THE COMPLEXES OF THE MITOCHONDRIAL ELECTRON TRANSPORT CHAIN

Complex I is also known as the *NADH dehydrogenase complex*. Complex II is the *succinate dehydrogenase complex*, where succinate dehydrogenase, one of the enzymes in the citric acid cycle, is one of the components. It is the only enzyme in the cycle that is located in the inner mitochondrial membrane instead of the matrix. Thus, succinate dehydrogenase serves dual purposes: an enzyme in the citric acid cycle and a part of complex II in the ETC. Complex III is also called the *cytochrome* bc_1 *complex* and Complex IV is the *cytochrome oxidase complex*.

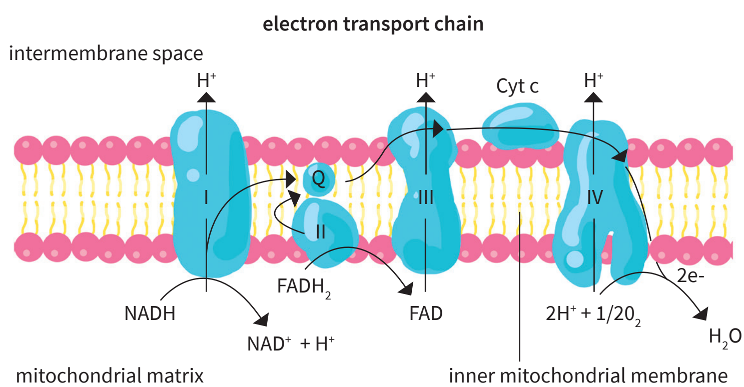

Fig. 8.7 Electrons from the oxidation of NADH and $FADH_2$ flow across the complexes of the mitochondrial electron transport chain and drive the transport of H^+ across the membrane.

Table 8.1 The four complexes of the electron transport chain

Feature	Complex I	Complex II	Complex IV	Complex IV
protein components	NADH dehydrogenase (enzyme) iron-sulfur protein (Fe-S)	succinate dehydrogenase (enzyme) iron-sulfur protein (Fe-S)	cytochrome b (cyt b) cytochrome c_1 (cyt c_1)	cytochrome a (cyt a) cytochrome a_3 (cyt a_3)
prosthetic group	[redacted]			
proton pump	Yes	No	Yes	Yes

An important component of these complexes is the *prosthetic group*, which refers to a non-protein component that is needed for an enzyme to function and the actual part of the complex that receives and transfers electrons. Thus, the prosthetic group is alternately reduced and oxidized. Table 8.1 lists the prosthetic groups as well as the protein components in each complex of the ETC. It also shows which among the complexes can pump protons across the membrane.

Transfer of Electrons through the Chain

Figure 8.7 shows the flow of electrons along the chain.

Step 1. NADH is oxidized, and the electrons released are passed on to Complex I. The electrons are then transferred to the prosthetic groups of this complex.

Step 2. The electrons from Complex I are received by *ubiquinone* (also called *coenzyme Q* or CoQ). This molecule is a mobile electron carrier so it is not part of any complex. It carries the electrons from Complex I to Complex III.

[redacted]

Step 6. The electrons are passed on to O_2, reducing it to form water. Therefore, O_2 is the final electron acceptor. Its reduction to water is shown in the equation below:

$$O_2 + 4H^+ + 4\,e^- \rightarrow 2\,H_2O$$

$FADH_2$ is also oxidized and passes its electrons from within Complex II to ubiquinone. Then from ubiquinone, the electrons follow the same pathway as the electrons from NADH oxidation, as shown in figure 8.7.

The process involves the important function of oxygen in respiration. Oxygen accepts the electrons that were previously extracted from glucose. Without oxygen, NADH and $FADH_2$ cannot be oxidized and no electrons would pass across the chain. This also means that NAD^+ and FAD^{2+} would not be produced. Without these oxidizing agents, glucose cannot be broken down. Hence, the stored energy from glucose would not be extracted.

But where does ATP production happen at this stage? The passing on of electrons across the chain does not directly produce ATP, but it provides the energy needed for ATP synthesis. This will be taken up in the next lesson.

DID YOU KNOW?

The flow of electrons across the respiratory chain produces reactive oxygen species (ROS) that are strong oxidizing agents.

Because ROS are highly reactive, they can damage enzymes, lipids, and nucleic acids in the cell. The enzymes superoxide dismutase and glutathione peroxidase catalyze a series of reactions to render these ROS harmless and protect the cell from damage. It was observed, however, that damage caused by ROS increases as your cells age.

Shuttle Systems for Cytosolic NADH

Glycolysis, which occurs in the cytosol, produces two NADH molecules. As previously learned, the electrons from these two molecules have to be passed on to the ETC in the inner mitochondrial membrane. However, this membrane is impermeable to NADH. This problem is solved through a shuttle system. Think of this system as like a bus or a train that carries passengers, in this case electrons, to a specific destination.

This system includes an enzyme that catalyzes the oxidation of NADH in the cytosol. The electrons released from that reaction reduce a cytosolic molecule that can be transported across the inner mitochondrial membrane. Inside the mitochondrial matrix, another oxidation reaction occurs to release these electrons. This time, the electrons reduce electron carriers in the matrix, either NAD^+ to recover NADH or FAD^{2+} to form $FADH_2$. These reduced electron carriers can now transfer their electrons to the ETC.