Biology 30S

THE CONTROL SYSTEMS:

THE ENDOCRINE AND THE NERVOUS SYSTEMS

Name: _______________________________________________________

This module adapted from Manitoba Blackboard Learn
About Control Mechanisms

In this unit you will learn about the human endocrine system and the nervous system as examples of control systems in the body. However, you have already considered a number of control systems and feedback mechanisms as you studied the digestive, circulatory, and respiratory systems. All of these play a vital homeostatic role in the body.

Lesson 1: The Human Endocrine System

The endocrine system is a collection of special organs in the body that produce chemicals called hormones. Hormone means to "excite". You have over 30 hormones busily orchestrating and regulating such things as: when you feel hungry or full; how you sleep; your body temperature; how you break down and utilize the food you eat; whether you are fat or thin; when you start puberty and how long it takes; how you handle stress; how much adrenaline you have in an emergency situation...even how and when you grow.

Hormones

A hormone is a chemical substance produced in one part of the body and transported in the blood to another part of the body where it exerts its effect. For this reason, hormones are described as chemical messengers.

Nearly all of the hormones produced in your body are synthesized in glands called endocrine glands. A gland is any group of cells or any organ that secretes a chemical substance. The body contains two kinds of glands that are grouped according to the way they secrete their product. Glands such as the lacrimal glands of the eye that secrete tears, salivary glands in the mouth that secrete saliva, or sweat glands that secrete perspiration on the skin, all deliver their
secretion through tiny tubes called ducts. These ducted glands are called **exocrine glands**.

Endocrine glands differ from exocrine glands in that their secretions diffuse directly into capillaries in endocrine tissue. Endocrine glands are known as ductless glands, or glands of internal secretion. A few glands have the ability to carry on both exocrine and endocrine functions. These glands are **heterocrine glands** or mixed glands. The pancreas, testes and ovaries are heterocrine glands.

Hormones are grouped into three classes based on their structure and function:

- steroids
- peptides
- amines

**Steroid hormones** are lipids derived from cholesterol. Examples include testosterone, which is the male sex hormone and estrogen which is responsible for many female sex characteristics. Steroid hormones are secreted by the gonads, adrenal cortex, and the placenta. Most hormones are **peptide hormones** (short chains of amino acids). They are secreted by the pancreas, pituitary, parathyroid, heart, stomach, liver, and kidneys. Examples include insulin and the growth hormone. **Amine hormones** are derived from the amino acid tyrosine and are secreted from the thyroid and the adrenal medulla. Examples include adrenaline and thyroxin.

**Mechanisms of Hormone Action**

Hormones are carried by the bloodstream to their destination or **target cells**. When a particular hormone reaches its target cells, special receptors on the cell’s surface combine with the hormone and carry it into the cell. The hormone then activates certain responses. For example, it may make the cell membrane more or less permeable to glucose or it may control the rate at which enzymes carry out reactions. Receptors on target cell membranes bind only to one type of hormone. More than fifty human hormones have been identified; all act by binding to receptor molecules.
There are two mechanisms of hormone action on all target cells; steroid and non-steroid.

**Non-steroid Hormones**

Non-steroid hormones (water soluble) do not enter the cell but bind to plasma membrane receptors, generating a chemical signal (second messenger) inside the target cell. Five different second messenger chemicals, including cyclic AMP have been identified. Second messengers activate other intracellular chemicals to produce the target cell response.
Steroid Hormones

The second mechanism involves steroid hormones, which pass through the plasma membrane and act in a two step process. Steroid hormones bind, once inside the cell, to the nuclear membrane receptors, producing an activated hormone-receptor complex. The activated hormone-receptor complex binds to DNA and activates specific genes, increasing production of proteins.

Feedback Mechanisms

As discussed in Unit 1, feedback mechanisms are the general mechanisms of hormonal regulation in animals that help to contribute to homeostasis. Feedback occurs when the response to a stimulus has an effect on the original stimulus. There are two types of feedback mechanisms, negative feedback and positive feedback. **Negative feedback** is most common in biological systems. Negative feedback is a chemical response to a stimulus that opposes the original change. Negative feedback regulates the secretion of almost every hormone in the body.
Negative feedback mechanisms act like a thermostat in the home. As the temperature falls (deviation from the ideal normal value), the thermostat detects the change and triggers the furnace to turn on and heat the house. Once the temperature reaches its thermostat setting (ideal normal value), the furnace turns off. If a home has a central air conditioner, it operates in the same manner.

An example of negative feedback in the human body is the regulation of the blood calcium levels. The parathyroid glands secrete parathyroid hormone, which regulates the blood calcium levels. If calcium levels decrease, the parathyroid glands sense the decrease and secrete more parathyroid hormone. The parathyroid hormone stimulates calcium release from the bones and increases the calcium uptake into the bloodstream from the collecting tubules in the kidneys. Conversely, if blood calcium increases too much, the parathyroid glands reduce parathyroid hormone production. Both responses are examples of negative feedback because in both cases the effects are negative (opposite) to the stimulus.

Figure 8.1.4 Negative Feedback and Thermostat Operation

Endocrine Glands

The endocrine system and the nervous system are so closely associated that they are collectively called the neuroendocrine system. Neural control centers in the brain control endocrine glands. The main neural control center in the brain is the hypothalamus. Suspended from the hypothalamus by a thin stalk is
the **pituitary gland**. The hypothalamus sends messages to the pituitary gland. The pituitary gland then releases hormones that regulate body functions.

The following diagram shows the location of the major endocrine glands in the human body and the hormones released from these glands.
Human Endocrine System

Endocrine glands produce hormones that control many body functions.

**Pituitary gland**
Responding to signals from the hypothalamus, the pituitary gland releases hormones some of which control other endocrine glands.

**Parathyroid gland**
These four patches of tissue on the thyroid gland release the parathyroid hormone, which regulates the blood calcium level.

**Thymus**
Thymosin, which stimulates the development of T cells for the immune system, is secreted by the thymus.

**Adrenal glands**
The adrenal glands make epinephrine and norepinephrine, two hormones which cause the “fight or flight” response. They also secrete aldosterone, which affects the body’s osmotic balance, and cortisol, which promotes glucose synthesis.

**Hypothalamus**
The hypothalamus makes hormones that control the pituitary gland. It also makes the hormones ADH and oxytocin, which are stored in the pituitary gland.

**Pineal gland**
The pineal gland secretes melatonin, which controls body functions in response to daylight and seasonal changes.

**Thyroid gland**
The hormone thyroxine, which speeds up metabolism and helps manage growth and development, is secreted by the thyroid gland.

**Pancreas**
The pancreas has patches of tissue called the islets of Langerhans, which have cells that make the hormones insulin and glucagon. Insulin and glucagon control the blood sugar level.

**Ovaries**
The hormones estrogen and progesterone are made in the ovaries. They maintain the female reproductive system and secondary sex characteristics. Progesterone maintains the uterus during pregnancy.

**Testes**
The testes make testosterone, a hormone that maintains the male reproductive system and secondary sex characteristics.
The pituitary gland is found on a small stalk at the base of the brain. It controls the action of all other endocrine glands and is therefore often referred to as the "master gland". It is composed of two separate halves: the posterior lobe which is derived from brain tissue and the anterior lobe which is derived from epithelial tissue of the roof of the mouth.

The posterior lobe of the pituitary gland secretes two hormones which are manufactured by specialized neurons of the hypothalamus and stored in the posterior lobe. These hormones are oxytocin and antidiuretic hormone (ADH), also known as vasopressin. Oxytocin causes contractions of the smooth muscle in the uterus during childbirth. It is also important in the transport of milk from the glands to the nipple. In males, it is needed to stimulate muscles of the sperm duct to propel the sperm out of the body.

Antidiuretic hormone (ADH) controls the elimination of water from the kidneys. If water concentration in the body decreases, the amount of ADH released into the bloodstream increases. More water is reabsorbed by the kidneys and retained in the body. If the hypothalamus does not produce ADH in sufficient quantities, a condition called diabetes insipidus results as the body eliminates too much water. ADH also influences blood pressure by causing the small arteries to contract.

There are at least seven hormones produced in and secreted by the anterior lobe of the pituitary gland. Most of these are important in regulating the secretion of other endocrine glands.

1. **Thyroid Stimulating Hormone** (TSH) stimulates the action of the thyroid gland to release thyroxin. If the concentration of thyroxin decreases in the blood, TSH is released to stimulate the thyroid. A negative-feedback mechanism keeps the final concentration constant.

2. **Adrenocorticotropic Hormone** (ACTH) stimulates and regulates the development and secretion of the adrenal cortex.
3. **Somatotropic Hormone** (STH) is the human growth hormone and acts by stimulating growth in hard and soft tissue mainly through its influence on the metabolism of proteins. By increasing the rate of active transport of amino acids into the cells and the synthesis of amino acids into proteins, STH causes cells to grow and multiply. Growth of the skeleton is also influenced by STH.

   - Undersecretion of the growth hormone STH during the growing years results in **dwarfism**. An adult dwarf is 3 to 4 feet high and has no mental or physical deformity.

   - Oversecretion of the hormone during the growing years results in **giantism**. Victims of this disease may reach heights of 7 to 8 feet.

   - Oversecretion during adulthood causes a condition known as **acromegaly**. With this condition, the bones of the hands, feet, jaw, and face become abnormally large resulting in coarse features.

4. **Melanocyte Stimulating Hormone** (MSH) controls the distribution and concentration of melanin (skin pigment). It is found concentrated in the melanocytes, specialized cells found in the skin.

5. **Follicle Stimulating Hormone** (FSH) is a hormone found in males and females. In the female, stimulates the development of follicle cells, which surround each developing egg in the ovary. It causes the maturing of one single follicle in the ovary so that one mature egg is produced at a time. In the male, FSH stimulates the testes to produce sperm cells.
6. **Luteinizing Hormone** (LH) is a hormone found in males and females. In the female, it is essential for ovulation (the discharge of the egg from the ovary) and the conversion of the follicle after ovulation into a separate glandular structure, the corpus luteum. In the male, LH stimulates the interstitial cells in the testes to produce testosterone.

7. **Luteotropic Hormone** (LTH), or prolactin, functions only in females and activates the breasts to produce milk. It is released only when progesterone concentrations are high in the body.

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**Thyroid Gland**

The thyroid gland is the largest endocrine gland. Appearing almost like two glands, it has two dark red lobes connected by a narrow band of tissue. The thyroid gland has a rich supply of blood vessels, and for its weight, about 30 g, it has the highest rate of blood flow of any organ in the body. About 3 or 4 cm high and 2.5 cm across, it is located in the neck at the junction of the larynx and the trachea.

The thyroid gland is made of epithelial tissue and contains many hollow sacs filled with a gelatinous material. This material is used to produce the hormones secreted by the gland: **thyroxin** and **calcitonin**.

**Thyroxin** regulates the rate of metabolism in the body. When blood sugar is low, it causes the conversion of glycogen to glucose and increases the rate at which simple sugars are absorbed from the small intestine, resulting in an increase in blood sugar. Throughout the body, thyroxin controls the growth and differentiation of tissues, thereby influencing the physical and mental growth of a child.

Careful regulation of thyroxin production is vital because this hormone controls the rate of metabolism in the body. If the metabolic rate decreases or the amount of thyroid hormones falls below a normal level, chemical sensors in the hypothalamus are activated to produce thyroid-stimulating hormone releasing
factor (TSHRF). TSHRF stimulates the anterior lobe of the pituitary gland to secrete thyroid-stimulating hormone (TSH). TSH activates the thyroid gland to release thyroxin. This activity continues until the metabolic rate is in balance again. As the level of thyroxin increases the negative-feedback system is activated to depress the quantity of TSHRF.

Since an essential element in the production of thyroxin is iodine, a deficiency of iodine in the diet interferes with the thyroid gland's secretion of the hormone. This results in an enlargement of the thyroid gland, a condition called goiter.

At the beginning of this disease, the thyroid gland is unable to supply a normal amount of thyroxin. This deficiency activates the negative-feedback system, causing an increase in TSH. The thyroid enlarges under this stimulus, apparently trying to remove all the iodine possible from the blood. Goiter caused by an iodine deficiency can be treated and prevented by adding iodine to the diet. Seafood and iodized salt are good sources of iodine.

When the thyroid secretes an excess of thyroxin, a condition called hyperthyroidism results. The person with this problem may show many symptoms: increased metabolic rate, increased appetite but loss in weight, increased thyroid size, rise in respiratory rate, profuse sweating, increase in heart rate and blood pressure, increased blood sugar, irritability, and protruding eyeballs.

Treatment of hyperthyroidism is difficult because a complex rebalancing of hormones must be achieved. Partial removal of the thyroid gland or the shunting of some of the blood supply to the gland may be successful in lowering the thyroxin level.

A deficiency of thyroxin is a condition known as hypothyroidism and is characterized by a reduction in metabolic rate. Accompanying this is an increase in weight, decrease in pulse rate, and general sluggishness.

If this condition should occur during the growing years, the skeleton and brain fail to develop normally. The resulting disease is called cretinism. A child with this disease is a dwarf and shows mental retardation. Regular treatment with thyroid hormones usually produces spectacular improvement in this condition.

Hypothyroidism during the adult years causes a condition known as myxedema. Lack of thyroxin results in a lowered metabolic rate. This causes a drop in body
temperature so that the hands and feet always feel cold. There is a decrease in heart rate, muscular weakness, general lethargy, and an increase in body weight. The patient will have edema, the retention of water in the body. The skin becomes puffy, especially about the face and has a rather dry and wax like texture. The condition can be improved by the use of thyroxin.

**Calcitonin** is a second hormone produced by the thyroid gland. An increase in the calcium content in the blood stimulates the thyroid gland to release calcitonin. The bones of the body contain a great deal of calcium, which they obtain from the blood and which they may also return to it. Calcitonin acts by preventing the release of calcium from the bones. This lowers the blood calcium level. Although calcitonin can lower a high calcium level, it cannot increase a low one. A hormone of the parathyroid gland takes on this function.

**Parathyroid Gland**

Attached to the posterior (back) surface of the two lobes of the thyroid gland are small, oval, reddish tan masses of tissue called the parathyroid glands. Although the number varies from individual to individual, there are usually four, two in each lobe of the thyroid gland.

The parathyroid glands secrete a hormone called **parathormone**, which raises a low calcium level in the blood. To do this, parathormone has three targets in the body: the bones, the kidneys, and the intestines. It causes calcium to be released by the bones, prevents calcium excretion by the kidneys, and increases the amount of calcium absorbed by the intestine.

Negative feedback mechanisms control the calcium level of the blood through calcitonin from the thyroid gland and parathormone from the parathyroid glands.

If the parathyroid glands secrete abnormally high amounts of parathormone, the bones become soft and weak as calcium is drawn from them, and spontaneous fractures may occur. Nerves and muscles become slow to respond, and the person becomes unresponsive to stimuli.
A deficiency of parathormone lowers the calcium level in the blood. Calcium may be deposited in bones in greater than normal quantities, and joints may become calcified. Muscles and nerves suffer from lack of calcium and convulsive twitching can result in death.

**Pancreas**

The exocrine function of the pancreas was studied in the digestion unit. Digestive secretions are delivered to the duodenum through the pancreatic duct. Since the pancreas is a heterocrine gland, it also functions an endocrine gland.

Scattered throughout the pancreas are many small clusters of cells, different from those that are involved in digestion, known as the **Islets of Langerhans**. There are estimated to be one million islets in the pancreas, weighing about 1g of a total weight of 60 g. Each Islet of Langerhans consists primarily of two kinds of cells: beta cells, which secrete the hormone insulin and alpha cells which produce the hormone glucagon.

**Insulin** performs two very important functions, both of which are designed to lower the blood sugar level. If the glucose content of the blood rises above its normal 0.1%, the beta cells of the Islets of Langerhans are stimulated to secrete insulin. When the insulin reaches the liver (also the skeletal muscles), glucose is converted into glycogen, removing glucose from the blood until the normal level is reached. Insulin also increases the rate at which glucose enters cells by altering the permeability of the cell membrane to glucose. As the glucose level in the blood decreases the production of insulin declines. This is a typical negative-feedback system.

If the beta cells of the Islets of Langerhans do not secrete enough insulin, **hyperglycemia** (elevated sugar in the blood) results. Sugar is not converted to glycogen and it accumulates in the blood plasma and the excess is excreted in the urine. Since glucose is not present for energy production in the cells, the body begins to digest fats and proteins and the patient loses weight. Circulatory problems often result because of fatty deposits in blood vessels. This disease is known as **diabetes mellitus**. Periodic injections of insulin are required to bring relief for patients suffering from this disease. Insulin is a protein and,
therefore cannot be taken orally; the protein digesting enzymes of the stomach and intestine would digest it before it reached the bloodstream.

Oversecretion of insulin leads to too little sugar in the blood, results in a condition known as hypoglycemia. In extreme cases it may lead to insulin shock.

**Glucagon**, the second hormone produced by the pancreas, secreted by the alpha cells of the Islets of Langerhans, has the opposite effect on the glucose level of the blood as insulin. Glucagon raises the concentration of glucose in the blood by increasing the rate of conversion of glycogen in the liver to glucose. When the blood sugar level falls below normal the alpha cells are stimulated to produce glucagon.

**Gonads: Ovaries and Testes**

The gonads are heterocrine glands. Their exocrine function is the production of sex cells, which are carried by ducts. The ovaries produce egg cells and the testes produce sperm.

The male gonads, functioning as endocrine glands, secrete the hormone **testosterone**. The production of this hormone is stimulated by **Interstitial Cell Stimulating Hormone** (ICSH) from the pituitary gland. The effects of this hormone become noticeable on boys of 12 to 15 years of age. This is the period known as puberty, when the young person begins to show the secondary sex characteristics. His voice becomes lower because of the growth of his larynx; extra hair grows in the pubic region (above the genitals), under the arms and on the face. At this time he develops a more angular and muscular frame. Testosterone is responsible for the development of male sex characteristics and for the proper function of the reproductive organs.

The female gonads, the ovaries, produce two hormones: **estrogen** and **progesterone**. Estrogen is the hormone responsible for the development of the female secondary sex characteristics at puberty and helps to maintain them during adult life. At puberty, a young lady begins to grow hair in the pubic region and under the arms; she develops wider hips and her breasts begin to enlarge. Progesterone is the hormone that prepares the uterus
to receive the fertilized egg cell. Its function will be studied in much greater detail in the unit on reproduction.

**Adrenal Glands**

The adrenal glands lie like small caps on top of the kidneys. Each adrenal gland has two parts: the outer part of the gland is called the **adrenal cortex**; the inner part is called the **adrenal medulla**.

The adrenal cortex produces several hormones, all of which are steroids. They fall into three groups: **glucocorticoids**, **mineralocorticoids**, and **sex hormones**.

The glucocorticoids, which include **cortisone**, are concerned with the metabolism of carbohydrates and proteins. They stimulate the liver to take up amino acids and convert them into glucose. In addition to promoting the production of new glucose, these hormones help the liver to store glycogen. This favors high glycogen content in the body tissues and helps to maintain the glucose level in the blood.

The mineralocorticoids, the most important being **aldosterone**, regulate the salt and water balance of the body. Aldosterone's function, besides water balance, is to regulate the reabsorption of sodium by the cells of the renal tubules of the kidneys. The production of aldosterone is controlled by the amount of sodium in the plasma of the blood. If the body is deprived of sodium, there is an increase in the production of aldosterone.

Insufficient secretion of glucocorticoids and mineralocorticoids results in a rare condition called **Addison's disease**. Symptoms include: pronounced fatigue and muscular weakness because of low blood sugar, dark pigment of the skin and mucus membranes, and a breakdown of connective tissue of the joints.

An oversecretion of these cortical hormones produces a condition known as **Cushing's disease**. Symptoms include: obesity, rounded "moon" face because of a redistribution of fat and edema, the retention of water in the cells, extreme nervousness, and a tendency to bruise easily with poor healing of cuts.
The adrenal medulla is the inner portion of each adrenal gland. Unlike the adrenal cortex, which secretes several hormones, the adrenal medulla produces only two hormones: adrenalin (also called epinephrine), and noradrenalin (also known as norepinephrine). Adrenalin is more potent in its action than noradrenalin and 80% of the total secretion of the adrenal medulla is adrenalin.

The hormone producing cells of the medulla are stimulated by neurons of the sympathetic division of the autonomic nervous system. Adrenalin and noradrenalin are often called the "fight or flight" hormones, because of their function in emergency situations. Their function is to increase the heart beat rate, the respiratory rate, and the blood supply to the muscles.
Homework Questions

1. Why are hormones referred to as chemical messengers?

2. Since hormones bathe many or even all of the cells of the body, why do only specific target cells respond to the hormones?

3. Describe how the hormones of the pancreas act together in a negative feedback mechanism to regulate the concentration of glucose in the blood.

4. Why is the pituitary sometimes called the "master gland"?

5. Match the following glands to the hormone(s) produced.

   1. parathyroid ________ h. insulin
   2. ovary ___________ i. adrenalin
   3. pituitary __________ j. calcitonin
   4. pancreas __________ k. estrogen
   5. testes ___________ l. somatotropic hormone (STH)
   6. adrenal __________ m. follicle stimulating hormone (FSH)
   7. thyroid __________ n. testosterone
   8. parathyroid __________ o. parathormone
   9. ovary ___________ p. thyroid-stimulating hormone (TSH)
   10. pituitary __________ q. glucagon
   11. pancreas __________ r. aldosterone
   12. testes ___________ s. antidiuretic hormone (ADH)
   13. adrenal __________ t. thyroxin
   14. thyroid __________ u. progesterone
   15. parathyroid ________ v. oxytocin
   16. ovary ___________ w. cortisone
   17. pituitary __________ x. luteinizing hormone (LH)
Lesson 2: Nervous Coordination and Regulation

Introduction

As you read this, light from the computer screen bombards your eyes. Touch-sensitive receptors all over the skin of your body are stimulated by your clothes and the chair in which you are sitting. You breathe and shift positions in your chair. Your hands manipulate the computer mouse. In addition to all these activities, your brain is using its reading skills to make sense of what is on the screen in front of you and storing memories of what you are reading. How is possible that your body can do so many different things at the same time?

Your nervous system coordinates and controls the essential functions in your body. It receives and relays information about activities within your body and monitors and responds to internal and external changes. You can think of your nervous system as a communication system by with the various cells and parts of your body interact with the outside world. Without your nervous system you would be incapable of responding to changes inside and outside your body. In other words, you would be unable to maintain homeostasis.

Stimulus and Response

One of the basic life functions of all living things is the ability to respond to a stimulus. There are many stimuli to which an organism must respond: a change in air temperature, a change in carbon dioxide level in the blood, contact with a hot or sharp object, the itch at the end of your nose, the hardness of your chair, the cramp in your leg, a feeling of hunger, and many more that have not been mentioned.

There are three main types of structures related to stimuli and responses. Each has a specific function in relation to the others. The three structures are receptors, neurons, and effectors. A receptor is a kind of sensor that picks up information about an organism's internal or external environment. Receptors may be neurons themselves, or they may be organs that are specialized for detecting stimuli. A receptor picks up a certain kind of stimulus. For example, the
eye is a receptor that is sensitive to light, but not to odour. A **neuron** is a specialized cell that transmits electrochemical messages, or nerve impulses, from the receptors to the effectors. An **effector** is a structure that responds when it is stimulated by nerve impulses. The principal effectors are muscles and glands. Muscles respond by contracting; glands respond by secreting.

**Neuron Structure**

The human nervous system is made up of 10 to 12 billion nerve cells called neurons. Some neurons, such as those in the brain, are a fraction of a centimeter in length. Others, such as those that run through the legs, are as long as a meter, going from the toes to the spinal cord.

A neuron has several distinct parts, as shown below. The cell body of the neuron contains the nucleus and most of the cytoplasm known as **soma**. Soma flows into the extensions. The shape of the cell body varies. Some are round, while others resemble a diamond or are irregular in shape.

Nerve fibers extend from the cell body. These fibers contain one long fiber, the **axon**, and one or more short fibers, the **dendrites**. A neuron can have as many as 200 dendrites. While the dendrites are shorter than the axon, they branch extensively because their function is to pick up impulses, either from receptors or other neurons in the vicinity, and conduct them toward the cell body. The axon carries the impulses away from the cell body, passing it on to other neurons or cells.

The axons of many neurons are covered with a white, fatty protein known as **myelin sheath**. The main function of this sheath is to insulate the axon, preventing the loss of chemical ions that are present in the nerve fiber. Since these ions are necessary
for the transmission of impulses along a nerve cell, the presence of a myelin sheath increases the speed of transmission. The myelin sheath is formed of flat Schwann cells, which are wrapped around the axon like a jellyroll. In myelinated axons, gaps that are not covered with the myelin sheath are called nodes of Ranvier. Nerve impulses jump from node to node, resulting in transmission up to 20 times faster than in nonmyelinated axons.

Myelinated nerve fibers found outside the brain and spinal cord (peripheral system) are covered with a delicate membrane known as the neurilemma. The function of the neurilemma is to promote regeneration of the damaged axons. Nerve cells which are not provided with this protection are unable to regenerate. For this reason, damage to the brain or spinal cord is very serious, for ordinarily it results in permanent damage, whereas there is some hope for repair of damage to peripheral nerve cells. Neurons are incapable of division, and those that die are not replaced.

### Types of Neurons

Biologists classify neurons according to their function. There are sensory neurons, associative neurons, and motor neurons.

**Sensory neurons** transmit impulses from receptors to the brain or spinal cord. These pick up the stimuli of sight, smell, sound, taste, and touch. Sensory neurons are important in carrying messages about a person's internal or external environment.

**Associative neurons**, (also called interneurons or association neurons) found only in the brain, ganglia, or spinal cord, are responsible for coordinating nervous activity (they “decide” what to do) and relaying the messages from the sensory neurons to the proper motor neurons to effect an appropriate action by the effectors (muscles and glands).

**Motor neurons** receive messages from the associative neurons in the brain and spinal cord and activate the muscles and glands (the effectors).
Nerves

A nerve is a bundle of nerve fibers (axons) bound together by a sheet of connective tissue. Nerves consist primarily of axons of neurons. The cell bodies of those neurons are gathered together into groups. A group of cell bodies that is located outside the brain or spinal cord makes up a ganglion. A group of cell bodies that is inside the brain or the spinal cord is referred to as a nerve center.

Within the brain and spinal cord, the myelinated fibers form areas referred to as white matter. The cell bodies of the neurons and unmyelinated fibers make up the gray matter of the brain and spinal cord.

Nerve Impulse – The Resting Neuron

The transmission of an impulse along a neuron is an electrochemical process and not a pure electric current, as was once thought. The transmission of an impulse from one neuron to another is a chemical process.

In a neuron at rest (one that is not transmitting an impulse), there is an unequal distribution of positive and negative ions inside and outside the membrane. This membrane that surrounds the nerve fiber is selectively permeable. That is, some molecules can pass through but others cannot. This membrane can control the passage of certain ions (electrically charged atoms) across it, letting them into or out of the cell. Chloride ions, for example, have an extra electron and are negatively charged, whereas sodium and potassium ions lack electrons and are therefore positively charged.

When a nerve cell is at rest (has not been stimulated), it is said to be polarized. The membrane of a polarized cell allows potassium and chloride ions to move freely across it in either direction, but it is impermeable to the large negative ions that are present inside the neuron. The membrane is very much more permeable to potassium ions than to sodium ions, and potassium ions (more concentrated inside the cell) move outward more quickly.
than the sodium ions (more concentrated outside the cell) move inward. In addition, a sodium-potassium pump moves, by active transport, three sodium ions to the outside for every two potassium ions it moves into the nerve cell. Therefore, the membrane has a net positive charge on its outer surface and a net negative charge on its inner surface.

Nerve Impulse – The Moving Impulse

A stimulus applied to a neuron starts a nervous impulse. The nature of the stimulus varies with the particular neuron. Light stimulates the light-sensitive neurons in the retina of the eye; sound stimulates the sound-sensitive neurons in the ears.

Whatever the stimulus, it initiates a nerve impulse by increasing the permeability of the membrane to sodium ions and they flow into the nerve fiber at the point where the stimulus is applied. The result is a reversal of the charge on the membrane (depolarization) at the point where the impulse is passing; the interior of the cell becoming positively charged and the outside negatively charged. The polarization reversal (reversal of charges inside and outside the membrane) of a small segment of a neuron causes the polarization of the adjacent area to become reversed as well.

When this happens, the part that was stimulated first becomes repolarized and returns to its original condition. The process repeats in the next region—polarization reversal at this point causes polarization reversal of the region beyond it and the second section becomes repolarized itself. This depolarization and repolarization of the membrane produce an action potential.
The reversal of the outside and inside charges on a small portion of a neuron lasts for about 0.001 second. This is the time it takes for the impulse to pass that segment of the neuron. Immediately after the impulse has passed, there is a period of time during which the neuron will not respond to a stimulus. This refractory period, during which the portion of the neuron is repolarizing (becoming positive on the outside and negative on the inside), requires only 0.001 to 0.005 second. Then, that segment is ready to respond to a stimulus again. Several hundred to a thousand impulses can be transmitted by a neuron in a second.

**The Nerve Threshold**

A nerve impulse is self-propagating. Once started, it moves along without outside help. All of the impulses passing along a nerve fiber are of the same strength. If a stimulus is strong, more impulses are sent, but not larger ones. If the stimulus is too weak, no impulse is sent at all. A dendrite needs a certain amount of stimulation before an impulse is initiated. This minimum amount of stimulation is called a neuron's threshold. If the stimulus is equal to or greater than the threshold, the neuron will respond by sending an impulse. This is known as the all-or-none response.
Because one neuron does not touch another, there is no contact between them, and the electrochemical impulse cannot pass directly from one nerve cell to another. The microscopic space that exists between the axon of one neuron and the dendrite of another is called a synapse.

An axon ends in many small fibers. The endings of axons (synaptic knobs) have cytoplasmic vesicles called synaptic vesicles inside them. These tiny sacs are filled with compounds called transmitter substances (also known as neurotransmitters). Neurotransmitters include the following compounds: acetylcholine, noradrenalin, dopamine and serotonin.

Transmission from Neuron to Neuron

Follow the link called "Synaptic transmission of nerve impulse" in the Web Links section to a site that shows an animation about transmission of nerve impulses across the synapse. When an impulse reaches the end of an axon, it stimulates the synaptic vesicles to release their transmitter substance into the synapse. The substance, acetylcholine, for example, diffuses across the synapse to the dendrite of the adjacent neuron. The acetylcholine combines with the receptor molecules in the cell membrane of the dendrite or cell body of the next neuron, increasing the permeability of the membrane at that point on the second neuron to sodium ions, and reversing the polarization of the membrane. The electrochemical impulse starts on its way along that neuron. Transmission of acetylcholine from a motor neuron axon to a muscle cell (across a neuromuscular junction) stimulates the muscle cell to contract.

Enzymes destroy the transmitters shortly after they are released into the synapses and neuromuscular junctions. Acetylcholinesterase, for example, digests acetylcholine to acetic acid and choline. These compounds diffuse back into the axon where they are used again in the synthesis of acetylcholine. If the excess transmitter substances were not broken down by enzymes, they would
continue to initiate impulses in dendrites indefinitely and cause muscles to contract continuously.

**The Reflex Act**

When an effector responds to an impulse as described on the previous page, the response is called a reflex act. A reflex act is an automatic or involuntary action, which is always the same when a particular stimulus is involved. The closing of the pupil of the eye in response to bright light or the rapid withdrawal of the hand after touching something hot, are both examples of the reflex act. Reflex activity is predictable; it provides a rapid reaction protecting the body from harm. Reflex acts occur in a fraction of a second, before a person has time to think consciously about what appropriate action is required.

A reflex arc is initiated by stepping upon a sharp stone. Impulses, started by receptors in the toe, travel along sensory neurons to the spinal chord, where associative neurons are stimulated. The impulses are "switched" to other neurons—among them motor neurons that stimulate leg muscles to contract and move the foot away from the rock.

Impulses going from the injured toe to the spinal cord result in reflex movement, but also travel up nerve pathways to the brain. Associative neurons in the brain are activated. Impulses may pass from the brain to many parts of the body, leading to voluntary movement.

**The Parts of the Reflex Arc**

The reflex arc consists of five parts, which usually involve three neurons (two or more than three are quite common). The reflex arc requires:

- **Receptor.** The receptor recognizes some change in the environment, whether heat, light, sound, or some other factor. The receptor is stimulated to initiate a nervous impulse
- **Sensory neuron.** The sensory neuron conducts the impulse from the receptor to the spinal cord.
- **Associative neuron.** The associative neuron directs the impulse from the sensory neuron to the motor neuron. It allows the impulse to be routed into a number of possible pathways.
- **Motor neuron.** The motor neuron carries the impulse to the appropriate organ (usually a muscle) to produce the response.
- **Effectors.** The effector is the muscle or organ that will contract or otherwise respond appropriately to the stimulus.

The **spinal cord** connects the brain with other parts of the body, and functions as a two-way conducting pathway, carrying impulses from sensory neurons up to the brain and conducting impulses from the brain for motor neurons to relay to the muscles and glands of the body. A second major function is to act as a center for reflex activity.

**The Reflex Arc**

When a doctor wants to check your reflexes, he sometimes strikes the tendon just below the knee cap with his little rubber hammer. He watches to see if your lower leg moves forward immediately. If it does, all is well. This forward movement of the lower leg is a **reflex act** and happens involuntarily.

The rubber hammer strikes the tendon, pulling it down, and stretches the muscles in the upper thigh. The stretch **receptors**, being embedded in the thigh muscles, pick up the stimuli. Let us follow the path of an impulse generated by only one receptor through the **reflex arc** to one **effector**.

Provided the stimulus has exceeded the receptor's threshold, an impulse will be initiated there and propagated along a **sensory neuron**. The impulse travels to
the spinal cord. At this point, the synaptic knobs on the axon's end fibers stimulate their synaptic vesicles to release acetylcholine into the synapse between them and the dendrites of associative neurons (sometimes called interneurons). One associative neuron takes the impulse to the brain; a second, using the same method of impulse transfer as related above, takes the impulse directly to a motor neuron's dendrites. The impulse propagates itself along the axon of the motor neuron. When the impulse reaches the motor end plates at the end of the neuron, they are stimulated and cause contraction of the upper thigh muscle (the effector), which moves the lower leg forward. Because of this quick responding reflex act, your leg responds to the tap of the hammer even before you are aware of the pain.
Homework Questions

Complete the following questions and check your answers with the key.

1. Describe the main functions of the nervous system.

2. Differentiate between the terms stimulus, receptor, impulse, and effector.

3. Describe the structure of a neuron and the functions the following parts: soma, axon, dendrites, myelin sheath, Schwann cells, nodes of Ranvier, neurilemma.

4. Differentiate among sensory, motor, and associative neurons.

5. What is a nerve?

6. a) What changes occur in the neuron during the resting potential

   b) What changes occur in the neuron during the acting potential?

7. What is the function of the sodium-potassium pump?
8. How does the all-or-none principal relate to the transmission of a nerve impulse?

9. a) What is a neurotransmitter?
   
b) How does its release controlled by a nerve impulse?

10. Why do enzymes such as acetylcholinesterase destroy the neurotransmitters shortly after they are released into the synapses and neuromuscular junctions?

11. a) What is the reflex act?
   
b) Provide some examples of reflex acts in your body.
   
c) How does the reflex act help protect you from harm?

12. Describe the reflex arc that would be involved if you touched a hot stove.
Disorders of the control systems

- multiple sclerosis
- Parkinson's disease
- Alzheimer's disease
- cerebral palsy
- meningitis
- paraplegia
- quadraplegia
- sciatica
- amyotrophic lateral sclerosis (ALS)
- attention deficit hyperactivity disorder
- lead poisoning
- mercury poisoning

2. Find a minimum of four sources of information about your topic. Two of the four sources may be a textbook or reference book for general background material. At least two additional sources must be from a search on the Internet.

3. Prepare a research report (minimum 2 word processed pages) of your findings. The report should include the following components:

- Description of the disease or disorder
- Percentage of population affected
- Signs/Symptoms
- Causes/Risk factors
- Effects of the disease on the body
- Current treatments
- Prognosis/Possible Complications
- Prevention
- Any research presently going on about this disease or disorder and any prospects for future treatments.
- Bibliography