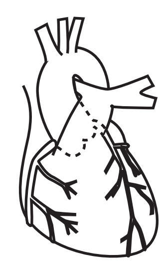
Energy and Cardiac Muscle Contraction

A primer on the

Energetics of Cardiac Muscle Contraction

and

β-*Oxidation*



By Noel Ways

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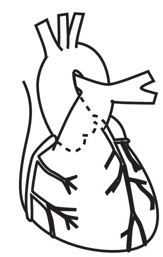

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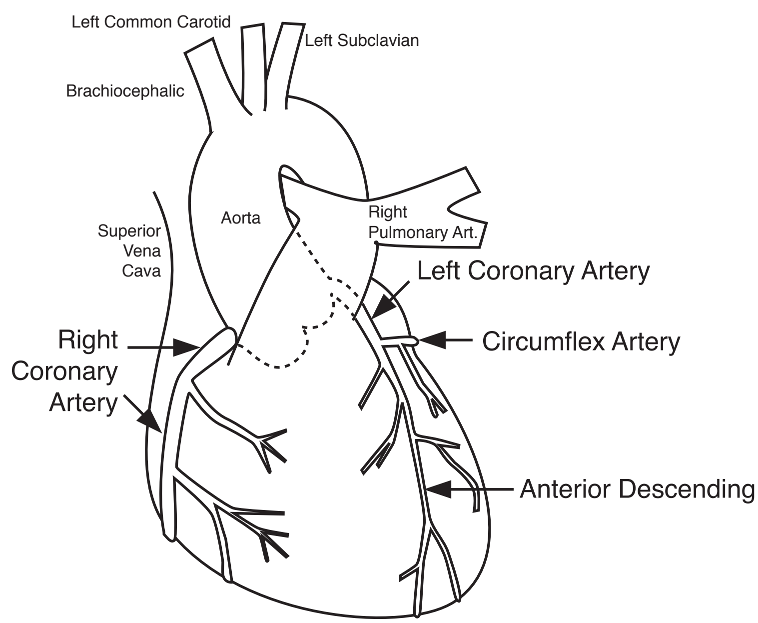
Introduction

The heart beats continuously, day after day, with the only opportunity to rest between beats. To fatigue or to “take a breather” are not options. In order maintain on-going cardiac activity, a continuous supply of oxygen is a requisite, as well as the removal of metabolic waste. Hence, coronary circulation is well developed. Further, the energy supply must be abundant and of high “caloric value”. Given that lipids have more than twice the energy as carbohydrate (9 kcal/gm compared to 4 kcal/gm), fatty acids are the preferred energy source for cardiac muscle.

The focus of this handout is to better understand the link between cellular respiration and lipids in cardiac muscle contraction. To this end, we begin with a brief review of cellular respiration. If you want or need a more in-depth review of this process, see the handout, "Cellular Respiration", in the A&P I site.

We will also take a more detailed look at the transition stage, as this the most important point at which the lipids will enter cellular respiration.



Review of Cellular Respiration

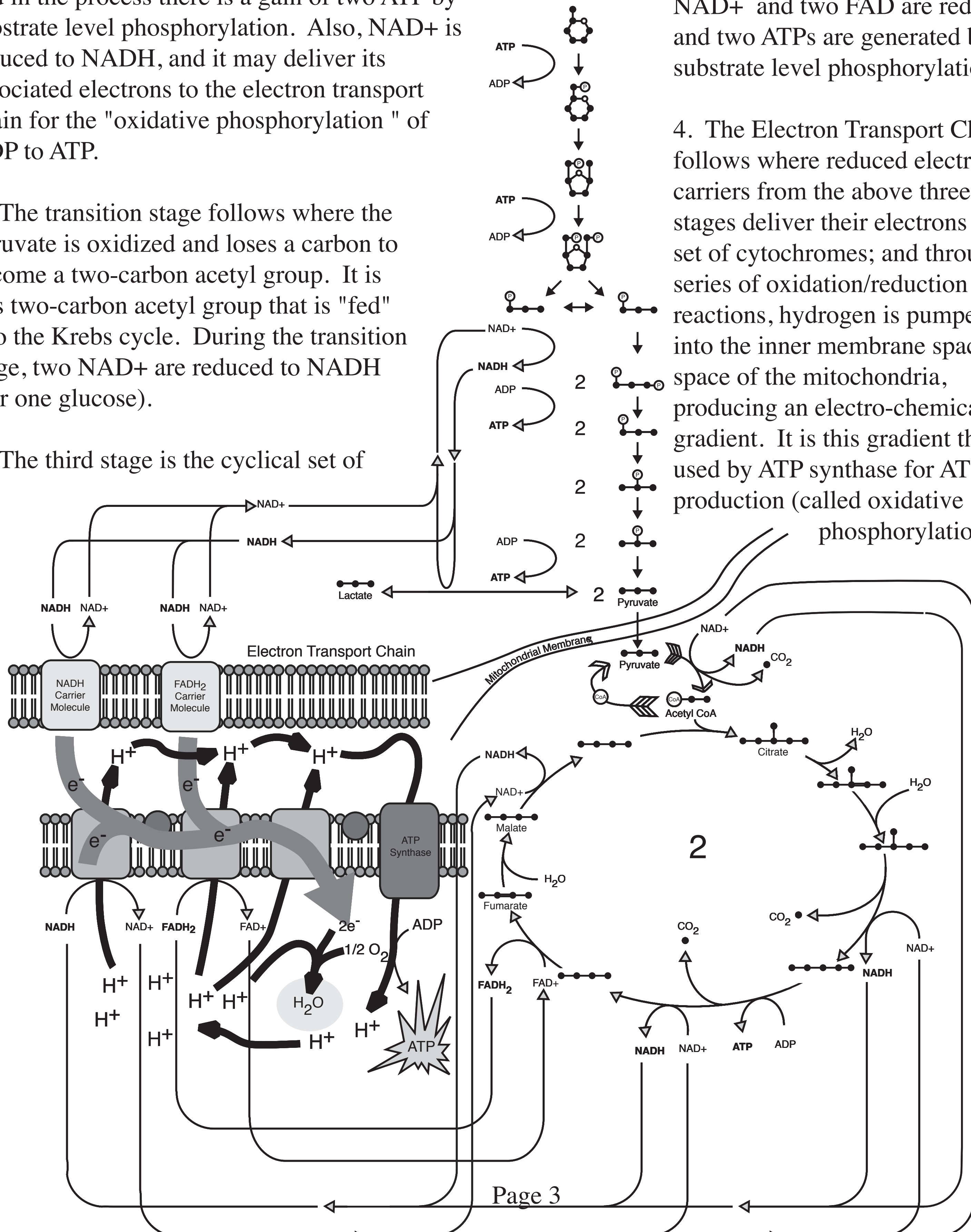
Cellular respiration is the process where chemical energy is converted into a useable energy form of ATP. If we use glucose as the of energy for cellular respiration, the process can be broken down into four essential steps.

1. The first step is glycolysis where glucose is broken down into two three-carbon pyruvates, and in the process there is a gain of two ATP by substrate level phosphorylation. Also, NAD+ is reduced to NADH, and it may deliver its associated electrons to the electron transport chain for the "oxidative phosphorylation " of ADP to ATP.

2. The transition stage follows where the pyruvate is oxidized and loses a carbon to become a two-carbon acetyl group. It is this two-carbon acetyl group that is "fed" into the Krebs cycle. During the transition stage, two NAD+ are reduced to NADH (per one glucose).

3. The third stage is the cyclical set of reactions called the Citric Acid Cycle (or Kreb's Cycle). Here, 6 NAD+ and two FAD are reduced, and two ATPs are generated by substrate level phosphorylation.

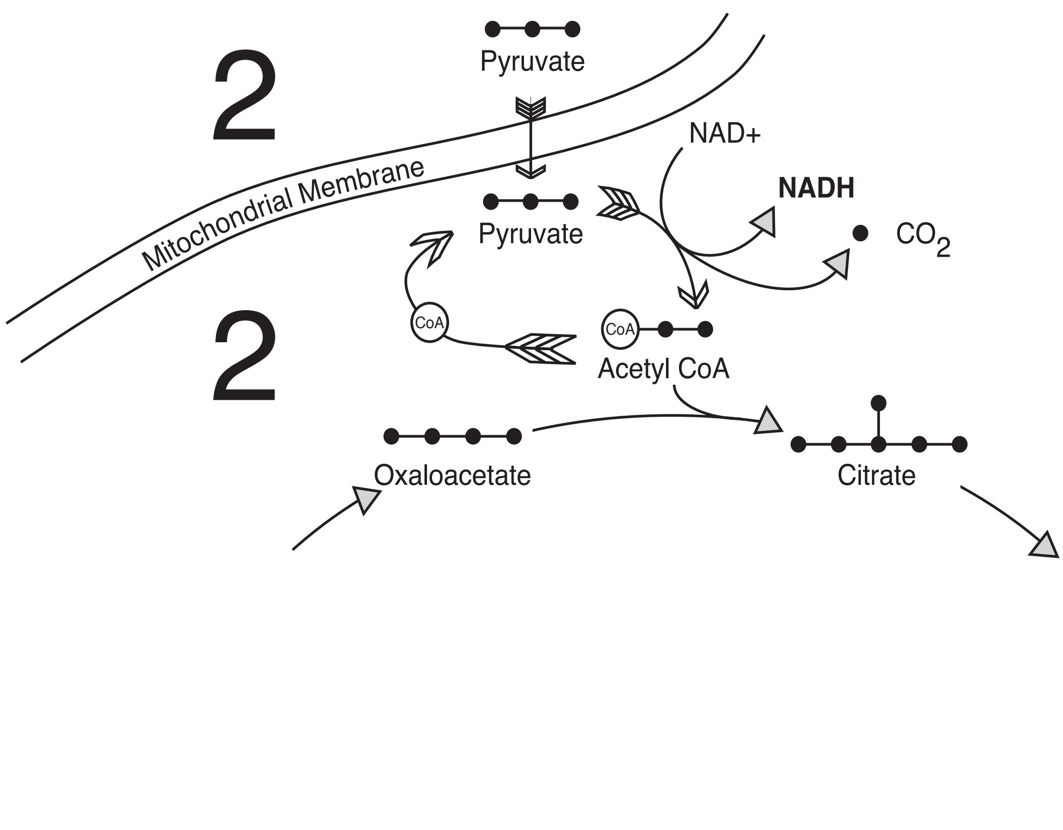
4. The Electron Transport Chain follows where reduced electron carriers from the above three stages deliver their electrons to a set of cytochromes; and through a series of oxidation/reduction reactions, hydrogen is pumped into the inner membrane space space of the mitochondria, producing an electro-chemical gradient. It is this gradient that is used by ATP synthase for ATP production (called oxidative phosphorylation).



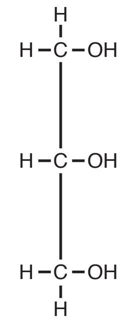
The Transition Stage

The transition stage functions to "transition" pyruvate into the cyclical citric acid cycle. This stage consists of essentially one complex step in which three things are happening almost simultaneously. First, an enzyme catalyzes the removal of a carbon as carbon dioxide. The remaining two carbons form an acetyl group. Second, pyruvate is oxidized, and as this is happening NAD+ is reduced to NADH. The NADH will transport its newly acquired electrons to the electron transport chain for ATP generating purposes by oxidative phosphorylation. Thirdly, for the reactions to proceed, a coenzyme (Coenzyme A [CoA]) is needed to "feed" the acetyl group into the citric acid cycle.

It is this transition stage that is used most heavily in the catabolism of lipids and bringing their energy rich components into cellular respiration.



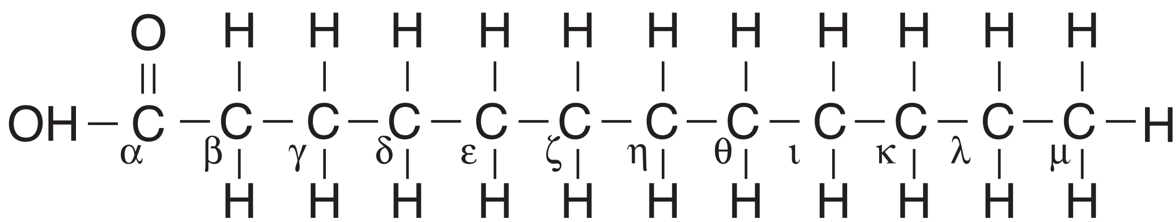
Triglycerides, Fatty Acids, and Nomenclature



Glycerol

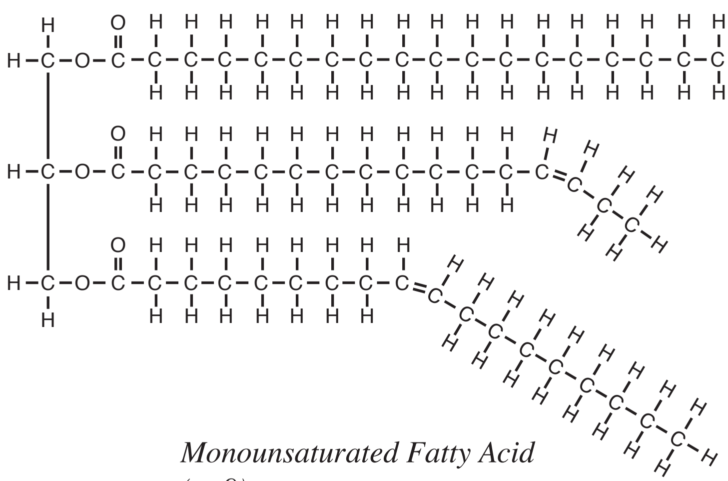
A triglyceride consists of a three-carbon glycerol that is covalently bonded to three fatty acids by three dehydration synthesis reactions.

The fatty acids are hydrocarbon chains of varying lengths. On such chains, each carbon is labelled according to the Greek alphabet: a, b, g, d, e, etc. The numbering system starts at the end (carboxyl group) that attaches to the glycerol. This will be important in a moment.



An example of a triglyceride in which three fatty acids are covalently attached to a glycerol is shown below.

Saturated Fatty Acid

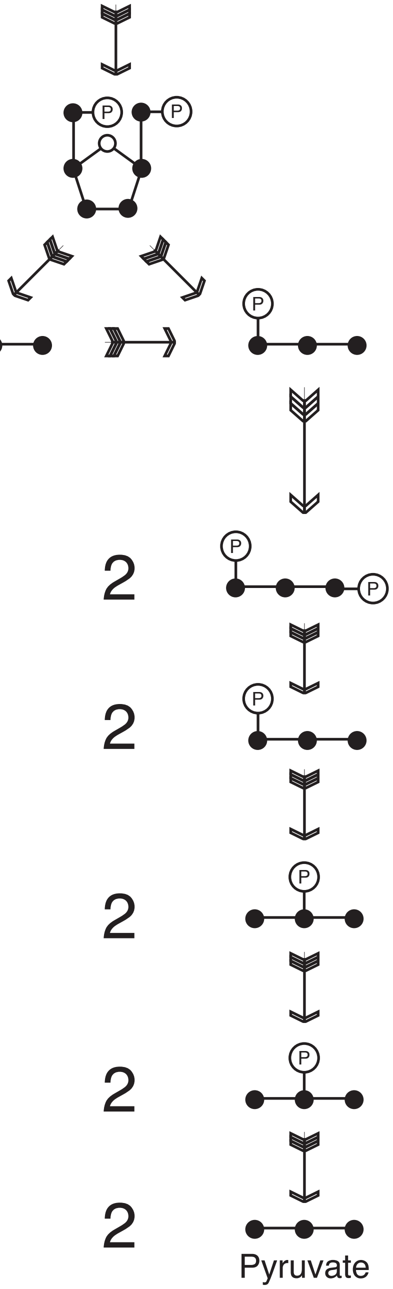


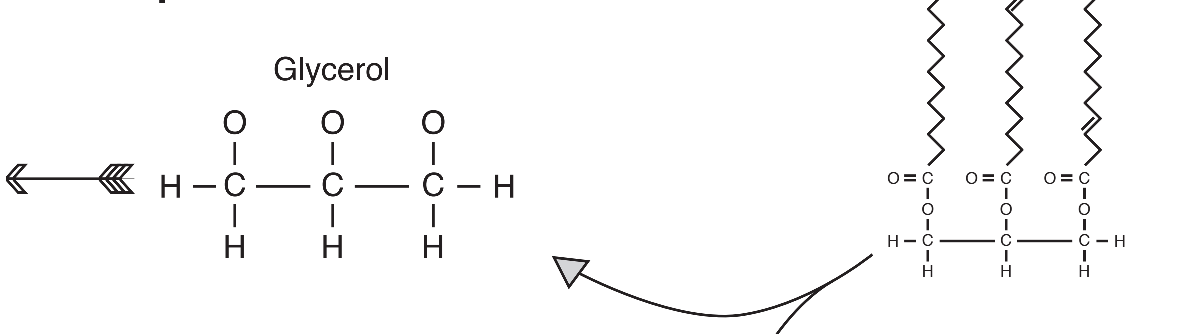
Monounsaturated Fatty Acid (ω-3)

Monounsaturated Fatty Acid (ω-9)

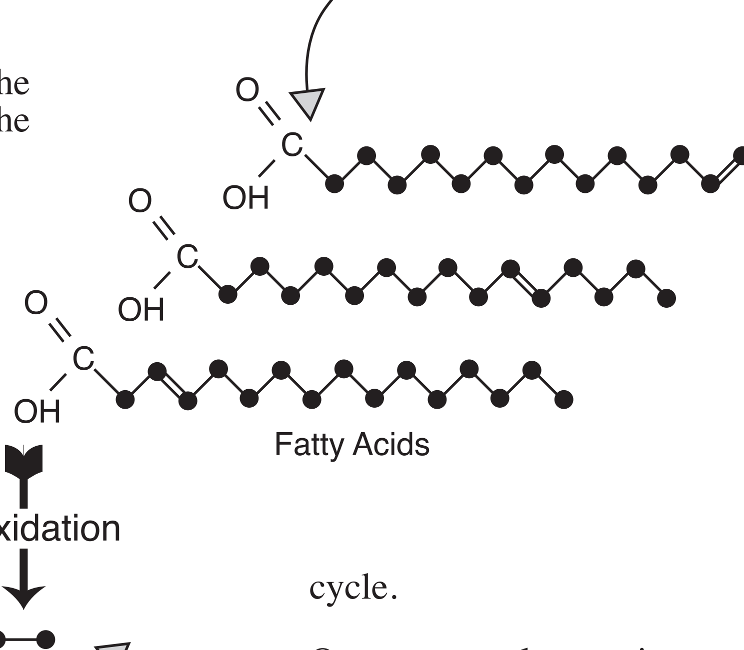
During the catabolism of a triglyceride the fatty acids are removed (hydrolysis reactions) from the glycerol. There is now one glycerol and three fatty acids.

Lipid Catabolism





During the catabolic breakdown of triglycerides, the glycerol enters directly into the glycolytic pathway (seen above). Fatty acids are broken down into two carbon acetyl groups at the beta (β) carbon (therefore the process is known as β-oxidation). Coenzyme A takes the two-carbon acetyl group and ferries it into the citric acid



cycle.

Once an acetyl group is removed, the carbons are relabeled, and we start at α again and again break the chain at the β carbon. The process continues in this manner until the fatty acid is completely catabolized.

It is interesting to note that fatty acids are also built using two carbon acetyl groups, and therefore, all fatty acids