

# Chapter 5 - Cell Respiration and Metabolism

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  - A. Glycolysis
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## Fig 5.1

### Metabolism

- All reactions that involve energy transformations.
- Divided into 2 categories:
  - **Catabolic:**
    - Release energy.
    - Breakdown larger organic molecules into smaller molecules
    - Serve as primary sources of energy for synthesis of ATP.
  - **Anabolic:**
    - Require input of energy.
    - Synthesis of large energy-storage molecules.

## Glycolysis

<http://www.youtube.com/watch?v=7hiwSCUoSZY>

<http://www.youtube.com/watch?v=A859eEESAFk&feature=related>

- Metabolic pathway by which glucose is converted to 2 molecules of pyruvic acid (pyruvate).
- Glycolysis Pathway:
- $\text{Glucose} + 2 \text{ NAD} + 2 \text{ ADP} + 2 \text{ P}_i \rightarrow 2 \text{ pyruvic acid} + 2 \text{ NADH} + 2 \text{ ATP}$

### Fig 5.2

- Glycolysis is exergonic.
- Glucose must be activated **first** before energy can be obtained.
  - ATP consumed at the beginning of glycolysis.
    - $\text{ATP} \rightarrow \text{ADP} + \text{P}_i$
  - $\text{P}_i$  is not released but added to intermediate molecules (phosphorylation).
    - Phosphorylation of glucose, traps the glucose inside the cell.
- **Net gain of 2 ATP, 2 NADH, + 2  $\text{H}^+$ .**

### Fig 5.3

## Lactic Acid Pathway

- Metabolic pathway by which glucose is converted to lactic acid (anaerobic respiration):
  - **Oxygen is not used in the process.**
  - $\text{NADH} + \text{H}^+ + \text{pyruvic acid} \rightarrow \text{lactic acid and NAD.}$
  - Produce 2 ATP/glucose molecule.

[http://www.youtube.com/watch?v=y\\_k8xLrBUfg](http://www.youtube.com/watch?v=y_k8xLrBUfg)

### Fig 5.4

- Some tissues better adapt to anaerobic conditions:
  - RBCs do not contain mitochondria and **only** use the lactic acid pathway.
  - Occurs in skeletal muscles and heart when ratio of oxygen supply to oxygen need falls below critical level.
    - Skeletal muscle:
      - Normal daily occurrence.
      - Does not harm muscle tissue.
    - Cardiac muscle normally respire aerobically:
      - Myocardial ischemia occurs under anaerobic conditions.

## Glycogenesis and Glycogenolysis

- Cells cannot store many glucose molecules.

**WHY?**

- Increased intracellular [glucose] increases osmotic pressure, drawing H<sub>2</sub>O into the cell.
- Many organs must store carbohydrates in form of **glycogen**.
  - **Glycogenesis**: formation of glycogen from glucose.
  - **Glycogenolysis**: conversion of glycogen to **glucose-6-phosphate**.
- Glucose-6-phosphate cannot leak out of the cell.
- Skeletal muscles generate glucose-6-phosphate for own glycolytic needs.
- Liver contains the enzyme glucose-6-phosphatase that can remove the phosphate group and produce free glucose.

## Fig 5.5

### Cori Cycle

- Lactic acid produced by **anaerobic** respiration delivered to the liver.
- LDH (lactic dehydrogenase) converts lactic acid to pyruvic acid.
- Pyruvic acid converted to glucose-6-phosphate:
  - An intermediate for glycogen synthesis.

- Can be converted to free glucose.

## Fig 5.6

### **Aerobic Respiration**

- The pyruvic acid formed by glycolysis enters interior of mitochondria.
- Converted by coenzyme A to 2 molecules of acetyl CoA and 2 CO<sub>2</sub>.
- Acetyl CoA serves as substrate for mitochondrial enzymes in the aerobic pathway.

## Fig 5.7

### **Krebs Cycle (Citric Acid Cycle)**

- Acetyl CoA subunit combines with **oxaloacetic acid** to form citric acid.
- Citric acid enters the Krebs Cycle.
- 1 Acetyl CoA Molecule Produces:
  - 1 GTP, 3 NADH, and 1 FADH<sub>2</sub>
  - NADH and FADH<sub>2</sub> transport electrons to Electron Transport System (ETC).

<http://www.youtube.com/watch?v=lvoZ21P4JK8&feature=related>

<http://www.youtube.com/watch?v=aCypoN3X7KQ&feature=related>

## Fig 5.8

### Electron Transport

Cristae of inner mitochondrial membrane contain molecules that serve as an electron transport system during aerobic respiration.

- Electron transport chain consists of **FMN cytochromes**.
- Each cytochrome transfers electron pairs from NADH and FADH<sub>2</sub> to next cytochrome.
- **Cytochrome a<sub>3</sub>** transfers electrons to O<sub>2</sub> (final electron acceptor).
- Oxidative phosphorylation occurs:
  - Energy derived is used to phosphorylate ADP to ATP.

## Fig 5.10

Oxygen is the final electron acceptor!

## Coupling Electron Transport to ATP Production

- **Chemiosmotic theory:**
  - ETC (powered by transport of electrons) pumps  $H^+$  from mitochondria matrix into the space between inner and outer mitochondrial membranes.
  - ETC grouped into 3 proton pumps:
    - Pump 1 (NADH-coenzyme Q reductase complex):
      - Transports 4  $H^+$  for every pair of electrons into the intermembrane space for every pair of electrons.
    - Pump 2 (Cytochrome C reductase complex):
      - Transports 4  $H^+$  into intermembrane space.
    - Pump 3 (Cytochrome C oxidase complex):
      - Transports 2  $H^+$  into intermembrane space.
  - Higher  $[H^+]$  in intermembrane space.
  - Inner mitochondrial membrane allows diffusion of  $H^+$  through respiratory assemblies.
  - Phosphorylation is coupled to oxidation, when  $H^+$  diffuse through the respiratory assemblies:



<http://www.youtube.com/watch?v=xbJ0nbzt5Kw&feature=related>

<http://www.youtube.com/watch?v=3y1dO4nNaKY&feature=related>

## Fig 5.11

### ATP Balance Sheet

- Direct substrate phosphorylation (glycolysis):
  - Net gain of **2 ATP**.
- Oxidative phosphorylation:
  - 2.5 ATP produced for pair of electrons each NADH donates.
  - 1.5 ATP produced for each pair of electrons FADH<sub>2</sub> donates (activates 2nd and 3rd proton pumps).
  - Net of **26 ATP produced**.

## Table 5.2

KNOW!

### Lipid Metabolism

- When more energy is taken in than consumed, ATP production is inhibited.

**An  $\uparrow$  [ATP]  $\rightarrow$   $\downarrow$  ATP production.**

**What kind of feedback is this?**

- Glucose converted into glycogen and fat.

## Fig 5.12

### Lipogenesis

- Formation of fat.

- Acetic acid subunits from acetyl CoA converted into various lipids.
- Occurs mainly in adipose tissue and liver.

### Fig 5.13

#### Lipid Metabolism

- Lipolysis: Breakdown of fat.
- Triglycerides → glycerol + 3 free fatty acids
- Free fatty acids serve as **blood-borne energy carriers**.
  - Free fatty acids serve as the major energy source derived from triglycerides.

#### Beta-Oxidation

- Process by which cells can use fatty acids.
- Enzymes remove 2-carbon acetic acid molecules from acid end of fatty acid chain.
  - Forms acetyl CoA.
- Acetyl CoA enters Krebs Cycle.
  - ATP, NADH and FADH<sub>2</sub> produced.

### Fig 5.14

## **Ketone Bodies**

- Triglycerides in adipose tissue broken down and resynthesized.
  - Ensure the blood will contain sufficient levels of fatty acids for aerobic respiration.

If ATP sufficient, acetyl CoA channeled into alternate pathway.

- Converted to ketone bodies.

## **Amino Acid Metabolism**

- Nitrogen is ingested primarily as protein.

WHY?

### **Amino Group - NH<sub>2</sub>**

## **Transamination**

- Adequate amounts of amino acids are required for growth and repair. A new amino acid can be obtained by transamination.
  - Amine group (NH<sub>2</sub>) transferred from one amino acid to form another amino acid and a keto acid.
  - Catalyzed by a specific enzyme (transaminase).

**Fig 5.15**

## **Oxidative Deamination**

- Process by which excess amino acids are eliminated.
- Amine group from glutamic acid removed, forming a keto acid and ammonia.
  - Keto acid can be used in the Krebs Cycle.
  - Ammonia is converted to urea and excreted.

### **Fig 5.16**

## **Uses of Different Energy Sources**

- Not all cells can use glucose as the energy source.
- Blood contains a variety of energy sources:
  - Glucose and ketone bodies, fatty acids, lactic acid, and amino acids.
- Brain uses glucose as its major source of energy.
  - Blood [glucose] maintained as many organs spare glucose.

### **Table 5.4**