ENERGY SYSTEMS TO POWER THE ATHLETE

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OVERVIEW

• Muscle contraction energetics
• Rest to Exercise transition
• Metabolic responses during recovery
• Influence of intensity and duration
• Estimation of fuel utilization
Adenosine Triphosphate (ATP)
Molecule which provides energy for muscle fibers to contract.

The amount stored in the muscle is limited.
Fuel Sources to Generate ATP for Muscle Contraction

**PCr** (phosphocreatine)
- High intensity ~5 s or less
- Regenerated during recovery

**Anaerobic Glycolysis**
- High intensity ~30 s – 3 min
- Glucose

**Aerobic Metabolism**
- Lower intensity Long duration
- Glucose Fatty Acids

**Notes:**
- Creatine is made in the body and consumed from meat. The PCr system is also the mechanism through which creatine supplements provide energy for high intensity muscle contraction.
- Glucose is supplied mainly from the breakdown of **GLYCOGEN**, the storage form of glucose in the muscle and liver.
- Amino acids can enter the aerobic glycolysis system, but their contribution to ATP generation is very small.

Hargreaves, M & Spriet, L. Nat Metab. 2020; https://doi.org/10.1038/s42255-020-0251-4.
HUMAN ENGINE

- FAT = ENDURANCE FUEL
- CARB = HIGH INTENSITY FUEL
- PCr = FAST ACCELERATIONS

CAR ENGINE

- ONE KIND OF FUEL
Anaerobic glycolysis

Lactate

Previously thought to cause fatigue and muscle soreness.
No longer believed to be the case, may provide an additional fuel source.

Aerobic Metabolism

CO₂

As oxygen is used in the process to convert fuels to ATP, carbon dioxide is produced.
Respiration increases to remove the excess CO2 from the body.

Hargreaves, M & Spriet, L. Nat Metab. 2020; https://doi.org/10.1038/s42255-020-0251-4.
TRANSITIONS
Imagine a football player is standing on the sideline. On coach’s whistle, he is to begin sprinting.

What is happening in the body to ensure the muscle has the fuel to go from rest to quick contractions?
Within the first step, muscles must increase their rate of ATP production.

Anaerobic energy sources (PCr + anaerobic glycolysis) are used first, giving time for the aerobic system to contribute.

**Take Home Message:** several energy systems are involved in rest-to-work transitions.

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Measurement of O$_2$ consumption can be used as an index of aerobic ATP production.

Provides information about aerobic metabolism during exercise.

$\text{VO}_2 \text{ max} =$ maximal oxygen consumption, often used as an indicator of fitness.

$\text{Oxygen deficit} =$ lag in O$_2$ update at the beginning of exercise, indicating the reliance on anaerobic systems.
Recovery from Exercise: Metabolic Responses

Metabolism (indicated by oxygen uptake) remains elevated for several minutes after exercise.

The magnitude of elevation depends on the intensity of exercise.

**EPOC = Excess Post-Exercise Oxygen Consumption**

**Why does EPOC occur?**
- Resynthesize PC
- Replace O₂ in muscle & blood
- Elevated body temperature
- Convert lactic acid to glucose
- Elevated epinephrine & norepinephrine
INFLUENCE OF INTENSITY AND DURATION ON ENERGY PATHWAY SELECTION
Most sports use a combination of anaerobic and aerobic pathways to produce ATP

**INFLUENCE OF DURATION ON SOURCE OF ATP**

- **PCR**
  - Anaerobic glycolysis
  - 1-5 s

- **PCR**
  - Anaerobic glycolysis
  - ~5-10 s

- **PCR**
  - Aerobic Systems*
  - > 1 min

- **Aerobic Systems**
  - Several minutes to hours

*Major pathway, muscle glycogen dominant fuel source

CHO and Fat provide almost all ATP

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## Contribution of Aerobic/Anaerobic Production of ATP During MAXIMAL Exercise as a Function of the Duration of the Event

<table>
<thead>
<tr>
<th>Duration of MAXIMAL Exercise</th>
<th>Seconds</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Percent Aerobic</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Percent Anaerobic</td>
<td>90</td>
<td>80</td>
</tr>
</tbody>
</table>

Short-Term Intense Exercise

- Energy comes primarily from anaerobic pathways
- Length of the activity determines if PCr or glycolysis is the predominant energy source
- Transition from PCr to glycolysis is a gradual shift

Example
50 m dash or single play in a football game: PCr

400 m dash (~55 s): PCr, glycolysis, and aerobic, with anaerobic glycolysis predominating
Prolonged Exercise

- Energy comes primarily from aerobic metabolism

- Steady-state oxygen update can be maintained during prolonged low-intensity exercise

- However, a hot/humid environment or higher intensity increases oxygen consumption over time

Reminder:
Oxygen consumption is an indicator of aerobic metabolism
ASSESSING METABOLISM DURING EXERCISE
Incremental exercise = gradually increasing exercise intensity over time

As intensity increases, oxygen uptake increases in a linear fashion until VO$_2$ max is reached

VO$_2$ max is the “physiological ceiling” for the ability to deliver O$_2$ to contracting muscles

Training can result in an increased VO$_2$ max, and sometimes training intensity is set at a %VO$_2$ max
VO₂ max is influenced by:

1. The maximal ability of the cardiorespiratory system to deliver oxygen to the muscle
2. The muscles ability to take up the oxygen and produce ATP aerobically
3. Genetics

“Excellent” VO₂ max values for ages 18-25 yo:

- > 56 mL/kg/min for females
- > 60 mL/kg/min for males

VO₂ max values of some of the best US male and female endurance athletes:

**Joan Benoit**
Distance Runner
1984 Olympic Marathon Champion
78.6 mL/kg/min

**Lance Armstrong**
Cyclist
84.0 mL/kg/min

https://www.topendsports.com/testing/records/vo2max.htm
Most of the ATP production in the early part of an incremental exercise test (lower intensities) comes from aerobic sources.

As intensity increases, blood levels of lactic acid begin to rise.

While there is debate, it is thought that the rise in lactic acid indicates an increasing reliance on anaerobic metabolism.

Lactate threshold (LT) = exercise intensity where there is an increase in lactic acid in the blood.
While the exact cause of the LT is unclear, it may occur due to:

1. Low muscle oxygen
2. Accelerated glycolysis
3. Reduced rate of lactate removal

In a practical setting, lactate threshold can be used to set training intensity.
Lactate is now known NOT to cause fatigue, however, the LT test is still utilized.

Click [here](https://www.youtube.com/watch?v=lgUMcal5TgM) to watch a YouTube video by Dr. Laurent Bannock explaining lactate and the utility of VO₂ max vs LT testing.
Respiratory Exchange Ratio (RER) = \frac{VCO_2}{VO_2} = \text{Ratio of carbon dioxide produced to oxygen consumed}

Based on their chemical structures, fat and carbohydrate differ in the amount of O_2 used and CO_2 produced during oxidation.

Fat oxidation requires more O_2 than carbohydrate.

Ignores protein, since protein contributes little as a fuel source.

Determined using a metabolic cart during steady state exercise.
### Percentage of Carbohydrate and Fat Utilization by RER value (R)

<table>
<thead>
<tr>
<th>R</th>
<th>% Fat</th>
<th>% CHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>0.85</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>1.0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
AEROBIC METABOLISM: INFLUENCE OF INTENSITY & DURATION ON FUEL SELECTION
Fat is the primary energy source for low-intensity exercise (\(< \sim 30\% \text{VO}_{2}\ max\)).

Carbohydrate is the primary energy source for high intensity exercise (> 70\% \text{VO}_{2}\ max).

Athletes are almost always using a mixture of carbohydrate and fat.
INTENSITY & FUEL SELECTION

Energy expenditure
(kJ·kg⁻¹·min⁻¹)

% VO₂ max

- Muscle glycogen
- Triglycerides
- Plasma FFA
- Plasma glucose

25  65  85
MYTH: Individuals exercising to lose weight should work out at a lower intensity, in the “fat burning zone.

TRUTH: Weight loss depends on overall calories expended. Exercising at a lower intensity results in lower calorie burn (given the same duration). It is more beneficial to work out at a higher intensity, to get a greater EPOC and use more fat for energy during recovery.
At a given **intensity**, as exercise duration increases there is a gradual shift from carbohydrate utilization to a greater reliance on fat as a fuel source.
Regular training can improve fatigue resistance and performance, partly through changes in muscle metabolism.

### High Intensity Interval Training (HIIT)
- Increases capacity for anaerobic energy production.
- Enhances tolerance to metabolic acidosis (increased buffering capacity).

### Endurance Training
- Increased VO2 max, leading to greater fatigue resistance.
- Increased skeletal muscle mitochondrial density.
- Increased fat oxidation.
- Increased capacity for carbohydrate oxidation, allowing for maintenance of higher power output.

Hargreaves, M & Spriet, L. Nat Metab. 2020; https://doi.org/10.1038/s42255-020-0251-4.
KEY TAKEAWAYS

- Most exercise uses a blend of PCr, anaerobic glycolysis and aerobic metabolism

- Fuel sources shift during the rest to exercise transition and transition to recovery

- VO₂ max, Lactate Threshold and RER are tests to estimate fuel utilization

- Intensity and duration dictate fuel utilization

- Training can alter fuel metabolism
SUMMARY VIDEO

Link to video

Video Link https://www.youtube.com/watch?v=YI95mrBt1a0