21.8: The Electron-Transport Chain and ATP Production

Learning Outcomes

- Summarize the electron transport chain.
- Recognize that electron transport chain is the third and final stage of aerobic cellular respiration.
- Identify the products of the citric acid cycle.

What do trains, trucks, boats, and planes all have in common? They are ways to transport. And they all use a lot of energy. To make ATP, energy must be "transported" - first from glucose to NADH, and then somehow passed to ATP. How is this done? With an electron transport chain, the third stage of aerobic respiration. This third stage uses energy to make energy.

The Electron Transport Chain: ATP for Life in the Fast Lane

At the end of the Krebs Cycle, energy from the chemical bonds of glucose is stored in diverse energy carrier molecules: four ATPs, but also two $FADH_2$ and ten NADH molecules. The primary task of the last stage of cellular respiration, the **electron transport chain**, is to transfer energy from the electron carriers to even more ATP molecules, the "batteries" which power work within the cell.

Pathways for making ATP in stage 3 of aerobic respiration closely resemble the electron transport chains used in photosynthesis. In both electron transport chains, energy carrier molecules are arranged in sequence within a membrane so that energy-carrying electrons cascade from one to another, losing a little energy in each step. In both photosynthesis and aerobic respiration, the energy lost is harnessed to pump hydrogen ions into a compartment, creating an **electrochemical gradient** or **chemiosmotic gradient** across the enclosing membrane. And in both processes, the energy stored in the chemiosmotic gradient is used with **ATP synthase** to build ATP.

For aerobic respiration, the electron transport chain or "respiratory chain" is embedded in the inner membrane of the mitochondria (see figure below). The $FADH_2$ and NADH molecules produced in glycolysis and the Krebs Cycle, donate high-energy electrons to energy carrier molecules within the membrane. As they pass from one carrier to another, the energy they lose is used to pump hydrogen ions into the mitochondrial intermembrane space, creating an electrochemical gradient. Hydrogen ions flow "down" the gradient - from outer to inner compartment - through the ion channel/enzyme ATP synthase, which transfers their energy to ATP. Note the paradox that it requires energy to create and maintain a concentration gradient of hydrogen ions that are then used by ATP synthase to create stored energy (ATP). In broad terms, it takes energy to make energy. Coupling the electron transport chain to ATP synthesis with a hydrogen ion gradient is **chemiosmosis**, first described by Nobel laureate Peter D. Mitchell. This process, the use of energy to phosphorylate ADP and produce ATP is also known as **oxidative phosphorylation**.

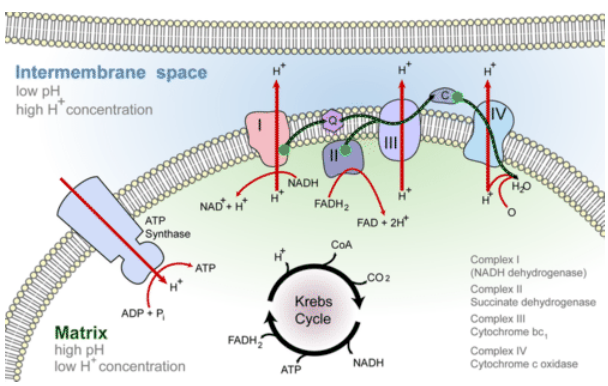

Figure 21.8.1: The third stage of cellular respiration uses the energy stored during the earlier stages in NADH and $FADH_2$ to make ATP. Electron transport chains embedded in the mitochondrial inner membrane capture high-energy electrons from the carrier molecules and use them to concentrate hydrogen ions in the intermembrane space. Hydrogen ions flow down their electrochemical gradient back into the matrix through ATP synthase channels which capture their energy to convert ADP to ATP. Notice that the process regenerates NAD^+, supplying the electron acceptor molecule needed in glycolysis. (CC BY-NC 3.0; Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation).

After passing through the electron transport chain, low-energy electrons and low-energy hydrogen ions combine with oxygen to form water. Thus, oxygen's role is to drive the entire set of ATP-producing reactions within the mitochondrion by accepting "spent" hydrogens. Oxygen is the final electron acceptor, no part of the process - from the Krebs Cycle through the electron transport chain- can happen without oxygen.

The electron transport chain can convert the energy from one glucose molecule's worth of $FADH_2$ and $NADH$ + H^+ into as many as 34 ATP. When the four ATP produced in glycolysis and the Krebs Cycle are added, the total of 38 ATP fits the overall equation for aerobic cellular respiration:

$$6\,O_2 + \underbrace{C_6H_{12}O_6}_{\text{stored chemical energy}} + 38\,ADP + 39\,P_i \rightarrow \underbrace{38\,ATP}_{\text{stored chemical energy}} + 6\,CO_2 + 6\,H_2O \tag{21.8.1}$$

Aerobic respiration is complete. If oxygen is available, cellular respiration transfers the energy from one molecule of glucose to 38 molecules of ATP, releasing carbon dioxide and water as waste. "Deliverable" food energy has become energy which can be used for work within the cell - transport within the cell, pumping ions and molecules across membranes, and building large organic molecules. Can you see how this could lead to "life in the fast lane" compared to anaerobic respiration (glycolysis alone)?

Contributors and Attributions

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