Mark and Deidre had in vain tried to have a child for more than two years. They had even timed their lovemaking to follow Deidre's monthly cycle of producing an egg. They finally learned that while Mark's sperm were healthy, his testes were making very few of them. The couple turned to an infertility clinic for help. Using hormones, physicians stimulated Deidre's ovaries to mature a bunch of eggs at once. The doctors surgically removed those eggs and injected a single sperm of Mark's into each one. Those eggs that were successfully fertilized were then implanted into Deidre's uterus. Nine months later, she gave birth to triplets.

Mark and Deidre were reluctant to tell others how their children were conceived. They were afraid that some would think they should not interfere with the natural course of events. And how would the children be affected by being one of three instead of receiving the full attention of their parents? How do you feel about such questions? Is it beneficial or not that medical science has learned to control human reproduction?

This chapter will describe how the male and female reproductive systems normally bring about this miracle of new life. And it will consider alternative means of human reproduction as well.

21.1 Male Reproductive System

The male reproductive system includes the organs depicted in Figure 21.1 and listed in Table 21.1. The male **gonads** are paired testes (sing., **testis**), which are suspended within the *scrotal sacs* of the **scrotum.**

Sperm produced by the testes mature within the **epididymis** (pl., epididymides), which is a tightly coiled tubule lying just outside each testis. Maturation seems to be required for the sperm to swim to the egg. Each epididymis joins with a **vas deferens** (pl., vasa deferentia), which descends through a canal called the inguinal canal and enters the abdominal cavity where it curves around the bladder and empties into the **urethra.** Sperm are stored in both the epididymides and the vasa deferentia.

At the time of ejaculation, sperm leave the penis in a fluid called seminal fluid **(semen).** The pair of seminal vesicles, the prostate gland, and the bulbourethral glands (Cowper's glands) add secretions to seminal fluid. The **seminal vesicles** lie at the base of the bladder and each has a duct that joins with a vas deferens. The **prostate gland** is a single doughnut-shaped gland that surrounds the upper portion of the urethra just below the bladder. In older men,

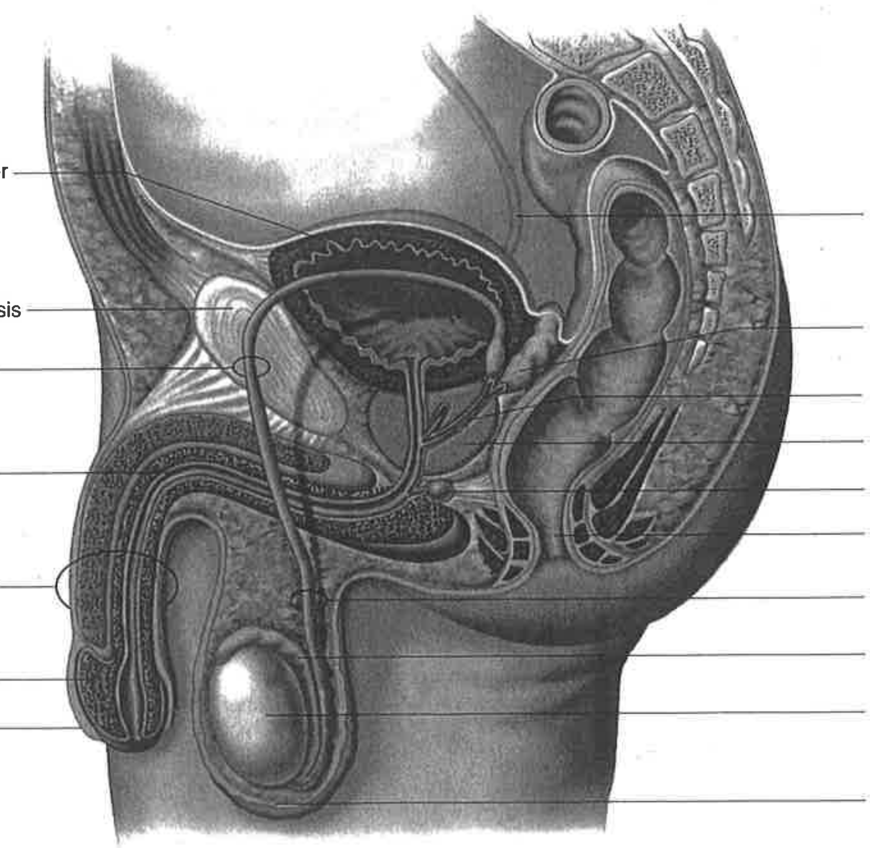

Figure 21.1 The male reproductive system.
The testes produce sperm. The seminal vesicles, the prostate gland, and the bulbourethral gland provide a fluid medium. Circumcision is the removal of the foreskin. Notice that the penis in this drawing is not circumcised because the foreskin is present.

21.2 Female Reproductive System

The female reproductive system includes the organs depicted in Figure 21.5 and listed in Table 21.2. The female **gonads** are paired **ovaries** that lie in shallow depressions, one on each side of the upper pelvic cavity. **Oogenesis** is the production of an **egg**, the female gamete. The ovaries alternate in producing one egg (ovum) a month. **Ovulation** is the process by which an egg bursts from an ovary and usually enters an oviduct.

The Genital Tract

The **oviducts,** also called uterine or fallopian tubes, extend from the uterus to the ovaries; however, the oviducts are not attached to the ovaries. Instead, they have fingerlike projections called fimbriae (sing., **fimbria**) that sweep over the ovaries. When an egg bursts from an ovary during ovulation, it usually is swept into an oviduct by the combined action of the fimbriae and the beating of cilia that line the oviducts.

Once in the oviduct, the egg is propelled slowly by cilia movement and tubular muscle contraction toward the uterus. Fertilization and **zygote** formation occurs in an oviduct because the egg only lives approximately 6 to 24 hours. The developing embryo normally arrives at the uterus after several days and then embeds, or implants, itself in the uterine lining, which has been prepared to receive it.

The **uterus** is a thick-walled, muscular organ about the size and shape of an inverted pear. Normally, it lies above and is tipped over the urinary bladder. The oviducts join the uterus anteriorly, while posteriorly the

Table 21.2 Female Reproductive System

Organ	Function
Ovaries	Produce egg and sex hormones
Oviducts (fallopian tubes)	Conduct egg; location of fertilization
Uterus (womb)	Houses developing fetus
Cervix	Contains opening to uterus
Vagina	Receives penis during sexual intercourse; serves as birth canal, and as an exit for menstrual flow

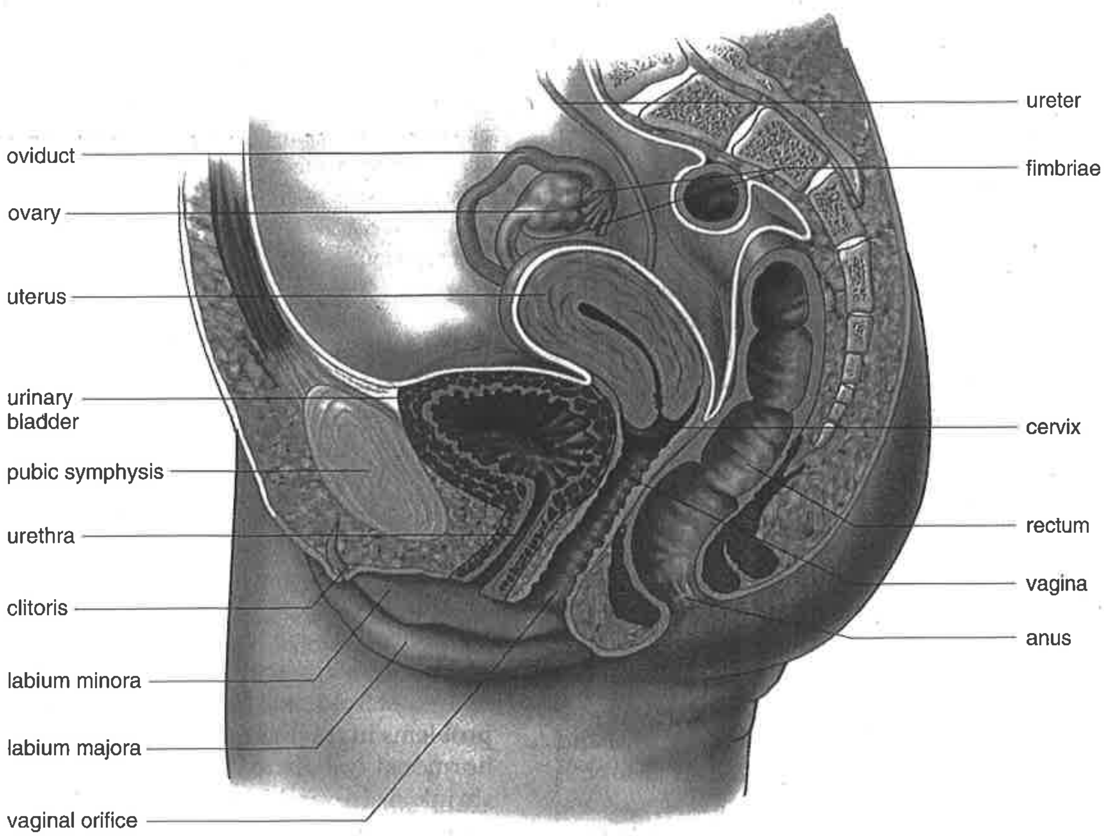

Figure 21.5 The female reproductive system.
The ovaries release one egg a month; fertilization occurs in the oviduct, and development occurs in the uterus. The vagina is the birth canal and the organ of sexual intercourse.

Table 21.1 Male Reproductive System

Organ	Function
Testes	Produce sperm and sex hormones
Epididymides	Maturation and some storage of sperm
Vasa deferentia	Conduct and store sperm
Seminal vesicles	Contribute fluid to semen
Prostate gland	Contributes fluid to semen
Urethra	Conducts sperm
Bulbourethral glands	Contribute fluid to semen
Penis	Organ of copulation

seminiferous tubule shows that it is packed with cells undergoing **spermatogenesis** (Fig. 21.3*b*), the production of sperm. Also present are **sustentacular (Sertoli) cells,** which support, nourish, and regulate the spermatogenic cells (Fig. 21.3*c*).

Mature **sperm,** or spermatozoa, have three distinct parts: a head, a middle piece, and a tail (Fig. 21.3*d*). There are mitochondria in the middle piece that provide the energy for the movement of the tail which has the structure of a flagellum. The head contains a nucleus covered by a cap called the **acrosome,** which stores enzymes needed to penetrate the egg. The ejaculated semen of a normal human male contains several hundred million sperm, assuring an adequate number for fertilization to take place. Only one sperm normally enters an egg.

Hormonal Regulation in Males

The hypothalamus has ultimate control of the testes' sexual function because it secretes a hormone called **gonadotropin-releasing hormone (GnRH)** that stimulates the anterior pituitary to secrete the gonadotropic hormones. There are two gonadotropic hormones—**follicle-stimulating hormone (FSH)** and **luteinizing hormone (LH)**—in both males and females. In males, FSH promotes the production of sperm in the seminiferous tubules, which also release the hormone inhibin.

LH in males is sometimes given the name *interstitial cell-stimulating hormone (ICSH)* because it controls the production of testosterone by the **interstitial cells,** which are found in the spaces between the seminiferous tubules. All these hormones are involved in a negative feedback relationship that maintains the fairly constant production of sperm and testosterone (Fig. 21.4).

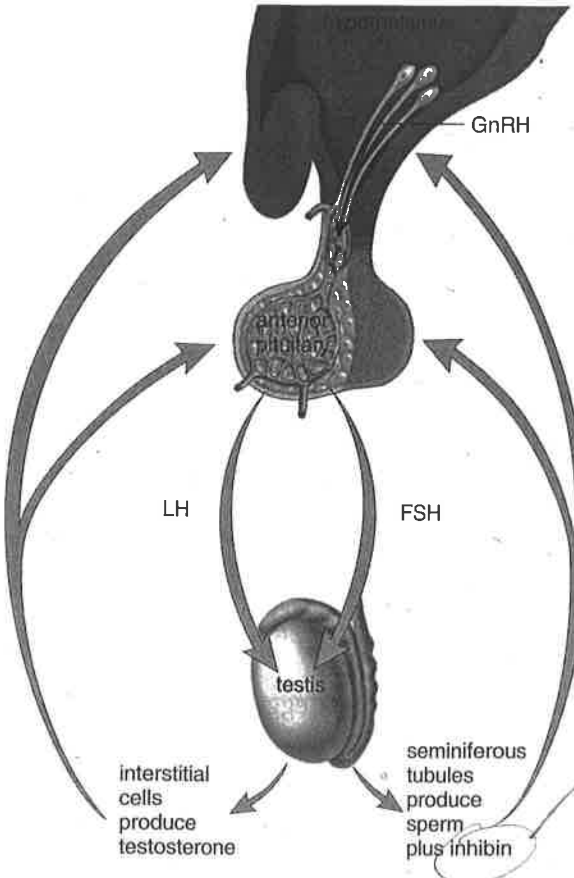

Figure 21.4 Hormonal control of testes.
GnRH (gonadotropin-releasing hormone) stimulates the anterior pituitary to secrete the gonadotropic hormones FSH and LH. FSH stimulates the testes to produce sperm, and LH stimulates the testes to produce testosterone. Testosterone and inhibin exert negative feedback control over the hypothalamus and the anterior pituitary, and this regulates the level of testosterone in blood.

Testosterone, the main sex hormone in males, is essential for the normal development and functioning of the organs listed in Table 21.1. Testosterone also brings about and maintains the male secondary sex characteristics that develop at the time of puberty. Males are generally taller than females and have broader shoulders and longer legs relative to trunk length. The deeper voice of males compared to females is due to a larger larynx with longer vocal cords. Since the so-called Adam's apple is a part of the larynx, it is usually more prominent in males than in females. Testosterone causes males to develop noticeable hair on the face, chest, and occasionally on other regions of the body such as the back. Testosterone also leads to the receding hairline and pattern baldness that occurs in males.

Testosterone is responsible for the greater muscular development in males. Knowing this, males and females sometimes take anabolic steroids, which are either testosterone or related steroid hormones resembling testosterone. Health problems involving the kidneys, the circulatory system, and hormonal imbalances can arise from such use. The testes shrink in size, and feminization in regard to other male traits occurs.

The gonads in males are the testes, which produce sperm as well as testosterone, the most significant male sex hormone.

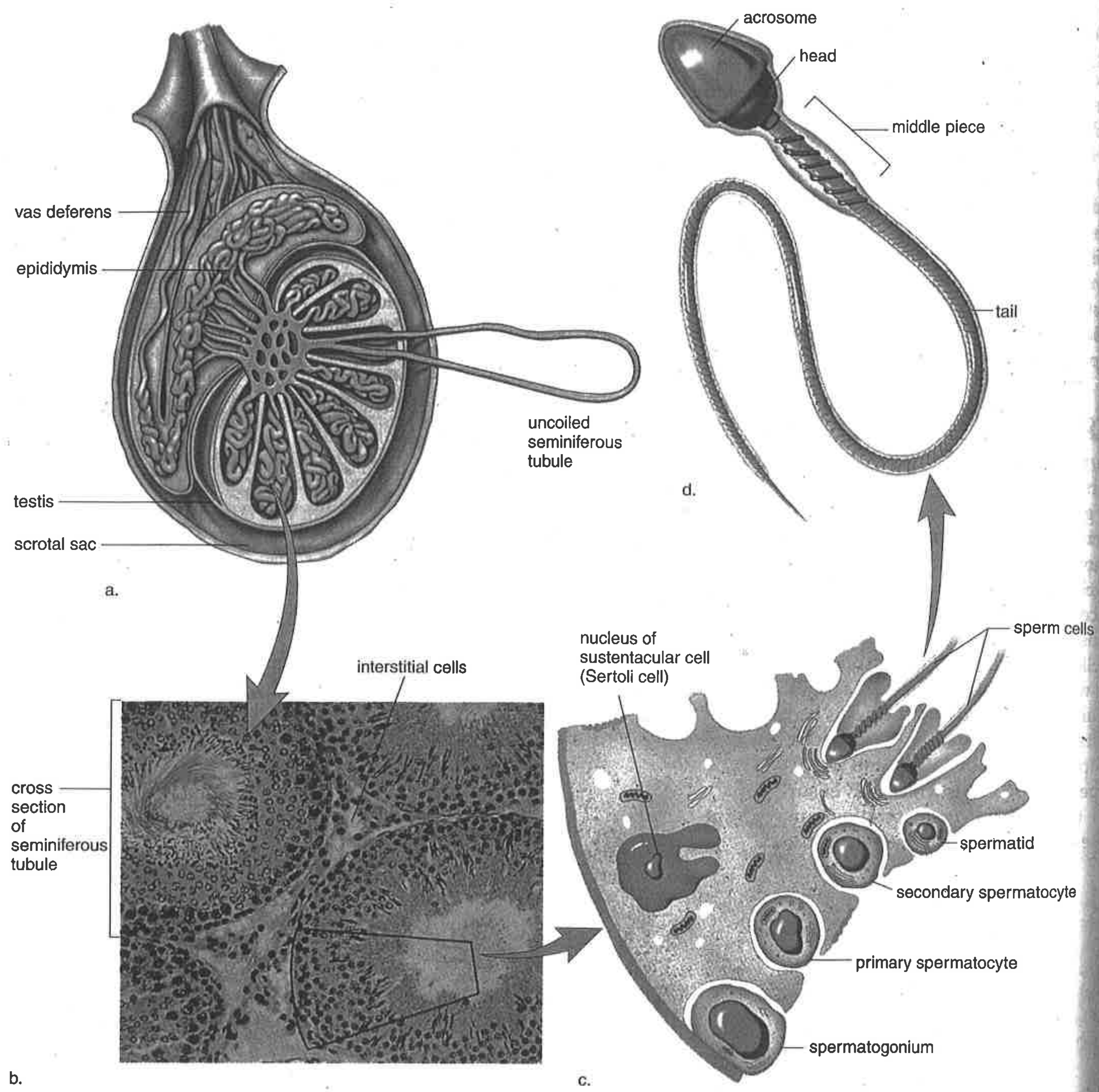

Figure 21.3 Testis and sperm.
a. The lobules of a testis contain seminiferous tubules. **b.** Light micrograph of cross section of seminiferous tubules where spermatogenesis occurs. **c.** Diagrammatic representation of spermatogenesis, which occurs in the wall of the tubules. **d.** A sperm has a head, a middle piece, and a tail. The nucleus is in the head, capped by the enzyme-containing acrosome.

The Male Gonads, the Testes

The testes lie outside the abdominal cavity of the male within the scrotum. The testes begin their development inside the abdominal cavity but descend into the scrotal sacs during the last two months of fetal development. If, by chance, the testes do not descend and the male is not treated or operated on to place the testes in the scrotum, sterility—the inability to produce offspring—usually follows. This is because the internal temperature of the body is too high to produce viable sperm. The scrotum helps regulate the temperature of the testes by holding them closer or farther away from the body.

A longitudinal section of a testis shows that it is composed of compartments called lobules, each of which contains one to three tightly coiled **seminiferous tubules** (Fig. 21.3*a*). Altogether, these tubules have a combined length of approximately 250 meters. A microscopic cross section of a the prostate can enlarge and squeeze off the urethra, making urination painful and difficult. The condition can be treated medically. **Bulbourethral glands** are pea-sized organs that lie posterior to the prostate on either side of the urethra.

Each component of seminal fluid seems to have a particular function. Sperm are more viable in a basic solution, and seminal fluid, which is milky in appearance, has a slightly basic pH (about 7.5). Swimming sperm require energy, and seminal fluid contains the sugar fructose, which presumably serves as an energy source. Seminal fluid also contains prostaglandins, chemicals that cause the uterus to contract. Some investigators believe that uterine contractions help propel the sperm toward the egg.

Orgasm in Males

The **penis** (Fig. 21.2) is the male organ of of sexual intercourse. The penis has a long shaft and an enlarged tip called the glans penis. The glans penis is normally covered by a layer of skin called the foreskin. Circumcision is the surgical removal of the foreskin, usually soon after birth.

Spongy, erectile tissue containing expandable blood spaces extends through the shaft of the penis. During sexual arousal, nerve impulses stimulate the release of cGMP (cyclic guanosine monophosphate), and the erectile tissue fills with blood. The veins that take blood away from the penis are compressed and the penis becomes erect. Impotency exists when the erectile tissue doesn't expand enough to compress the veins. The new drug Viagra inhibits an enzyme that breaks down cGMP, ensuring that a full erection will take place. Vision problems may occur because the same enzyme occurs in the retina.

As sexual stimulation intensifies, sperm enter the urethra from each vas deferens and the glands contribute secretions to seminal fluid (semen). Once seminal fluid is in the urethra, rhythmic muscle contractions cause it to be expelled from the penis in spurts. During ejaculation, a sphincter closes off the bladder so that no urine enters the urethra. (Notice that the urethra carries either urine or semen at different times.)

The contractions that expel seminal fluid from the penis are a part of male orgasm, the physiological and psychological sensations that occur at the climax of sexual stimulation. The psychological sensation of pleasure is centered in the brain, but the physiological reactions involve the genital (reproductive) organs and associated muscles, as well as the entire body. Marked muscular tension is followed by contraction and relaxation.

Following ejaculation and/or loss of sexual arousal, the penis returns to its normal flaccid state. After ejaculation, a male typically experiences a period of time, called the refractory period, during which stimulation does not bring about an erection. The length of the refractory period increases with age.

There may be in excess of 400 million sperm in the 3.5 ml of semen expelled during ejaculation. The sperm count can be much lower than this, however, and fertilization of the egg by a sperm still can take place.

Sperm are produced in the testes, mature in the epididymis, and pass from the vas deferens to the urethra. After glands add fluid to sperm, semen is ejaculated from the penis at the time of male orgasm.

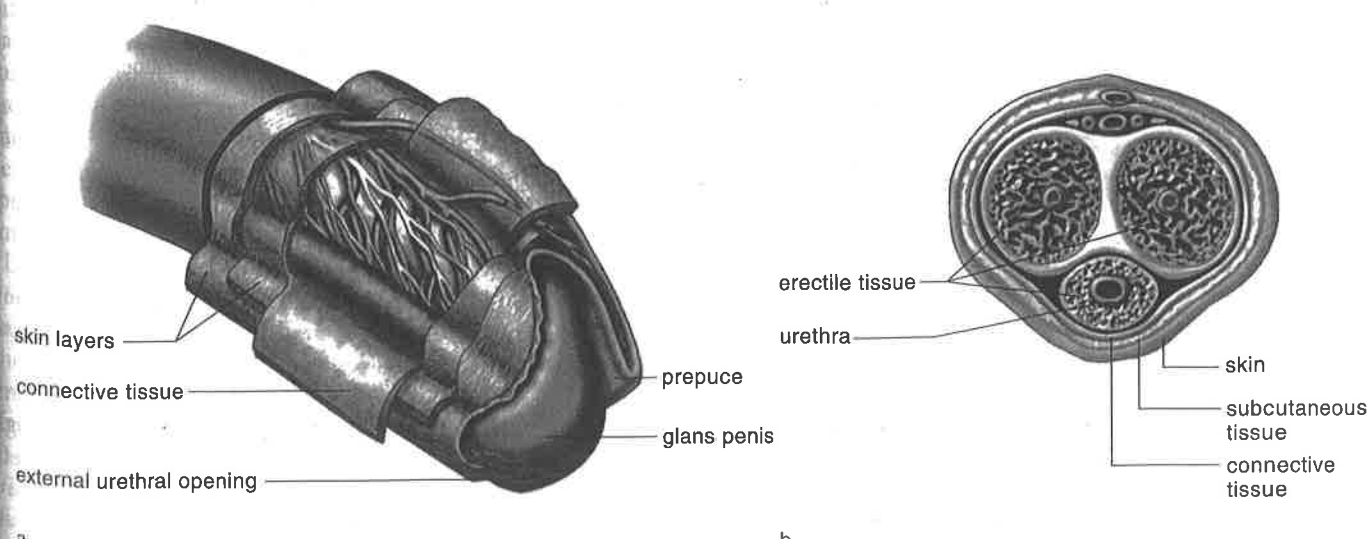

Figure 21.2 Penis anatomy.
a. Beneath the skin and the connective tissue lies the urethra, surrounded by erectile tissue. This tissue expands to form the glans penis, which in uncircumcised males is partially covered by the foreskin. **b.** Two other columns of erectile tissue in the penis are located dorsally.

cervix enters the vagina nearly at a right angle. A small opening in the cervix leads to the vaginal canal. Development of the embryo normally takes place in the uterus. This organ, sometimes called the womb, is approximately 5 cm wide in its usual state but is capable of stretching to over 30 cm wide to accommodate the growing baby. The lining of the uterus, called the **endometrium,** participates in the formation of the placenta (p. 429) which supplies nutrients needed for embryonic and fetal development. The endometrium has two layers, a basal layer and an inner functional layer. In the nonpregnant female, the functional layer of the endometrium varies in thickness according to a monthly reproductive cycle, called the uterine cycle.

Cancer of the cervix is a common form of cancer in women. Early detection is possible by means of a **Pap test,** which requires the removal of a few cells from the region of the cervix for microscopic examination. If the cells are cancerous, a hysterectomy may be recommended. A hysterectomy is the removal of the uterus, including the cervix. Removal of the ovaries in addition to the uterus is termed an ovariohysterectomy. Because the vagina remains, the woman still can engage in sexual intercourse.

The **vagina** is a tube at a 45° angle with the small of the back. The mucosal lining of the vagina lies in folds and can extend. This is especially important when the vagina serves as the birth canal. It also facilitates sexual intercourse, when the vagina receives the penis, and acts as an exit for menstrual flow.

External Genitals

The external genital organs of the female are known collectively as the **vulva** (Fig. 21.6). The vulva includes two large, hair-covered folds of skin called the labia majora. They extend backward from the mons pubis, a fatty prominence underlying the pubic hair. The labia minora are two small folds lying just inside the labia majora. They extend forward from the vaginal opening to encircle and form a foreskin for the clitoris, an organ that is homologous to the penis. Although quite small, the clitoris has a shaft of erectile tissue and is capped by a pea-shaped glans. The glans clitoris also has sense receptors that allow it to function as a sexually sensitive organ.

The vestibule, a cleft between the labia minor, contains the openings of the urethra and the vagina. The vagina may be partially closed by a ring of tissue called the hymen. The hymen ordinarily is ruptured by initial sexual intercourse; however, it also can be disrupted by other types of physical activities. If the hymen persists after sexual intercourse, it can be surgically ruptured.

Notice that the urinary and reproductive systems in the female are entirely separate. For example, the urethra carries only urine, and the vagina serves only as the birth canal and the organ for sexual intercourse.

Orgasm in Females

Sexual response in the female may be more subtle than in the male, but there are certain corollaries. The clitoris is believed to be an especially sensitive organ for initiating sexual sensations. It is possible for the clitoris to become ever so slightly erect as its erectile tissues become engorged with blood, but vasocongestion is more obvious in the labia minora, which expand and deepen in color. Erectile tissue within the vaginal wall also expands with blood, and the added pressure in these blood vessels causes small droplets of fluid to squeeze through the vessel walls and to lubricate the vagina. Another possible source of lubrication is from mucus-secreting glands beneath the labia minora on either side of the vagina.

Release from muscular tension occurs in females, especially in the region of the vulva and vagina but also throughout the entire body. Increased uterine motility may assist the transport of sperm toward the oviducts. Since female orgasm is not signaled by ejaculation, there is a wide range in normalcy of sexual response.

Once each month, an egg produced by an ovary enters an oviduct. If fertilization occurs, the developing embryo is propelled by cilia to the uterus where it implants itself in the uterine lining. The vagina (which is also the birth canal) and the external genitals play an active role in the sexual response of females.

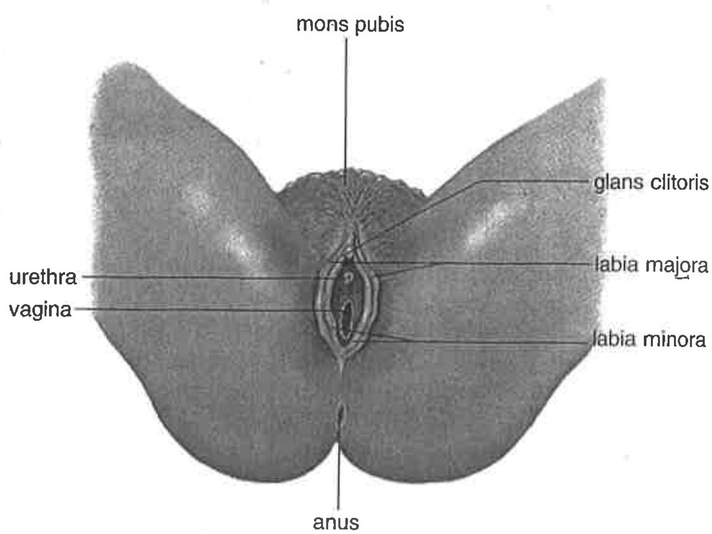

Figure 21.6 External genitals of the female.
At birth, the opening of the vagina is partially blocked by a membrane called the hymen. Physical activities and sexual intercourse disrupt the hymen.

Visual Focus

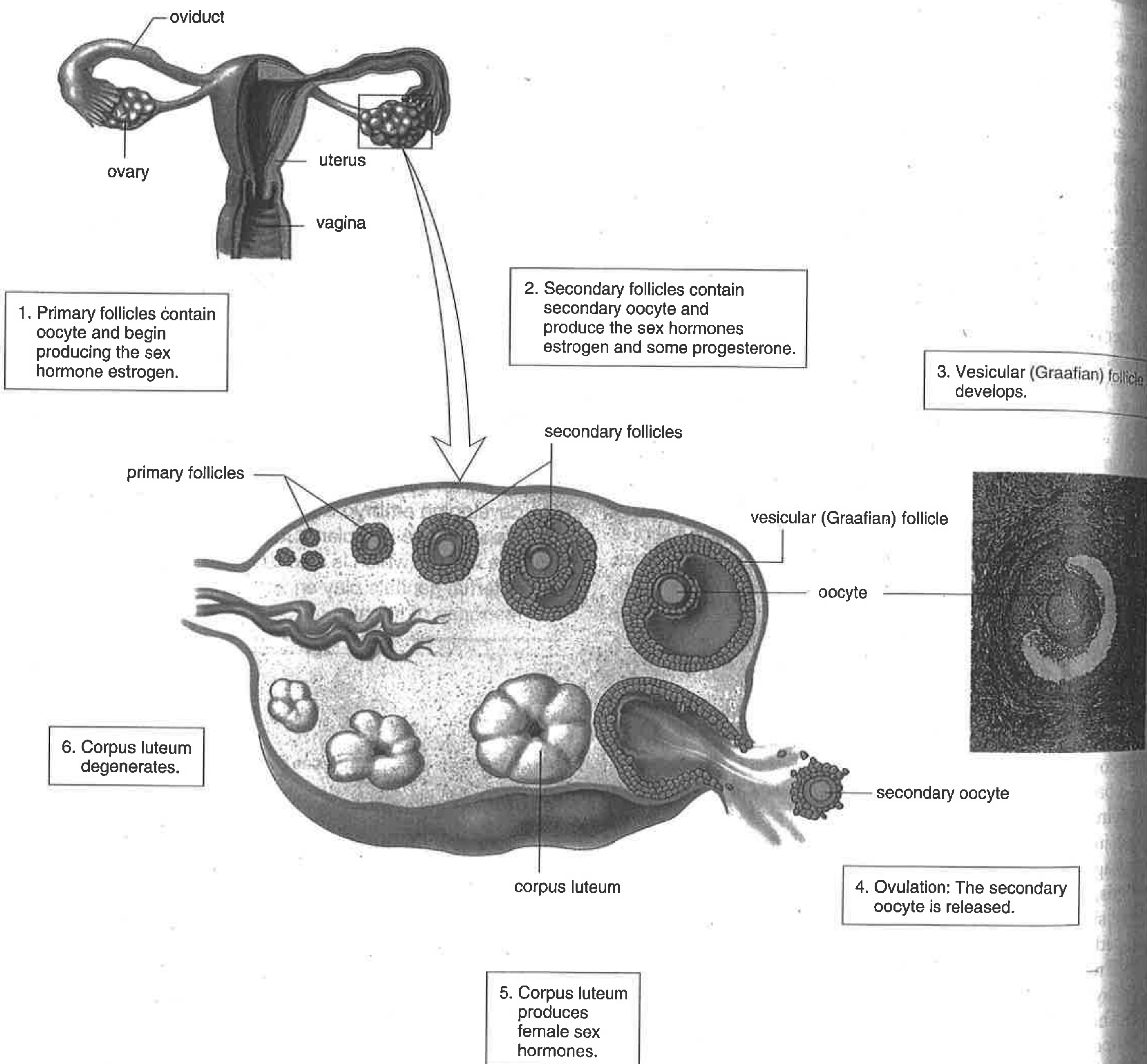

Figure 21.7 Anatomy of ovary and follicle.
As a follicle matures, the oocyte enlarges and is surrounded by layers of follicular cells and fluid. Eventually, ovulation occurs, the mature follicle ruptures, and the secondary oocyte is released. A single follicle actually goes through all stages in one place within the ovary.

21.3 Female Hormone Levels

Hormone levels cycle in the female on a monthly basis, and the ovarian cycle drives the uterine cycle as discussed in this section.

The Ovarian Cycle

A longitudinal section through an ovary shows that it is made up of an outer cortex and an inner medulla (Fig. 21.7). There are many **follicles** in the cortex and each one contains an immature egg, called an oocyte. A female is born with as many as 2 million follicles, but the number is reduced to 300,000–400,000 by the time of puberty. Only a small number of follicles (about 400) ever mature because a female usually produces only one egg per month during her reproductive years. Since oocytes are present at birth, they age as the woman ages. This may be one possible reason why older women are more likely to produce children with genetic defects.

As the follicle undergoes maturation, it develops from a primary follicle to a secondary follicle to a vesicular (Graafian) follicle. A secondary follicle contains a secondary oocyte pushed to one side of a fluid-filled cavity. In a *Graafian follicle,* the fluid-filled cavity increases to the point that the follicle wall balloons out on the surface of the ovary and bursts, releasing the secondary oocyte surrounded by a clear membrane and follicular cells. As mentioned, this is referred to as *ovulation.* Actually, the second meiotic division is not completed unless fertilization occurs. In the meantime, the follicle is developing into the **corpus luteum.** If pregnancy does not occur, the corpus luteum begins to degenerate after about ten days.

These events, called the **ovarian cycle,** are under the control of the gonadotropic hormones, *follicle-stimulating hormone (FSH)* and *luteinizing hormone (LH)* (Fig. 21.8). The gonadotropic hormones are not present in constant amounts but instead are secreted at different rates during the cycle. For simplicity's sake, it can be emphasized that during the first half, or *follicular phase,* of the cycle, FSH promotes the development of a follicle, which secretes estrogen. As the estrogen level in the blood rises, it exerts feedback control over the anterior pituitary secretion of FSH so that the follicular phase comes to an end.

Presumably, the high level of estrogen in the blood also causes the hypothalamus suddenly to secrete a large amount of GnRH. This leads to a surge of LH production by the anterior pituitary and to ovulation at about the 14th day of a 28-day cycle.

During the second half, or *luteal phase,* of the ovarian cycle, LH promotes the development of the corpus luteum, which secretes progesterone. Progesterone causes the uterine lining to build up. As the blood level of progesterone rises, it exerts feedback control over anterior pituitary secretion of LH so that the corpus luteum begins to degenerate. As the luteal phase comes to an end, menstruation occurs.

One ovarian follicle per month produces a secondary oocyte. Following ovulation, the follicle develops into the corpus luteum.

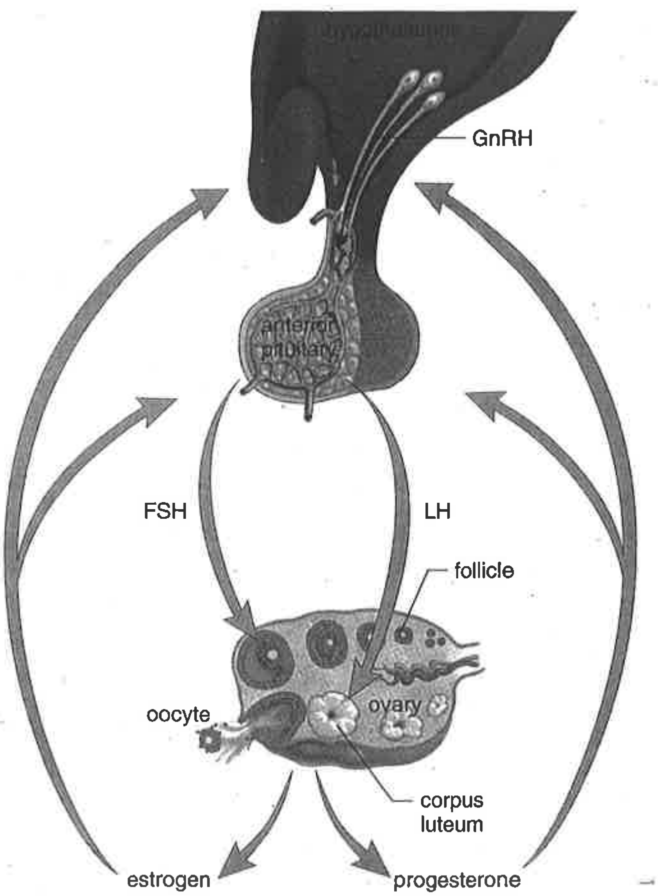

Figure 21.8 Hormonal control of ovaries.
The hypothalamus produces GnRH (gonadotropin-releasing hormone). GnRH stimulates the anterior pituitary to produce FSH (follicle-stimulating hormone) and LH (luteinizing hormone). FSH stimulates the follicle to produce estrogen, and LH stimulates the corpus luteum to produce progesterone. Estrogen and progesterone maintain the sex organs (e.g., uterus) and the secondary sex characteristics, and exert feedback control over the hypothalamus and the anterior pituitary.

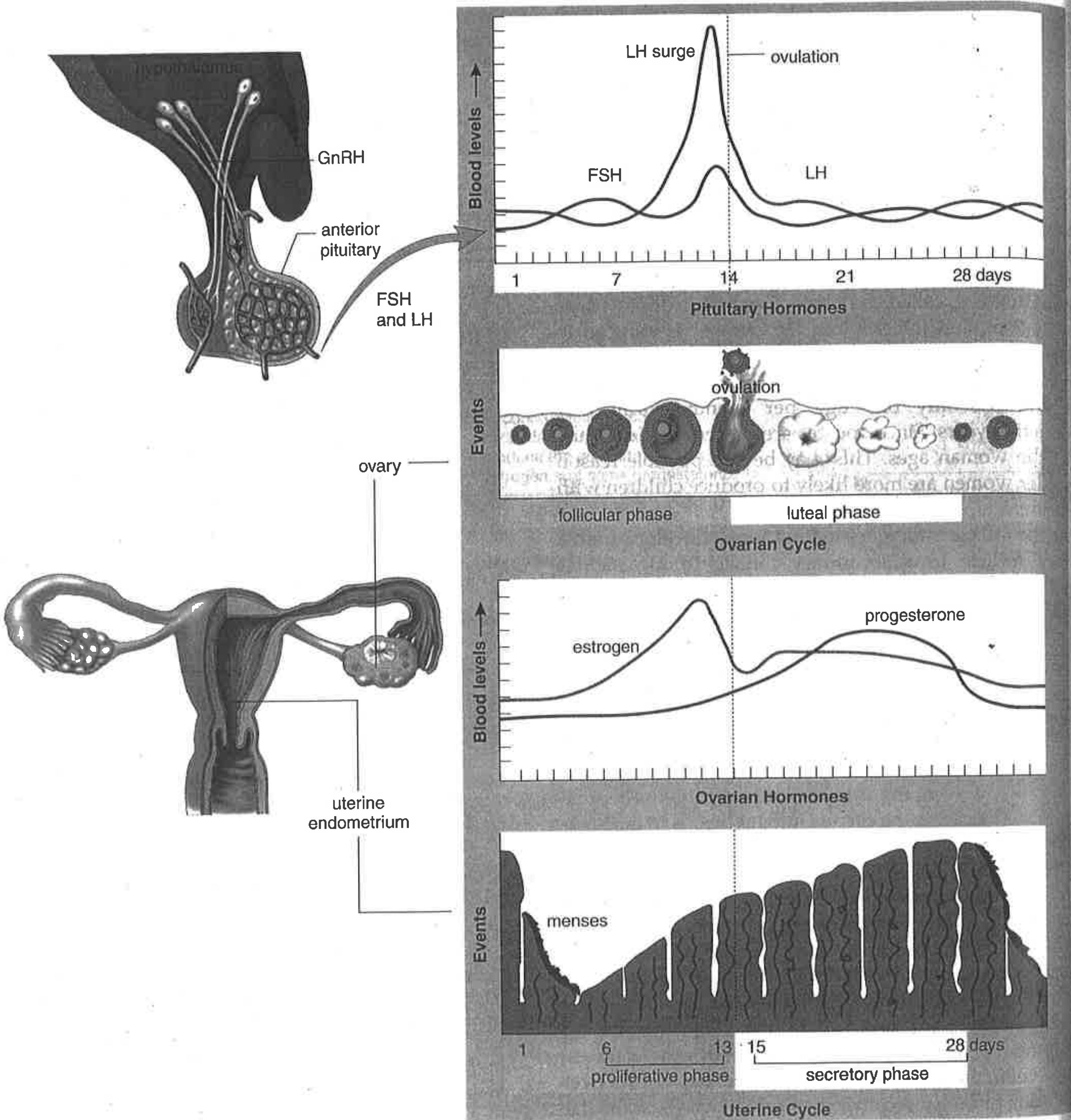

Figure 21.9 Female hormone levels.
During the follicular phase of the ovarian cycle, FSH released by the anterior pituitary promotes the maturation of a follicle in the ovary. The ovarian follicle produces increasing levels of estrogen, which causes the endometrium to thicken during the proliferative phase of the uterine cycle. After ovulation and during the luteal phase of the ovarian cycle, LH promotes the development of the corpus luteum. This structure produces increasing levels of progesterone, which causes the endometrial lining to become secretory. Menstruation begins when progesterone production declines to a low level.

The First Week

Fertilization occurs in the upper third of an oviduct (Fig. 22.10), and cleavage begins even as the embryo passes down this tube to the uterus. By the time the embryo reaches the uterus on the third day, it is a morula. The morula is not much larger than the zygote because, even though multiple cell divisions have occurred, there has been no growth of these newly formed cells. By about the fifth day, the morula is transformed into the blastocyst. The **blastocyst** has a fluid-filled cavity, a single layer of outer cells called the **trophoblast** and an inner cell mass. Later, the trophoblast, reinforced by a layer of mesoderm, gives rise to the *chorion*, one of the extraembryonic membranes (see Fig. 22.9). The *inner cell mass* eventually becomes the embryo, which develops into a fetus.

The Second Week

At the end of the first week, the embryo begins the process of *implanting* in the wall of the uterus. The trophoblast secretes enzymes to digest away some of the tissue and blood vessels of the uterine wall (Fig. 22.10). The embryo is now about the size of the period at the end of this sentence. The trophoblast begins to secrete **human chorionic gonadotropin (HCG),** the hormone that is the basis for the pregnancy test and that serves to maintain the corpus luteum past the time it normally disintegrates. Because of this, the endometrium is maintained and menstruation does not occur.

As the week progresses, the inner cell mass detaches itself from the trophoblast, and two more extraembryonic membranes form (Fig. 22.11*a*). The *yolk sac,* which forms below the embryonic disk, has no nutritive function as in

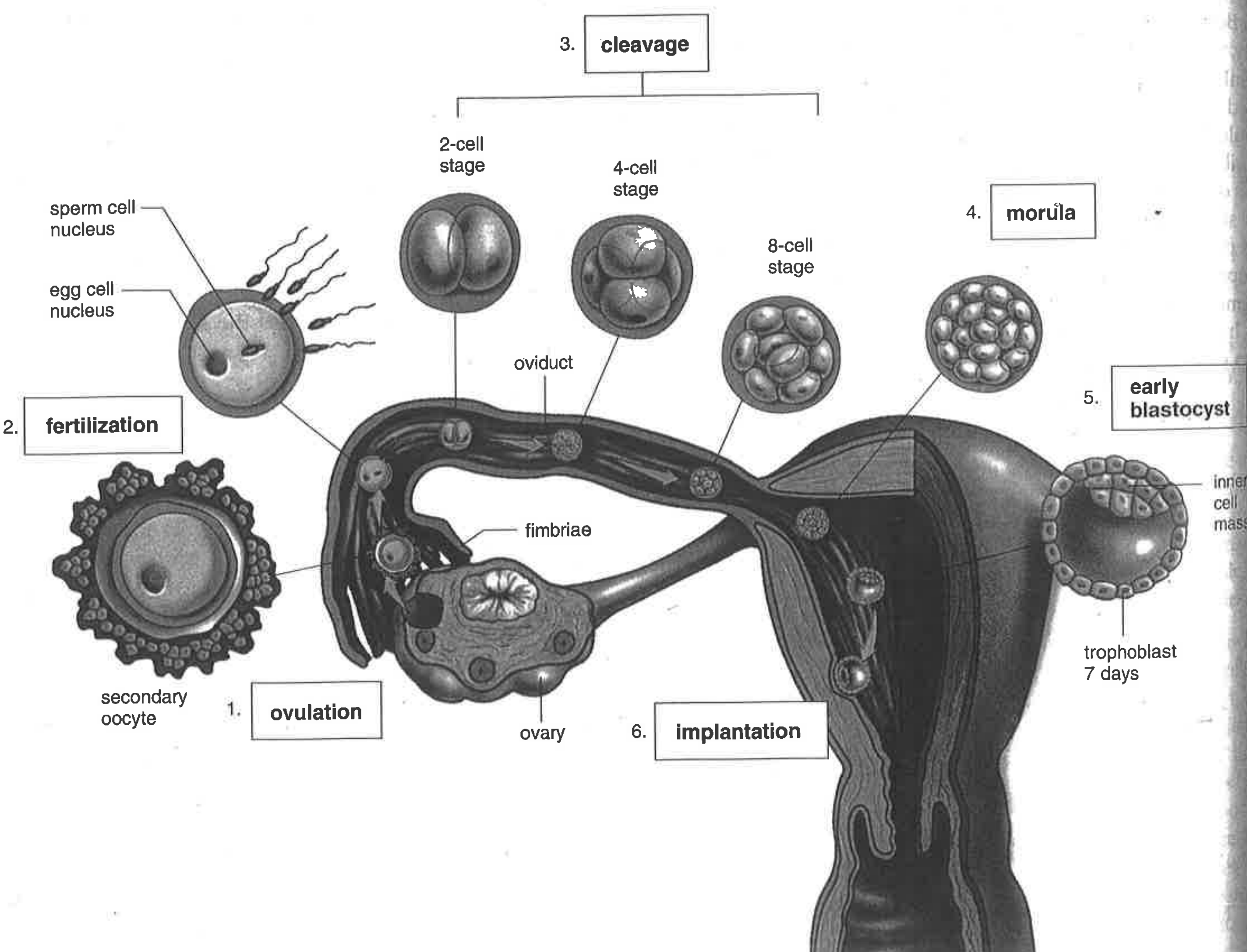

Figure 22.10 Human development before implantation.
Structures and events proceed counterclockwise. At ovulation (1), the secondary oocyte leaves the ovary. A single sperm penetrates the zona pellucida, and fertilization (2) occurs in the oviduct. As the zygote moves along the oviduct, it undergoes cleavage (3) to produce a morula (4). The blastocyst forms (5) and implants itself in the uterine lining (6).

22.3 Human Embryonic and Fetal Development

In humans, the length of the time from conception (fertilization followed by **implantation**) to birth (parturition) is approximately nine months. It is customary to calculate the time of birth by adding 280 days to the start of the last menstruation, because this date is usually known, whereas the day of fertilization is usually unknown. Because the time of birth is influenced by so many variables, only about 5% of babies actually arrive on the forecasted date.

Human development is often divided into embryonic development (months 1 and 2) and fetal development (months 3–9). The **embryonic period** consists of early formation of the major organs, and fetal development is the refinement of these structures.

Before we consider human development chronologically, we must understand the placement of **extraembryonic membranes.** Extraembryonic membranes are best understood by considering their function in reptiles and birds. In reptiles, these membranes made development on land first possible. If an embryo develops in the water, the water supplies oxygen for the embryo and takes away waste products. The surrounding water prevents desiccation, or drying out, and provides a protective cushion. For an embryo that develops on land, all these functions are performed by the extraembryonic membranes.

In the chick, the extraembryonic membranes develop from extensions of the germ layers, which spread out over the yolk. Figure 22.9 shows the chick surrounded by the membranes. The **chorion** lies next to the shell and carries on gas exchange. The **amnion** contains the protective amniotic fluid, which bathes the developing embryo. The **allantois** collects nitrogenous wastes, and the **yolk sac** surrounds the remaining yolk, which provides nourishment.

Humans (and other mammals) also have these extraembryonic membranes. The chorion develops into the fetal half of the placenta; the yolk sac, which lacks yolk, is the first site of blood cell formation; the allantoic blood vessels become the umbilical blood vessels; and the amnion contains fluid to cushion and protect the embryo, which develops into a fetus. Therefore, the function of the membranes in humans has been modified to suit internal development, but their very presence indicates our relationship to birds and to reptiles. It is interesting to note that all animals develop in water, either in bodies of water or within amniotic fluid.

The presence of extraembryonic membranes in reptiles made development on land possible. Humans also have these membranes, but their function has been modified for internal development.

Embryonic Development

Embryonic development includes the first two months of development.

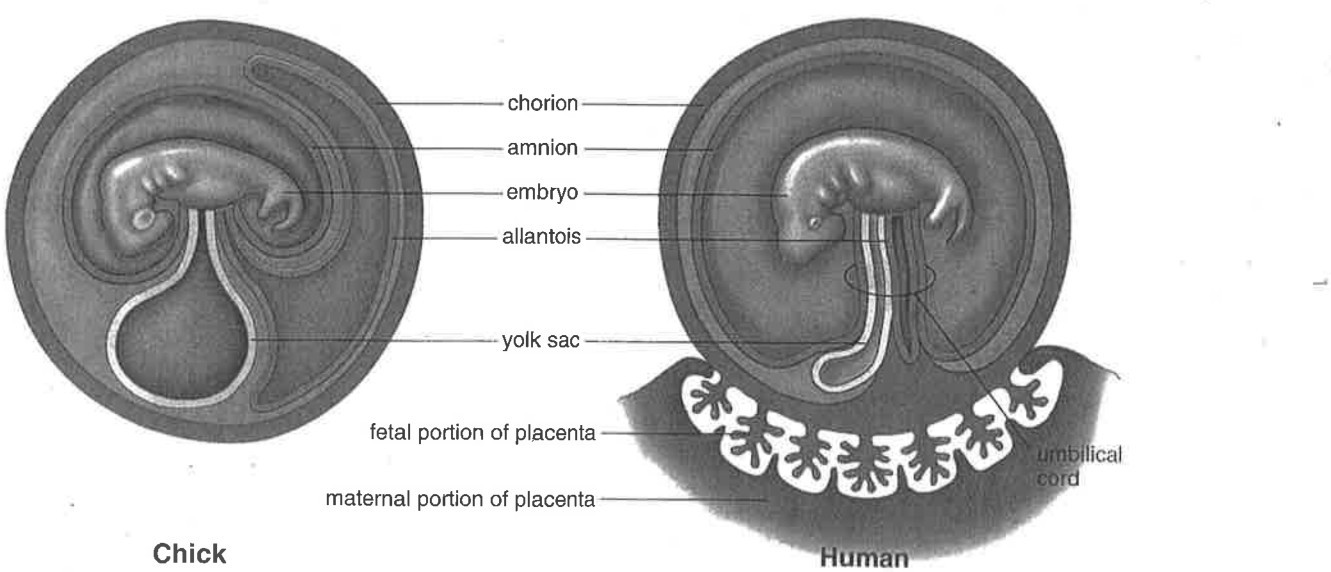

Figure 22.9 Extraembryonic membranes.
The membranes, which are not part of the embryo, are found during the development of chicks and humans, where each has a specific function.