Following Ca\(^{2+}\) release:

**Actin & Myosin Interact:**

- Myosin binding causes:
  1. **Strengthens**:
     - Open to closed cleft conformation of myosin head
  2. Causes conformational changes in:
  3. **Cross bridge Conformational changes result in:**
    - a. Swing hinge:
    - b. Produce piconewtons of:
    - c. Move Thin filaments nanometers of:
    - d. Reduce affinity for ADP: Release:

*Called*:

- Single power stroke shortens Sarcomere by:
  - ADP released following:

**Release of “Flexed” Cross bridge**

- a. Requires:
  - Myosin returns to:
  - Myosin decreases affinity to:
  - Result:
- b. ATP is hydrolyzed into:
  - Resulting in cross bridge:
  - Cross bridge:
  - Ready to:

✓ **IMPORTANT**: ATP hydrolysis necessary for cross bridge:

**Complete Muscle Contraction**

- a. Repeated Cross Bridge “Cycling”
  - One Cycle pulls: 1% of total contraction distance
  - \(~ 100\) cycles =
  - **Complete Contraction**
    - A Band meets

✓ Entire muscle is shortened by:
Contraction Mechanism:

⇒ Excitation-Contraction Coupling

- Action potential stimulates:
  - Calcium initiates:

  IMPORTANT: Calcium is the:

Muscle Relaxation:

a. ATP required to detach:

⇒

b. Calcium RE-uptAKE into:

⇒ Requires:

c. Calcium removal:

⇒ Calcium cannot bind:

⇒ Troponin cannot move:

⇒ Myosin binding site:

⇒ Myosin cannot:

✓ NO Cross bridges =:

IMPORTANCE of ATP: Needed to

1. “Cock” cross bridge:

2. Break:

  • NOT directly responsible for:

3. Relax Muscle !!!!!

★ ACTIVE reuptake of Ca²⁺ into sarcoplasmic reticulum

⇒
Rigor Mortis: Muscle Stiffness following death

**MUSCLE ENERGY REQUIREMENTS**

1. **Cellular Respiration: ATP Source**
   
   ✯ **Resting muscle** (w/ muscle tone) & muscle during light exercise:
   - Utilize: ~80%
   - ~20%
   - Origin: Adipose tissue, muscle triglycerides & plasma glucose
   - ATP demand is low enough that there is time for:
   
   ✯ **Moderate Exercise**:
   - Utilize: ~50%
   - ~50%
   - Increased ATP demand requires:
   - Glucose is:
   - Origin: Adipose tissue, muscle glycogen, muscle triglycerides & plasma glucose
   - ATP demand is high enough that:
   
   ✯ **Intense Exercise**:
   - Utilize: ~33%
   - ~66%
   - Increased ATP demand requires:
   - Adipose tissue, muscle glycogen, & blood glucose
   - Fuel is almost exclusively pulled from:

2. **Phosphate Source (for ATP):**
   
   ✯ Sustained muscle activity: ATP used faster than it can be supplied through:
   - Alternate Source of ATP: Phosphocreatine
During Exercise: Phosphocreatine breaks into:

- Makes P available for: P + ADP →

Muscle Fiber Specialization: Slow & Fast Twitch

- Distinguished by:
  1. Slow Twitch: Type I (slow oxidative fibers)
     - Slow to reach:
       - Utilize:
         - Slow - Soleus: 100 msec
         - Fast - Ocular Muscles: 7.3 msec
     - High oxidative capacity:
       - Capillary density:
       - Concentration mitochondria:
       - Myoglobin: Muscle oxygen=
       - Calcium Capacity: LOW -
       - Force: LOW =
       - Fatigue:

  2. Fast Twitch: Type II (A & B)
     - Type IIB: Fast Glycolytic
       - ATPase isoenzyme:
       - Capillary density:
       - Concentration mitochondria:
       - Myoglobin: LOW Muscle oxygen=
       - Calcium Capacity: HIGH -
       - Force: HIGH =
       - Fatigue:
     - Type IIA: Fast Oxidative
ATPase isoenzyme: Quick ATP utilization

- Capillary density:
- Concentration mitochondria:
- Myoglobin: Intermediate - Muscle oxygen = 
- Calcium Capacity: Intermediate -
- Force: Intermediate =

Fatigue:

- Whole muscle is a:
  - Individuals vary in:
    - Long distance runners:
    - Sprinters:

MUSCLE FATIGUE:

- Exercise induced reduction in contraction:

3 Primary Causes:

1. Decreased Energy storage:
   - Depletion of stored molecules: Glycogen & Phosphocreatine

2. Decreased pH due to Lactic Acid
   - Decreased pH interferes with:
     - Glycogen metabolism
     - Contraction - Coupling
     - Ca²⁺ availability

3. Accumulation of:
   - Sustained maximal contraction;
   - Accumulation of:
     - Interferes with:

Short-lived Fatigue:

Study Questions:
1. How does the motor neuron stimulate muscle contraction? What affect does the arrival of ACH have on the muscle cell membrane?
2. Once initiated, describe where the action potential travels. What affect does the action potential have on calcium inside the muscle cells and how does it stimulate these changes?
3. How does the calcium couple the action potential to the initiation of contraction?
4. During rest, describe the state of the thin filament (describe the actin, troponin and tropomyosin)?
5. During rest, describe the state of the thick filament (myosin globular head, and cross bridge)?
6. Describe the changes which occur during one cross bridge cycle (include all changes in the cross bridge positions, and myosin globular head status with regards to ATP)
7. How many cross bridge cycles is required for contraction to end? How much shorter is the sarcomere from the original muscle length?
8. How is contraction stopped following cross bridge cycling? Where is ATP utilized in relaxation?
9. Rigor mortis is the characteristic rigidity which occurs in the muscle following death. Explain why this rigidity would occur using your knowledge of the importance of ATP. (Remember when you are dead there is no longer the ability to make ATP BUT the muscle proteins are still functional – as in our burger experiment).
10. What is the preferred energy source for muscle during : rest, moderate and intense exercise? Explain why each nutrient is appropriate for the muscles energetic demands. Where are these nutrients acquired for each exercise intensity? Why does the exercise intensity cause the muscle change the energy source it uses?
11. What are some of the limitations to ATP production? How does the muscle modify to adjust for these limitations?
12. What is phosphocreatine? What is it’s function in contraction? How does it serve to increase function during sustained muscle contraction?
13. What are the Three main fiber types in human muscle? What is the primary differences between Type I and Type IIA and Types IIB fibers? Which type would be found in: sprinter muscle or endurance muscle?
14. Do muscle have a combination of fiber types or just one type within the muscle? Is the distribution of fiber types variable between individuals?
15. Define muscle fatigue? What can cause muscle fatigue? Explain

---

**Table 18.2 - Classification Schemes of Skeletal Muscle Fiber Types**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Fast-Twitch Type IIB</th>
<th>Type IIA</th>
<th>Slow-Twitch Type I</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical activity patterns</strong></td>
<td>Phasic; high frequency</td>
<td>FTa</td>
<td>Tonic; low frequency</td>
</tr>
<tr>
<td><strong>Morphology</strong></td>
<td>White</td>
<td>White/red</td>
<td>ST</td>
</tr>
<tr>
<td><strong>Fiber diameter</strong></td>
<td>Large</td>
<td>Intermediate</td>
<td>Red</td>
</tr>
<tr>
<td><strong>Capillaries/mm²</strong></td>
<td>Low</td>
<td>Intermediate</td>
<td>Small</td>
</tr>
<tr>
<td><strong>Mitochondrial volume</strong></td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
<tr>
<td><strong>Histochemistry and biochemistry</strong></td>
<td>FG</td>
<td>FOG</td>
<td>SO</td>
</tr>
<tr>
<td><strong>Myosin ATPase</strong></td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Glycolytic capacity</strong></td>
<td>High</td>
<td>Medium/high</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Oxidative capacity</strong></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Function and contractility</strong></td>
<td>FF</td>
<td>FR</td>
<td>S</td>
</tr>
<tr>
<td><strong>Speed of action</strong></td>
<td>Fast</td>
<td>Fast</td>
<td>ST</td>
</tr>
<tr>
<td><strong>Speed of relaxation</strong></td>
<td>Fast</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td><strong>Fatigue resistance</strong></td>
<td>Low</td>
<td>Moderate/high</td>
<td>Slow</td>
</tr>
<tr>
<td><strong>Force capacity</strong></td>
<td>High</td>
<td>Intermediate</td>
<td>High</td>
</tr>
</tbody>
</table>


FT, fast twitch; FG, fast glycolytic; FOG, fast oxidative glycolytic; SO, slow oxidative; FF, fast contracting, fast fatigue; FR, fast contracting, fatigue resistant; S, slow contracting.
A minimal ATPase cycle for the actin and myosin cross-bridge cycle. Filled circles represent the actin monomers in a thin filament and the blue shape represents the motor domain of myosin. M is myosin, A is actin, T is ATP, D is ADP and Pi is inorganic phosphate. AMD, for example, represents a complex between actin, myosin and ADP. A hyphen between two letters indicates the association is relatively weak, i.e., AMD represents ADP tightly bound to AM, AM-D represents ADP weakly bound to AM. When detached, or only weakly bound to actin, a large cleft in the 50 kDa domain of the myosin motor is open. Tight binding of myosin binding to actin requires the cleft to close, such that both sides of the cleft contribute to actin binding. The rear of the motor domain (comprising the converter and lever arm) swings through an angle of 60 deg relative to the 50 kDa domain in response to events in the nucleotide pocket. The equilibrium constants for each step are shown in green and are defined as $K_i = k_i / k_j$, where $i$ is the name of the step, $k_i$ is the rate constant in the forward direction and $k_j$ in the reverse direction. Starting with the actin-myosin rigor-like complex, AM, at the top right, ATP binding to AM ($K_{ATP}$) is followed by a rapid change in myosin conformation, leading to the cleft opening ($K_{coup}$) and rapid detachment of actin ($K_{act}$). The opening of the 50 kDa cleft leads to a conformational change in the head that swings the lever-arm/converter domain through 60 deg (the recovery stroke) and positions catalytic residues to hydrolyse ATP ($K_{h}$). After hydrolysis, the myosin can reattach to actin ($K_{act}$) and the cleft can close; the power stroke and Pi release follow ($K_{p}$). ADP remains firmly attached to myosin until the working stroke is complete, which then allows actin to release a conformational change ($K_{act}$) that then allows ADP to escape, and the cycle is complete ($K_{act}$).