THE PHYSIOLOGY OF EXERCISE
LECTURE OUTLINE

I  METABOLISM: Muscle Fuel Sources

II  ENERGY SYSTEMS: Sport Specific

III  STRATEGIES: Performance Enhancement
All physical activities require energy to be released to the muscles in order to fuel contraction and prevent fatigue.
How do muscle cells obtain the energy to perform exercise?
ATP or *adenosine triphosphate* is the energy currency used by our body everyday to perform a number of tasks:

- Maintain body temperature
- Repair damaged cells
- Digestion of food
- Mechanical work – movement

\[
\text{ATP} \leftrightarrow \text{ADP} + \text{Energy}
\]
Fact: Our muscles already contain ATP molecules

Problem: There are not enough!

Result: Find other ways to provide our body with ATP

In order to maintain exercise we need to supply our muscles with an adequate amount of ATP or energy.

Physiology Principle: ATP Supply = ATP Demand
METABOLISM: Sources of Energy

**Question:** Where does the additional ATP come from?

The chemical breakdown of the fuel sources in our body:

a. Muscle Glycogen  
b. Blood Glucose (Liver)  
c. Fats (Adipose Tissue)  
d. Proteins (Amino Acids)*

ATP ↔ ADP + Energy
STAGE 1: BREAKDOWN OF LARGE MACROMOLECULES TO SIMPLE SUBUNITS

- Proteins
- Polysaccharides
- Fats

- Amino acids
- Simple sugars
- Fatty acids and glycerol

STAGE 2: BREAKDOWN OF SIMPLE SUBUNITS TO ACETYL CoA ACCOMPANIED BY PRODUCTION OF LIMITED AMOUNTS OF ATP AND NADH

- Glucose
- Cytosol
- ATP
- NADH
- Pyruvate
- Acetyl CoA

STAGE 3: COMPLETE OXIDATION OF ACETYL CoA TO H₂O AND CO₂ ACCOMPANIED BY PRODUCTION OF LARGE AMOUNTS OF NADH AND ATP IN MITOCHONDRIUM

- Mitochondrial membranes
- Plasma membrane of eucaryotic cell
- Oxidative phosphorylation
- ATP
- NADH
- Reducing power as NADH

- Water (H₂O)
- Carbon dioxide (CO₂)
- Ammonia (NH₃)
- Waste products
ADIPOSE TISSUE

Triacylglycerol (5,000 grams)

FFA

BLOOD PLASMA

Glycerol

FFA-Albumin

FFA

Muscle

Intramuscular Triglyceride (350 grams)

Glycogen (600 grams)

LIVER

Glycogen (100-120 grams)

Glucose (25 grams)

FFA

Mitochondria

Acetyl-CoA

Krebs Cycle & Electron Transport

ATP

O₂
Important: two factors determine the amount of ATP required to perform exercise and the types of fuel used:

a. Exercise Intensity – rate of ATP production
b. Exercise Duration – amount of ATP production
ATP is able to be produced by *more than one system/ pathway*

A system can be categorised as either:

1. Anaerobic “O\(_2\) independent”
   
   *Does not require oxygen*

2. Aerobic “O\(_2\) dependent”
   
   *Requires oxygen*
Remember: these pathways generate energy *without* using $O_2$

ATP is produced by these energy systems:

1. **ATP-CP system**
   - ATP ‘reservoir’
   - Immediate energy system

2. **Anaerobic Glycolysis system**
   - Exclusively uses CHO
   - Short-term “lactic acid” system
Remember: these pathways require \(O_2\) to generate energy

ATP is produced by these energy systems:

3. Aerobic glycolytic (CHO) system
   - Moderate- to high-intensity exercise
   - Finite energy source (CHO → ATP)

4. Aerobic lipolytic (Fat) system
   - Prolonged low-intensity exercise
   - Unlimited energy source (Fat → ATP)
The body has 4 distinct systems it can use to supply energy for these different types of events:

<table>
<thead>
<tr>
<th>Event</th>
<th>Energy System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Power (Jump)</td>
<td>ATP-CP system (phosphagen)</td>
</tr>
<tr>
<td>2. Speed (Sprint)</td>
<td>Anaerobic system (O₂ independent)</td>
</tr>
<tr>
<td>3. Endurance (Run)</td>
<td>Aerobic glycolytic (CHO) system</td>
</tr>
<tr>
<td>4. Ultra-Endurance</td>
<td>Aerobic lipolytic (Fat) system</td>
</tr>
</tbody>
</table>
Event Type: *Maximal* strength & speed
Event Duration: 0 - 6 sec (Dominant System)

**Energy Sources**

1. **ATP** ↔ ADP + Pi + H⁺
2. **CP** + ADP + H⁺ ↔ ATP + Cr

Availability: Immediate- stored in muscle
Anaerobic Power: Large
Anaerobic Capacity: Small

**ENERGY SYSTEMS: ATP-CP (Phosphagen)**
ENERGY SYSTEMS: Anaerobic (O_2 independent)

Event Type: *Maximal* speed or *high-intensity* efforts
Event Duration: 6 - 60 sec (Dominant System)

Energy Sources

**Muscle Glycogen** $\leftrightarrow$ 2 ATP + 2 Lactate + 2H^+

Availability: Rapid - via glycogen breakdown (glycolysis)
Anaerobic Power: Moderate
Anaerobic Capacity: Larger than ATP-CP
ENERGY SYSTEMS: Aerobic Glycolytic (CHO)

Event Type: *Moderate and High-intensity* exercise
Event Duration: 2 min – 1.5 hours (Dominant System)

Energy Sources

**Carbohydrates** + O₂ ↔ 38 ATP + by-products

Availability: Fast - via breakdown CHO
Aerobic Power: Large
Aerobic Capacity: Large but limited
Event Type: *Low-intensity* exercise
Event Duration: 4 hours\(^+\) (Dominant System)

Energy Sources

**Fats** + O\(_2\) ↔ 456 ATP + by-products

Availability: Slow- via fat breakdown (lipolysis)
Aerobic Power: Low
Aerobic Capacity: Unlimited
STRATEGIES: To increase fat availability

1. Fasting
2. Caffeine ingestion
   • (6-9 mg/kg BM)
3. Fat ingestion
   • Medium-chain fatty acids (MCFA)
   • Long-chain fatty acids (LCFA)
4. Intralipid (& heparin) infusion
5. Short-term fat-adaptation
Why sprinter will never win with long-distance runner at the distance of 3000m?
Fast exhaustive exercise (eg. sprint)

- ↑ in anaerobic glycolysis rate (role of Ca^{2+})
- In the absence of oxygen (anaerobic conditions) muscle is able to work for about 1-2 minutes because of H^{+} accumulation and ↓pH;
- Sprinter can resynthesize ATP at the maximum speed of the anaerobic pathway for less than about 60s
- **Lactic acid** accumulates and one of the rate-controlling enzymes of the glycolytic pathway is strongly inhibited by this acidity
Muscle fatigue

- Lactic acid

- ↓ATP (accumulation of ADP and P_i, and reduction of creatine phosphate) →
  → ↓Ca^{++} pumping and release to and from SR→
  ↓ contraction and relaxation

- Ionic imbalances → muscle cell is less responsive to motor neuron stimulation
Lactic acid

- ↓ the rate of ATP hydrolysis,
- ↓ efficiency of glycolytic enzymes,
- ↓ Ca\(^{2+}\) binding to troponin,
- ↓ interaction between actin and myosin (muscle fatigue)
- during rest is converted back to pyruvic acid and oxidized by skeletal muscle, or converted into glucose (in the liver)