Exercise Metabolism

Chapter 4
pp 51-66

Chapter 5
pp 87-99
1. Rest-to-Exercise: Anaerobic
1. Rest-to-Exercise: Anaerobic

- Going from rest to an explosive jump. What energy system provides the majority of the energy?
1. Rest-to-Exercise: Anaerobic

- Going from rest to an **explosive** jump. What energy system provides the majority of the energy?

- Going from rest to an all out sprint for **10 seconds**. What energy system provides the majority of the energy?
1. Rest-to-Exercise: Anaerobic

- Going from rest to an **explosive** jump. What energy system provides the majority of the energy?

- Going from rest to an all out sprint for **10 seconds**. What energy system provides the majority of the energy?

- Going from rest to a **1-2 minute** sprint. What energy system provides the majority of the energy?
1. Rest-to-Exercise: Anaerobic
2. Rest-to-Exercise: Aerobic
2. Rest-to-Exercise: Aerobic

- Example....
2. Rest-to-Exercise: Aerobic

- Example....
- Assume standing requires 15 ATP and 0.4 liters/min of oxygen
2. Rest-to-Exercise: Aerobic

- Example....
- Assume standing requires 15 ATP and 0.4 liters/min of oxygen
- Assume running at 6 mph requires 100 ATP and 1.5 liter/min of oxygen
2. Rest-to-Exercise: Aerobic

- Example....
- Assume standing requires 15 ATP and 0.4 liters/min of oxygen
- Assume running at 6 mph requires 100 ATP and 1.5 liter/min of oxygen
- A person can go from standing to running 6 mph in a matter of seconds.
2. Rest-to-Exercise: Aerobic

- Example....

- Assume standing requires 15 ATP and 0.4 liters/min of oxygen.

- Assume running at 6 mph requires 100 ATP and 1.5 liter/min of oxygen.

- A person can go from standing to running 6 mph in a matter of seconds.

- But, it takes 2-3 minutes for the oxygen requirement to go from 0.4 to 1.5 liters/min.
2. Rest-to-Exercise: Aerobic

• Example....

• Assume standing requires 15 ATP and 0.4 liters/min of oxygen

• Assume running at 6 mph requires 100 ATP and 1.5 liter/min of oxygen

• A person can go from standing to running 6 mph in a matter of seconds.

• But, it takes 2-3 minutes for the oxygen requirement to go from 0.4 to 1.5 liters/min

• Where does the ATP needed to run 6 m.p.h come from until adequate oxygen can be supplied?
Rest-to-Exercise

The diagram illustrates the oxygen consumption ($\dot{V}O_2$) during rest-to-exercise transition. It shows an oxygen deficit and the steady-state $\dot{V}O_2$ during exercise. The graph plots $\dot{V}O_2$ (liter/min) on the y-axis against exercise time (min) on the x-axis.
3. Recovery
3. Recovery

• What needs to happen in recovery?
3. Recovery

- What needs to happen in recovery?
- ATP-PC system recovery?
3. Recovery

- What needs to happen in recovery?
- ATP-PC system recovery?
- P and Cr
3. Recovery

- What needs to happen in recovery?
- ATP-PC system recovery?
  - P and Cr
- Glycolysis recovery?
3. Recovery

- What needs to happen in recovery?
- ATP-PC system recovery?
  - P and Cr
- Glycolysis recovery?
  - Lactic acid
3. Recovery

- What needs to happen in recovery?
- ATP-PC system recovery?
  - P and Cr
- Glycolysis recovery?
  - Lactic acid
- Glycogen/glucose
• What does E.P.O.C. stand for
• What does E.P.O.C. stand for

note: oxygen consumption = energy
• What does E.P.O.C. stand for

note: oxygen consumption = energy

• What contributes to the excess oxygen consumption?
Factors Contributing to Excess Post-Exercise Oxygen Consumption

- Oxygen Debt or Excess Post-Exercise Oxygen Consumption
- Resynthesis of PC in muscle
- Elevated hormones
- Lactate removal (Used as a fuel)
- Post-exercise elevation of HR and breathing
- Restoration of muscle and blood oxygen stores
- Elevated body temperature
Factors Contributing to Excess Post-Exercise Oxygen Consumption

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Effects of an active recovery on lactic acid removal
Recovery

• Which energy system is most active during the recovery process?
  
  • Aerobic
    
    • Oxygen + fuel $\rightarrow$ ATP. Then, ATP + Cr $\rightarrow$ PCr + ADP.
    
    • Lactic acid $\rightarrow$ pyruvate $\rightarrow$ acetyl-CoA
    
    • Heart and respiratory muscles
4. Prolonged Aerobic Exercise
4. Prolonged Aerobic Exercise

- Aerobic energy requires O₂
- *oxygen demand*
4. Prolonged Aerobic Exercise

- Aerobic energy requires O$_2$
  - *oxygen demand*
- O$_2$ transported via cardiopulmonary system
  - *oxygen supply*
Prolonged Aerobic Exercise
Prolonged Aerobic Exercise

- Deficit: \( O_2 \) supply < \( O_2 \) demand
Prolonged Aerobic Exercise

• Deficit: O2 supply < O2 demand

• STEADY STATE:
Prolonged Aerobic Exercise

- **Deficit**: O₂ supply < O₂ demand

- **STEADY STATE**:
  - O₂ supply = O₂ demand
Prolonged Aerobic Exercise

- **Deficit**: \( O_2 \) supply < \( O_2 \) demand

- **STEADY STATE**:  
  - \( O_2 \) supply = \( O_2 \) demand  
  - Heart rate? Breathing rate?
Prolonged Aerobic Exercise

(a) Hot/humid environment

(b) High-intensity exercise

Exercise time (min)
Prolonged Aerobic Exercise

- **Steady State Exceptions** (O$_2$ supply < O$_2$ demand)
Prolonged Aerobic Exercise

- **Steady State Exceptions** ($O_2$ supply < $O_2$ demand)
  - Hot weather
Prolonged Aerobic Exercise

- Steady State Exceptions (O₂ supply < O₂ demand)
  - Hot weather
  - High intensity (>70% of maximal effort)
Prolonged Aerobic Exercise

- **Steady State Exceptions** (O₂ supply < O₂ demand)
  - Hot weather
  - High intensity (>70% of maximal effort)

- What affect would these conditions have on lactic production? Why?
5. Measurement of Aerobic Energy/Performance

- Maximal oxygen uptake
- Lactate threshold
Oxygen Uptake

Ventilation (Liters of air per minute)

79% N
~17% O2
~4% CO2

79% N
20.97% O2
0.03% CO2
Oxygen Uptake (VO₂)

- 79% N
- 20.97% O₂
- 0.03% CO₂

- 79% N
- ~17% O₂
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Oxygen Uptake (VO₂)

79% N
20.97% O₂
0.03% CO₂

79% N
~17% O₂
~4% CO₂
Oxygen Uptake (VO₂)

- What does it measure?
- How is it expressed?
  - VO₂ ml/kg/min
  - VO₂ liters/min
Maximum Oxygen Uptake (VO2max)

What is VO2max? What does it represent?
Oxygen Uptake

The graph illustrates the relationship between exercise intensity and energy expenditure, with a focus on aerobic and anaerobic energy sources. The x-axis represents exercise intensity, while the y-axis shows energy expenditure.

- **Walking** is depicted at 50% of VO2max.
- **Cycling** is shown at 75% of VO2max.
- **Running** and **Sprinting** are represented by the highest energy expenditure, approaching VO2max.

The graph also highlights the impact of training, with VO2 after training indicated by a dotted line.
## VO2max Values

<table>
<thead>
<tr>
<th>Percentile</th>
<th>20-29</th>
<th>30-39</th>
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<tr>
<td>90</td>
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Source: ACSM
<table>
<thead>
<tr>
<th><strong>Maximal Oxygen Uptake (ml/kg/min) in Various Population Groups</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non Athletes</strong></td>
</tr>
<tr>
<td><strong>Age</strong></td>
</tr>
<tr>
<td>10-19</td>
</tr>
<tr>
<td>20-29</td>
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<table>
<thead>
<tr>
<th><strong>Athletes</strong></th>
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<tbody>
<tr>
<td><strong>Baseball/softball</strong></td>
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<tr>
<td><strong>Basketball</strong></td>
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<tr>
<td><strong>Bicycling</strong></td>
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<td><strong>Canoeing</strong></td>
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<td><strong>Jockey</strong></td>
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<tr>
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* General Population, Male, Aged 20-29: 44-51
* US College Track, Male: 57.4
* College Students, Male: 44.6
* Highest Recorded Female (Cross-Country Skier): 74
* Highest Recorded Male (Cross-Country Skier): 94
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<tr>
<td>70-79</td>
<td>28-35</td>
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**Athletes**

- Baseball/softball 18-32 48-56 52-57
- Basketball 18-30 40-60 43-60
- Bicycling 18-26 62-74 47-57
- Canoeing 22-28 55-67 48-52
- Football 20-36 42-60
- Gymnastics 18-22 52-58 36-50
- Ice Hockey 10-30 50-63
- Jockey 20-40 50-60
- Orienteering 20-60 47-53 46-60
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- Swimming 10-25 50-70 40-60
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- Track & field, running 18-39 60-85 50-75
- Track & field, shot put 22-30 40-46
- Volleyball 18-22 40-46
- Weightlifting 20-30 38-52
- Wrestling 18-30 30-35

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Table 2. Physiological characteristics of this individual from the ages of 21 to 28 yr

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<td>Maximal aerobic ability</td>
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<td>Maximal O₂ uptake, l/min</td>
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<td>Maximal O₂ uptake, ml·kg⁻¹·min⁻¹</td>
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<tr>
<td>Lactate threshold O₂ uptake, l/min</td>
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<tr>
<td>Power at O₂ uptake of 5.0 l/min, W</td>
<td>374</td>
<td>382</td>
<td>399</td>
<td>404</td>
<td></td>
</tr>
<tr>
<td><strong>Lance by the Numbers</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>-------------------------</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tour de France victories</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Must Tours won by anyone else</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Americans who won Tour de France before Armstrong (Greg LeMond in 1986, 1989, 1990)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual income</td>
<td>$16 million</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armstrong's resting heart rate</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average heart rate during a race</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Average heart rate during a time trial</td>
<td>190</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pedal rpm during a time trial</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂ max*</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average male VO₂ max</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedal strokes by Armstrong in 2004 Tour</td>
<td>about 465,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heartbeats during the race</td>
<td>2.1 million</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Daily calorie intake during training</td>
<td>6,000</td>
<td></td>
<td></td>
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<tr>
<td>Body fat during race season</td>
<td>5–6%</td>
<td></td>
<td></td>
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<tr>
<td>Body fat during off-season</td>
<td>10–11%</td>
<td></td>
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<tr>
<td>Calories burned during 3 hours of racing</td>
<td>3,150</td>
<td></td>
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<tr>
<td>Calories expended during the race</td>
<td>132,000</td>
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<tr>
<td>Number of Big Macs represented by 132,000 calories</td>
<td>236</td>
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<td></td>
</tr>
</tbody>
</table>

"A lot of people run a race to see who is fastest. I run to see who has the most guts."

Steve Prefontaine
6. Lactate Threshold
6. Lactate Threshold

• Glycolysis produces Hydrogen (removed via NADH)
6. Lactate Threshold

- Glycolysis produces **Hydrogen** (removed via NADH)
- Low intensity, most H goes into mitochondria (electron transport chain)
6. Lactate Threshold

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  - Therefore, most pyruvate converted to acetyl-CoA
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  - Most **H** + Pyruvate = Lactate or **Lactic Acid**
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- Low intensity, most **H** goes into mitochondria (electron transport chain)
  - Therefore, most pyruvate converted to acetyl-CoA
- Moderate to high intensity, not enough O2 for all **H**
  - Most **H** + Pyruvate = Lactate or **Lactic Acid**
  - Initially lactic acid removed from muscle cell
  - Eventually, lactic acid levels increase inside the muscle
Lactate Threshold

Sarcoplasm → Lactic acid ← Pyruvic acid
LDH

Mitochondrial membrane

"Hydrogen shuttle"

Electron Transport Chain

Glycolysis

NADH + H⁺

H⁺ + O₂
Lactate Threshold

Light to Moderate Exercise. LA removed

Sarcoplasm → Lactic acid ← Pyruvic acid

Mitochondrial membrane

"Hydrogen shuttle"

Electron Transport Chain

Glycolysis → NADH + H⁺

LA removed → H⁺ + O₂
Lactate Threshold

Light to Moderate Exercise.
LA removed

Heavy Exercise.
LA accumulates

Glycolysis

NADH + H⁺?

"Hydrogen shuttle"

Electron Transport Chain
H⁺ + O₂
Lactate Threshold

Speed (mph)

Lactate (mmols)

3 4 5 6 7 8 9 10
Lactate Threshold

![Graph showing lactate threshold vs speed in mph with data points at 4, 5, and 6 mph.](image)
Lactate Threshold

Lactate (mmols)

Speed (mph)

3 4 5 6 7 8 9 10
Lactate Threshold

Speed (mph)

Lactate (mmols)
Lactate Threshold

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Lactate (mmols)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Light to Moderate Exercise. LA removed</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
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<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Lactate Threshold

Light to Moderate Exercise.
LA removed
Lactate Threshold

Light to Moderate Exercise.
LA removed
Lactate Threshold

Lactate (mmols)

Speed (mph)

3 4 5 6 7 8 9 10

Light to Moderate Exercise.

LA removed
Lactate Threshold

Speed (mph)

3 4 5 6 7 8 9 10

Light to Moderate Exercise. LA removed

Heavy Exercise. LA accumulates

Lactate (mmols)
What is significant about the intensity level at the lactate threshold?
7. Fuel Utilization During Exercise
Measuring Fuel Utilization During Exercise

It takes more O2 to burn fats so the R value for fats will be lower.
Measuring Fuel Utilization During Exercise

Respiratory exchange ratio (RER or R)

\[ R = \frac{VCO_2}{VO_2} \]

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Measuring Fuel Utilization During Exercise

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\[ R = \frac{VCO_2}{VO_2} \]

Fat (palmitic acid) = \( C_{16}H_{32}O_2 \)

\[ C_{16}H_{32}O_2 + 23O_2 \leftrightarrow 16CO_2 + 16H_2O + ATP \]

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\[ R = \frac{VCO_2}{VO_2} = \frac{16 CO_2}{23O_2} = 0.70 \]

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Measuring Fuel Utilization During Exercise

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\[ R = \frac{VCO_2}{VO_2} = \frac{16 CO_2}{23O_2} = 0.70 \]

Glucose = \( C_6H_{12}O_6 \)

\[ C_6H_{12}O_6 + 6O_2 \leftrightarrow 6CO_2 + 6H_2O + ATP \]

It takes more \( O_2 \) to burn fats so the \( R \) value for fats will be lower.
Measuring Fuel Utilization During Exercise

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Glucose = \( C_6H_{12}O_6 \)

\[ C_6H_{12}O_6 + 6O_2 \leftrightarrow 6CO_2 + 6H_2O + ATP \]

\[ R = \frac{VCO_2}{VO_2} = \frac{6 CO_2}{6O_2} = 1.00 \]

It takes more O2 to burn fats so the R value for fats will be lower.
Fuel Utilization During Exercise

- Carbohydrates and Fats (very little Protein)

<table>
<thead>
<tr>
<th>Resistance (R)</th>
<th>% Fat</th>
<th>% Carbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>99</td>
<td>1</td>
</tr>
<tr>
<td>0.75</td>
<td>83</td>
<td>17</td>
</tr>
<tr>
<td>Low Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>0.85</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>High Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>0.95</td>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>Max. Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>1</td>
<td>99</td>
</tr>
</tbody>
</table>
Fuel Utilization During Exercise

![Bar chart showing fuel utilization during exercise at different intensities. The chart indicates the percentage of total fuel source contributing to energy expenditure at 25%, 65%, and 85% of VO2 max.](chart.png)
Fuel Utilization During Exercise

The graph shows the percentage of total fuel source utilization during exercise at different intensities. The intensities are indicated as a percentage of VO2 max (%VO2 max). The categories on the x-axis are 25, 65, and 85. The categories on the y-axis represent the % of total fuel source. The bars are color-coded to represent different fuel sources:

- Muscle glycogen
- Plasma glucose
- Plasma FFA
- Muscle triglycerides

The graph illustrates how the utilization of these fuel sources changes with varying exercise intensities.
Fuel Utilization During Exercise

![Graph showing fuel utilization during exercise at different intensity levels. The graph compares % of total fuel source from Muscle glycogen, Plasma glucose, Plasma FFA, and Muscle triglycerides across exercise intensities.]
Fuel Utilization During Exercise

Which fuel is used more as the exercise INTENSITY increases? Why?
Fuel Utilization During Exercise

Which fuel is used more as the exercise INTENSITY increases? Why?

Why the shift towards carbohydrates?
Fuel Utilization During Exercise

![Graph showing fuel utilization during exercise](image)

- **% Fat** increases with exercise time.
- **% CHO** decreases with exercise time.

Exercise time (min): 0, 20, 40, 60, 80, 100, 120

% Fat or carbohydrate metabolism: 30, 35, 40, 45, 50, 55, 60, 65, 70
Fuel Utilization During Exercise

What fuel is used more as the exercise DURATION increases? Why?
8. Fuels for Exercise

MyPyramid.gov

Steps to a healthier you

Grains
Vegetables
Fruits
Oils
Milk
Meat & Beans

www.eatsmart.org
Sources of Carbohydrate During Exercise
Sources of Carbohydrate During Exercise

- Muscle glycogen
Sources of Carbohydrate During Exercise

- Muscle glycogen
- Liver glycogen
Sources of Carbohydrate During Exercise

- Muscle glycogen
- Liver glycogen
- Total of about 2,000 kcals (1-2 hrs)
Sources of Carbohydrate During Exercise

- Muscle glycogen
- Liver glycogen
- Total of about 2,000 kcals (1-2 hrs)
- Systems
  - Glycolysis
    - Lactic acid
  - Aerobic
Lactate as a Fuel During Exercise

- Slow twitch muscle fibers
- Heart muscle
- Liver via the Cori cycle
Sources of Fat During Exercise
Sources of Fat During Exercise

- Adipose tissue
- Triglycerides to fatty acids
Sources of Fat During Exercise

- Adipose tissue
  - Triglycerides to fatty acids
- Muscle cells
Sources of Fat During Exercise

- Adipose tissue
  - Triglycerides to fatty acids
- Muscle cells
- Total of about 72,000 kcals
Protein for Energy During Exercise
Protein for Energy During Exercise

- Skeletal muscle

- Amino acids

  - Directly

  - Indirectly
Protein for Energy During Exercise

- Skeletal muscle
  - Amino acids
    - Directly
    - Indirectly
- Why is protein not an optimal fuel source?
The Glucose-Alanine Cycle
Gluconeogensis
Gluconeogenesis

- The Cori cycle and the Glucose-Alanine cycle
Gluconeogenesis

- The Cori cycle and the Glucose-Alanine cycle
- What do they have in common?
Gluconeogenesis

- The Cori cycle and the Glucose-Alanine cycle
- What do they have in common?
- *Gluconeogenesis*
Energy Related Fatigue
Energy Related Fatigue

- Glycogen depletion
Energy Related Fatigue

- Glycogen depletion
- Hypoglycemia
9. Fuel Regulation

Chapter 5 pp 87-99
Blood

Adipose cells

Liver cells

Skeletal muscle

Blood
Increase blood levels of:

- Growth Hormone (GH)
- Glucagon
- Cortisol
- Epinephrine & Norepinephrine
Increase blood levels of:

- Growth Hormone (GH)
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Blood

Adipose cells

Triglycerides

Fatty Acids

Liver cells

Glycogen

Glucose

Skeletal muscle

Blood
Increase blood levels of:
- Growth Hormone (GH)
- Glucagon
- Cortisol
- Epinephrine & Norepinephrine

Adipose cells
- Triglycerides
  - Fatty Acids

Liver cells
- Glycogen
  - Glucose

Skeletal muscle
- Glycogen
  - Glucose
Increase blood levels of:

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Increase in fatty acid. Increase in glucose.
Increase blood levels of:
• Growth Hormone (GH)
• Glucagon
• Cortisol
• Epinephrine & Norepinephrine

Triglycerides → Fatty Acids

Glycogen → Glucose

Blood → Adipose cells

Blood → Liver cells

Blood → Skeletal muscle

Increase in fatty acid. Increase in glucose.

Fatty acids & Glucose
Hormones and Fuel Regulation
Hormones and Fuel Regulation

• **Goal**: Maintain glucose levels
  • Increase glucose and fatty acid levels
Hormones and Fuel Regulation

• Goal: Maintain glucose levels
  - Increase glucose and fatty acid levels
• What hormones are involved and what fuels do they affect?
  - Glucagon (p.83 & 95)
  - Catecholamines [epinephrine and norepinephrine] (p. 94)
  - Growth hormone (p.78 & 93)
  - Cortisol (p. 82 & 92)
Summary

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Glycogen to Glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>Glycogen to Glucose</td>
</tr>
<tr>
<td>Amino Acid Mobilization</td>
<td>(a.a. converted to glucose in the liver)*</td>
</tr>
<tr>
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<td></td>
</tr>
</tbody>
</table>

*Gluconeogenesis
## Summary

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
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<tr>
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<td></td>
</tr>
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<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Muscle Glycogen to Glucose</td>
<td></td>
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</tr>
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<td></td>
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<td>✓</td>
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<td>Mobilization</td>
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<td>(a.a. converted</td>
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