Nutrients and Metabolism

Nutrient: any molecule that serves one or more of the following functions:

1. Supply energy for life processes
2. Synthesize structural or functional molecules
3. Stored for future use

6 classes of nutrients or foodstuffs:

- Carbohydrates
- Proteins
- Fats (lipids)
- Water
- Minerals (inorganic salts)
- Vitamins

Water

- ❖ Solvent
- ❖ Hydrolysis reactions
- ❖ Coolant
- ❖ Lubricant
- ❖ Releases/absorbs heat slowly; maintains body temperature

Proteins

- ❖ Composed of amino acids
- ❖ Dipeptides: 2aa
- ❖ Oligopeptides 2-10 aa
- ❖ Polypeptides: 10-100 aa
- ❖ Proteins: >100 aa
- ❖ 10 essential aa
- ❖ Quality of protein depends on aa composition

Carbohydrates

Classified as monosaccharides, disaccharides, or polysaccharides; depending on the number of five or six carbon units

- ❖ Monosaccharides: ribose, glucose, fructose and galactose
- ❖ Disaccharides: 2 monos together—sucrose, maltose, lactose
- ❖ Polysaccharides: more than two monos—starch, glycogen, cellulose
- ❖ Starch is a food reserve of most plants; excellent source of energy
- ❖ Glycogen—storage form of CHO (glucose) in animals; liver and muscle stores glycogen
- ❖ Cellulose—structural component of plants; digested only by fermentation

Lipids
Triglycerides: glycerol plus 3 fatty acids (FA)
Phospholipids: complex lipids that contain phosphate
Cholesterol: fatty substance derived from triglycerides; 80% of all cholesterol is formed in the liver to form bile salts

Minerals

- Inorganic
- Measured as ash
- Important for many body functions
- Macro and micro minerals (trace)

Vitamins

- Organic
- Function as metabolic catalysts (coenzymes)
- Fat soluble: ADEK
- Water soluble: thiamine, riboflavin, pantothenic acid

Niacin, pyridoxine, biotin, folic acid, choline, B12,
Inositol, and paraaminobenzoic acid, Vit. C

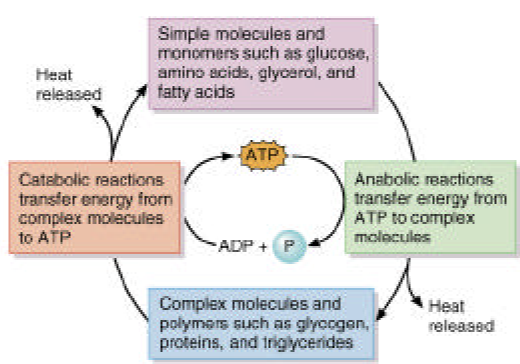
Metabolism

- Functions of food
  - source of energy
  - essential nutrients
  - stored for future use
- Metabolism is all the chemical reactions of the body
  - some reactions produce the energy stored in ATP that other reactions consume
  - all molecules will eventually be broken down and recycled or excreted from the body

Catabolism and Anabolism

- Catabolic reactions breakdown complex organic compounds
  - providing energy (exergonic)
  - glycolysis, Krebs cycle and electron transport
- Anabolic reactions synthesize complex molecules from small molecules
  - requiring energy (endergonic)
- Exchange of energy requires use of ATP (adenosine triphosphate) molecule.

ATP Molecule & Energy



- Each cell has about 1 billion ATP molecules that last for less than one minute
- Over half of the energy released from ATP is converted to heat

Energy Transfer

- Energy is found in the bonds between atoms
- Oxidation is a decrease in the energy content of a molecule
- Reduction is the increase in the energy content of a molecule
- Oxidation-reduction reactions are always coupled within the body
  - whenever a substance is oxidized, another is almost simultaneously reduced.

Oxidation and Reduction

- Biological oxidation involves the loss of (electrons) hydrogen atoms
  - dehydrogenation reactions require coenzymes to transfer hydrogen atoms to another compound
  - common coenzymes of living cells that carry H+
    - NAD (nicotinamide adenine dinucleotide)
    - NADP (nicotinamide adenine dinucleotide phosphate)
    - FAD (flavin adenine dinucleotide)
- Biological reduction is the addition of electrons (hydrogen atoms) to a molecule
  - increase in potential energy of the molecule

Mechanisms of ATP Generation

- Phosphorylation is
  - bond attaching 3rd phosphate group contains stored energy
- Mechanisms of phosphorylation
  - within animals
    - substrate-level phosphorylation in cytosol
    - oxidative phosphorylation in mitochondria
  - in chlorophyll-containing plants or bacteria
    - photophosphorylation.

Carbohydrate Metabolism--In Review

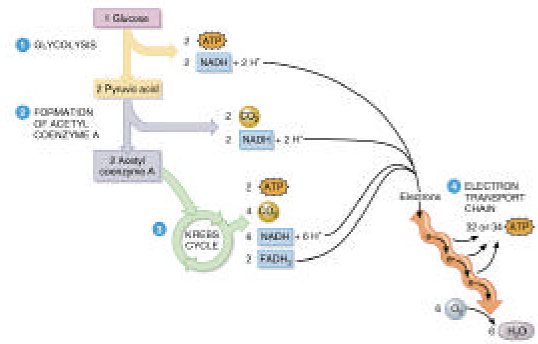
- In GI tract
  - polysaccharides broken down into simple sugars
  - absorption of simple sugars (glucose, fructose & galactose)
- In liver
  - fructose & galactose transformed into glucose
  - storage of glycogen (also in muscle)
- In body cells --functions of glucose
  - oxidized to produce energy
  - conversion into something else
  - storage energy as triglyceride in fat

Fate of Glucose

- ATP production during cell respiration
  - uses glucose preferentially
- Converted to one of several amino acids in many different cells throughout the body
- Glycogenesis
  - hundreds of glucose molecules combined to form glycogen for storage in liver & skeletal muscles
- Lipogenesis (triglyceride synthesis)
  - converted to glycerol & fatty acids within liver & sent to fat cells

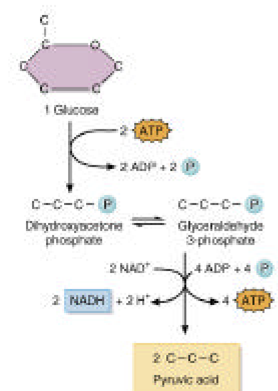
Glucose Catabolism

- Cellular respiration
  - 4 steps are involved
  - glucose + O2 produces H2O + energy + CO2
- Anaerobic respiration
  - called glycolysis (1)
  - formation of acetyl CoA (2) is transitional step to Krebs cycle
- Aerobic respiration
  - Krebs cycle (3) and electron transport chain (4)



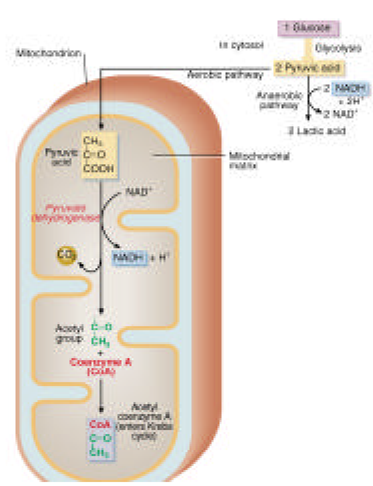
Glycolysis of Glucose & Fate of Pyruvic Acid

- Breakdown of six-carbon glucose molecule into 2 three-carbon molecules of pyruvic acid
  - 10 step process occurring in cell cytosol
  - produces 4 molecules of ATP after input of 2 ATP
  - utilizes 2 NAD+ molecules as hydrogen acceptors
- If O2 shortage in a cell
  - pyruvic acid is reduced to lactic acid so that NAD+ will be still available for further glycolysis
  - rapidly diffuses out of cell to blood
  - liver cells remove it from blood & convert it back to pyruvic acid



Formation of Acetyl Coenzyme A

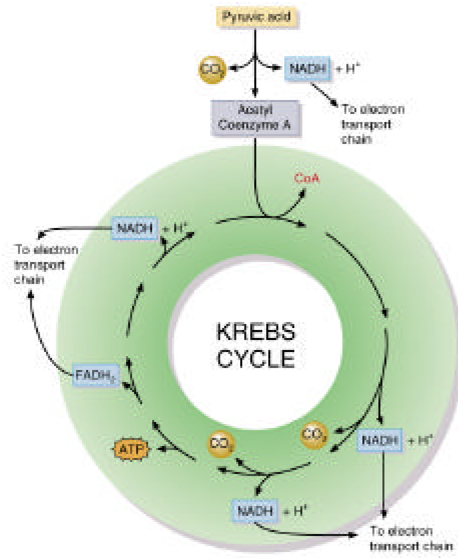
- Pyruvic acid enters the mitochondria with help of transporter protein
- Decarboxylation
  - pyruvate dehydrogenase converts 3 carbon pyruvic acid to 2 carbon fragment (CO2 produced)
  - pyruvic acid was oxidized so that NAD+ becomes NADH
- 2 carbon fragment (acetyl group) is attached to Coenzyme A to form Acetyl coenzyme A which enter Krebs cycle
  - coenzyme A is derived from pantothenic acid (B vitamin).



Krebs Cycle (Citric Acid Cycle)

- Series of oxidation-reduction & decarboxylation reactions occurring in matrix of mitochondria
- It finishes the same as it starts (4C)
  - acetyl CoA (2C) enters at top & combines with a 4C compound
  - 2 decarboxylation reactions peel 2 carbons off again when CO2 is formed

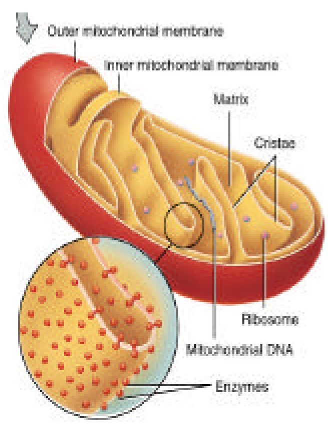
Krebs Cycle



- Energy stored in bonds is released step by step to form several reduced coenzymes (NADH & FADH2) that store the energy
- In summary: each Acetyl CoA molecule that enters the Krebs cycle produces
  - 2 molecules of C02
    - one reason O2 is needed
  - 3 molecules of NADH + H+
  - one molecule of ATP
  - one molecule of $FADH_2$
- Remember, each glucose produced 2 acetyl CoA molecules

The Electron Transport Chain

- Series of integral membrane proteins in the inner mitochondrial membrane capable of oxidation/reduction
- Each electron carrier is reduced as it picks up electrons and is oxidized as it gives up electrons
- Small amounts of energy released in small steps
- Energy used to form ATP by chemiosmosis



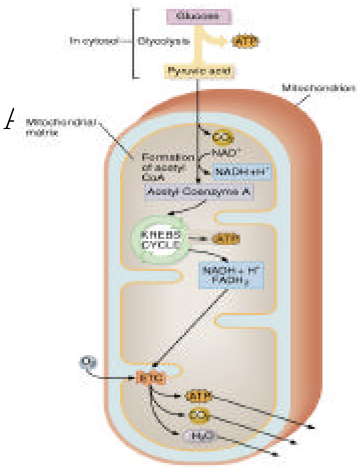
Electron Carriers

- Flavin mononucleotide (FMN) is derived from riboflavin (vitamin B2)
- Cytochromes are proteins with heme group (iron) existing either in reduced form (Fe+2) or oxidized form (Fe+3)
- Iron-sulfur centers contain 2 or 4 iron atoms bound to sulfur within a protein
- Copper (Cu) atoms bound to protein
- Coenzyme Q is nonprotein carrier mobile in the lipid bilayer of the inner membrane

Summary of Cellular Respiration

- Glucose + O2 is broken down into CO2 + H2O + energy used to form 36 to 38 ATPs
  - 2 ATP are formed during glycolysis
  - 2 ATP are formed by phosphorylation during Krebs cycle
  - electron transfers in transport chain generate 32 or 34 ATPs from one glucose molecule
- Points to remember

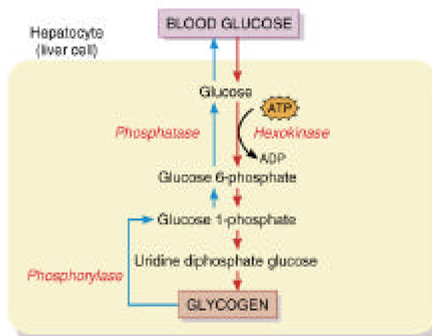
– ATP must be transported out of mitochondria in exchange for A
  • uses up some of proton motive force
– Oxygen is required or many of these steps can not occur



Carbohydrate Loading

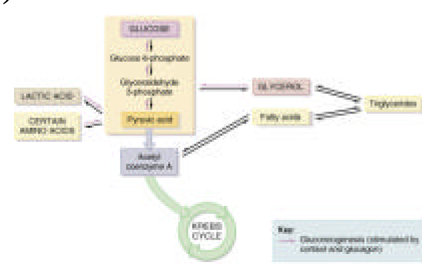
- Long-term athletic events (marathons) can exhaust glycogen stored in liver and skeletal muscles
- Eating large amounts of complex carbohydrates (pasta & potatoes) for 3 days before a marathon maximizes glycogen available for ATP production
- Useful for athletic events lasting for more than an hour

Glycogenesis & Glycogenolysis



- Glycogenesis
  - glucose storage as glycogen
  - 4 steps to glycogen formation in liver or skeletal muscle
  - stimulated by insulin
- Glycogenolysis
  - glucose release not a simple reversal of steps
  - enzyme phosphorylase splits off a glucose molecule by phosphorylation to form glucose 1-phosphate
  - enzyme only in hepatocytes so muscle can't release glucose
  - enzyme activated by glucagon (pancreas) & epinephrine (adrenal)

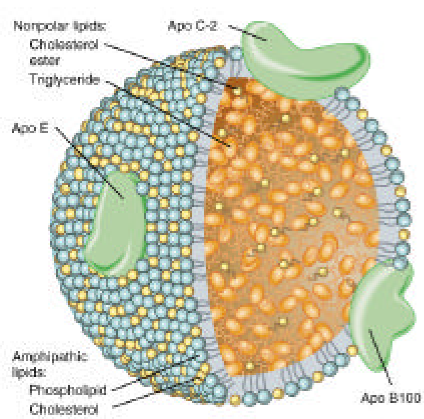
Gluconeogenesis



- Liver glycogen runs low if fasting, starving or not eating carbohydrates forcing formation from other substances
  - lactic acid, glycerol & certain amino acids (60% of available)
- Stimulated by cortisol (adrenal) & glucagon (pancreas)
  - cortisol stimulates breakdown of proteins freeing amino acids
  - thyroid mobilizes triglycerides from adipose tissue

Transport of Lipids by Lipoproteins

- Most lipids are nonpolar and must be combined with protein to be transported in blood
- Lipoproteins are spheres containing hundreds of molecules
  - outer shell polar proteins (apoproteins) & phospholipids
  - inner core of triglyceride & cholesterol esters
- Lipoprotein categorized by function & density
- 4 major classes of lipoproteins
  - chylomicrons, very low-density, low-density & high-density lipoproteins



Classes of Lipoproteins

- Chylomicrons (2 % protein)
  - form in intestinal epithelial cells to transport dietary fat
    - apo C-2 activates enzyme that releases the fatty acids from the chylomicron for absorption by adipose & muscle cells
    - liver processes what is left
- VLDLs (10% protein)
  - transport triglycerides formed in liver to fat cells
- LDLs (25% protein) --- “bad cholesterol”
  - carry 75% of blood cholesterol to body cells
  - apo B100 is docking protein for receptor-mediated endocytosis of the LDL into a body cell
    - if cells have insufficient receptors, remains in blood and more likely to deposit cholesterol in artery walls (plaque)
- HDLs (40% protein) --- “good cholesterol”
  - carry cholesterol from cells to liver for elimination

Blood Cholesterol

- Sources of cholesterol in the body
  - food (eggs, dairy, organ meats, meat)
  - synthesized by the liver
- All fatty foods still raise blood cholesterol
  - liver uses them to create cholesterol
  - stimulate reuptake of cholesterol containing bile normally lost in the feces
- Desirable readings for adults
  - total cholesterol under 200 mg/dL; triglycerides 10-190 mg/dL
  - LDL under 130 mg/dL; HDL over 40 mg/dL
  - cholesterol/HDL ratio above 4 is undesirable risk
- Raising HDL & lowering cholesterol can be accomplished by exercise, diet & drugs

Fate of Lipids

- Oxidized to produce ATP
- Excess stored in adipose tissue or liver
- Synthesize structural or important molecules
  - phospholipids of plasma membranes
  - lipoproteins that transport cholesterol
  - thromboplastin for blood clotting
  - myelin sheaths to speed up nerve conduction
  - cholesterol used to synthesize bile salts and steroid hormones.

Triglyceride Storage

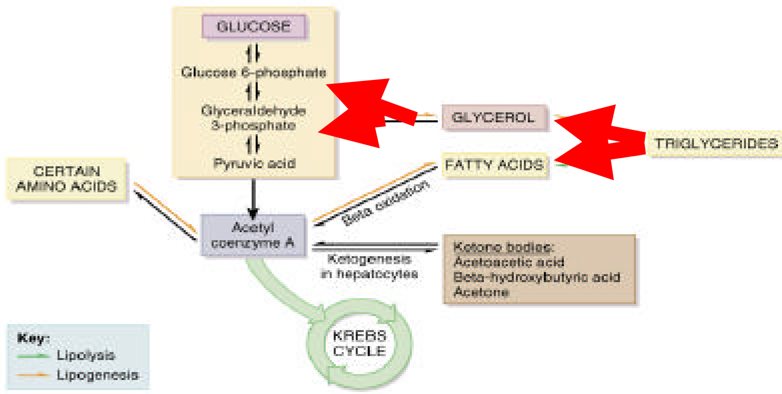
- Adipose tissue removes triglycerides from chylomicrons and VLDL and stores it
  - 50% subcutaneous, 12% near kidneys, 15% in omenta, 15% in genital area, 8% between muscles
- Fats in adipose tissue are ever-changing

– released, transported & deposited in other adipose

- Triglycerides store more easily than glycogen
  – do not exert osmotic pressure on cell membranes
  – are hydrophobic

Lipid Catabolism: Lipolysis & Glycerol

- Triglycerides are split into fatty acids & glycerol by lipase
  – glycerol
    - if cell ATP levels are high, converted into glucose
    - if cell ATP levels are low, converted into pyruvic acid which enters aerobic pathway to ATP production



Lipolysis & Fatty acids

- Beta oxidation in mitochondria removes 2 carbon units from fatty acid & forms acetyl coenzyme A
- Liver cells form acetoacetic acid from 2 carbon units & ketone bodies from acetoacetic acid (ketogenesis)
  – heart muscle & kidney cortex prefer to use acetoacetic acid for ATP production

Lipid Anabolism: Lipogenesis

- Synthesis of lipids by liver cells = lipogenesis
  – from amino acids
    - converted to acetyl CoA & then to triglycerides
  – from glucose
    - from glyceraldehyde 3-phosphate to triglycerides
- Stimulated by insulin when eat excess calories

Ketosis

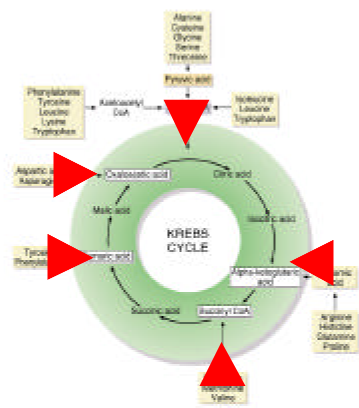
- Blood ketone levels are usually very low
  – many tissues use ketone for ATP production
- Fasting, starving or high fat meal with few carbohydrates results in excessive beta oxidation & ketone production
  – acidosis (ketoacidosis) is abnormally low blood pH

- sweet smell of ketone body acetone on breath
- occurs in diabetic since triglycerides are used for ATP production instead of glucose & insulin inhibits lipolysis

Fate of Proteins

- Proteins are broken down into amino acids
  - transported to the liver
- Usage
  - oxidized to produce ATP
  - used to synthesize new proteins
    - enzymes, hemoglobin, antibodies, hormones, fibrinogen, actin, myosin, collagen, elastin & keratin
  - excess converted into glucose or triglycerides
    - no storage is possible
- Absorption into body cells is stimulated by insulinlike growth factors (IGFs) & insulin

Protein Catabolism



- Breakdown of protein into amino acids
- Liver cells convert amino acids into substances that can enter the Krebs cycle
  - deamination removes the amino group (NH_2)
    - converts it to ammonia (NH_3) & then urea
    - urea excreted in the urine
- Converted substances enter the Krebs cycle to produce ATP

Protein Anabolism

- Production of new proteins by formation of peptide bonds between amino acids
  - 10 essential amino acids are ones we must eat because we can not synthesize them
  - nonessential amino acids can be synthesized by transamination (transfer of an amino group to a substance to create an amino acid)
- Occurs on ribosomes in almost every cell
- Stimulated by insulinlike growth factor, thyroid hormone, insulin, estrogen & testosterone
- Large amounts of protein in the diet do not cause the growth of muscle, only weight-bearing exercise

Metabolic Rate

- Rate at which metabolic reactions use energy
  - energy used to produce heat or ATP
- Basal Metabolic Rate (BMR)
  - measurements made under specific conditions
    - quiet, resting and fasting condition
- Basal Temperature maintained at 98.6 degrees
  - shell temperature is usually 1 to 6 degrees lower