HOMEOSTASIS – Chemical Signals and Maintaining Homeostasis

H. The Importance of the Endocrine System

- the endocrine system is a system of glandular tissues that produce and secrete special messenger molecules directly into the blood
- these special molecules are called **endocrine hormones** – they are produced in one part of the body, travel in the blood until they reach a target tissue cell, bind to it, and affect it in some way
- hormones are classified according to their activation site – they can be target, or non-target hormones
- several examples of non-target hormones are:
    - **growth hormone (GH) or somatotropin (STH)** – regulate the development of long bones
    - **insulin** – regulates blood sugar by increasing the permeability of cells to glucose
    - **epinephrine (adrenalin)** – produced in times of stress to promote action responses
- several examples of target hormones are:
    - **parathyroid hormone** -- regulates calcium levels in the body
    - **gastrin** – stimulates cells of the stomach to produce digestive enzymes

CHEMICAL CONTROL SYSTEMS

- the nervous system enables the body to adjust quickly to changes in the environment, whereas the endocrine system is designed to maintain control over a longer duration
- some examples of endocrine effects are the effects of sex hormones – they regulate and sustain development for many years
- the hypothalamus is the point of division between the nervous system and the endocrine system
- the hypothalamus innervates the pituitary gland, regulating its operation

- the endocrine glands, stimulated by the pituitary, secrete chemicals that affect the nerve activity of the hypothalamus (see Figure 2, p. 373)

- the word "hormone" means "to excite or set into motion" – they regulate biochemical processes either by slowing them down, or speeding them up

- when specific organs that produce a particular hormone are removed or do not function properly, the effects of its absence are quite noticeable in the organism, however, most times when a hormone is not produced any more due to a defect in the organ that produces it, other hormones often increase in concentration to help compensate for the disorder, so it is difficult to determine which hormone causes the effect when it is produced with others

- some glands may in fact produce many different hormones, which means that any effect cannot be attributed to a single hormone

- hormones need only be produced in small quantities to have an effect on tissue cells, and their concentrations vary throughout the day, which means that isolating them can be a "hit and miss" scenario

- just in the past few years, microscopy and chemical analysis techniques have increased our knowledge of the endocrine system (see Figure 3, p. 373)

- how?

  - radioactive tracers enable scientists to follow messenger chemicals from the organ in which they are produced to the target cells
  - radioactive tracers enable researchers to discern how the chemical messenger is broken down into other compounds and removed as waste
  - with new chemical analysis equipment, scientists can determine and measure the concentration of even the smallest amounts of a hormone as the body responds to changes in the external and internal environments
  - high-power microscopes provide a clearer picture of the structure of cell membranes and allow a better understanding of how chemical messengers attach themselves to target sites

1. Chemical Signal Molecules: The Steroid and The Protein Hormones

- it is important to note that hormones don't affect all cells – cells may have receptors for one hormone, but not for another

- for example, liver cells and muscle cells have many receptor sites for insulin, whereas less active cells like bone and cartilage cells, have less

- there are two types of hormones that differ both in chemical structure and action:

  - **steroid hormones**

    - made of cholesterol

    - includes male and female sex hormones and cortisol

    - composed of complex fused rings of carbon, hydrogen, and oxygen molecules and are not soluble in water but are soluble in fat

    - these hormones diffuse from the capillaries into the interstitial fluid and then into the target cell, where they combine with receptor molecules located in the cytoplasm

    - the hormone-receptor complex then moves into the nucleus and attaches to a segment of chromatin that has a complementary shape
    - the hormone then activates a gene that sends a message to the ribosomes in the cytoplasm to begin producing a specific protein
    - Figure 4, p. 374 illustrates this whole process

  - **protein hormones**

    - includes insulin and growth hormone
    - contain chains of amino acids varying in length that are soluble in water
    - protein hormones don't diffuse into a cell like steroid hormones do – instead, specific hormones combine at specific receptor sites
    - some form a hormone-receptor complex that activates the production of an enzyme called adenyl cyclase, which in turn, causes the cell to convert ATP into **cyclic adenosine monophosphate (cyclic AMP)**
    - the cyclic AMP functions as a messenger , activating enzymes in the cytoplasm to carry out their normal functions
    - Figure 5, p. 375 illustrates this whole process
    - for example when TSH attaches to the receptor sites in the thyroid gland, cyclic AMP is produced in thyroid cells, not anywhere else – because other tissue cells don't have receptor sites for TSH – the cyclic AMP in the thyroid cell activates enzymes, which begin producing **thyroxine**, a hormone that regulates metabolism

2. The Master Gland: The Pituitary

- it is often referred to as "the master gland" because it exercises control over other endocrine glands
- the pituitary gland is like a small sac-like structure that is connected to the hypothalamus via a stalk
- Figure 6, p. 376 illustrates the pituitary
- basically, the pituitary gland produces and stores hormones
- the hypothalamus stimulates the release of hormones by the pituitary gland by way of nerves
- the pituitary is composed of two separate lobes: (see Figure 6, p. 376)

  - the posterior lobe (lobe in the back)

    - stores and releases ADH and oxytocin, both produced by the hypothalamus
    - ADH acts on the kidneys and helps regulate body water, and oxytocin initiates strong uterine contractions during labor
    - the hormones travel by way of specialized nerve cells from the hypothalamus to the pituitary

- the pituitary stores the hormones, releasing them in the blood when necessary

- the anterior lobe (lobe in the front)

  - stores and releases ADH and oxytocin, both produced by the hypothalamus
  - hormones are secreted from the nerve ends of the cells of the hypothalamus
  - and transported in the blood to the pituitary gland
  - most of these hormones cause the pituitary to release hormones, which are often carried by the blood to target tissues
  - sometimes the hypothalamus releases certain substances called factors that inhibit the anterior lobe of the pituitary from secreting substances
  - for example, the release factor dopamine inhibits the secretion of prolactin (PRL), a pituitary hormone that stimulates milk production in women who have given birth, and the release factor somatostatin inhibits the secretion of somatotropin, the pituitary hormone associated with growth of the long bones
  - the regulating hormone TSH, for example, is stored in the anterior pituitary
  - the anterior pituitary is also responsible for secreting reproductive-stimulating hormones, growth-stimulating hormones, prolactin, and adrenocorticotropic hormone (ACTH), the hormone that stimulates the adrenal cortex

- the hormones secreted by the pituitary are:

Hormone	**Target**	**Primary Function**
Anterior lobe		
Thyroid-stimulating hormone (TSH)	thyroid gland	• stimulates release of thyroxine form the thyroid • thyroxine regulates cell metabolism
adrenocorticotropic hormone (ACTH)	adrenal cortex	• stimulates release of hormones involved in stress responses
somatotropin (STH) or growth hormone (GH)	most cells	• promotes growth
follicle-stimulating hormone (FSH)	ovaries, testes	• in females, stimulates follicle development in ovaries • in males, promotes the development of sperm cells in testes

lutenizing hormone (LH)	ovaries, testes	• in females, stimulates ovulation and formation of the corpus leteum • in males, stimulates the production of sex hormone testosterone
prolactin	mammary glands	• stimulates and maintains mile production in lactating females
Posterior lobe		
oxytocin	uterus, mammary glands	• initiates strong contractions • triggers milk release in lactating females
antidiuretic hormone (ADH)	kidneys	• increases water reabsorption by kidneys

Homework: **1-4, p. 377**

I. Blood Sugar Level Hormones

- the pancreas is divided into two types of tissues – those that produce digestive enzymes, and those that produce hormones
- the structures that produce hormones are located in structures called islets of Langerhans
- there are more than 2000 tiny islets, each containing thousands of cells
- the cells are either beta or alpha
- beta produce **insulin**, and alpha produce **glucagons**
- for example, after a meal, glucose levels rise, and the appropriate amount of insulin is released by beta cells of the pancreas
- Figure 1, p. 378 illustrates this
- the effect is that the membrane of cells of the muscles, the liver, and other organs becomes more permeable to glucose, drawing it out of the blood
- in the liver, glucose is converted to glycogen – the storage form of glucose
- glucagons and insulin have antagonistic effects
- when blood levels are low, glucagon is released by the alpha cells of the islets of Langerhans
- during periods of fasting, glucagon is released and promotes the conversion of glycogen to glucose, which is released in the blood – raising the blood sugar level

I. DIABETES

- a person with diabetes cannot produce enough insulin to regulate blood glucose levels
- if untreated, it can cause blindness, kidney failure, nerve damage, and nontraumatic limb amputation
- if a deficiency of insulin exists, blood sugar rises substantially, resulting in **hyperglycemia** – high blood sugar
- the symptoms associated with hyperglycemia are:
  - the kidneys are unable to reabsorb all the blood glucose that is filtered through them, resulting in glucose in urine
  - glucose in the nephron draws out water out of the blood, resulting in dehydration and thirst
  - low energy levels – since the permeability of glucose into the cells does not increase due to lack of insulin, less glucose is burned and less ATP is made – the cells basically starve or resort to consuming fats and proteins for energy – proteins and fats are not broken down as easily as are carbohydrates – the byproducts of this kind of metabolism can build up to toxic levels, such as acetone (which can in fact be smelled on the breath of an untreated diabetic
- there are three types of diabetes mellitus:

1. Type 1 (juvenile onset diabetes):
   - the inability to produce insulin due to an early degeneration of the beta cells in the islets of Langerhans
   - happens in early childhood
   - insulin must be taken in order to survive
   - accounts for 10% of the diabetes cases
2. Type 2 (adult onset diabetes):
   - results from a decrease in insulin production or an ineffective use of the insulin that the body does produce
   - diagnosed in adulthood
   - can be controlled with diet, exercise, and sulfanomide drugs – drugs that stimulate the beta cells of the islets of Langerhans
   - accounts for 90% of the diabetes cases
3. Gestational Diabetes

- a temporary condition that occurs in 2% - 4% of pregnant moms
- this condition does increase the risk of type 2 diabetes in the mom, and type 1 in the unborn child

Research and Technological Developments for the Treatment of Diabetes

- insulin was discovered by Banting and Best, two U of T scientists
- they removed the pancreas from dogs and noticed the same symptoms that people experienced who had diabetes
- when they injected islet cells from extracted pancreatic tissue into the bloodstream of dogs whose pancreas was removed, they notice that the diabetic symptoms ceased
- after isolating the molecule that helped eliminate diabetic symptoms, they called it insulin
- Type 1 diabetes is the second leading cause of blindness in Canada
- 50 000 Canadians are affected by other side effects of Type 1 diabetes such as kidney and heart failure, stroke, and peripheral nerve damage
- insulin is only a control for people with diabetes…..it's not a cure!
- this means that it cannot necessarily prevent blindness or strokes to occur
- one treatment that has had a better effect on diabetic patients is the transplantation of islet cells
- this has helped replace the body's natural mechanism for monitoring and producing insulin – it more resembles the natural process of insulin production and blood glucose regulation, and also helps to reverse the effects of diabetes
- one of the obstacles of this process is immune rejection
- if anti-rejection drugs are given, they often cause toxic effects to islet function
- if immunosuppression treatment is administered, the person is susceptible to infection
- there is a team of researchers in Alberta that have developed a special treatment called the **Edmonton Protocol**
- this treatment uses a steroid-free combination of three drugs to prevent rejection of the transplanted islets and to prevent diabetes from returning
- the success of the treatment depends on new methods of isolating and transplanting pancreatic cells
- the procedure is non invasive and has few risks – islets are extracted from a donor and infused into the recipient's liver by way of a large vein
- the skin is frozen, a large needle is used, and an ultrasound helps the doctor work through the procedure
- the islets are transplanted in the liver because when it is damaged by the injection process, it is able to regenerate new blood vessels and cells
- as it does this, it permanently connects the new islet cells to the liver

II. ADRENAL GLANDS

- the adrenal glands are found above each kidney
- there are two parts to the gland, both of which are enclosed in one shell:

1. the inner gland called the **adrenal medulla** – which is regulated by the nervous system

    - produces two hormones – **epinephrine** (adrenalin) and **norepinephrin** that respond to **short-term stress** (see Figure 5, p. 382)
    - like the nervous system, the adrenal medulla produces epinephrine
    - the sympathetic nerves stimulate the adrenal medulla to produce these hormones and release them into the blood in times of stress
    - the effects of these hormones in the blood are as follows:

        - when they exist in the blood, they cause the blood sugar level to rise as glycogen is quickly converted to glucose – a quick energy source
        - heart rate increases, breathing rate increases, and cell metabolism increases
        - blood vessels dilate, allowing more oxygen and nutrients to reach the tissues
        - iris of the eye dilates to allow more light to reach the retina, which in turn, increases visual perception and awareness of external environment

2. the outer land, that encases the adrenal medulla called the **adrenal cortex** – which is regulated by hormones

    - produces three different types of hormones – **glucocorticoids**, **mineralocorticoids**, and small amounts of **sex hormones** that respond to **long-term stress** (see Figure 5, p. 382)
    - long-term stress response works as follows:

        - the hypothalamus sends a releasing hormone to the anterior lobe of the pituitary, which stimulates the release of a hormone called **corticotrophin**, also known as adrenocorticotropic hormone (ACTH)
        - the blood carries the ACTH to the adrenal cortex
        - the ACTH influence the adrenal cortex to release mineralocorticoids, as well as glucocorticoids, which are in turn, carried to target cells in the liver and muscles

        - ***glucocorticoids***

- ✓ one of the most important glucocorticoids is **cortisol** because of its unique association with blood sugar levels
- ✓ cortisol increases the amount of amino acids in the blood in an attempt to help the body recover from stress
- ✓ the amino acids are converted to glucose by the liver, thereby raising the level of blood sugar, which in turn, increases the amount of energy reserves in the blood
- ✓ fats are converted to fatty acids, producing yet another energy source for the body
- ✓ any non-converted amino acid is readily available for the protein manufacturing to repair damaged cells

➢ ***mineralocorticoids***

- ✓ **aldosterone** is the most important minerlocorticoid
- ✓ aldosterone in the blood increases sodium retention and water reabsorption by the kidneys, thereby helping to maintain body fluid levels

Homework: **1-7, p. 383.**

J. Hormones Affecting Metabolism

- three different glands affect metabolism:

1. the **thyroid** gland, which regulates body metabolism or the rate at which blood glucose is oxidized, through the action of the hormones that it produces -- **triiodothyronine**, **thryroxine**, and **calcitonin**
2. the **parathyroid** glands, which regulates calcium and phosphate levels in the blood through the action of the hormones it produces -- **parathyroid hormone**
3. the **anterior pituitary** gland, which influences the growth of long bones and accelerates protein synthesis through the action of the hormone it secretes -- **growth hormone (somatotropin)**

A. The Thyroid Gland

- ✓ Figure 1, p. 384 illustrates the thyroid gland
- ✓ located at the base of the neck, in front of the windpipe and trachea
- ✓ the thyroid secretes three hormones: thyroxine (T4) and triiodothyronine (T3), which both regulate body metabolism and the growth and differentiation of tissues, and calcitonin, which acts on the bone cells to lower the level of calcium found in the blood
- ✓ differential amounts of T4 and T3 between individuals explains why some people can eat like pigs and never gain weight!
- ✓ those that eat and never gain, produce high levels of T4 and T3, a condition called hyperthyroidism

- ✓ these people often feel warm due to the higher respiratory rates that occur because of increased glucose oxidation
- ✓ those that gain weight easily due to low levels of T4 and T3 production have hypothyroidism – glucose is not consumed at normal rates, and it gets stored in the liver -- once the liver reserves are full, then the body converts sugar into fat
- ✓ people who secrete low levels of T4 and T3 often experience muscle weakness, cold intolerance, and dry skin and hair (see Figure 2, p. 384)
- ✓ the control of T4 and T3 is through negative feedback (see Figure 3, p. 385)
- ✓ receptors in the hypothalamus are activated when the metabolic rate decreases
- ✓ nerve cells secreted thyroid releasing hormone (TRH), which stimulates the pituitary to release TSH
- ✓ the TSH is carried through the blood and reaches the thyroid gland, which in turn, releases T4 and T3
- ✓ the T4 and T3 stimulate sugar oxidation
- ✓ when levels of thyroxine and triiodothyronine increase to a critical point, they cause the pathway to be turned off by inhibiting the release of TRH from the hypothalamus, thus turning off the production of TSH from the pituitary

B. The Parathyroid Gland

- ✓ four glands are hidden within the larger thyroid gland
- ✓ without these glands symptoms such as muscle twitching (tetanus), abnormal calcium levels, and easily excitable nerves
- ✓ parathyroid glands are not stimulated by nerves or other hormones, like most endocrine glands are – instead the parathyroid gland responds directly to chemical changes in their immediate surroundings
- ✓ low calcium levels in the blood stimulate the release **parathyroid hormone (PTH)** (see Figure 5, p. 386)
- ✓ when PTH increases in the blood, calcium levels in the blood increase, and phosphate levels decrease
- ✓ PTH acts on three different organs: the kidneys, the intestines, and the bones
- ✓ it causes the kidneys and gut to retain calcium while promoting calcium release from bone
- ✓ the bone cells break down, and calcium is separated from phosphate ions
- ✓ then calcium is reabsorbed and returned to the blood while phosphate is excreted in the urine
- ✓ the result is that much of the body's calcium that is dissolved in the plasma is conserved
- ✓ as PTH increases, the absorption of calcium increases
- ✓ once the calcium levels are elevated, the release PTH is inhibited
- ✓ if PTH levels are too high, then abnormal calcium levels are removed from bone – this can cause breakdown of bone, and stones to develop in the kidneys
- ✓ PTH also helps activate vitamin D – low levels of vitamin D can cause a disease called rickets (see Figure 6, p. 386) – too little calcium and phosphorous are absorbed from foods and the bones develop improperly

C. Anterior Pituitary

- ✓ low secretion of GH during childhood can result in dwarfism; high secretions result in gigantism
- ✓ the effect is on the whole body, but mostly on cartilage and bone cells
- ✓ if the production of GH continues even after the cartilage plates are fused, the long bones don't respond, but other bones do, such as the jaw, forehead, fingers, and toes
- ✓ this disorder is known as **acromegaly** – the broadening of facial features
- ✓ excessive GH levels also affect cells by increasing their number (**hyperplasia**) and their size (**hypertrophy**)
- ✓ this is because GH promotes protein synthesis and not protein degradation
- ✓ as a person ages, GH production drops, which could explain why cellular repair and protein replacement is compromised – as one ages, protein is replaced by fat, the growth of which is not influence by GH
- ✓ in fact GH increases fatty acid levels in the blood by promoting the breakdown of fats held in adipose tissue – this is so the muscles use the fatty acids instead of glucose as a source of metabolic fuel
- ✓ this explains why quick growth spurts are often accompanied by a loss of body fat
- ✓ by switching to fat and not using up blood glucose, the glucose level rises in the blood – this is very important for the developing and growing brain
- ✓ GH also stimulates the production of insulin-like factors, which are produced by the liver, which stimulate cell division in the growth plates, causing the elongation of the skeleton

- table 1, p. 387 lists the hormones that affect metabolism

Homework: **1-9, p. 387**

K. Adjustments to Stress

- both the nervous system and the endocrine system respond to the exposure to long-term stress
- any disruption of the external and internal environment causes the body to undergo a general adaptation syndrome
- the nervous system increases the heart rate and diverts blood to the needed muscles, while the endocrine system releases hormones that provide a more sustained response to the stimulus
- here are some of the hormonal changes in response to stress:

HORMONE	CHANGE	ADJUSTMENT
epinephrine	increases	• mobilizes carbohydrates and fat energy strores

		• increases blood glucose and fatty acids • accelerates heart rate and the activity of the respiratory system
cortisol	increases	• mobilizes energy stores by converting proteins to glucose • elevates blood amino acids, blood glucose, and blood fatty acids
glucagons	increases	• coverts glycogen to glucose
insulin	decreases	• decreases the breakdown of glycogen in the liver

- basically, stress hormones provide more blood glucose to help cope with increased energy requirements
- the release of insulin is inhibited in order to maintain the state hyperglycemia caused by stress
- the renin-angiotensin-aldosterone pathway is activated by the nervous system during stress which increases sodium permeability of the nephron, causing more water to be reabsorbed into the blood stream – this helps to maintain increased blood volume so that the blood pressure is elevated, which in turn, increases blood flow
- the hypothalamus is activated, which causes an increased release of ADH, making the distal tubule more permeable to water – this also helps maintain body fluids
- athletic competition has the same effect as stress – the heart rate increases, greater oxygen delivery to the tissues for cellular respiration, increase blood sugar and fatty acid levels to provide more fuel for metabolic processes, which in turn, helps to make more ATP
- prolonged exposure to such responses can cause further problems:

NEW OPERATING LIMIT	**PROBLEM CREATED**
higher blood sugar	• alters osmotic balance between blood and extracellular fluids; can lead to increased fluid uptake by the blood and increased blood pressure • increased water loss from nephron
increased blood pressure	• possible rupture of blood vessels due to higher pressure • increased blood clotting

Increased heart rate	• can lead to higher blood pressure • possible destruction of heart muscle

1. PROSTAGLANDINS

- prostaglandins are like mediator cells that detect local changes in the immediate environment of cells and have a pronounced effect in a small localized area
- there are more than 16 different types of prostaglandins that alter cell activity in a manner that counteracts or adjusts for the change
- the secretions of prostaglandins is constant and in low concentrations normally, however they will increase when changes take place
- when they are released, they tend to be absorbed rapidly by surrounding tissues – few of the prostaglandin molecules are absorbed by capillaries and carried in the blood
- effects of prostaglandins:
    - when the body is stressed, there are two different prostaglandins that can adjust blood flow, triggered by the release of epinephrine
    - other prostaglandins respond to stress by triggering the relaxation of smooth muscle in the passages leading to the lung
    - during allergic reactions, they are released to help dilate blood vessels, which increases blood flow

2. ENHANCED SPORTS PERFORMANCE

- for a long time, it has been known that caffeine can produce the same effects as epinephrine – increased heart rate, blood pressure, and alertness
- **anabolic steroids** – chemicals that mimic many muscle-building traits of the sex hormone testosterone
- anabolic steroids have been known to improve physical performance for short/quick spurts like weightlifting or sprinting, however, they do not provide increased agility or skill level, nor do they enhance the ability of the cardiovascular system to deliver oxygen – they in fact harm athletes that require high levels of aerobic activity
- their effect on injury recovery rates is controversial
- a few risks have been associated with taking anabolic steroids to enhance performance:
    - prematurely fuse growth plates in the long bones – thereby stunting growth
    - mood swings and feelings of rage
    - in males – baldness, development of breasts in males, shrinking testes, reduced sperm count

- in females – growth of facial hair, breast reduction, changes in reproductive cycle
- in both males and females – acne, bad breath, high blood pressure, liver disease, cancer

- other sports enhancement drugs like beta blockers, are used as well – they have a calming effect
- sophisticated tests are used to help determine whether these particular enhancement drugs are taken or are naturally produced in the body
- the following are banned performance-enhancing drugs by the International Olympic Committee:

DRUG	ADVANTAGE	SIDE EFFECTS
Anabolic Steroids		
• stanozolol, androstenedoil, nandrolone	• increase muscle mass and strength	• decreased growth, kidney problems, hair loss, oily skin, acne, shrinking testes, infertility, and cancer
Peptide Hormones		
• growth hormone	• decrease fat • improve muscle mass	• diabetes, abnormalities of bones, liver, heart, and kidneys, and liver disease • high blood pressure
• erythropoietin (EPO)	• increases red blood cells that carry greater oxygen	• thickens the blood increasing chances of stroke • heart problems
Beta Blockers		
• atenolol, bisoprolol, nandolol	• slows heart rate	• reduces cardiac response time • makes skin more sensitive to sun
Stimulants		
• amphetamine	• increases endurance • relief of fatigue • improves reaction time	• irregular heart beat, nervousness, difficulty sleeping
• caffeine	• increases alertness	• increased blood pressure

• pseudoephedrine	• increases alertness	• narrows blood vessels and increases blood pressure
Masking Agents		
• bromantan	• makes steroid difficult to detect	• unknown
• probenecid	• stops excretion of steroids for a few hours	• headache, tissue swelling, nausea

Homework: **1-9, p. 392**

L. Reproductive Hormones

1. THE MALE REPRODUCTIVE SYSTEM

- Figure 1, p. 393 shows a detailed view of the male reproductive system
- interstitial cells (cells found between the seminiferous cells) produce **androsterone** and **testosterone**
- testosterone:
    - stimulates **spermatogenesis** – the process by which spermatogonia divide and differentiate into mature sperm
    - influences the development of secondary sex characteristics at puberty
    - stimulates the maturation of the testes and penis
    - is associated with sex drive
    - promotes the development of facial and body hair
    - promotes the growth of the larynx, causing the lowering of the voice
    - promotes the strengthening of the muscles
    - increases the secretion of body oils – linked to the development of acne and body odour

- the hypothalamus and the pituitary gland in the brain control the production of sperm and male sex hormones in the testes
- Figure 2, p. 394 illustrates how negative feedback ensures that adequate numbers of sperm cells and constant levels of testosterone are maintained:
    - **gonadotropic hormones** are released and stored by the pituitary gland, which in turn, regulates the function of the testes
    - male **follicle-stimulating hormone (FSH)** stimulates the production of sperm cells in the seminiferous tubules
    - male **luteinizing hormone (LH)** promotes the production of testosterone by the interstitial cells

- at puberty, the hypothalamus secretes the **gonadotropin-releasing hormone (GnRH)**, which activates the pituitary gland to secrete and release FSH and LH
- the subsequent effects are as follows:

  - FSH acts directly on the sperm-producing cells of the seminiferous tubules
  - LH stimulates the interstitial cells to produce testosterone
  - testosterone increases sperm production

- when high levels of testosterone result, the hypothalamus detects it, and through negative feedback, the process is regulated
- the feedback loop for sperm production is not well understood – it is believed that the FSH acts on support cells, known as Sertoli cells, which produce a peptide hormone called **inhibin** that sends a feedback message to the pituitary, inhibiting production of FSH
- Table 1, p. 394, lists the structure and function of the male reproductive system

2. THE FEMALE REPRODUCTIVE SYSTEM

- more complicated than the male's
- one egg matures each month
- hormone levels fluctuate through the reproductive years, which end at menopause
- Table 2, p. 395, lists the structure and function of the female reproductive system

a. Oogenesis and Ovulation

- ovaries contain fibrous connective tissue and small groups of cells called **follicles**, of which there are two types:

  - primary oocyte -- contains 46 chromosomes, and undergoes meiosis and is transformed into a mature oocyte, or ovum
  - granulose cells – provide nutrients for the oocyte

- unlike the testes, which replenish sperm all the time, the female ovaries undergo continual decline after the onset of puberty
- at puberty, females contain about 400 000 follicles
- in each female reproductive cycle, many follicles develop, but usually only a single follicle becomes dominant and reaches maturity
- approximately 400 eggs will mature during a female's reproductive stage
- few follicles remain by the time a woman reaches menopause
- the actual age of follicles can be linked to higher incidence of genetic defects in children produced by older women

- this means that the longer the follicle lives, the greater the chance of genetic damage
- menopause marks the end of a female's reproductive life and signals a drop in the production of female hormones
- Figure 5, p. 396 illustrates the process of **ovulation**:
  - pituitary hormones regulate the events of follicle development, ovulation, and the formation of the corpus leteum
  - a hormone produced by the pituitary gland causes nutrient follicle cells surrounding the primary oocyte to divide
  - the primary oocyte undergoes meiosis I, and the majority of the cytoplasm and nutrients move to one of the poles and form a secondary oocyte, which contains 23 chromosomes
  - the remaining cell, called the polar body, receives little cytoplasm and dies
  - as the secondary cells surrounding the secondary oocyte develop, a fluid-filled cavity forms, and the dominant follicle pushes outward, ballooning the outer wall of the ovary
  - as blood vessels along the wall of the ovary collapse, the wall weakens, and the outer surface of the ovary bursts, causing the secondary oocyte is released
  - the surrounding follicle cells remain within the ovary and are transformed into the **corpus luteum** – this secretes hormones necessary for pregnancy, only if the egg is fertilized within 10 days
  - if no fertilization takes place, then the corpus luteum degenerates, leaving behind a scar called the corpus albicans
  - the secondary oocyte enters the oviduct and begins meiosis II, which is completed by the entry of the sperm into the egg cell
  - the division of cytoplasm in meiosis II is also unequal – the cell that retains most of thy cytoplasm and nutrients is called the mature oocyte or ovum, and the other one deteriorates and is called a polar body

b. Menstrual Cycle

- the entire cycle takes 28 days, with some degree of variation
- Table 3, p. 398 summarizes the entire cycle
- as seen in Figure 6, p. 397, the cycle is divided into four distinct phases:
  - flow phase
    - the shedding of the endometrium or menstruation
    - this phase marks the beginning of the menstrual cycle
    - lasts for approximately 5 days

- follicular phase
    - characterized by the development of the follicles within the ovary
    - as the follicle cells develop, the hormone **estrogen** is secreted and its concentration increases
    - takes place during days 6 to 13 of the cycle
- ovulatory phase
    - estrogen levels decline and the egg bursts form the ovary and follicular cells differentiate into the corpus luteum
- luteal phase
    - estrogen levels are restored as the corpus luteum develops
    - occurs between days 15 and 28
    - prepares the uterus to receive a fertilized egg as the corpus luteum releases both estrogen and **progesterone** – which does two things:
        1. stimulates the endometrium and prepares the uterus for an embryo
        2. inhibits further ovulation and prevents uterine contractions – if progesterone levels fall, uterine contractions would begin
    - if fertilization does not occur, the concentration of estrogen and progesterone drop, thereby causing weak uterine contractions – which, in turn, cause the endometrium to pull away from the uterine wall
    - this shedding marks the end of the cycle and the beginning of the next

c. Hormonal Control of the Female Reproductive System

- the hypothalamus-pituitary complex regulates the production of estrogen and progesterone – the hormones of the ovary
- the female's gonadotropins are the same as the male's – **FSH** and **LH**
- they both regulate the control of hormones produced by the ovaries – estrogen and progesterone
- the amount of estrogen and progesterone, in turn, regulate the release of FSH and LH in a negative feedback loop
- Figure 7, p. 398 illustrates how ovarian hormones are regulated:

- at puberty, GnRH is released from the hypothalamus
- this activates the pituitary, which releases and stores FSH and LH
- during the follicular phase, the blood carries the FSH secretions to the ovary, where the follicle development is stimulated
- the follicles then secrete estrogen, which initiates the development of the endometrium
- with the increase of estrogen, a few things happen simultaneously:

1. the negative feedback loop shuts down the production of FSH, which ends the follicular phase

2. a positive message is exerted on the LH-producing cells of the pituitary gland to secrete LH in order to stimulate ovulation and force the remaining follicular cells to become the corpus luteum

- the corpus luteum secretes both estrogen and progesterone, which both further develop the endometrium
- as these two hormones build up, a second negative feedback mechanism kicks in – FSH and LH are inhibited
- this causes the corpus luteum to degenerate, which results in menstruation
- Table 4, p. 399 lists the female reproductive hormones and describes the function of each

- there are a lot of similarities between male and female systems:

  - both produce the same GnRHs – FSH and LH
  - both systems can produce androgens and estrogens
  - male characteristics are merely the result of having more adrogens than estrogens
  - this is because males excrete female hormones at an accelerated rate – whereas females don't
  - the relative abundance of male and female hormones has noticeable effects on the physiology of an animal
  - for example:

    - castration of various animals increases the body mass and makes males less aggressive
    - injection of female hormones causes the meat of animals to be more tender
    - injection of estrogen-like compounds slows the development of the male's prostate gland, thus reducing the size of cancerous tumors

Homework: **1-13, p. 399**