RBI-205 LECTURE--STUDY NOTES METABOLISM AND NUTRITION

I. INTRODUCTION TO METABOLISM

A.General

1. Meaning--metabolism basically involves the body's energy exchanges. That is, all chemical changes in which energy is made available and utilized in the body.

2. Significance--all body functions ultimately depend upon chemical and physio-chemical reactions. Thus, from the above definition, it should be inferred that metabolism is, in a word, everything (i.e. all chemical processes in the body). Regardless of the process being considered, it will always be caused by reactions--in other words, energy exchanges.

B. Processes

1. Nutrition--the most common use of this term is for the science of nutritional mechanisms and concerns. But, that is not the meaning intended at this time. Nutrition will mean all of the body's processes which are involved in the acquisition of raw materials--termed metabolites.

2. Respiration--this involves the production of usable energy, intracellularly, from some metabolites. Basically, this is glycolysis and the Krebs cycle.

3. Synthesis--this involves the joining of two or more molecules, producing a single larger molecule.

C. Interrelationships--all three of the above processes are simultaneously dependent upon each other.

1. Nutrition--the metabolites provided will be respired and utilized for synthesis. At the same time, though, the nutritive mechanisms require chemical energy (from respiration) and specialized chemical substances (from synthesis).

2. Respiration--this provides the energy for nutrition and synthesis, as well as requiring metabolites to respire and synthesized substances (e.g. enzymes).

3. Synthesis--while supplying complex compounds for nutritional and respiratory reactions, this process itself requires raw material from nutrition and respiratory energy.

D. Cellular versus whole body processes

1. General--even though there are differences in kind and magnitude when each of the three metabolic processes are compared on the cellular and whole body levels, keep in mind that these are interrelated as well.

2. Nutrition

   a. Whole body--this involves digestion and the circulation of absorbed metabolites.

b. **Cellular**--this is the transport of the metabolites into and out of cells.

3. **Respiration**

a. **Whole body**--this aspect would include breathing to obtain O_2 and eliminate CO_2, as well as the circulation of these gases.

b. **Cellular**--this would be the actual metabolite (e.g. glucose) decomposition and energy harvesting (ATP formation).

4. **Synthesis**

a. **Whole body**--this is quite broad, consisting of embryonic development, plus the life long regeneration or replacement of tissues, and organs.

b. **Cellular**--this is the synthesis of new protoplasm.

E. Energy exchanges

1. **General**--there is another way of classifying metabolic energy exchanges. This is based on whether the reactions involved are destructive or constructive.

2. **Catabolism**

a. **Meaning**--catabolic reactions result in the breakdown of larger molecules into smaller ones.

b. **Respiration**--this is mostly catabolic, since compounds such as glucose are broken down to transfer some of their chemical energy to other compounds.

c. **Hydrolysis**--obviously, this principal digestive type of reaction is destructive.

3. **Anabolism**

a. **Meaning**--anabolic reactions result in the building up of larger molecules from smaller ones.

b. **Synthesis**--this is the only metabolic process which is exclusively anabolic. The final part of cellular respiration, ATP synthesis, <u>is</u> technically anabolic.

F. Oxidation

1. **Energy-production**--this is a critical concept for all of metabolism, simply because energy exchanges are its basis. Oxidation-reduction reactions are responsible for transferring usable chemical energy from one molecule to another.

2. **ATP**--adenosine-triphosphate is responsible for holding the final energy from oxidations in reserve, due to its particular type of phosphate bonding. This is typically referred to as <u>stored energy</u>, for use in driving other metabolic reactions.

3. **Creatine-phosphate**--muscle cells also synthesize this compound, which contains high-energy phosphate bonds as well.

4. **Safety**--there is a safety factor in utilizing ATP and creatine-phosphate for energy holding. Without it, the excessive energy bursts occurring would be damaging to cells.

II. CARBOHYDRATES

A. **Absorption and distribution**--These are absorbed as monosaccharides (simple sugars). Most of this will be glucose, with lesser amounts of fructose, galactose, and less important ones (e.g. mannose and xylose). They are transported by the blood circulation first to the liver, which is the ultimate controller of their distribution. This is hormonally regulated, as will be shown later.

B. **Fates**

1. **Scope**--this will be presented for <u>glucose only</u>, since it is the primary monosaccharide.

2. **Storage and release**

a. **Glycogenesis**--this is the synthesis of glycogen (termed animal starch). It mostly occurs within hepatic cells of the liver, and muscle cells; the latter contain over twice as much as the liver, but in a much greater total mass. The liver is storing glucose to be distributed by the blood circulation to all cells of the body as needed. By contrast, muscle cells utilize all of their glucose, with none being available as blood sugar (glucose); this is necessitated by their extremely high ATP requirement and need for a dependable supply of glucose.
Storage in this particular insoluble form is necessary in order to prevent osmotic upset, which would occur with high concentrations or soluble glucose or oligosaccharides of it.

b. **Glycogenolysis**--this is glycogen hydrolysis, which frees the glucose from storage. The liver, primarily, carries this out at a sufficient rate to maintain a blood sugar level of 80-120 mg/100 ml.

3. **Respiration**--cellular respiration of glucose can occur directly, or after release from storage. All cells of the body are capable of this series of reactions. Each mole of glucose can produce 686,000 calories of energy; 304,000 go towards forming ATP, with the rest lost as heat.

4. **Conversions <u>to</u> other simple organic compounds**

a. **General**--all of these involve rearrangements of the glucose molecule, with both splitting off and additions of groups. These conversion reactions occur primarily in the liver.

b. **Fatty acids**.

c. **Glycerol**--this is a relatively simple conversion, since glucose and glycerol are both alcohols.

d. **Amino acids**--this conversion is more complicated, since <u>amination</u> (amino attachment) to obtain the nitrogen component, is a prerequisite.

e. **Other monosaccharides**--glucose can be rather freely converted into any other simple sugar.

5. **Conversions from non-glucose organic compounds**--this is termed gluconeogenesis, meaning "new glucose formation."

a. **From glycerol**--this is about the easiest conversion.

b. **From amino acids**--after deamination (amino removal), the remaining portion of many amino acids can be converted either directly or indirectly (via other sugars initially) into glucose.

6. **Excretion**--excess glucose will be excreted by the kidneys.

C. Control

1. **General**--the control of blood glucose is by the coordinated efforts of a number of hormones. [These were discussed in greater detail with the endocrine system]

2. **Insulin**--this hormone lowers blood glucose via several reinforcing mechanisms, namely:

- Increased diffusion into cells.
- Increased active transport into cells.
- Increased glycogenesis.
- Decreased gluconeogenesis.

3. **Glucagon**--this hormone, also from the pancreas, elevates blood glucose, by stimulating glycogenolysis to provide an increased concentration intracellularly.

4. **Growth hormone**--this pituitary hormone elevates blood sugar by decreasing the rate of active transport into cells.

5. **Epinephrine**--from the adrenal glands, this hormone elevates blood glucose by also stimulating general glycogenolysis and muscle use.

6. **Thyroxin**--this is from the thyroid gland. It stimulates glucose oxidation and gluconeogenesis.

7. **Cortisol**--this adrenal hormone promotes gluconeogenesis as well.

III. LIPIDS

A. Absorption and distribution

1. **Absorption**--digested fatty acids, glycerol (and related compounds), phospholipids, and cholesterol, are absorbed into lymphatic vessels of the small intestine.

2. **Transport**--due to most of the absorbed fatty acids, etc. (see above), reforming into lipids, which are insoluble, they are first transformed into globules termed chylomicrons and lipoproteins, which are

more soluble and mobile. These are composed of varying proportions of triglycerides, cholesterol, proteins, and some other components (e.g. phospholipids). There are various lipoproteins, named according to the relative amounts of their denser protein component. This yields: very low density, low density, and high density lipoproteins, which are termed VLDL, LDL, and HDL, respectively. Eventually these particles will enter the blood circulation.

3. Distribution--those transported particles will mostly be taken in by hepatic cells or adipose cells (throughout the body).

B. Fates

1. General--due to the diversity and complexity of lipids, primarily triglycerides (true fats or tricarboxylic acids) and their component fatty acids and glycerol will be considered.

2. Adipose

   a. Storage--adipose (fat) cells absorb fatty acids and glycerol, then resynthsize them into triglycerides for storage. This is such an efficient form of stored energy due to the high potential ATP yield when they are respired.

   b. Insulation--there is a thermal benefit from adipose tissue, which is a great part of the explanation for its distribution within the body. An example would be the subcutaneous layer.

   c. Protection--this is mechanical protection, exemplified by the thick layers of adipose around the kidneys.

3. Respiration

   a. Glycerol--this is first converted into glucose, then respired identically.

   b. Fatty acids--these are initially split into 2-carbon fragments, then each one will enter the Krebs cycle. Each fragment has a net yield of 12 ATP molecules. Considering the several to many fragments for each of the three fatty acids, plus more ATP's from the splitting process itself, and the glycerol, then it is easy to see why this is considered as a highly concentrated energy source.

4. Synthesis--this involves the formation of various structural components of cells--e.g. the phospholipids of cell and organelle membranes, and cholesterol for conversion to a number of hormones.

5. Conversions to other simple organic compounds

   a. General--these reactions mostly take place in the liver's hepatic cells.

   b. Amino acids--this would necessitate amination initially.

   c. Glucose--this would be part of gluconeogenesis.

   d. Ketone bodies--these are produced by fatty acid breakdown. An example is acetoacetic acid (related to acetone). These can be utilized for cellular respiration.

6. Conversions from non-lipid organic compounds

   a. **General**--these reactions, termed lipogenesis, occur in the liver as well. These conversions would only occur if the non-lipid precursors were in excess.

   b. **Amino acids**--the necessary reactions are the reverse of those just considered in part 5 above. Deamination would obviously be necessary.

   c. **Glucose**--this would furnish glycerol.

7. **Excretion**--excess ketone bodies will be excreted by the kidneys.

IV. PROTEINS

A. **Absorption and distribution**--they are absorbed as free amino acids, into the blood circulation (with some in the lymphatics) of the small intestine. Again, the liver is the primary organ to extract them from the blood and to determine their distribution and fates.

B. Fates

1. **Synthesis**--the overwhelming majority of amino acids are utilized directly or indirectly in the synthesis of proteins. These are needed for cell and organelle membranes, enzymes, hormones, and blood carrier substances.

2. Conversion to other organic compounds

   a. **General**--deamination will usually occur first; an example of an exception is part 2,b just below. These reactions mostly occur in the liver.

   b. **Other amino acids**--this process is termed transamination, in which one amino acid can be converted into nearly any other amino acid. This depends upon the body's needs.

   c. **Other nitrogenous compounds**--examples are heme (for hemoglobin), epinephrine (hormone), melanin (skin pigment), serotonin (neurotransmitter), and niacin (vitamin).

   d. **Gluconeogenesis**--following deamination.

   e. **Lipogenesis**--again, following deamination.

3. **Respiration**--amino acids are only utilized for cellular respiration when in great excess, or under starvation conditions when the preferred carbohydrate and lipid sources are depleted. Keep in mind that taking amino acids for respiration would usually be removing structural and functional cellular components.

The ATP yield from an amino acid is quite low--about 9 ATP, net.

4. **Conversion from non-amino acid organic compounds**--this would necessitate amination. Sources are fatty acids and monosaccharides.

5. **Excretion**--excess amino acids will be excreted primarily via the kidneys. Also, ammonia, which forms as a result of deaminations, is heavily excreted.

V. LIVER FUNCTIONS

A. Secretion and excretion

800-1200 ml of bile is produced per day. Bile is composed of salts (for lipid emulsification), pigments (from red blood cell destruction), and cholesterol. The latter two are considered to be excretions.

B. Blood

1. **Volume**--this is regulated by expansion and contraction.

2. **Synthesis**--forms prothrombin, fibrinogen, and heparin, which are involved in blood coagulation.

3. **Destruction**--with the spleen, disposes of red blood cells (RBC's or erythrocytes). It also processes the breakdown products, recycling some (e.g. iron) and excreting others (heme of hemoglobin, minus the iron).

C. Storage

1. **Nutrients**--all classes of carbohydrates, proteins, lipids, and their component smaller molecules.

2. **Vitamins**--D, B_{12} and A (also synthesizes this one).

3. **Iron**.

4. **Toxins**--[see D,2 just below].

D. Detoxification

1. **Digestive products**--examples are phenol and benzoic acid (a food preservative).

2. **Drugs and heavy metals**--via the bile. They are stored and released slowly. This is effective unless critical levels are exceeded. Examples--mercury, lead, cadmium, morphine, and strychnine.

3. **Phagocytosis**--phagocytic cells line the sinusoids. These are some of the white blood cells (leukocytes).

E. Nutrient interconversions

1. **General**--most of these were discussed previously under protein, lipid, and carbohydrate metabolism. Thus, little further explanation will be necessary.

The liver also performs most reactions with the various by-products of the specific compounds given below.

2. Carbohydrates

   a. Glycogen

      (1) Glycogenesis

      (2) Glycogenolysis

   b. Conversion <u>to</u> glucose--from other monosaccharides.

   c. Gluconeogenesis--primarily related with blood glucose maintenance.

   d. Conversion <u>from</u> glucose--e.g. glycerol.

   e. Synthesis--other than glycogenesis--e.g. glycoproteins.

3. Lipids

   a. Ketogenesis

   b. Synthesis

      (1) Lipoproteins

      (2) Cholesterol

      (3) Phospholipids

   c. Lipogenesis

   d. Conversions <u>from</u> lipid products--e.g. to amino acids (from fatty acids, primarily).

4. Proteins

   a. Deamination--prerequisite to conversions (e.g.).

   b. Amination--necessary for amino acid synthesis.

   c. Transamination

   d. Synthesis

      (1) To proteins--from amino acids. Examples--plasma proteins and enzymes.

      (2) Conjugated proteins--lipoproteins and glycoproteins.

   e. Conversion <u>from</u> amino acids--e.g. to fatty acids.

5. Nucleic acids

a. **Catabolism**--performed on absorbed nucleosides into sugar and base components.

b. Synthesis

(1) **General**--nearly all cells in the body can perform these conversions.

(2) DNA synthesis

(3) RNA synthesis

(4) **Related**--e.g. ATP.

VI. VITAMINS AND MINERALS

[*Refer to tables in textbook and/or handouts*]