Metabolism & Nutrition

Physiology 1

Metabolism

- Metabolic reactions contribute to homeostasis by harvesting chemical energy from consumed nutrients to contribute to the body's growth, repair, and normal functioning
- Metabolism denotes the sum of all body chemical reactions.

Catabolic Reactions

- Catabolism is breaking down larger molecules into smaller molecules. Catabolic reactions provide more energy than they consume; they are exergonic – they liberate heat

Anabolic Reactions

- Anabolism is building up smaller molecules into larger molecules. Anabolic reactions consume more energy than they produce; they are endergonic – they consume heat.

Metabolism Summary

- Metabolism is an energy-balancing act between catabolic reactions and anabolic reactions.
- The molecule that participates most often in energy exchanges in living cells is ATP (adenosine triphosphate),
- The exact reactions that occur depend on which enzymes are active in a particular cell at a particular time

Nutrients

- a “food or liquid that supplies the body’s metabolic needs
- Nutrients include:
  - A necessary chemical (such as Na+ and other minerals)
  - A substance that provides energy (such as lipids or carbohydrates like glucose)
  - Something that helps in growth of new body components (such as vitamins)
  - A substance that repairs or maintains body functions (such as proteins, or amino acids to make proteins).

Oxidation and Reduction

- Oxidation is the removal of electrons
- Reduction is the addition of electrons
- Oxidation – Reduction reactions always occur together

ATP

- Catabolic reactions transfer energy into the “high-energy” phosphate bonds of ATP, where it can be released quickly and easily

ATP production

- 4 Types
  - Glycolysis
  - occurs in almost all cells. This process is an anaerobic catabolism of glucose that converts a molecule of glucose into two molecules of pyruvic acid and two molecules of ATP. These molecules are then used as energy by various systems in the body. In eukaryotic organisms, glycolysis occurs in the cytosol

Oxidative Phosphorylation

- major producer of ATP in organisms -- 26 out of 30 molecules of ATP generated from glucose are produced through oxidative phosphorylation.
- ATP is produced when electrons flow from chemicals known as NADH or FADH to oxygen.

Beta Oxidation

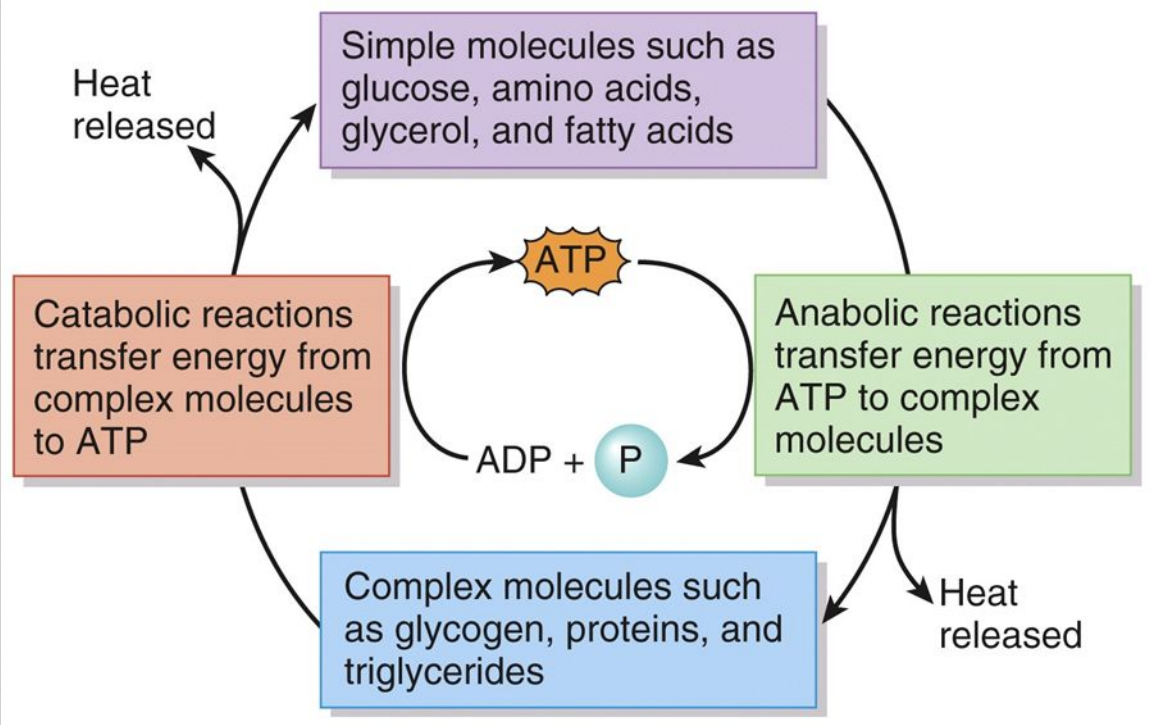
- process that converts lipids into energy. Part of this process produces ATP, which is then used to produce acetyl CoA.
- takes place in the mitochondria and is closely related to the conversion of ATP to AMP. Beta oxidation also involves the fatty acid cycle, which resembles the citric acid cycle.

Aerobic Respiration

- Aerobic respiration is the final way that ATP is formed. Aerobic respiration also uses glucose to produce ATP and as the name indicates, oxygen must be present for the process to occur. Without oxygen, aerobic respiration converts to anaerobic respiration, which only produces 2 ATP compared to aerobic respirations 34.

ATP Cycle

- https://youtu.be/o7fpyP2IFrQ



Carbohydrate Metabolism

- Glucose is indeed the body's preferred source of fuel.
- During digestion, polysaccharides and disaccharides are hydrolyzed into the monosaccharide glucose (80%), fructose, and galactose
- These three monosaccharide are absorbed into the villi of the small intestine and carried to the liver; hepatocytes (liver cells) convert galactose and fructose to glucose.

Cellular Respiration

- The oxidation of glucose to form ATP:-
- Glucose ($C_6H_{12}O_6$) + O_2 = CO_2 + H_2O + ATP … is known as “Cellular Respiration” and occurs in 4 steps

Step 1

- oxidize one 6-carbon molecule of glucose into two 3-carbon molecules of pyruvate (pyruvic acid) in a series of steps called glycolysis.
- Once glucose is transported into the cell via facilitated diffusion (in the presence of insulin), it is combined with a phosphate molecule (phosphorylation)
- Glucose-6-phosphate is different from glucose, so it does not affect the concentration gradient for transport of more glucose into the cell
- Another phosphate group is then added to form glucose-1, 6-diphosphate. Each phosphate group requires 1 ATP worth of energy in order to be added to the glucose.
- Glycolysis occurs solely in the cytoplasm of the cell

Step 2

- If sufficient oxygen is present in the cell acetyl-CoA will be formed and cellular respiration continues; if not, lactic acid is formed
- If oxygen is plentiful, the formation of acetyl-CoA is a transition step to prepare carbon fragments to enter the Krebs cycle
- Two 2-carbon molecules of acetyl-CoA are formed from the oxidation of two 3-carbon molecules of pyruvic acid molecules.

Step 3 (Kreb's Cycle)

- To begin the Krebs cycle, acetyl-CoA diffuses into the matrix of the mitochondria where the 2-carbon fragments are "dropped off" – the CoA is now free to diffuse back into the cytoplasm and "reload" With each turn of the cycle, a 2-carbon acetyl fragment is completely oxidized yielding ATP, FADH2, and NADH

Step 4

- The 4thstep in cellular respiration - the electron transport chain – (ETC) is a system for extracting the energy stored in the reduced coenzymes formed in the previous steps, the ETC is composed of a series of electron carriers (integral membrane proteins) embedded within the inner membrane of the mitochondrium

Step 4 Continued

- The cytochromes pump H+ ions into the inner mitochondrial space. The high numbers of protons put into the inner-mitochondrial space become a reservoir of potential energy – setting up both a concentration gradient and an electrical gradient.
- Other role players in cellular respiration include:
  - Pantothenic acid (Vitamin B5), a water-soluble vitamin needed to form coenzyme-A
  - Riboflavin and niacin (Vitamin B2 and B3), are used as structural components of NAD and FAD cofactors
  - CO2 is produced by decarboxylation reactions in glycolysis and the Krebs cycle
  - Metabolic water is formed in the electron transport chain.
  - In the total oxidation of 1 molecule of glucose, 36-38 molecules of ATPs are generated, depending on the tissue

ATP numbers

- In the total oxidation of 1 molecule of glucose, 36-38 molecules of ATPs are generated, depending on the tissue
- Only 4 ATP are generated by substrate level phosphorylation (directly transferring a high energy phosphate from one organic molecule to another) in glycolysis and the Krebs cycle
- Most of the ATP (either 32 or 34) is made by oxidative phosphorylation using the cytochromes of the electron transport chain and O2 as the final electron acceptor
- The Krebs cycle takes place in the mitochondrial matrix

Glucose Storage and Release

- If glucose is not needed immediately for ATP production, it combines with many other molecules of glucose to form glycogen, a polysaccharide that is the only stored form of carbohydrate in our bodies, this process is called glycogenesis, and the body can store about 500 g of it (75% in skeletal muscle fibers and the rest in liver cells)

Glycogenolysis

- Glycogenolysis is the opposite of glycogenesis: When body activities require ATP, stored glycogen is broken down into glucose and released into the blood to be transported to cells, where it will be catabolized by the processes of cellular respiration.

Gluconeogenesis

- Gluconeogenesis is the process of forming “new” glucose or its metabolites from fat or protein (from non-carbohydrate sources). Gluconeogenesis is always taking place, but it occurs on a large scale during fasting, starving, or eating a low carbohydrate diet.
- Lactic acid, amino acids, and the glycerol portion of triglycerides are used to form glucose molecules or pyruvic acid to enter the Krebs cycle.

Lipid Metabolism

- Although the word “fat” is commonly used to mean lipids, fats are, in fact, just one subgroup of lipids called triglycerides
- Other lipids include waxes, sterols (steroid hormones), fat-soluble vitamins (such as vitamins A, D, E and K), monoglycerides, diglycerides, phospholipids, and others
- For metabolic purposes, triglycerides are a condensed form of useable energy.

Triglycerides

- All triglycerides are composed of a glycerol backbone combined with 3 fatty acids
- Fatty acids are anywhere from 4 to 24 carbons long, and they may have all single carbon-carbon bonds (saturated), or some double or triple bonds (making them unsaturated)
- Triglycerides are nonpolar, and therefore very hydrophobic molecules
  - To be transported in watery blood, they must first be made more water-soluble by combining them with carrier molecules called lipoproteins (produced in the liver)

Lipoproteins

- Lipoproteins vary in their size, density, and the amount of cholesterol and protein in their make-up.
- All lipoproteins have:
  - An outer shell that is made hydrophilic due to polar proteins (plus amphipathic phospholipid and cholesterol)
  - An inner core that is hydrophobic - a place where the triglycerides are transported.

Lipids & storage etc

- Lipogenesis means fat synthesis, while lipolysis refers to the oxidation (catabolism) of lipids to yield glucose (which then yields ATP).
- If the body has no immediate needs, lipids are stored in adipose tissue.
- The oxidation of triglycerides results in the formation of ketoacids, (ketone bodies) which must be eliminated by the kidneys in order to maintain homeostasis

Ketogenesis

- Ketogenesis is a normal part of fat breakdown, but an excess will cause a metabolic acidosis.
- A mild ketoacidosis can occur even with a short 24 hour fast, and is responsible for the headaches and some of the other symptoms that are part of fasting.

Protein Metabolism

- Proteins are not a primary source of energy;
- Proteins are not stored, but a certain amount of protein catabolism occurs in the body each day as proteins from worn-out cells are broken down into amino acids. Some amino acids are converted into other amino acids, peptide bonds are re-formed, and new proteins are synthesized as part of the recycling process.
- In protein synthesis, transamination refers to the transfer of an amino group (NH2) to pyruvic acid or another acid in the Krebs cycle to form an amino acid
- In protein catabolism, deamination refers to the removal of an amino group leaving the carbons of a carboxylic acid to be used to make ATP

Amino Acids

- Essential amino acids are the 10 amino acids that can't be synthesized by the body
- Non-essential amino acids are the others that can be synthesized by the body.

Protein Metabolism Continued

- Soon after a meal, glucose, amino acids, and lipid nutrients enter the blood. Triglycerides enter the blood carried in large lipoproteins called chylomicrons. There are 2 metabolic hallmarks of this state:
  - Glucose is oxidized to produce ATP in all body cells
  - Any excess fuel molecules are stored in hepatocytes, adipocytes, and skeletal muscle cells

- Pancreatic beta cells begin to release insulin to promote entry of glucose and amino acids into cells.
- Maintaining a steady blood glucose is critical because the nervous system and red blood cells depend solely on glucose as an energy source.
- About 4 hours after the last meal, absorption in the small intestine is nearly complete and blood glucose levels start to fall. The main metabolic challenge at this point is to maintain normal blood glucose levels
- As blood glucose levels decline, insulin secretion falls and glucagon secretion increases
- Blood glucose levels are sustained by the breakdown of liver glycogen, lipolysis, and gluconeogenesis using lactic acid and/or amino acids. The process is supported by sympathetic nerve endings that release norepinephrine, and by the adrenal medulla that releases epinephrine and norepinephrine directly into the blood.

Basal Metabolic Rate

- The metabolic rate is the overall rate at which metabolic reactions use energy. Basal metabolic rate (BMR) is measured with the body in a quiet, fasting condition.
- Whatever the metabolic rate, heat is a constant by-product of metabolic reactions, and can be expressed in calories
- The BMR is 1200–1800 Cal/day in adults, or about 24 Cal/kg of body mass in adult males and 22 Cal/kg in adult females.

Body Temperature

- Despite wide fluctuations in environmental temperatures, homeostatic mechanisms maintain a normal range for internal (core) body temperature at 37°C (98.6°F)
- Peripheral tissues can be much cooler , Body temperature is maintained by hormonal regulation of the BMR, exercise, and sympathetic nervous system stimulation.

Heat and Energy Balance

- Heat loss occurs through:
- Conduction - to solid materials in contact with the body, e.g. walking barefoot on the floor.
- Convection - is the transfer of heat when a gas or liquid flows over an object, e.g. using a fan on a hot day.
- Thermal radiation - is the transfer of heat in the form of electromagnetic energy (infrared, and encompassing visible light) between two bodies not in contact.
- Evaporation - occurs when converting a liquid to a gas.

Continued

- The control center that functions as the body's thermostat is a group of neurons in the anterior part (preoptic area) of the hypothalamus that receives impulses from thermoreceptors scattered throughout the body.
- If the core temperature declines, skin blood vessels constrict and thyroid hormones and catecholamines (epinephrine and norepinephrine) are released. Cellular metabolism increases and shivering may ensue.
- If core body temperature rises, blood vessels of the skin dilate, sweat glands are stimulated, and the metabolic rate is lowered.

Nutrition

- Nutrients are chemical substances in food that body cells use for growth, maintenance, and repair.
- There are 6 main types of nutrients:-
  - water , which is needed in the largest amount
  - carbohydrates
  - lipids
  - proteins
  - minerals
  - vitamins

Continued

- Basic guidelines for nutritious eating include:
  - Eat a variety of foods
  - Maintain a healthy weight
  - Choose foods low in fat, saturated fat and cholesterol
  - Eat plenty of vegetables, fruits and grain products
  - Use sugars in moderation only

- Recommendations are to eat foods that contain enough calcium, phosphorus, iron and iodine
  - Excess amounts of most minerals are excreted in urine and feces
  - Vitamins are organic nutrients required in small amounts to maintain growth and normal metabolism - they do not provide energy or serve as the body's building materials
    - Most cannot be synthesized by us, and no single food contains all the required vitamins
    - They are divided into those that are water soluble (several B vitamins and vitamin C), and those that are fat soluble (A, D, E, K).

Vitamin Deficiency

- Vitamin A is needed for proper skin, proper vision.
  - Deficiency leads to night blindness and a weakened immune system.
- Vitamin D is needed for calcium absorption.
  - Deficiency results in impaired bone mineralization, and leads to bone softening diseases such as rickets in children and osteomalacia in adults.
- Vitamin K is needed to make clotting factors II, VII, and IX, X
  - A deficiency such as due to long-term antibiotic therapy or taking anticoagulant medications leads to delayed clotting times

- Vitamin C is necessary for proper growth of connective tissues like collagen
  - Deficiency manifests as a disease called Scurvy
- Niacin (B3) plays essential metabolic roles in living cells.
  - A deficiency (which is called Pellagra) results from an all corn diet, and manifests as dermatitis, diarrhea, and dementia
- Thiamine (B1) is essential for neural function and carbohydrate metabolism
  - A deficiency (called Beriberi) results from a polished rice diet, and manifests with muscle wasting, and impaired reflexes.
- Folic Acid (vitamin B9) is needed to synthesize the bases used to replicate DNA
  - A deficiency manifests as a macrocytic anemia without nerve involvement
- Cyanocobalamin (B12) is important for normal nerve function and for the formation of blood
  - A deficiency manifests as pernicious anemia, ataxia, memory loss, weakness, personality and mood changes

Obesity

- Obesity is defined as a body weight 10-20% (or more) above the desirable level because of excess fat.
- An explanation for the prevalence of obesity in our society is not universally agreed upon. In a complex interplay, many psychosocial and physiological issues appear to contribute
- Obesity puts an individual at risk for a large number of diseases and conditions – cardiovascular disease predominant

- Factors that are especially prevalent in western society include:
  - An abundance of good-tasting food
  - Working longer hours (less time preparing good food)
  - Fast-foods
  - Sedentary jobs
  - Lack of Exercise