Biochemistry of muscle

Department of Animal Science and Food Sciences
Advance Meat Science and Muscle Biology

The ATP (adenosine triphosphate) is the ultimate source of energy for:

- **The contractile process.**
- **The pumping of calcium back into the sarcoplasmic reticulum during relaxation.**
- **Maintaining the sodium/potassium ion gradients across the sarcolema (membrane potential).**

Pathways that provide for ATP synthesis on aerobic conditions:

- **Phosphocreatine.**
- **Glycolysis from Glycogen or Glucose.**
- **Tricarboxylic acid cycle (TCA or Krebs cycle).**
- **Electron transport chain.**

Phosphocreatine

Phosphocreatine

It is also known as creatine phosphate or Pcr, that is an important energy stored in the skeletal muscle.

Creatine is synthesized in the liver (from Arg, Gly, Met), and transported to the muscle cells, where it is phosphorylated by creatine kinase (ATP is required) to creatine phosphate.

Phosphocreatine

ADP

+

Phosphocreatine

Creatine Kinase

ATP

+

Creatine

Phosphocreatine

- This reaction occurs in the sarcoplasm.
- ATP broken down during contraction is rapidly restored.
- Phosphocreatine is subject to depletion during extended periods of contraction (intense effort).
- Rephosphorylation of creatine occurs at the mitochondrial membrane.

Glycolysis

Glycolysis

It is the sequence of reactions that converts glucose into pyruvate with the concomitant production of a relatively small amount of adenosine triphosphate (ATP).

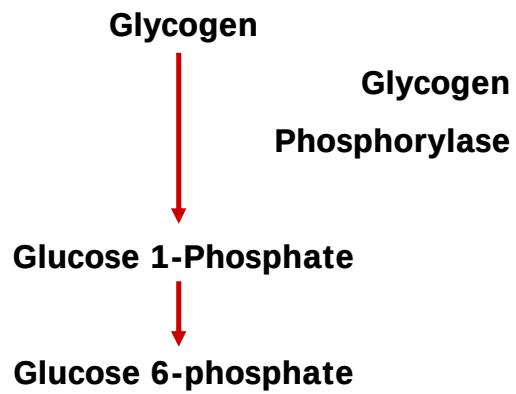
Glycolysis

Glycogen

Glycogen is a polysaccharide of glucose (Glc) which functions as the primary short term energy storage in muscle cells (myofiber).

Glycogen is found in the form of granules in the sarcoplasm, and plays an important role in the glucose cycle.

Glycolysis



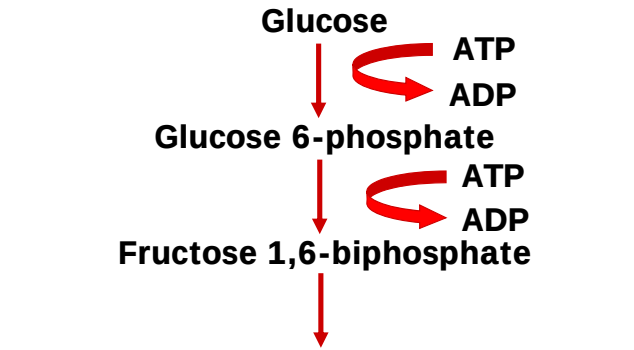
Glycolysis

Preparatory phase

The first five steps are regarded as the preparatory (or investment) phase since they consume energy to convert the glucose into two three-carbon sugar phosphates (G3P).

Glycolysis

Preparatory phase



Glycolysis

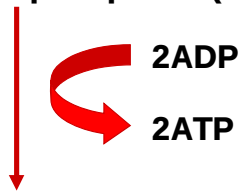
Pay-off phase

The second half of glycolysis is characterized by a net gain of the energy-rich molecules ATP and NADH.

Glycolysis

Pay-off phase

2Glyceraldehyde 3-phosphate (GADP)



2 Pyruvate

Glycolysis

Summary

1 Glucose + 2ADP + 2P_i +2NAD

2 Pyruvate + 2ATP + 2NADH +2H + 2H_2O

Glycolysis

Summary

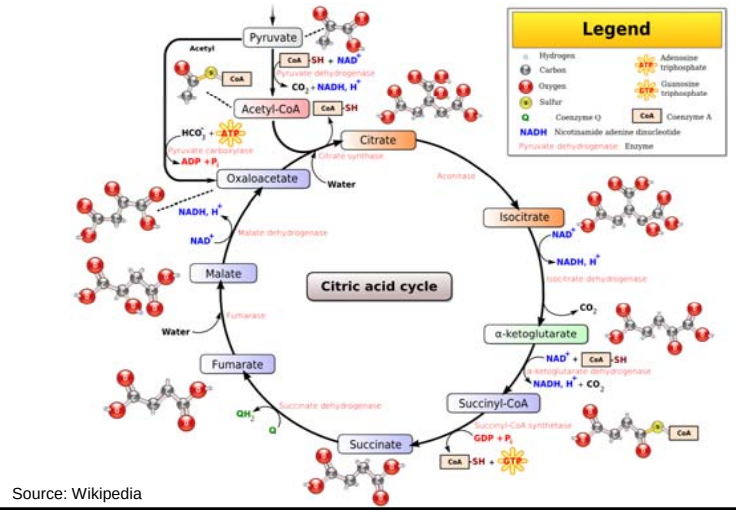
- http://www.science.smith.edu/departments/Biology/Bio231/glycolysis.html

TCA cycle

The tricarboxylic acid cycle (TCA cycle)

- It is also known as citric acid cycle or the Krebs cycle.
- It is a series of enzyme-catalyzed chemical reactions of central importance in all living cells that use oxygen as part of cellular respiration.

TCA cycle



Source: Wikipedia

TCA cycle

The process:

- **The citric acid cycle begins with acetyl CoA transferring its two-carbon acetyl group to the four-carbon acceptor compound (Oxaloacetate) to form a six-carbon compound (citrate).**
- **The citrate then goes through a series of chemical transformations, losing CO_2 and gives Oxaloacetate.**

TCA cycle

- For each acetyl group that enters the citric acid cycle, three molecules of NADH are produced.
- Electrons are also transferred to the electron acceptor FAD, forming $FADH_2$.
- At the end of each cycle, the four-carbon Oxaloacetate has been regenerated, and the cycle continues.

TCA cycle

Summary

Pyruvate

↓

1ATP + 4NADH + 1FADH + $3CO_2$

TCA cycle

Summary

- http://www.science.smith.edu/departments/Biology/Bio231/glycolysis.html

ETC

Electron transport chain (ETC)

- **It is a chemical reaction between an electron donor (such as NADH) and an electron acceptor (such as O_2) to the transfer of H+ ions across a membrane.**
- **These H+ ions are used to produce ATP, as they move back across the membrane.**

ETC

The process 1:

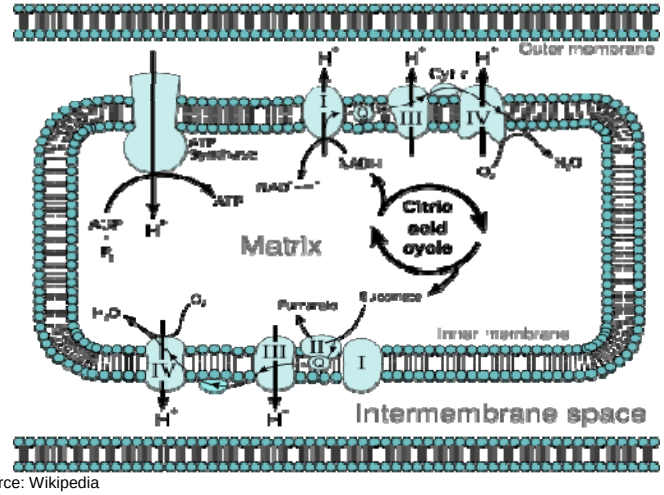
- **Electrons from these donors (NADH) are passed through an electron transport chain (redox process) to oxygen, which is reduced to water.**
- **The enzymes that catalyze these reactions create a proton gradient across the membrane, producing a thermodynamically unlikely high-energy state with the potential to do work.**

ETC

Enzymes:

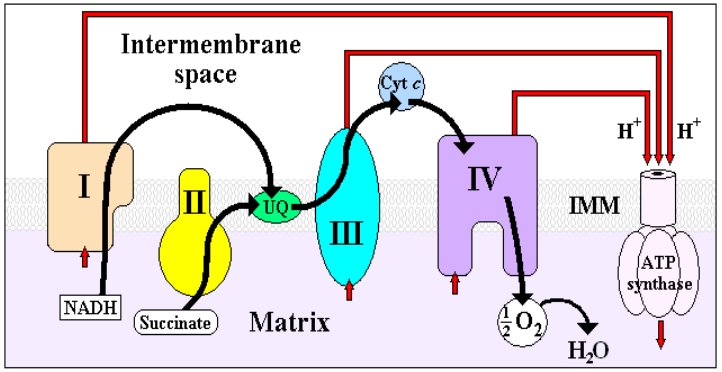
- **Complex I: NADH coenzyme Q reductase (I).**
- **Coenzyme Q: ubiquinone (UQ)**
- **Complex II: succinate dehydrogenase; (II).**
- **Complex III: cytochrome bc1 complex; (III).**
- **Cytochrome c (cyt c).**
- **Complex IV: cytochrome c oxidase; (IV)**

ETC



Source: Wikipedia

ETC



Source: Wikipedia

ETC

The process 2 :

- **This proton gradient is used by the F_OF_1 ATP synthase complex (sub-units) to make ATP via oxidative phosphorilation.**
- **The F_O component of ATP synthase (sub-unit) acts as an ion channel for return of protons back to mitochondrial matrix.**

ETC

The process 2:

- **During their return, the free energy produced during the generation of the oxidized forms of the electron carriers (NAD+ and FAD+) is used to drive ATP synthesis, catalyzed by the F1 component of the complex.**

ETC

Summary

NADH

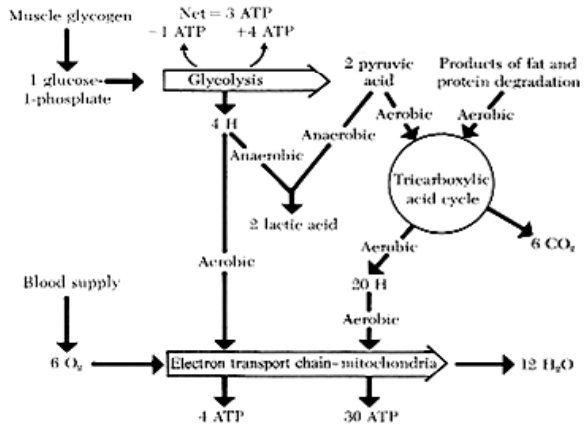
NAD + 3ATP + $4H_2O$

ETC

Summary

- http://www.science.smith.edu/departments/Biology/Bio231/glycolysis.html

Complete oxidation process



Source: Aberle, et al., 2001

Complete oxidation, ATP yield

Process	Direct product	Final ATP
Glycolysis	2 NADH 2ATP	4 or 6 2
Pyruvate oxidation (two per glucose)	2 NADH (mitochondrial matrix)	6
Acetyl-CoA oxidation (two per glucose)	6 NADH (mitochondrial matrix) 2 $FADH_2$ 2 ATP	18 4 2
Total yield per molecule of glucose		36 or 38

Source: Lehninger et al., 1993