A = high energy state at rest
B = low energy state during activity. Actin dragged along as myosin changes shape
C = ATP required to return to high energy state
D = myosin ATPase activity splits ATP and rephosphorylate myosin to high energy position
ENERGY SYSTEMS

- **CYTOPLASMIC**
  - CREATIN PHOSPHATE
  - GLYCOLYSIS

- **MITOCHONDRIAL**
  - OXIDATIVE PHOSPHORYLATION

ATP for muscle contraction

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ENERGY SYSTEMS

- **ANAEROBIC SYSTEMS**
  - CREATIN PHOSPHATE
  - ANEROBIC GLYCOLYSIS

- **AEROBIC**

ATP for muscle contraction
Traditional Energy System Dogma

- **ANAEROBIC PROVISION**
  1. Phosphagen System \( \text{ATP} + \text{PC} = 30 \text{ seconds ALL OUT SPRINTING AT FASTEST PACE} \)
  2. Lactic acid generation = 30-90 seconds ALL OUT SPRINTING AT SLOWER PACE

- **AEROBIC**
  1. Glycogen = 2 hrs ALL OUT \( \Rightarrow \) 5.1 KCALS PER LITER \( \text{O}_2 \) USED
  2. Fatty Acid = Lower intensity \( \Rightarrow \) 4.7 KCALS PER LITER \( \text{O}_2 \) USED

<table>
<thead>
<tr>
<th>Approximate % of maximum power</th>
<th>Primary energy system stressed</th>
<th>Typical exercise duration</th>
<th>Range of exercise-to-rest period ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-100</td>
<td>Phosphagen</td>
<td>5-10 seconds</td>
<td>1:12 to 1:20</td>
</tr>
<tr>
<td>75-90</td>
<td>Glycolytic</td>
<td>15-30 seconds</td>
<td>1:3 to 1:5</td>
</tr>
<tr>
<td>30-75</td>
<td>Glycolytic and oxidative</td>
<td>1-3 minutes</td>
<td>1:3 to 1:4</td>
</tr>
<tr>
<td>20-35</td>
<td>Oxidative</td>
<td>&gt;3 minutes</td>
<td>1:1 to 1:3</td>
</tr>
</tbody>
</table>

**Table 3.** Work-to-rest ratios for various exercise durations.

Adapted from Baechle and Earle 2000, p. 88.
### Energy Sources for Contraction Related ATP Production

**CREATIN PHOSPHATE (PHOSPHAGEN SYSTEM)**
- fuels duty and recovery cycles of sarcomere as activity occurs

\[
\text{ADP (from myosin) + CP } \rightarrow \text{ ATP + C}
\]

1. Buffers ATP concentration so it remains stable
   - ATP replenishment for myosinATPase activity during contraction phase of duty cycle
2. CP replenished in “relaxation” phase of duty cycle by ATP from glycolysis which generates Lactate
   \[
   \text{ATP + C } \rightarrow \text{ ADP + CP}
   \]
3. CP splitting also supports Ca++ activity during so there can be rapid relaxation phase of duty cycle
4. Fatigue not generally considered to be due to inadequate ATP, but depletion of Creatin Phosphate does decrease rate of muscle contraction

---

**Glycolysis (ANAEROBIC GLYCOLYSIS):**

\[
\text{Muscle glycogen} \rightarrow \text{3 ATP + 2 LACTATE}
\]

1. ATP produced replenishes CP during relaxation phase of duty cycle
2. ATP Supports Ca++ activity during relaxation phase of duty cycle
   - \[ \text{ATP + C } \rightarrow \text{ ADP + CP} \]
   - ADP used in glycolysis
   - LACTATE to MITOCHONDRIA for oxidation
3. When duty cycles more rapidly, supports contraction and relaxation as well
   - Muscle glycogen \[ \rightarrow \text{3 ATP + 2 LACTATE} \]
   - CAN PRODUCE MORE LACTATE THAN MITOCHONDRIA OF PRODUCING CELL CAN HANDLE
     - Lactate transported out of muscle that made it to blood .. Goes to cells that can oxidize it
     - Training adds mitochondria to muscle so it deals with its own lactate better
Energy Sources for Contraction Related ATP Production

• Oxidative phosphorylation (AEROBIC)

**CITRIC ACID CYCLE AND ELECTRON TRANSPORT SYSTEM**

**ACETYL COA FROM PYRUVATE, LACTATE OR FATTY ACID OXIDIZED WITHIN MUSCLE MITOCHONDRIA**

– makes 12 ATP/KREBS CYCLE
– End products ATP and H2O  Waste products: CO2 and Heat
  • ATP has to get to cytoplasm from mitochondria for use in replenishing CP or by myosin ....this required transport which costs time
    – Once in SARCOPLASM ATP supports myosin ATPase and Ca++ ATPase during contraction and relaxation parts of duty cycle
    – May work through replenishing CP for duty cycle

• GLYCOGEN CONTENT may limit capacity to use glycolysis
  – As glycogen content decreases, rate of ATP expenditure decreases, i.e. muscle duty cycle occurs slower

Energy Sources for Contraction Related ATP Production

• Oxidative phosphorylation

**CITRIC ACID CYCLE AND ELECTRON TRANSPORT SYSTEM**

– Exercise Intensity and Duration dictate fuel oxidized
  • Lower intensity exercise or longer duration:
    – more FATTY ACID OXIDIZED and BLOOD GLUCOSE than stored muscle GLYCOGEN
  • Higher intensity exercise or shorter duration
    – more GLYCOGEN BLOOD GLUCOSE
  • When intensity is so low muscle mitochondria is at functional rest, then FATTY ACID oxidation makes ATP in Krebs Cycle & ETC via OXIDATIVE PHOSPHORYLATION
Summary

• 3 ways to make ATP in muscle cell
  – Work cooperatively to match muscle’s rate of activation and duty cycle
  – No system ever works alone
  – Practical descriptions such as aerobic and anaerobic are convenient but not really true
  – Practical descriptions such as “PHOSPHAGEN, ANAEROBIC, and AEROBIC SYSTEM” are convenient but not really true