4.6 Respiratory substrates

Energy values of different biological molecules as respiratory substrates

We know that the majority of ATP produced during aerobic respiration is done so during oxidative phosphorylation in the electron transport chain, which occurs as hydrogen ions (protons) flow through ion channel proteins which drives the rotation of ATP synthase, to join an ADP molecule and an inorganic phosphoryl group to form ATP. Therefore, we can assume the more hydrogen atoms there are in the **respiratory substrate** (organic compound respired during respiration) the more ATP will be generated. Likewise we can assume that the more hydrogens there are, the more oxygen will be required to respire that substrate.

Carbohydrates

The main respiratory substrate is *glucose*, a saccharide of the carbohydrate family. Some mammalian cells (such as brain cells and erythrocytes) can only respire glucose. It is stored in animals as glycogen and in plants as starch, both of which can be hydrolysed to produce the monomer glucose whenever. Other monosaccharides such as fructose or galactose may be converted to glucose to be used in respiration.

The theoretical maximum energy yield for glucose is 2,870kJ mol^{-1}, and it takes 30.6kJ to produce 1 mole of ATP. So theoretically, the respiration of one mole of glucose should produce nearly 94 ATP, whereas the actual yield is around 30, giving an efficiency of around 32% - the remaining energy is given off as heat, helping to maintain a suitable body temperature allowing enzyme-controlled activity to proceed.

Proteins

Excess amino acids may be **deaminated** (this involves removing their amine groups and converting them to urea), and the rest of the molecule changing to glycogen or fat, which can be stored and respired later to release energy.

When an organisms is fasting or starving, proteins may be hydrolysed to amino acids which can be respired. Some can be converted to pyruvate or acetate which can be carried through to Krebs cycle. NAD accepts a slightly higher number of hydrogen atoms during Krebs cycle from amino acids than it does from glucose, so respired amino acids have a higher energy yield, although only by a small amount.

Lipids

Lipids are a particularly important respiratory substrate for muscle tissues. Triglycerides can be hydrolysed by lipase to fatty acids and glycerol. Glycerol can be converted to glucose, and then respired as normal.

Fatty acids, however, cannot be converted to glucose. They are long-chain hydrocarbons with a carboxylic acid group at their terminus. This means they contain a great deal of carbon and even more hydrogen. The hydrogen atoms make them a great source of protons for the oxidative phosphorylation stage, as they produce a lot of ATP molecules.

Each fatty acid is combined with coenzyme-A, which requires the energy of hydrolysis of one ATP molecule into a molecule of AMP and two phosphates. The fatty acid-CoA complex is then transported into the mitochondrial matrix where it is broken down into 2-carbon acetyl groups that are attached to coenzyme-A. During this breakdown (known as the β-oxidation pathway, reduced NAD and reduced FAD are formed. The acetyl groups are released and enter Krebs cycle, where as normal they produce 3 reduced NAD, 1 reduced FAD and 1 ATP each. The large amounts of reduced NAD are reoxidised during the electron transport chain afterwards, and during oxidative phosphorylation, very large numbers of ATP are produced due to the large number of protons available.

Respiratory substrate	Mean energy value (kJ g^{-1})
Carbohydrate	15.8
Protein	17.0
Lipid	39.4

It is important to remember that lipids and proteins can only be respired aerobically, and cannot undergo glycolysis. Both can be hydrolysed into substances which enter Krebs cycle, and then the electron transport chain.