Carbohydrates defined

- made of **carbon**, **hydrogen** and **oxygen**
  - originally come from… **sun**! plants convert for us!
- carbs a.k.a. **sugar**, **starch** and **fiber**!
- can be **simple** or **complex**
  - in general, the **simples** are the **sugars**
  - the complex are the **starches** and **fibers**
- **MAJOR ROLE**: Provide energy
Carbohydrate Basics

Simple Sugars: mono & di saccharides

- **Simple Sugars (simple carbs) = monosaccharides**
- **SINGLE** sugar molecule
- three are more common in foods than any others:
- same #, kinds of atoms but chemical bonds arranged differently - gives each different taste

- **GLUCOSE** a.k.a. dextrose
  - **most abundant** in nature!
  - **usually not in foods as monosaccharide**
  - ALWAYS at least one of the two sugar molecules in dietary disaccharides
  - **easiest form of energy for body to process**
  - (almost) only form of energy that **brain, RBCs** will use
    - Found in fruits, vegetables, honey
    - “blood sugar” – used for energy

- **FRUCTOSE** a.k.a. levulose, fruit sugar - sweetest!
  - does **occur naturally** in fruits, veggies
  - [estimated to supply ~5% of human energy intake in U.S.]
    - Found in fruits, honey, corn syrup
Foods high in simple carbs

- Naturally present
  - fruits
  - fruit juices
  - skim milk
  - plain nonfat yogurt

- Added sugars
  - angel food cake
  - soft drinks
  - sherbet
  - syrups
  - sweetened nonfat yogurt
  - candy, cookies, frosting
  - jams, jellies
  - gelatin
  - sweetened breakfast cereals
Complex Carbs: Starches

- **polysaccharide** = >20 sugar subunits
  - **some digestible**, some not

Digestable polysaccharide: **Starch**
- 3,000 or more monosaccharides bound together
- (alpha glycosidic bonds)
- **plant** energy storage!
- Found in grains, tubers (potatos, yams), legumes

- **Two predominant storage forms** of starch in plants:
  - **amylose** - long **unbranched** chains of **glucose** molecules
  - **amylopectin** - long chains of **glucose** molecules but **branched**
    - Modified food starch (bonding starch molecules together) and gel formation - widely used because increases stability of food e.g. puddings, salad dressings
  - **resistant** starch = not digested because **inaccessible** to digestive enzymes- enclosed in cell structure

- Foods high in starch
  - bagels
  - tortillas
  - cereals
  - crackers
Second type of digestible polysaccharide: Glycogen

- **animal energy storage**
- **Highly branched** chains of glucose units
- **Body’s storage form of carbohydrate**
  - most in liver, skeletal muscle
    - in **liver**
      - used to **regulate blood glucose**
    - in **skeletal muscle**
      - used to supply glucose for **strenuous muscle activity**
- NOT a significant dietary source of carbs
  - plants don’t have glycogen
Complex carbohydrates (carb with three or more carbohydrate subunits)

- **oligo** = scant (few) = 3 to 10 sugar subunits
- **raffinose & stachyose are nutritionally relevant**
  - found in legumes
  - we have no enzymes to break the bonds so we don’t digest them – the bacteria that live in our colon do
  - **not digestible** – so they are considered “fiber”
Complex Carbohydrates: Dietary **Fiber**
- cellulose not digestible because chemical bonds between glucose molecules are different than in starch
- stachylose different arrangement of monosaccharides
  - Beano! Enzyme preparation!

• Dietary + Functional = Total Fiber
• Indigestible chains of monosaccharides
  • Non-starch polysaccharides: long chains
    • Cellulose, hemicellulose, pectins, gums, mucilages
    • Lignins
• Found in fruits, vegetables,
  • grains, legumes
• Indigestible chains of monosaccharides
• Dietary Fiber Classification (besides oligosaccharides)
• Insoluble
  • Non-carbohydrate polysaccharides: Lignins - polymer of phenols
    • very tough! e.g. strawberry seeds
  • Carbohydrate polysaccharides:
    • Cellulose (grass, trees, celery), primary constituent in plant cell walls
    • Hemicellulose - main constituent of cereal fibers (cereals = grains used for food)
• Soluble (all are carbohydrate)
  • Pectins (give fruit body, when overripe break down & fruit gets mushy),
  • Gums, mucilages - think, used as thickeners/stabilizers/texturizers by food industry
    • e.g. gum arabic, guar gum, xanthan gum, carrageenan mucilage
  • Fermentable by intestinal bacteria!
    • Products = Short-chain fatty acids
      • Enhances health of large intestine cells
      • Fuel source for intestinal cells
      • Absorbed into the blood stream
      • Yields kcal ~ 1.5-2.5 kcal/g
• Found in ALL types of plant foods: fruits, vegetables, grains, legumes, nuts, and seeds
• Why nondigestible? E.g. starch and cellulose are BOTH just chains of glucose! All are just chains of monosaccharides!

<table>
<thead>
<tr>
<th>Table 5-1 Classification of Dietary Fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Insoluble (poorly fermented)</td>
</tr>
<tr>
<td>Noncarb.</td>
</tr>
<tr>
<td>Carbohydrate</td>
</tr>
<tr>
<td>Soluble (viscous)</td>
</tr>
<tr>
<td>Carbohydrate</td>
</tr>
</tbody>
</table>

Wardlaw Table 5-1
How can grains be sources of both starch and fiber?
Check out anatomy of a grain kernel!

- **Four basic parts** to grains
- **germ** - will be the new plant
  - lots of proteins, fats, vitamins, minerals
- **endosperm** (starch)
  - energy reserve for new plant to grow
- **bran** (fiber)
  - protective layer, rich in fiber
- **husk** - outer covering, inedible

- **Refined** grains = husk, bran removed, sometimes germ gone too
- “whole wheat”, “whole grain” = entire grain kernel still there
Carbohydrate Digestion and Absorption

• **Mouth**
  - *Salivary amylase* begins digestion of starch
    - breaks into shorter polypeptides and a little maltose

• **Stomach**
  - no digestion of starch in stomach!

• **Small intestine**: MAJORITY of carb digestion
  - *Pancreatic amylase* completes starch digestion
    - break remaining starch into maltose
  - *Microvilli* (Brush border) enzymes digest disaccharides into monomers
  - **End products of carbohydrate digestion**
    - Glucose, fructose, galactose, and INDIGESTIBLE carbs (fiber!)

• **Large intestine**
  - *bacterial* population HUGE! *Ferment* some of the fiber!
    - make **short-chain fatty acids** -> absorbed by colon, colon cells use for energy
    - make **GAS** - stinky!
  - remaining fiber **passes**, softening stool/adding bulk
Lactose maldigestion
• lactose broken down by LACTASE into glucose & galactose
  • lactase activity highest right after birth
  • levels decrease as person ages
• intolerance: body not able to digest all lactose ingested
  • body producing none? or just not enough to keep up with ingestion?
    • genetic - normal decrease in production with age
    • damage to intestinal microvilli - should reverse when heal
    • RARE that person BORN with inability to make lactase
  • estimated to occur in 25% U.S. population, 75% worldwide population
• extra lactose sitting attracts water, causes bloating, diarrhea
  • also, bacteria DO digest - GAS, acid produced
• maldigestion: term sometimes used interchangeably with intolerance
Carbohydrate absorption

- End products of carbohydrate digestion
  - Glucose, fructose, galactose
- Monosaccharides then absorbed into bloodstream thru intestinal villi
  - [glucose & galactose - active xport, fructose - facilitated diff]
- Sent to liver via portal vein - liver converts galactose & fructose to glucose
- Liver then has 3 options:
  - convert to glycogen, store (not much stored - very bulky)
  - burn it (convert to ATP) for it’s own energy needs or send into circulation to raise blood glucose
  - convert to fat (least likely)
Carbohydrates in the Body: Regulating Blood Glucose

- If BG levels too high (hyperglycemia), person becomes lethargic, confused, sometimes dyspneic

- **Pancreas** senses high BG levels, releases hormone **insulin**
  - travels thru bloodstream to body cells - “unlocks” cells so glucose can enter
  - also tells **liver** to increase glycogen stores

- When pancreas loses ability to make insulin - **Type I diabetes**
- When cells lose ability to respond to insulin - **Type II diabetes**
• cells of body MUST have supply of glucose for energy!
• many cells can also burn fat for energy, but some can ONLY use glucose! (I.e. brain, RBCs)
• if BG gets low (hypoglycemia), pancreas sense and secretes hormone glucagon
  • tells liver to break down, release glycogen
  • [stimulates glucose synthesis from protein]
• what happens if BG low and no glucose, glycogen available?
  • body starts making glucose from protein
  • body also tries to break down fat to use for energy but glucose necessary for complete breakdown of fat
    • end up making ketone bodies - most cells can use for energy
    • buildup causes “ketoadidosis” - blood becomes acidic
  • will talk a little more later
Other hormonal influences

- Epinephrine/norepinephrine
  - “fight or flight” response
  - breakdown glycogen
  - raises blood glucose
- Cortisol and growth hormone
  - increase gluconeogenesis
  - raise blood glucose
- combined influences - glucagon, above hormones balance insulin
Biological Functions of Carbohydrates

• Energy
• Protein sparing
• Prevention of ketosis

Energy
• glucose primary fuel for CNS, RBCs
• also preferred fuel for placenta and fetus
• other tissues CAN use glucose but usually use fat first

Protein sparing
• brain, RBCs need glucose - if not enough from diet, body will make from protein
• not so important in America, where we have access to plenty of protein - but CAN be problematic in times of starvation

Preventing ketosis
• if not enough glucose, fatty acids are released from adipose tissue and are metabolized into ketone bodies - can lead to problems (will discuss more later)
• (estimate body needs at least 50 - 100 g carbs/day to prevent ketosis)
How much do we need?

- **RDA: 130 g/day**
  - based on amount needed to supply CNS
- Average American consumes 180 - 330 g carbohydrates/day

- **Top 5 sources in U.S.:**
  - white bread
  - soft drinks
  - cookies/cakes (incl. doughnuts)
  - sugars/syrups/jams
  - potatoes
ARTIFICIAL SWEETENERS

•artificial sweeteners, are intensely sweet synthetic substances, often used in place of other sugars in food manufacturing and cooking because they are LOW OR FREE OF CALORIES. The United States Food and Drug Administration (FDA) has approved SOME OF THESE sweeteners for use in food: acesulfame K, aspartame, saccharin, and, sucralose.

Sucralose Splenda
Neotame n/a
Sugar Alcohols sorbitol, xylitol, mannitol, maltitol etc bloating, gas or diarrhea in large quantity may cause
Tagatose Naturlose flatulence, bloating, nausea or diarrhea in large quantity may cause
Aspartame Equal, NutraSweet, NatraTaste Some people reported headaches. People with PKU should avoid Aspartame
Acesulfame Potassium Sweet One, Sunnett, Acesulfame Potassium (Ace-K)
Stevia Sweet Leaf, Honey Leaf Stevia is not allowed to be added in food; only sold as a supplement.
Saccharin Sweet 'N Low
The problem with sucrose…

• Text page-159
Microbial Flora of the Mouth:

It’s a zoo!

- over 1000 species of microbes have been found in the human mouth!
- millions of bacteria per mL of saliva!
  - some transient (on food), some resident

- Niches for residents
  - attached to teeth
  - attached to tongue
  - under the gums

- we make ~ 1 L saliva/day! Microbes have to hang on REALLY tight!

- on right: SEM of the root surface of a tooth extracted due to periodontal abscess. The location of the selected picture stems from an area close to the gingival margin. Filamentous organisms covered by cocci predominate- Corncob formations
Why does sucrose increase risk of cavities?

- saliva forms coating that *Strep* can attach to
  - *Strep* makes fructose and glucan from sucrose (refined sugar)
    - other bacteria stick to glucan - community = plaque = BIOFILM
  - Once fructose produced, trouble! Lots of other bacteria can ferment it. Consequently, lots of acid produced!
    - acid erodes enamel!
  - note: Don’t have to memorize all the bacteria that can metabolize fructose. DO know *S. mutans* and role in fermenting sucrose!
• **natural defense** to these tooth decay? Washing effect of saliva
• saliva also contains **lysozyme**, (an ENZYME- Needs certain pH to function)
• also makes **ptyalin** - a protein which helps degrade carbohydrates
• Problem: lysozyme **works most effectively in the pH range of 6.3 - 6.8**.

• pH of mouth gets lower and lower as *S. mutans* goes to work - denatures lysozyme
• introduction of sugar to human diet = main cause of ineffective salivary enzymes.

• since so many people have sugar in their diets, tooth brushing has been shown to be the most effective weapon
  - procedure destroys the sucrose environment and also washes away many of the bacteria themselves.
  - Many types of toothpaste contain sodium lauryl sulfate, which is known to destroy bacterial cell walls.

• After having noted the effectiveness of tooth brushing, why should we consider the usefulness of sugar-free gum in preventing dental caries? Most people do not brush after every meal as would be optimal. Many people are busy, lazy, or feel inconvenienced by the need to brush after lunch at work or at school. Chewing sugar-free gum has been shown to be better than doing nothing at all. The act of mastication stimulates the release of saliva. The increased amount of saliva in the mouth right after meals helps kill more of the acid-producing bacteria and helps reintroduce ions for re-mineralization of the tooth enamel.
Glycemic Index

- measure of a particular food’s effect on blood glucose levels
- **high** GI = fast, high rise in blood glucose levels (e.g. white bread in picture)
- **low** GI = slower, lower rise in blood glucose levels
- influenced by:
  - starch structure, fiber content, physical structure, food processing, other macronutrients concurrently consumed
- lots of debate about the usefulness of GI
  - low GI foods - decrease risk of Type II diabetes, help control BG levels in diabetic pts, MAY help decrease risk of heart disease, colon CA
  - GI not predictable, not known for most foods so difficult to use in practice - lots of other ways to get same benefits

Glycemic load = grams of carbs multiplied by glycemic index

Foods with high glycemic load:

- Stimulates the release of insulin
  - [Insulin increases LDL] - book says smaller LDLs
  - Insulin increases fat synthesis
  - Increases risk for CVD
  - Returns to hunger quicker
  - Muscle may become resistant to the insulin
Gluconeogenesis

- Pyruvate, lactate
- Glycerol
- Some amino acids
- Ketogenesis

What about making glucose itself, if person not eating enough?

**GLUCONEOGENESIS**
- starting material is oxaloacetate
- can make from carbohydrates pyruvate, lactate
- can make from noncarbs glycerol and some amino acids (not all)
- CANNOT make from fatty acids

If not possible to do gluconeogenesis and energy needed, body will do ketogenesis
- formation of ketone bodies
- normal process, happens anyway when fatty acids metabolized (not all Acetyl CoA from beta-oxidation goes into kreb’s cycle)
- heart & kidneys actually prefer the ketone body acetoacetate
Key steps in ketosis

- Low carb intake leads to…
  - decreased insulin levels, increased glucagon levels (to increase blood sugar)
  - depletion of kreb’s intermediates
    - CAN convert pyruvate directly to oxaloacetate instead of acetyl CoA but have to have glucose to get pyruvate (or break down muscle)
- Increased lipolysis (caused by low insulin levels) causes large numbers of fatty acids to be released into circulation, majority of which are picked up by the liver
  - use of fatty acids for kreb’s cycle in liver limited -
    - kreb’s cycle can’t keep up with large numbers of fatty acids because oxaloacetate depleted
    - increased ATP production leads to feedback inhibition of kreb’s cycle enzymes
- end result: large number of ketone bodies produced and subsequently released into bloodstream
  - body cells pick up SOME of the ketone bodies
Why do we have to have carbs to avoid making ketone bodies?

- remember that b-ox product is acetyl CoA! MOST should feed into kreb’s cycle
- BUT have to have oxaloacetate to do kreb’s cycle. **starvation, low-carb diets deplete oxaloacetate**
- CAN convert pyruvate directly to oxaloacetate instead of acetyl CoA but have to have glucose to get pyruvate (or break down muscle)
- if no oxaloacetate, acetyl CoA gets converted to ketone bodies
  - if build up, problematic!