CHAPTER 21

The Reproductive System

Testes *are the male gonads, or primary reproductive organs. Male sex hormones and sperm are produced in the testes.*

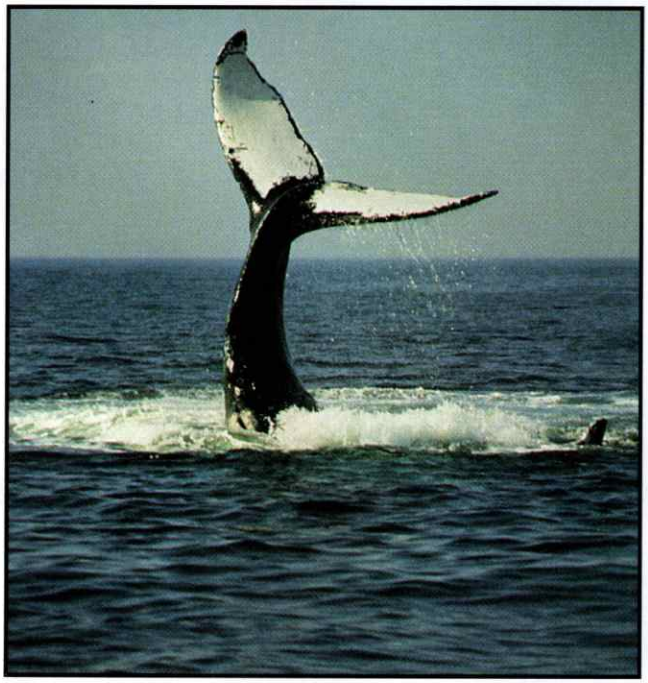


Figure 21.1

From the smallest one-celled organisms to the largest mammals, all living things reproduce, ensuring the survival of the species.

IMPORTANCE OF REPRODUCTION

Reproduction ensures the survival of a species. Sexual reproduction involving the fusion of male and female sex cells creates new gene combinations. The diversity produced by new gene combinations provides a basis for natural selection: only the best-adapted survive. Species survival is based on providing numerous and varied offspring.

Female oysters produce an estimated 115 million eggs for each spawning. Each year, female frogs produce hundreds of thousands of eggs for fertilization. In contrast, human females have 400 000 egg cells, of which only 400 mature throughout the reproductive years—from about age 12 to age 50. According to one source, the greatest number of offspring ever born to one woman was 57. The limited capacity of females to produce sex cells is contrasted with that of males. The average male, beginning at about age 13 to well into his eighties and nineties, can produce as many as one billion sex cells every day.

The human reproductive system involves separate male and female reproductive systems. The male gonads, the **testes** (singular: "testis"), produce male sex

cells called *sperm*. The female gonads, the **ovaries,** produce "eggs." The fusion of a male and a female sex cell, in a process called **fertilization,** produces a **zygote.** The zygote divides many times to form an embryo, which in turn continues to grow into a fetus.

THE MALE REPRODUCTIVE SYSTEM

Male and female sex organs originate in the same area of the body—the abdominal cavity—and are almost indistinguishable until about the third month of embryonic development. At that time, the genes of the sex chromosomes cause differentiation. During the last two months of fetal development, the testes descend through a canal into the **scrotum,** a pouch of skin located below the pelvic region. A thin membrane forms over the canal, thereby preventing the testes from re-entering the abdominal cavity. Occasionally, an injury may cause the rupture of the membrane, producing an inguinal hernia. The hernia can be dangerous because a segment of the small intestine can be forced into the scrotum. The small intestine creates pressure on the testes, and blood flow to either the testes or small intestine may become restricted.

The temperature in the scrotum is a few degrees cooler than that of the abdominal cavity. The cooler temperatures are important, since sperm will not develop at body temperature. Should the testes fail to descend into the scrotum, the male will not be able to produce viable sperm. This makes the male sterile.

Ovaries *are the female gonads, or reproductive organs. Female sex hormones and egg cells are produced in the ovaries.*

Fertilization *occurs when a male and a female sex cell fuse.*

A **zygote** *is the cell resulting from the union of a male and female sex cell.*

The **scrotum** *is the sac that contains the testes.*

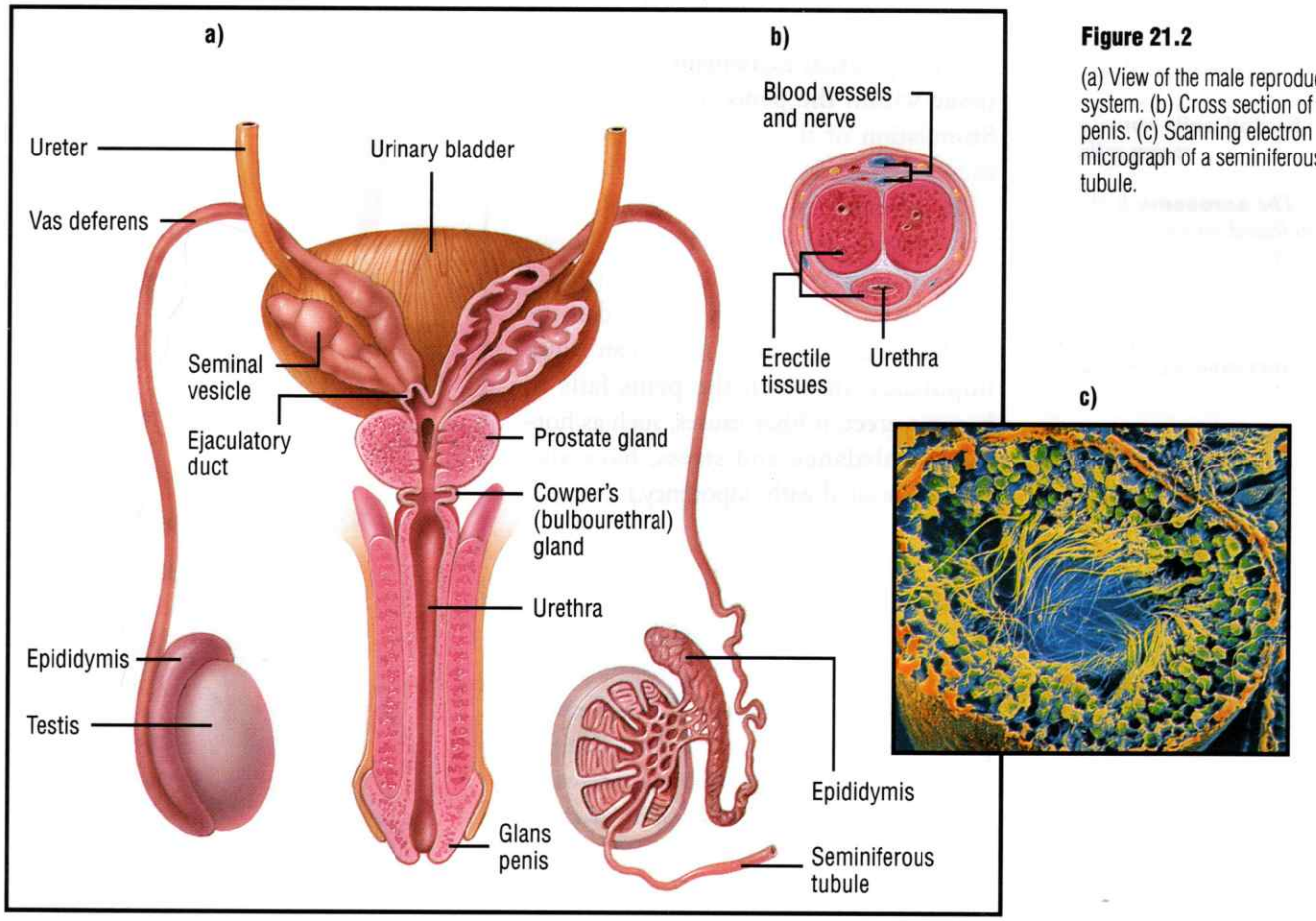


Figure 21.2

(a) View of the male reproductive system. (b) Cross section of the penis. (c) Scanning electron micrograph of a seminiferous tubule.

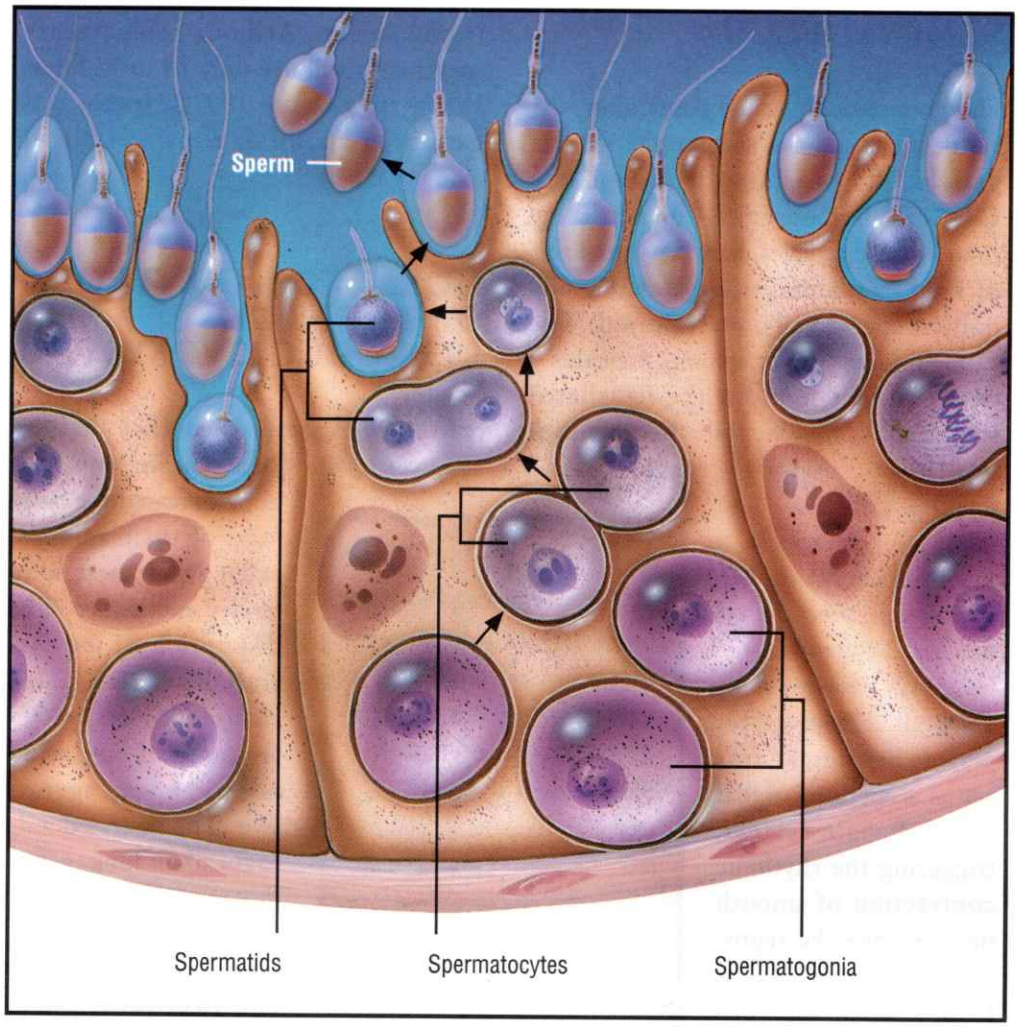


Figure 21.4
Development of sperm cells inside the seminiferous tubule.

The inside of each testis is filled with twisting tubes, called **seminiferous tubules,** that measure approximately 250 m in length. The seminiferous tubules are lined with sperm-producing cells called *spermatogonia*. These immature sperm cells contain a full complement of 46 chromosomes. During a process called *meiosis*, the spermatogonia divide into *spermatocytes*, which contain 23 chromosomes. (Meiosis is described in detail in the chapter Sexual Cell Reproduction.) Human sex cells of both males and females carry 23 chromosomes, which unite at fertilization to restore the original number of 46. Within 9 to 10 weeks, the spermatocytes differentiate into sperm cells. Although sperm cells are produced in the testes, they mature in the **epididymis,** a compact, coiled tube attached to the outer edge of the testis. Sperm cells develop their flagella and begin swimming motions within four days. It is believed that some defective sperm cells are destroyed by the immune system during their time in the epididymis.

BIOLOGY CLIP
The male sperm cell is dwarfed by the much larger female egg cell. In humans, the egg cell is 100 000 times larger than the sperm cell.

***Seminiferous tubules** are coiled ducts found within the testes, where immature sperm cells divide and differentiate.*

*The **epididymis** is located along the posterior border of the testis and consists of coiled tubules that store sperm cells.*

SEMINAL FLUID

Fluid is secreted by three glands along the vas deferens and the urethra: the seminal vesicle, the prostate gland, and the Cowper's (bulbourethral) gland. Every time a man ejaculates, between 3 to 4 mL of fluid, containing approximately 500 million sperm cells, are released. The fluid, referred to as semen, provides a swimming medium for the flagellated sperm cells. Fluids from the **seminal vesicles** contain fructose and prostaglandins. The fructose provides a source of energy for the sperm cell. Recall that the sperm cell carries little energy reserves in its drastically reduced cytoplasm. Prostaglandins act as a chemical signal in the female system, triggering the rhythmic contraction of smooth muscle along the reproductive tract. It is believed that the contraction of muscles along the female reproductive pathways assists the movement of sperm cells toward the egg. The **prostate gland** secretes an alkaline buffer that protects sperm cells against the acidic environment of the vagina.

Seminal vesicles *contribute to the seminal fluid (semen), a secretion that contains fructose and prostaglandins.*

The **prostate gland** *contributes to the seminal fluid (semen), a secretion containing buffers that protect sperm cells from the acidic environment of the vagina.*

Cowper's (bulbourethral) gland *contributes a mucus-rich fluid to the seminal fluid (semen).*

Testosterone *is the male sex hormone produced by the interstitial cells of the testes.*

Anabolic steroids *are strength-enhancing drugs.*

Gonadotropic hormones *are produced by the pituitary gland and regulate the functions of the testes and ovaries.*

BIOLOGY CLIP

Boy sopranos are renowned for the beauty of their voices. However, as boys reach puberty, their larynxes begin to change and their voices become lower. During the 17th and 18th centuries, adult male sopranos were very popular. These singers, called *castrati*, had had their testes removed before puberty so that their voices would remain high. In 1878, Pope Leo XVII ended the inhumane practice of castrating boys for the papal choir.

Cowper's (bulbourethral) gland secretes mucus-rich fluids prior to ejaculation. It is believed that the fluids protect the sperm cells from the acids found in the urethra associated with the passage of urine. The fluid may also assist sperm movement.

Although sperm cells can exist for many weeks in the epididymis, they have a much reduced life span when they come in contact with the various fluids in the semen. At body temperature, sperm cells will live only 24 to 72 hours. When stored at $-100°C$, sperm cells have been known to remain viable for many years.

HORMONAL CONTROL OF THE MALE REPRODUCTIVE SYSTEM

Ancient herdsmen discovered that the removal of the testes, known as castration, increased the body mass of their animals, making their meat more tender and savory. The disposition of the castrated males also changed. Steers, which are castrated bulls, tend not to be very aggressive. The castrated animals also lack a sex drive and are sterile.

The male sex hormones—androsterone and **testosterone**—are produced in the *interstitial cells* of the testes. As the name suggests, the interstitial cells are found between the seminiferous cells. Although both hormones carry out many functions, testosterone is the more potent and abundant. Testosterone stimulates spermatogenesis, the process by which spermatogonia divide and differentiate into mature sperm cells. Testosterone also influences the development of secondary male sexual characteristics at puberty, stimulating the maturation of the testes and penis. Testosterone levels have also been associated with sex drive. Evidence comes from ancient times, when eunuchs—males who had had their testes

removed—were used to guard the harems and households of these rulers. Because they no longer were able to produce testosterone, the eunuchs had a decreased sex drive.

The male sex hormone also promotes the development of facial and body hair, the growth of the larynx, which causes the lowering of the voice, and the strengthening of muscles. In addition, testosterone increases the secretion of body oils and has been linked to the development of acne in males as they reach puberty. Once males adjust to higher levels of testosterone, skin problems decline. The increased oil production can also create body odor. Testosterone, or testosterone-related compounds, are used in the production of **anabolic steroids,** the strength-building drugs often associated with athletes.

The production of sperm and male sex hormones in the testes is controlled by the hypothalamus and the pituitary gland in the brain. Negative-feedback systems ensure that adequate numbers of sperm cells and constant levels of testosterone are maintained. The pituitary gland produces and stores the **gonadotropic hormones,** which regulate the functions of the testes; the male **follicle-stimulating hormone (FSH),** which stimulates the production of sperm cells in the seminiferous tubules; and the male **luteinizing hormone (LH),** which promotes the production of testosterone by the interstitial cells.

At puberty, the hypothalamus secretes the **gonadotropin-releasing hormone (GnRH).** GnRH activates the pituitary gland to secrete and release FSH and LH. The FSH acts directly on the sperm-producing cells of the seminiferous tubules, while LH stimulates the interstitial cells to produce testosterone. In turn, the testosterone itself increases sperm production. Once high levels of testosterone are detected by the hypothalamus, a negative-feedback system is activated. Decreased GnRH production slows the production and release of LH, leading to less testosterone production. Testosterone levels thus remain in check. The feedback loop for sperm production is not well understood. It is believed that FSH acts on Sertoli cells, which produce a peptide hormone that sends a feedback message to the pituitary, inhibiting production of FSH.

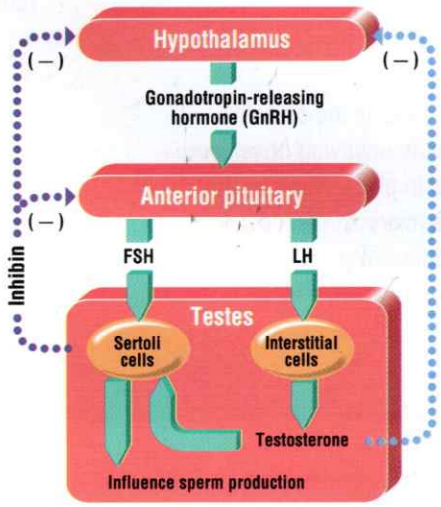


Figure 21.5

Negative feedback regulatory system for FSH and LH hormones. Testosterone inhibits LH production by the pituitary by deactivating the hypothalamus. The hypothalamus will release less GnRH, leading to decreased production of LH. The feedback mechanism for FSH is less understood. It has been suggested that a signalling chemical produced by the Sertoli cells inhibits both GnRH and FSH production.

REVIEW QUESTIONS ?

1. Name the primary male and female reproductive organs.
2. What would happen if the testes failed to descend into the scrotum?
3. Describe the function of the following structures: Sertoli cells, seminiferous tubules, and epididymis.
4. What is semen? Where is it found? What function does it serve?
5. What is spermatogenesis?
6. Outline the functions of testosterone.
7. How do gonadotropic hormones regulate spermatogenesis and testosterone production?
8. Using examples of LH and testosterone, explain the mechanism of negative feedback.

The **follicle-stimulating hormone (FSH)** *increases sperm production in males.*

The **luteinizing hormone (LH)** *regulates the production of testosterone in males.*

The **gonadotropin-releasing hormone (GnRH)** *is a chemical messenger from the hypothalamus that stimulates secretions of FSH and LH from the pituitary.*

DEMONSTRATION

MICROSCOPIC VIEW OF THE TESTES

Objective

To view structures within the testes.

Materials

lens paper
light microscope
prepared slide of testes (cross section)
pencil

Procedure

1 Using lens paper, clean the ocular and all the objective lenses of the microscope. Rotate the revolving nosepiece so that the low-power objective is in place. Position the prepared slide on the stage of the microscope and view the cross section of the testes under low power.

a) Estimate the number of seminiferous tubules seen under low-power magnification.

2 Center the slide on a single seminiferous tubule and rotate the revolving nosepiece to the medium-power objective. Use only the fine adjustment to focus the cells. Locate an interstitial cell and a seminiferous tubule.

b) Estimate the size of the seminiferous tubule and the interstitial cell.

3 Rotate the nosepiece to the high-power objective lens and view the immature sperm cells within the seminiferous tubules.

c) Diagram five different cells viewed in the seminiferous tubule.

d) Would you expect to find mature sperm cells in the seminiferous tubule? Give your reasons. ■

THE FEMALE REPRODUCTIVE SYSTEM

Menopause *marks the termination of the female reproductive years.*

The **oviduct,** *or* **Fallopian tube,** *is the passageway through which an ovum moves from the ovary to the uterus, or womb.*

In many ways the female reproductive system is more complicated than that of the male. Once sexual maturity is reached, males continue to produce sperm cells at a somewhat constant rate. By contrast, females follow a complicated sexual cycle, in which one egg matures approximately every month. Hormonal levels fluctuate through the reproductive years that end at **menopause.**

During fetal development, paired ovaries (flattened, olive-shaped organs) form near the kidneys. Like the similarly shaped testes, the ovaries migrate along a canal, but unlike the testes, which come to rest outside of the abdominal cavity, the ovaries remain in the pelvic region. Egg cells, or *ova* (singular: "ovum"), are found within the ovary. The ovary is also responsible for the production of female sex hormones.

An **oviduct,** or **Fallopian tube** (named after Gabriello Fallopio, a 16th-century Italian anatomist), is found next to each of the ovaries. Once mature, an ovum will enter the oviduct through wide, open ends called *fimbria*. As the ovum is moved along the oviduct by cilia, it goes through its final stages of development. Fertilization of the ovum occurs in the oviduct. However, unless the ovum is fertilized, the cell will deteriorate within 48 hours and die. The paired oviducts join a hollow, inverted, pear-shaped organ called the **uterus,** or **womb.** The length of time required for the fertilized ovum to travel the

10–12 cm oviduct to the uterus is between three and five days.

The uterus, the site where the **embryo** and **fetus** develop, is composed of two major tissues. The muscular outer lining of the uterus, known as the *myometrium*, provides support for the developing embryo. During the last phase of pregnancy, strong muscular contractions help move the baby into the birth canal. The glandular inner lining of the uterus, known as the **endometrium,** provides nourishment for the developing embryo. If pregnancy does not occur, the endometrium is shed. The process is called **menstruation.** Normally, the embryo embeds itself in the rich glandular tissue of the endometrium located in the uterus; however, the embryo will occasionally embed in a less-developed layer of the endometrium that extends into the oviduct. This type of pregnancy, called an *ectopic pregnancy*, can be dangerous. Not only is the amount of glandular tissue and nutrients limited, but the delicate oviduct is unable to stretch to accommodate a growing embryo.

The vagina connects the uterus with the outer environment. Sexual intercourse occurs within the vagina, which also serves as the birth canal. The vagina is strongly acidic, which creates a hostile environment for microbes that might attempt to enter the female reproductive system. A muscular band, called the **cervix,** separates the vagina from the uterus and is designed to hold the fetus in place. Dilation of the cervix during birth permits the fetus to enter the birth canal.

Cancer of the cervix is one of the major forms of cancer in females. Fortunately, early detection makes the prospects of arresting the tumor favorable. A *Pap test* provides physicians with a sample of cells from the cervix. Like skin cells and the cells that line your mouth, cells will slough off the cervix; therefore, the procedure requires no surgery. Physicians simply use a swab to collect epithelial cells from the cervix.

The **uterus (womb)** *is the female organ in which the fertilized ovum normally becomes embedded and in which the embryo and fetus develop.*

Embryo *refers to the early stages of an animal's development. In humans, the embryo stage lasts until the ninth week of pregnancy.*

Fetus *refers to the later stages of an unborn offspring's development. In humans, the embryo is called a fetus after the ninth week of development.*

The **endometrium** *is the glandular lining of the uterus that prepares the uterus for the embryo.*

Menstruation *is the shedding of the endometrium.*

The **cervix** *is a muscular band that prevents the fetus from prematurely entering the birth canal.*

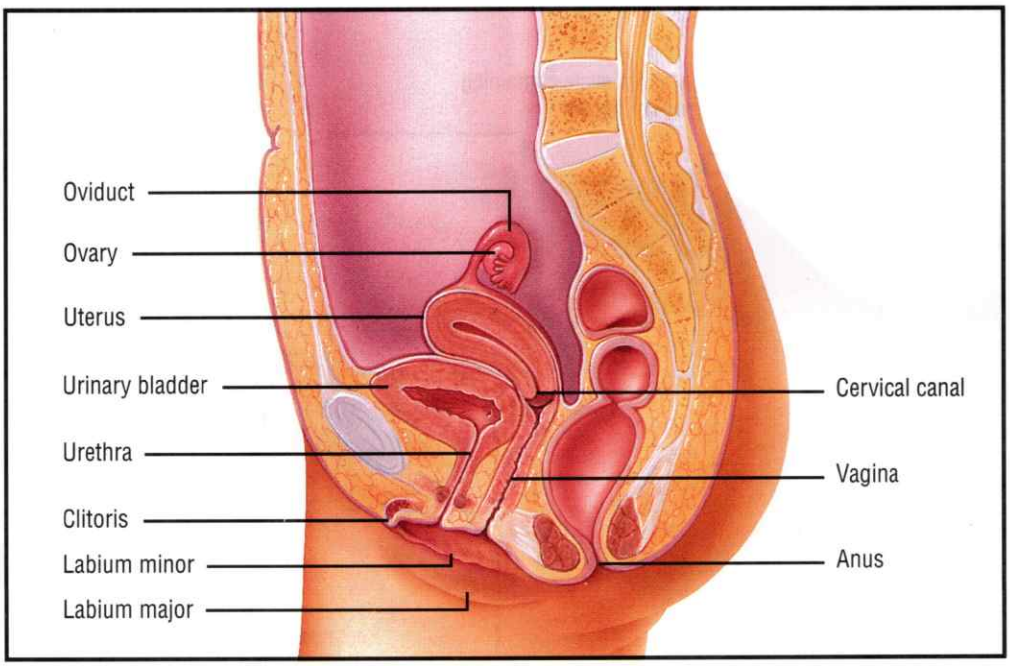


Figure 21.6

Female reproductive anatomy, side view. Note that two ovaries and two oviducts are present.

OOGENESIS AND OVULATION

The ovary contains fibrous connective tissue and small groups of cells called **follicles.** The follicles are composed of two types of cells: the *primary oocyte* and the *granulosa cells.* The oocyte, containing 46 chromosomes, undergoes meiosis and is transformed into a mature oocyte, or *ovum.* The granulosa cells provide nutrients for the oocyte.

Unlike the testes, which replenish sex cells, the female ovary undergoes continual decline after the onset of puberty. As mentioned earlier, the ovary contains about 400 000 follicles at puberty. Approximately 1000 follicles develop during each female reproductive cycle, but usually only a single follicle becomes dominant and reaches maturity. The remaining follicles deteriorate and are reabsorbed within the ovary. Between the ages of 12 and 50 in a woman's life about 400 eggs will mature. By the time a woman reaches menopause, few follicles remain. It has been suggested that the higher incidence of genetic defects in children produced by older women can be linked to the age of the follicles. The longer the follicle lives, the greater is the chance of genetic damage. Because female sex hormones are produced within the ovary, menopause not only marks the end of a female's reproductive life, but also signals a drop in the production of female hormones.

Follicle development is controlled by a hormone produced by the pituitary gland. Nutrient follicle cells surrounding the primary oocyte begin to divide. As the primary oocyte undergoes meiosis I, the majority of cytoplasm and nutrients move to one of the poles and form a secondary oocyte. The secondary oocyte contains 23 chromosomes. The remaining cell, referred to as the *polar body*, receives little cytoplasm and dies. As the secondary cells surrounding the secondary oocyte develop, a fluid-filled cavity forms.

Follicles *are structures in the ovary that contain the egg and secrete estrogen.*

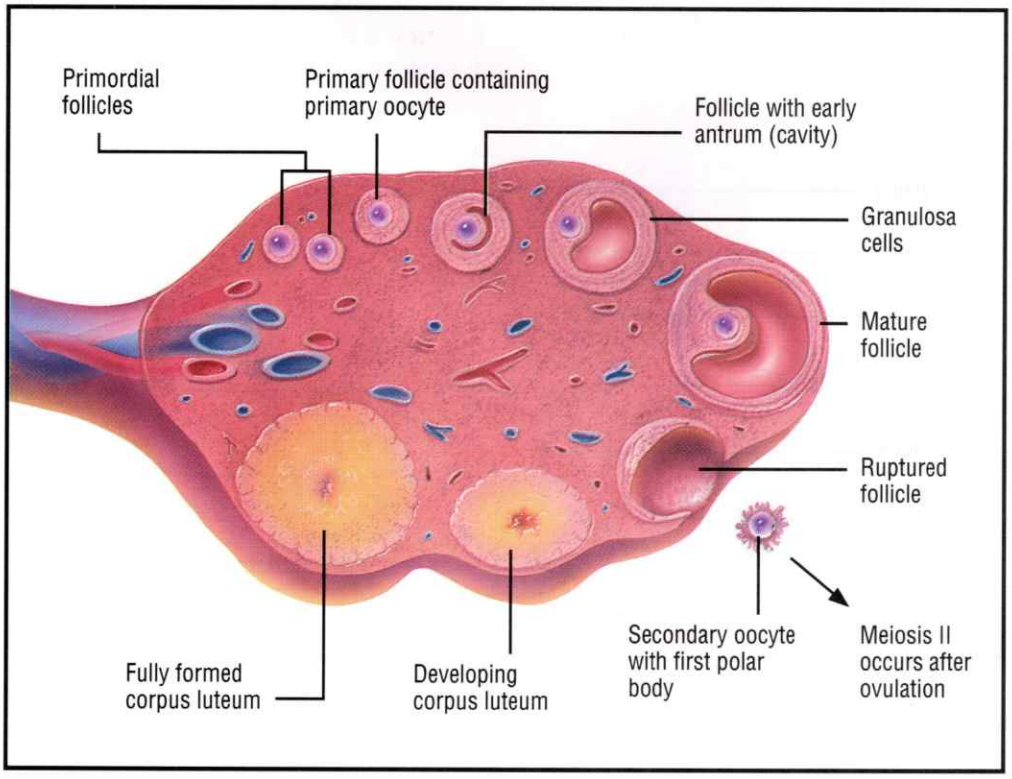


Figure 21.7

The process of ovulation. Pituitary hormones regulate the events of follicle development, ovulation, and the formation of the corpus luteum.

Eventually the dominant follicle pushes outward, ballooning the outer wall of the ovary. Blood vessels along the distended outer wall of the ovary collapse, and the wall weakens. The outer surface of the ovary wall bursts and the secondary oocyte is released. This process is referred to as **ovulation.** Surrounding follicle cells remain within the ovary and are transformed into the **corpus luteum,** which secretes hormones essential for pregnancy; however, if pregnancy does not occur, the corpus luteum degenerates after about 10 days. All that remains is a scar, referred to as the *corpus albicans*. The secondary oocyte enters the oviduct and undergoes meiosis II. Once again, the division of cytoplasm and nutrients is unequal; the cell that retains most of the cytoplasm and nutrients is referred to as the mature oocyte, or ovum. As in meiosis I, the polar body deteriorates.

BIOLOGY CLIP

The English word "hysteria," meaning emotional excitability, derives from *hystera*, the Greek word for uterus. It was originally thought that women were more prone to hysteria than men. The surgical operation, hysterectomy, literally means removal of the uterus.

MENSTRUAL CYCLE

The human female menstrual cycle, which is repeated throughout a woman's reproductive lifetime, takes an average of 28 days, although great variation in this cycle is not uncommon. The menstrual cycle can be divided into four distinct phases: flow phase, follicular phase, ovulatory phase, and luteal phase. The **flow phase** is marked by the shedding of the endometrium, or menstruation. This is the only phase of the female reproductive cycle that can be determined externally. For this reason, the flow phase is used to mark the beginning of the menstrual cycle. Approximately five days are required for the uterus to shed the endometrium.

The **follicular phase** is characterized by the development of follicles within the ovary. As follicle cells develop, the hormone **estrogen** is secreted. Estrogen promotes the development of secondary female sex characteristics, which include development of the breasts and body hair, and increased thickening of the endometrium. As follicles continue to develop, estrogen concentration in the blood increases. The follicular phase normally takes place between days 6 and 13 of the female menstrual cycle.

During ovulation, the third phase of the female menstrual cycle, the egg bursts from the ovary, and follicular cells differentiate into the corpus luteum.

The development of the corpus luteum marks the beginning of the **luteal phase.** Estrogen levels begin to decline when the oocyte leaves the ovary, but are restored somewhat when the corpus luteum forms. The corpus luteum secretes both estrogen and progesterone. **Progesterone** continues to stimulate the endometrium and prepares the uterus for an embryo. It also inhibits further ovulation. Does this provide any clues about why birth control pills contain high concentrations of progesterone? Progesterone, as used in birth control pills, prevents ovultion. In addition, progesterone prevents uterine contractions. Should progesterone levels fall, uterine contractions would begin. The luteal phase, which occurs between days 15 and 28, prepares the uterus to receive a fertilized egg. Should fertilization of an ovum not

Ovulation *involves the release of the egg from the follicle held within the ovary.*

The **corpus luteum** *is made up of the follicle cells of the ovary following ovulation. The corpus luteum secretes estrogen and progesterone.*

The **flow phase** *of the menstrual cycle is marked by the shedding of the endometrium.*

The **follicular phase** *is marked by the development of the ovarian follicles prior to ovulation.*

Estrogen *is a female sex hormone.*

The **luteal phase** *is characterized by the formation of the corpus luteum following ovulation.*

Progesterone *is a female sex hormone.*

occur, the concentrations of estrogen and progesterone will decrease, thereby causing weak uterine contractions. These weak uterine contractions cause the endometrium to pull away from the uterine wall. The shedding of the endometrium marks the beginning of the next flow phase.

Table 21.1 Female Menstrual Cycle

Phase	Description of events	Hormone produced	Days
Flow	Menstruation		1–5
Follicular	Follicles develop in ovaries. Endometrium is restored.	Estrogen produced by follicle cells.	6–13
Ovulation	Oocyte bursts from ovary.		14
Luteal	Corpus luteum forms: endometrium thickens.	Estrogen and progesterone	15–28

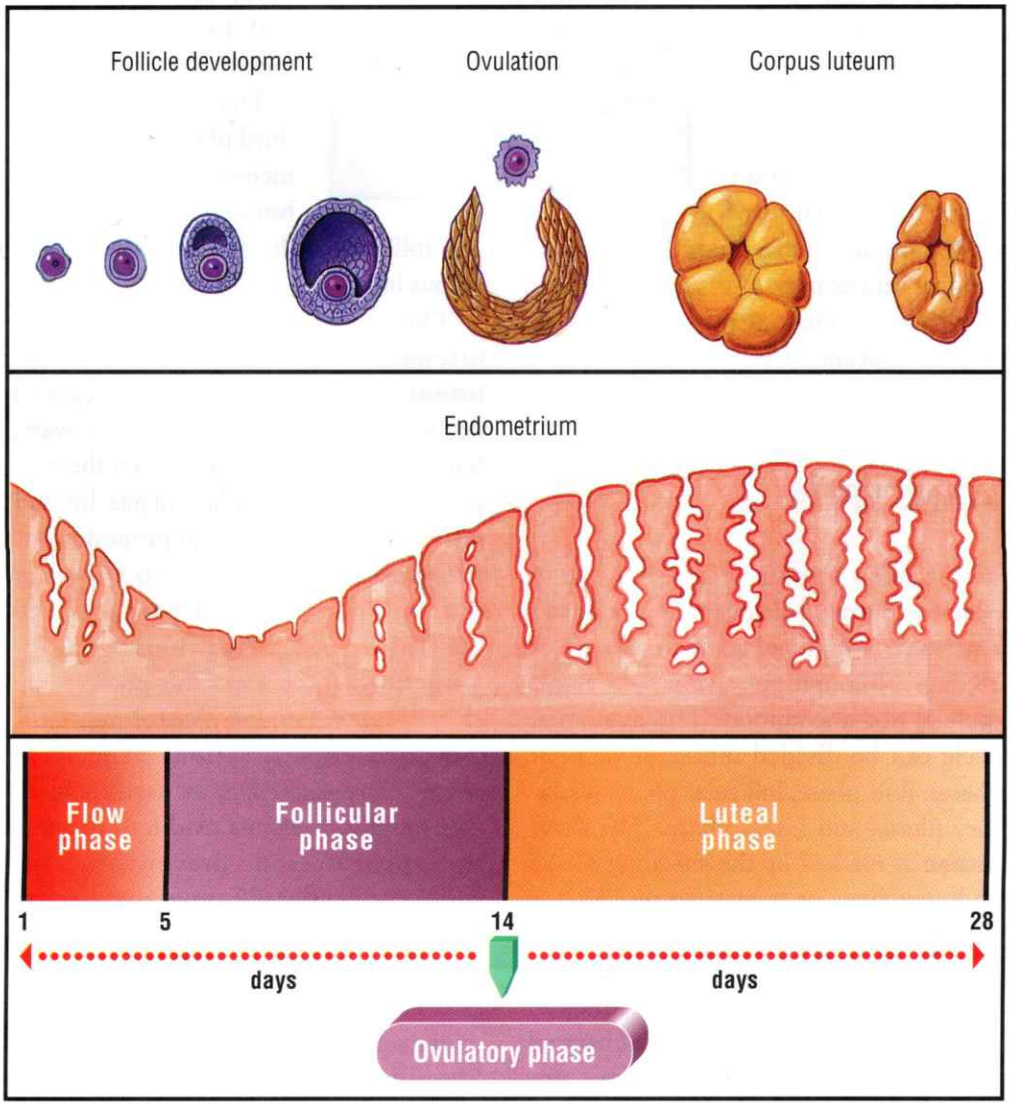


Figure 21.8

The thickness of the endometrium increases from the beginning of the follicular phase to the end of the luteal phase. The development of blood vessels and glandular tissues helps prepare the uterus for a developing embryo. Should no embryo enter the uterus, menstruation occurs, and the menstrual cycle begins again.

HORMONAL CONTROL OF THE FEMALE REPRODUCTIVE SYSTEM

The production of estrogen and progesterone—hormones of the ovary—is regulated by the hypothalamus-pituitary complex. Gonadotropins—female **FSH** (follicle-stimulating hormone) and **LH** (luteinizing hormone)—regulate the control of hormones produced by the ovaries: estrogen and progesterone. In turn, the gonadotropins are regulated by ovarian hormones as part of a complex negative-feedback mechanism.

The onset of female puberty is signalled by the release of GnRH (gonadotropin-releasing hormone) from the hypothalamus. GnRH activates the pituitary gland, which is the storage site of FSH and LH. During the follicular phase of the menstrual cycle, FSH secretions are carried by the blood to the ovary, where follicle development is stimulated. The follicles within the ovary secrete estrogen, which is carried in the blood, stimulating the development of secondary female characteristics and initiating the development of the endometrium. As estrogen levels rise, a negative-feedback message is sent to the pituitary gland to turn off secretions of FSH. The follicular phase of the menstrual cycle has come to an end. Simultaneously, the rise in estrogen exerts a positive message on the LH-producing cells of the pituitary gland. LH secretion rises and ovulation occurs.

After ovulation, the remaining follicular cells, under the influence of LH, are transformed into a functioning corpus luteum. The luteal phase of the menstrual cycle has begun. Cells of the corpus luteum secrete both estrogen and progesterone. The build-up of estrogen and progesterone will further increase the development of the endometrium. As progesterone and estrogen build up within the body, a second negative-feedback mechanism is activated. Progesterone and estrogen work together to inhibit the release of both FSH and LH. Without gonadotropic hormones, the corpus luteum begins to deteriorate, slowing estrogen and progesterone production. The drop in ovarian hormones signals the beginning of menstruation.

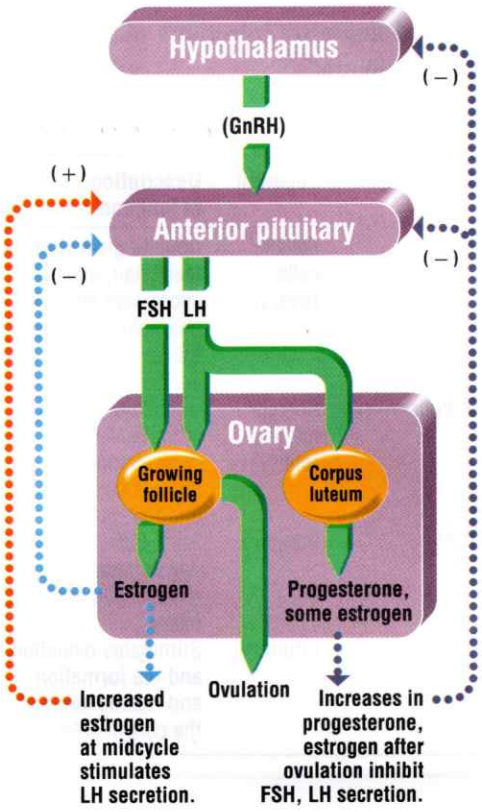


Figure 21.9
Feedback loop showing the regulation of ovarian hormones.

FSH *(follicle-stimulating hormone) is a gonadotropin that promotes the development of the follicles in the ovary.*

LH *(luteinizing hormone) is a gonadotropin that promotes ovulation and the formation of the corpus luteum.*

The similarities between male and female systems extend beyond the secretion of FSH and LH. Androgens (male sex hormones) and estrogen (the female sex hormone) can be produced by either gender. Male characteristics result not because androgens are the only hormones produced, but because the levels of androgens exceed the levels of estrogen. Males are ensured of maintaining low levels of female hormones by excreting them at an accelerated rate. This may explain why the urine of a stallion contains high

levels of estrogen. The importance of balancing androgen and estrogen levels has been demonstrated with roosters. The removal of the testes from a rooster will caponize it. Injections of estrogen will bring about the same effect. In humans, the secretions of androgens will stimulate the development of the male's prostate gland, but injections of estrogen will slow the process. This may explain why cancerous tumors of the male prostate can be slowed down by injections of estrogen-like compounds.

Table 21.2 Female Reproductive Hormones

Hormone	Location	Description of function
Estrogen	Follicle cells (ovary)	Inhibits growth of facial hair, initiates secondary female characteristics, and thickening of the endometrium.
Progesterone	Corpus luteum (ovary)	Inhibits ovulation, inhibits uterine contractions, stimulates the endometrium.
FSH	Pituitary	Stimulates the development of the follicle cells in the ovary.
LH	Pituitary	Stimulates ovulation, and the formation and maintenance of the corpus luteum.

BIOLOGY CLIP

Acne is a common inflammatory disease of skin areas where oil glands are largest and most numerous. Acne is attributable to the effect of androgen hormones on hair follicles and their oil glands. It is very common at puberty and affects more than 80% of teenagers to some degree. Certain foods seem to aggravate it, particularly chocolate, nuts, and cola drinks. Before, during, or following the menstrual period flare ups are common, but interestingly, estrogen treatment is rarely effective.

REVIEW QUESTIONS ?

9 Draw a diagram of the female reproductive system and label the following parts: vagina, ovaries, cervix, oviducts, uterus, and endometrium.

10 Can a woman who has reached menopause ever become pregnant? Explain your answer.

11 What is menstruation? Why is it important?

12 Explain why ectopic pregnancies are dangerous.

13 What is a Pap test?

14 Describe the process of ovulation. Differentiate between primary oocytes, secondary oocytes, and mature ova.

15 Describe how the corpus luteum forms in the ovary.

16 Describe the events associated with the flow phase, follicular phase, and luteal phase of menstruation.

17 Outline the functions of estrogen and progesterone.

18 How do gonadotropic hormones regulate the function of ovarian hormones?

19 Predict how low secretions of GnRH from the hypothalamus would affect the female menstrual cycle.

20 With reference to the female reproductive system, provide an example of a negative-feedback control system.

CASE STUDY

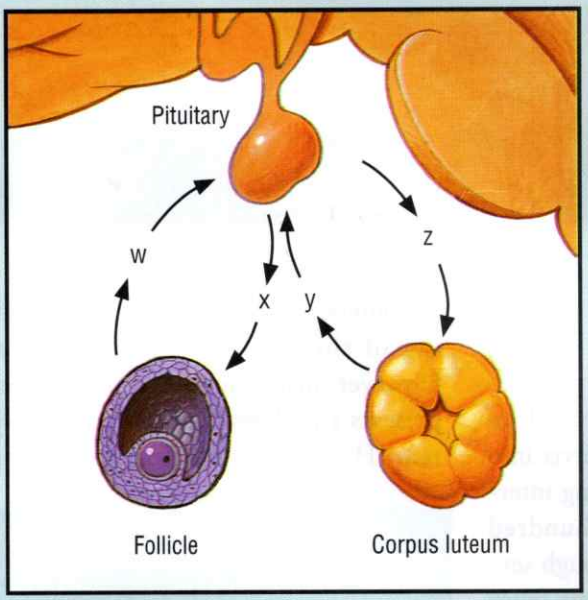
HORMONE LEVELS DURING THE MENSTRUAL CYCLE

Objective

To investigate how hormone levels regulate the female menstrual cycle.

Procedure

1 Ovarian hormones are regulated by gonadotropic hormones. Study the feedback loop shown in the diagram below.



a) Identify as w, x, y, or z, the two gonadotropic hormones represented in the diagram.
b) Identify the ovarian hormones shown in the diagram.
c) Which two hormones exert negative-feedback effects?

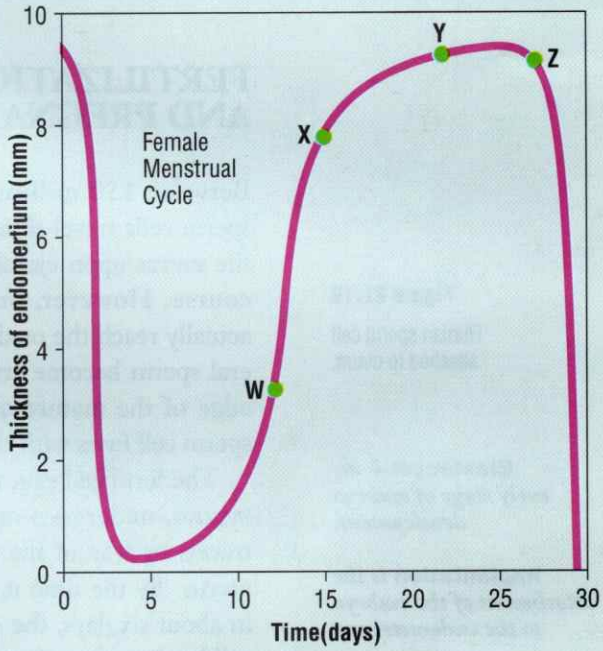
2 Body temperatures of two women were monitored during their menstrual cycles. One woman ovulated; the other did not.

d) Graph the data provided. Plot changes in temperature along the *y*-axis (vertical axis) and the days of the menstrual cycle along the *x*-axis (horizontal axis).
e) Assuming this menstrual cycle represents the average 28-day cycle, label the ovulation day on the graph.

	Temperature °C	
Days	Ovulation occurs	No ovulation occurs
5	36.4	36.3
10	36.2	35.7
12	36.0	35.8
14	38.4	36.2
16	37.1	36.1
18	36.6	36.0
20	36.8	36.3
22	37.0	36.3
24	37.1	36.4
28	36.6	36.5

f) Describe changes in temperature prior to and during ovulation.
g) Compare body temperatures with and without a functioning corpus luteum.

3 The graph below shows changes in the thickness of the endometrium throughout the female menstrual cycle.



h) Identify the events that occur at times *X* and *Z*.
i) Identify by letter the time when follicle cells produce estrogen.
j) Identify by letter the time when the corpus luteum produces estrogen and progesterone.

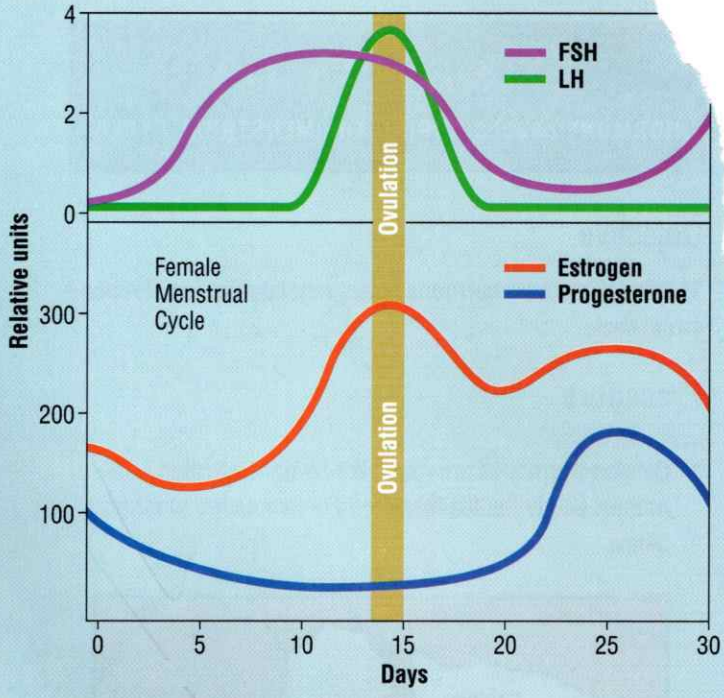
4 Levels of gonadotropic hormones are monitored throughout the female reproductive cycle. Levels are recorded in relative units.

k) How does LH affect estrogen and progesterone?

Case-Study Application Questions

1 Explain why birth control pills often contain high concentrations of progesterone and estrogen.

2 Why would a woman not take birth control pills for the entire 28 days of the menstrual cycle? On which days of the menstrual cycle would the pill not be taken? ■



FERTILIZATION AND PREGNANCY

Between 150 million and 300 million sperm cells travel through the cervix into the uterus upon ejaculation during intercourse. However, only a few hundred actually reach the oviducts. Although several sperm become attached to the outer edge of the mature ovum, only a single sperm cell fuses with the ovum.

The fertilized egg, now referred to as a zygote, undergoes many divisions as it travels by way of the oviduct toward the uterus. By the time it reaches the uterus, in about six days, the single fertilized egg cell has been transformed into a cell mass, called a **blastocyst.** Once in the uterus, the blastocyst becomes attached to the wall of the endometrium, a process referred to as **implantation.**

For pregnancy to continue, menstruation cannot occur. Any shedding of the endometrium would mean the dislodging of the embryo from the uterus. However, maintaining the endometrium presents a problem for the hormonal system. High levels of progesterone and

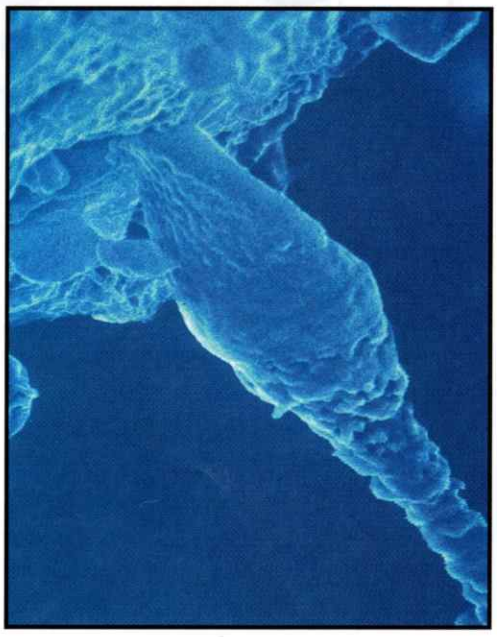


Figure 21.10
Human sperm cell attached to ovum.

Blastocyst *is an early stage of embryo development.*

Implantation *is the attachment of the embryo to the endometrium.*

estrogen have a negative-feedback effect on the secretion of gonadotropic hormones. LH levels must remain high to sustain the corpus luteum. Should the corpus luteum deteriorate, the levels of estrogen and progesterone would drop, stimulating uterine contractions and the shedding of the endometrium. For pregnancy to continue, progesterone and estrogen levels must be maintained.

The outer layer of the developing cell mass forms a hormone called **HCG** (human chorionic gonadotropic hormone), which maintains the corpus luteum for the first three months of pregnancy. The functioning corpus luteum continues producing progesterone and estrogen, which in turn maintain the endometrium. The endometrium and embryo thus remain in the uterus. Pregnancy tests identify HCG levels in the urine of women.

Cells from the embryo and endometrium combine to form the placenta, through which materials are exchanged between the mother and developing embryo. At approximately the fourth month of pregnancy, the placenta begins to produce estrogen and progesterone. High levels of progesterone prevent further ovulation. This means that once a woman is pregnant, she cannot become pregnant again during that pregnancy.

BIOLOGY CLIP

It has been estimated that 1 in 85 births will produce twins, 1 in 7500 will produce triplets, 1 in 650 000 will produce quadruplets, and 1 in 57 000 000 will produce quintuplets.

PRENATAL DEVELOPMENT

The outer layer of the blastocyst gives rise to two cell membranes. The outer membrane is the **chorion,** which produces HCG. The inner membrane, the **amnion,** develops above the embryo. The amnion evolves into a fluid-filled sac that insulates the embryo, and later the fetus, protecting it from infection, dehydration, impact, and changes in temperature. By the fourth week of pregnancy the yolk sac, which is a vestigial formation in humans, forms below the embryo.

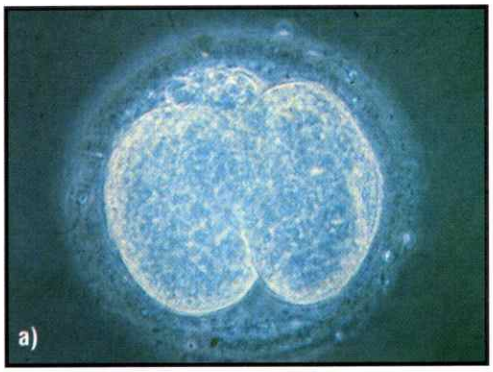


Figure 21.11

(a) Two-cell stage.
(b) Blastocyst after 4 to 6 days.

***HCG** is a placental hormone that maintains the corpus luteum.*

*The **chorion** is the outer membrane of a developing embryo.*

*The **amnion** is a fluid-filled embryonic membrane.*

*The **placenta** is the site for the exchange of nutrients and wastes between mother and fetus.*

*The **allantois** is an embryonic membrane.*

Cells of the fetus and cells of the endometrium comprise the **placenta.** The placenta is richly supplied with blood vessels. Projections called *chorionic villi* ensure that many blood capillaries of the mother are exposed to a large number of blood capillaries of the fetus. A third membrane, the **allantois,** provides blood vessels in the placenta. However, unlike the chorion and amnion, the allantois does not envelop the fetus. The placenta provides a lifeline between mother and fetus. Nutrients and oxygen diffuse from the mother's blood into the

blood of the developing fetus. Wastes diffuse in the opposite direction, moving from the fetus to the mother. The **umbilical cord** connects the embryo with the placenta.

The nine months of pregnancy are divided into three trimesters. The **first trimester** extends from fertilization to the end of the third month. By the second week of development, three germ layers begin to form: the ectoderm, the mesoderm, and the endoderm. Each of the organs shown in Table 21.3 develops from one of the germ layers.

The **umbilical cord** *connects the fetus to the placenta.*

The **first trimester** *extends from conception until the third month of pregnancy.*

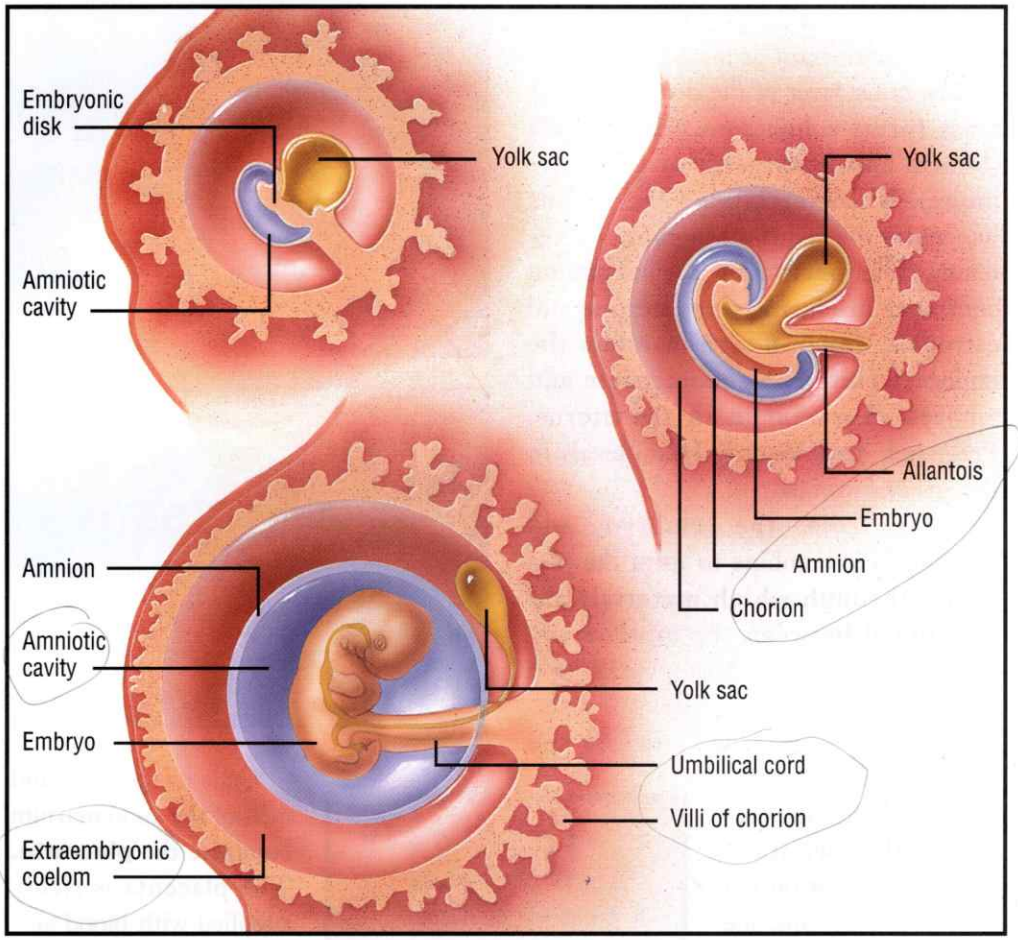


Figure 21.12
Formation of the membranes that protect the embryo.

Table 21.3 Organs from Germ Layers

Germ Layer	Organ and Accessory Structures
Ectoderm	Skin, hair, finger nails, sweat glands
	Nervous system, brain, peripheral nerves
	Lens, retina, and cornea
	Inner ear, cochlea, semicircular canals
	Teeth, and inside lining of mouth
Mesoderm	Muscles (skeletal, cardiac, and smooth)
	Blood vessels and blood
	Kidneys and reproductive structures
	Connective tissue, cartilage, and bone
Endoderm	Liver, pancreas, thyroid, parathyroid
	Urinary bladder
	Lining of digestive system
	Lining of the respiratory tract

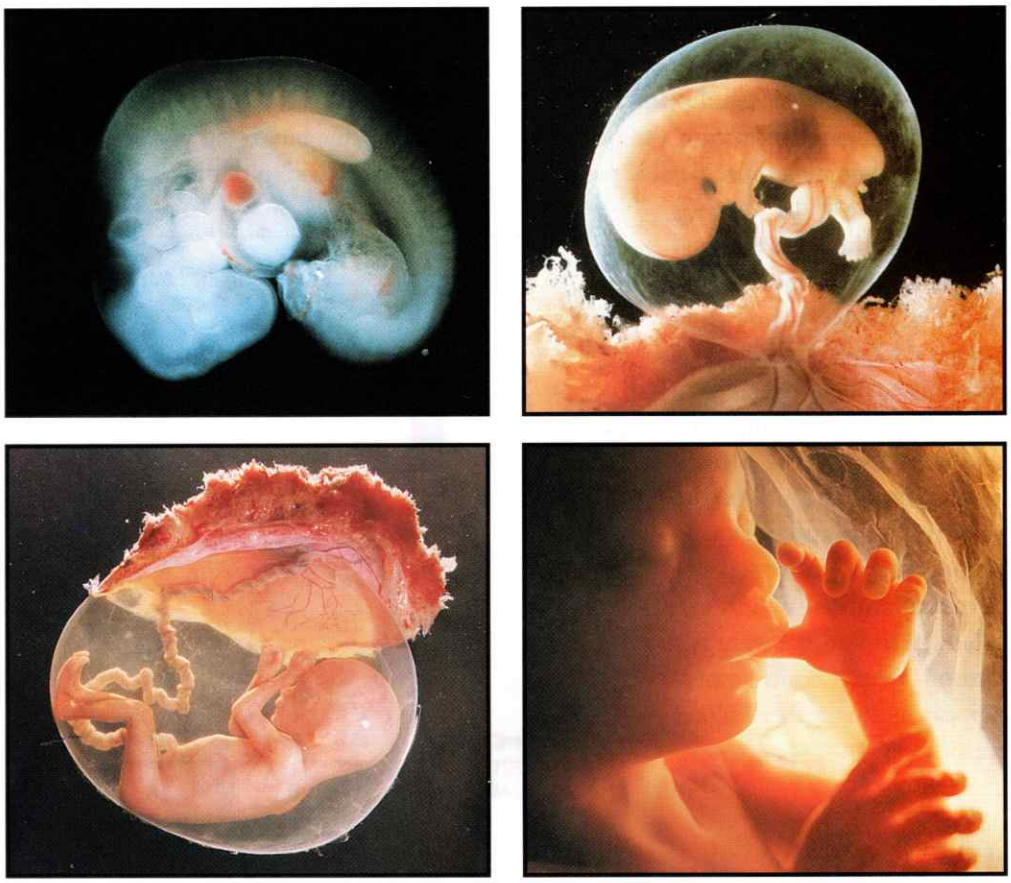


Figure 21.13
Human embryo at four weeks, and the fetus at nine weeks, sixteen weeks, and at eighteen weeks.

By the end of the first month, the 7 mm embryo is 500 times larger than the fertilized egg. The four-chambered heart has formed, a large anterior brain is visible, and limb buds with tiny fingers and toes have developed. By the ninth week, the embryo is referred to as a fetus. Arms and legs begin to move and a sucking reflex is evident.

By the **second trimester,** the 57 mm fetus moves enough to make itself known to the mother. All of its organs have formed and the fetus begins to look more like a human infant. As in other mammals, soft hair begins to cover the entire body. By the sixth month eyelids and eyelashes form. Most of the cartilage that formed the skeleton has been replaced by bone cells. Should the mother go into labor at the end of the second trimester, there is a chance that the 350 mm, 680 g fetus will survive.

During the **third trimester,** the baby grows rapidly. Organ systems have been established during the first two trimesters; all that remains is for the body mass to increase and the organs to become more developed. At birth, the average human infant is approximately 530 mm long and weighs about 3400 g.

***The* second trimester** *extends from the third month to the sixth month of pregnancy.*

***The* third trimester** *extends from the seventh month of pregnancy until birth.*

BIRTH

Approximately 266 days after implantation, uterine contractions signal the beginning of labor. The cervix thins and begins to dilate. The amniotic membrane is forced into the birth canal. The amniotic membrane often bursts and amniotic fluid lubricates the canal (a process referred to as the breaking of the water). As the cervix dilates, uterine contractions move the baby through the birth canal.

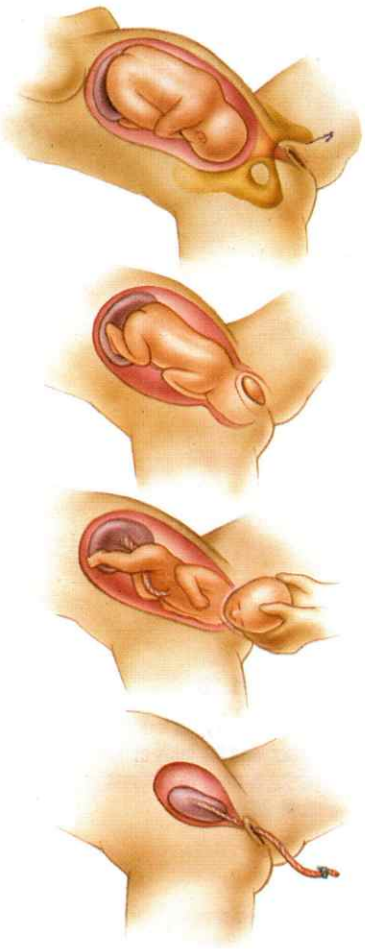


Figure 21.14
Movement of the baby through the birth canal.

Hormones play a vital role in the birthing process. **Relaxin,** a hormone produced by the placenta prior to labor, causes the ligaments within the pelvis to loosen, providing a more flexible passageway for the baby during delivery. Although the actual mechanism is not completely understood, it is believed that a decreased production of progesterone is crucial to the onset of labor. **Oxytocin,** a hormone from the posterior pituitary gland, causes strong uterine contractions. Prostaglandins, which are also believed to trigger strong uterine contractions, appear in the mother's blood prior to labor.

LACTATION

Breast development is stimulated from the onset of puberty by estrogen and progesterone. During pregnancy, elevated levels of estrogen and progesterone prepare the breasts for milk production. Each breast contains about 20 lobes of glandular tissue, each supplied with a tiny duct that carries fluids toward the nipple. A hormone called **prolactin,** produced by the pituitary gland, is believed to be responsible for stimulating glands within the breast to begin producing fluids. Although small concentrations of prolactin are secreted throughout pregnancy, the levels rise dramatically after birth has occurred. The fact that the rise of prolactin levels coincides with rapid decreases in both estrogen and progesterone levels has led scientists to speculate that the female sex hormones suppress prolactin. Prolactin causes the production of a fluid called *colostrum*, a fluid that closely resembles breast milk. Colostrum contains milk sugar and milk proteins, but lacks the milk fats found in breast milk. A few days after birth, the prolactin stimulates the production of milk.

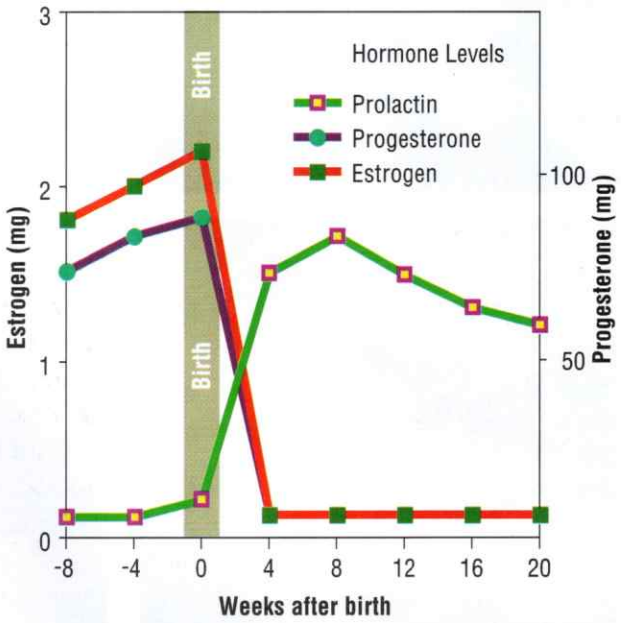


Figure 21.15
A dramatic increase in prolactin is attributed to lowering levels of estrogen and progesterone. Estrogen and progesterone levels drop following childbirth. Measurements for prolactin are in relative amounts.

Although prolactin increases milk production, the milk does not flow easily. Milk produced in the lobes of glandular tissue must be forced into the ducts that lead to the nipple. The suckling action of the newborn stimulates nerve endings in the areola of the breast. Sensory nerves carry information to the pituitary gland, causing the release of oxytocin. The hormonal reflex is completed as oxytocin is carried by the blood to the breasts and uterus. Within the breast, oxytocin causes weak contractions of smooth muscle, forcing milk into the ducts. Within the uterus, oxytocin causes weak contractions of smooth muscle, allowing the uterus to slowly return to its pre-pregnancy size and shape.

***Relaxin,** a hormone produced by the placenta prior to labor, causes the ligaments within the pelvis to loosen.*

***Oxytocin,** a hormone from the posterior pituitary gland, causes strong uterine contractions.*

***Prolactin** is a hormone produced by the pituitary and is associated with milk production.*

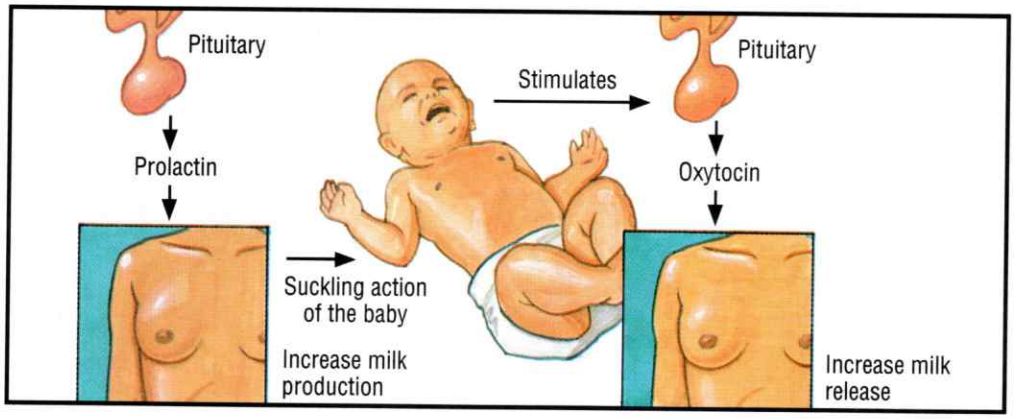


Figure 21.16

The hormone prolactin stimulates the breast to produce milk. The suckling action of the baby initiates a hormonal reflex involving the hormone oxytocin.

Although most North American mothers prefer to end breast-feeding once their youngster begins to develop teeth, women in some countries, especially where sources of protein are scarce, often continue to breast-feed for four or five years. Milk production causes a metabolic drain on the mother. At the height of lactation a woman can produce as much as 1.5 L of milk each day. A mother producing that much milk would lose approximately 50 g of fat and up to 100 g of lactose sugar. In addition, a breast-feeding mother would have to replace some 2 to 3g of calcium phosphate each day. To maintain adequate levels of calcium and phosphate, the parathyroid glands enlarge and bones decalcify. Failure to replace the needed calcium results in a progressive deterioration of the skeleton and teeth. Mother's milk also supplies an important source of antibodies, a topic that is dealt with in the chapter Blood and Immunity.

FRONTIERS OF TECHNOLOGY: *IN VITRO* FERTILIZATION

Approximately 13% of Canadian couples are unable to conceive a child. Sterility, hormonal imbalances, and the destruction of reproductive organs by infections are the leading causes of infertility. ***In vitro*** fertilization, in which the egg is fertilized outside of the body, has provided renewed hope for many people who are unable to have children. On July 25, 1978, Drs. Patrick Steptoe and Robert Edwards of Cambridge, England, announced the first successful *in vitro* fertilization. The baby, Louise Brown, became the world's first so-called "test-tube baby." The name "test-tube baby" is actually a misnomer, since neither the egg nor sperm spend any time in a test tube.

In vitro ***fertilization occurs outside of the female's body.*** **In vitro** ***is Latin for "in glass."***

In this procedure, a device, called a *laparoscope* is inserted into the woman's abdomen. An optical device within the instrument enables the physician to locate the ovary. A suction apparatus in the laparoscope allows the extraction of eggs from the ovary. The eggs are placed in a glass petri dish and fertilized by the sperm. Following a brief incubation period, one or more of the embryos is transferred into the uterus by a small catheter. If one of the embryos implants, a baby will be born nine months later.

A second technique, involving embryo freezing, has been combined with *in vitro* fertilization. Because *in vitro* fertilization uses multiple eggs, of which only a limited number can be placed in the uterus, freezing permits storage of any unused embryos and implantation without undergoing the laparoscope procedure. In 1990, Dr. Peter Leung of Toronto's East General Hospital was the first doctor in Canada to implant a frozen embryo.