Muscles 3:

Contractions, Adaptations & Energy Use
Contractions

• **Isotonic**: Muscle changes length in response to resistance
  - *Concentric*: muscle tension exceeds resistance & muscle shortens
  - *Eccentric*: Resistance exceeds muscle tension and muscle lengthens

• **Isometric**: muscle tension does not exceed resistance and muscle length remains constant
Isotonic

- Tension exceeds Resistance just enough to produce movement
- Muscle shortens as long as Tension > Resistance
  - Ex: lifting this pen
Isometric

- Tension *does not exceed* Resistance
- Muscle remains same length (isometric) as long as Tension < Resistance
  - Ex: pushing against this wall
What affects Tension and speed of contraction?

(a) Increased contractile force
- Large number of muscle fibers activated
- Asynchronous tetanic contractions
- Muscle and sarcomere length slightly over 100% of resting length

(b) Increased contractile velocity
- Predominance of fast glycolytic (fatigable) fibers
- Small load

(c) Increased contractile duration
- Predominance of slow oxidative (fatigue-resistant) fibers

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What fuels our muscles?

1. Adenosine triphosphate (ATP)
2. Creatine Phosphate (CP)
3. Glucose
4. Fats
What fuels our bodies?

• **Adenosine triphosphate (ATP)** - THE energy carrying molecule in the body

• **Muscles store only enough ATP for 1 – 3 sec. of activity (~ 10 twitches)**
  - ATP must be generated continuously
    • Usually via carbohydrate metabolism **with or without** $O_2$
ATP structure
Alternative Fuels

- After depleting ATP stores, muscles turn to other sources:
  - Creatine phosphate (CP) stores energy, in the form of a bound phosphate molecule, that is used to make ATP
  - CP stores enough energy for ~ 15 sec. of muscle contractions (~ 70 twitches)
CP transfers P to make ATP
Glucose (Glycogen)

- After CP, **Glucose** is the next source of energy for production of ATP

- **Metabolism of glucose**
  - *Anaerobic* breakdown of glucose (*glycolysis*) yields 2 ATP molecules (no $O_2$ needed), & provides energy for ~ 130 sec. of contractions (670 twitches)
  - *Aerobic* breakdown of glucose yields 36 - 38 molecules of ATP (*demands* $O_2$), & provides Energy for 2400 sec. (12,000 twitches)
Glucose metabolism

In cytoplasm

In mitochondria
Fat as fuel

- **Triglycerides** (storage form of fats) can be metabolized to generate ATP
  - For low intensity exercise
  - For exercise of long duration
    - Ex: 10 hr. car-to-car approach + climb
- Abundant energy source, even in lean people
- Provides 2x more energy, per gram, as carbohydrate
Resting muscle

- Plenty of $O_2$ around
- Fatty acids are "burned" through **aerobic metabolism** to make reserves of ATP, CP & glycogen
Moderate muscle activity

- Enough $O_2$ around
- Fatty acids and glucose “burned” through **aerobic metabolism** to make ATP as it is used up to power contractions
Peak muscle activity

- Not enough $O_2$ around
- Most (~ 66%) ATP produced via glycolysis.
  - Lactic acid is byproduct
    - At high concentrations, interferes with actin-myosin binding & other cellular enzymes

(c) Peak activity: Most ATP is produced through glycolysis, with lactic acid as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.
Muscle fatigue

• When a muscle can no longer perform at required activity level

• Causes:
  - Not enough energy (ATP, CP, Glycogen)
  - Too many waste products:
    • Drop in blood pH (due to high lactic acid and \( CO_2 \) concentrations)
    • Drop in muscle fiber pH (same cause), reduces \( Ca^{2+} \) binding efficiency and protein interactions
Muscle fiber types = Continuum

**Fast twitch**
- Large diameter
- rapid contraction phase
- few mitochondria
- poor vascularization
- huge ATP hogs

**Slow twitch**
- Small diameter
- slow contraction phase
- tons of mitochondria
- heavily vascularized
- Lots of myoglobin (O₂ storage protein)
Fast vs. Slow

- **Slow fibers**
  - Smaller diameter,
  - Darker color due to myoglobin; fatigue resistant

- **Fast fibers**
  - Larger diameter, paler color; easily fatigued
Muscle Adaptations

- “Rapid” adaptations
- “Long-term” adaptations
- Read the article!
Muscle Adaptations

“Rapid” adaptations

• Increase glycogen storage
• Increase ATP and CP storage
• Increase glucose transport proteins
• Increase neuromuscular coordination

“Long-term” adaptations

• Increased mitochondrial density
• Increased capillary density
• Hypertrophy: increase in size of fibers
  - Only caused by repeated exhaustive stimulation
Physical conditioning (training)

**Anaerobic endurance**
- Muscle activity supported by energy reserves and glycolysis alone
- Affected by:
  - ATP & CP
  - Glycogen stores
  - Tolerance of lactic acid

**Aerobic endurance**
- Muscle activity supported by mitochondrial activities
- Affected by:
  - Substrates available for aerobic respiration (fats, carbs, proteins)