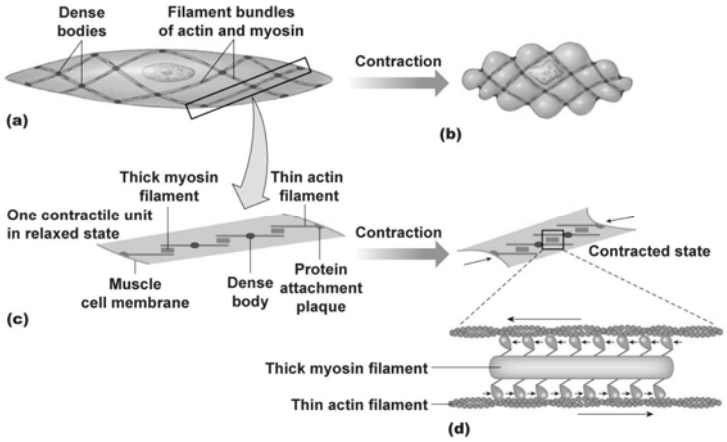
- Functional Anatomical Characteristics
  - actin – myosin are longer but still create contractile force
    - Smooth muscle myosin isoform is slower and longer
    - More actin in smooth muscle (10 to 15:1 actin:myosin ratio vs. 2-4:1 ratio in skeletal)
  - actin anchored in focal adhesions (attachment plaques) on the sarcolemma and dense bodies intracellularly
  - Caveolae
    - Contain variety (see previous slides) of membrane receptors and proteins
  - Autonomic nerves terminate with multiple swellings called varicosities

Smooth Muscle

- Differences between single and multi-unit smooth muscle

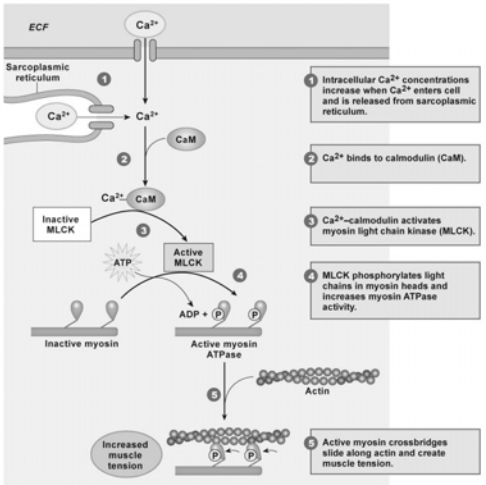


Smooth Muscle



Smooth Muscle

Contraction



Smooth Muscle

Relaxation