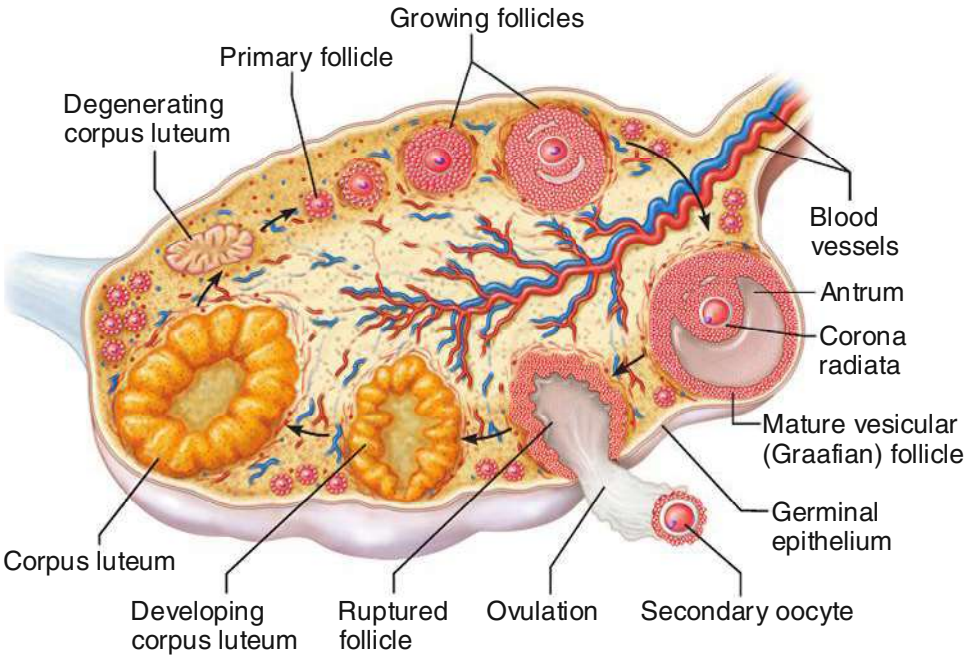


Figure 16.7 **Sagittal view of a human ovary showing the developmental stages of an ovarian follicle.**

his interstitial cells to produce testosterone) results in a decrease in the size and function of his reproductive organs, as well as a decrease in his sex drive. **Sterility** also occurs because testosterone is necessary for the final stages of sperm production.

DID YOU GET IT?

7. Which pituitary hormone stimulates spermatogenesis?
8. How does the final product of meiosis differ from the final product of mitosis?
9. How are nonmotile spermatids converted to functional sperm?
10. Which pituitary hormone prompts testosterone production?

For answers, see Appendix D.

Anatomy of the Female Reproductive System

- ✓ When provided with an appropriate model or diagram, identify the organs of the female reproductive system, and discuss the general function of each.
- ✓ Describe the functions of the vesicular follicle and corpus luteum of the ovary.
- ✓ Define *endometrium, myometrium,* and *ovulation.*
- ✓ Indicate the location of the following regions of the female uterus: cervix, fundus, body.

The reproductive role of the female is much more complex than that of the male. Not only must she produce the female gametes (ova), but her body must also nurture and protect a developing fetus during 9 months of pregnancy. **Ovaries** are the primary female reproductive organs. Like the testes, ovaries produce both an exocrine product (eggs, or *ova*) and endocrine products (estrogens and progesterone). The other organs of the female reproductive system serve as accessory structures to transport, nurture, or otherwise serve the needs of the reproductive cells and/or the developing fetus.

Ovaries

The paired *ovaries* (o′ vah-rēz) are pretty much the shape of almonds but are nearly twice as large. An internal view of an ovary reveals many tiny saclike structures called **ovarian follicles** (Figure 16.7). Each follicle consists of an immature egg, called an **oocyte** (o′o-sīt; *oo* = egg), surrounded by one or more layers of very different cells called

follicle cells. As a developing egg within a follicle begins to ripen or mature, the follicle enlarges and develops a fluid-filled central region called an *antrum.* At this stage, the follicle, called a **vesicular,** or **Graafian** (graf′e-an), **follicle,** is mature, and the developing egg is ready to be ejected from the ovary, an event called **ovulation.** After ovulation, the ruptured follicle is transformed into a very different-looking structure called a **corpus luteum** (kor′pus lu′te-um; "yellow body"), which eventually degenerates. Ovulation generally occurs every 28 days, but it can occur more or less frequently in some women. In older women, the surfaces of the ovaries are scarred and pitted, which attests to the fact that many eggs have been released.

The ovaries are secured to the lateral walls of the pelvis by the **suspensory ligaments.** They flank the uterus laterally and anchor to it medially by the **ovarian ligaments** (Figure 16.8). In between, they are enclosed and held in place by a fold of peritoneum, the **broad ligament.**

Duct System

The *uterine tubes, uterus,* and *vagina* form the duct system of the female reproductive tract (see Figure 16.8).

Uterine (Fallopian) Tubes

The **uterine** (u′ter-in), or **fallopian** (fal-lo′pe-an), **tubes** form the initial part of the duct system. They receive the ovulated oocyte and provide a site where fertilization can occur. Each of the uterine tubes is about 10 cm (4 inches) long and extends medially from an ovary to empty into the superior region of the uterus. Like the ovaries, the uterine tubes are enclosed and supported by the broad ligament.

Unlike in the male duct system, which is continuous with the tubule system of the testes, there is little or no actual contact between the uterine tubes and the ovaries. The distal end of each uterine tube expands as the funnel-shaped *infundibulum,* which has fingerlike projections called **fimbriae** (fim′bre-e) that partially surround the ovary. As an oocyte is expelled from an ovary during ovulation, the waving fimbriae create fluid currents that act to carry the oocyte into the uterine tube, where it begins its journey toward the uterus. (Many potential eggs, however, are lost in the peritoneal cavity.) The oocyte is carried toward the uterus by a combination of peristalsis and the rhythmic beating of *cilia.*

Because the journey to the uterus takes 3 to 4 days and the oocyte is viable for up to 24 hours after ovulation, the usual site of fertilization is the uterine tube. To reach the oocyte, the sperm must swim upward through the vagina and uterus to reach the uterine tubes. Because they must swim against the downward current created by the cilia, it is rather like swimming against the tide!

HOMEOSTATIC IMBALANCE

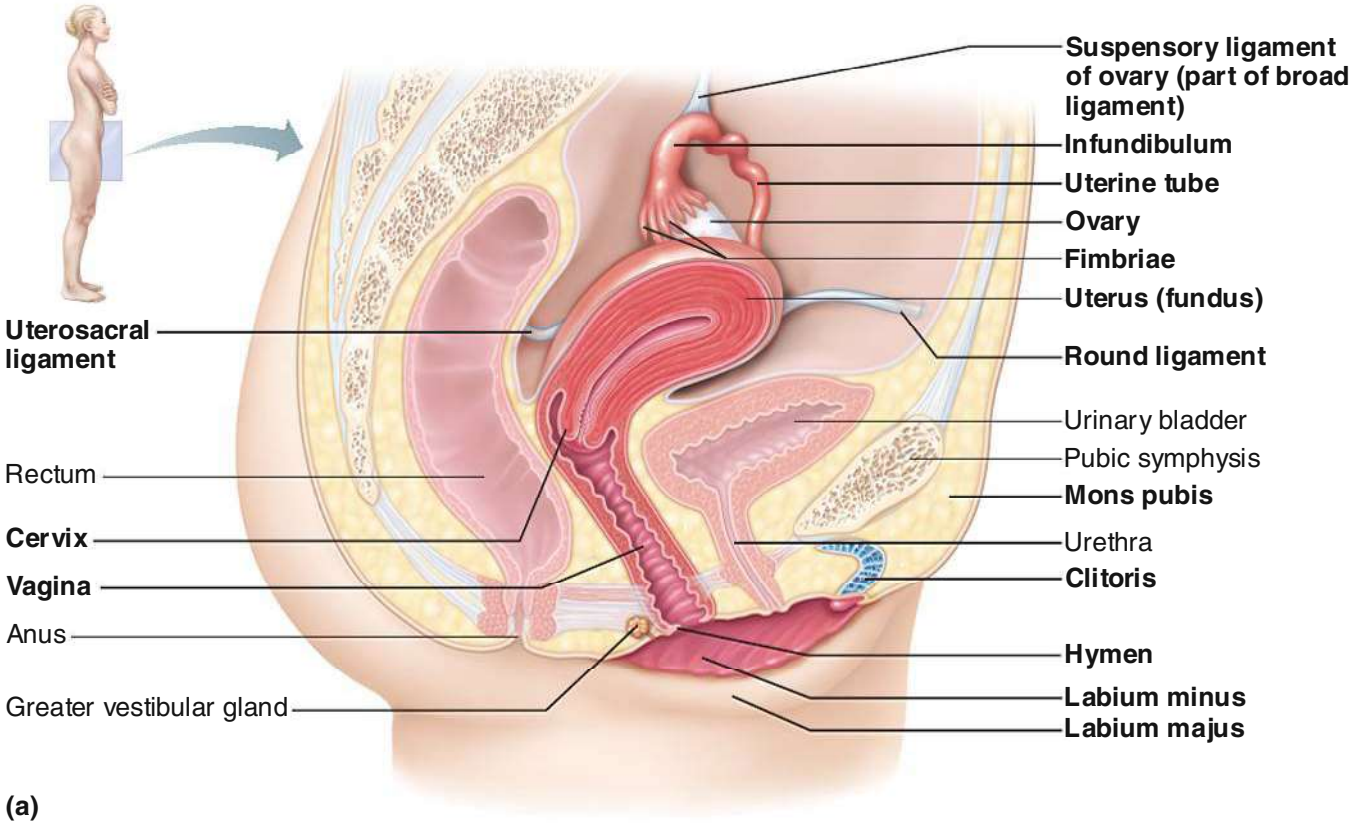
The fact that the uterine tubes are not continuous distally with the ovaries places women at risk for infections spreading into the peritoneal cavity from the reproductive tract. **Gonorrhea** (gon″o-re′ah) and other sexually transmitted bacteria sometimes infect the peritoneal cavity in this way, causing an extremely severe inflammation called **pelvic inflammatory disease (PID).** Unless treated promptly, PID can cause scarring and closure of the narrow uterine tubes, which is one of the major causes of female infertility.

Uterus

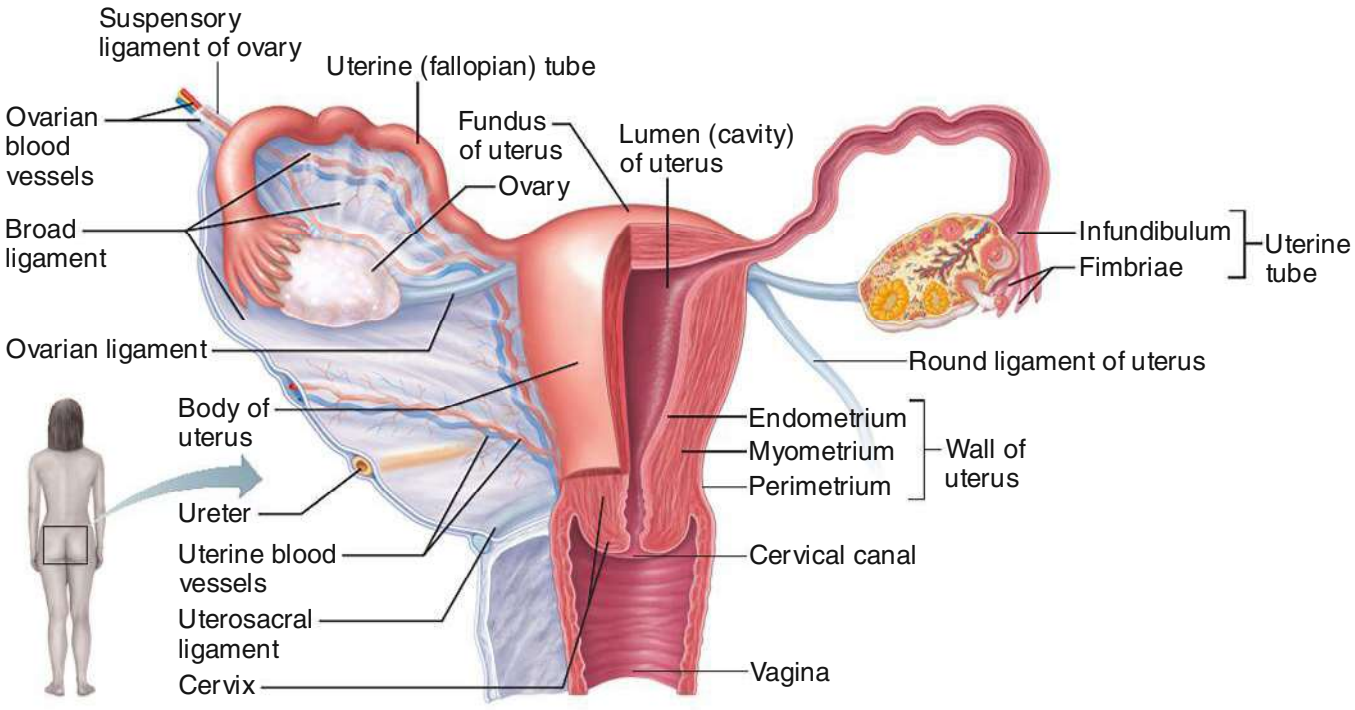
The **uterus** (u′ter-us; "womb"), located in the pelvis between the urinary bladder and rectum, is a hollow organ that functions to receive, retain, and nourish a fertilized egg. In a woman who has never been pregnant, it is about the size and shape of a pear. (During pregnancy, the uterus increases tremendously in size and can be felt well above the umbilicus during the latter part of pregnancy.) The uterus is suspended in the pelvis by the broad ligament and anchored anteriorly and posteriorly by the **round** and **uterosacral ligaments,** respectively (see Figure 16.8).

The major portion of the uterus is referred to as the **body.** Its superior rounded region above the entrance of the uterine tubes is the **fundus,** and its narrow outlet, which protrudes into the vagina below, is the **cervix.**

The wall of the uterus is thick and composed of three layers. The inner layer or mucosa is the **endometrium** (en-do-me′tre-um). If fertilization occurs, the fertilized egg (actually the young embryo by the time it reaches the uterus) burrows into the endometrium (in a process called **implantation**) and resides there for the rest of its development. When a woman is not pregnant, the



(a)



(b)

Figure 16.8 **The human female reproductive organs.** **(a)** Sagittal section. (The plurals of *labium minus* and *majus* are *labia minora* and *majora,* respectively.) **(b)** Posterior view. The posterior organ walls have been removed on the right side to reveal the shape of the lumen of the uterine tube, uterus, and vagina.

endometrial lining sloughs off periodically, usually about every 28 days, in response to changes in the levels of ovarian hormones in the blood. We discuss this process, called menstruation or *menses,* on pp. 554–556.

HOMEOSTATIC IMBALANCE

Cancer of the cervix is common among women between the ages of 30 and 50. Risk factors include frequent cervical inflammation, sexually transmitted diseases, multiple pregnancies, and many sexual partners. A yearly *Pap smear* is the single most important diagnostic test for detecting this slow-growing cancer. When results are inconclusive, a test for the sexually transmitted human papillomavirus (HPV), the cause of most cervical cancer, can be done from the same Pap sample or from a blood sample.

Gardasil, a three-dose vaccine that provides protection from HPV-induced cervical cancer, is the latest addition to the official childhood immunization schedule. It is recommended for all 11- and 12-year-old girls. In unexposed girls, the vaccine specifically blocks two cancer-causing kinds of HPV as well as two additional types which are not associated with cervical cancer. Whether or not this vaccine will become a requirement for school is presently decided on a state-to-state basis.

The **myometrium** (mi-o-me′tre-um), composed of interlacing bundles of smooth muscle, is the bulky middle layer of the uterus (see Figure 16.8b). The myometrium plays an active role during the delivery of a baby, when it contracts rhythmically to force the baby out of the mother's body. The outermost serous layer of the uterus is the **perimetrium** (per-ĭ-me′tre-um), or the visceral peritoneum.

Vagina

The **vagina** (vah-ji′nah) is a thin-walled tube 8 to 10 cm (3 to 4 inches) long. It lies between the bladder and rectum and extends from the cervix to the body exterior (see Figure 16.8). Often called the *birth canal,* the vagina provides a passageway for the delivery of an infant and for the menstrual flow to leave the body. Because it receives the penis (and semen) during sexual intercourse, it is the female organ of copulation.

The distal end of the vagina is partially closed by a thin fold of the mucosa called the **hymen** (hi′men). The hymen is very vascular and tends to bleed when it is ruptured during the first sexual intercourse. However, its durability varies. In some women, it is torn during a sports activity, tampon insertion, or pelvic examination. Occasionally, it is so tough that it must be ruptured surgically if intercourse is to occur.

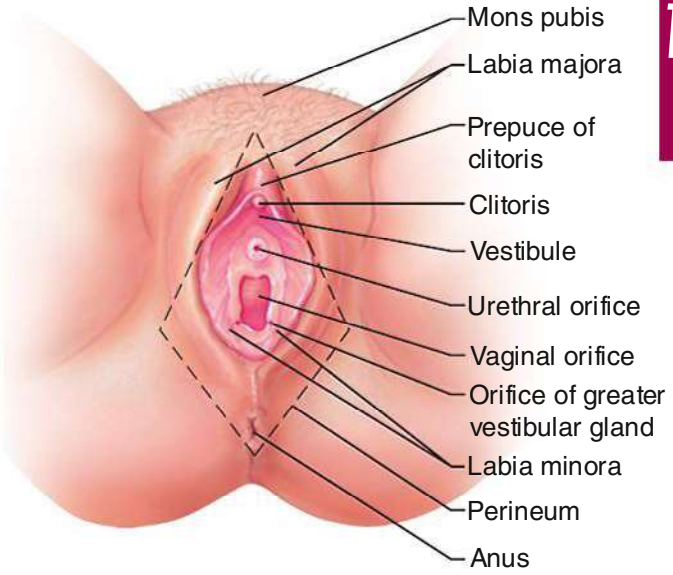


Figure 16.9 **External genitalia of the human female.**

External Genitalia and Female Perineum

The female reproductive structures that are located external to the vagina are the **external genitalia** (Figure 16.9). The external genitalia, also called the **vulva,** include the *mons pubis, labia, clitoris, urethral* and *vaginal orifices,* and *greater vestibular glands.*

The **mons pubis** ("mountain on the pubis") is a fatty, rounded area overlying the pubic symphysis. After puberty, this area is covered with pubic hair. Running posteriorly from the mons pubis are two elongated hair-covered skin folds, the **labia majora** (la′be-ah ma-jo′ra), which enclose two delicate, hair-free folds, the **labia minora.** The labia majora enclose a region called the **vestibule,** which contains the external openings of the urethra,* followed posteriorly by that of the

*The male urethra carries both urine and semen, but the female urethra has no reproductive function—it is strictly a passageway for urine.

vagina. A pair of mucus-producing glands, the **greater vestibular glands,** flank the vagina, one on each side (see Figure 16.8a). Their secretion lubricates the distal end of the vagina during intercourse.

Just anterior to the vestibule is the **clitoris** (kli′to-ris; "hill"), a small, protruding structure that corresponds to the male penis. Like the penis, it is hooded by a prepuce and is composed of sensitive erectile tissue that becomes swollen with blood during sexual excitement. The clitoris differs from the penis in that it lacks a reproductive duct. The diamond-shaped region between the anterior end of the labial folds, the anus posteriorly, and the ischial tuberosities laterally is the **perineum** (per″ĭ-ne′um).

DID YOU GET IT?

11. What is the exocrine product of the ovary?

12. Which organ of the female duct system serves as an "incubator" for fetal development? What is the most common site of fertilization?

13. What name is given to an ovarian follicle that is ready or nearly ready to ovulate?

For answers, see Appendix D.

Female Reproductive Functions and Cycles

As described earlier, sperm production begins at puberty and generally continues throughout life. The situation is quite different in women. Traditionally, it has been assumed that the total supply of eggs that a female can release is already determined by the time she is born. In addition, a female's reproductive ability (that is, her ability to release eggs) usually begins during puberty and ends in her fifties or before. The period in which a woman's reproductive capability gradually declines and then finally ends is called *menopause* (see pp. 569 and 572).

Oogenesis and the Ovarian Cycle

- ✓ Define *oogenesis.*
- ✓ Describe the influence of FSH and LH on ovarian function.

Meiosis, the special kind of cell division that occurs in the testes to produce sperm, also occurs in the ovaries. But in this case, ova or female gametes are produced, and the process is called **oogenesis** (o″o-jen′ĕ-sis; "the beginning of an egg"). This process is shown in **Figure 16.10** and described in more detail next.

In the developing female fetus, **oogonia** (o″o-go′ne-ah), the female stem cells, multiply rapidly to increase their number, and then their daughter cells, **primary oocytes,** push into the ovary connective tissue, where they become surrounded by a single layer of cells to form the *primary follicles.* By birth, the oogonia no longer exist,* and a female's lifetime supply of primary oocytes (approximately 2 million of them) is already in place in the ovarian follicles, awaiting the chance to undergo meiosis to produce functional eggs. Because the primary oocytes remain in this state of suspended animation all through childhood, their wait is a long one—10 to 14 years at the very least.

At puberty, the anterior pituitary gland begins to release *follicle-stimulating hormone (FSH),* which stimulates a small number of primary follicles to grow and mature each month, and ovulation begins to occur each month. These cyclic changes that occur monthly in the ovary constitute the **ovarian cycle.** At puberty, perhaps 250,000 oocytes remain; and, beginning at this time, a small number of oocytes are activated each month. The reproductive life of a female is at best about 40 years (from the age of 11 to approximately 51), and there is typically only one ovulation per month; therefore, fewer than 500 ova out of her potential of 250,000 are released during a woman's lifetime. Again, nature has provided us with a generous oversupply of sex cells.

As a follicle prodded by FSH grows larger, it accumulates fluid in the central chamber called the *antrum* (see Figure 16.7), and the primary oocyte it contains replicates its chromosomes and begins meiosis. The first meiotic division produces two cells that are very dissimilar in size (see Figure 16.10). The larger cell is a **secondary oocyte** and the other, very tiny cell is a **polar body.** By the time a follicle has ripened to the mature (*vesicular follicle*) stage, it contains a secondary oocyte and protrudes like an angry boil from the external

*A recent study in mice indicated that germ stem cells are alive and exist in adult females. However, more studies are needed to overturn the "no new eggs" theory.

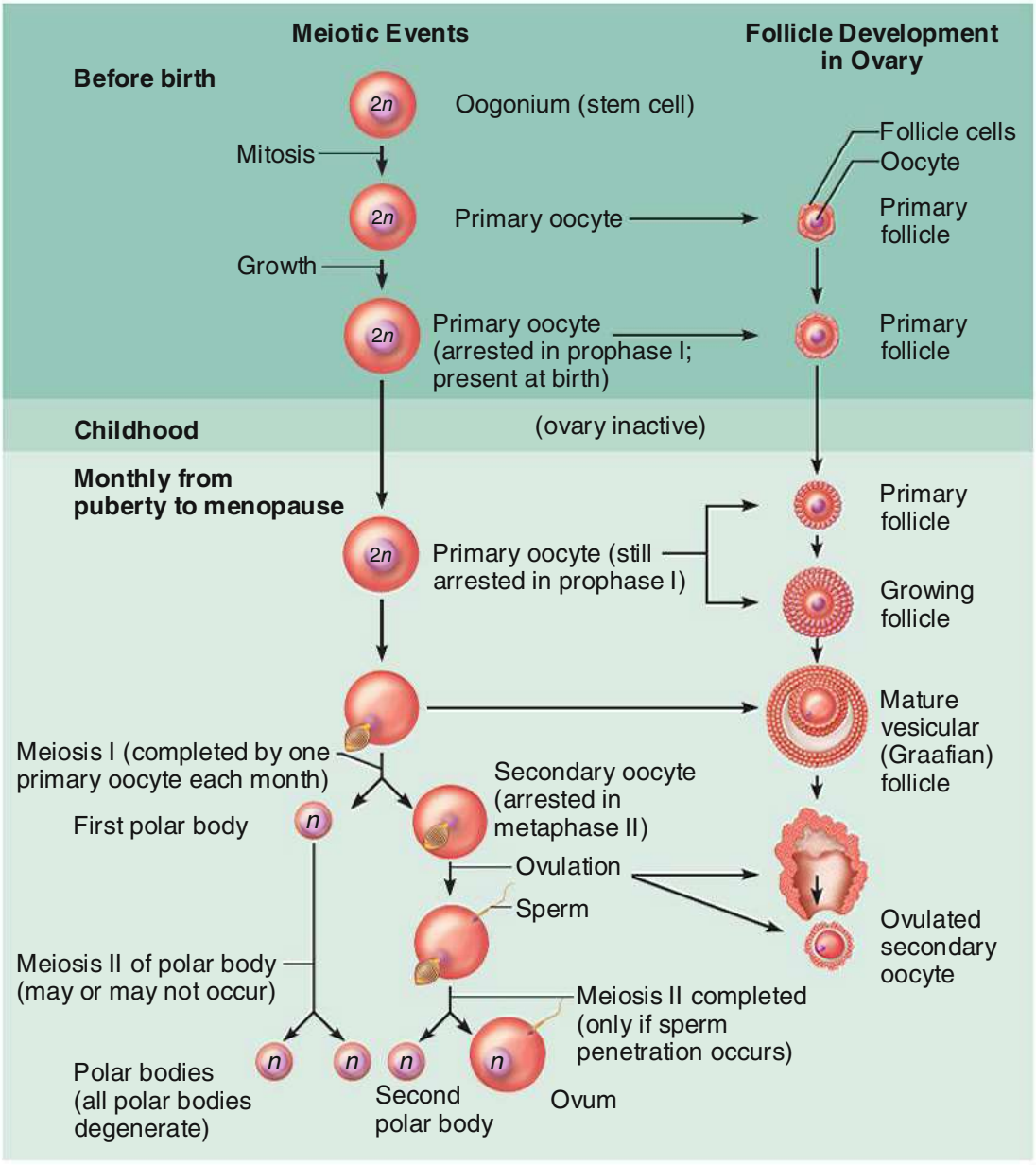


Figure 16.10 **Events of oogenesis.** Left, flowchart of meiotic events. Right, correlation with follicular development and ovulation in the ovary.

surface of the ovary. Follicle development to this stage takes about 14 days, and ovulation (of a secondary oocyte) occurs at just about that time in response to the burstlike release of a second anterior pituitary hormone, *luteinizing hormone (LH)*. As shown in **Figure 16.11** and Figures 16.7 and 16.10, the ovulated secondary oocyte is still surrounded by its follicle-cell capsule, now called the *corona radiata* ("radiating crown").

Some women experience a twinge of abdominal pain in the lower abdomen when ovulation occurs. This phenomenon, called *mittelschmerz* (mit′el-shmārts; German for "middle pain"), is caused by the intense stretching of the ovarian wall during ovulation.

Generally speaking, one of the developing follicles outstrips the others each month to become the dominant follicle. Just how this follicle is selected or selects itself is not understood, but the follicle that is at the proper stage of maturity when the LH stimulus occurs ruptures and releases its oocyte into the peritoneal cavity. The mature follicles

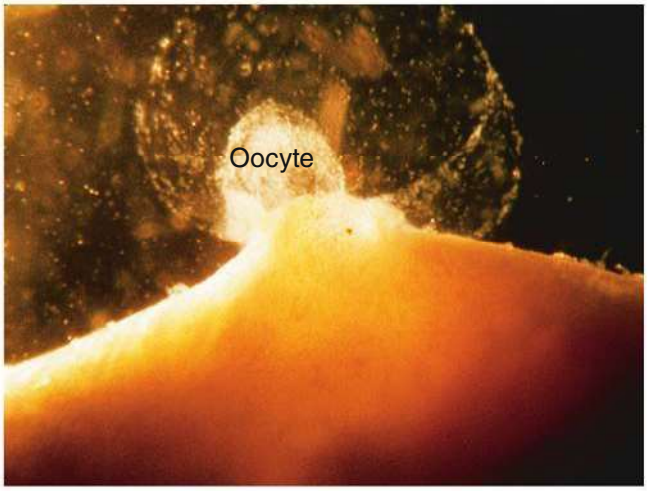


Figure 16.11 **Ovulation.** A secondary oocyte is released from a follicle at the surface of the ovary. The orange mass below the ejected oocyte is part of the ovary. The "halo" of follicle cells around the secondary oocyte is the *corona radiata*.

that are not ovulated soon become overripe and deteriorate. In addition to triggering ovulation, LH also causes the ruptured follicle to change into a very different glandular structure, the *corpus luteum*. (Both the maturing follicles and the corpus luteum produce hormones, as we will describe later.)

If the ovulated secondary oocyte is penetrated by a sperm in one of the uterine tubes, the oocyte undergoes the second meiotic division that produces another polar body and the **ovum.** Once the ovum is formed, its 23 chromosomes are combined with those of the sperm to form the fertilized egg, which is the first cell of the yet-to-be offspring. However, if the secondary oocyte is not penetrated by a sperm, it simply deteriorates without ever completing meiosis to form a functional egg. Although meiosis in males results in four functional sperm, meiosis in females yields only one functional ovum and three tiny polar bodies. The polar bodies have essentially no cytoplasm, so they deteriorate and die quickly.

Another major difference between men and women concerns the size and structure of their sex cells. Sperm are tiny and equipped with tails for locomotion. They have little nutrient-containing cytoplasm; thus, the nutrients in seminal fluid are vital to their survival. In contrast, the egg is a large, nonmotile cell, well stocked with nutrient reserves that nourish the developing embryo until it can take up residence in the uterus.

DID YOU GET IT?

14. Besides the one functional gamete (ovum), what other cell types are produced during oogenesis, and what happens to them?

15. Which anterior pituitary hormone promotes follicle development in the ovary?

16. Which anterior pituitary hormone causes ovulation?

For answers, see Appendix D.

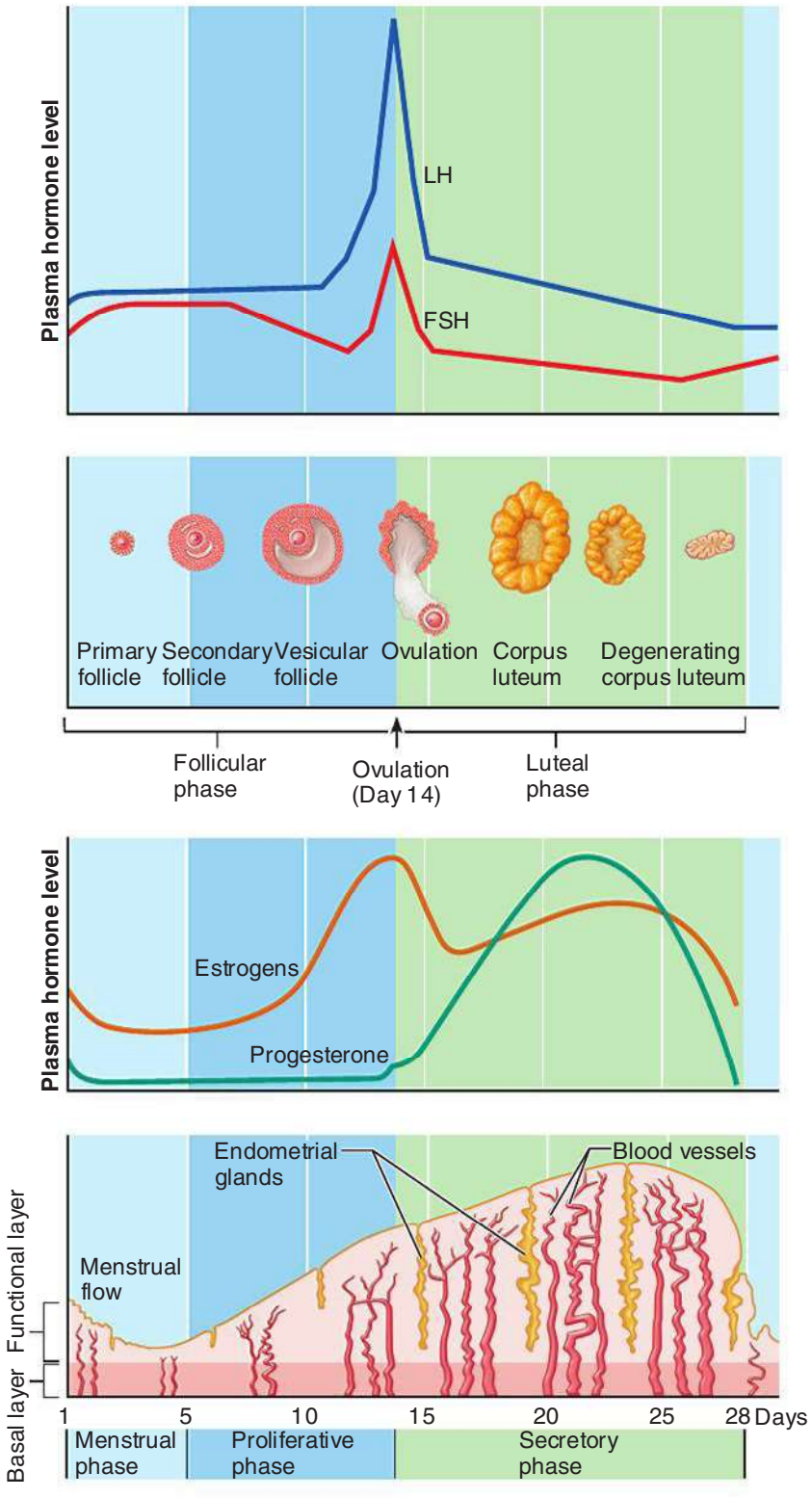
Uterine (Menstrual) Cycle

✓ Describe the phases and controls of the menstrual cycle.

Although the young embryo implants and develops in the uterus, this organ is receptive to implantation only for a very short period each month. Not surprisingly, this brief interval coincides exactly with the time when a fertilized egg would begin to implant, approximately 7 days after ovulation. The events of the **uterine,** or **menstrual, cycle** are the cyclic changes that the endometrium, or mucosa of the uterus, goes through month after month as it responds to changes in the levels of ovarian hormones in the blood.

The cyclic production of estrogens and progesterone by the ovaries is, in turn, regulated by the anterior pituitary gonadotropic hormones, FSH and LH. It is important to understand how these "hormonal pieces" fit together. Generally speaking, both female cycles (the ovarian and the uterine cycles) are about 28 days long (a period commonly called a *lunar month*). Ovulation typically occurs midway in the cycles, on or about day 14. **Figure 16.12** illustrates the events occurring both in the ovary (the ovarian cycle) and in the uterus (menstrual cycle) at the same time. We describe the three stages of the menstrual cycle next.

- **Days 1–5: Menstrual phase.** During this interval, the superficial *functional layer* of the thick endometrial lining of the uterus is sloughing off (detaching) from the uterine wall. This is accompanied by bleeding for 3 to 5 days. The detached tissues and blood pass through the vagina as the menstrual flow. The average blood loss during this period is 50 to 150 ml (or about ¼ to ½ cup). By day 5, growing ovarian follicles are beginning to produce more estrogen.



(a) Fluctuation of gonadotropin levels: Fluctuating levels of pituitary gonadotropins (FSH and LH) in the blood regulate the events of the ovarian cycle.

(b) Ovarian cycle: Structural changes in the ovarian follicles during the ovarian cycle are correlated with (d) changes in the endometrium of the uterus during the uterine cycle.

(c) Fluctuation of ovarian hormone levels: Fluctuating levels of ovarian hormones (estrogens and progesterone) cause the endometrial changes of the uterine cycle. The high estrogen levels are also responsible for the LH/FSH surge in (a).

(d) The three phases of the uterine cycle:

- Menstrual: Shedding of the functional layer of the endometrium.
- Proliferative: Rebuilding of the functional layer of the endometrium.
- Secretory: Begins immediately after ovulation. Enrichment of the blood supply and glandular secretion of nutrients prepare the endometrium to receive an embryo.

The menstrual and proliferative phases occur before ovulation, and together correspond to the follicular phase of the ovarian cycle. The secretory phase corresponds in time to the luteal phase of the ovarian cycle.

Figure 16.12 Hormonal interactions of the female cycles.
Relative levels of anterior pituitary gonadotropins correlated with hormonal and follicular changes of the ovary and with the menstrual cycle.

- **Days 6–14: Proliferative phase.** Stimulated by rising estrogen levels produced by the growing follicles of the ovaries, the basal layer of the endometrium regenerates the functional layer, glands form in it, and the endometrial blood supply increases. The endometrium once again becomes velvety, thick, and well vascularized. (Ovulation occurs in the ovary at the end of this stage, in response to the sudden surge of LH in the blood.)
- **Days 15–28: Secretory phase.** Rising levels of progesterone production by the corpus luteum of the ovary act on the estrogen-primed endometrium and increase its blood supply even more. Progesterone also causes the endometrial glands to increase in size and to begin secreting nutrients into the uterine cavity. These nutrients will sustain a developing embryo (if one is present) until it has implanted. If fertilization does occur, the embryo produces a hormone very similar to LH that causes the corpus luteum to continue producing its hormones.

  If fertilization does not occur, the corpus luteum begins to degenerate toward the end of this period as LH blood levels decline. Lack of ovarian hormones in the blood causes the blood vessels supplying the functional layer of the endometrium to go into spasms and kink. When deprived of oxygen and nutrients, those endometrial cells begin to die, which sets the stage for menses to begin again on day 28.

Although this explanation assumes a classic 28-day cycle, the length of the menstrual cycle is quite variable. It can be as short as 21 days or as long as 40 days. Only one interval is fairly constant in all females; the time from ovulation to the beginning of menses is almost always 14 or 15 days.

Hormone Production by the Ovaries

As the ovaries become active at puberty and start to produce ova, they also begin to produce ovarian hormones. The follicle cells of the growing and mature follicles produce **estrogens,*** which cause the appearance of the *secondary sex characteristics* in the young woman. Such changes include the following:

- Enlargement of the accessory organs of the female reproductive system (uterine tubes, uterus, vagina, external genitals)
- Development of the breasts
- Appearance of axillary and pubic hair
- Increased deposits of fat beneath the skin in general, and particularly in the hips and breasts
- Widening and lightening of the pelvis
- Onset of menses, or the menstrual cycle

Beyond its promotion of secondary sex characteristics, estrogen also has metabolic effects. For example, it helps maintain low total blood cholesterol levels (and high HDL levels) and facilitates calcium uptake, which sustains bone density.

The second ovarian hormone, **progesterone,** is produced by the glandular *corpus luteum* (see Figure 16.7). As mentioned earlier, after ovulation occurs the ruptured follicle is converted to the corpus luteum, which looks and acts completely different from the growing and mature follicle. Once formed, the corpus luteum produces progesterone (and some estrogen) as long as LH is still present in the blood. Generally speaking, the corpus luteum stops producing hormones by 10 to 14 days after ovulation. Except for working with estrogen to establish the menstrual cycle, progesterone does not contribute to the appearance of the secondary sex characteristics. Its other major effects are exerted during pregnancy, when it helps maintain the pregnancy by inhibiting contraction of the myometrium of the uterus, and helps prepare the breasts for milk production. (However, the source of progesterone during pregnancy is the placenta, not the ovaries.)

Mammary Glands

✓ Describe the structure and function of the mammary glands.

The **mammary glands** are present in both sexes, but they normally function only in women. Because the biological role of the mammary glands is to produce milk to nourish a newborn baby, they are actually important only when reproduction has already been accomplished. Stimulation by female sex hormones, especially estrogens, causes the female mammary glands to increase in size at puberty.

*Although the ovaries produce several different estrogens, the most important are *estradiol*, *estrone*, and *estriol*. Of these, estradiol is the most abundant and is most responsible for estrogenic effects.