10.7 The Reproductive Hormones

gonads glands responsible for the production of sex hormones, as well as the egg and sperm cells; called testes in males and ovaries in females

androgens predominantly male sex hormones, including testosterone, that control sexual development and reproduction

The reproductive system in vertebrates involves separate male and female reproductive systems. The sex glands or **gonads**—the testes in males and the ovaries in females—are the primary source of sex hormones. The steroid hormones that they produce—the **androgens,** estrogens, and progestins—have similar functions in regulating the development of male and female reproductive systems, sexual characteristics, and mating behaviour. Both males and females produce all three types of hormones, but in different proportions. Androgen production is predominant in males, whereas estrogen and progestin production is predominant in females.

The Female Reproductive System

Human females have a pair of ovaries (singular: *ovary*) suspended in the abdominal cavity (**Figure 1**). As well as producing the female gametes (*ova*, or *eggs*), the ovaries produce estrogens, which are steroid hormones that stimulate and control the development and maintenance of the female reproductive system. The principal estrogen, called estradiol, stimulates the maturation of the sex organs at puberty; the development of secondary sexual characteristics such as breast development, the growth of body hair, and the widening of the pelvis; and the development of the sex drive. The ovaries also produce progestins. The main progestin is progesterone, which is the steroid hormone that prepares and maintains the uterus for the implantation of a fertilized egg and the subsequent growth and development of an embryo. The synthesis and secretion of progesterone by cells in the ovaries are controlled by the release of follicle-stimulating hormone (FSH) from the anterior pituitary. The release of FSH and luteinizing hormone (LH) is controlled by **gonadotropin-releasing hormone (GnRH)** from the hypothalamus. CAREER LINK

gonadotropin-releasing hormone (GnRH) a hormone released by the hypothalamus that controls the release of LH and FSH from the anterior pituitary, which, in turn, control the synthesis and release of the male or female sex hormones in the gonads

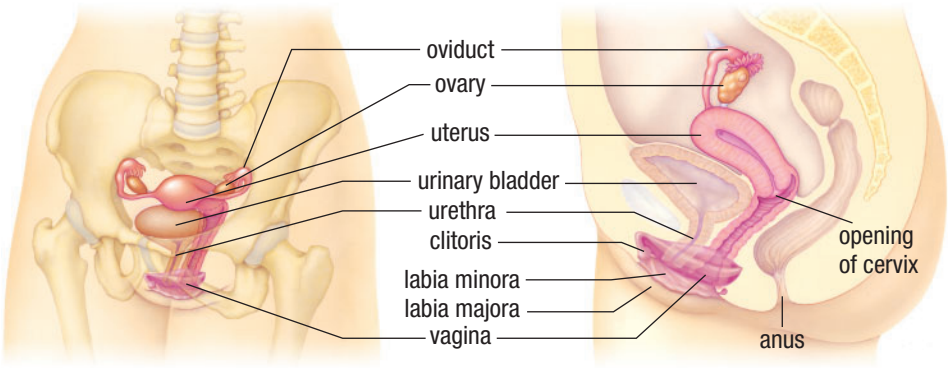

Figure 1 The reproductive organs of a human female

An oviduct leads from each ovary to the uterus. The uterus is a hollow structure with walls that contain smooth muscle. It is lined by the endometrium, which is formed by layers of connective tissue with embedded glands and a rich supply of blood vessels. If an egg is fertilized and begins to develop, it must implant in the endometrium to continue developing. The lower end of the uterus, called the cervix, opens into a muscular canal, called the vagina, which leads to the exterior. Sperm enter the female reproductive tract through the vagina. At birth, the baby passes from the uterus through the vagina to the outside.

oogenesis the production of eggs, or ova, from oocytes in the ovaries by two meiotic divisions

The process by which the ovaries produce and release eggs, or ova, is called **oogenesis** and is controlled by hormones produced by the pituitary gland. In some animals, including humans, the ovary does not release mature eggs. Instead, it releases oocytes, which are immature eggs that have undergone only their first meiotic division. An oocyte finishes the first meiotic division to become a secondary oocyte and a non-functional, underdeveloped cell called a polar body. Even before a female infant is born, each of her ovaries contains about one million oocytes whose

development is arrested at the end of the first meiotic prophase. Although 200 000 to 380 000 oocytes survive until a female reaches sexual maturity, only about 380 oocytes are actually ovulated before **menopause**, the end of a female's reproductive capability. Ovulation is the monthly release of one or a few developing oocytes into the nearby oviduct. Once ovulated, an ovum is pulled through the oviduct by a current produced by the beating of the cilia that line the oviduct. The cilia propel the egg along the oviduct, where fertilization may occur. The second meiotic division occurs only if the oocyte is penetrated by a sperm. When this happens, a mature ovum and a polar body form, and the nucleus of the ovum immediately fuses with the nucleus of the sperm to form a fertilized egg, or zygote. The zygote is propelled into the uterus by the cilia of the oviduct. If the ovum is not fertilized, it degenerates and disappears.

menopause the end of a female's reproductive capability, after which menstruation ceases and female hormone levels drop

In most vertebrates, ovulation occurs during a well-defined mating season. Humans, however, do not show any evidence of a mating season. Mating and fertilization can occur at any time of the year. Furthermore, women do not generally know when they are ovulating, and neither do their partners.

Reproduction in human females is under neuroendocrine control. It involves complex interactions between the hypothalamus, pituitary gland, ovaries, and uterus. The ovarian cycle occurs from puberty to menopause and involves the events in the ovaries that lead to the release of a mature egg approximately every 28 days. The ovarian cycle is coordinated with the **menstrual cycle** (from *menses* meaning "month")—the monthly cycle of events in the uterus that prepare the uterus to implant the egg if fertilization occurs (**Figure 2**, next page).

menstrual cycle the monthly cycle of events in a sexually mature female that prepares the uterus for the implantation of a fertilized egg

The beginning of the ovarian cycle is stimulated by the release of GnRH by the hypothalamus. GnRH stimulates the pituitary to release follicle-stimulating hormone (FSH) and luteinizing hormone (LH) into the bloodstream. FSH stimulates 6 to 20 oocytes in the ovaries to begin meiosis. As the oocytes develop, they become surrounded by cells that form a follicle (the ovum and follicle cells). During this phase, the follicle grows and develops. At its largest size, it becomes filled with fluid and may be 12 to 15 mm in diameter. Usually, only one follicle develops to maturity, with the release of the egg by ovulation. Multiple births can result if two or more follicles develop and their eggs ovulate and are fertilized in one cycle.

As the follicle enlarges, FSH and LH interact to stimulate estrogen secretion by the follicular cells. Initially, the estrogens are secreted in low amounts and have a negative feedback effect on the pituitary, inhibiting the secretion of FSH. As a result, the FSH secretion declines briefly. However, estrogen secretion increases steadily, and its level peaks about 12 days after the beginning of follicle development. A high estrogen level has a positive feedback effect on the hypothalamus and pituitary, increasing the secretion of GnRH and stimulating the pituitary to release a burst of FSH and LH.

Ovulation occurs after the burst in LH secretion stimulates the follicle cells to release enzymes that digest the wall of the follicle, causing it to rupture and release the egg. LH also causes the follicle cells that remain at the surface of the ovary to grow into an enlarged, yellowish structure called the corpus luteum (from *corpus* meaning "body" and *luteum* meaning "yellow"). This initiates the luteal phase, which prepares the uterus to receive a fertilized egg. The corpus luteum acts as an endocrine gland that secretes estrogens, as well as large quantities of progesterone and another hormone called inhibin. Progesterone stimulates the growth of the uterine lining and inhibits contractions of the uterus. Progesterone and inhibin have a negative feedback effect on the hypothalamus and pituitary gland. Progesterone inhibits the secretion of GnRH and, in turn, the secretion of FSH and LH by the pituitary gland. Inhibin specifically inhibits FSH secretion. The decrease in FSH and LH levels diminishes the signal for follicular growth, so no new follicles begin to grow in the ovary.

If fertilization does not occur, the corpus luteum gradually shrinks, perhaps because of the low level of LH. About 10 days after ovulation, the shrinkage of the corpus luteum inhibits the secretion of estrogen, progesterone, and inhibin. In the absence of progesterone, menstruation begins. As progesterone and inhibin levels decrease, FSH and LH secretion is no longer inhibited and a new monthly cycle begins.

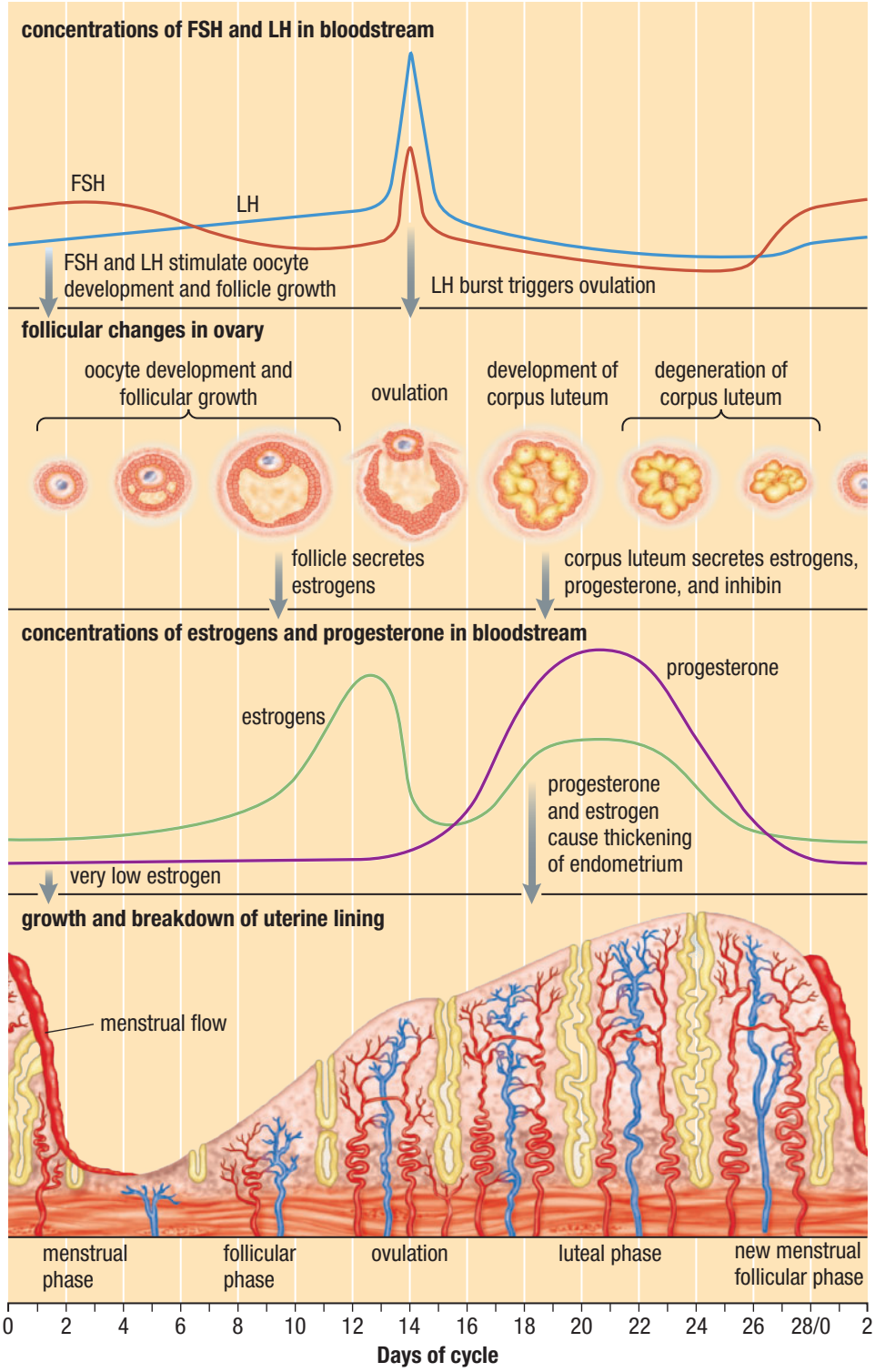

Figure 2 The ovarian and menstrual cycles of a human female

The Menstrual Cycle

The menstrual cycle involves the changes in the uterus over one ovarian cycle. The same hormones that control the ovarian cycle also control the menstrual cycle, physiologically connecting the two processes. Day 0 of the monthly cycle is the beginning of follicular development in the ovary and the beginning of menstrual flow in the uterus. Menstrual flow results from the breakdown of the endometrium, which releases blood and tissue breakdown products from the uterus to the outside through the vagina.

When the flow ceases (at day 4 or 5 in the cycle), the endometrium begins to grow again. As the endometrium gradually thickens, oocytes in both ovaries begin to develop further, eventually leading to ovulation (usually a single egg from one ovary) at about 14 days into the cycle. The uterine lining continues to grow for another 14 days after ovulation. At this time, if fertilization has not taken place, the absence of progesterone results in the contraction of the arteries that supply blood to the uterine lining, shutting down the blood supply and causing the lining to disintegrate. The menstrual flow begins. Contractions of the uterus, no longer inhibited by progesterone, help to expel the debris. Prostaglandins released by the degenerating endometrium add to uterine contractions, making them severe enough to be felt as painful cramps and sometimes producing other effects, such as nausea, vomiting, and headaches.

The monthly cycle of high levels of sex hormones eventually stops in later adulthood, usually when a woman is in her late 40s or early 50s, during a period called menopause. The menstrual cycle also stops at this time. The great reduction in estrogens can produce undesirable side effects, including hot flashes, headaches, and mood swings. These symptoms can be reduced by hormone replacement therapy (HRT). HRT supplies an outside source of estrogen, either through oral medication or a skin patch. While HRT has many benefits, the treatment has become controversial in recent years because of the increased risk of heart disease, breast cancer, and stroke.

Menstruation occurs only in human females and in our closest primate relatives, gorillas and chimpanzees. In other mammals, the uterine lining is completely reabsorbed if a fertilized egg does not implant during the period of reproductive activity. The uterine cycle in these mammals is called the estrous cycle, and females are said to be in estrus when fertile.

Investigation 10.7.1

Hormone Levels during the Ovarian and Menstrual Cycles (p. 504)
You now understand the stages of the ovarian and menstrual cycles. This investigation will help you understand the relative levels of the various hormones throughout the menstrual cycle.

Fertilization and Pregnancy

Inside the human body, an egg can be fertilized only during its passage through the third of the oviduct that is nearest the ovary. If the egg is not fertilized during the 12 to 24 h it is in this location, it disintegrates and dies. To fertilize the egg, sperm cells must first penetrate the layer of follicle cells surrounding the egg (**Figure 3**). As soon as the first sperm cell reaches the egg, the sperm and egg plasma membranes fuse, the tail of the sperm is detached, and the head of the sperm cell is engulfed by the cytosol of the egg.

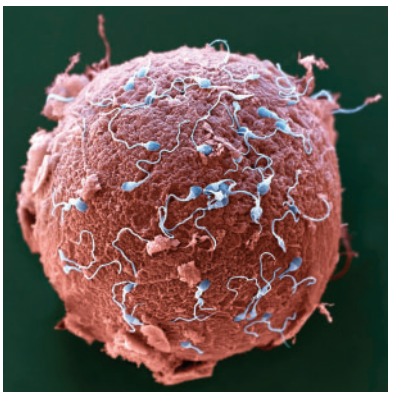

Figure 3 A human egg cell (ovum), surrounded by sperm cells

Membrane fusion activates the egg. The sperm that enters the egg releases nitric oxide, stimulating the release of stored Ca^{2+} in the egg. The Ca^{2+} prevents other sperm from reaching the plasma membrane of the egg and triggers the completion of meiosis of the egg. The sperm and egg pronuclei then fuse, and the cell becomes the zygote. Mitotic divisions of the zygote soon initiate embryonic development.

The first cell divisions of embryonic development take place in the oviduct. About seven days after ovulation, the embryo passes from the oviduct and implants in the uterine lining. During and after implantation, cells associated with the embryo secrete human chorionic gonadotropin (hCG), a hormone that keeps the corpus luteum in the ovary from breaking down. It also suppresses the mother's immune system to prevent it from rejecting the embryo. Excess hCG is excreted in the urine. Its presence in the urine or blood provides the basis of pregnancy tests. After implantation, the embryo begins to grow more rapidly, and a placenta forms. The placenta is an organ formed from the uterine lining with membranes from the uterus. It supports the growth of the embryo.

Continued activity of the corpus luteum keeps estrogen and progesterone secretion at high levels, which maintains the uterine lining and prevents menstruation. The high progesterone level also thickens the mucus secreted by the uterus, forming a plug that seals the opening of the cervix from the vagina. The plug keeps bacteria, viruses, and sperm cells from further copulations from entering the uterus.

About 10 weeks after implantation, the placenta takes over the secretion of progesterone, hCG secretion drops off, and the corpus luteum regresses. However, the corpus luteum continues to secrete the hormone relaxin, which inhibits the contraction of the uterus until near the time of birth. CAREER LINK

The Male Reproductive System

The male sex hormones affect the development of the male secondary sex characteristics. If you have ever had a pet that was neutered at a young age, you may have noticed differences in its development compared with the development of animals that were not neutered. For example, neutered cats and dogs may grow larger and fatter. Neutered animals generally have a milder temperament than unneutered animals, as well. For centuries, farmers have castrated livestock (removed their testes) in order to have animals with a milder temperament, greater body mass, and fattier meat. A steer, which most beef comes from, is a castrated bull. There are even historical examples from around the world of castration being used on humans for various purposes: choir boys were once castrated to maintain their high voices, eunuchs who supervised harems were castrated, and criminals and mental patients were sometimes castrated as a punishment or treatment.

The testes (singular: *testis*) of male vertebrates secrete androgens, which are steroid hormones that stimulate and control the development and maintenance of the male reproductive system. The principal androgen is testosterone, the male sex hormone. In young adult males, a jump in the testosterone level stimulates puberty and the development of secondary sexual characteristics, including the growth of facial and body hair, muscle development, changes in the vocal cords, and the development of the sex drive. The synthesis and secretion of testosterone by cells in the testes are controlled by the release of LH from the anterior pituitary gland. The release of LH is controlled by GnRH from the hypothalamus, the same hormone that regulates the sex hormones in females.

spermatogenesis the production and development of sperm cells in the testes

Testosterone also controls **spermatogenesis**, the process by which sperm cells are produced in the testes from precursor cells called spermatogonia. The organs that produce and deliver sperm make up the male reproductive system (**Figure 4**). Human males have a pair of testes suspended in a baglike scrotum, which serves to regulate their temperature. In human males, each testicle is packed with about 125 m of seminiferous tubules, in which sperm proceed through all the stages of spermatogenesis.

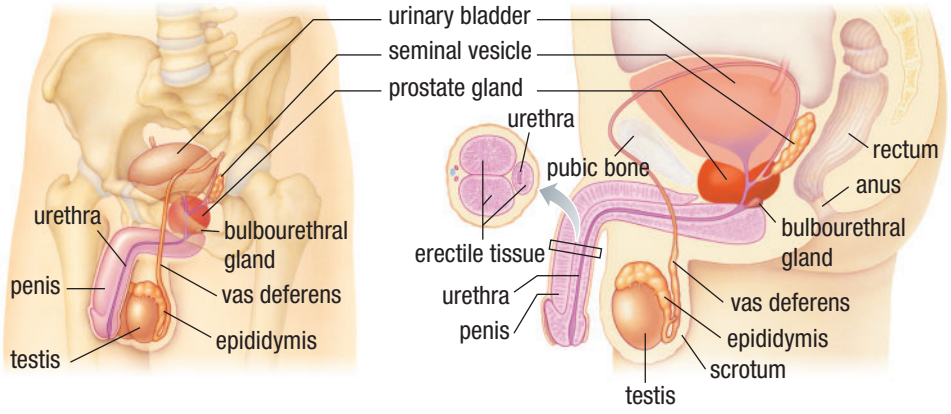

Figure 4 The reproductive organs of a human male

The entire process, from spermatogonium to sperm, takes 9 to 10 weeks. The testes produce about 130 million fertile sperm each day. This number varies among men. In the last 50 years, however, the average sperm count of men has fallen, sometimes to a level that makes it difficult for couples to conceive. While scientists agree that the average sperm count has fallen, there is no clear cause. Some evidence points to chemicals in the environment that mimic hormones in the body. It may be a male's exposure during prenatal development, rather than his exposure after birth, that affects his sperm count.

Sertoli cells are supportive cells that completely surround the developing spermatocytes in the seminiferous tubules. They supply nutrients to the spermatocytes and seal off the spermatocytes from the body's blood supply. Leydig cells, located

in the tissue surrounding the developing spermatocytes, produce the male sex hormones (androgens), particularly testosterone.

Mature sperm flow from seminiferous tubules into the epididymis, which is a coiled storage tubule attached to the surface of each testis. Rhythmic muscular contractions of the epididymis move sperm into a thick-walled, muscular tube, the vas deferens (plural: *vasa deferentia*), which extends through the abdominal cavity.

Many of the hormones that regulate the menstrual cycle, including GnRH, FSH, LH, and inhibin, also regulate the male reproductive functions. Testosterone, secreted by the Leydig cells in the testes, also plays a key role (**Figure 5**). In sexually mature males, the hypothalamus secretes GnRH in brief pulses every one to two hours. GnRH stimulates the pituitary gland to secrete LH and FSH. LH stimulates the Leydig cells to secrete testosterone, which stimulates sperm production and controls the growth and function of the male reproductive structures. FSH stimulates Sertoli cells to secrete a protein and other molecules required for spermatogenesis.

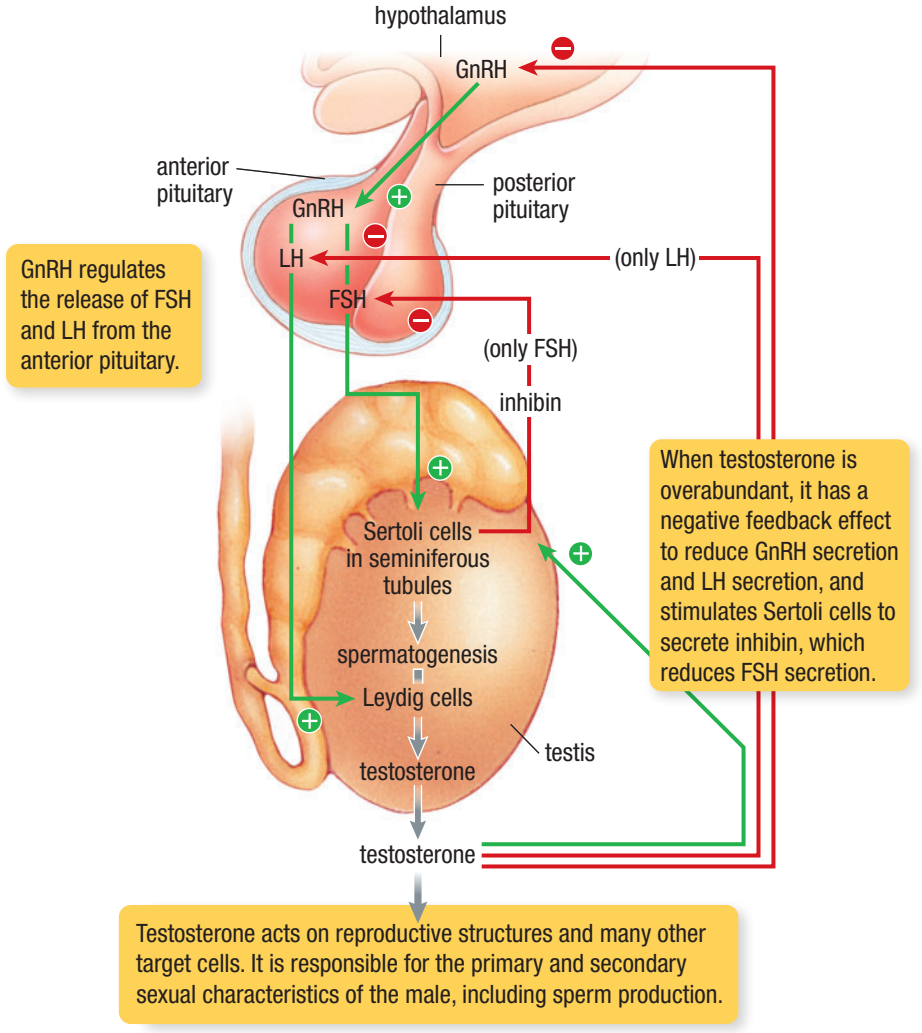

Figure 5 The hormonal regulation of reproduction in the male, and the negative feedback systems that control the hormone levels

Concentrations of the male reproductive hormones are maintained by negative feedback mechanisms (Figure 5). If the concentration of testosterone falls in the bloodstream, the hypothalamus responds by increasing GnRH secretion. If the concentration of testosterone becomes too high, the overabundance inhibits LH secretion. An overabundance of testosterone also stimulates Sertoli cells to secrete inhibin, which inhibits FSH secretion by the pituitary gland. As a result, testosterone secretion by the Leydig cells drops off, returning the concentration to optimal levels in the bloodstream. CAREER LINK

Controlling Reproduction with Hormones

Knowledge about the details of reproduction can allow us to control fertility. In some cases, this means increasing the chance of reproducing. In other cases, it means minimizing the chance. Knowledge about the timing of ovulation, for example, can provide a way to maximize or minimize the chance of pregnancy.

Hormonal birth control involves administering estrogen and/or progesterone, or chemical mimics of these hormones, to females in carefully controlled doses throughout the month in order to control the menstrual cycle and prevent ovulation. These hormones may be given as pills, injections, or patches, or as an implant that slowly releases hormones into the bloodstream.

Side effects are a concern when hormones are used for birth control. Birth control pills are usually considered safe and effective, but if they are used inappropriately side effects may include nausea and weight gain, lighter periods, or sore breasts. More rarely, women may experience headaches; blurred vision; or pain in the chest, abdomen, or thighs. Older women, particularly smokers with a history of cardiovascular problems, may be at increased risk for heart or liver disease, thromboses, or breast or uterine cancer.

There are also concerns about the long-term environmental impact of hormonal birth control use, or the use of any hormonal medications. Birth control pills contain estrogen and/or progestin. These hormones end up in the environment and possibly in drinking water. Human urine in wastewater, farm-waste runoff, flushing or dumping of prescription medications, and the use and disposal of products that we purchase all contribute to the presence of hormones and potentially harmful chemicals in our environment. Some pesticides and plastics have been shown to contain chemicals that mimic the effects of estrogen or block actions of the endocrine system, raising concerns about risks to human health.

Research This

Assessing the Risks of Bisphenol A

Skills: Researching, Analyzing, Evaluating, Communicating, Defining the Issue, Defending a Decision

SKILLS HANDBOOK A4.1

Many chemicals in the environment have impacts on plants and animals, including humans. Some of these effects are known, but some are still unknown and under investigation. Some chemicals supplement the effects of hormones that are naturally produced in the body. Other chemicals mimic the effects of hormones such as estrogen. Chemicals known as endocrine disruptors (or endocrine-disrupting compounds, EDCs) interfere with the normal functions of the endocrine system.

One of the most well-known and widespread chemicals that can affect the endocrine system is bisphenol A, known as BPA. BPA is a chemical that has been widely used in the production of hard plastic food and beverage containers and can liners. Trace amounts of BPA can be found in the food that comes in these containers.

1. Investigate and identify current scientific research on the potential link between BPA and human health problems. Investigate the extent of its use in plastic production. In particular, compare positions taken by governments, industries, and scientific researchers.

A. Make and justify a personal decision about the use of BPA. T/I A

B. What potential effects does BPA have on human health? T/I

C. Describe the possible link between BPA and the falling sperm count in males over the past half century. T/I

D. What will you do or not do to avoid any potential risks of BPA to your own health? Consider the idea of "the absence of evidence versus the evidence of absence." Can you distinguish between the two in researching this issue? Consider the risk associated with drawing conclusions based on the absence of evidence. If there is no evidence that BPA is a dangerous substance, can you reasonably conclude that BPA is not a dangerous substance? K/U A

E. Prepare a report, in a format of your choice, that summarizes your research on this issue, identifies how BPA gets into the human body, summarizes the potential health risks associated with BPA, and compares these risks with other everyday risks. T/I C

F. Write a letter to Health Canada, either supporting or criticizing the decision to identify BPA as a toxic substance. Provide evidence to support your position. C

WEB LINK

10.7 Review

Summary

- Reproduction is controlled by the sex hormones, which are primarily produced in the gonads: the testes in males and the ovaries in females.
- Testosterone is the primary sex hormone in males, and estrogen is the primary sex hormone in females. These hormones control the development of the secondary sexual characteristics and the sex drive.
- Follicle-stimulating hormone (FSH) is released by the pituitary gland in response to gonadotropin-releasing hormone (GnRH) from the hypothalamus. FSH stimulates the development of oocytes in the ovaries.
- Ova (eggs) are produced from oocytes in a process called oogenesis. Once an oocyte is released during ovulation, it travels along the oviduct. There, it may become fertilized by a sperm cell. The developing embryo then travels to the uterus, where it implants.
- The menstrual cycle prepares the uterus to receive the fertilized egg. The hormones estrogen and progesterone carefully control the menstrual cycle to go along with the ovarian cycle and prepare the body for pregnancy.
- Spermatogenesis, the production of sperm in the testes of the male, is controlled by the male androgen hormone testosterone. Males produce sperm constantly, at a rate of about 130 million per day.
- The manipulation of hormones in females can be used to control reproduction.

Questions

1. What are the main male and female sex hormones? Describe their functions. K/U
2. What is the relationship between the ovarian cycle and the menstrual cycle? Explain how reproduction is determined by these two cycles. K/U
3. Use a flow chart or another graphic organizer to explain the main steps in the menstrual cycle. K/U C
4. Research the risks and benefits of hormone replacement therapy (HRT) in menopausal women. What are some of the risks of HRT? T/I C
5. Construct a flow chart that shows the events leading up to the implantation of an embryo in the uterus. Begin with the ripening of a follicle in the ovary. K/U C
6. Name three hormones common to both males and females that regulate both the menstrual cycle and the male reproductive functions. K/U
7. How does the sexual cycle of human females differ from the sexual cycle of other vertebrates? K/U
8. What result would you expect if a fertilizing sperm cell did not released nitric oxide when it entered an egg? Why? K/U A
9. How are the effects of testosterone on males and estrogen on females similar? K/U
10. What is the importance of human chorionic gonadotropic hormone (hCG)? K/U
11. A woman discovers that she is not ovulating. Which endocrine glands might a doctor suspect are not functioning properly? Explain your answer. K/U T/I
12. Estrogen and progesterone are no longer produced when a woman reaches menopause. Which body systems do you think could be affected by these changes in hormonal production? Explain your choices. K/U T/I

WEB LINK