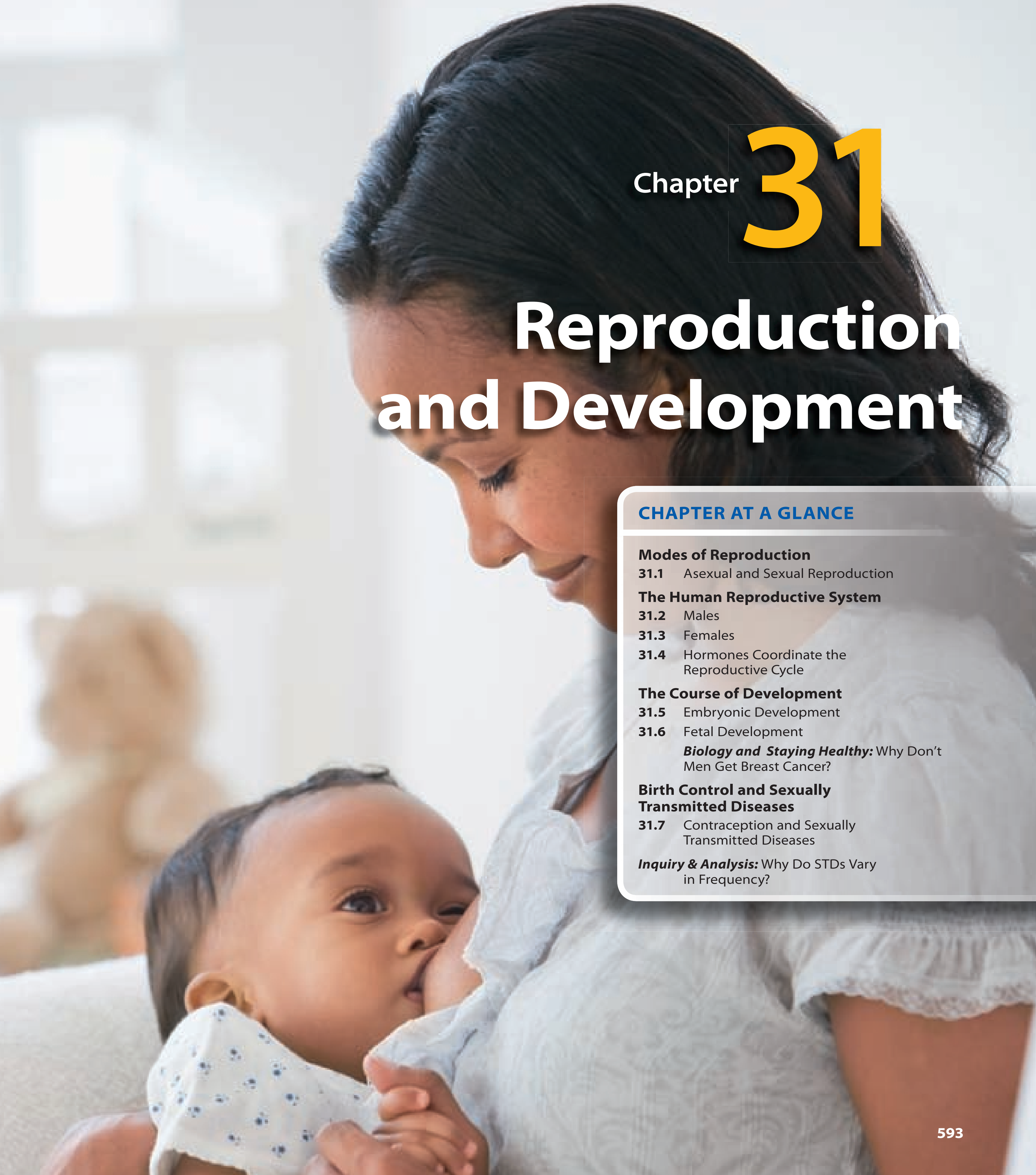

Chapter 31

Reproduction and Development

CHAPTER AT A GLANCE

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Modes of Reproduction

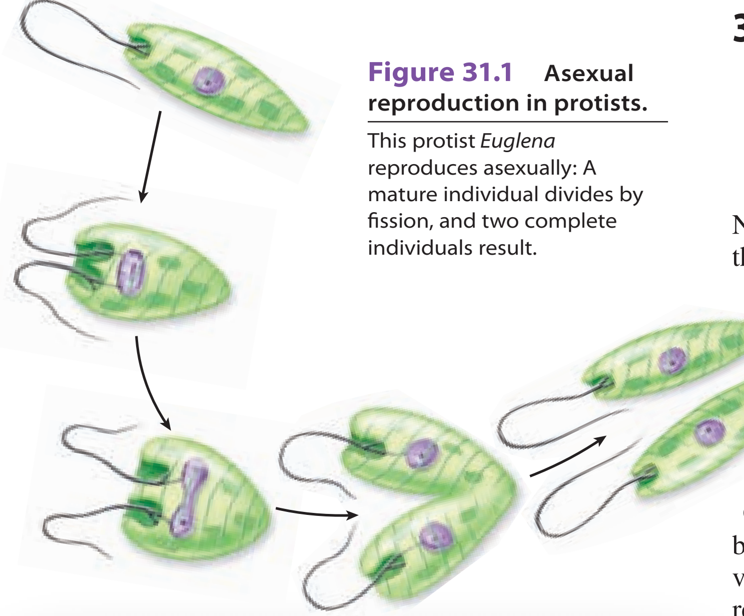


Figure 31.1 Asexual reproduction in protists.

This protist *Euglena* reproduces asexually: A mature individual divides by fission, and two complete individuals result.

31.1 Asexual and Sexual Reproduction

CONCEPT PREVIEW: While sexual reproduction is common among animals, many reproduce asexually by fission, budding, or parthenogenesis. Some animal species are hermaphroditic, while others change sex.

Not all reproduction involves two parents. Asexual reproduction, in which the offspring are genetically identical to the parent, is the primary means of reproduction among protists, cnidarians, and tunicates, and also occurs in some more complex animals.

Through mitosis, genetically identical cells are produced from a single parent cell. This permits asexual reproduction to occur in the *Euglena* in figure 31.1 by division of the organism, or **fission.** The DNA replicates and organs, such as the flagellum, duplicate. The nucleus divides with identical nuclei going to each daughter cell. Cnidaria commonly reproduce by **budding,** where a part of the parent's body becomes separated from the rest and differentiates into a new individual. The new individual may become an independent animal or may remain attached to the parent, forming a colony.

Unlike asexual reproduction, sexual reproduction occurs when a new individual is formed by the union of *two* cells. These cells are called **gametes,** and the two kinds that combine are generally called *sperm* and *eggs* (or ova). The union of a sperm and an egg produces a fertilized egg, or **zygote,** that develops by mitotic division into a new multicellular organism. The zygote and the cells it forms by mitosis are diploid; they contain both members of each homologous pair of chromosomes. The gametes, formed by meiosis in the sex organs, or **gonads**—the *testes* and *ovaries*—are haploid (see chapter 9). The processes of spermatogenesis (sperm formation) and oogenesis (egg formation) are described in later sections.

Most animals undergo sexual reproduction. In the animals, diploid cells make up the majority of the life cycle; the only haploid cells in the life cycle are the gametes, as discussed on page 145.

(a)

(b)

Different Approaches to Sex

Parthenogenesis, a type of reproduction in which offspring are produced from unfertilized eggs, is common in many species of arthropods. Some species are exclusively parthenogenic, whereas others switch between sexual reproduction and parthenogenesis in different generations. In honeybees, for example, a queen bee mates only once and stores the sperm. She then can control the release of sperm. If no sperm are released, the eggs develop parthenogenetically into drones, which are males; if sperm are allowed to fertilize the eggs, the fertilized eggs develop into other queens or worker bees, which are female. Parthenogenesis also occurs among populations of some lizard genera.

Figure 31.2 Hermaphroditism and protogyny.

(a) The hamlet bass (genus *Hypoplectrus*) is a deep-sea fish that is a hermaphrodite. In the course of a single pair-mating, one fish may switch sexual roles as many as four times. Here, the fish acting as a male curves around its motionless partner, fertilizing the upward-floating eggs. (b) The bluehead wrasse *Thalassoma bifasciatium* is protogynous. Here a large male, or sex-changed female, is seen among females, which are typically much smaller.

Another variation in reproductive strategies is **hermaphroditism,** when one individual has both testes and ovaries and so can produce both sperm and eggs. The hamlet bass in figure 31.2*a* are hermaphroditic, producing both eggs and sperm. During mating each fish switches from producing eggs that are fertilized by its partner, to producing sperm that fertilizes its partner's eggs. A tapeworm is hermaphroditic and can fertilize itself as well as cross fertilize, a useful strategy because it is unlikely to encounter another tapeworm living inside its host. Most hermaphroditic animals, however, require another individual to reproduce. Two earthworms, for example, are required for reproduction—like the hamlet bass, each functions as both male and female. Each leaves the encounter with fertilized eggs.

Numerous fish genera include species in which individuals can change their sex in response to social or environmental conditions, a process called *sequential hermaphroditism.* Among coral reef fish, for example, both **protogyny** ("first female," a change from female to male) and **protandry** ("first male," a change from male to female) occur. In the protogynous bluehead wrasse in figure 31.2*b*, the sex change appears to be under social control. These fish commonly live in large groups, or schools, where successful reproduction is typically limited to one or a few large, dominant males. If those males are removed, the largest female rapidly changes sex and becomes a dominant male (the blue-headed fish in the photo).

Sex Determination

In mammals, the sex is determined early in embryonic development. The reproductive systems of human males and females appear similar for the first 40 days after conception. During this time, the cells that will give rise to ova or sperm migrate to the embryonic gonads, which have the potential to become either ovaries in females or testes in males. If the embryo is XY, it is a male and will carry a gene on the Y chromosome whose protein product converts the gonads into testes (as on the left in figure 31.3). In females, who are XX, this Y chromosome gene and the protein it encodes are absent, and the gonads become ovaries (as on the right). Recent evidence suggests that the sex-determining gene may be one known as ***SRY*** (for "*s*ex-determining *r*egion of the *Y* chromosome"). The *SRY* gene appears to have been highly conserved during the evolution of different vertebrate groups.

Once testes form in the embryo, they secrete testosterone and other hormones that promote the development of the male external genitalia and accessory reproductive organs (indicated in the blue box in the figure). If testes do not form, the embryo develops female external genitalia and accessory reproductive organs. The ovaries do not promote this development of female organs because the ovaries are nonfunctional at this stage. In other words, all mammalian embryos will develop female sex accessory organs and external genitalia by default unless they are masculinized by the secretions of the testes.

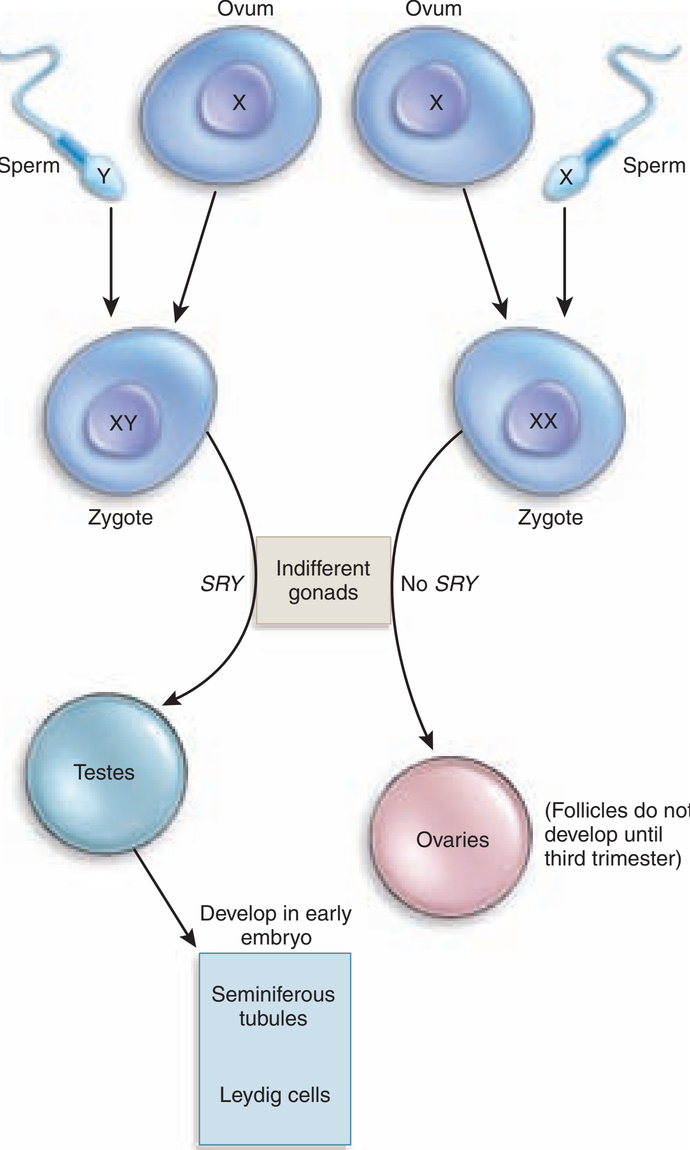


Figure 31.3 **Sex determination.**

Sex determination in mammals is made by a gene of the Y chromosome designated *SRY*. Testes are formed when the Y chromosome and *SRY* are present; ovaries are formed when they are absent.

IMPLICATION Imagine if genetic engineering could be used to transfer the *SRY* gene into an X chromosome. Would a zygote carrying a normal X and this *SRY*-X be a female or a male? Explain why you think so. Do you think carrying out this sort of experiment in humans should be legal?

Concept Check

1. Explain the key difference between asexual and sexual reproduction.
2. What is parthenogenesis? Give an example of a parthenogenic animal.
3. How is sex determined among mammals?

The Human Reproductive System

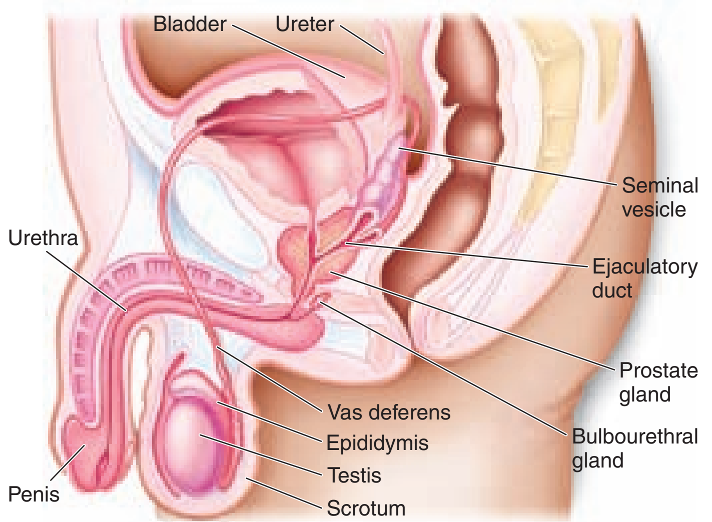


Figure 31.4 The male reproductive organs.

The testis is where sperm are formed. Cupped above the testis is the epididymis, a highly coiled passageway within which sperm complete their maturation. Extending away from the epididymis is a long tube, the vas deferens.

31.2 Males

CONCEPT PREVIEW: Male testes continuously produce large numbers of male gametes, sperm, which mature in the epididymis, are stored in the vas deferens, and are delivered through the penis into the female.

The human male gamete, or **sperm,** is highly specialized for its role as a carrier of genetic information. Produced by meiosis, sperm cells have 23 chromosomes instead of the 46 found in other cells of the male body. Sperm do not successfully complete their development at 37°C (98.6°F), the normal human body temperature. The sperm-producing organs, the **testes** (singular, **testis**), move during the course of fetal development into a sac called the scrotum (figure 31.4), which hangs between the legs of the male, maintaining the two testes at a temperature about 3°C cooler than the rest of the body. The testes contain cells that secrete the male sex hormone **testosterone.**

Male Gametes Are Formed in the Testes

An internal view of a testis in figure 31.5 ❶ shows that it is composed of several hundred compartments, each packed with large numbers of tightly coiled tubes called **seminiferous tubules** (seen in cross section in ❷). Sperm production, *spermatogenesis,* takes place inside the tubules. The process of spermatogenesis begins in germi-

Figure 31.5 presents an overview of the process of meiosis during sperm development. Detailed descriptions of the stages of meiosis can be found on pages 146 through 149.

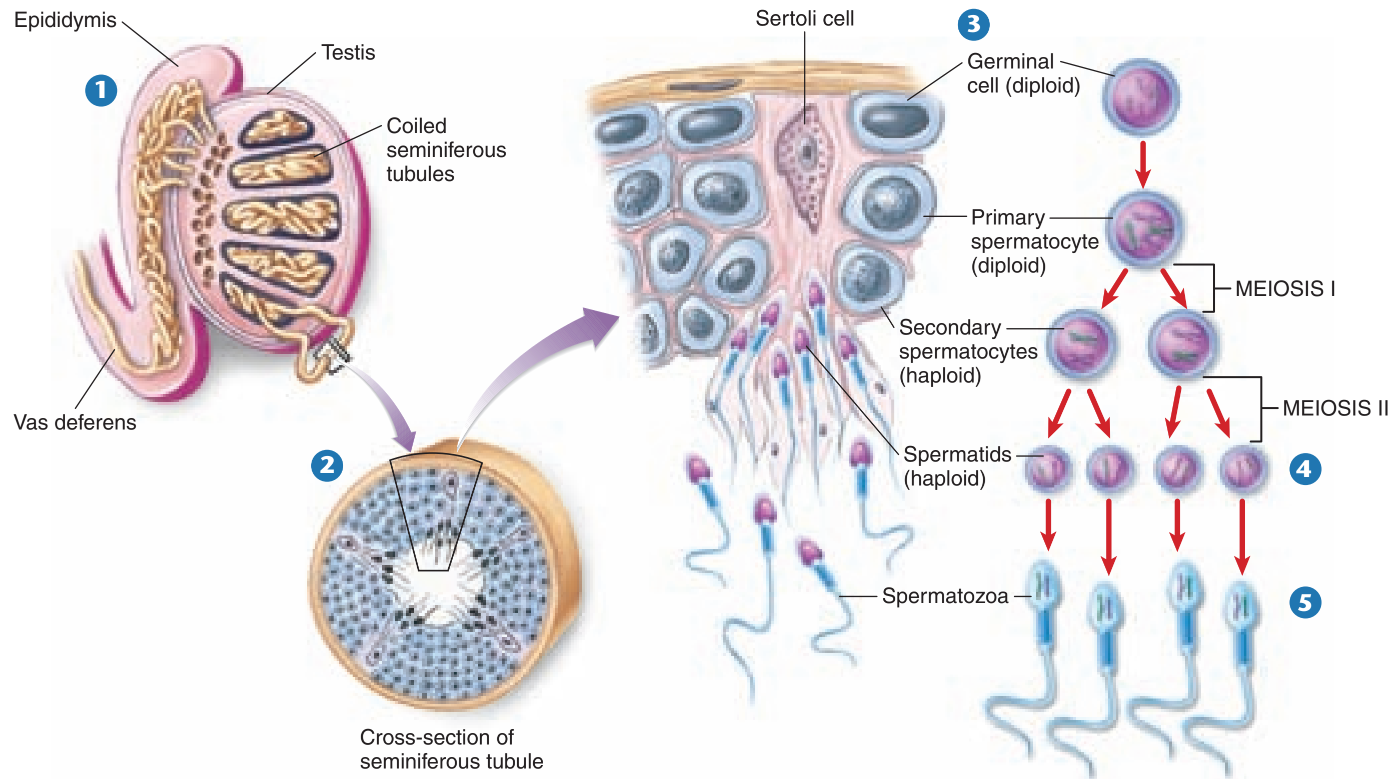


Figure 31.5 The testis and formation of sperm.

Inside the testis ❶, the seminiferous tubules ❷ are the sites of sperm formation. Germinal cells in the seminiferous tubules ❸ give rise to primary spermatocytes (diploid), which undergo meiosis to form haploid spermatids ❹. Spermatids develop into mobile spermatozoa, or sperm ❺. Sertoli cells are nongerminal cells within the walls of the seminiferous tubules. They assist spermatogenesis in several ways, such as helping to convert spermatids into spermatozoa.

nal cells toward the outside of the tubule (shown in the enlarged view in 3). As the cells undergo meiosis, they move toward the lumen of the tubule, with spermatozoa being released into the tubule. The number of sperm produced is truly incredible. A typical adult male produces several hundred million sperm each day of his life! Those that are not ejaculated from the body are broken down, and their materials are reabsorbed and recycled.

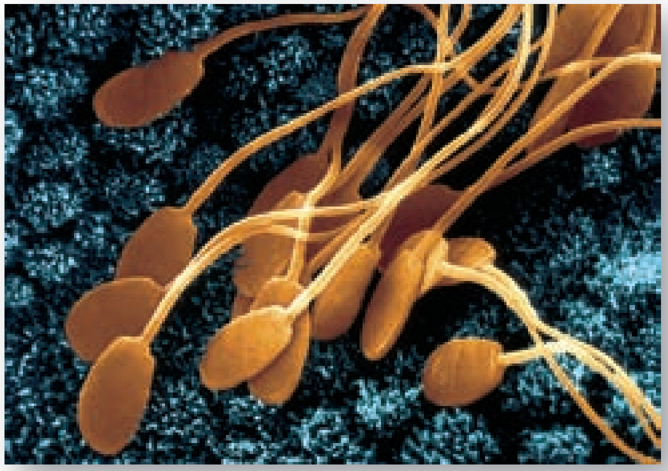
After a sperm cell is manufactured within the testes through intermediate stages of meiosis, it is delivered to a long, coiled tube called the **epididymis** (see figure 31.5), where it matures. A sperm cell is not motile when it arrives in the epididymis, and it must remain there for at least 18 hours before its motility develops. Mature sperm are relatively simple cells, consisting of a head, body, and tail (figure 31.6). The head encloses a compact nucleus and is capped by a vesicle called an *acrosome*. The acrosome contains enzymes that aid in the penetration of the protective layers surrounding the egg. The body and tail provide a propulsive mechanism: Within the tail is a flagellum, and inside the body are centrioles, which act as a basal body for the flagellum, and mitochondria, which generate the energy needed for flagellar movement.

From the epididymis, the sperm is delivered to another long tube, the **vas deferens.** When sperm are released during intercourse, they travel through a tube from the vas deferens to the urethra, where the reproductive and urinary tracts join, emptying through the penis. Sperm is released in a fluid called **semen,** which also contains secretions mostly from the seminal vesicles and the prostate gland that provide metabolic energy sources for the sperm. Benign enlargement of the prostate occurs in 90% of men by age 70, but it can be cancerous. Prostate cancer is the second most common cancer in men and can be treated effectively if detected early during physical examinations, before it spreads.

Male Gametes Are Delivered by the Penis

In the case of humans and some other mammals, the **penis** is an external tube containing two long cylinders of spongy tissue side by side (seen in longitudinal and cross sections in figure 31.7). A third cylinder of spongy tissue contains in its center a tube called the urethra, through which both semen (during ejaculation) and urine (during urination) pass. Why this unusual design? The penis is designed to inflate. The spongy tissues that make up the three cylinders are riddled with small spaces between the cells, and when nerve impulses from the CNS cause the arterioles leading into this tissue to expand, blood collects within these spaces. Like blowing up a balloon, this causes the penis to become erect and rigid. Continued stimulation by the CNS is required for erection to continue.

Erection can be achieved without any physical stimulation of the penis, but physical stimulation is required for semen to be delivered. Stimulation of the penis, as by repeated thrusts into the vagina of a female, leads first to the mobilization of the sperm. In this process, muscles encircling the vas deferens contract, moving the sperm along the vas deferens into the urethra. The bulbourethral glands also secrete a clear, slippery fluid that neutralizes the acidity of any residual urine and lubricates the head of the penis. Further penis stimulation then leads to the strong contraction of the muscles at the base of the penis. The result is **ejaculation,** the forceful ejection of 2 to 5 milliliters of semen. Within this small 5-milliliter volume are several hundred million sperm. Because the odds against any one individual sperm cell successfully completing the long journey to the egg and fertilizing it are extraordinarily high, successful fertilization requires a high sperm count. Males with fewer than 20 million sperm per milliliter are generally considered sterile.



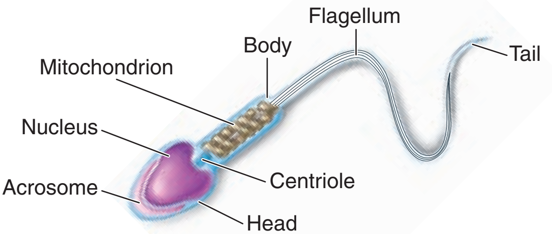


Figure 31.6 Human sperm cells.

Each sperm possesses a long tail that propels the sperm and a head that contains the nucleus. The tip, or acrosome, contains enzymes to help the sperm cell digest a passageway into the egg for fertilization.

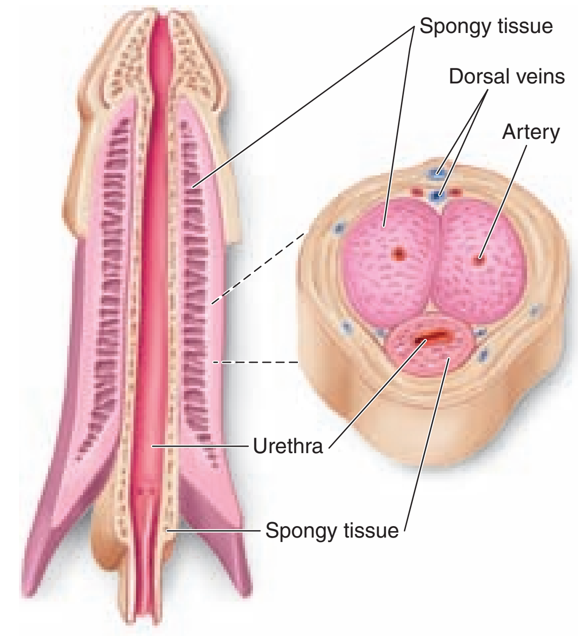


Figure 31.7 Structure of the penis.

(*Left*) longitudinal section; (*right*) cross section.

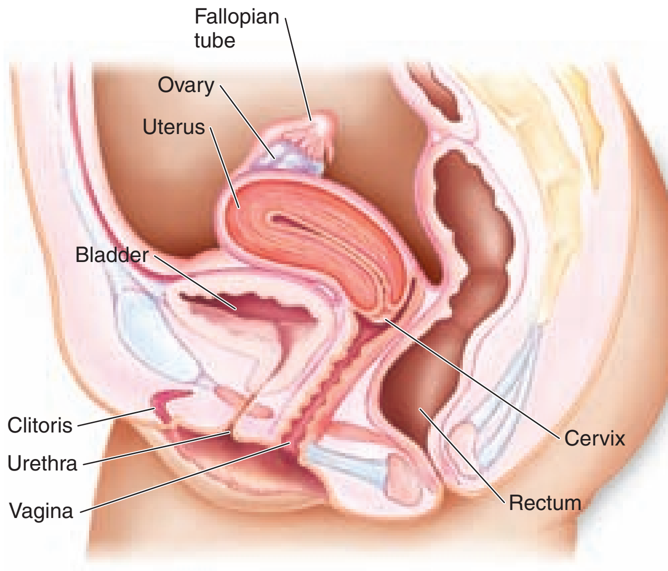


Figure 31.8 The female reproductive system.

The organs of the female reproductive system are specialized to produce gametes and to provide a site for embryonic development if the gamete is fertilized.

31.3 Females

CONCEPT PREVIEW: In human females, hormones trigger the development of one or a few oocytes once a month (about every 28 days). After ovulation, an egg cell travels down the fallopian tube and, if fertilized during its journey, implants in the wall of the uterus.

In females, eggs develop from cells called **oocytes,** located in the outer layer of compact masses of cells called **ovaries** within the abdominal cavity (figure 31.8). Recall that in males the gamete-producing cells are constantly dividing. In females all of the oocytes needed for a lifetime are already present at birth. During each reproductive cycle, one or a few of these oocytes are initiated to continue their development in a process called **ovulation;** the others remain in developmental holding patterns.

Only One Female Gamete Matures Each Month

At birth, a female's ovaries contain some 2 million oocytes, all of which have begun the first meiotic division. At this stage they are called *primary oocytes* (1 in figure 31.9). Each primary oocyte waits to receive the proper developmental "go" signal before continuing on with meiosis. Until then, its meiosis remains arrested in prophase of the first meiotic division. Very few primary

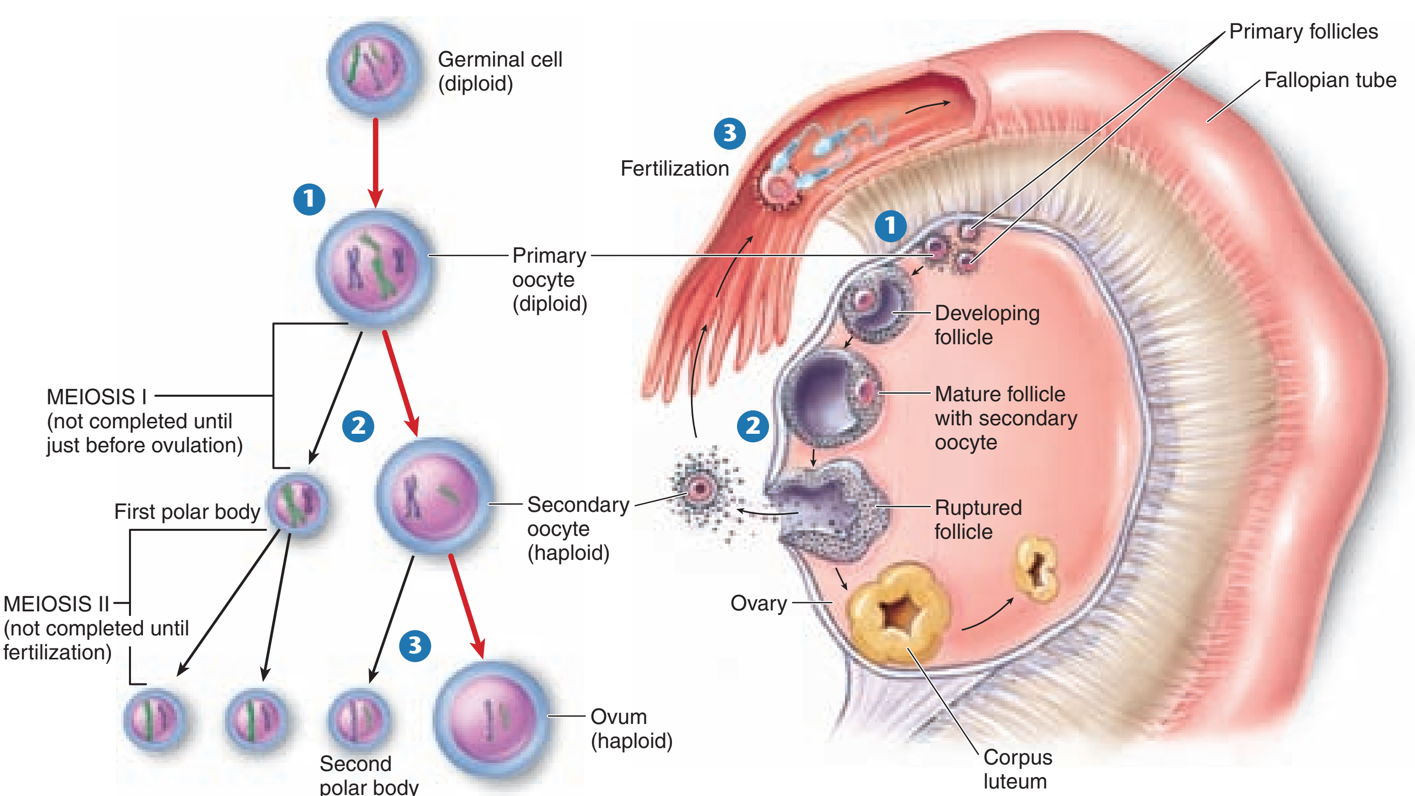


Figure 31.9 The ovary and formation of an ovum.

In this figure, the maturation of the ovum through meiosis is shown on the left, and the developmental journey of the ovum is on the right, with corresponding stages numbered on each. At birth, a human female's ovaries contain about 2 million egg-forming cells called oocytes, which have begun the first meiotic division and stopped. At this stage, they are called primary oocytes 1, and their further development is halted until they receive the proper developmental signals, which are the hormones FSH and LH. Beginning at puberty, a monthly cycle of hormone secretion is established. When the hormones FSH and LH are released, meiosis resumes in a few oocytes, but only one oocyte usually continues to mature while the others regress. The primary oocyte (diploid) completes the first meiotic division, and one division product becomes a nonfunctional polar body. The other product, the secondary oocyte, is released during ovulation 2, along with the polar body. The secondary oocyte does not complete the second meiotic division until fertilization 3; that division yields two more nonfunctional polar bodies and a single haploid egg, or ovum. Fusion of the haploid egg with a haploid sperm during fertilization produces a diploid zygote.

oocytes ever receive the awaited signal, which turns out to be the pituitary hormones FSH and LH, which were discussed in chapter 30.

FSH and LH are hormones that are released from the anterior pituitary gland in response to the release of the gonadotropin-releasing hormone (GnRH) from the hypothalamus, as discussed on page 583.

With the onset of puberty, females mature sexually. At this time, the release of FSH and LH initiates the resumption of the first meiotic division in a few oocytes. The first meiotic division produces the *secondary oocyte* and a nonfunctional *polar body* 2. In humans, usually only a single oocyte is ovulated and the others regress. In some instances more than one oocyte develops; if both are fertilized, they become fraternal twins. Approximately every 28 days after that, another oocyte matures and is ovulated, although the exact timing may vary from month to month. Only about 400 of the approximately 2 million oocytes a woman is born with mature and are ovulated during her lifetime.

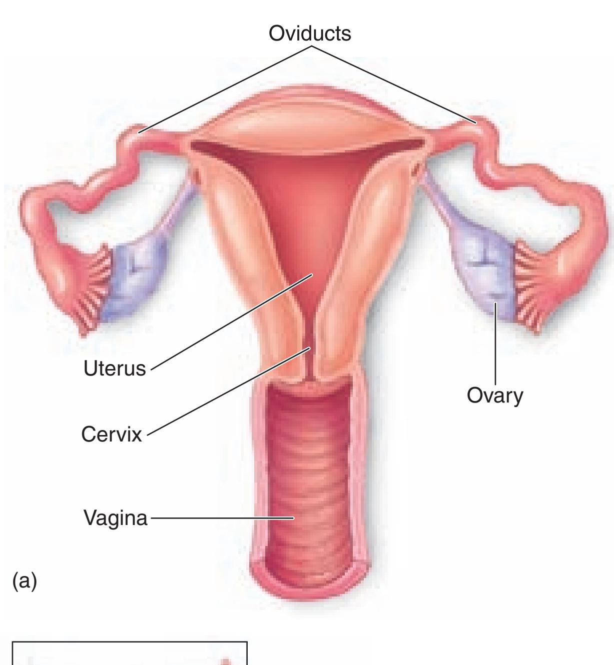
Fertilization Occurs in the Oviducts

The **oviducts** (also called **fallopian tubes** or uterine tubes) transport eggs from the ovaries to the **uterus.** In humans, the uterus is a muscular, pear-shaped organ about the size of a fist that narrows to a muscular ring called the **cervix,** which leads to the vagina (figure 31.10*a*). Mammals other than primates have more complex female reproductive tracts, where part of the uterus divides to form uterine "horns." The uterus is lined with a stratified epithelial membrane, called the **endometrium.** The surface of the endometrium is shed approximately once a month during menstruation, while the underlying portion remains to generate a new surface during the next cycle.

The movement of food through the digestive system is by peristaltic muscle contractions, discussed on page 510 and illustrated in figure 26.11.

After ovulation, smooth muscles lining the fallopian tubes contract rhythmically, moving the egg down the tube to the uterus in much the same way that food is moved down through your digestive system, pushing it along by squeezing the tube behind it. The journey of the egg through the fallopian tube is a slow one, taking from five to seven days to complete. However, if the egg is not fertilized within 24 hours of ovulation, it loses its capacity to develop.

During sexual intercourse, sperm are deposited within the vagina, a thin-walled muscular tube about 7 centimeters long that leads to the mouth of the uterus. Using their flagella, sperm entering the uterus swim up to and enter the fallopian tubes. Sperm can remain viable within the female reproductive tract for up to six days. If sexual intercourse takes place five days before ovulation or one day after, a viable egg will be present high up in the fallopian tubes. Of the several hundred million sperm that are ejaculated, only a few dozen make it to the egg. Once they reach the egg, the sperm must penetrate through two protective layers that surround the secondary oocyte (figure 31.10*b* 1): a layer of granulosa cells and a protein layer called the zona pellucida. Enzymes within the acrosome cap of the sperm help digest the second of these layers 2. The first sperm to make it through the second layer stimulates the oocyte to block the entry of other sperm 3 and to complete meiosis II. Meiosis II produces the **ovum** (plural, **ova**) and two more nonfunctional polar bodies (see figure 31.9). When the female haploid nucleus within the ovum combines with the male haploid nucleus, the egg is fertilized and becomes a zygote. The zygote then begins a series of cell divisions while traveling down the fallopian tube. After about six days, it reaches the uterus, attaches itself to the endometrial lining, and continues the long developmental journey that eventually leads to the birth of a child.



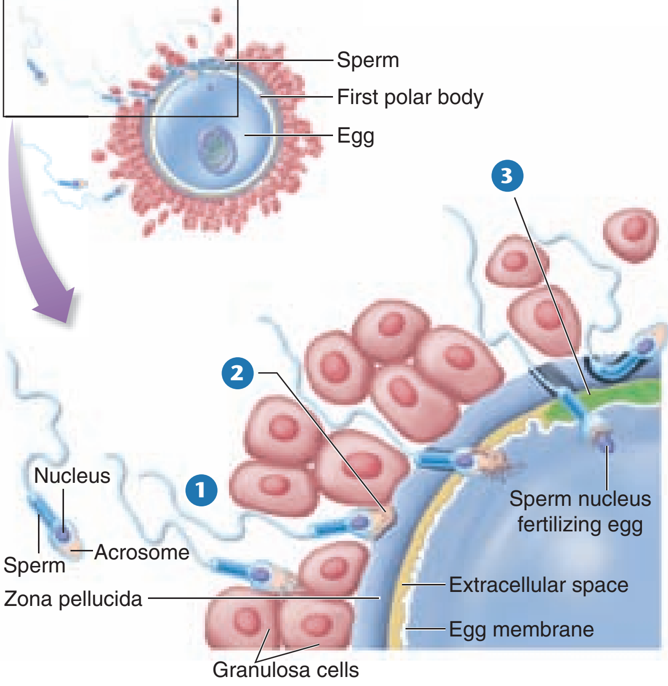


Figure 31.10 Fertilization occurs in the oviducts.

(a) The oviducts extend out from the uterus. Sperm are deposited in the vagina and travel to the oviducts. (b) Fertilization occurs in the oviduct when a sperm cell penetrates the outer layers of the egg cell.

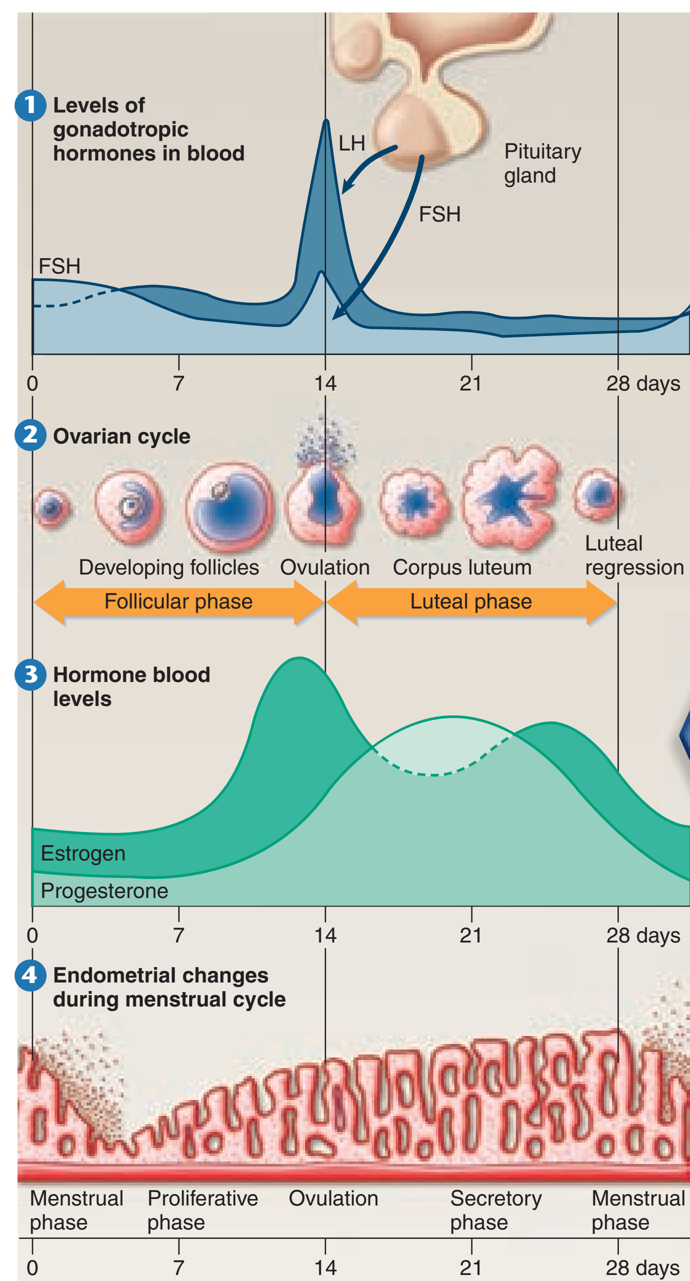


Figure 31.11 The human menstrual cycle.

Ovulation and the preparation of the uterine lining for implantation is controlled by a group of four hormones during the menstrual cycle.

IMPLICATION Men do not exhibit a reproductive cycle, and are able to donate sperm at any time of the month. Why do you think evolution has favored development of a menstrual cycle in women? Do you think it might have been possible to have evolved human females without a menstrual cycle? What is the basis of your conclusion?

31.4 Hormones Coordinate the Reproductive Cycle

CONCEPT PREVIEW: Humans and apes have menstrual cycles driven by cyclic patterns of hormone secretion and ovulation. The cycle is composed of two distinct phases, follicular and luteal, coordinated by a family of hormones.

The female reproductive cycle, called a **menstrual cycle,** is composed of two distinct phases, the *follicular phase,* in which an egg reaches maturation and is ovulated, and the *luteal phase,* where the body continues to prepare for pregnancy. These phases are coordinated by a family of hormones. Hormones play many roles in human reproduction. Sexual development is initiated by hormones, released from the anterior pituitary and ovary, that coordinate simultaneous sexual development in many kinds of tissues. The production of gametes is another closely orchestrated process, involving a series of carefully timed developmental events. Successful fertilization initiates yet another developmental "program," in which the female body continues its preparation for the many changes of pregnancy.

The hypothalamus is the control center of the neuroendocrine system. As discussed on page 559, the hypothalamus integrates all internal activities in the body through neural connections. It also exerts control over the pituitary, as discussed on page 583.

Production of the sex hormones that coordinate all these processes is coordinated by the hypothalamus, which sends releasing hormones to the pituitary, directing it to produce particular sex hormones. Negative feedback, discussed in chapters 27 and 30, plays a key role in regulating these activities of the hypothalamus. When target organs receive a pituitary hormone, they begin to produce a hormone of their own, which circulates back to the hypothalamus, shutting down production of the pituitary hormone. In addition, *positive feedback* mechanisms play a role too. In these cases, a hormone circulates back to the hypothalamus and increases the production of a pituitary hormone.

Triggering the Maturation of an Egg

The first phase of the menstrual cycle, the follicular phase, corresponds to days 0 through 14 in figure 31.11. During this time, several follicles (an oocyte and its surrounding tissue is called a *follicle*) are stimulated to develop. This development is carefully regulated by hormones. The anterior pituitary, after receiving a chemical signal (GnRH) from the hypothalamus, starts the cycle by secreting small amounts of **follicle-stimulating hormone (FSH)** and **luteinizing hormone (LH)** 1. These hormones stimulate follicular growth 2 and the secretion of the female sex hormone **estrogen** 3, more technically known as *estradiol,* from the developing follicles. Several follicles are stimulated to grow under FSH stimulation.

Estrogen is a steroid hormone, and as shown in figure 30.3 on page 580, steroid hormones are able to pass through the plasma membrane and bind to receptors inside the cell. The binding of estrogen to its receptor activates the transcription of a receptor protein for progesterone.

Initially, the relatively low levels of estrogen have a negative-feedback effect on FSH and LH secretion. The low but rising levels of estrogen in the bloodstream feed back to the hypothalamus, which responds to the rising estrogen by commanding the anterior pituitary to decrease production of FSH and LH. As FSH levels fall, usually only one follicle achieves maturity. Late in the follicular phase, estrogen levels in the blood have increased drastically, and these higher levels of estrogen begin to have a positive-feedback effect on FSH and LH secretion. The rise in estrogen levels signals the completion of the follicular phase of the menstrual cycle.

Preparing the Body for Fertilization

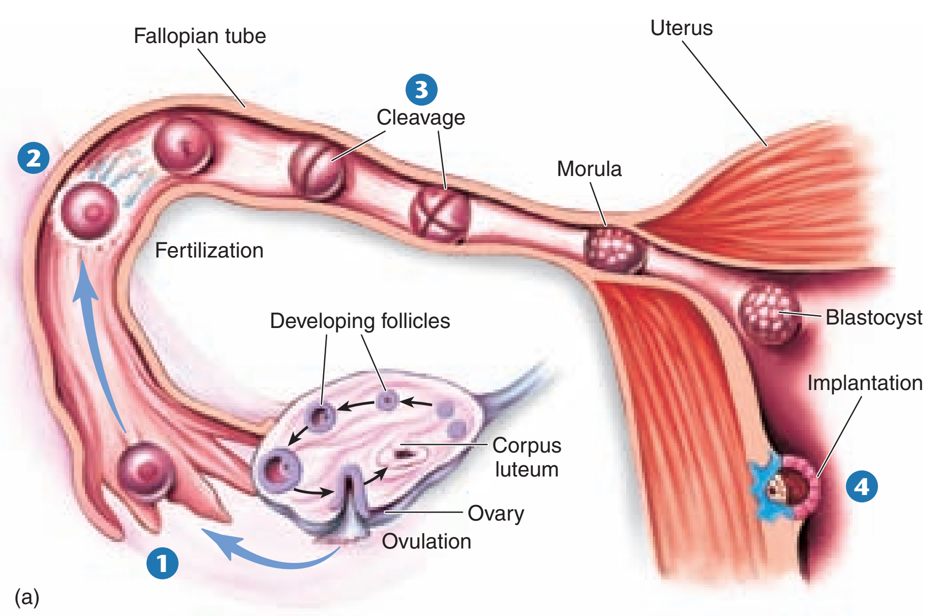
The second phase of the cycle, the luteal phase (days 14 through 28), follows smoothly from the first. In a positive-feedback response to high levels of estrogen, the hypothalamus causes the anterior pituitary to rapidly secrete large amounts of LH and FSH (see figure 31.11 ❶). The surge of LH is larger than the surge of FSH and can last up to 24 hours. The peak in LH secretion triggers ovulation: LH causes the wall of the follicle to burst, and the egg within the follicle is released into one of the fallopian tubes extending from the ovary to the uterus (see ❶ in figure 31.12).

After the egg's release and departure, estrogen levels decrease, and LH directs the repair of the ruptured follicle, which fills in and becomes yellowish. In this condition, it is called the *corpus luteum,* which is simply the Latin phrase for "yellow body." The corpus luteum soon begins to secrete the hormone **progesterone** (the light green curve in figure 31.11 ❸), in addition to small levels of estrogen. Increased levels of progesterone and estrogen have a negative-feedback effect on the secretion of FSH and LH, preventing further ovulations. Progesterone completes the body's preparation of the uterus for fertilization including the thickening of the endometrium (figure 31.11 ❹). If fertilization does *not* occur soon after ovulation, however, production of progesterone slows and eventually ceases, marking the end of the luteal phase. The decreasing levels of progesterone cause the thickened layer of blood-rich tissue to be sloughed off, a process that results in the bleeding associated with menstruation. **Menstruation,** or "having a period," usually occurs about midway between successive ovulations (shown in figure 31.11 at 28 days).

At the end of the luteal phase, neither estrogen nor progesterone is being produced. In their absence, the anterior pituitary can again initiate production of FSH and LH, thus starting another reproductive cycle. Each cycle begins immediately after the preceding one ends. A cycle usually occurs every 28 days, or a little more frequently than once a month, although this varies in individual cases. The Latin word for "month" is *mens,* which is why the reproductive cycle is called the menstrual cycle, or monthly cycle.

If fertilization does occur high in the fallopian tube (❷ in figure 31.12*a*), the zygote undergoes a series of cell divisions called cleavage ❸, while traveling toward the uterus. At the blastocyst stage, it implants in the lining of the uterus ❹. The tiny embryo secretes human chorionic gonadotropin (hCG), an LH-like hormone, which maintains the corpus luteum. By maintaining the corpus luteum, hCG keeps the levels of estrogen and progesterone high, thereby preventing menstruation, which would terminate the pregnancy. Because hCG comes from the embryo and not from the mother, it is hCG that is tested in all pregnancy tests.

As discussed on page 544, pregnancy tests use monoclonal antibodies which are produced using hCG as the antigen. The test strip is coated with the hCG monoclonal antibodies. If hCG is present in the urine, it will react with the antibodies and produce a positive result.



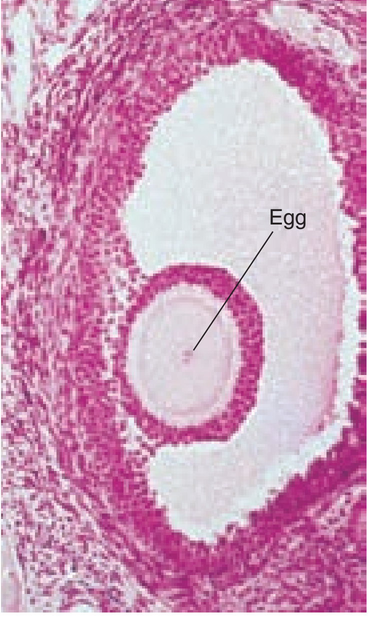


Figure 31.12 The journey of an ovum.

(a) Produced within a follicle and released at ovulation, an ovum is swept up into a fallopian tube ❶ and carried down by waves of contraction of the tube walls. Fertilization occurs within the tube ❷ by sperm journeying upward. Several mitotic divisions occur while the fertilized ovum undergoes cleavage and continues its journey down the fallopian tube ❸, becoming first a morula then a blastocyst. The blastocyst implants itself within the wall of the uterus ❹, where it continues its development. (b) A mature egg within an ovarian follicle. In each menstrual cycle, a few follicles are stimulated to grow under the influence of FSH and LH, but usually only one achieves full maturity and ovulation.

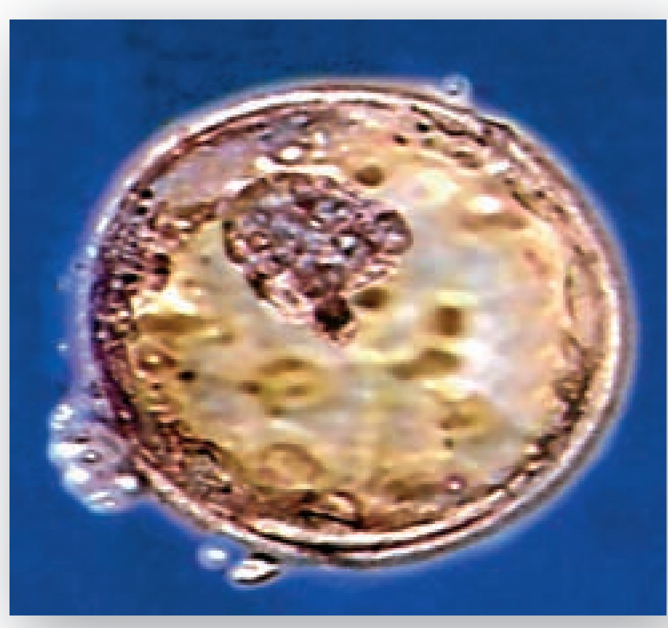
Concept Check

1. What is the function of the prostate gland?
2. Where is the endometrium found?
3. When in the menstrual cycle does luteinizing hormone peak?

The Course of Development

31.5 Embryonic Development

CONCEPT PREVIEW: The vertebrate embryo develops in three stages: cleavage, a hollow ball of cells forms; gastrulation, cells move into the interior, forming the primary tissues; and neurulation, organs form.



(a)

Ectoderm	Epidermis, central nervous system, sense organs, neural crest
Mesoderm	Skeleton, muscles, blood vessels, heart, gonads
Endoderm	Lining of digestive and respiratory tracts; liver, pancreas

(b)

Figure 31.13 The beginnings of human development.

(a) A human blastocyst. The formation of the blastocyst occurs when the zygote undergoes cleavage producing a hollow ball of cells. An inner cell mass will later differentiate into the different tissues of the embryo. (b) The fate of the three primary germ layers.

Cleavage: Setting the Stage for Development

Fertilization begins a carefully orchestrated series of developmental events. Table 31.1 traces the major stages of mammalian development, beginning with fertilization. Follow down the table as the stages of development are discussed here.

The first major event in human embryonic development is the rapid division of the zygote into a larger and larger number of smaller and smaller cells, becoming first 2 cells, then 4, then 8, and so on. The first of these divisions occurs about 30 hours after union of the egg and the sperm, and the second, 30 hours later. During this period of division, called **cleavage,** the overall size does not increase from that of the zygote. The resulting tightly packed mass of about 32 cells is called a **morula,** and each individual cell in the morula is referred to as a **blastomere.** The cells of the morula continue to divide, each cell secreting a fluid into the center of the cell mass. Eventually, a hollow ball of 500 to 2,000 cells is formed. This is the **blastocyst,** which contains a fluid-filled cavity called the **blastocoel** (figure 31.13*a*) Within the ball is an *inner cell mass* concentrated at one pole that goes on to form the developing embryo. The outer sphere of cells, called the *trophoblast,* releases the hCG hormone, discussed earlier.

During cleavage, the morula journeys down the mother's fallopian tube. On about the sixth day, the blastocyst has formed and reaches the uterus; it attaches to the uterine lining, and penetrates into the tissue of the lining. The blastocyst now begins to grow rapidly, initiating the formation of the membranes that will later surround, protect, and nourish it. One of these membranes, the **amnion,** will enclose the developing embryo, whereas another, the **chorion,** which forms from the trophoblast, will interact with uterine tissue to form the **placenta,** which will nourish the growing embryo (see figure 31.15). The placenta connects the developing embryo to the blood supply of the mother. Fully 61 of the cells at the 64-celled stage develop into the trophoblast and only 3 into the embryo proper.

Gastrulation: The Onset of Developmental Change

Ten to 11 days after fertilization, certain groups of cells move inward from the surface of the cell mass in a carefully orchestrated migration called **gastrulation.** First, the lower cell layer of the blastocyst cell mass differentiates into **endoderm,** one of the three primary embryonic tissues, and the upper layer into **ectoderm.** Just after this differentiation, much of the **mesoderm** arises by the invagination of cells that move from the upper layer of the cell mass *inward,* along the edges of a furrow that appears at the embryo midline, the primitive streak.

These three germ layers appear early in the evolution of the animal kingdom. As discussed on page 340, the development of the endoderm, ectoderm, and mesoderm layers first appears in the lower invertebrate group of solid worms, called flatworms.

During gastrulation, about half of the cells of the blastocyst cell mass move into the interior of the human embryo. This movement largely determines the future development of the embryo. By the end of gas-

trulation, distribution of cells into the three primary germ layers has been completed. The ectoderm is destined to form the epidermis and neural tissue. The mesoderm is destined to form the connective tissue, muscle, and vascular elements. The endoderm forms the lining of the gut and its derivative organs (figure 31.13*b*).

Neurulation: Determination of Body Architecture

In the third week of embryonic development, the three primary cell types begin their development into the tissues and organs of the body. This stage in development is called **neurulation.**

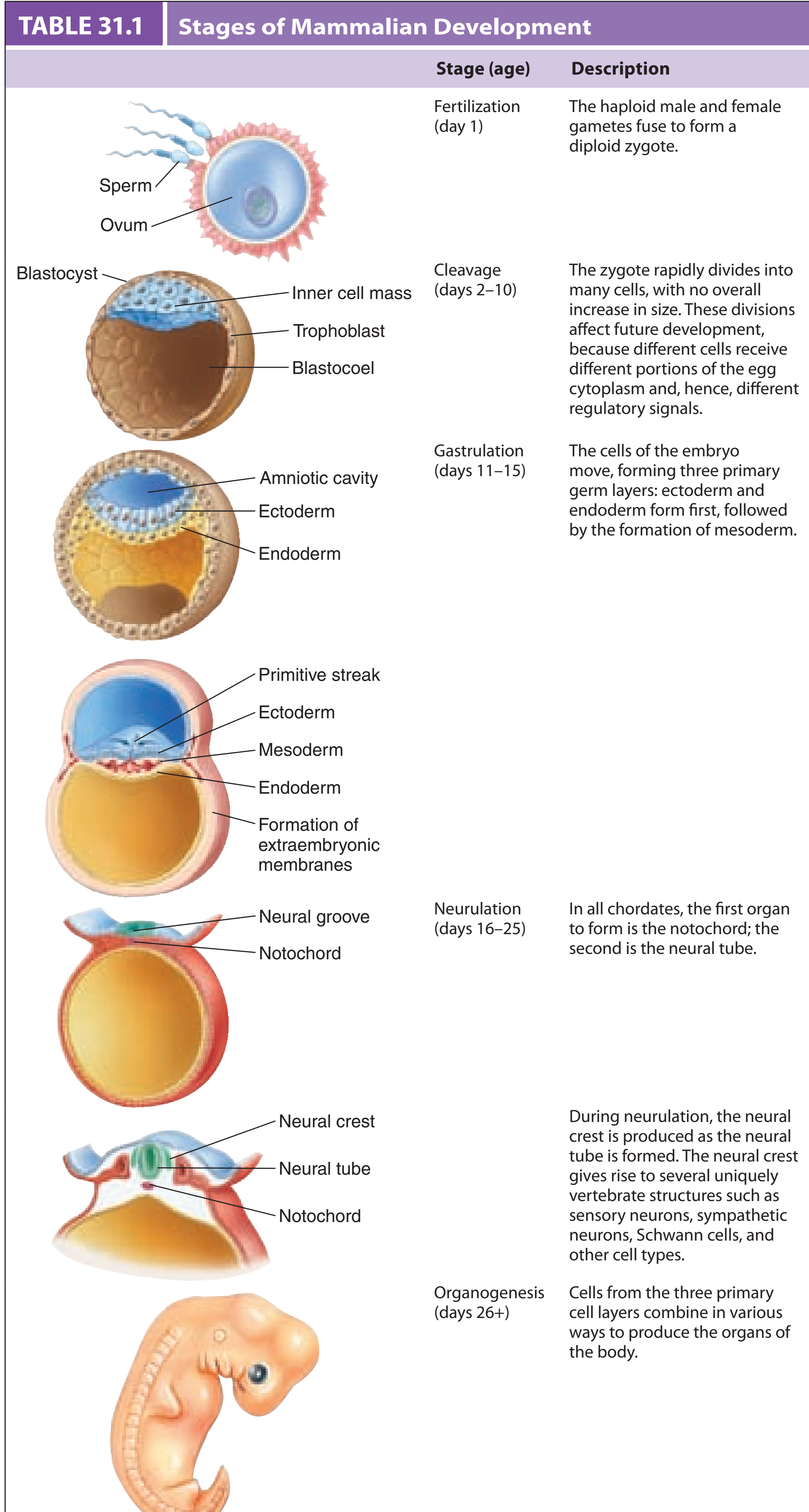
The first characteristic vertebrate feature to form is the **notochord,** a flexible rod. Soon after gastrulation is complete, it forms from mesoderm tissue along the midline of the embryo, below its dorsal surface. After the notochord has been formed, the second characteristic vertebrate feature, the **neural tube,** forms from the region of the ectoderm that is located above the notochord and later differentiates into the spinal cord and brain. Just before the neural tube closes, two strips of cells break away and form the **neural crest.** These neural crest cells give rise to neural structures found in the vertebrate body.

While the neural tube is forming from ectoderm, the rest of the basic architecture of the human body is being rapidly determined by changes in the mesoderm. On either side of the developing notochord, segmented blocks of tissue form. Ultimately, these blocks, or **somites,** give rise to the muscles, vertebrae, and connective tissues. As development continues, more and more somites are formed. Within another strip of mesoderm that runs alongside the somites, many of the significant glands of the body, including the kidneys, adrenal glands, and gonads, develop. The remainder of the mesoderm layer moves out and around the inner endoderm layer of cells and eventually surrounds it entirely. As a result, the mesoderm forms two layers. The outer layer is associated with the body wall and the inner layer is associated with the gut. Between these two layers of mesoderm is the **coelom,** which becomes the body cavity of the adult.

By the end of the third week, over a dozen somites are evident, and the blood vessels and gut have begun to develop. At this point the embryo is about 2 millimeters (less than a tenth of an inch) long.

TABLE 31.1 Stages of Mammalian Development

Stage (age)	Description
Fertilization (day 1)	The haploid male and female gametes fuse to form a diploid zygote.
Cleavage (days 2–10)	The zygote rapidly divides into many cells, with no overall increase in size. These divisions affect future development, because different cells receive different portions of the egg cytoplasm and, hence, different regulatory signals.
Gastrulation (days 11–15)	The cells of the embryo move, forming three primary germ layers: ectoderm and endoderm form first, followed by the formation of mesoderm.
Neurulation (days 16–25)	In all chordates, the first organ to form is the notochord; the second is the neural tube.
	During neurulation, the neural crest is produced as the neural tube is formed. The neural crest gives rise to several uniquely vertebrate structures such as sensory neurons, sympathetic neurons, Schwann cells, and other cell types.
Organogenesis (days 26+)	Cells from the three primary cell layers combine in various ways to produce the organs of the body.



31.6 Fetal Development

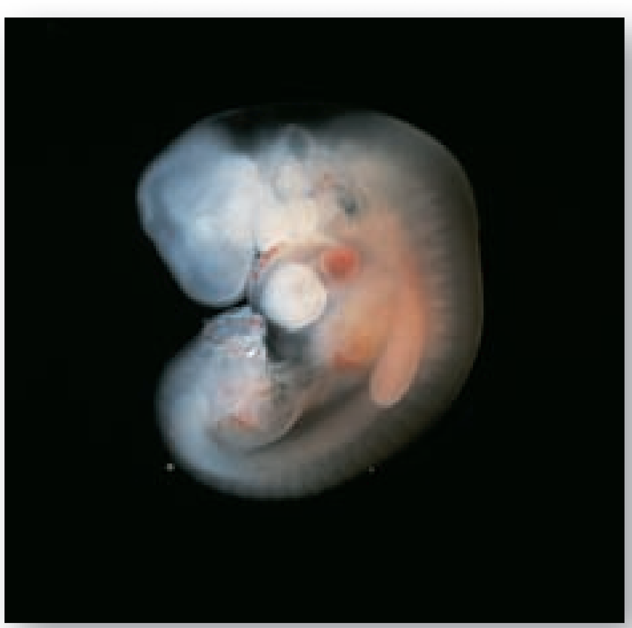
CONCEPT PREVIEW: Most of the key events in fetal development occur early. Organs begin to form in the fourth week, and by the end of the second month the development of the embryo is essentially complete. What remains in the second and third trimesters is primarily growth.

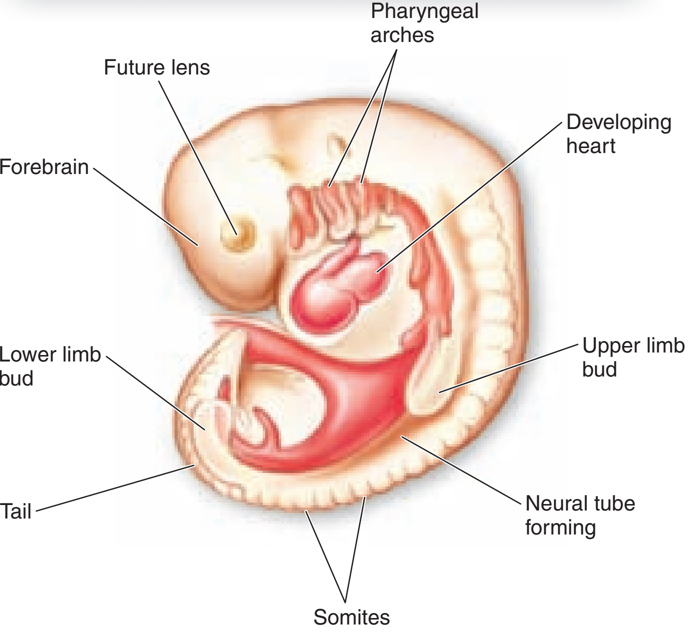
The Fourth Week: Organ Formation

In the fourth week of pregnancy, the body organs begin to form, a process called **organogenesis** (figure 31.14*a,* the drawing helps identify the structures in the photo). The eyes form, and the heart begins a rhythmic beating and develops four chambers. At 70 beats per minute, the little heart is destined to beat more than 2.5 billion times during a lifetime of about 70

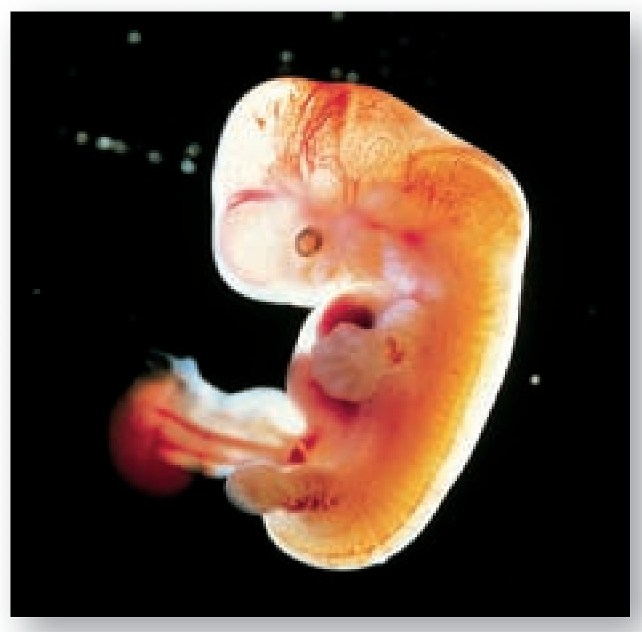
Figure 31.14 The developing human.

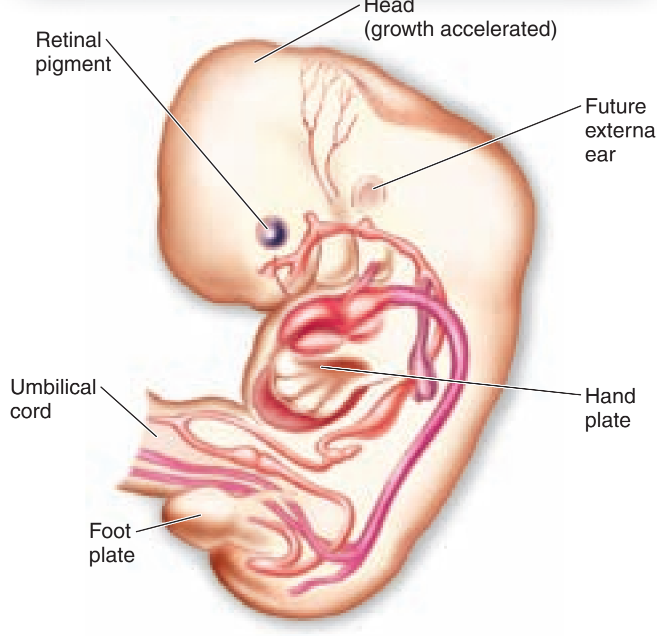
(a) Four weeks; (b) seven weeks; (c) three months; and (d) four months.





(a)

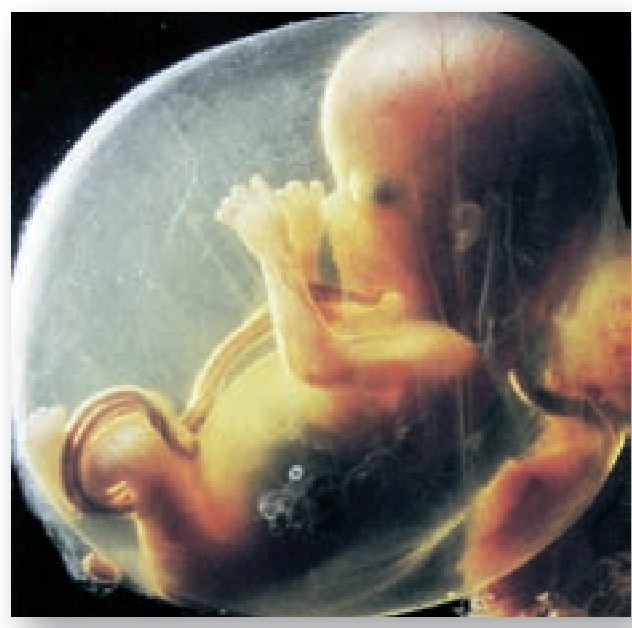




(b)

years. More than 30 pairs of somites are visible by the end of the fourth week, and the arm and leg buds have begun to form. The embryo more than doubles in length during this week, reaching about 5 millimeters.

By the end of the fourth week, the developmental scenario is far advanced, although most women are not yet aware that they are pregnant. This is a crucial time in development because the proper course of events can be interrupted easily. For example, alcohol use by pregnant women during the first months of pregnancy is one of the leading causes of birth defects, producing *fetal alcohol syndrome,* in which the baby is born with a deformed face and often severe mental retardation. One in 250 newborns in the United States is affected with fetal alcohol syndrome.



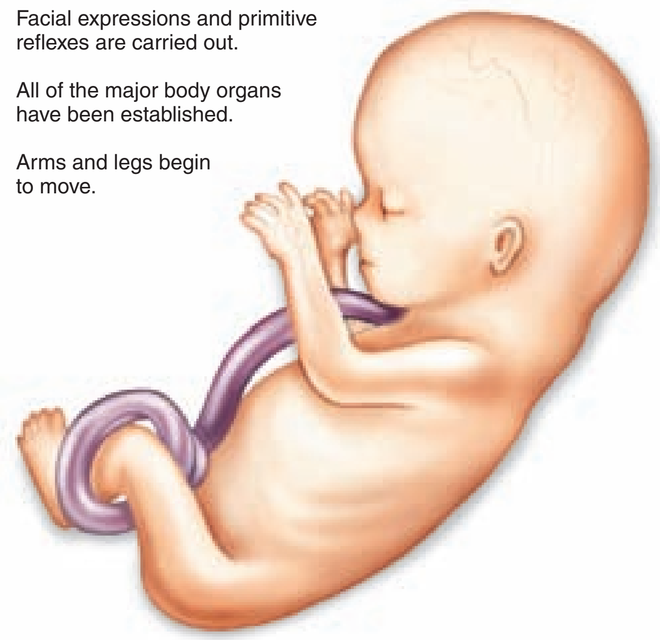
Development is essentially complete.

The developing human is now referred to as a fetus.

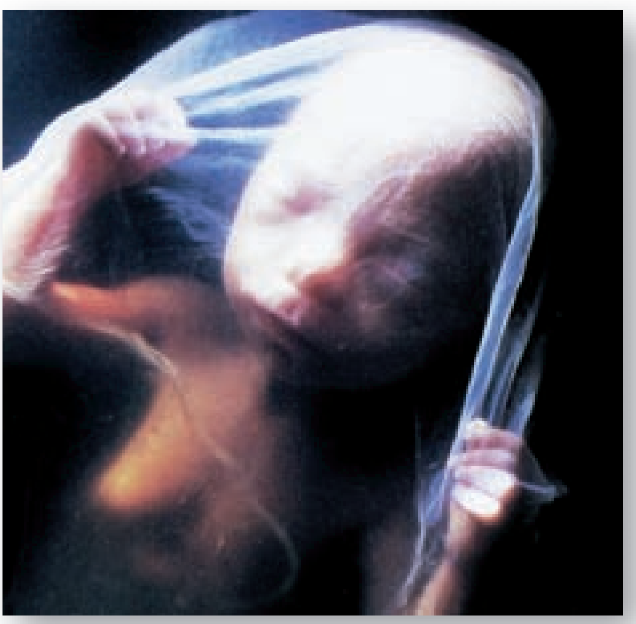
Facial expressions and primitive reflexes are carried out.

All of the major body organs have been established.

Arms and legs begin to move.



(c)



Bones actively enlarge.

Mother can feel baby kicking.

Following a period of rapid growth, the fetus is born.

Neurological growth continues after birth.

(d)

The Second Month: The Embryo Takes Shape

During the second month of pregnancy, great changes in morphology occur as the embryo takes shape (figure 31.14*b*). The miniature limbs of the embryo assume their adult shapes. The arms, legs, knees, elbows, fingers, and toes can all be seen as well as a short, bony tail. The bones of the embryonic tail, an evolutionary reminder of our past, later fuse to form the coccyx, or tailbone. Within the body cavity, the major internal organs are evident, including the liver and pancreas. By the end of the second month, the embryo has grown to about 25 millimeters in length—it is 1 inch long. It weighs perhaps a gram and is beginning to look distinctly human.

IN THE NEWS

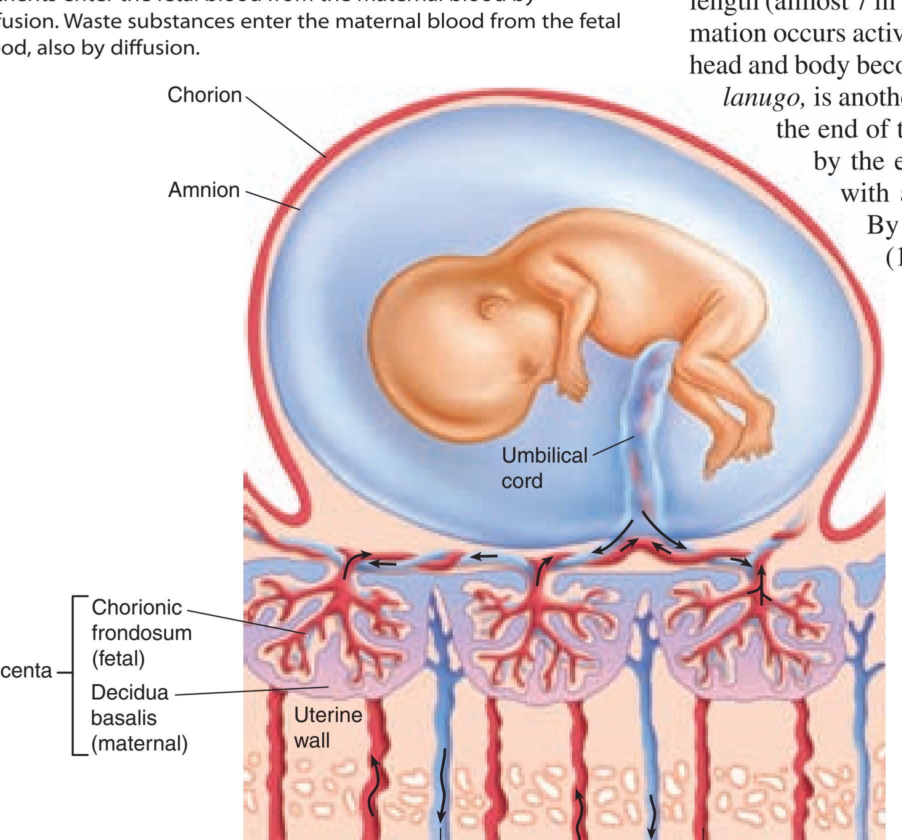
Eating for Boys. British researchers reported in 2008 that pregnant women who eat a lot of calories early in pregnancy seem to be more likely to bear boys than girls. Researchers at the University of Exeter divided 740 British women into three groups according to what they ate during the first months of pregnancy. Only 45% of those in the group with the lowest energy intake carried boys, while fully 56% of the women in the highest-calorie group did. This result supports the controversial Trivers-Willard sociobiology hypothesis that females in better condition will have more male offspring.

The Third Month: Completion of Development

Development of the embryo is essentially complete except for the lungs and brain. The lungs don't complete development until the third trimester, and the brain continues to develop even after birth. From this point on, the developing human is referred to as a **fetus** rather than an embryo. What remains is essentially growth. The nervous system and sense organs develop during the third month. The fetus begins to show facial expressions and carries out primitive reflexes such as the startle reflex and sucking. By the end of the third month, all of the major organs of the body have been established and the arms and legs begin to move (figure 31.14*c*).

Figure 31.15 Structure of the placenta.

The placenta contains a fetal component, the chorionic frondosum, and a maternal component, the decidua basalis. Oxygen and nutrients enter the fetal blood from the maternal blood by diffusion. Waste substances enter the maternal blood from the fetal blood, also by diffusion.



The Second Trimester: The Fetus Grows in Earnest

The second trimester is a time of growth. In the fourth (figure 31.14*d*) and fifth months of pregnancy, the fetus grows to about 175 millimeters in length (almost 7 in long), with a body weight of about 225 grams. Bone formation occurs actively during the fourth month. During the fifth month, the head and body become covered with fine hair. This downy body hair, called *lanugo,* is another evolutionary relic and is lost later in development. By the end of the fourth month, the mother can feel the baby kicking; by the end of the fifth month, she can hear its rapid heartbeat with a stethoscope. In the sixth month, growth accelerates. By the end of the sixth month, the baby is over 0.3 meters (1 ft) long and weighs 0.6 kilograms (about 1.5 lb)—and most of its prebirth growth is still to come. At this stage, the fetus cannot yet survive outside the uterus without special medical intervention.

The Third Trimester: The Pace of Growth Accelerates

The third trimester is a period of rapid growth. In the seventh, eighth, and ninth months of pregnancy, the weight of the fetus more than doubles. This increase in bulk is not the only kind of growth that occurs. Most of the major nerve tracts are formed within the brain during this period, as are new brain cells.

All of this growth is fueled by nutrients provided by the mother's bloodstream, passing into the fetal blood supply within the placenta. The placenta in figure 31.15 contains blood vessels that extend from the umbilical cord into tissues that line the uterus (the *decidua basalis* in the figure). The mother's blood

bathes this tissue so that nutrients can pass from the mother's blood into the blood vessels that carry it back to the fetus without the two blood systems ever mixing blood.

By the end of the third trimester, the neurological growth of the fetus is far from complete, but by this time the fetus is about as large as it can get and still be delivered through the pelvis without damage to mother or child. As any woman who has had a baby can testify, it is a tight fit. Birth takes place as soon as the probability of survival is high.

Birth

At approximately 40 weeks from the last menstrual cycle, the process of birth begins as hormonal changes in the mother initiate the onset of **labor.** During labor and delivery the cervix gradually dilates (the opening becomes larger), the amnion ruptures causing amniotic fluid to flow out through the vagina (sometimes referred to as the "water breaking"), and uterine contractions become strong and regular, usually resulting in the expulsion of the fetus from the uterus. Hormones called **oxytocin** and **prostaglandins** work in a positive-feedback mechanism to stimulate and increase uterine contractions. The fetus is usually in a head-down position near the end of pregnancy. In a vaginal birth, the fetus is pushed down through the cervix and out through the vagina (figure 31.16). After the birth of the fetus, continuing uterine contractions expel the placenta and associated membranes, collectively called the "afterbirth." In some cases, such as when a vaginal delivery would cause harm to the fetus or the mother, the fetus and placenta are surgically removed from the uterus in a procedure called a *caesarian section (C-section).* The umbilical cord is still attached to the baby, and a doctor, nurse, or parent clamps and cuts the cord. The baby transitions from living in a fluid environment to a gaseous one, and many of its organ systems undergo major changes.

In the mother, hormones during late pregnancy prepare the *mammary glands* for nourishing the baby after birth. For the first couple of days after childbirth, the mammary glands produce a fluid called *colostrum,* which contains protein (including antibodies) and lactose but little fat. Then milk production is stimulated by the anterior pituitary hormone **prolactin,** usually by the third day after delivery. When the infant suckles at the breast, the posterior pituitary hormone oxytocin is released, initiating milk release, or milk "letdown."

Postnatal Development

Growth continues rapidly after birth. Babies typically double their birth weight within a few months. Different organs grow at different rates, however, and the body proportions of infants are different than that of adults. The head, for example, is disproportionately large in newborns, but after birth it grows more slowly than the rest of the body. Such a pattern of growth, in which different components grow at different rates, is referred to as *allometric growth.*

The fact that the human brain continues to grow significantly for the first few years of postnatal life means that adequate nutrition and a safe environment are particularly crucial during this period.

Concept Check

1. Describe the events of gastrulation.
2. What tissues do mesoderm cells give rise to in the adult body?
3. What is the role of the hormone oxytocin? Prolactin?

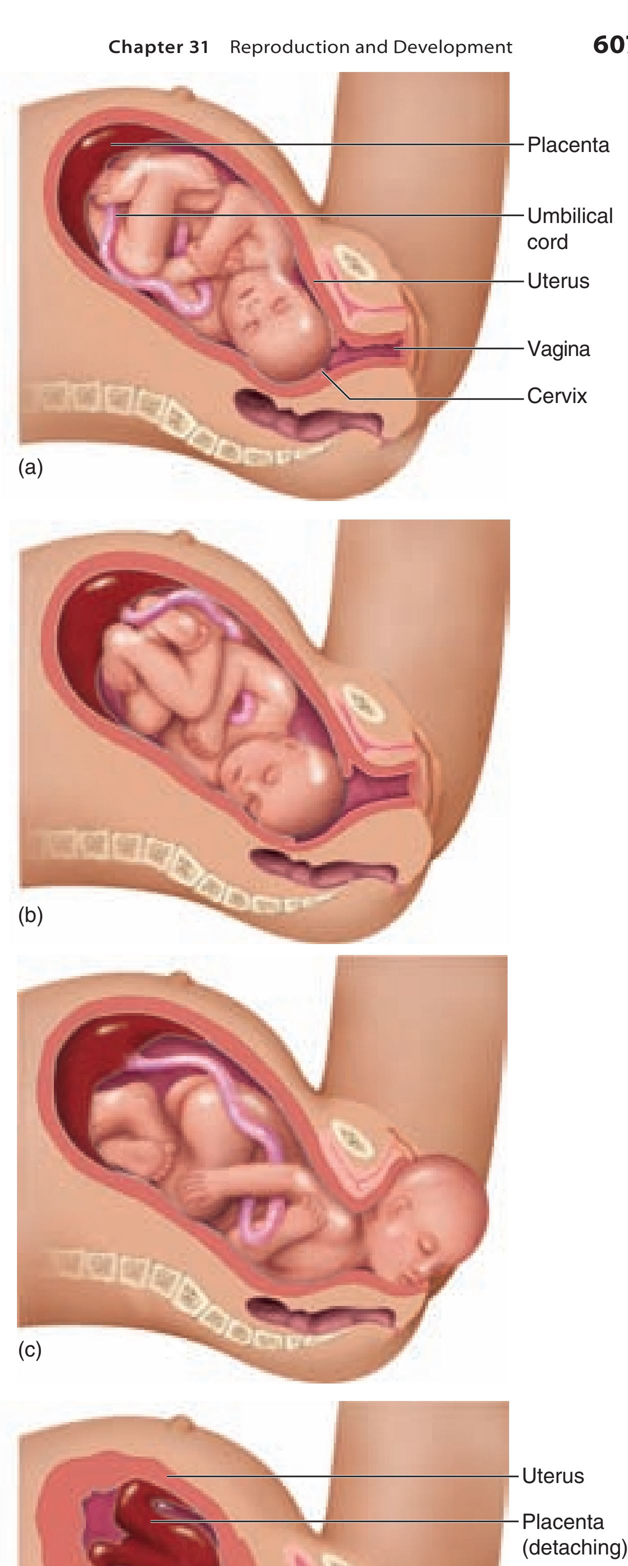


Figure 31.16 Stages of childbirth.

Biology and Staying Healthy

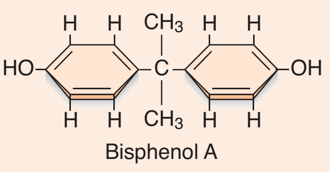
Why Don't Men Get Breast Cancer?

In 2007, an estimated 240,510 new cases of breast cancer were expected among women in the United States and 2,030 new cases among men—over 99% of the new breast cancer victims were women. Similarly, of 40,460 breast cancer deaths anticipated that year, all but 450 of them were women. It is impossible not to wonder, why so few men? An obvious answer would be that men don't have breasts, but men do have breast tissue, it just isn't as developed as a woman's. So we are back to the same question: why so few men?

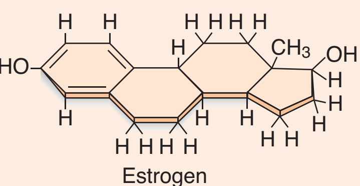
While 5% of breast cancers are due to inherited genetic mutations (*BRCA1* and *BRCA2*), the cause of 95%—the overwhelming majority—remains a mystery. Hormone differences seem the most promising place to start, as the female sex hormone estrogen controls breast development in women; men, by contrast, lack physiologically significant amounts of estrogen. A logical suggestion is that in breast cancer patients, the effect of estrogen on breast cells is being altered by exposure to a so-called endocrine disrupter. Endocrine disrupters are man-made chemicals that mimic hormones. By sheer chance, their molecules are perfectly shaped to fit particular hormone receptors. In this case, the culprit would be a chemical mimic of estrogen that promotes cancerous growth in breast cells.

One candidate is bisphenol A (BPA), a molecule that is structurally similar to estrogen, with carbon rings at each end tipped with OH groups. Used to form the plastic packaging of many foods and drinks, as well as the clear plastic liners of metal food and beverage cans, BPA is a chemical to which all of us are exposed daily. Six billion pounds are produced worldwide each year.

It has been known since 1938 that BPA promotes excess estrogen production in rats. Alarmingly, in 1993 BPA was shown to have the same effects on human breast cancer cells growing in culture. What was alarming was that the effect could be measured at concentrations as low as two parts per billion, not much above the levels to which we humans are routinely exposed.

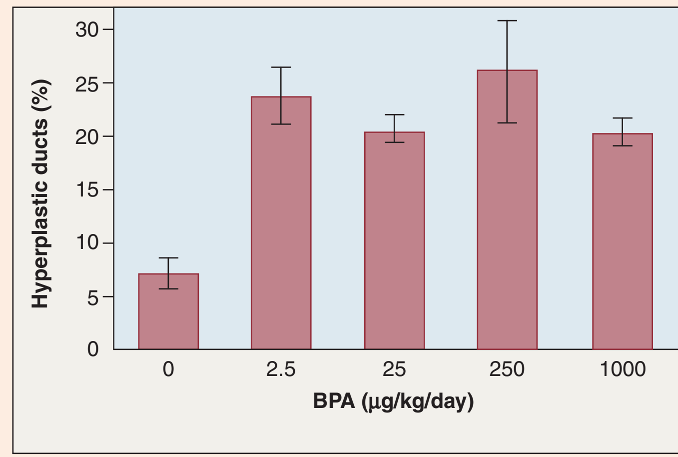


Bisphenol A



Estrogen

Does BPA in fact induce breast cancer? To test this possibility, Dr. Ana Soto of Tufts University School of Medicine and her research team in 2006 tested its effects on rats, which get breast cancer in much the same way as humans do. They exposed pregnant female rats to a range of BPA concentrations, and after 50 days sacrificed them for examination of their breast tissue. The researchers looked in particular for aberrant cell growth patterns in breast tissue called ductal hyperplasias, which in both rats and people are considered to be the precursors of breast cancer. BPA was administered to four groups of rats. Some received low doses not unlike what humans are exposed to, while others received much higher doses. In a fifth group, which served as a control, no BPA was administered.



Effect of bisphenol A on breast cancer.

The histogram above shows what the researchers found. Amounts of BPA administered to the rats are reported in micrograms of BPA per kilogram of body weight per day. The incidence of breast cancer detected is presented as the percent of examined breast tissue ducts which were hyperplastic (that is, precancerous). Vertical black lines (called error bars) represent 5% confidence intervals (a measure of scatter among the data—95% of replicate experiments would be expected to fall within the ranges of the error bars).

What are we to make of the data the researchers obtained? Did any of the four doses of BPA they administered result in a percent of hyperplastic ducts significantly higher than that seen in the BPA control group? (Hint: If their error bars overlap with the control's, the difference is not significant.) The answer—yes, all four doses are significant. Do higher doses of BPA increase the incidence of hyperplastic ducts? Do the error bars of the four doses fail to overlap? No, all doses yielded similar results. It is difficult to avoid the conclusion that exposure to even low levels of bisphenol A induces ductal hyperplasias in laboratory rats.

These results suggest the rather alarming conclusion that BPA, a chemical to which we are all exposed every day, may cause breast cancer. The study is small, and a rat is not a human, but the possibility that BPA is a carcinogen certainly merits further investigation. Most government-funded breast cancer research has focused on the search for more effective breast cancer treatments; far less money is spent on searching for the causes of breast cancer. The most encouraging aspect of this study is its suggestion that such a search, if it became a priority, might prove fruitful.

Birth Control and Sexually Transmitted Diseases

31.7 Contraception and Sexually Transmitted Diseases

CONCEPT PREVIEW: A variety of birth control methods are available, many quite effective. STDs are diseases spread through sexual contact.

Contraception

Not all couples want to initiate a pregnancy every time they have sex, yet sexual intercourse may be a necessary and important part of their emotional lives together. The solution to this dilemma is to find a way to avoid reproduction without avoiding sexual intercourse, an approach that is commonly called **birth control,** or **contraception.** Table 31.2 on the next page provides a summary of birth control methods commonly available.

Abstinence. The simplest and most reliable way to avoid pregnancy is not to have sex at all. Of all methods of birth control, this is the most certain—and the most limiting, because it denies a couple the emotional support of a sexual relationship. A variant of this approach is to avoid sex only on the days which successful fertilization is likely to occur. The rest of the sexual cycle is considered relatively "safe" for intercourse. This approach, called the rhythm method, or natural family planning when other indicators are also monitored, is satisfactory in principle but difficult in application because ovulation is not easy to predict and may occur unexpectedly. Failure rate are as high as 20% to 30%.

Prevention of Egg Maturation. A widespread form of birth control in the United States has been the daily ingestion of hormones, or **birth control pills** (figure 31.17*a*). These pills contain estrogen and progesterone which shut down production of the pituitary hormones FSH and LH. The ovarian follicles do not ripen in the absence of FSH, and ovulation does not occur in the absence of LH. Other methods of hormone delivery include medroxy progesterone (Depo-Provera), which is injected every one to three months, the weekly birth control patch, which releases the hormones through the skin, and surgically implanted capsules that release hormones. Failure rates are less than 2%.

Emergency contraception, called **Plan B** or the "morning after pill," is a hormone manipulation therapy that blocks ovulation. It can be used as backup contraception after unprotected sex (either birth control wasn't used or is suspected of failure). Plan B is a high-dose progesterone pill taken in two doses 12 hours apart. It is most effective when taken within the first 24 hours, but can still offer some protection up to five days. The high levels of progesterone will block ovulation or may also inhibit fertilization or implantation. It will have no effect if pregnancy has occurred. Failure rates vary depending how quickly it is used following intercourse, from 5% to 40%.

Prevention of Embryo Implantation. The insertion of a coil or other irregularly shaped object into the uterus is an effective means of birth control. The irritation in the uterus prevents the implantation of the descending embryo within the uterine wall. Such **intrauterine devices (IUDs)** are very effective because once inserted, they can be forgotten. They have a failure rate of less than 2%,

A chemical means of preventing embryo implantation or ending an early pregnancy is **RU486.** This pill blocks the action of progesterone, causing the endometrium to slough off. RU486 must be administered under a doctor's care because of potentially serious side effects.

BIOLOGY & YOU

RU486. Emergency contraception like the "morning after" pill Plan B should not be confused with the highly publicized RU486 (Mifepristone). RU486 is not an emergency contraceptive—it is not a contraceptive at all. It ends an unwanted pregnancy after conception. To be effective, RU486 has to be administered within 49 days (or seven weeks) following the first day of the last menstrual period. An RU486-terminated pregnancy involves two drugs given two days apart. The first drug is RU486 (Mifepristone), a synthetic steroid compound that works by blocking progesterone receptors in the uterus. Without progesterone stimulation, the endometrium degenerates and is sloughed off, ejecting the embryo with the shed lining of the uterus. Because RU486 by itself is only effective 60% of the time in inducing removal of the embryo, a second medication, a prostaglandin called misoprostol, is given two days later to induce strong contractions of the uterus, forcing the embryo's expulsion. Because RU486 has numerous side effects, some potentially severe (including sepsis, a severe infection of the bloodstream, and excessive bleeding), it must be administered by a doctor.

Sperm Blockage. If sperm cannot reach the uterus, fertilization cannot occur. One way to prevent the delivery of sperm is to encase the penis within a thin sheath, or condom (figure 31.17*b*). In principle, this method is easy to apply and foolproof, but in practice it has a failure rate of 3 to 15% because of incorrect use or inconsistent use. Nevertheless, it is the most commonly employed form of birth control in the United States. Condoms are also widely used to prevent the transmission of AIDS and other sexually transmitted diseases (STDs).

A second way to prevent the entry of sperm into the uterus is to place a cover over the cervix. The cover may be a relatively tight-fitting cervical cap, which is worn for days at a time, or a rubber dome called a diaphragm (figure 31.17*c*), which is inserted immediately before intercourse. Because the dimensions of individual cervices vary, a cervical cap or diaphragm must be fitted by a physician. Failure rates average 4 to 25% for dia-

TABLE 31.2 Methods of Birth Control

Device	Action	Failure Rate (percent)	Advantages	Disadvantages
Oral contraceptive	Hormones (progesterone analogue alone or in combination with other hormones) primarily prevent ovulation	1–5, depending on type	Convenient; highly effective; provides significant noncontraceptive health benefits, such as protection against ovarian and endometrial cancers	Must be taken regularly; possible minor side effects which new formulations have reduced; not for women with cardiovascular risks (mostly smokers over age 35)
Condom	Thin sheath for penis that collects semen; "female condoms" sheath vaginal walls	3–15	Easy to use; effective; inexpensive; protects against some sexually transmitted diseases	Requires male cooperation; may diminish spontaneity; may deteriorate on the shelf
Diaphragm	Soft rubber cup covers entrance to uterus, prevents sperm from reaching egg, holds spermicide	4–25	No dangerous side effects; reliable if used properly; provides some protection against sexually transmitted diseases and cervical cancer	Requires careful fitting; some inconvenience associated with insertion and removal; may be dislodged during intercourse
Intrauterine device (IUD)	Small plastic or metal device placed in the uterus; prevents implantation; some contain copper, others release hormones	1–5	Convenient; highly effective; infrequent replacement	Can cause excess menstrual bleeding and pain; risk of perforation, infection, expulsion, pelvic inflammatory disease, and infertility; not recommended for those who eventually intend to conceive or are not monogamous; dangerous in pregnancy
Cervical cap	Miniature diaphragm covers cervix closely, prevents sperm from reaching egg, holds spermicide	Probably similar to that of diaphragm	No dangerous side effects; fairly effective; can remain in place longer than diaphragm	Problems with fitting and insertion; comes in limited number of sizes
Foams, creams, jellies, vaginal suppositories	Chemical spermicides inserted in vagina before intercourse that prevent sperm from entering uterus	10–25	Can be used by anyone who is not allergic; protects against some sexually transmitted diseases; no known side effects	Relatively unreliable; sometimes messy; must be used 5–10 minutes before each act of intercourse
Implant (levonorgestrel; Norplant)	Capsules surgically implanted under skin slowly release hormone that blocks ovulation	.03	Very safe, convenient, and effective; very long lasting (five years); may have nonreproductive health benefits like those of oral contraceptives	Irregular or absent periods; minor surgical procedure needed for insertion and removal; some scarring may occur
Injectable contraceptive (medroxy-progesterone; Depo-Provera)	Injection every 3 months of a hormone that is slowly released and prevents ovulation	1	Convenient and highly effective; no serious side effects other than occasional heavy menstrual bleeding	Animal studies suggest it may cause cancer, though new studies in humans are mostly encouraging; occasional heavy menstrual bleeding
Plan B (“morning after pill”)	Emergency contraception taken within one to five days following intercourse. High levels of progesterone taken in two doses blocks ovulation and may prevent fertilization or implantation	5–40	Can prevent ovulation or possibly pregnancy following unprotected sex (if another method of birth control wasn’t used or is suspected of failing, such as condom breaking or irregular use of oral contraception)	Available over the counter for women 18 and over but under 18 requires a prescription; effectiveness decreases after the first 24 hours; is emergency contraception, shouldn’t be used in place of other methods of birth control

phragms, perhaps because of the propensity to insert them carelessly when in a hurry. Failure rates for cervical caps are lower.

Sperm Destruction. A final general approach to birth control is to eliminate the sperm after ejaculation. This can be achieved in principle by washing out the vagina immediately after intercourse, before the sperm have a chance to enter the uterus. Such a procedure is called a douche (French, "wash"). It involves a rapid dash to the bathroom immediately after ejaculation and a very thorough washing. Its failure rate is as high as 40%. Alternatively, sperm delivered to the vagina can be destroyed there with spermicidal jellies or foams. These treatments generally require application immediately before intercourse. Their failure rates vary from 10 to 25%. The use of a spermicide with a condom or diaphragm increases the effectiveness over each method used independently.

Sexually Transmitted Diseases

Sexually transmitted diseases (STDs) are diseases that spread from one person to another through sexual contact. AIDS, discussed in chapter 28, is a deadly viral STD. Other significant sexually transmitted diseases include:

Gonorrhea. Caused by the bacterium *Neisseria gonorrhoeae*. The primary symptom of this disease is discharge from the penis or vagina. It can be treated with antibiotics. If left untreated in women, gonorrhea can cause pelvic inflammatory disease (PID), a condition in which the fallopian tubes become scarred and blocked. PID can eventually lead to sterility.

Chlamydia. Caused by the bacterium *Chlamydia trachomatis,* this disease is sometimes called the "silent STD" because women usually experience no symptoms until after the infection has become established. Like gonorrhea, chlamydia can cause PID in women if left untreated.

Syphilis. Caused by the bacterium *Treponema pallidum,* this disease is one of the most potentially devastating STDs. Left untreated, the disease progresses to heart disease, mental deficiency, and nerve damage that may include loss of motor function or blindness.

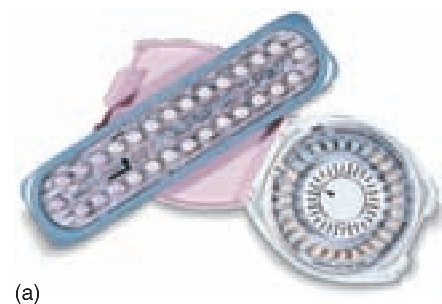
Genital herpes. Caused by the herpes simplex virus type 2 (HSV-2), this disease is the most common STD in the United States. The virus causes red blisters on the penis or on the labia, vagina, or cervix that scab over.

Cervical Cancer. About 70% of cervical cancer is caused by HPV (human papillomavirus), a sexually transmitted virus. Gardasil, a newly developed vaccine which blocks HPV in women not yet exposed to the virus, could cut worldwide deaths by about 290,000 women each year.

This summary of STDs may give the impression that sexual activity is fraught with danger, and when practiced with unknown partners it is. In light of this, it is folly not to take precautions to avoid STDs. Anyone responsible enough to have sex should be responsible enough to protect themselves.

Concept Check

1. What is the failure rate of condoms? of birth control pills?
2. What are the active agents in birth control pills?
3. Which STD is the most common in the United States?



(a)

(b)

(c)

Figure 31.17 Three common birth control methods.

(a) Oral contraceptives; (b) condom; and (c) diaphragm and spermicidal jelly.

Inquiry & Analysis

Why Do STDs Vary in Frequency?

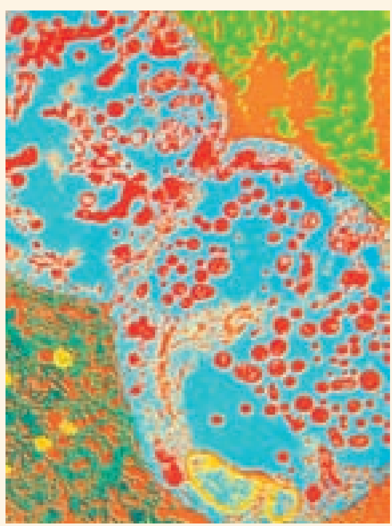
As a general rule, the incidence of a sexually transmitted disease is expected to increase with increasing frequencies of unprotected sexual contact. With the emergence of AIDS, intense publicity and education has lessened such dangerous behavior. Both the number of sexual partners and the frequency of unprotected sex have fallen significantly in the United States in the last decade. It would follow, then, that the frequencies of sexually transmitted diseases (STDs) like syphilis, gonorrhea, and chlamydia should also be falling.

However, the level of one STD sometimes rises while another falls. What are we to make of this? The simplest explanation of such a difference is that the two STDs are occurring in different populations, and one population has rising levels of sexual activity, while the other has falling levels. However, nationwide statistics encompass all population subgroups, and there is no reason to expect subgroups to contain different STDs. Certainly each major subgroup contains all three major STDs mentioned above. So this would seem an unlikely explanation for the frequency of one STD to be rising while another falls.

A second possible explanation would be a change in the infectivity of one of the STDs. A less infective STD would tend to fall in frequency in the population, for the simple reason that fewer sexual contacts result in infection. To assess this possibility, we must examine the individual STDs more closely.

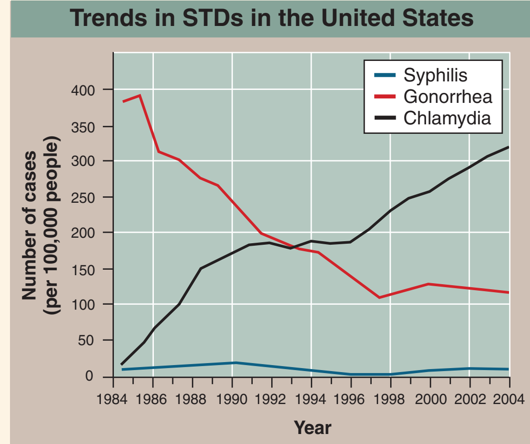
Syphilis is most infective in its initial stage, but this stage lasts only about a month. Most transmissions occur during the much longer second stage, marked by a pink rash and sores in the mouth. The bacteria can be transmitted at this stage by kissing or shared liquids. Any drop in infectivity of this STD would be expected to shorten this stage—but no such shortening has been observed.

Gonorrhea can be transmitted by various forms of sexual contact with an infected individual at any time during the infection. There has been no drop in infectivity per sexual contact reported.



Chlamydia offers the most interesting possibility of changes in infectivity, because of its unusual nature. *Chlamydia trachomatis* is genetically a bacterium but is an obligate intracellular parasite, much like a virus in this respect—it can reproduce only inside human cells. The red structures in the photo are chlamydia bacteria inside human cells. Like gonorrhea, chlamydia is transmitted through vaginal, anal, or oral intercourse with an infected person. With chlamydia, the person may show no symptoms. Because the disease agent lives inside cells, its infectivity would not be expected to change unless the number of cells of an infected individual to which his or her sex partner would be exposed during intercourse were to change, a very unlikely possibility.

So a drop in infectivity doesn't seem very likely. There is, however, a third possible explanation for why the frequency of one STD in a population might rise while the frequency of another STD in that same population falls. To grasp this third possible explanation, we will need to examine carefully the trends in the incidence in the United States of the gonorrhea, chlamydia, and syphilis. Detailed yearly statistics are reported in the graph above.



Analysis

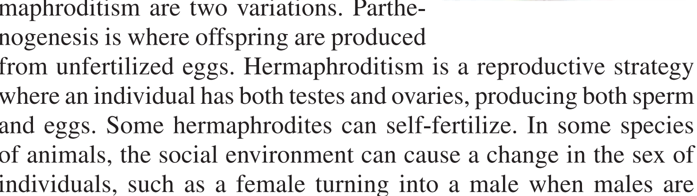
1. **Making Inferences**
   a. Gonorrhea: What is the incidence in 1985? in 1995? Has the frequency declined or increased? In general, are individuals aware they are infected when they transmit the STD?
   b. Chlamydia: What is the incidence in 1985? in 1995? Has the frequency declined or increased? In general, are individuals aware they are infected when they transmit the STD?
2. **Drawing Conclusions** How might heightened public awareness explain why the trend in levels of gonorrhea differs from that of chlamydia?

Concept Summary

Modes of Reproduction

31.1 Asexual and Sexual Reproduction

- Asexual reproduction through fission (**figure 31.1**) or budding is the primary means of reproduction among protists and some animals, but most animals reproduce sexually.



- Sexual reproduction is most common in animals, but parthenogenesis and hermaphroditism are two variations. Parthenogenesis is where offspring are produced from unfertilized eggs. Hermaphroditism is a reproductive strategy where an individual has both testes and ovaries, producing both sperm and eggs. Some hermaphrodites can self-fertilize. In some species of animals, the social environment can cause a change in the sex of individuals, such as a female turning into a male when males are scarce (**figure 31.2**), a process called sequential hermaphroditism.
- In mammals, sex is genetically determined and appears during embryonic development. An embryo that is XY develops into a male and an XX embryo develops into a female. The Y chromosome carriers a gene, possibly the *SRY* gene that converts the gonads into testes. The lack of this gene in females results in the formation of ovaries (**figure 31.3**).

The Human Reproductive System

31.2 Males

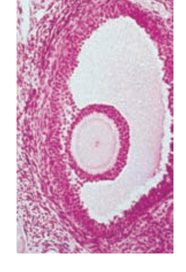
- Sperm is produced in the testes (**figure 31.4**). The testes contain a large number of tightly coiled tubes called seminiferous tubules, where sperm develop in a process called spermatogenesis (**figure 31.5**). As sperm develop and undergo meiosis, they move toward the lumen of the tubules, and from there they pass into the epididymis. Once matured, they are stored in the vas deferens. During sexual intercourse, sperm are delivered through the penis (**figure 31.7**) into the female.

31.3 Females

- Female gametes, eggs or ova, develop in the ovary from oocytes. The ovaries are located in the lower abdomen (**figure 31.8**). A female is born with some 2 million oocytes, all arrested during the first meiotic division. The hormones FSH and LH initiate the resumption of meiosis I in a few oocytes, but usually only one oocyte completes development.
- The egg ruptures from the ovary, called ovulation, and enters the fallopian tube (**figure 31.9**). Sperm deposited in the vagina travel up through the cervix and uterus, shown here from **figure 31.10*a*,** and into the fallopian tube, or oviduct, to reach the egg. Usually only one sperm cell penetrates the egg's protective layers (**figure 31.10*b***). At this point, the oocyte completes meiosis II, and fertilization occurs. The fertilized egg, called a zygote, is transported to the uterus through the oviduct. The zygote attaches to the endometrial lining of the uterus where it completes development.

31.4 Hormones Coordinate the Reproductive Cycle

- The human reproductive cycle, called a menstrual cycle, is divided into two phases, the follicular and luteal phases (**figure 31.11**). The follicular phase begins with the secretion of FSH and LH, which stimulates the resumption of oocyte development and the secretion of estrogen. The estrogen acts as a negative-feedback signal to stop the secretion of FSH from the anterior pituitary.
- As the level of estrogen increases it begins to have a positive-feedback effect on FSH and LH. The luteal phase begins with a surge of LH, which causes ovulation and the formation of the corpus luteum (**figure 31.11**). The corpus luteum begins secreting progesterone, which acts to prepare the uterus for implantation of the zygote.
- If fertilization does not occur, estrogen and progesterone levels drop and the endometrial lining of the uterus sloughs off, a process called menstruation, and a new cycle begins.



- If a zygote implants in the lining of the uterus (**figure 31.12**), estrogen and progesterone levels remain high due to the release of human chorionic gonadotropin (hCG) from the embryo. The uterus is maintained and no further egg maturation occurs.

The Course of Development

31.5 Embryonic Development

- The vertebrate embryo develops in three stages (**table 31.1**). The first stage, called cleavage, involves hundreds of cell divisions that eventually produce a hollow ball of cells called a blastocyst. The second stage, called gastrulation, involves the orchestrated movement of cells, forming the three germ layers: endoderm, ectoderm, and mesoderm (**figure 31.13**). The third stage is neurulation, where the notochord and neural tube form.

31.6 Fetal Development

- Organs begin forming by the fourth week, and by the end of the second month the embryo looks distinctly human. By the end of the third month, all major organs except the brain and lungs are developed (**figure 31.14**).
- The second and third trimesters are periods of considerable growth, with the fetus receiving nourishment from the placenta (**figure 31.15**).
- During labor and delivery, the fetus and placenta are expelled from the uterus (**figure 31.16**). Hormones coordinate the production of milk in the mother for nourishing the newborn. Brain development continues in the baby after birth.

Birth Control and Sexually Transmitted Diseases

31.7 Contraception and Sexually Transmitted Diseases

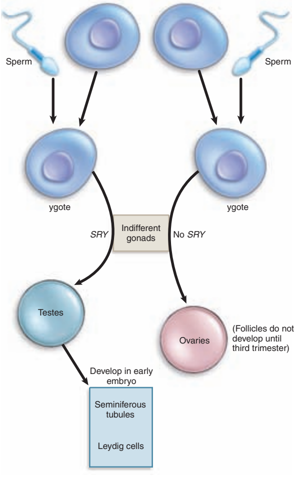
- Various birth control methods are available and work by preventing egg maturation, preventing embryo implantation, and blocking or killing sperm (**table 31.2**).
- Sexually transmitted diseases are spread through sexual contact. AIDS is a deadly STD. Other STDs may not be as fatal as AIDS but are quite destructive, especially if left untreated.

Self-Test

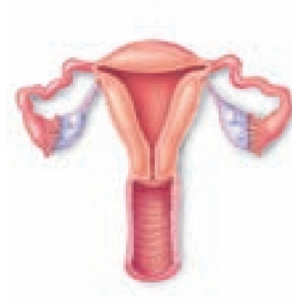
1. If offspring are not genetically identical to each other or to the parent, then the organism reproduces through
   a. fission. **c.** budding.
   b. sexual reproduction. **d.** all of the above.
2. An animal that contains both ovaries and testes and produces both eggs and sperm reproduce by
   a. parthenogenesis.
   b. asexual reproduction.
   c. hermaphroditism.
   d. They cannot reproduce; they are sterile.
3. In mammals, the embryonic gonads will develop into ovaries
   a. if the *SRY* gene is expressed.
   b. if both sex chromosomes are X.
   c. if the sex chromosomes are X and Y.
   d. within the first 40 days.
4. Temperature regulation of spermatogenesis in human males is controlled by the location of the
   a. seminiferous tubules. **c.** vas deferens.
   b. epididymis. **d.** scrotum.
5. Oocyte development in human females requires the hormones
   a. estrogen and testosterone.
   b. FSH and LH.
   c. progesterone and testosterone.
   d. oxytocin and prolactin.
6. When pregnancy occurs, the endometrium is maintained by the
   a. embryo releasing hCG.
   b. decrease in levels of progesterone.
   c. hypothalamus releasing GnRH.
   d. increasing levels of FSH.
7. A human embryo has formed the three germ layers from which all tissues form by the time
   a. the blastula forms. **c.** the blastocyst forms.
   b. neurulation is complete. **d.** gastrulation is complete.
8. In a developing human, the first tissues to begin forming are the
   a. skeletal. **c.** neural.
   b. muscular. **d.** digestive.
9. Contractions of the uterus during labor are stimulated by the hormone
   a. estrogen. **c.** oxytocin.
   b. prolactin. **d.** progesterone.
10. Which of the following is *not* a method of contraception?
    a. destruction of the egg
    b. prevention of egg maturation
    c. sperm blockage
    d. prevention of embryo implantation

Visual Understanding

1. **Figure 31.3** Up until 40 days after conception, an embryo is neither male nor female. Explain what happens after that point in an embryo that carries the *SRY* gene.



2. **Figure 31.10** Sometimes a zygote implants in the fallopian tube rather than in the uterus. This is called an ectopic pregnancy (ectopic meaning "out of place"). It is necessary to terminate an ectopic pregnancy because it endangers the mother and the fetus cannot survive. Explain why the mother is in danger and why the fetus can't survive.



Challenge Questions

1. Why are all the parents of parthenogenic offspring female?
2. Speculate on why males produce so many sperm and females produce, comparatively, so few viable eggs.
3. Explain some of the ways that a pregnant woman's use of drugs—alcohol, cocaine, prescription drugs, over-the-counter drugs—can affect the embryo or fetus that she is carrying.
4. A friend tells you that the most reliable method of contraception and prevention of sexually transmitted disease is communication. Explain what she means.