

**Human Physiology**  
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**Week - 06**  
**Lecture - 02**

Hello everyone, welcome to another new class on human physiology. In today's class, we will discuss the digestion of carbohydrates. You remember in the last class, we discussed the general anatomy of various digestive organs in our body, and briefly we discussed their functions. Now, let us see how carbohydrate digestion happens. So, what different concepts or topics will be covered in this class? We will see what carbohydrates are, how digestion happens in the mouth for carbohydrates, how the digestion of carbohydrates happens in the small intestine, and finally, after digestion, how the absorption of carbohydrates occurs, and what the role of the liver is in carbohydrate metabolism. So, the introduction of carbohydrates, carbohydrates are the body's primary source of energy.

They are composed of elements like carbon, hydrogen, and oxygen, right? You can see some of the carbohydrate structure here, where you can see that we have hydrogen and oxygen. So mostly all the carbohydrates, including glucose, lactose, sucrose, and fructose, are made of carbon, hydrogen, and oxygen. Then what are different classifications like carbohydrates can be very simple types of monosaccharides or simple sugars. For example, glucose, fructose, and galactose are simple carbohydrates.

Why? Because they do not have any glycosidic bonds like this. So, for this kind of glucose, this is only like one unit. There is no interconnection between the other units of carbohydrate. Then carbohydrates can be disaccharides where double sugars can be found. So, you can see that lactose is an example of a disaccharide, where there are two components of sugars that are interconnected by a glycosidic bond, and it can also be a polysaccharide.

So, in cases of multiple sugar entities that are getting kind of bound with the glycosidic bond, you can get a polysaccharide type of carbohydrate like starch, glycogen, or cellulose. So, examples of monosaccharides are glucose, then examples of disaccharides are sucrose, lactose, and maltose, and more complex ones are polysaccharides such as starch and cellulose. You can see that their structure of glucose is like that of monosaccharides, glucose 6-phosphate, fructose, and galactose. So, these are all examples of what monosaccharides are, and then you can see that with this glycosidic bond, multiple sugar units can get connected. For example, lactose, maltose, and sucrose are disaccharides that we already discussed, while cellulose and starch have much more complex structures with multi-molecular combinations of sugars, resembling a polymeric type of combination.

So, how the digestion of carbohydrates happens in the mouth is most important. Let us see, first mechanical digestion happens in our mouth, right? We discussed what the function of our teeth is and, overall, how our tongue and teeth help break down larger chunks of molecules into smaller particles. So, basically, the function of the mouth is to break down the food into smaller pieces, and it also increases the surface area for enzymatic action. And then chemical

digestion happens, as our mouth has various salivary glands that secrete amylase, a type of enzyme. So, salivary amylase can be secreted, which is also known as Ptyalin.

It is produced by the salivary glands, especially by the parotid, submandibular, and sublingual glands. And this salivary amylase helps to break down the digestion of carbohydrates. So, what salivary amylase does is break down the alpha 1,4 glycosidic bonds of disaccharides or polysaccharides, right? For the monosaccharides, it is not a problem because it is already the simplest form of carbohydrate. But in cases like whatever food we consume, it is mostly starch, right, or a complex type of carbohydrate structure where they have these bonds, like one-four glycosidic bonds or one-six glycosidic bonds.

So, basically, the salivary amylase breaks down or hydrolyzes this 1,4 hydrolytic bond. Then this process converts starch into smaller carbohydrate fragments. So, some of the smaller carbohydrate fragments once this 1,4-glycosidic bond is cleaved are like dextrans. These are short chains of glucose, then maltose. Which is like a disaccharide composed of two glucose molecules, then maltotriose, which is like a trisaccharide composed of three glucose molecules, then alpha-limit dextrans, which are mostly like branched oligosaccharides, right? So basically, all these processes of converting the complex carbohydrate or polycarbohydrate to these small components happen using salivary amylase.

And how the mechanism exactly happens is that there is a receptor binding site on the enzyme; these are the salivary amylases. So, this enzyme has a receptor-binding active site that is generally vacant, and when bisucrose, polysucrose, or the polycarbohydrate comes, this component of sugar molecules first binds with this active site when the active sites were initially free of this salivary amylase enzyme. So, once they bind, once the sucrose binds with the enzymatic active site, they form an enzyme-substrate complex. So, the first enzyme site has a binding cavity, and once the sucrose binds with it, they form an enzyme-substrate complex, and then the enzyme slowly starts to hydrolyze this 1,4-glycosidic bond. So, once the binding is done, the hydrolyzing process it initiates slowly cleaves this 1,4-glycosidic bond.

And once this bond is cleaved, what will happen is these two components will get liberated, which will give us one component of glucose and another component of fructose. So, this is the enzymatic reaction, a biochemical reaction in which carbohydrate digestion occurs from complex carbohydrates, such as polycarbohydrates or disaccharides, breaking down into monosugars or monosaccharides. Then pancreatic amylase in the small intestine, apart from salivary amylase, there are different forms of amylase in other parts of our digestive organs also. This is one important one, which is like pancreatic amylase. So, what is the origin and secretion of pancreatic amylase? Pancreatic amylase is an enzyme produced by the acinar cells.

So this is the exocrine part of the pancreas, where most of the pancreas is made up of acinar cells, and they produce the pancreatic amylase enzyme. So it is secreted as part of pancreatic juice, which contains digestive-type enzymes; it also secretes bicarbonate ions to maintain the acidity or basicity of the cells. So, it tries to create the neutral condition for the duodenum. So, bicarbonate ions help to neutralize acidic conditions to bring the pH to around 7 to 8, making it more neutral. Pancreatic amylase is crucial for the efficient digestion of dietary starch; without proper pancreatic amylase, dietary starch will not be broken down, will not be able to be digested, and we may experience significant complications, including constipation, ulcers of the digestive system, or any other type of inflammation.

So, its deficiency can also lead to malabsorptions. So, proper absorption of the nutrients will not happen if there is a deficiency of the pancreatic amylase enzyme. So, then you can experience a lot of digestive discomfort. This is a very important enzyme in our digestive system. Then in the small intestine, pancreatic amylase is also present, similar to other parts.

So, pancreatic amylase also has a very important role in the small intestine. Let us see what it basically does: it targets and hydrolyzes the alpha 1,4 glycosidic linkages of starch, mostly in amylose, amylopectin, and dextrin. Eventually, it breaks down amylose, amylopectin, and dextrin to smaller fragments. The same fragments are what we discussed before, like maltose, maltotriose, and alpha-limit dextrins. These are either disaccharides, trisaccharides, or branched oligosaccharides; the goal is the same.

Amylase breaks down more complex forms of carbohydrates into smaller units, such as disaccharides or trisaccharides; pancreatic amylase is more efficient than salivary amylase because it is much stronger and more efficient due to its higher concentration and optimal pH in the small intestine. So, both amylases function in the same way, but pancreatic amylase is much stronger in terms of its functions because it is more concentrated and functions in an optimal pH. It breaks down the remaining starch that escaped the initial salivary amylase activity. So, it is very important to kind of know that pancreatic amylase is much more efficient compared to salivary amylase. Why? Because of two reasons.

One is that pancreatic amylase is much more concentrated in nature, and second, it also performs at a much more optimal pH. So, due to both reasons, if certain complex starches escape the action of salivary amylase, they can still be chopped, degraded, or digested by pancreatic amylase. Then another very important type of enzyme that is present is the brush border enzyme. So, brush border enzymes are located on the microvilli of the absorptive type of enterocytes lining the small intestine. What are these enzymes? So, there are a lot of different types of enzymes like lactase, maltase, sucrose, and isomaltase, and they have different kinds of breaking down or digestion activities.

So, let us see them one by one. Lactase breaks down lactose into glucose and galactose. What does maltase do? It breaks down maltose to two components of glucose molecules. Sucrose breaks down into glucose and fructose, so these are like monosaccharides, right? And then isomaltase targets and breaks down alpha-1,6 glycosidic bonds in the alpha-limit dextrin. So, these different types of brush border enzymes have a very important role in breaking down disaccharides or polysaccharides into more monosaccharides.

And then finally, trehalase hydrolyzes trehalose into two glucose molecules. So, these are a few examples of brush border enzymes. Then after all these digestive steps, it is important for absorption. So, you remembered all these digestive processes kind of like the flowchart. So, first it is important to have digestion followed by absorption.

So, once those digestive enzymes take their part in breaking down the complex starch, it is important to understand how the absorption will happen. So, let us see how the mechanism of absorption happens. Glucose and galactose are mostly absorbed across the apical membrane of the brush border of the enterocytes via secondary active transport. So, if you remember our membrane transport class, secondary active transport, which is also dependent on primary active transport, remember why? So, let us draw it. So, in cases of primary active transport, what happens is that 3 sodium ions are removed from the cell, and only 2 potassium ions are accepted.

It is to maintain the salt balance inside the cells, and now if the three ions of sodium are removed from the cell, then what will happen? Sodium concentrations will build up outside the cells. That will cause a diffusion phenomenon because now sodium is more outside and sodium is low inside the cell, which will cause a simple diffusion process, and while the diffusion happens, sodium will act like a piggyback kind of system that will carry the glucose. which was more outside the cells, and this glucose will be transported inside the cells in a secondary active transport process. This is also called the sodium-glucose symporter, right? It is also called the SGLT1 symporter or sodium-glucose symporter. So, one very important thing to remember is that this secondary active transport is directly dependent on the sodium-potassium ATPase pump.

So, unless this sodium-potassium ATPase pump activity happens, the initial sodium ion concentration gradient will not be built up. And once the sodium concentration gradient is built up, where more sodium is present outside of the cells and a lower amount of sodium is present inside. Then the diffusion happens, and along with the primary diffusion, glucose enters the cell by the process of secondary active transport. And then, once inside the enterocyte, glucose and galactose are transported across the basolateral membrane into the bloodstream via facilitated diffusion. So, there are basically two different transporters or transport membrane proteins: one is like GLUT2 and the other is like GLUT5.

So once this glucose is considered, like this is the cell, and initially, by secondary active transport, sodium and glucose enter the cell. These are mostly like the interstitial lining of the gastrointestinal tract or like the small intestine. Now, when glucose is entered into those intestinal cell lines, it has to eventually come out from those intestinal cell lines and go to the bloodstream. So, glucose is basically building up inside those intestinal lining cells and then, thereafter, by the GLUT-2 receptor or by the GLUT-5 receptor, either glucose or fructose, by simple diffusion, will eventually be transported or absorbed into the blood. And when they are absorbed in the blood, what will happen eventually is that blood will carry those smaller components of the carbohydrate, which are basically glucose and fructose, and they will be circulated throughout the body, throughout different parts of the body, different organs, different tissues, and different cells for their cellular respiration and production of our energy.

So, this is like a general system of how the absorption of carbohydrates happens; this is the same image that we have dissected and discussed. So, initially, when the primary active transport happens, sodium concentration will build up, and then sodium will enter by the diffusion process. During the diffusion, glucose molecules will also enter the cells by secondary active transport; then, this glucose molecule will build up inside the cell, and through the GLUT2 and GLUT5 receptors, the glucose will eventually be transported or absorbed into the blood. So, this is the whole mechanism of how glucose is digested and further absorbed into the blood from the initial consumption of food particles. And then finally, we also need to discuss the liver's central role in carbohydrate processing.

So, the liver receives all the absorbed monosaccharides like glucose, fructose, and galactose. They directly receive blood from the small intestine via the hepatic portal vein. This direct connection also allows the liver to act as a primary regulator of carbohydrate metabolism. So, the liver is very important; as you can see, it efficiently converts fructose and galactose to glucose. Also, you remember that insulin can convert excess amounts of glucose to glycogen and store it for future use.

So what insulin can do is convert glucose to glycogen, and glycogen can be stored for future use in the liver. Whenever there is a fasting condition or lack of food intake in the body, this glycogen, in response to the alpha cells secreting glucagon, can be converted back to glucose. So, in this way, the liver is also a storehouse for glucose regulation. So, all these steps will not be discussed in detail, but all these steps of glycogenesis, glycogenolysis, gluconeogenesis, and lipogenesis can happen in the liver. So, when glucose levels are high after a meal, insulin can convert it to glycogen; this is called glycogenesis.

Then glycogenolysis occurs when, after a prolonged fasting condition, glucose levels are low, and by the action of glucagon, it converts glycogen back to glucose. Then, during prolonged fasting or starvation, the liver can directly synthesize glucose from non-carbohydrate precursors like fat or amino acids. So, that is also a very special function of the liver: when the glycogen stores are full, the liver can actually convert some of this excess glucose into fatty acids through the process of lipogenesis. So, in case a lot of high glucose is present in the body through the process of lipogenesis, it can convert the excess glucose back to lipids and store it for future use. So, this is like the overall glucose homeostasis in the body, as you can see in this diagram.

Whenever there is excess glucose, insulin can transport this excess glucose, which generally transports it through the blood to different types of tissue cells and other cells. If some excess glucose is still present, it can be converted to glycogen in the liver. And in cases of fasting conditions, the same glycogen can break down to glucose by the action of glucagon, and again this glucose will eventually be circulated throughout the blood by the action of insulin. So, in this way, glucose and glycogen can be interconverted by the action of insulin and glucagon, and it maintains glucose homeostasis in our body. So, do you know that dietary fiber is not actually digested by your body? So, unlike other carbohydrates, proteins, and fats, fiber passes through your digestive system relatively intact, and this is because humans lack the right enzymes to digest dietary fiber.

Okay, mostly soluble and insoluble types of fibers are present, right? So, you can additionally look into these things and read more about them if you are interested. Again, activity questions read like the nutrition levels of the three different food products. For example, there are fruit juice, cereal, and yogurt. Identify the types of carbohydrates listed in those kinds of food products. What are the different types of sugars, and dietary fiber is mentioned? For each product, explain how different carbohydrates are digested and absorbed in the body.

Consider also the roles of specific enzymes that are present in our different digestive organs. So, if you have any further questions, please drop us an email, and we will also be conducting some interactive sessions. If you have any doubts, please clear them up. Thank you again for attending the class on digestive organs and the overall digestion and absorption of carbohydrates.

So, I hope you enjoyed the class. Let us meet with all of you in another new class of human physiology very soon. Thank you.