Life 27 – Hormonal control - Raven & Johnson Chapters 53 & 56 (parts)

Objectives

1: Understand how breathing is regulated by the nervous system.

2: Know why the pancreas is both an endocrine and exocrine gland, and how its secretions are involved with the regulation of blood glucose.

3: Identify and describe the effects of the hormones released by the posterior pituitary gland.

4: Identify and describe the functions of some hormones produced by the hypothalamus and the anterior pituitary gland.

5: Understand how the regulation of GH, prolactin and MSH differs from that of TSH, corticotropin, LH and FSH.

6: Compare regulation by the nervous and endocrine systems.

Nervous and endocrine systems
Comparing the two systems. Seen nerve cell interactions in Neurobiology, now look at an example of nervous control - regulation of breathing in man, following on from respiration

Neurons in the brain stem respiratory control centre (medulla oblongata) initiate each breath (Fig. 53.14 – note position of pituitary for later)

Send impulses to the diaphragm & external intercostal muscles, cause these to contract and so expand chest cavity, inspiration by negative pressure. Muscles relax when neurons stop firing, expiration

Urge to breathe largely due to high P_{CO_2}, through increased acidity

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \text{ (carbonic acid)} \leftrightarrow H^+ + HCO_3^- \text{ (bicarbonate)}$$

H^+ increases acidity, lowers pH, stimulates neurons in aortic & carotid bodies – peripheral chemoreceptors in the aorta & carotid artery. Send nerve impulses to the respiratory control centre, which then stimulates breathing

Blood does not reach central chemoreceptors in brain due to blood-brain barrier. But after a brief delay high blood CO_2 stimulates them via decrease in pH of cerebrospinal fluid

Peripheral chemoreceptors stimulate immediate increase in breathing from high blood CO_2

Central chemoreceptors slower system, stimulates sustained increase in breathing to eliminate high CO_2 after exercise

Nervous control system. Sensory neurons (chemoreceptors) → interneurons (wholly within the central nervous system, process information) → motor neurons → effector organs (intercostal & diaphragm muscles)

Hormonal control
Some hormone systems achieve control largely independently of the nervous system. E.g. the regulation of blood glucose levels

Seen adrenaline stimulating hydrolysis of glycogen to glucose in liver cells, for "fight or flight". But glucose normally regulated at a stable level in blood

Pancreas situated near stomach, connected to duodenum (small intestine) by pancreatic duct. Most tissue is exocrine (with duct) secretion of digestive enzymes into duodenum (Fig. 51.19)

Small groups of endocrine cells in the islets of Langerhans. β-cells secrete insulin, α-cells secrete glucagon, its antagonist

Digestion of carbohydrate leads to increase in blood glucose, stimulates secretion of insulin & inhibits secretion of glucagon (Fig. 56.20)

Insulin promotes uptake of glucose by liver & muscle cells, where it is stored as glycogen, and adipose cells, where stored as fat

Blood glucose falls between meals as it is taken into cells, insulin secretion decreases & glucagon secretion increases

Glucagon promotes hydrolysis of stored glycogen in liver, and fat in adipose tissue, so glucose & fatty acids released into the blood, taken up by cells and catabolised for energy

Negative feedback loops as each hormone has effects that reverse the conditions that stimulate its secretion

Neuroendocrine control

However in most cases secretion of hormones is controlled by the nervous system. This is where information about the environment and other animals is obtained and processed

Nervous control acts through the neuroendocrine cells. Apart from the adrenal medulla (produces adrenaline), vertebrates have two groups of these cells

One group in the pineal gland, the other in the hypothalamus and nearby cells. All other endocrine glands made up of secretory cells, not neurons

Hypothalamus is in the base of the brain, above the pituitary gland which sticks out underneath. Hypothalamus-pituitary system is the major control of the endocrine system

One group of neuroendocrine cells in the supraoptic nucleus (blue) are controlled by neurons in the nearby hypothalamus (Fig. 56.13)

Their axons pass into the posterior pituitary, which is their neurohaemal organ, and release two hormones into blood capillaries there

1: Antidiuretic hormone (ADH), stimulates water reabsorption in the kidney
2: Oxytocin, stimulates smooth muscle contraction in labour or egglaying

Main group of neuroendocrine cells are in the hypothalamus itself (yellow). Their axons pass to the primary capillaries in the pituitary stalk

There is direct blood circulation from the primary capillaries to the anterior pituitary, through the portal venules

Anterior pituitary is an endocrine gland, made of secretory cells (not neurons)

Neurohormones from hypothalamus cells pass to the anterior pituitary in the blood, and stimulate secretory cells there to produce hormones

These hormones pass into capillaries of the hypophyseal portal system, then into the general blood circulation

There are 10 hypothalamic hormones, which control the secretion of many other hormones in different organs (OHP Figure)

Shows complete system to emphasise the hypothalamus-pituitary as the major control of the endocrine system. Hormones may have alternative names in Raven & Johnson

Neurohormones in red, other hormones in blue. The important point is the three types of control:

1: The posterior pituitary system already described, secretes neurohormones (ADH and oxytocin) that directly affect target organs

Note supraoptic nucleus under nervous control of the hypothalamus

2: Some hypothalamic hormones have antagonists - shown on left

Pairs of neurohormones that stimulate or inhibit the release of a hormone from the anterior pituitary, which then affects the target organ

E.g. Growth hormone-releasing hormone (GH-RH) stimulates secretion of growth hormone (GH), which affects the whole body - growth of tissues

Growth hormone-release-inhibiting hormone (GH-RIH) inhibits GH secretion. So secretion of GH can be stimulated or inhibited

Feedback control acts through the nervous system, to stimulate secretion of either GH-RH or GH-RIH by the hypothalamus

Also for prolactin (stimulates milk production by mammary glands) and …

Melanocyte-stimulating hormone (MSH), stimulates dispersal of pigment in melanophores (see in *Xenopus* tadpoles)

3: Other hypothalamic hormones do not have antagonists. These act only to stimulate hormone secretion by the anterior pituitary - shown on right

These hormones from the anterior pituitary all act on another endocrine organ, to secrete another hormone, which then affects the target organ

E.g. Thyroid-stimulating hormone-releasing hormone (TSH-RH) from the hypothalamus stimulates secretion of thyroid-stimulating hormone (TSH) from the anterior pituitary

TSH stimulates the thyroid gland to secrete two other hormones, T_3 and T_4 (thyroxine – Life 26). These increase aerobic respiration in target cells

In this third type the hypothalamic hormone can only increase the secretion of hormone from the anterior pituitary

Feedback control acts through the concentration of the final hormone in the blood, stops secretion of the intermediate hormone, also of the neurohormone by the hypothalamus (Fig. 56.15)

Similar systems for control of endocrine function by the adrenal cortex (glucose & salt regulation, e.g. cortisol) and gonads (reproduction, e.g. testosterone)

One result of multiple hormones is a cascade effect. Amplification so the final process can be controlled by minute amounts of the initial hormone

E.g. the corticosteroid system gives 400 $\times$ amplification:
Hypothalamus secretes 0.1 μg of corticotropin-RH
Anterior pituitary secretes 1 μg of corticotropin
Adrenal cortex secretes 40 μg of corticosteroids

Compare nervous and hormonal control

Functions of endocrine and nervous systems are complementary. Nervous communication is very rapid, and the path to an effector is precise. Nerves may affect only a single muscle fibre

Hormonal communication is slow but long lasting, controls growth or seasonal events. The hormone reaches every cell in the body, and limiting the response depends on specific receptors in the target cells

Even so, hormones usually have more widespread action than nerves, affecting large organs (e.g. skin or blood vessels) or several organs together (e.g. adrenaline affects liver, heart, blood vessels, bronchioles)

The endocrine system is involuntary. Compare it to the nervous reflex arc as a pathway to an effector or target organ (OHP Figure)

In the simple monosynaptic reflex arc, a sensory neuron acts on a motor neuron, and then on the effector organ

The equivalent of the monosynaptic reflex is a first order neuroendocrine loop

There is a direct effect of the neurohormone on the effector organ. It is called a loop because there is feedback control (not shown)

E.g. adrenaline and noradrenaline from the adrenal medulla, and the posterior pituitary system

Second order loops have an endocrine gland and hormone between the neuroendocrine cells and the effector organ

E.g. GH-RH, then growth hormone. Endocrine gland is anterior pituitary

Third order loops have two endocrine glands and two hormones between the neuroendocrine cells and the effector organ

E.g. TSH-RH, then TSH, then T_3 and T_4. Endocrine glands are anterior pituitary and thyroid

So the basic patterns are simple, despite the names of hormones and the structures that secrete them

Diagram also stresses that most of the endocrine system is ultimately under nervous control from the CNS, depending on information from sense organs

Read the remainder of chapter 56 and parts of chapter 59 for details of particular hormone systems