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Energy Nutrient Metabolism: The Inter-Conversions and the Chain Reaction Leading To Oxidative-Phosphorilation and Production of Adenosine Tri- Phosphate (ATP)

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Abstract
Enlightening people on the fate of energy nutrients after they have been digested and absorbed in the blood stream up until they are broken down to yield ATP, is the thrust of this paper. It addresses aspects on what energy is and its metabolism and why the body requires energy. The study also pays attention to the pathways to be followed to produce energy under both the aerobic and anaerobic conditions such as the glycolytic pathway, Krebs cycle and the electron transport phosphorilation. The role of the cell organelles such as the cytosol and mitochondria cannot go unnoticed as well as that of certain vitamins that help in energy metabolism. These include niacin in the form of Nicotinamine Adenine Dinucleotide (NAD) and Riboflavin as Flavin Adenine Dinucleotide (FAD) which is used in accepting and transporting electrons. The end product of glycolysis is 3 Carbon Pyruvate which is then converted to 2 Carbon AcetylcoA, an essential intermediate which ushers-in the next pathway, the Citric acid cycle or Krebs cycle. This is followed by electron transport chain and oxidative phosphorilation of ADP to ATP with a total theoretical maximum of about 38 ATP being yielded from the complete breakdown of one glucose molecule. This energy is thus used to fuel various body activities as and when necessary. Therefore, the purpose of this paper is to clarify the mechanisms that take place in our bodies after ingested food has been absorbed in order to yield energy. It is significant in that it will help individuals and families, health professionals, as well as nutrition specialists in particular, to be able to come up with more balanced diets basing on the physiological individual needs and activity levels. The study is hoped to positively impact on the attainment of good health by all, as individuals will be enlightened on what their bodies require and people will not eat anything that comes their way. Infact, they will be more analytical of their diets such that both deficient and affluent diseases will be a thing for the past.

Keywords: metabolism, energy, phosphorilation,, glycolysis, nutrients, electron, blood sugar

INTRODUCTION

Many a times when people consume food, there is a general misconception that the ingested food is the one that will directly and immediately provide the energy, heal worn out tissues or facilitate growth. In actual fact, the ingested food first undergoes the process of digestion to break it into smaller pieces to allow nutrients to be extracted from the food. Nutrients are chemical substances obtained from food and these go through a whole lot of series of chemical reactions in order to yield energy for the body. The energy currency for the body is in the form of Adenosine Tri-Phosphate (ATP) and is obtained by the phosphorilation of Adenosine Di- Phosphate (ADP). The macro-nutrients Carbohydrates, Proteins and Lipids/Fats are completely metabolized or broken down to produce ATP energy through pathways such as glycolysis, Krebs cycle and the Electron Transport Phosphorilation. Therefore, the main objective of this paper is to bring awareness in individuals, families and Nutrition specialists in particular, on the need to appreciate proper intake of food which will translate into ATP energy for effective use by the body. People will then be able to calculate their daily energy requirements and the specific foodstuffs supplying their required nutrients, basing on their physiological make-up and activity levels, thus helping to curb mal-nutritional disorders.

LIMITATION OF THE STUDY

Many food consumers eat foods whose nutritional value they are not very conversant of. Most of their meals are not balanced resulting in mal-nutrition and this will then pose a health challenge as some foodstuffs may be taken in excess or sub-optimally. This very wide knowledge gap is therefore the major limitation to the consumption of balanced meals by most individuals.

CONCEPTUAL FRAMEWORK

What is energy?

Energy has been defined as the ability to do work and the body cannot survive without energy. It is needed to enable all body activities to run smoothly and exists in various forms such as mechanical energy needed when lifting a chair, heat energy for maintanance of body temperature, chemical energy for metabolic processes as well as electrical energy for nervous impulses, neurons and axons, (Campbell, 2008). The energy input which is affected by factors such as hunger, exercise, growth and choice of food, should balance the output. Output on the other side, is affected by factors such as exercise and general RME, according to www.nature.com>home>biologicalsciences. The units for energy referred to in Nutrition are the Kilo Joule (KJ) and the Kilocalorie (kcal) where 4.19KJ is equal to 1Kcal. All energy nutrients when metabolized yield a certain amount of energy. For instance, 1 gram of protein = 4 Kcal; 1 gram of carbohydrate =3.75 Kcal; 1 gram fats= 9 Kcal, while 1 gram of alcohol yields 7 Kcal, according to Wardlaw and Smith, (2011).

Metabolism

Metabolism has been defined as the total of the chemical reactions by which nutrients are used in order to produce energy and material for growth and maintenance of the body cells, according to Fox and Cameron (1995). Adding on to that, www.nature.com/subjects/energy states that energy metabolism is the process of generating energy (ATP) from nutrients. It comprises a series of interconnected pathways that can function in the presence or absence of Oxygen (O2). Aerobic metabolism converts one glucose molecule into 30-32 ATP molecules. Fermentation or anaerobic metabolism is less efficient than aerobic metabolism. Also sharing the same sentiments, www.wisegeek.com/what-is-energy-metabolism.htm concurring with Mackean (1987) define energy metabolism as the entirety of an organism's chemical processes and these chemical processes typically take the form of complex metabolic pathways within the cell. These are generally categorized as being either catabolic or anabolic.

Catabolism

This is the oxidative breakdown of large molecules of nutrients. As a result of catabolic processes, Carbohydrates, Fatty acids, Glycerol and deaminated amino acids release energy and waste products, H_2O and CO_2 inside the body cells, (Fox and Cameron, 1995). Catabolic pathways are those that break down large molecules into their constituent parts, releasing energy in the process. The human body is able to synthesize and store its own ATP through both anaerobic and aerobic energy metabolism, (Mackean, 1987) concurring with Roberts (1986).

Anabolism:This is the reductive synthesis of small or bio-molecules to large ones. Campbell (2008) agrees with Guthrie (1995) that anabolic pathways use ATP energy to power cellular work. The building of macromolecules from smaller components, such as synthesis of proteins from amino acids, and the use of ATP to power muscular contraction are examples of anabolic pathways. Roberts (1995) elaborates that to power anabolic processes, ATP has to donate a single Phosphate molecule thereby releasing stored energy. Once a working cell's ATP is depleted, more must be generated by catabolic energy metabolism for cellular work to continue.

Basal Metabolism

Fox and Cameron (1995) define basal metabolism as housekeeping energy that is required when the body is at complete rest, to facilitate other activities like breathing and digestion. Vander et.al (1090) state that there is a resting metabolic rate factor (RMR) which is 1 for men and 0.9 for women and this can be used to measure one's daily requirements. The procedure is such that the body weight should first be converted to kilogrammes (kg). The weight is then multiplied by one's RMR factor (1 kcal/ per gram/ hr for men and 0.9 kcal/ per gram/ hr for women) and the figure obtained is multiplied by 24 hrs (1 day). For example: Weight of 55kg x 0.9 (RMR factor) x 24 hrs = 1188 k Calories per day for a woman. Since it costs energy to generate energy and the Thermal Effect of Food (TEF) is calculated at 10% of BMR then activity level percentage is added depending with the person's activity. Thirty percent is a low energy level, 50% is moderate, 75% is moderately active while100% is active. Factors affecting metabolic rate include physical activity and TEF (Thermal Effect of Food) / Thermogenesis and it takes between 6-10% ATP energy to digest the food, (Campbell, 2008).

Aerobic and Anaerobic Metabolism

As put in by breakingmuscle.com/health-medicine, the determining factor in fast or slow glycolysis is the direction in which the end product goes. In fast glycolysis, pyruvate is converted to lactate which our body uses to resythesize ATP at a faster rate especially in activities that require a high energy demand. In slow glycolysis, it is shuttled to the mitochondria to enter the citric acid cycle (CAC), or the oxidative system. Mader (1996) agrees with Wardlaw and Smith on the notion that resynthesis of ATP takes place at a much slower rate at the same time maximizing the number of ATPs produced yielding the highest amount of energy. This also confirmed by Williams (1993) who states that even though glycolysis takes long to kick start, it will be able to supply a higher amount of total energy as compared to the anaerobic process.

Anaerobic Glucose Metabolism/ Fast Glycolysis

This process yields energy fast from the glucose in blood and glycogen in the muscle. Lactic acid is the byproduct and in organisms capable of alcohol fermentation, it is ethanol. According to Wardlaw and Smith (2011), it occurs when O_2 supply in the muscle is limited and the glucose is broken down into a 3Carbon compound, Pyruvic acid which accumulates in the muscle and is then converted to lactic acid. Guthrie (1995) confirms that as the fast glycolysis progresses, lactic acid accumulates in the muscle resulting in lactic acidosis or muscle burn. Glycogen stored in the muscle tissue serves an important role as well. The main function of the cell is to move bones, therefore it is best to store energy within the tissues that require it for facilitating moving us around. Anaerobic metabolism is the only energy source in mammalian red blood cells, (Hergaty, 1995). Only about 5% of the total amount of ATP that could be formed from complete breakdown of glucose is released through this anaerobic process, (Wardlaw and Smith, 2011). It is associated with brief, intense bursts of activity e.g. power lifting or sprinting, when the cardio respiratory system does not have time to deliver adequate O2 to the working cells. Fast glycolysis produces most of the ATP that is used from 10 seconds to 2 minutes of exercise, after which the cardio-respiratory system has had opportunity to deliver O2, to facilitate aerobic metabolism, (breakingmuscle.com/health-medicine/understanding glycolysis).

Advantages of Anaerobic Glucose breakdown

Wardlaw and Smith (2011), notes that it is the fastest way to resupply ATP, other than the PhosphoCreatine (PCr) breakdown. It therefore provides most of the energy needed for events that require a quick burst of energy (from 30 sec - 2 minutes), e.g. when swimming or sprinting 100 meters. It is also the only source of energy in the red blood cells of mammals.

Disadvantages of Glucose Breakdown

Apart from the advantages aforementioned, there are two major disadvantages of anaerobic breakdown. The first one, according to Mader (1996) is that the rate of ATP production cannot be sustained for long periods. Secondly, the rapid accumulation of lactic acid greatly increases the acidity of the muscle, which will then inhibit the activities of key enzymes in muscle cells, slowing anaerobic ATP production and causing short term fatigue. In most cases, lactic acid builds up in active muscle cells until it is released into the blood stream. The liver and to some extend the kidneys, take up the lactic acid and resynthesises it into glucose. Glucose can then re-enter the blood stream where it is available for cell uptake and breakdown, (http://answers.yahoo.com/question/index?qid).

Aerobic Glucose Breakdown

If plenty of O_2 is available in the muscle, when the exercise is of low to moderate intensity, the glucose and glycogen is broken down to produce ATP. The bulk of the 3-C Pyruvate is shuttled to the mitochondria to be fully metabolized into CO_2 and H_2O and the glucose yields approximately 95% of the ATP made from complete glucose metabolism, according to Wardlaw and Smith (2011). Aerobic glucose breakdown supplies more ATP than does the anaerobic process, but it releases the energy more slowly, as stated by Roberts (1986). While fast glycolysis produces 2 ATP for every glucose molecule, slow glycolysis is able to produce 38 ATP from the same amount of fuel with no accumulation of lactic acid, muscle burn or fatigue. This slower rate of aerobic energy supply can be sustained for hours. The products are CO_2 and H_2O. Hergarty (1995) confirms that aerobic glucose breakdown makes a major contribution to the activities that last anywhere from 2 minutes to 3 hours or more. According to Wardlaw and Smith (2011), examples of such activities include jogging or distance swimming. The bulk of useful energy yielded by metabolism comes from the transfer of hydrogen atoms or electrons and O_2 must be available to accept the H_2 from the final carrier, (Vander, et. al, 1990). Aerobic metabolism is the breaking of macromolecules in the presence of O2, and is associated with low intensity exercise, as well as daily work of the cell, according to wisegeek.com/what-is-energy-metabolism.

Finally, the slowest yet most efficient form of energy metabolism is **fatty acid oxidation**. It powers activities such as digestion, cellular repair and growth, as well as long duration exercise activities e.g. marathon or swimming. The process burns fatty acids stored in the body and is capable of producing as many as 100 ATP molecules per unit of Fatty Acid. While this is a highly efficient, high energy process, it requires large amounts of O2 and only occurs after 30-45 minutes of low intensity activity, (www.nature.com>biologicalsciences).

All organisms produce ATP by releasing energy stored in glucose and other sugars over a course of 3 major reaction pathways, glycolysis, Krebs cycle and electron transport phosphorilation, www.biology-online.org>bodyindex>generalbiology>cellbiology.

Glycolyisis

Glycolysis is one of the most ancient known metabolic pathways occurring in most organisms in the cytosol. According to (en.wikipedia.org/wiki/glycolysis), it is also called the Embden-Meyerhoff-Parnas (EMP) pathway after its discovery by Gustav Embden, Otto Meyerhoff and Jakub Parnus. Glycolysis is aimed at oxidizing glucose or glycogen to pyruvate or lactate. It is a

determined sequence of 10 enzyme catalysed reactions. The energy released is used to form compounds ATP and NADH. Carbohydrates are important especially for muscles. They provide glucose through digestion and are the only macronutrient that can be synthesized into usable ATP under anaerobic conditions (en.wikipedia.org/wiki/glycolysis). A reduction in muscle glycogen is associated with fatigue, (Wardlaw and Smiyh, 2011 concurring with (breakingmuscle.com/health-medicine/understanding-glycolysis).

Glucose is split into 2 molecules of 3C pyruvate which either becomes acetyl-coA, Ethanol or Lactate in the cytoplasm of eukaryiotic cells with the key regulatory enzyme being phosphofructokinase, (www.biocarta.com/pathfiles/h-glycolysispathway.asp).

Stages in the Glycolytic Pathway

The glycolytic pathway is divided into 3; the Priming, Splitting and the Oxido-reduction phosphorilation stages which are further broken down into 10 enzymatically activated steps. The first stage/priming stage sees 2 ATP being consumed for each glucose. Glucose is primed to glucose 6-Phosphate by **hexokinase** with a Phosphate being is used up from ATP, resulting in ADP being produced. In step 2, the glucose-6-Phosphate is isomerised to fructose-6-Phosphate an isomer of glucose, by **Glucose Phosphate Isomerase**. In this case, the aldolase sugar is converted into the keto isoform by phosphoglucomutase in a reversible reaction. In the 3rd reaction, Fructose 6-Phosphate formed is converted to fructose1, 6-Diphosphate by enzyme **phosphofructokinase,** thus regulating the pace of glycolysis. An ATP molecule is also hydrolysed to ADP and Pi in yet another irreversible reaction. In other words, Glucose is trapped inside the cell and at the same time converted to an unstable form that can be readily cleaved into 3-C units, (www.csun.edu/jm77307/glycolysis.pdf).

The Glycolytic Pathway (Embden-Meyerhoff-Parnas Pathway)

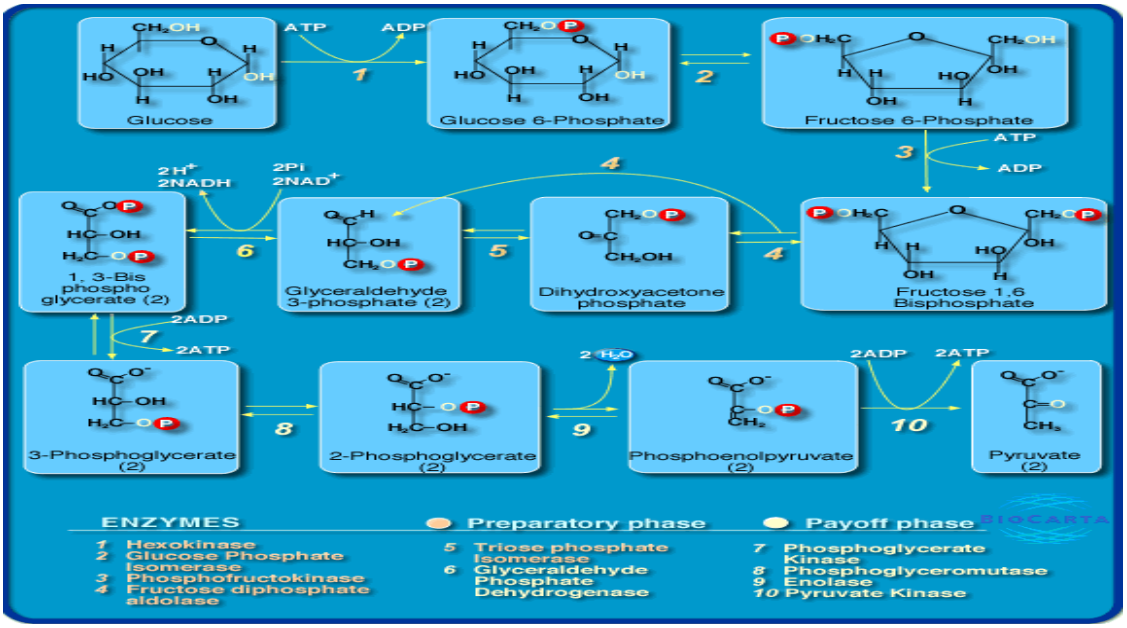

Figure extracted from: www.csun.edu/jm77307/glycolysis.pdf

The second stage, begins at step 4, and is the splitting stage. Fructose di-phosphate aldolase catalyses this branching into two 3-Carbon units of Dihydroxyacetone Phosphate (DHAP) and Glyceraldehyde 3-Phosphate (GAP). These isomers can readily inter-convert by the action of enzyme Triose-Phosphate Isomerase. GAP is a substrate for the next step in Glycolysis, so all of the DHAP is eventually depleted, according to www.csun.edu/jm77307/glycolysis.pdf. Therefore 2 molecules of GAP are formed from each molecule of glucose and up to this step, 2 molecules of ATP were required for each molecule of glucose being oxidized. Adding on to this, Roberts (1986) states that steps, 5 and 6 are the only reactions in the sequence in which high energy phosphate linkage is created from inorganic phosphate. These 2 steps lie at the heart of glycolysis and also provide an excellent illustration of the way in which reactions in the cell can be coupled by enzymes to harvest the energy released by

oxidation. Besides being central to glycolysis, these reactions are driven in reverse during photosynthesis by the large quantities of NADPH and ATP produced by the light activated reactions.

Oxido-reduction phosphorilation is the **final stage** which yields a total of 4 moles of ATP and 2 mols of NADH, being gained from each initial mole of glucose. When the high energy bond is hydrolysed to a carboxylic acid, the released energy is used to generate ATP from ADP with 3-Phosphoglycerate as the product and facilitated by 3-**Phosphoglycerate kinase**. This is followed by **phosphoglycerate mutase** which shifts the phosphate from C3 to C2 to form 2-Phosphoglycerate. This occurs before enzyme **Enolase** (a lyase) catalyses dehydration and a water molecule is removed to form phosphoenol pyruvate. The last step in Glycolysis sees Enolphosphate (a high energy bond), being hydrolysed to form the enolic form of pyruvate with the synthesis of ATP and this reaction is irreversible and is catalysed by **pyruvate kinase**. Enol pyruvate quickly changes to keto pyruvate which is far more stable, according to www.csun.edu/jm77307/glycolysis.pdf.

End Products of the Glycolytic Process

The Glycolysis energy balance-sheet shows that, Hexokinase (-1 ATP); Phosphofructokinase (- ATP); Glyceraldehyde Phosphate Dehydrogenase (+2NADH); Phosphoglucerate Kinase (+2ATP); Pyruvate Kinase (+2ATP). Therefore, the total yield per glucose unit is +2ATP and +2 NADH, (www.csun.edu/jm77307/glycolysis.pdf). Although glycolysis does not require O2, the fate of the pyruvate molecules depends on whether O2 is present. If O2 isn't available, the result is lactate and no additional ATP is produced from this conversion. If O2 is present, the pyruvate is quickly transported into the mitochondrial matrix where it is converted into 2C acetylcoenzyme A which links glycolysis with the next series of reactions and is also formed in the breakdown of fats and proteins, (Campbell, 2008).

Energy From Fat

When Carbohydrate is in short supply, fat is split into fatty acids and glycerol with the latter being phosphorylated and converted into 3C sugar and into pyruvic acid. It is fed into Kreb's cycle with the production of energy, according to Roberts (1986) and Guthrie (1995). Fatty acid molecule goes through a series of reactions in which 2C atoms are lost, at a time forming a molecule of Acetyl COA which enters the Krebs' cycle. Hydrogen atoms are removed and passed through the carrier system with formation of ATP. When an acetyl-coA has been formed, the fatty acid now contains fewer Carbon atoms than before, returns to the beginning and goes through the same reactions again until the fat is completely broken down. The whole sequence is productive of energy for ATP synthesis and still more energy is released each time an acetylcoA molecule is fed into Krebs cycle, (Vander, et al, 1990). A fatty acid with a long chain of C atoms will obviously give more molecules of acetylo-coA than one with a relatively short chain.

Energy From Proteins

There are abnormal circumstances where tissue protein is used as a source of energy as put in by Fox and Cameron (1995), concurring with Vander et.al. (1990). A certain amount of energy is always derived from excess dietary protein. Protein is the first broken into amino acids, each amino acid is then deaminated (the NH2 group is split off to form NH3 which is then excreted). The residual Carbon compound then enters Carbohydrate metabolism with the subsequent release of energy. The amino acids residue may be converted into acetyl coA, pyruvic acid or a Krebs cycle intermediate. These are reversible reactions so that certain amino acids can be synthesised from Carbohydrates and vice versa (Campbell, 2008).

Mitochondria (many) or Mitochondrion (one)

These are the cell power-houses/plants and are housed within the cytoplasm. In singular, it is called a mitochondrion while many of them are termed mitochondria. According to Wardlaw and Smith (2011) agreeing with Campbell (2008) the mitochondria are capable of converting the energy in energy-yielding nutrients from food to a form that cells can use. This is an aerobic process, and also utilizes H2O, enzymes and other compounds. With the exception of red blood cells, all cells contain mitochondria, only the size, shape and quantity will vary.

The Citric Acid Cycle /Krebs Cycle/ Tricarboxylic Acid Cycle

The Krebs' cycle is named after Sir Hans Adolph Krebs who first investigated and recognized the pathway in 1937 after having earlier identified the urea cycle in 1932, (www.wisegeek.org/what-is-the-krebs-cycle-htm). It is also called the Tri-carboxylic acid cycle. The Krebs cycle takes place in the mitochondria of all cells that utilize Oxygen as part of their respiration process. According to Davies (1997), it also provides the opportunity for metabolic inter-conversions between Carbohydrates, Fats and Proteins. Wardlaw and Smith (2011) elaborate the critical role played by the liver in mammals, as being a central role in controlling these metabolic interactions. Carbohydrates, Fats and Protein all produce chemical energy in the form of ATP, according to en.wikipedia.org/wiki/citric-acid-cycle. ATP provides cells with the energy required for the synthesis of proteins from amino acids and replication of DNA, (education.seattlepi.com /follows-glycolysis-oxygen-present-43361.html). At

the end of the cycle, the 4-Carbon Oxaloacetate has been regenerated and the cycle continues.

Key Features of the Citric Acid Cycle/ Krebs Cycle/ Tri-Carboxylic Acid Cycle

The CAC has 8 steps, each catalysed by a different enzyme. In order for Pyruvate from Glycolysis to enter the Krebs cycle, it must first be converted into AcetylcoA by the Pyruvate dehydrogenase complex found in the mitochondria. This is an oxidative process wherein NADH and CO2 are formed, (chemwiki.ucdavies.edu/Biological-Chemistry /metabolism).

According to Campbell (2008), acetyl-coA enters the citric acid cycle where two or more molecules of CO2 are produced for each molecule of acetyl-coA that enters the cycle, and electrons are transferred in the process. Hergarty (1995) stresses that in this first step, the 2 Carbon Acetyl group combines with the 4 C oxaloacetate ion resulting in 6C Citrate ion, with the assistance of **citrate sythetase**. The process is a condensation reaction which requires the input of water. In the second step, the Citrate isomerizes into iso-citrate and this is facilitated by **Aconitase.** The isomerisation process is accomplished by the removal and addition of water to yield an isomer. It then both loses CO2 and is oxidized in a process called oxidative decarboxylation, thus producing the 5 C α-ketogluterate by **iso-citrate dehydrogenase**, with NADH and CO2 as by-products. In the forth step, Alpha ketogluterate is again oxidatively decarboxylated to produce 4 C compound Succinate/ Succynl-coA by **α-ketogluterate dehydrogenase**. NADH and CO2 are produced once again. These 2 steps (3 and 4) involve the loss of CO2 (Decarboxylation).

At step 5, succynyl-coA is then converted into succinate by **succinyl-coA synthatase** which yields ATP per succinyl-coA. According to (chemwiki.ucdavis.edu/biological-chemistry), the previously formed succinate converts into Fumerate by way of the enzyme **succinate dehydrogenase.** FAD is reduced to $FADH_2$ which is a prosthetic group of succinate dehydrogenase. This same enzyme is a direct part of the E.T.C. and is also known as electron carrier ii. Step 7 sees Fumerate now being converted by Fumerase to Malate. To round off the cycle, Malate is converted or regenerated into Oxaloacetate by M**alate dehydrogenase**, with NADH as the by-product. The immediate electron acceptor in all cases but one is NAD which is reduced to NADH. In the one case in which there is another electron acceptor, FAD (Flavin Adenine Dinucleotide) which is derived from Riboflavin (B2), takes up two electrons and two Hydrogen ions to produce FADH2. Campbell (2008), states that the electrons are passed from NADH to FADH2 through several stages. The final electron acceptor is Oxygen, with water as the product. Starting from pyruvate, Carbons are lost as CO2 via the production of acetyl-coA and one turn of the cycle. The cycle produces energy in the form of reduced electron equivalents (the NADH and FADH) that will enter the electron transport chain, but the Carbon skeletons are effectively lost. The cycle also produces one high energy compound directly, Guanosine Tri- Phosphate (Guthrie, 1995).

The Citric Acid/Krebs/Tri-Carboxylic Acid Cycle Illustrated

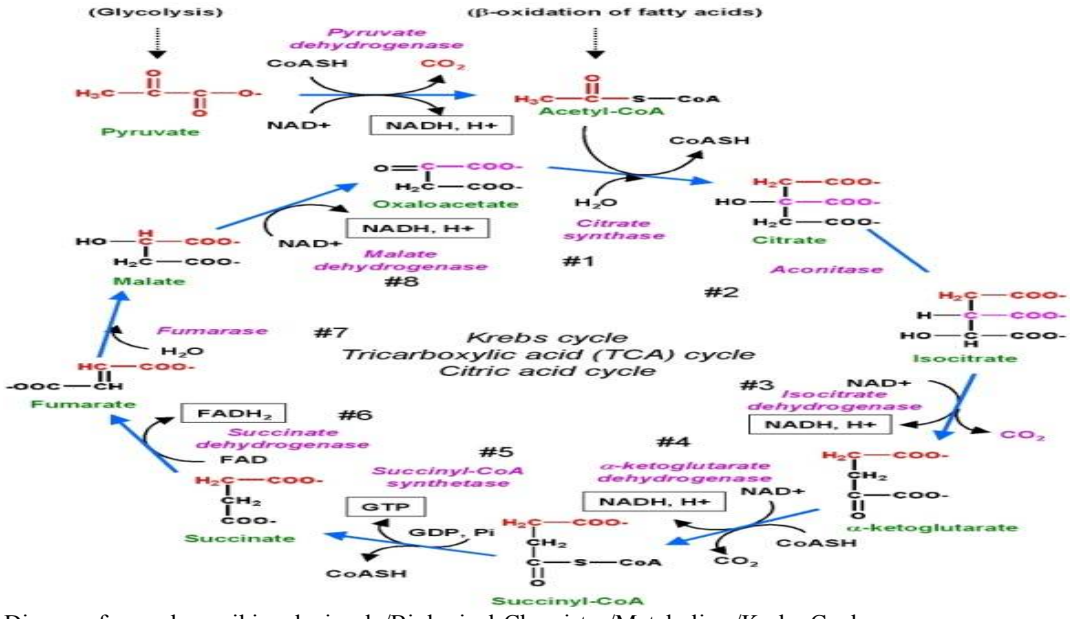

Diagram from: chemwiki.ucdavis.edu/Biological-Chemistry/Metabolism/Krebs-Cycle

In other words, it can be conclusively spelt out that the sole purpose of the Krebs cycle is to take pyruvate into the TCA cycle to produce NADH and FADH2 in the Mitochondria. Pyruvate is first converted to AcetylcoA and the reactions result in the production of 2ATP, 8NADH and 2 FADH2 per glucose molecule. Six NADHs are generated, 3 per AcetylcoA; 2 FADH2, one per AcetylcoA; 2ATP, one per AcetylcoA that enters and 4 CO2s, two per AcetylcoA. Therefore the total numbers of molecules generated in the oxidation of pyruvate and the Krebs cycle is 8NADH, 2 FADH2, 2ATP and 6 CO2, (www.uic.edu/classes/bios100/lecturesf04am). From the Krebs cycle, then follows the Electron Transport Phosphorilation.

Electron Transport Chain (ETC) and Oxidative Phosphorilation

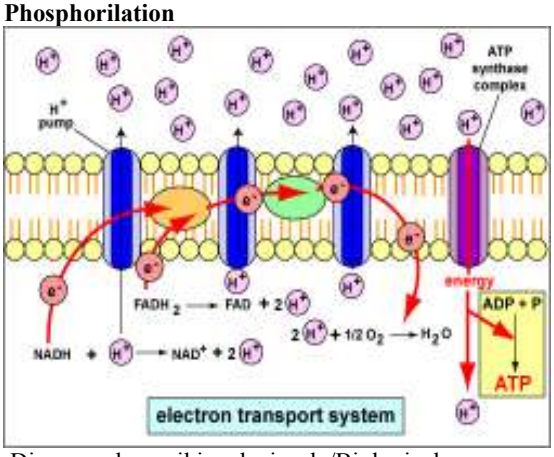

Diagram:chemwiki.ucdavis.edu/Biological-Chemistry/Metabolism/Krebs-Cycle

This Electron Transport Chain is the most complex and productive pathway of cellular respiration and it requires a membrane in order to work. E.T.C. energy comes from redox reactions. When these molecules are reduced, they accept and carry electrons and Hydrogen ions which is potential energy that can be used later in cellular respiration. Electrons are passed from coenzyme Q also known as Ubiquinone to cytochromes and eventually to O_2 (www.scienceprofileonline.com/metabolism).

Oxygen in metabolism, being the ultimate electron acceptor, is reduced to H2O thus completing the process by which glucose is completely oxidized to CO_2 and H_2O, in the inner mitochondrial membrane. The electron transport from one carrier to another creates or establishes a proton/pH gradient across the inner mitochondrial membrane. As electrons are passed through the ETC, this leads to the pumping of protons (H ions) from the matrix across the inner mitochondrial membrane, to the inter membrane space, thus creating a Ph/proton gradient which represents stored potential energy and provides the basis of the coupling mechanism. These reactions of the ETC are tightly coupled to the synthesis of ATP by Phosphorilation of ADP, (com/metabolism/electron-transport-chain). The production of ATP in the mitochondria is the result of oxidative phosphorilation in which ADP is phosphorilated to give ATP as stated by (scienceprofileonline.com/metabolism/electron-transport-chain).

Total ATP Production

More ATP is produced by the coupling process in aerobic oxidation of glucose than in anaerobic oxidation. Each glucose unit produces 2 pyruvates and the theoretical maximum ATP yield per glucose molecule when Oxygen is present is 38. However, the actual amount of ATP produced in the cells is usually less than the theoratical maximum, according to Williams (1993) and Vander (1990). Transporting NADH produced in the cytoplasm during glycolysis requires ATP thereby reducing the net ATP yield from these NADH molecules. The ETP typically produces 32 ATP, Glycolysis 2ATP, and Krebs cycle 2ATP. NADH is worth 3 ATP, but it costs an ATP to transport the NADH into the mitochondria, so there is a net gain of 2ATP for each NADH produced in glycolysis, www.uic.edu/classes/bios100/lectures04am.

SUMMARY

Energy has been defined as the ability to do work and it is produced after ingested food has been metabolized. The three energy nutrients are Carbohydrates, Fats and Proteins work together with other vitamins such as Niacin (NAD) and Riboflavin (FAD). It costs some energy to generate energy, therefore the body depends on a considerable amount of this energy in order to execute its various tasks even when it is at rest (basal metabolism). The body energy currency is in the form of ATP and this is obtained by the phosphorilation of ADP by high energy Pi. This takes place in the inner mitochondrial membrane within the cell. Aerobic metabolism yields more ATP as compared to the anaerobic process. Three major pathways that are linked to metabolism of energy nutrients are Glycolysis, Krebs cycle and the Electron Transport Phosphorilation. The end product of glycolysis is 3 Carbon pyruvate, which is later converted into 2 Carbon AcetylcoA an essential intermediate linking Glycolysis and Krebs cycle. NAD and FAD are the immediate electron acceptors which are then reduced to NADH and FADH2 respectively. Oxygen is the final acceptor of electrons which is then reduced to H2O thereby completing the oxidation of glucose with Carbon Dioxide and water being given off. The theoretical maximum ATP yield per glucose molecule is 38 even though in practice this is not reached and this energy harvested is used for a multiple of purposes as the body demands.

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