Eating: Some Facts About Metabolism

Clearly, eating is one of the most important things we do, and it can also be one of the most pleasurable. Much of what an animal learns to do is motivated by the constant struggle to obtain food; therefore, the need to ingest undoubtedly shaped the evolutionary development of our own species. Control of eating is even more complicated than the control of drinking and sodium intake. We can achieve water balance by the intake of two ingredients: water and sodium chloride. When we eat, we must obtain adequate amounts of carbohydrates, fats, amino acids, vitamins, and minerals other than sodium. Therefore, our food-ingestive behaviors are more complex, as are the physiological mechanisms that control them.

To stay alive, our cells must be supplied with fuel and oxygen. Obviously, fuel comes from the digestive tract, and its presence there is a result of eating. But the digestive tract is sometimes empty; in fact, most of us wake up in the morning in that condition. So there has to be a reservoir that stores nutrients to keep the body’s cells nourished when the gut is empty. Indeed, there are two reservoirs: one short-term and the other long-term. The short-term reservoir stores carbohydrates, and the long-term reservoir stores fats.

The short-term reservoir is located in the cells of the liver and the muscles, and it is filled with a complex, insoluble carbohydrate called glycogen. For simplicity I will consider only one of these locations: the liver. Cells in the liver convert glucose (a simple, soluble carbohydrate) into glycogen and store the glycogen. They are stimulated to do so by the presence of insulin, a peptide hormone produced by the pancreas. When insulin and insulin are present in the blood, some of the glucose is used as a fuel, and some of it is stored as glycogen. Later, when all of the food has been absorbed from the digestive tract, the level of glucose in the blood begins to fall.

The fall in glucose is detected by cells in the pancreas and in the brain. The pancreas responds by stopping its secretion of insulin and starting to secrete a different peptide hormone: glucagon. The effect of glucagon is opposite that of insulin: It stimulates the conversion of glycogen into glucose. (Unfortunately, the terms glucose, glycogen, and glucagon are similar enough that it is easy to confuse them. Even worse, you will soon encounter another one: glycerol.) (See Figure 11.10.)

glycogen (gly ko jen) A polysaccharide often referred to as animal starch; stored in the liver and muscle; constitutes the short-term store of nutrients.

insulin A pancreatic hormone that facilitates entry of glucose and amino acids into the cell, conversion of glucose into glycogen, and transport of fats into adipose tissue.

glucagon (gloo ka gahn) A pancreatic hormone that promotes the conversion of liver glycogen into glucose.
Thus, the liver soak up excess glucose and stores it as glycogen when plenty of glucose is available, and it releases glucose from its reservoir when the digestive tract becomes empty and the level of glucose in the blood begins to fall.

The carbohydrate reservoir in the liver is reserved primarily for the central nervous system. When you wake in the morning, your brain is being fed by your liver, which is in the process of converting glycogen to glucose and releasing it into the blood. The glucose reaches the CNS, where it is absorbed and metabolized by the neurons and the glia. This process can continue for a few hours, until all of the carbohydrate reservoir in the liver is used up. (The average liver holds approximately 300 calories of carbohydrate.) Usually, we eat some food before this reservoir gets depleted, which permits us to refill it. But if we do not eat, the CNS (and the rest of the body) must start living on the products of the long-term reservoir.

Our long-term reservoir consists of adipose tissue (fat tissue). This reservoir is filled with fats, or, more precisely, with triglycerides. Triglycerides are complex molecules that contain glycerol (a soluble carbohydrate, also called glycine) combined with three fatty acids (stearic acid, oleic acid, and palmitic acid). Adipose tissue is found beneath the skin and in various locations in the abdominal cavity. It consists of cells that are capable of absorbing nutrients from the blood, converting them to triglycerides, and storing them. These cells can expand enormously in size; in fact, the primary physical difference between an obese person and a person of normal weight is the size of their fat cells, which is determined by the amount of triglycerides that these cells contain.

The long-term fat reservoir is obviously what keeps us alive when we are fasting. As we begin to use the contents of our short-term carbohydrate reservoir, fat cells start converting triglycerides into fuels that the cells can use and releasing these fuels into the bloodstream. As we just saw, when we wake in the morning with an empty digestive tract, our brain (in fact, all of the central nervous system) is living on glucose released by the liver. But what about the other cells of the body? They are living on fatty acids, sparing the glucose for the brain. As you will recall from Chapter 3, the sympathetic nervous system is primarily involved in the breakdown and utilization of stored nutrients. When the digestive system is empty, there is an increase in the activity of the sympathetic axons that innervate adipose tissue, the pancreas, and the adrenal medulla. All three effects (direct neural stimulation, secretion of glucagon, and secretion of catecholamines) cause triglycerides in the long-term fat reservoir to be broken down into glycerol and fatty acids. The fatty acids can be directly metabolized by cells in all of the body except the brain, which needs glucose. That leaves glycerol. The liver takes up glycerol and converts it to glucose. That glucose, too, is available to the brain.

You may be asking why the rest of the body’s cells treat the brain so kindly, letting it consume almost all the glucose that the liver releases from its carbohydrate reservoir and constructs from glycerol. The answer is simple: Insulin has several other functions besides causing glucose to be converted to glycogen. One of these functions is controlling the entry of glucose into cells. To be taken into a cell, glucose must be transported there by glucose transporters—protein molecules that are situated in the membrane and are similar to those responsible for the uptake of transmitter substances. Glucose transporters contain insulin receptors, which control their activity; only when insulin binds with those receptors can glucose be transported into the cell. But the cells of the nervous system are an exception to this rule. Their glucose transporters do not contain insulin receptors; these cells can absorb glucose even when insulin is not present.

Figure 11.11 reviews what I have said so far about the metabolism that takes place while the digestive tract is empty, which physiologists refer to as the fasting phase of metabolism. A fall in blood glucose level causes the pancreas to stop secreting insulin and to start secreting glucagon. The absence of insulin means that most of the cells of the body can no longer use glucose; thus, all the glucose present in the blood is reserved for the central nervous system. The presence of glucagon and the absence of insulin instructs the liver to start drawing on the short-term carbohydrate reservoir—to start converting its glycogen into glucose. The presence of glucagon and the absence of insulin, along with increased activity of the sympathetic nervous system, also instruct fat cells to start drawing on the long-term fat reservoir—to start breaking down triglycerides into fatty acids and glycerol. Most of the body lives on the fatty acids, and the glycerol, which is converted into glucose by the liver, gets used by the brain. If fasting is prolonged, proteins (especially protein found in muscle) will be broken down to amino acids, which can be metabolized by all of the body except the central nervous system. (See Figure 11.11 and Simulate Metabolism in MyPsychLab, which summarizes these processes.)
The phase of metabolism that occurs when food is present in the digestive tract is called the **absorptive phase**. Now that you understand the fasting phase, this one is simple. Suppose that we eat a balanced meal of carbohydrates, proteins, and fats. The carbohydrates are broken down into glucose, and the proteins are broken down into amino acids. The fats basically remain as fats. Let's consider each of these three nutrients.

1. As we start absorbing the nutrients, the level of glucose in the blood rises. This rise is detected by cells in the brain, which causes the activity of the sympathetic nervous system to decrease and the activity of the parasympathetic nervous system to increase. This change tells the pancreas to stop secreting glucagon and to begin secreting insulin. The insulin permits all the cells of the body to use glucose as a fuel. Extra glucose is converted into glycogen, which fills the short-term carbohydrate reservoir. If some glucose is left over, it is converted into fat and stored by fat cells.

2. A small proportion of the amino acids received from the digestive tract are used as building blocks to construct proteins and peptides; the rest are converted to fats and stored in adipose tissue.

3. Fats are not used as a fuel at this time; they are simply stored in adipose tissue. (See Figure 11.11.)

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**SECTION SUMMARY**

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Metabolism consists of two phases. During the absorptive phase we receive glucose, amino acids, and fats from the intestines. The blood level of insulin is high, which permits all cells to metabolize glucose. In addition, the liver and the muscles convert glucose to glycogen, which replenishes the short-term reservoir. Excess carbohydrates and amino acids are converted to fats, and fats are placed into the long-term reservoir in the adipose tissue.

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