

# Anatomy and Physiology: The Endocrine System

## CHAPTER 1

**U**nderstanding the detailed functions of the endocrine system is key to comprehending various health conditions, how they manifest and the pharmacological interventions that may be used in the delivery of patient care. This chapter provides a comprehensive overview of the anatomy and physiology of the endocrine system, providing the reader with a fundamental knowledge base that is necessary for practice.

### HOMEOSTASIS

Homeostasis refers to the process of maintaining a stable internal environment. In other words, homeostasis refers to the maintenance of normal physiological balance and functioning within the body (Clare 2020). Every cell in the human body is influenced by the endocrine system (Fitzgerald-O'Connor and Long 2020). There are two key systems in the body that play important roles in maintaining homeostasis:

1. The nervous system
2. The endocrine system

While both the endocrine and nervous systems are essential for coordinating physiological processes and maintaining homeostasis in the body, they differ in several key aspects. Table 1.1 outlines the differences between these two systems.

The nervous system reacts rapidly to stimuli and affects its changes over a period of seconds or minutes; thus, it is involved in the immediate and short-term maintenance of homeostasis. Owing to its rapid onset of action, the nervous system is responsible for the control of rapid bodily processes such as breathing and movement. The endocrine system is often responsible for the regulation of longer term processes.

The endocrine system, however, typically oversees longer term processes, regulating physiological functions over extended periods. The major functions it manages are:

- Homeostasis, maintenance of the internal body environment
- Storage and use of energy substrates (carbohydrates, proteins and fats)
- Regulation of growth and reproduction
- Control of the body's responses to external stimuli (particularly stress)

It is important to note, that while these two systems are separate, they often work together, complementing each other in the maintenance of homeostasis.

**Table 1.1** The differences between the nervous system and endocrine system

	Nervous system	Endocrine system
Speed of action	Seconds  Responses mediated by the nervous system are rapid and short lived. Nerve impulses travel quickly along neurones, allowing for immediate responses to stimuli, but these responses are typically brief.	Minutes to hours (may even be days)  Responses mediated by the endocrine system tend to be slower and more prolonged. Hormones travel through the bloodstream, which may take time to reach target tissues and their effects may persist for longer durations.
Duration of action	Seconds to minutes  Nerve impulses trigger rapid but short-lived responses. Once the stimulus ceases, the nerve impulse stops and the response subsides relatively quickly.	Minutes to days  Hormonal effects often have a longer duration of action due to the slower onset and degradation of hormones in the bloodstream. Changes initiated by hormones may persist for hours, days or even longer.
Methods of transmitting messages	Electrical  Neural signalling is electrical and chemical, involving the generation and propagation of action potentials along neurones and the release of neurotransmitters at synapses to transmit signals between neurones or from neurones to target cells.	Chemical  Hormonal signalling is chemical and involves the release of hormones into the bloodstream, which then bind to specific receptors on target cells to initiate a response.
Transportation method	Neurones  The nervous system communicates through electrochemical impulses along neurones. Neurones transmit nerve impulses or action potentials, to specific target cells or tissues, allowing for rapid and precise communication.	Hormones  The endocrine system communicates through the secretion of hormones into the bloodstream. Hormones are chemical messengers that travel to target cells or tissues throughout the body, exerting their effects.

Source: Adapted from Clare (2020); Chandler, Wood, and Hyde (2023).

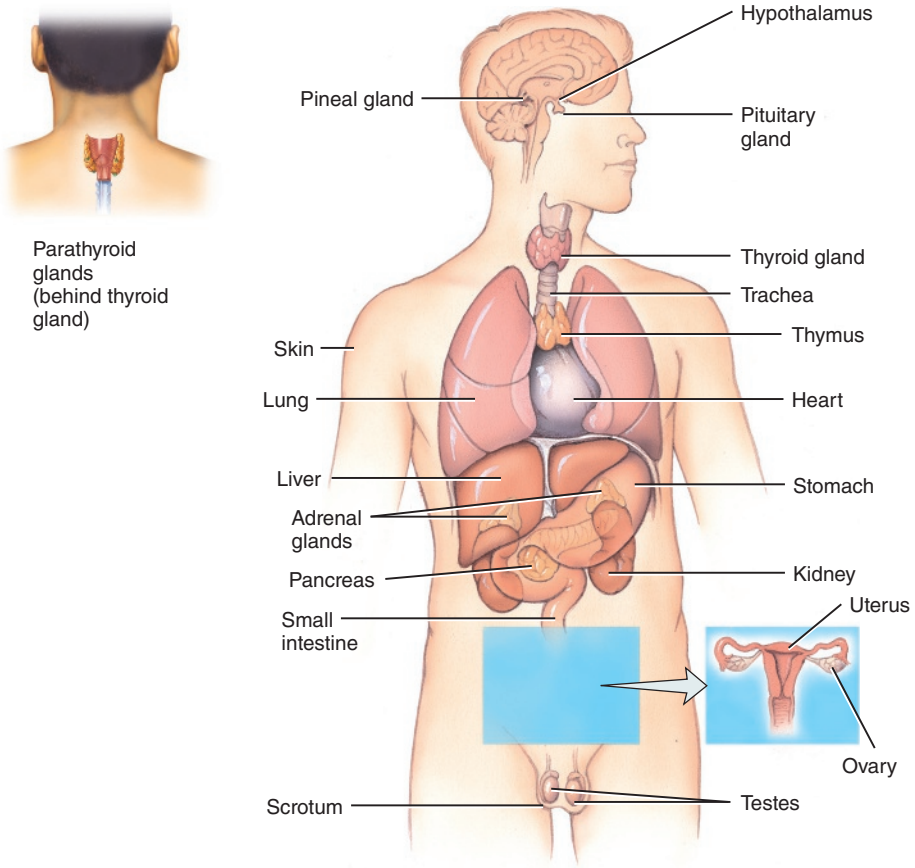
## THE ENDOCRINE ORGANS

The endocrine system is composed of glands that produce and secrete hormones. These hormones regulate the activity of cells or organs. Hormones control metabolism and sexual development and function (Peate 2019).

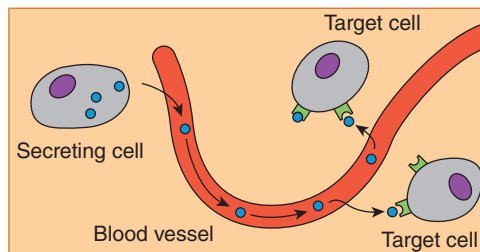
The endocrine system is the name given to a collection of small organs that are scattered throughout the body, each of which releases hormones. Hormones are chemical substances released into the blood by the endocrine system exerting physiological control over the function of cells or organs other than those that created them. The purpose of each hormone varies. Their common primary role, however, is to maintain homeostasis.

Figure 1.1 shows the endocrine organs and their position in the body. Each of these organs will usually have a rich blood supply that is delivered by numerous blood vessels. The hormone-producing cells within the organ are arranged into branching networks around

this blood supply. This arrangement of blood vessels and hormone-producing cells ensures that hormones enter the bloodstream rapidly and are then transported throughout the body to the target cells (see Figure 1.2).



**FIGURE 1.1** The endocrine organs and their location in the body



**FIGURE 1.2** The transportation of hormones in the blood

## **ENDOCRINE, PARACRINE, EXOCRINE AND AUTOCRINE SIGNALLING**

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Understanding the concepts of endocrine, paracrine, exocrine and autocrine signalling is essential as it relates to how cells communicate and how physiological processes are regulated within the body.

### **ENDOCRINE SIGNALLING**

Endocrine signalling involves the release of hormones by specialised glands directly into the bloodstream. These hormones travel to distant target cells or tissues, where they exert their effects by binding to specific receptors.

Understanding the role of hormones in regulating various bodily functions, including metabolism, growth, reproduction and stress response are important concepts so as to offer people care that is safe and effective. Healthcare workers may care for patients with endocrine disorders such as diabetes, thyroid disorders or adrenal insufficiency, where hormone regulation is disrupted.

### **PARACRINE SIGNALLING**

Paracrine signalling occurs when signalling molecules are released by one cell and act on nearby target cells or tissues within the same tissue or organ. Paracrine refers to hormones that act locally and diffuse to the cells in the immediate neighbourhood to produce their action.

Consideration must be given to paracrine signalling's role in regulating local cellular activities and maintaining tissue homeostasis. Inflammation, for example, involves paracrine signalling as it coordinates immune responses and tissue repair.

### **EXOCRINE SIGNALLING**

Exocrine signalling involves the secretion of signalling molecules, such as enzymes or mucus, into ducts or body cavities that lead to external surfaces or internal organs other than the bloodstream. Exocrine refers to glands/organs that secrete substances into ducts that eventually lead to the outside of the body (for instance, the sweat glands, the part of the pancreas that secretes digestive juices and the gallbladder).

The function of exocrine glands will be encountered in various healthcare settings, such as assessing patients with conditions affecting sweat glands, salivary glands or mammary glands. Understanding exocrine signalling helps in comprehending the functions of these glands and how their dysfunction may impact patients' health.

### **AUTOCRINE SIGNALLING**

Autocrine signalling occurs when a cell secretes signalling molecules that bind to receptors on the same cell or neighbouring cells of the same type, leading to self-stimulation or stimulation of nearby cells. Autocrine refers to hormones that act on the cells that produce it.

Recognising autocrine signalling's role in regulating cellular processes such as growth, proliferation and differentiation promotes understanding. Cancer cells, for example, may use autocrine signalling pathways to promote their own growth and survival, contributing to tumour progression.

Understanding endocrine, paracrine, exocrine and autocrine signalling is key for knowing how cells communicate and regulate physiological processes in health and disease. This knowledge enables the assessment, diagnosis and management of patients with various endocrine disorders, inflammatory conditions, exocrine gland dysfunction and cancer. Developing further insight into these signalling mechanisms can enhance holistic care and enable healthcare providers to support patients safely and effectively.

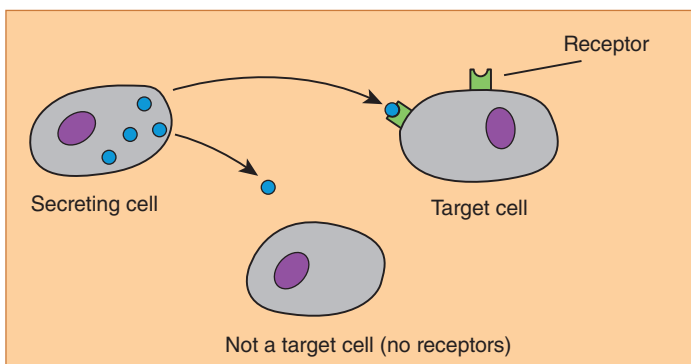
## HORMONES

Hormones act as chemical messengers that are released into the bloodstream or extracellular fluid by one cell, influencing the functioning of other cells. Unlike the nervous system, which relies on wired connections (neurons) similar to a telegraph, the endocrine system operates more like a radio broadcast. Just as a radio transmission requires a receiver to interpret the message, hormones necessitate specific receptors on target cells for their actions to be realised. Although hormones travel throughout the body via the bloodstream, their effects are only exerted on cells equipped with receptors for that particular hormone. This interaction resembles a lock and key mechanism, where the hormone serves as the key that fits into a specific receptor like a lock, initiating cellular responses (see Figure 1.3).

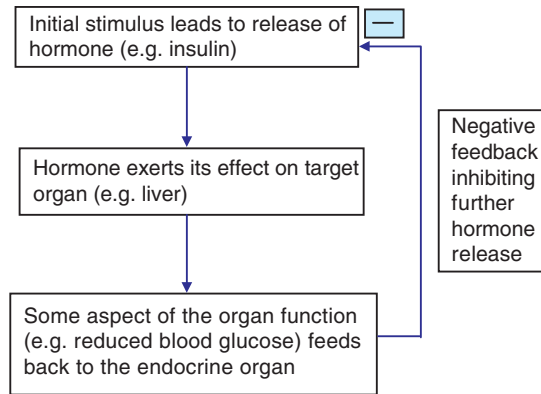
## THE TRANSPORTATION OF HORMONES

The majority of hormones are released into the bloodstream, except for those that are directed into a local circulatory system known as a portal circulation. There are two portal circulations in the human body: one connects the hypothalamus and the anterior pituitary gland and the other is the hepatic portal circulation, which merges to form the portal vein entering the liver.

Steroid hormones are primarily transported in the bloodstream by binding to transport proteins, with less than 10% existing as the 'free fraction' of the hormone (Jenkins and Tortora 2019). There are certain blood tests that aim to measure both the bound and free components of a hormone; one common example is thyroid function tests, which assess both bound thyroxine (T4) and free T4 levels. Water-soluble hormones, on the other hand, circulate freely in the blood.



**FIGURE 1.3** Target cells and non-target cells



**FIGURE 1.4** The negative feedback system

## CONTROL OF HORMONE RELEASE

The production and secretion of the majority of hormones are triggered by a stimulus, which can originate from internal or external sources, such as an increase in blood glucose levels or exposure to cold temperatures. Subsequently, the synthesis and release of hormones are typically regulated by a negative feedback mechanism. As illustrated in Figure 1.4, the impact of a stimulus, whether internal or external (such as elevated blood glucose levels), prompts the release of a hormone (insulin). Following this, some aspect of the target organ function inhibits any further response to the stimulus, thereby preventing additional hormone release by the organ.

## THE PHYSIOLOGY OF THE ENDOCRINE ORGANS

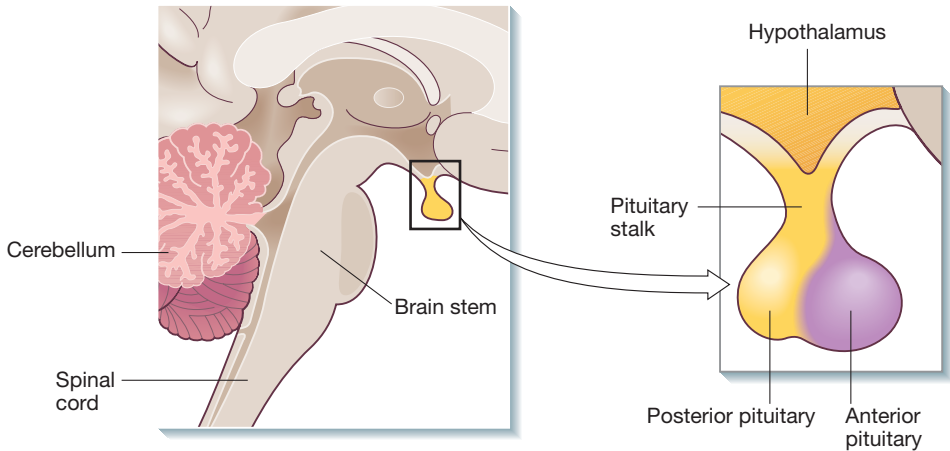
Endocrine-releasing organs can be divided into three main categories:

1. Endocrine glands: the sole function of these organs is the production and release of hormones. The pituitary, thyroid, parathyroid and adrenal glands are examples.
2. Organs that are not pure glands but contain relatively large areas of hormone-producing tissue, including the pancreas, the hypothalamus and the gonads.
3. Other tissues and organs also produce hormones: areas of hormone-producing cells are found in the wall of the small intestine, the stomach, the kidneys and the heart.

## THE HYPOTHALAMUS AND THE PITUITARY GLAND

The hypothalamus is a region of the brain with diverse functions. It is a small, cone-shaped structure that weighs approximately 4g. It is directly linked to the pituitary gland by the pituitary stalk, also known as the infundibulum. One of the primary roles of the hypothalamus is to establish a connection between the nervous system and the endocrine system through the pituitary gland. Nearly, all hormone secretion from the pituitary gland is regulated by either hormonal or electrical signals originating from the hypothalamus (see Figure 1.5).

The hypothalamus receives signals from nearly all sources within the nervous system but is also subject to negative feedback control by hormones regulated by the pituitary gland.



**FIGURE 1.5** The hypothalamus and surrounding structures

Consequently, when hormone levels in the blood supplying the hypothalamus are low, it triggers the release of appropriate releasing hormones or factors, stimulating the pituitary gland to release the corresponding hormone. Conversely, as the level of the target hormone increases in the bloodstream, receptors in the hypothalamus detect this change, leading to the removal of the stimuli for releasing factors and subsequently reducing their release. A classic example of this mechanism is the release of thyrotropin-releasing hormone (TRH), followed by the release of thyroid-stimulating hormone (TSH) by the anterior pituitary gland.

The pituitary gland secretes at least nine major hormones and is approximately the size and shape of a pea situated on a stalk. Functionally and anatomically, it is divided into two parts:

1. **Posterior lobe (known as the neurohypophysis):** Composed mainly of nerve fibres originating in the hypothalamus, the posterior lobe terminates on the surface of capillaries within it. This lobe releases two hormones received directly from the hypothalamus. In essence, it functions more as a storage area than a gland in the traditional sense. The hypothalamus and posterior pituitary are connected by a nerve bundle known as the hypothalamic-hypophyseal tract.
2. **Anterior lobe (known as the adenohypophysis):** Significantly larger than the posterior lobe, the anterior lobe partially surrounds it along with the infundibulum. Comprising glandular tissue, it produces and releases several hormones. Although the hypothalamus and anterior pituitary lack direct nerve connections, they are linked by a vascular connection called the hypothalamo-hypophyseal portal system. Through this system, venous blood from the hypothalamus flows to the anterior lobe, enabling control of the anterior pituitary by releasing and inhibiting factors (or hormones) released by the hypothalamus.

The hormones secreted by the posterior pituitary are:

1. **Oxytocin:** This has an effect on uterine contraction in childbirth and is responsible for the 'let down' response in breastfeeding mothers (the release of milk in response to suckling). In men and non-pregnant women, it appears to play a role in sexual arousal and orgasm (Jenkins and Tortora 2019).

**Table 1.2** Hormones released by the anterior pituitary gland

Hypothalamus	Anterior pituitary gland	Target organ or tissues	Action
Growth-hormone-releasing factor	Growth hormone	Several (particularly bones)	Stimulates growth of body cells
Growth-hormone-release-inhibiting factor	Growth hormone (inhibits release)	Many	
Thyroid-releasing hormone	Thyroid-stimulating hormone	Thyroid gland	Stimulates thyroid hormone release
Corticotropin-releasing hormone	Adrenocorticotropic hormone	Adrenal cortex	Stimulates corticosteroid release
Prolactin-releasing hormone	Prolactin	Breasts	Stimulates the production of milk
Gonadotropin-releasing hormone	Follicle-stimulating hormone, luteinising hormone	Gonads	Various reproductive functions

2. Antidiuretic hormone: Under resting conditions, large quantities of ADH accumulate in the posterior pituitary; excitation by nervous impulses leads to the release of the ADH where it is stored in the neighbouring blood vessels. The effects of ADH are that it increases water retention by the kidneys by increasing the permeability of the collecting ducts located in the kidneys. The secretion of ADH is stimulated:

- By increased plasma osmolality – increased levels of certain substances in the plasma, for example, sodium
- By decreased extracellular fluid volume
- By pain and other stressed states
- In response to some drugs

Table 1.2 summarises the range of hormones the anterior pituitary gland releases as well as the releasing or inhibiting hormones (or factors) from the hypothalamus that are responsible for influencing this release.

## GROWTH HORMONE

### EFFECTS

Growth hormone, as its name suggests, promotes the growth of bone, cartilage and soft tissue. It stimulates the production and release of insulin-like growth factor (IGF-1).

### REGULATION

Growth hormone released from the anterior pituitary is regulated by the release of growth-hormone-releasing hormone and growth-hormone-release-inhibiting hormone (somatostatin) by the hypothalamus. Growth hormone as well as IGF-1 produce a negative feedback effect on the hypothalamus.

## **PROLACTIN**

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### **EFFECTS**

Prolactin stimulates the milk secretion in the breast.

### **REGULATION**

Secretion is inhibited by the release of dopamine from the hypothalamus. This can be intermittently increased by the release of prolactin-releasing hormone from the hypothalamus in response to the baby suckling at the breast.

## **FOLLICLE-STIMULATING HORMONE AND LUTEINISING HORMONE (GONADOTROPHINS)**

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### **EFFECTS**

In males, FSH stimulates sperm production. In females, this leads to the early maturation of ovarian follicles and oestrogen secretion. LH is responsible for the final maturation of the ovarian follicles and oestrogen secretion in females, and in males, it stimulates testosterone secretion.

### **REGULATION**

In males and females, LH and FSH production are regulated by the release of gonadotrophin-releasing hormone (GnRH). Testosterone and oestrogen exert a negative feedback effect on the release of GnRH from the hypothalamus.

## **THYROID-STIMULATING HORMONE**

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### **EFFECTS**

Thyroid-stimulating hormone stimulates the activity of the cells of the thyroid gland, leading to an increased production and secretion of T4 and triiodothyronine (T3).

### **REGULATION**

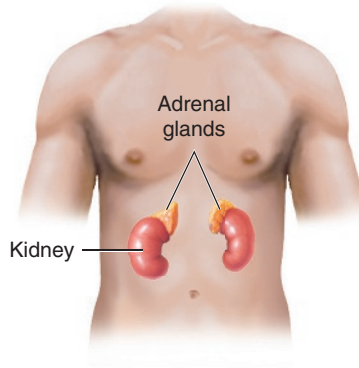
Thyroid-stimulating hormone is produced and released in response to the release of TRH from the hypothalamus. The hypothalamus can also inhibit the release of TSH through the action of somatostatin. Free T3 and T4 in the blood will have a direct negative feedback effect on the hypothalamus and the anterior pituitary gland.

## **ADRENOCORTICOTROPHIC HORMONE**

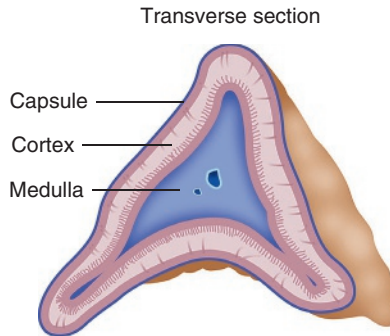
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### **EFFECTS**

Adrenocorticotrophic hormone stimulates the production of cortisol and androgens from the cortex of the adrenal glands (see Figures 1.6 and 1.7). It also leads to the production of aldosterone in response to increased concentrations of potassium ions, increased angiotensin levels or decreased total body sodium.



**FIGURE 1.6** Position of the adrenal glands



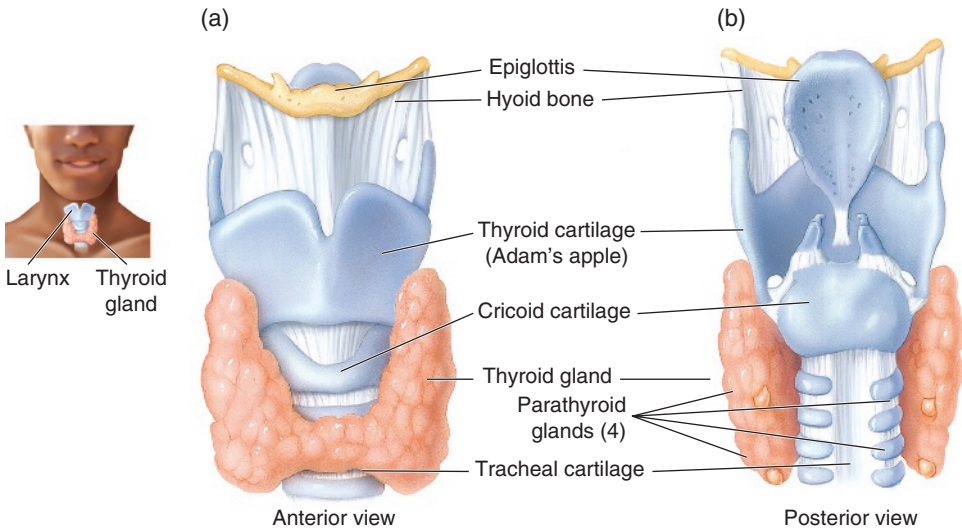
**FIGURE 1.7** Transverse section of an adrenal gland

## REGULATION

Adrenocorticotrophic hormone is secreted from the anterior pituitary in response to the secretion of corticotropin-releasing hormone (CRH) from the hypothalamus. Excitation of the hypothalamus by any form of stress leads to the release of CRH and the consequent release of ACTH and then cortisol. Cortisol will exert direct negative feedback on the hypothalamus and the anterior pituitary gland.

## THE THYROID GLAND

This gland is located in the neck, anterior to the larynx and the trachea, sited at the level of the fifth, sixth and seventh cervical vertebrae and the first thoracic vertebra. This is a butterfly-shaped gland (Figure 1.8) with two lobes found on either side of the thyroid cartilage and the upper incomplete cartilaginous rings of the trachea. It consists of a fibrous capsule that weighs around 25 g, it is brownish red in colour. Lying in front of the trachea is the narrow isthmus that joins the left and right lobes. Each of the lobes is cone-shaped, measuring approximately 5 cm long and 3 cm wide.



**FIGURE 1.8** The thyroid and parathyroid glands

The upper portions of the lobes are known as the upper poles and the lower ends are the lower poles. The lobes are made up of hollow spherical follicles that are surrounded by capillaries.

The blood supply to this gland is extensive (it is said to be a highly vascular gland). The arterial blood supply comes from the superior and inferior thyroid arteries. Venous return is through the thyroid veins that drain into the internal jugular vein. Principal innervation arises from the autonomic nervous system. Parasympathetic fibres come from the vagus nerves; sympathetic fibres are distributed from the superior, middle and inferior ganglia of the sympathetic trunk. These small nerves enter the gland accompanied by the blood vessels. Autonomic nervous regulation of the glandular secretion is not fully understood.

Resting against the posterior surfaces of each lobe are the parathyroid gland surfaces. These are nestled within the thyroid tissues. The recurrent laryngeal nerve rises in close proximity to the lobes of the gland. Made up of a single layer of epithelial cells, the follicles create a cavity housing thyroglobulin molecules bound to iodine molecules; these molecules are responsible for the formation of thyroid hormones.

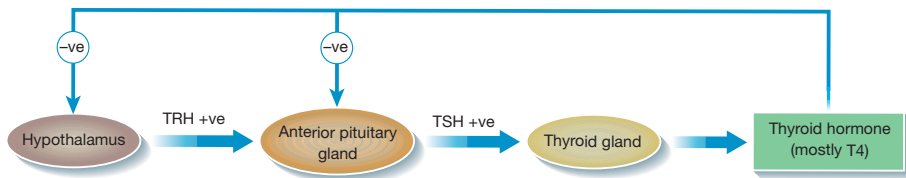
The gland releases two types of thyroid hormone: thyroxine (T<sub>4</sub>) and tri-iodothyronine (T<sub>3</sub>). Iodine is an essential requirement for the synthesis of these hormones. Dietary iodine is concentrated in the thyroid gland and is converted into iodine in the follicle cells. Thyroid-stimulating hormone (TSH) stimulates thyroid hormone production.

The primary hormone released by the thyroid gland is T<sub>4</sub>, which is converted into T<sub>3</sub> by the target cells. Thyroid hormones are required for normal growth and development. When there is deficiency of iodine, TSH is secreted in excess, which causes proliferation of thyroid gland cells that is accompanied by an enlargement of the gland.

In Table 1.3, the common effects associated with abnormal thyroid hormone secretion are outlined. The majority of cells in the body are affected by thyroid hormone, including an increase in basal metabolic rate and production of heat.

**Table 1.3** Effects associated with abnormal secretion of thyroid hormones

Increased secretion of T3 and T4 (hyperthyroidism)	Decreased secretion of T3 and T4 (hypothyroidism)
Increased basal metabolic rate	Decreased basal metabolic rate
Weight loss (despite good/increased appetite)	Weight gain (despite anorexia)
Tachycardia, palpitations, arrhythmia	Bradycardia
Excitability, nervousness, irritability	Tiredness, depression
Tremor	Numbness in the hands
Hair loss	Lifeless hair
Changes in menstruation patterns	Irregular menstrual periods
Goitre	Deep voice
Diarrhoea	Constipation
Exophthalmos	Feeling cold

**FIGURE 1.9** Control of thyroid hormone production and negative feedback mechanism

The regulation of thyroid hormone secretion occurs via a negative feedback mechanism that involves the amount of circulating hormone, the hypothalamus and the adenohypophysis (Figure 1.9).

The parafollicular cells of the thyroid gland secrete calcitonin. This hormone combats the action of the parathyroid glands by reducing the levels of calcium in the blood. If blood calcium becomes too high, calcitonin is secreted until calcium ion levels decrease to normal.

## PARATHYROID GLANDS

The parathyroid glands, consisting of four small masses of epithelial tissue enclosed within a connective tissue capsule situated at the posterior surface of the thyroid gland, play vital roles in regulating calcium levels in the body (see Figure 1.8). These roles include facilitating intestinal calcium absorption, promoting renal calcium absorption and stimulating osteoclast activity to release calcium from bones. When blood calcium levels drop, the parathyroid glands secrete parathyroid hormone to elevate calcium levels.

Hypoparathyroidism, characterised by insufficient parathyroid hormone secretion, results in heightened nerve excitability due to decreased blood calcium levels. This condition leads to spontaneous and continuous nerve impulses, triggering muscle contractions. Calcium is essential for the synthesis of clotting factors in the blood, a process that is monitored by cells within the gland. Decreased blood calcium levels prompt an increase in parathyroid hormone production and secretion.

## THE ADRENAL GLANDS

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The adrenal glands are positioned adjacent to the upper portion of each kidney. Each gland comprises an outer cortex and an inner medulla, analogous to the anterior and posterior lobes of the pituitary, which secrete distinct hormones. Although the adrenal cortex is indispensable for sustaining life, the medulla can be surgically removed without posing life-threatening consequences.

The hypothalamus exerts influence over both components of the adrenal gland through varying mechanisms. Negative feedback involving the hypothalamus and adrenocorticotrophic hormone regulates the adrenal cortex, whereas the medulla is regulated by nerve impulses originating from the hypothalamus.

### ADRENAL CORTEX HORMONES

The adrenal cortex is subdivided into three distinct regions, each responsible for producing a specific group of steroid hormones. The outermost region secretes mineralocorticoids, predominantly aldosterone, which conserve sodium ions and water in the body. Glucocorticoids, primarily cortisol, are secreted by the middle region, elevating blood glucose levels. The innermost region produces gonadocorticoids (sex hormones), including androgens and oestrogens, albeit in minimal amounts. In both sexes, the effects of these hormones are often obscured by those originating from the testes and ovaries. However, in females, the masculinising effects of androgen secretion may become apparent post-menopause as ovarian oestrogen levels decline.

### ADRENAL MEDULLA HORMONES

The adrenal medulla secretes two hormones, epinephrine and norepinephrine, in response to stimulation by sympathetic nerves, particularly during stressful circumstances. A deficiency of adrenal medulla hormones has negligible effects, while hypersecretion can lead to prolonged or continuous sympathetic responses.

## THE PANCREAS

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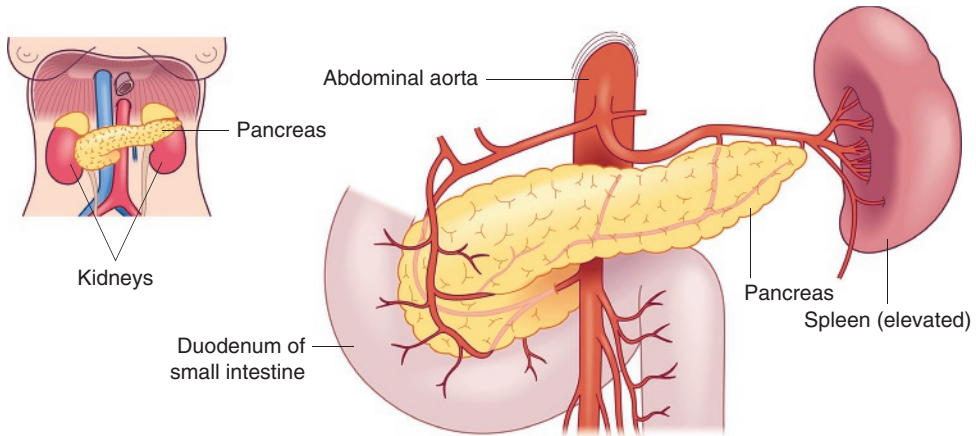
The pancreas is an elongated gland with a pale grey colour, positioned in the epigastric and left hypochondriac regions of the abdomen (see Figure 1.10). Situated close to the first section of the small intestine, the duodenum, the head of the pancreas lies nearby, while the body is situated behind the stomach. Extending towards the spleen, the tail of the pancreas completes its structure. Its length measures approximately 12–15 cm, and it weighs around 60g.

Blood supply to the pancreas comes from the splenic and mesenteric arteries. The splenic and mesenteric veins drain the pancreas and their drainage joins to form the portal vein. The pancreas is innervated by both the parasympathetic and sympathetic nervous systems. The secretion of insulin and glucagon is influenced by neural input from these systems.

This gland has both endocrine and exocrine functions. Most of the tissue within the pancreas is made up of exocrine tissue and associated ducts.

### THE EXOCRINE PANCREAS

The exocrine element of the gland consists of several lobules comprising acini that produce digestive enzymes. These enzymes are transported to the duodenum. The role of the



**FIGURE 1.10** The pancreas

exocrine component is to generate pancreatic juice abundant in enzymes essential for digesting carbohydrates, proteins and fats.

## THE ENDOCRINE PANCREAS

The endocrine portion is strewn within the exocrine tissue and comprises pancreatic islets, also known as the islets of Langerhans. These islets serve as the endocrine cells of the pancreas, secreting insulin and glucagon. Since the islets lack ducts, the hormones they produce diffuse directly into the bloodstream. Within the islets, there are three principal cell types, each responsible for synthesising a distinct hormone:

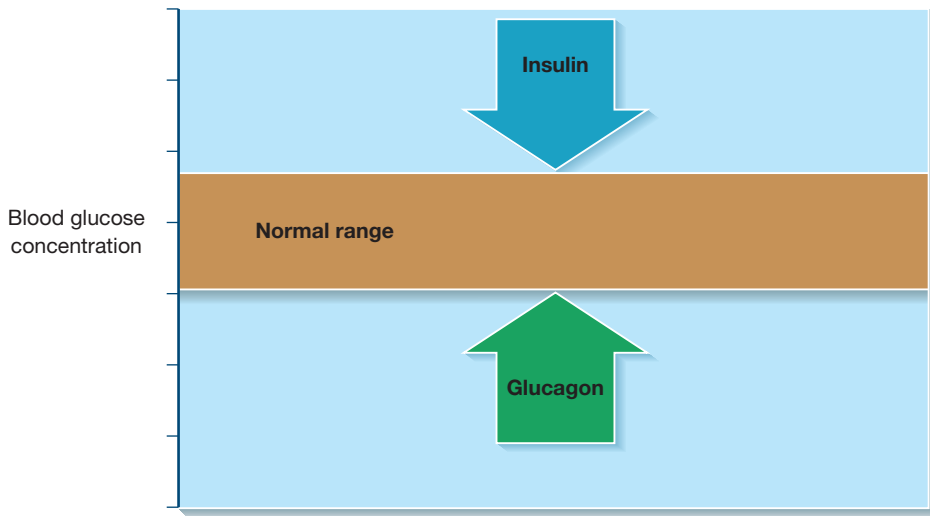
1. Alpha cells secreting glucagon
2. Beta cells secreting insulin – the most abundant of the three cell types
3. Delta cells secreting somatostatin

All three cell types – alpha, beta and delta cells – are specifically located within the islets of Langerhans, with the beta cells positioned centrally and surrounded by the alpha and delta cells.

## INSULIN

The hormone insulin plays an important role in various metabolic processes, including protein, mineral and lipid metabolism. One of its primary functions is to lower blood glucose levels (see Figure 1.11). Insulin facilitates the transport of glucose into muscle, adipose and other tissues (although the brain and liver do not rely on insulin for glucose uptake). Additionally, insulin prompts the liver to store glucose as glycogen.

The synthesis of insulin primarily occurs in response to elevated blood glucose levels, with increases in blood amino acids and fatty acids also exerting a stimulating effect. Conversely, when blood glucose levels decrease, insulin production and secretion decrease accordingly. This leads to a reduction in glycogen synthesis in the liver and activation of enzymes responsible for glycogen breakdown.



**FIGURE 1.11** Insulin and glucagon effects on blood glucose

## GLUCAGON

This hormone is also accountable for regulating normal blood glucose levels. Glucagon functions in direct opposition to insulin regarding blood glucose regulation (see Figure 1.11). It elevates blood glucose levels by promoting the conversion of glycogen into glucose in the liver and skeletal muscles. Factors such as low blood glucose levels, physical activity and reduced levels of somatostatin and insulin trigger the release of glucagon.

## SOMATOSTATIN

Somatostatin inhibits the release of insulin and glycogen; when this hormone is released, it has effects locally. The exact functions of this hormone are unknown.

## THE GONADS

The gonads serve as the principal reproductive organs: the testes in males and the ovaries in females. These structures are responsible for generating sperm and ova while also secreting hormones, classifying them as endocrine glands.

## THE OVARIES

The ovaries, as part of the female reproductive system, have crucial functions within the endocrine system. Their primary role is the production of female sex hormones, including oestrogen and progesterone, which play central roles in regulating the menstrual cycle, pregnancy and various aspects of female physiology.

Oestrogen and progesterone are steroid hormones and contribute to the development and function of the female reproductive organs and sex characteristics. At the onset of puberty, oestrogens promote breast development, fat distribution and maturation of reproductive organs such as the uterus and vagina. Progesterone causes the uterine lining to thicken

in preparation for pregnancy. Progesterone and oestrogens are responsible for the changes occurring in the uterus during the female menstrual cycle.

## THE TESTES

The testes, as part of the male reproductive system, play significant roles in both reproduction and the endocrine system. They are responsible for producing sperm cells and synthesising and secreting male sex hormones, primarily testosterone.

Male sex hormones are called androgens. The main androgen is testosterone, secreted by the testes; the adrenal cortex also produces a small amount. Testosterone production commences during fetal development, continuing for a short time after birth. It almost ceases during childhood, and then it resumes at puberty. This hormone is responsible for the growth and development of the male reproductive structures, increased skeletal and muscular growth, enlargement of the larynx accompanied by voice changes, growth and distribution of body hair and increased male sexual drive. The secretion of testosterone is regulated by a negative feedback system involving the release of hormones from the hypothalamus and gonadotrophins from the anterior pituitary.

## OTHER ENDOCRINE GLANDS

In addition to the major endocrine glands discussed in this chapter, several other organs have some hormonal activity as part of their function. These include the thymus, stomach, small intestines, heart and placenta (Table 1.4).

The organs identified in Table 1.4 play important roles in the endocrine system, secreting hormones that regulate various physiological processes and contribute to overall health and homeostasis in the body.

**Table 1.4** Other endocrine glands

Organ	Hormones produced
Thymus	Thymosin, a hormone produced by the thymus gland, has an important role in the development of the immune system.
Stomach	The lining of the stomach, the gastric mucosa, produces gastrin when food is present in the stomach. This stimulates the production of hydrochloric acid and the enzyme pepsin, which is used in the digestion of food.
Small intestine	The mucosa of the small intestine secretes secretin and cholecystokinin. When secreted, this promotes the pancreas to produce a fluid that neutralises the stomach acid. Cholecystokinin stimulates contraction of the gallbladder, releasing bile and stimulates the pancreas to secrete digestive enzymes.
Heart	The heart also acts as an endocrine organ as well as pumps blood. Special cells in the wall of the atria produce atrial natriuretic hormone or atriopeptin.
Placenta	The placenta develops as a source of nourishment and gas exchange for the developing fetus. It also serves as a temporary endocrine gland. One hormone it secretes is human chorionic gonadotropin. This signals the ovaries to secrete hormones to maintain the uterine lining so that it does not degenerate and slough off in menstruation.

Source: Adapted from Peate (2020).

## CONCLUSION

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The endocrine system is a complex network of glands and organs in the body that produce and secrete hormones. These hormones are chemical messengers they travel through the bloodstream to various target tissues and organs, where they regulate various physiological processes and maintain homeostasis.

The release of hormones can be triggered by nervous impulses, hormonal signals or alterations in the body's levels of ions and nutrients. Subsequent regulation of hormone secretion frequently involves negative feedback loops. For a hormone to exert its effects on a cell, that cell must possess receptors specific to the hormone. Nonetheless, it seems that virtually every cell in the body is influenced by the endocrine system.

## GLOSSARY OF TERMS

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**Adrenal glands:** A pair of endocrine glands located on top of each kidney, responsible for producing hormones such as cortisol, aldosterone, adrenaline and noradrenaline.

**Adrenaline (epinephrine) and noradrenaline (norepinephrine):** Hormones produced by the adrenal glands that are involved in the body's 'fight or flight' response, increasing heart rate, blood pressure and energy availability during times of stress.

**Endocrine system:** A network of glands and organs that secrete hormones into the bloodstream to regulate various bodily functions and maintain homeostasis.

**Follicle-stimulating hormone (FSH) and luteinising hormone (LH):** Hormones produced by the pituitary gland that regulate the function of the gonads (testes in males, ovaries in females), including the production of sperm and eggs, as well as the secretion of sex hormones.

**Glucagon:** A hormone produced by the pancreas that raises blood glucose levels by stimulating the breakdown of glycogen into glucose and promoting gluconeogenesis in the liver.

**Gonads:** The reproductive organs responsible for producing gametes (sperm in males, eggs in females) and sex hormones. In males, the gonads are the testes and in females, the gonads are the ovaries.

**Homeostasis:** The body's ability to maintain stable internal conditions, such as temperature, pH and blood glucose levels, through self-regulating mechanisms and feedback loops.

**Hormone:** Chemical messengers produced by endocrine glands that travel through the bloodstream to target cells or organs, where they regulate various physiological processes.

**Insulin:** A hormone produced by the pancreas that lowers blood glucose levels by facilitating the uptake of glucose into cells and promoting its storage as glycogen in the liver and muscles.

**Oestrogen:** A group of hormones primarily produced by the ovaries in females, responsible for the development of female secondary sexual characteristics and regulating the menstrual cycle.

**Ovaries:** The female reproductive organs responsible for producing eggs (ova) and female sex hormones, including oestrogen and progesterone.

**Pancreas:** A gland located behind the stomach that plays a dual role in the endocrine and digestive systems, producing hormones such as insulin and glucagon to regulate blood glucose levels.

**Parathyroid gland:** Four small glands located behind the thyroid gland that secrete parathyroid hormone (PTH), which regulates calcium and phosphate levels in the blood and bone metabolism.

**Pituitary gland:** A small gland located at the base of the brain that serves as the master gland of the endocrine system, producing and secreting various hormones that regulate growth, reproduction, metabolism and other bodily functions.

**Progesterone:** A hormone primarily produced by the ovaries in females, which plays a key role in preparing the uterus for pregnancy and maintaining pregnancy.

**Somatostatin:** A hormone produced by the hypothalamus and pancreas that inhibits the release of growth hormone from the pituitary gland and regulates the secretion of other hormones, including insulin and glucagon.

**Testes:** The male reproductive organs responsible for producing sperm and male sex hormones, including testosterone.

**Thymus:** A gland located in the chest behind the sternum that plays a role in the development and maturation of T lymphocytes (T cells), a type of white blood cell involved in the immune response.

**Thyroid gland:** A butterfly-shaped gland located in the neck that produces hormones such as thyroxine (T4) and triiodothyronine (T3), which regulate metabolism, growth and development.

**Thyroid-stimulating hormone (TSH):** A hormone produced by the pituitary gland that stimulates the thyroid gland to produce thyroxine (T4) and triiodothyronine (T3), regulating metabolism and energy production.

**Thyroxine (T4) and triiodothyronine (T3):** Hormones produced by the thyroid gland that regulate metabolism, energy production and the function of various organs and tissues in the body.

## MULTIPLE CHOICE QUESTIONS

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1. Which gland is considered the ‘master gland’ of the endocrine system?
  - a) Thyroid gland
  - b) Pancreas
  - c) Pituitary gland
  - d) Adrenal gland
2. Which hormone is produced by the adrenal glands in response to stress?
  - a) Insulin
  - b) Cortisol
  - c) Thyroxine
  - d) Glucagon
3. Where are the parathyroid glands located?
  - a) On top of the kidneys
  - b) Behind the thyroid gland

- c) Within the pancreas
  - d) In the brain
4. What is the primary function of insulin?
- a) To raise blood glucose levels
  - b) To stimulate glycogen breakdown
  - c) To lower blood glucose levels
  - d) To promote fat storage
5. Which hormone regulates calcium and phosphate levels in the blood?
- a) Insulin
  - b) Thyroxine
  - c) Parathyroid hormone (PTH)
  - d) Aldosterone
6. Which hormone is responsible for the development of male secondary sexual characteristics?
- a) Oestrogen
  - b) Progesterone
  - c) Testosterone
  - d) Glucagon
7. Which hormone is produced by the ovaries and is primarily responsible for preparing the uterus for pregnancy?
- a) Oestrogen
  - b) Progesterone
  - c) Testosterone
  - d) Insulin
8. What is the function of thyroxine (T4) and triiodothyronine (T3) hormones?
- a) To regulate calcium levels
  - b) To stimulate growth and development
  - c) To raise blood glucose levels
  - d) To promote fat breakdown
9. Which gland regulates metabolism and energy production in the body?
- a) Thyroid gland
  - b) Pituitary gland
  - c) Adrenal gland
  - d) Pancreas
10. Where is the pituitary gland located?
- a) In the neck
  - b) In the brain
  - c) In the abdomen
  - d) In the chest

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