Regulating Blood Sugar

10.3

Like most processes of the endocrine system, the regulation of our blood sugar level normally occurs automatically—we do not have to think about it. The only time most of us may think about our blood sugar level is when we are feeling very hungry or after we have eaten something very sweet. Imagine having to monitor and control your blood sugar level. The body's ability to regulate its own internal processes and maintain homeostasis is one of the amazing things about the endocrine system. Since all of the body's cells use glucose as fuel, the regulation of the blood glucose level is crucial to maintaining homeostasis.

Sometimes, the endocrine system can have problems. If homeostasis is not maintained, some of the bodily processes may become imbalanced or may not be properly regulated. Many people have a problem with their blood glucose monitoring system, a condition called diabetes mellitus (Section 8.1). In 2000, there were an estimated 2 million diagnosed cases of diabetes in Canada. More than 60 000 new cases are diagnosed each year. People who have diabetes, called diabetics, have a blood glucose level that may fluctuate abnormally, changing their metabolism and leading to some serious health risks and long-term problems. Diabetics must be aware of their blood glucose level at all times. Thankfully, scientific research has led to modern technologies that can help diabetics. Electronic monitors allow diabetics to test their blood glucose level throughout the day, and modern syringes, pens, and pumps allow them to administer insulin to control their blood glucose level (**Figure 1**). Finding treatments for people with diabetes and other endocrine system failures has been a long-time goal and major success of modern medical research. Imagine how life would have been different for Chris Jarvis if these technologies were not available.

Figure 1 People with diabetes may need to inject insulin to control their blood glucose level.

Hormones That Control Blood Sugar

The two main hormones that control blood sugar are produced in the pancreas. The pancreas is a long gland, about the size of a hand, located between the small intestine and the spleen. Most of the pancreas forms an exocrine gland that secretes digestive enzymes into the small intestine, but about 2 % of the cells in the pancreas are specialized endocrine cells that form clusters called the **islets of Langerhans**. Found in all vertebrates, these islets produce the protein hormones insulin and glucagon, which work together to control the blood glucose level. You will read about the discovery of insulin in the early twentieth century by Canadian medical scientist Frederick Banting and his colleagues, including Charles Best, in Section 10.4.

islets of Langerhans endocrine cell clusters inside the pancreas that produce insulin and glucagon

Insulin and glucagon regulate the ability of most tissues in the body to metabolize fuel substances. Insulin is secreted by beta cells in the islets. A rise in the blood glucose level, such as after a meal, triggers the beta cells to release insulin. Insulin lowers the blood glucose level by instructing its target cells to uptake glucose from the blood. Insulin acts mainly on skeletal muscles, liver cells, and adipose tissue (fat). In the liver, insulin inhibits the breakdown of glycogen into glucose, further helping to lower blood glucose levels. Insulin also lowers fatty acid levels by promoting fatty acid uptake and storage in adipose tissue, while inhibiting the breakdown of fats into fatty acids. Similarly, insulin lowers amino acid levels by promoting protein synthesis from amino acids, while inhibiting the breakdown of proteins into amino acids.

The effects of glucagon, secreted by alpha cells in the islets, are opposite to the effects of insulin. Glucagon raises the blood glucose level by stimulating the breakdown of glycogen into glucose in the liver. Glucagon also stimulates the breakdown of fats into fatty acids and of proteins into amino acids. Cells can use amino acids and other non-carbohydrates to synthesize glucose as well. This helps to maintain the blood glucose level during fasting.

Negative feedback mechanisms control the concentration of glucose in the blood and increase or decrease the secretions of both insulin and glucagon in order to maintain

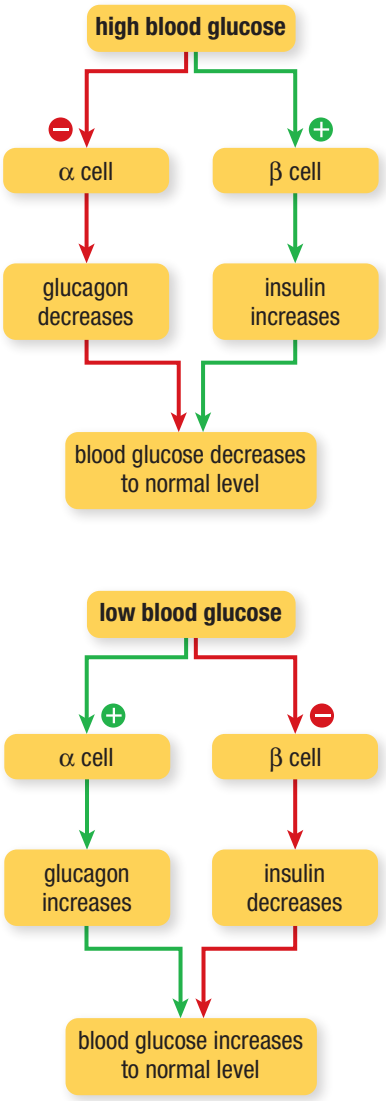

Figure 2 The opposing actions of insulin and glucagon work together through negative feedback mechanisms to maintain the blood glucose level.

glucose homeostasis. The alpha and beta cells of the islets in the pancreas respond directly to the glucose level within their cytosol. When the blood glucose level is high, the beta cells turn up their insulin production while the alpha cells turn down their glucagon production (**Figure 2**). Both of these actions lower the blood glucose level. When the blood glucose level is low, the opposite occurs: alpha cells turn up their glucagon production while beta cells turn down their insulin production, thus raising the blood glucose level.

The adrenal glands also play a role in controlling blood sugar. The adrenal cortex secretes steroid hormones called glucocorticoids. (As you learned in Section 10.2, the main glucocorticoid is cortisol.) The glucocorticoids help to raise the blood glucose level using three major mechanisms. First, they stimulate the synthesis of glucose from non-carbohydrate sources, such as fats and proteins. Second, they reduce glucose uptake by the body cells, except those in the central nervous system. Third, they promote the breakdown of fats and proteins, releasing fatty acids and amino acids into the blood as alternative fuels when the glucose supply is low. The favouring of glucose uptake in the central nervous system keeps the brain well supplied with glucose between meals and during periods of extended fasting.

The secretion of glucocorticoids is ultimately under the control of the hypothalamus. A low glucose concentration in the blood, or an elevated level of epinephrine secreted by the adrenal medulla in response to stress, is detected in the hypothalamus. This leads to the secretion of adrenocorticotropic hormone (ACTH) by the anterior pituitary. ACTH then promotes the secretion of glucocorticoids by the adrenal cortex.

Despite the body's different mechanisms for maintaining glucose homeostasis, the level of glucose in the blood is not completely constant. It varies throughout the day, largely due to meals and sleep. The graph of the blood glucose level in **Figure 3** shows an overall slow decrease during the night, with spikes bringing the level of glucose up after each meal during the day. Notice that the scale indicating the insulin level is much smaller than the scale used to indicate the glucose level: 1 mmol (the unit used to measure blood glucose) is equal to 1 million pmols (the unit used to measure serum insulin). So, the concentration of insulin in the blood is much lower than the concentration of glucose, but, as this graph shows, it rises and falls with the glucose level.

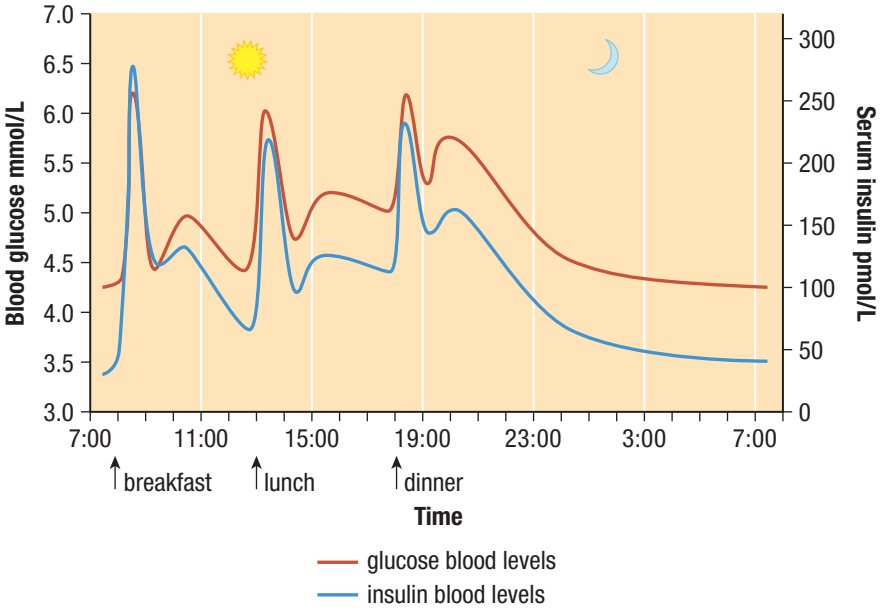

Figure 3 Typical levels of blood glucose and insulin over a 24 h period

A blood glucose level that is too high can cause a condition called hyperglycemia. Symptoms of hyperglycemia may include thirst, frequent urination, sugar in the urine, vision problems, fatigue, and weight loss. A blood glucose level that is too low can cause a condition called hypoglycemia. Symptoms of hypoglycemia may include nervousness, shaking, cold sweats, hunger, headaches, and weakness.

Diabetes

Think about what you have learned about diabetes in previous courses or in your everyday experiences. Perhaps you or someone you know has diabetes. Although little can be done about the cause of diabetes, there are a few factors that can be addressed to reduce the risk of developing diabetes.

Diabetes mellitus, commonly known as diabetes, is a disease characterized by a high blood glucose level caused by problems with insulin production and/or action. Diabetes afflicts about 6 % of the world's population. The three classic diabetes symptoms are frequent urination, increased thirst (and consequently increased fluid intake), and increased appetite. Frequent urination occurs because the ability of the body cells to take up glucose is impaired, leading to an abnormally high glucose concentration in the blood. This results in a high level of glucose in the kidneys, which causes more water to be pulled from the blood by osmosis in the nephrons, which, in turn, leads to excessive amounts of urine. The need to replace the excreted water causes increased thirst. Increased appetite occurs because the body cells cannot get enough energy from glucose, since there is no insulin to help with the glucose uptake. Without insulin, glucose does not enter the body cells very well. Proteins and fats may be broken down as energy sources instead, leading to further deficiencies that increase hunger for these nutrients. Without extra food intake, weight loss will occur. Other symptoms of diabetes can include blurred vision, lethargy, nausea, vomiting, and abdominal pain. If left untreated, diabetes can lead to long-term health problems, including loss of vision, kidney failure, hypertension, and cardiovascular problems.

Diabetes is classified into three different types: type 1, type 2, and gestational diabetes. The reasons for the failure of insulin to regulate the blood sugar are what distinguish these three types.

Type 1 diabetes occurs because the beta cells in the islets of Langerhans in the pancreas do not produce any insulin. This degeneration of beta cells can begin in infancy, so people with type 1 diabetes are usually diagnosed in childhood. Type 1 diabetes is sometimes called juvenile diabetes or insulin-dependent diabetes. Type 1 diabetics must be closely monitored, with frequent blood glucose tests, and treated with the daily administration of insulin, usually by injections or a pump.

Type 2 diabetes occurs from reduced insulin production and/or the inability of insulin to bind to its receptors properly. Type 2 diabetes usually develops in adulthood and is strongly associated with obesity. About 90 % of diabetics have type 2 diabetes. There is a strong genetic link associated with type 2 diabetes—more than 80 % of type 2 diabetics have a family member with type 2 diabetes. Because type 2 diabetics still have the ability to produce insulin, treatment often involves controlling diet and exercise to restore a normal level of insulin production. Since lifestyle factors (such as obesity, a high-calorie diet, and physical inactivity) play a role in developing type 2 diabetes, changing these factors can delay or prevent its onset in some people. Oral drugs may also be given to type 2 diabetics to increase insulin production or to encourage the binding of insulin to its receptors.

A third type of diabetes is called gestational diabetes. It occurs in about 2 to 10 % of pregnant women, due to a high blood glucose level that develops during pregnancy. It is usually a temporary condition, but it can increase the risk that both mother and child may develop diabetes later in life.

Although there is currently no cure for diabetes, there is a significant amount of ongoing medical research into finding a cure and developing better treatments for people who have diabetes (Section 8.1). Most diabetics now have a wide variety of electronic and mechanical devices to help them test their blood sugar level throughout the day and administer their own insulin. The latest external insulin pumps can both monitor the blood glucose level continuously and deliver insulin by a tube through the abdomen. It is certainly not too much of a leap to imagine an entirely internal device that does the same, essentially acting as a mechanical pancreas.

UNIT TASK BOOKMARK

Depending on the case study you choose to develop, you may be able to apply what you learned in this section about diabetes to the Unit Task described on page 566.

Mini **Investigation**

Analyzing the Effects of Hormones on the Blood Glucose Level

Skills: Hypothesizing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

The graph in **Figure 4** shows the blood glucose levels of two people, John and Ehud, over a 12 h period. John has diabetes; Ehud does not. They ate identical meals and exercised for 1 h at the same times.

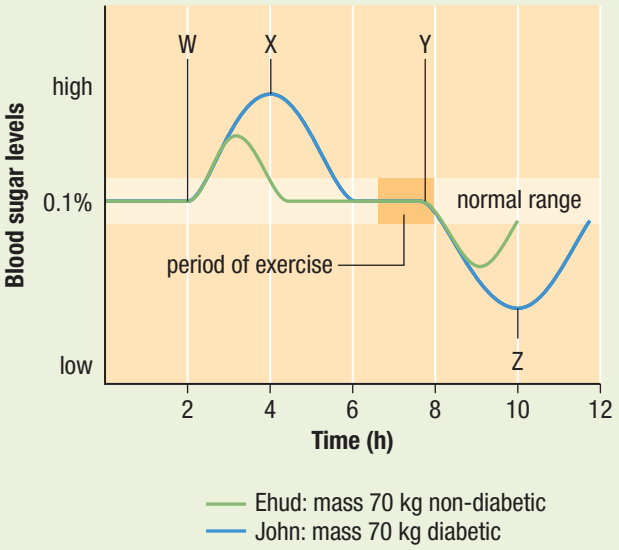

Figure 4 Blood glucose levels for two people, one diabetic and one not, over a 12 h period

1. Analyze Figure 4.

A. Hypothesize the hour at which John and Ehud ate the identical meals. How do you know? T/I

B. Hypothesize what John did at point X to change his blood sugar level. What would have happened if he had not done what he did? T/I A

C. Propose why Ehud's blood glucose level started to decrease before time X. T/I

D. Explain why both John's and Ehud's blood glucose levels began to decrease at time Y. T/I

E. Hypothesize what might have happened to decrease John's blood glucose level below Ehud's at time Z. T/I

F. Explain why it is more valid to make these kinds of comparisons between two people with the same body mass and composition, rather than two people with very different body masses and compositions. T/I

G. Describe the overall differences in Ehud's and John's blood glucose levels that these data show. T/I

Research This

Medications for Non–insulin Dependent Diabetes

Skills: Researching, Evaluating, Communicating

SKILLS HANDBOOK A4.1, A4.2

By now, you know that people with type 1 diabetes must have daily injections of insulin. Many people with type 2 diabetes do not need insulin injections. They are often referred to as non–insulin dependent diabetics. Their bodies still produce insulin, but either do not produce enough insulin or cannot properly use the insulin that they do produce. Some non–insulin dependent diabetics may be treated by controlling their diet and exercise. When further help is still needed, various oral medications are available to treat type 2 diabetes.

1. Research what diabetes medications are available. Use your findings to answer the following questions.

A. Under what circumstances might it be possible to manage diabetes by taking oral medications? T/I

B. What types of diabetes medications are available? T/I

C. How do diabetes medications work? T/I

D. How effective are diabetes medications at controlling diabetes? T/I

E. What are the side effects, risks, benefits, and costs of diabetes medications? T/I

F. Prepare a report, in whatever format you choose, to summarize your research. Write your report as if you are providing information for people who have just been diagnosed with diabetes. T/I C

WEB LINK

10.3 Review

Summary

- Diabetes mellitus is a disease in which the blood glucose level is not properly regulated due to a failure of insulin production or action.
- The islets of Langerhans in the pancreas secrete insulin, which lowers the blood glucose level, and glucagon, which raises the blood glucose level. The balance of insulin and glucagon regulates the concentration of glucose in the blood.
- Insulin stimulates the uptake of glucose by the cells, glycogen synthesis, the uptake of fatty acids, fat synthesis from fatty acids, and protein synthesis from amino acids.
- Glucagon raises the blood glucose level by stimulating glycogen, fat, and protein degradation. Glucocorticoids, which are secreted by the adrenal glands, can also raise the blood glucose level.
- Type 1 diabetes is caused by an inability to produce insulin, due to a failure of the beta cells in the islets of Langerhans. It tends to develop during childhood. Type 1 diabetes must be treated by injections of insulin.
- Type 2 diabetes is caused by insulin insufficiency and/or by the inability of the cells to respond correctly to insulin. It tends to develop during adulthood, often as a result of obesity. Type 2 diabetes is often treated by controlling diet and exercise.

Questions

1. What two hormones, produced by the pancreas, regulate the blood glucose level? K/U
2. What are the three classic symptoms of diabetes mellitus? K/U
3. Remember that the adrenal glands primarily produce hormones that help the body deal with stress, such as the stress of fight-or-flight situations. Why do you think the adrenal glands also produce glucocorticoids, which raise the blood glucose level? T/I
4. Describe the differences between type 1 diabetes and type 2 diabetes. K/U
5. Stress is often listed as a risk factor for weight gain or obesity. Why do you suppose that is? A
6. Canadian law requires that packaged foods display a Nutrition Facts label. T/I A
   (a) Use the Internet to research what information is listed on a Nutrition Facts label.
   (b) How can a Nutrition Facts label help a diabetic person choose foods?
7. Why might an insulin pump, which delivers constant and very small doses of insulin to the body, be preferable to insulin injections? T/I
8. Using the Internet and other sources, research some of the new developments in medicine that may lead to a cure for diabetes. Summarize your findings in a report. You are free to choose the format for your report. For example, you could choose to do a written report, an oral presentation, or a slide show. T/I C
9. Explain the principles of negative feedback using the regulation of blood sugar levels by the pancreatic hormones. K/U
10. In the past, doctors tested patients for diabetes by tasting their urine. Today, doctors have chemical tests that indicate the presence of glucose in urine. Using the Internet or other sources, research these tests. Describe two common tests and a positive result for each one. T/I

WEB LINK