Color enhanced scanning electron micrograph of the ciliated epithelial surface of a uterine tubule.

Reproductive System

CHAPTER 28

Without the reproductive system, the human species could not survive. However, this system, unlike other organ systems, is not necessary for the survival of individual humans. The reproductive system controls the development of the structural and functional differences between males and females, and it influences human behavior. Most organ systems of the body show little difference between males and females. This isn't the case with the reproductive systems. The male reproductive system produces sperm cells and can transfer them to the female. The female reproductive system produces oocytes and can receive sperm cells, one of which may unite with an oocyte. The female reproductive system is then intimately involved with nurturing the development of a new individual until birth and usually for some considerable time after birth.

Although the male and female reproductive systems show such striking differences, they also share a number of similarities. Many reproductive organs of males and females are derived from the same embryologic structures (see chapter 29). In addition, some hormones are the same in males and females, even though they act in very different ways (table 28.1).

This chapter discusses the *anatomy of the male reproductive system* (1017), the *physiology of male reproduction* (1028), the *anatomy of the female reproductive system* (1032), the *physiology of female reproduction* (1040), and the *effects of aging on the reproductive system* (1051).

Table 28.1 Major Reproductive Hormones

Hormone	Source	Target Tissue	Response
Males			
Gonadotropin-releasing hormone (GnRH)	Hypothalamus	Anterior pituitary	Stimulates secretion of LH and FSH
Luteinizing hormone (LH) (also called interstitial cell-stimulating hormone [ICSH] in males)	Anterior pituitary	Interstitial cells in the testes	Stimulates synthesis and secretion of testosterone
Follicle-stimulating hormone (FSH)	Anterior pituitary	Seminiferous tubules (sustentacular cells)	Supports spermatogenesis
Testosterone	Leydig cells in the testes	Testes and body tissues	Supports spermatogenesis, development and maintenance of reproductive organs and secondary sexual characteristics
		Anterior pituitary and hypothalamus	Inhibits GnRH, LH, and FSH secretion through negative feedback
Females			
Gonadotropin-releasing hormone (GnRH)	Hypothalamus	Anterior pituitary	Stimulates secretion of LH and FSH
Luteinizing hormone (LH)	Anterior pituitary	Ovaries	Causes follicles to complete maturation and undergo ovulation; causes the ovulated follicle to become the corpus luteum
Follicle-stimulating hormone (FSH)	Anterior pituitary	Ovaries	Causes follicles to begin development
Prolactin	Anterior pituitary	Mammary glands	Stimulates milk secretion following parturition
Estrogen	Follicles of ovaries	Uterus	Proliferation of endometrial cells
		Mammary glands	Development of the mammary glands (especially duct systems)
		Anterior pituitary and hypothalamus	Positive feedback before ovulation, resulting in increased LH and FSH secretion; negative feedback with progesterone on the hypothalamus and anterior pituitary after ovulation, resulting in decreased LH and FSH secretion
		Other tissues	Secondary sexual characteristics
Progesterone	Corpus luteum of ovaries	Uterus	Hypertrophy of endometrial cells and secretion of fluid from uterine glands
		Mammary glands	Development of the mammary glands (especially alveoli)
		Anterior pituitary	Negative feedback, with estrogen, on the hypothalamus and anterior pituitary after ovulation, resulting in decreased LH and FSH secretion
		Other tissues	Secondary sexual characteristics
Oxytocin*	Posterior pituitary	Uterus and mammary glands	Contraction of uterine smooth muscle during intercourse and childbirth; contraction of myoepithelial cells in the breast resulting in milk letdown in lactating women
Human chorionic gonadotropin (HCG)	Placenta	Corpus luteum of ovaries	Maintains the corpus luteum and increases its rate of progesterone secretion during the first one-third (first trimester) of pregnancy

*Covered in chapter 29.

Anatomy of the Male Reproductive System

Objectives

- ***Explain the structure and function of the scrotum and perineum.***
- ***Describe the structure of the testes and explain their descent.***

The male reproductive system consists of the testes (sing., testis), a series of ducts, accessory glands, and supporting structures. The ducts include the epididymides (sing., epididymis), ductus deferentia (sing., deferens; also vas deferens), and urethra. Accessory glands include the seminal vesicles, prostate gland, and bulbourethral glands. Supporting structures include the scrotum and penis (figure 28.1*a*).

Sperm cells are very temperature-sensitive and don't develop normally at usual body temperatures. The testes and epididymides, in which the sperm cells develop, are located outside the body

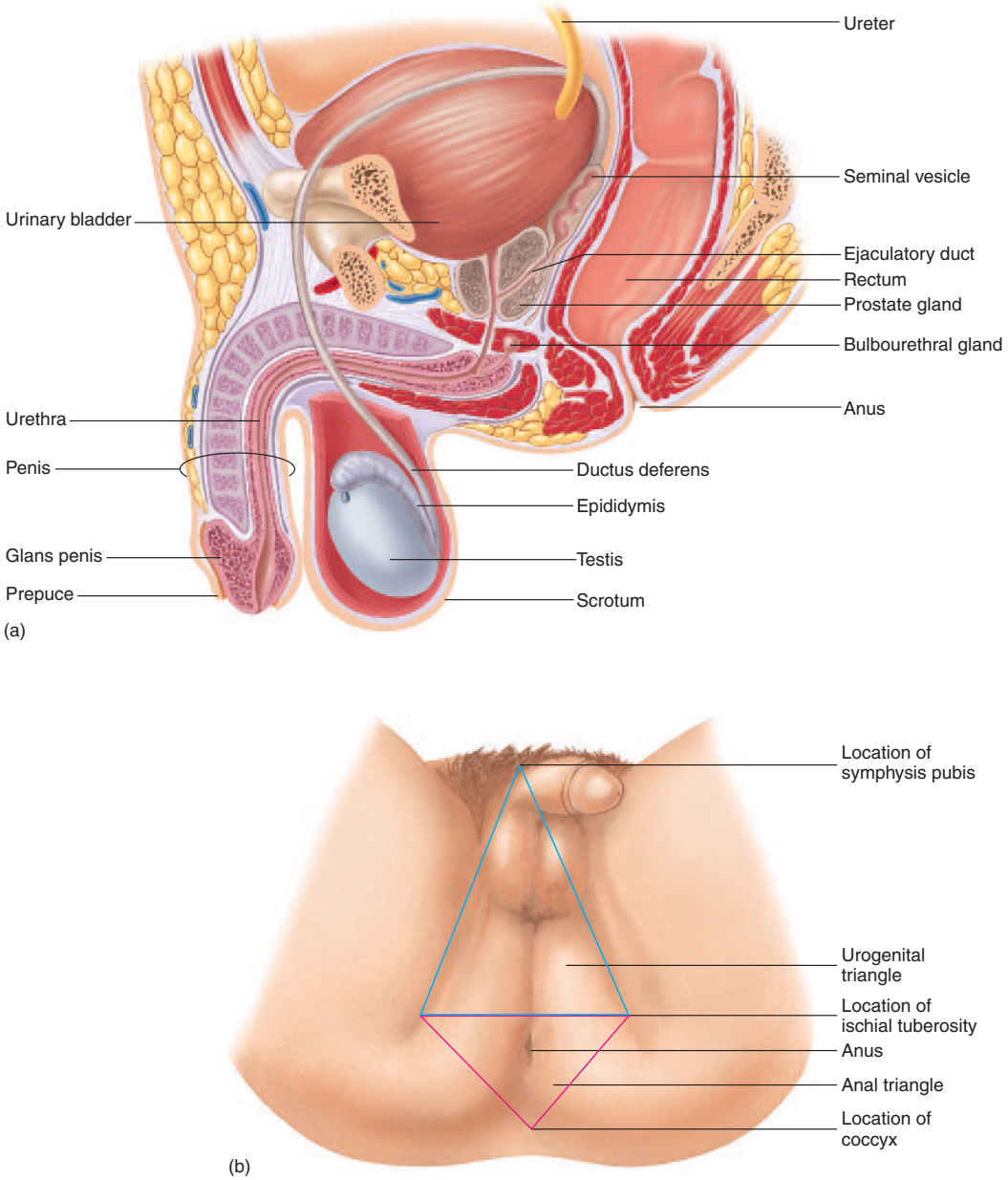


Figure 28.1 Male Pelvis

(*a*) Sagittal section of the male pelvis showing the male reproductive structures. (*b*) Inferior view of the male perineum.

cavity in the scrotum, where the temperature is lower. The ductus deferentia lead from the testes into the pelvis, where they join the ducts of the seminal vesicles to form the ampullae. Extensions of the ampullae, called the ejaculatory ducts, pass through the prostate and empty into the urethra within the prostate. The urethra, in turn, exits from the pelvis and passes through the penis to the outside of the body.

Scrotum

The **scrotum** (skrō′tŭm) contains the testes and is divided into two internal compartments by an incomplete connective tissue septum. Externally, the scrotum is marked in the midline by an irregular ridge, the **raphe** (rā′fē; a seam), which continues posteriorly to the anus and anteriorly onto the inferior surface of the penis. The outer layer of the scrotum includes the skin, a layer of superficial fascia consisting of loose connective tissue, and a layer of smooth muscle called the **dartos** (dar′tōs; to skin) **muscle.**

When the scrotum is exposed to cool temperatures, the dartos muscle contracts, causing the skin of the scrotum to become firm and wrinkled and reducing its overall size. At the same time, the **cremaster** (krē-mas′ter) **muscles** (see figure 28.5), which are extensions of abdominal muscles into the scrotum, contract and help pull the testes nearer the body, which helps keep the testes warm. When the scrotum is exposed to warm temperatures or becomes warm because of exercise, the dartos and cremaster muscles relax, and the skin of the scrotum becomes loose and thin, allowing the testes to descend away from the body, which helps keep the testes cool. The response of the dartos and cremaster muscles is important in the regulation of temperature in the testes. If the testes become too warm or too cold, normal sperm cell formation does not occur.

Perineum

The area between the thighs, which is bounded by the symphysis pubis anteriorly, the coccyx posteriorly, and the ischial tuberosities laterally, is called the **perineum** (per′i-nē′ŭm). The perineum is divided into two triangles by a set of muscles, the superficial transverse and deep transverse perineal muscles, that runs transversely between the two ischial tuberosities (see figure 10.19). The anterior, or **urogenital** (ū′rō-jen′i-tăl), **triangle,** contains the base of the penis and the scrotum. The smaller posterior, or **anal, triangle,** contains the anal opening (figure 28.1*b*).

Testes

Testicular Histology

The **testes** (tes′tēz) are small ovoid organs, each about 4–5 cm long, within the scrotum (see figure 28.1). They are both exocrine and endocrine glands. Sperm cells form a major part of the exocrine secretions of the testes, and testosterone is the major endocrine secretion of the testes.

The outer part of each testis is a thick, white capsule consisting of mostly fibrous connective tissue called the **tunica albuginea** (al-bū-jin′ē-ă; white). Connective tissue of the tunica albuginea enters the testis and forms incomplete **septa** (sep′tă; figure 28.2*a*). The septa divide each testis into about 300–400 cone-shaped **lobules.** The substance of the testis between the septa includes two types of tissue: **seminiferous** (sem′i-nif′er-ŭs; seed carriers) **tubules** in which sperm cells develop and a loose connective tissue stroma that surrounds the tubules and contains clusters of endocrine cells called **interstitial cells,** or **Leydig cells,** which secrete testosterone.

The combined length of the seminiferous tubules in both testes is nearly half a mile. The seminiferous tubules empty into a set of short, straight tubules, the **tubuli recti,** which in turn empty into a tubular network called the **rete** (rē′tē; net) **testis.** The rete testis empties into 15–20 tubules called **efferent ductules** (dŭk′tools). They have a ciliated pseudostratified columnar epithelium that helps move sperm cells out of the testis. The efferent ductules pierce the tunica albuginea to exit the testis.

Descent of the Testes

The testes develop as retroperitoneal organs in the abdominopelvic cavity, and each testis is connected to the scrotum by a **gubernaculum** (goo′ber-nak′ū-lŭm), a fibromuscular cord (figure 28.3*a*; see chapter 29). The testes move from the abdominal cavity through the **inguinal** (ing′gwi-năl) **canals** (figure 28.3*b*) to the scrotum (figure 28.3*c*). As they move into the scrotum, each testis is preceded by an outpocketing of the peritoneum called the **process vaginalis** (vaj′i-nă-lis). The superior part of each process vaginalis usually becomes obliterated, and the inferior part remains as a small, closed sac, the **tunica** (too′ni-kă) **vaginalis.** The tunica vaginalis surrounds most of the testis in much the same way that the pericardium surrounds the heart. The visceral layer of the tunica vaginalis covers the anterior surface of the testis, and the parietal layer lines the scrotum. The tunica vaginalis is a serous membrane consisting of a layer of simple squamous epithelium that rests on a basement membrane.

The inguinal canals are bilateral oblique passageways in the anterior abdominal wall. They originate at the **deep inguinal rings,** which open through the aponeuroses of the transversus abdominis muscles. The canals extend inferiorly and obliquely and end at the **superficial inguinal rings,** openings in the aponeuroses of the external abdominal oblique muscles. In females the inguinal canals do develop, but they are much smaller than in males and the ovaries do not descend through them.

Cryptorchidism (krip-tōr′ki-dizm) is failure of one or both of the testes to descend into the scrotum. The higher temperature of the abdominal cavity prevents normal sperm cell development and, if it involves both testes, results in no sperm cell production (see chapter 29, page 1078).

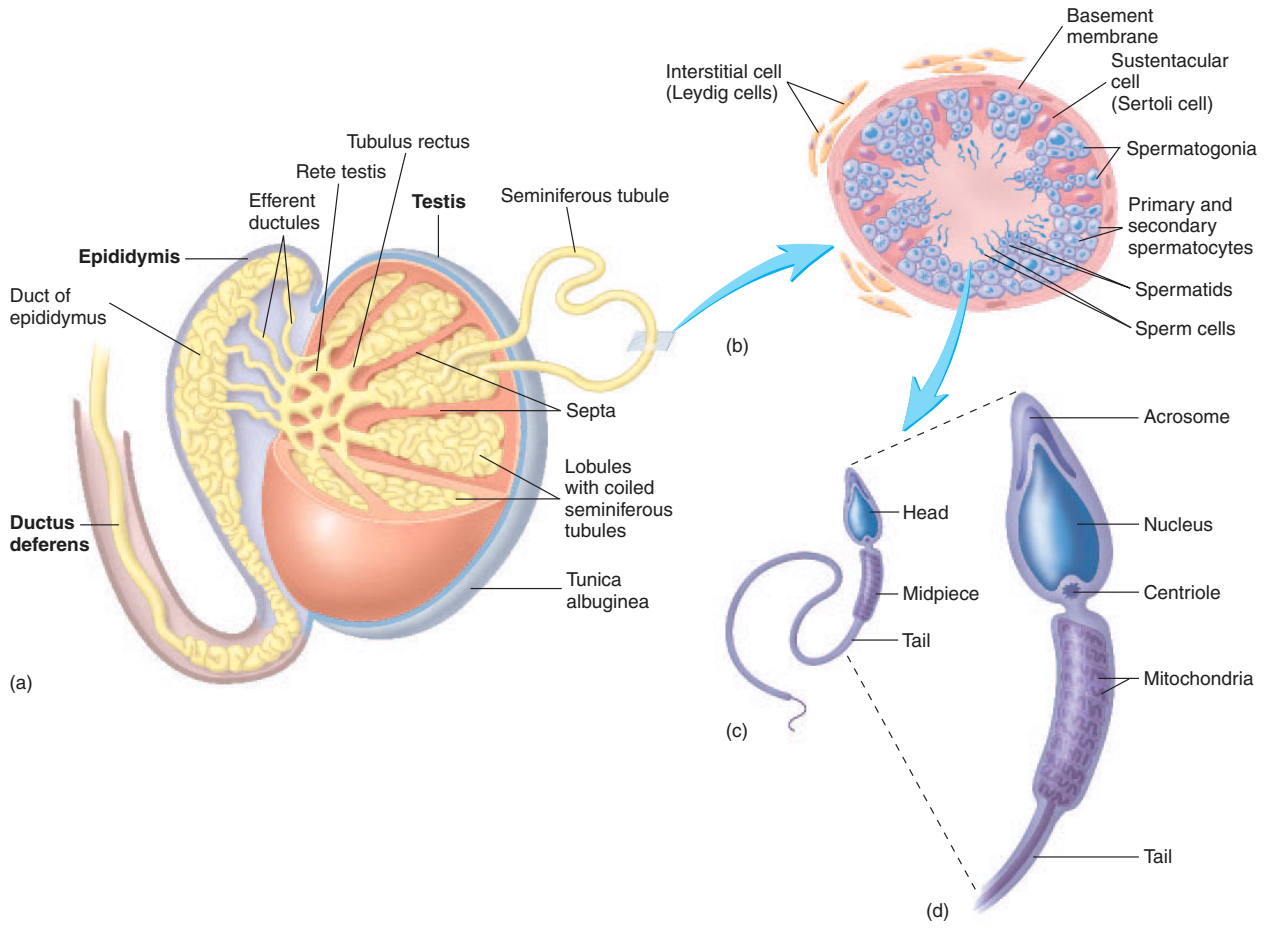


Figure 28.2 Histology of the Testis

(*a*) Gross anatomy of the testis with a section cut away to reveal internal structures. (*b*) Cross section of a seminiferous tubule. Spermatogonia are near the periphery, and mature sperm cells are near the lumen of the seminiferous tubule. (*c*) Mature sperm cell. (*d*) Head of a mature sperm cell.

Inguinal Hernia

Normally, the inguinal canals are closed, but they do represent weak spots in the abdominal wall. **Inguinal hernias** (ing′gwi-năl her′nē-ăz) are abnormal openings in the abdominal wall in the inguinal region through which structures such as a portion of the small intestine can protrude. If the deep inguinal ring remains open, or if it is weak and enlarges later in life, a loop of intestine can protrude into or even pass through the inguinal canal resulting in indirect inguinal hernia. A direct inguinal hernia results from a tear, or rupture, in a weakened area of the anterior abdominal wall near the inguinal canal, but not through the inguinal canal. These hernias can be quite painful and even very dangerous, especially if a portion of the small intestine is compressed so its blood supply is cut off. Fortunately, inguinal hernias can be repaired surgically. Males are much more prone to inguinal hernias than are females because a male's inguinal canals are larger and weakened because the testes pass through them on their way into the scrotum.

1. *What is the scrotum? Explain the function of the dartos and cremaster muscles.*
2. *Define the perineum. Describe the two triangles that make up the perineum.*
3. *Describe the covering and structure of a testis.*
4. *When and how do the testes descend into the scrotum? Describe the tunica vaginalis.*

Sperm Cell Development

Objective

- ***Describe the process of sperm cell development.***

Before puberty, the testes remain relatively simple and unchanged from the time of their initial development. The interstitial cells are not particularly prominent during this period, and the

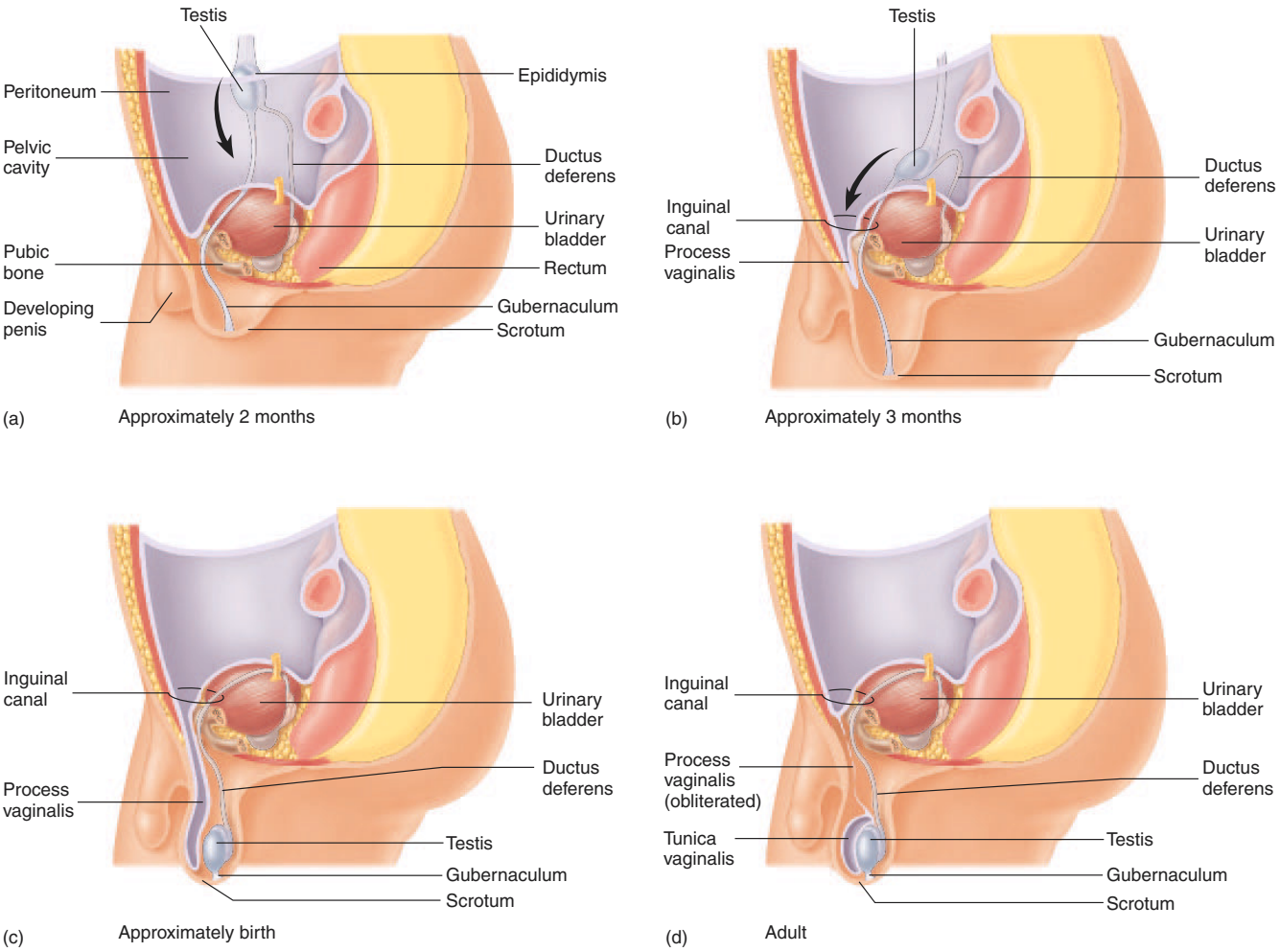


Figure 28.3 Descent of the Testes

(*a*) Testes form as retroperitoneal structures near the level of each kidney. (*b*) The testis descends toward the inguinal canal. (*c*) The testis descends into the scrotum. (*d*) The process vaginalis is obliterated and its inferior portion becomes the tunica vaginalis.

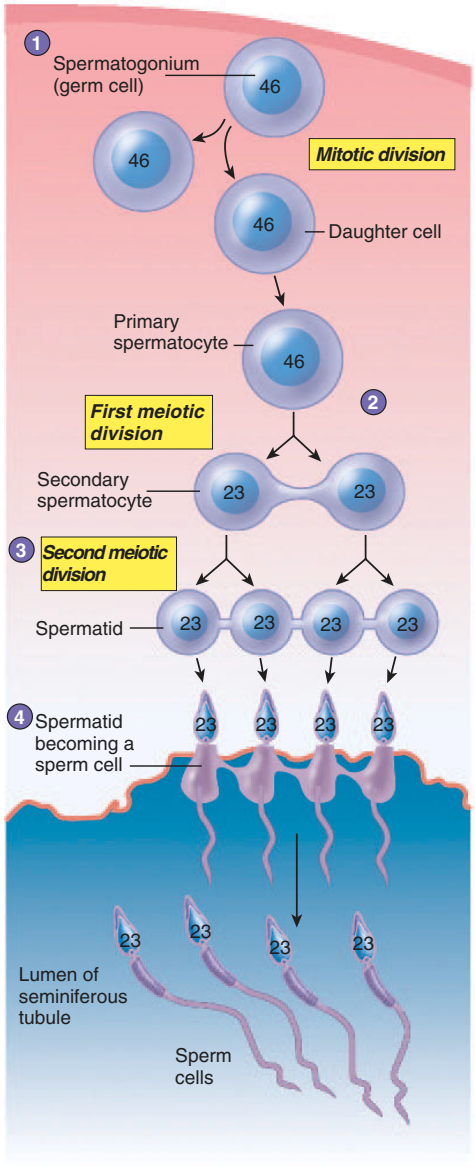
seminiferous tubules lack a lumen and are not yet functional. At 12–14 years of age, the interstitial cells increase in number and size, a lumen develops in each seminiferous tubule, and sperm cell production begins.

A cross section of a mature seminiferous tubule reveals the various stages of sperm cell development, a process called **spermatogenesis** (sper′mă-tō-jen′ĕ-sis; see figures 28.2*b* and 28.4*a*). The seminiferous tubules contain two types of cells, **germ cells** and **sustentacular** (sŭs-ten-tak′ū-lăr), or **Sertoli** (sēr-tō′lē; named for an Italian histologist) **cells.** The sustentacular cells are also sometimes referred to as **nurse cells.**

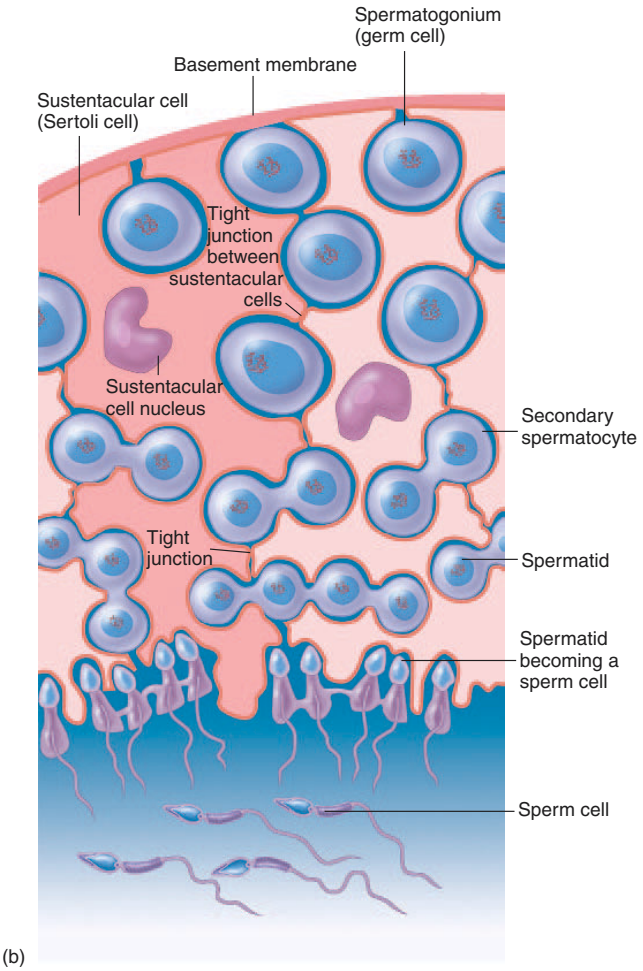
Sustentacular cells are large cells that extend from the periphery to the lumen of the seminiferous tubule. They nourish the germ cells and probably produce, together with the interstitial cells, a number of hormones, such as androgens, estrogens, and inhibins. In addition, tight junctions between the sustentacular cells form a **blood–testes barrier,** which isolates the sperm cells from the immune system (figure 28.4*b*). This barrier is necessary because, as the sperm cells develop, they form surface antigens that could stimulate an immune response, resulting in their destruction (see figure 28.4*b*).

Testosterone, produced by the interstitial cells, passes into the sustentacular cells and binds to receptors. The combination of testosterone with the receptors is required for the sustentacular cells to function normally. In addition, testosterone is converted to two other steroids in the sustentacular cells: **dihydrotestosterone** (dī-hī′drō-tes-tos′ter-ōn) and **estrogen** (es′trō-jen). The sustentacular cells also secrete a protein called **androgen-binding** (an′drō-jen) **protein** into the seminiferous tubules. Testosterone

1. Spermatogonia are the cells from which sperm cells arise. The spermatogonia divide by mitosis. One daughter cell remains a spermatogonium that can divide again by mitosis. One daughter cell becomes a primary spermatocyte.
2. The primary spermatocyte divides by meiosis to form secondary spermatocytes.
3. The secondary spermatocytes divide by meiosis to form spermatids.
4. The spermatids differentiate to form sperm cells.



(a)



(b)

Process Figure 28.4 Spermatogenesis

(*a*) Meiosis during spermatogenesis. A section of the seminiferous tubule illustrating the process of meiosis and sperm cell formation. (*b*) The tight junctions that form between adjacent sustentacular cells form the blood–testis barrier. Spermatogonia are peripheral to the blood–testis barrier, and spermatocytes are central to it.

and dihydrotestosterone bind to androgen-binding protein and are carried along with other secretions of the seminiferous tubules to the epididymis. Estradiol and dihydrotestosterone may be the active hormones that promote sperm cell formation.

Scattered between the sustentacular cells are smaller germ cells from which sperm cells are derived. The germ cells are arranged so that the most immature cells are at the periphery and the most mature cells are near the lumen of the seminiferous tubules. The most peripheral cells, those adjacent to the basement membrane of the seminiferous tubules, are **spermatogonia** (sper′mă-tō-gō′nē-ă), which divide by mitosis (see figure 28.4*a*). Some of the daughter cells produced from these mitotic divisions remain spermatogonia and continue to produce additional spermatogonia. The others divide through mitosis and differentiate to form **primary spermatocytes** (sper′mă-tō-sītz).

Meiosis (see Meiosis on next page or see chapter 3) begins when the primary spermatocytes divide. Each primary spermatocyte passes through the first meiotic division to become two

Clinical Focus Meiosis

Sperm cell development and oocyte development involve meiosis (mī-ō′sis; see chapter 3). This kind of cell division occurs only in the testes and ovaries. It consists of two consecutive nuclear divisions without a second replication of the genetic material between the divisions. Four daughter cells are produced, and each has half as many chromosomes as the parent cell (figure A).

The normal chromosome number in human cells is 46. This number is called a **diploid** (dip′loyd), or a **2*n*,** number of chromosomes. The chromosomes consist of 23 pairs, each of which is called a **homologous** (hŏ-mol′ō-gŭs) **pair.** One chromosome of each homologous pair is from the male parent, and the other is from the female parent. The chromosomes of each homologous pair look alike, and they contain genes for the same traits.

In sperm cells and oocytes, the number of chromosomes is 23. This number is called a **haploid** (hap′loyd), or ***n*,** number of chromosomes. Each gamete contains one chromosome from each of the homologous pairs. Reduction in the number of chromosomes in sperm cells or oocytes to an *n* number is important. When a sperm cell and an oocyte fuse to form a fertilized egg, each provides an *n* number of chromosomes, which reestablishes a 2*n* number of chromosomes. If meiosis did not take place, each time fertilization occurred the number of chromosomes in the fertilized oocyte would double. The extra chromosomal material would be lethal to the developing offspring.

The two divisions of meiosis are called **meiosis I** and **meiosis II.** The stages of meiosis have the same names as these stages in mitosis, that is, prophase, metaphase, anaphase, and telophase; but distinct differences exist between mitosis and meiosis.

Before meiosis begins, all the DNA in the chromosomes is duplicated. At the beginning of meiosis, each of the 46 chromosomes consists of two sister **chromatids** (krō′mă-tid) connected by a **centromere** (sen′trō-mēr; figure A). In prophase of meiosis I, the chromosomes become visible, and the homologous pairs of chromosomes come together. This process is called **synapsis** (si-nap′sis). Because each chromosome consists of two chromatids, the pairing of the homologous chromosomes brings two chromatids of each chromosome close together, an arrangement called a **tetrad.** Occasionally, part of a chromatid of one homologous chromosome breaks off and is exchanged with part of another chromatid from the other homologous chromosome of the tetrad. This exchange of genetic material is called **crossing-over** (see chapter 3). Crossing-over allows the exchange of genetic material between maternal and paternal chromosomes (figure A).

During metaphase, homologous pairs of chromosomes line up near the center of the cell. For each pair of homologous chromosomes, however, the side of the cell on which the maternal or paternal chromosome is located is random. The way the chromosomes align during synapsis results in the random assortment of maternal and paternal chromosomes in the daughter cells during meiosis. Crossing-over and the random assortment of maternal and paternal chromosomes are responsible for the large degree of diversity in the genetic composition of sperm cells and oocytes produced by each individual.

During anaphase I, the homologous pairs are separated to each side of the cell. During telophase I, new nuclei form and the cell completes division of form two cells. As a consequence, when meiosis I is complete, each daughter cell has one chromosome from each of the homologous pairs. Each of the 23 chromosomes in each daughter cell consists of two chromatids joined by a centromere.

It's during the first meiotic division that the chromosome number is reduced from a 2*n* number (46 chromosomes, or 23 pairs) to an *n* number (23 chromosomes, or one from each homologous pair). The first meiotic division is, therefore, called a **reduction division.**

The second meiotic division is similar to mitosis. The chromosomes, each consisting of two chromatids, line up near the middle of the cell (figure A). Then, the chro- matids separate at the centromere, and each daughter cell receives one of the chromatids from each chromosome. When the centromere separates, each of the chromatids is called a chromosome. Consequently, each of the four daughter cells produced by meiosis contains 23 chromosomes.

secondary spermatocytes. Each secondary spermatocyte undergoes a second meiotic division to produce two even smaller cells called **spermatids** (sper′mă-tidz). Each spermatid undergoes the last phase of spermatogenesis called **spermiogenesis** (sper′mē-ō-jen′ĕ-sis) to form a mature **sperm cell,** or **spermatozoon** (sper′mă-tō-zō′on; pl., spermatozoa, sper′mă-tō-zō′ă; see figures 28.2*c* and *d* and 28.4). Each spermatid develops a head, midpiece, and a tail, or flagellum. The head contains chromosomes, and at the leading end it has a cap, the **acrosome** (ak′rō-sōm), which contains enzymes necessary for the sperm cell to penetrate the female sex cell. The flagellum is similar to a cilium (see chapter 3), and movement of microtubules past one another within the tail causes the tail to move and propel the sperm cell forward. The midpiece has large numbers of mitochondria, which produce the ATP necessary for microtubule movement.

At the end of spermatogenesis, the developing sperm cells gather around the lumen of the seminiferous tubules with their heads directed toward the surrounding Sustentacular cells and their tails directed toward the center of the lumen (see figures 28.2*b* and 28.4). Finally, sperm cells are released into the lumen of the seminiferous tubules.

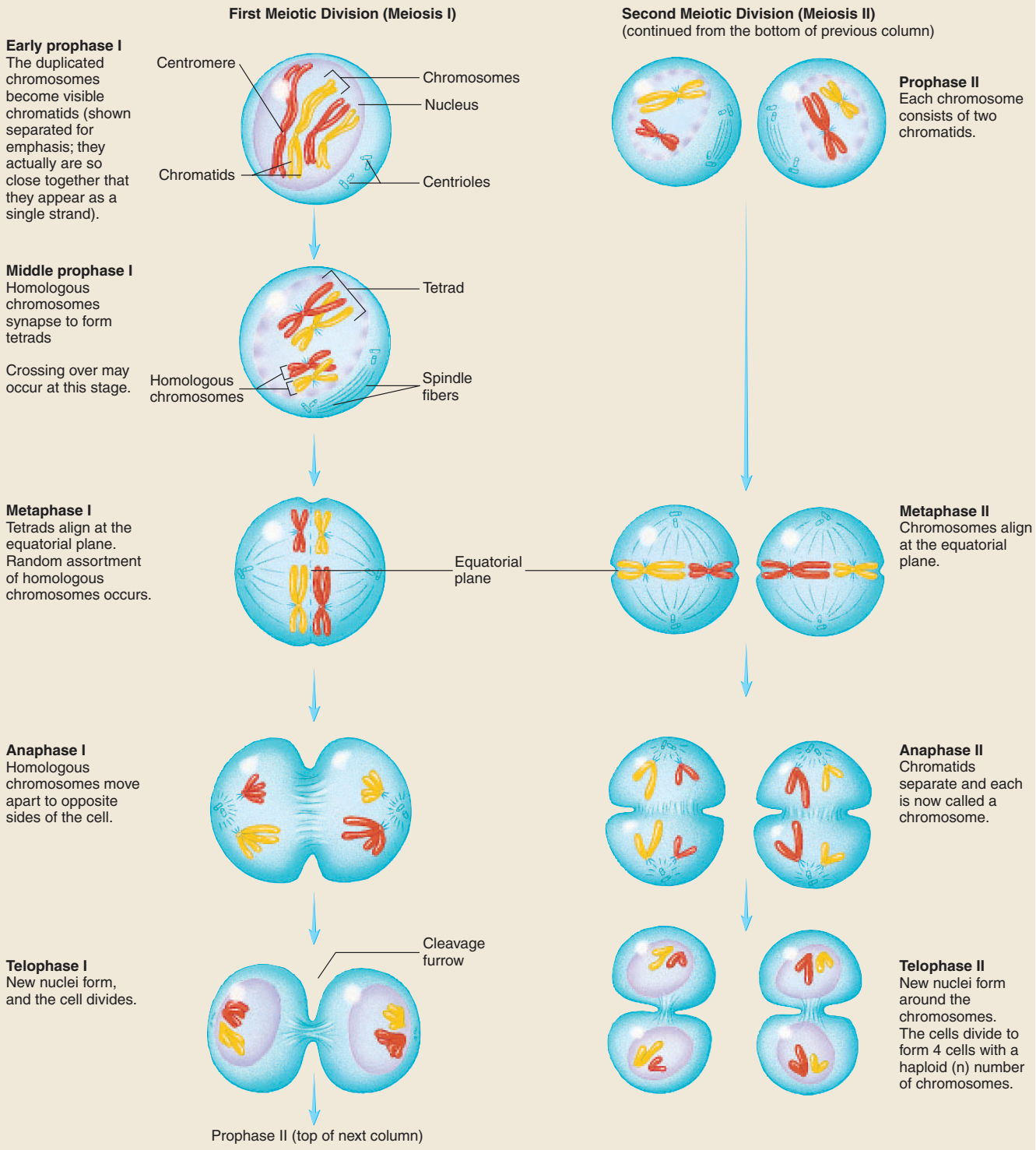


Figure A Meiosis

Ducts

Objective

- ***Describe and give the function of the ducts associated with the male reproductive system.***

After their release into the seminiferous tubules, the sperm cells pass through the tubuli recti to the rete testis. From the rete testis, they pass through the efferent ductules, which leave the testis and enter the epididymis to join the duct of the epididymis. The sperm cells then leave the epididymis, passing through the ductus epididymis, ductus deferens, ejaculatory duct, and urethra to reach the exterior of the body.

Epididymis

The **efferent ductules** from each testis become extremely convoluted and form a comma-shaped structure on the posterior side of the testis called the **epididymis** (ep-i-did′i-mis; pl., epididymides, ep-i-di-dim′i-dēz; on the twin; "twin" refers to the paired, or twin, testes; figure 28.5). The final maturation of the sperm cells occurs within the epididymis. Sperm cells taken directly from the testes in

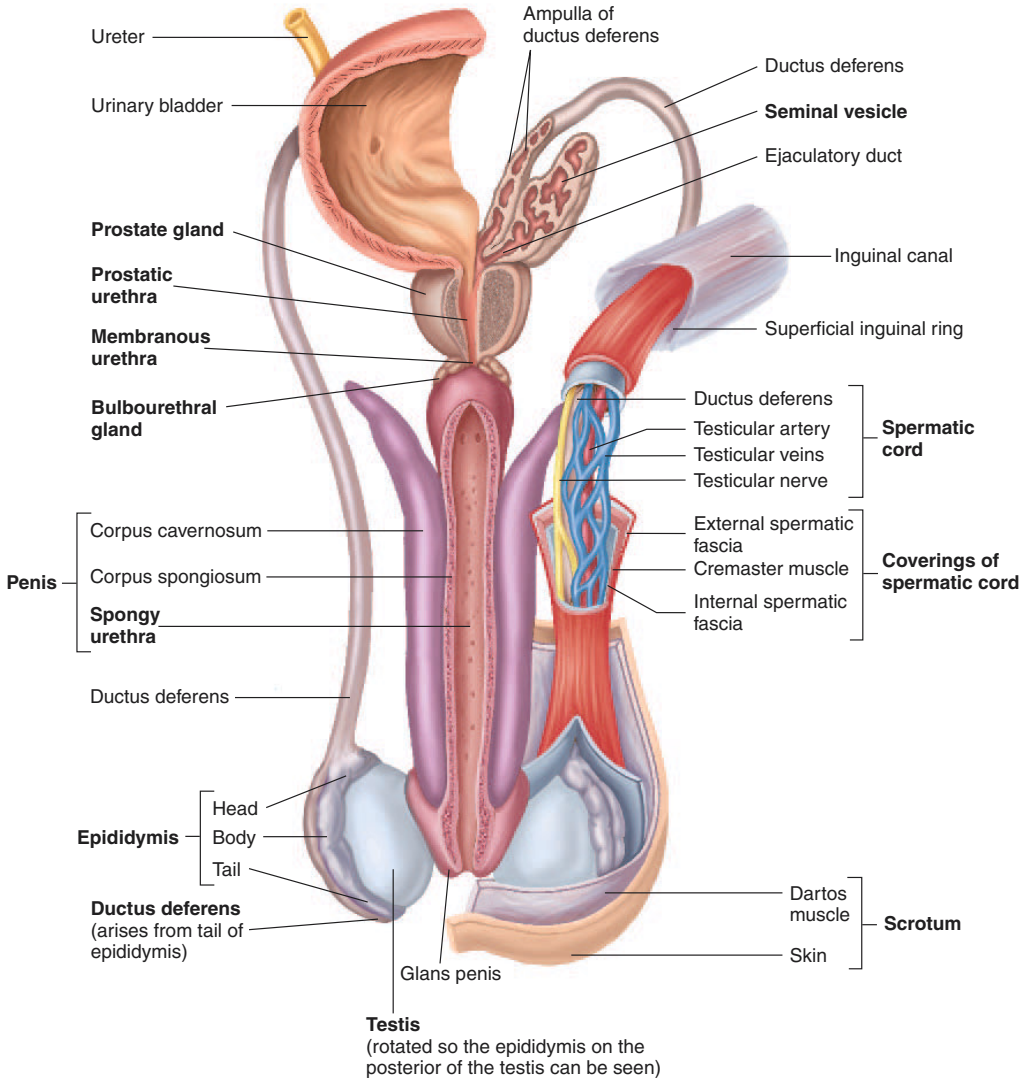


Figure 28.5 Male Reproductive Structures

Frontal view of the testes, epididymis, ductus deferens, and glands of the male reproductive system. The urethra is cut open along its dorsal side.

experimental animals are not capable of fertilization, but, after spending one to several days in the epididymides, they develop the capacity to fertilize the female sex cell.

Each epididymis consists of a head, a body, and a long tail (see figures 28.2*a* and 28.5). The head contains the convoluted efferent ductules, which empty into a single convoluted tube, the **duct of the epididymis,** located primarily within the body of the epididymis (see figure 28.2*a*). This duct alone, if unraveled, would extend for several meters. The duct of the epididymis has a pseudostratified columnar epithelium with elongated microvilli called **stereocilia** (ster′ē-ō-sil′ē-ă). The stereocilia function to increase the surface area of epithelial cells that absorb fluid from the lumen of the duct of the epididymis. The duct of the epididymis ends at the tail of the epididymis, which is located at the inferior border of the testis.

Ductus Deferens

The **ductus deferens,** or **vas deferens,** emerges (see figures 28.1*a*, 28.2*a*, and 28.5) from the tail of the epididymis and ascends along the posterior side of the testis medial to the epididymis and becomes associated with the blood vessels and nerves that supply the testis. These structures constitute the **spermatic cord.** The spermatic cord consists of (1) the ductus deferens, (2) the testicular artery and venous plexus, (3) lymphatic vessels, (4) nerves, and (5) fibrous remnants of the process vaginalis. The coverings of the spermatic cord include the **external spermatic fascia** (fash′ē-ă); the **cremaster muscle,** an extension of the muscle fibers of the internal abdominal oblique muscle of the abdomen; and the **internal spermatic fascia** (see figure 28.5).

The ductus deferens and the rest of the spermatic cord structures ascend and pass through the inguinal canal to enter the pelvic cavity (see figures 28.1 and 28.5). The ductus deferens crosses the lateral and posterior walls of the pelvic cavity, travels over the ureter, and loops over the posterior surface of the urinary bladder to approach the prostate gland. The end of the ductus deferens enlarges to form an **ampulla** (am-pul′lă). The lumen of the ductus deferens is lined by pseudostratified columnar epithelium, which is surrounded by smooth muscle. Peristaltic contractions of this smooth muscle tissue help propel sperm cells through the ductus deferens.

Ejaculatory Duct

Adjacent to the ampulla of each ductus deferens is a sac-shaped gland called the seminal vesicle. A short duct from the seminal vesicle joins the ductus deferens to form the **ejaculatory** (ē-jak′ū-lă-tōr-ē) **duct.** The ejaculatory ducts are approximately 2.5 cm long. These ducts project into the prostate gland and end by opening into the urethra (see figures 28.1 and 28.5).

Urethra

The **male urethra** (ū-rē′thră) is about 20 cm long and extends from the urinary bladder to the distal end of the penis (see figures 28.1, 28.5, and figure 28.6). The urethra is a passageway for both urine and male reproductive fluids. The urethra is divided into three parts: the prostatic part, the membranous part, and the spongy part. The **prostatic** (pros-tat′ik) **urethra** is connected to the bladder and passes through the prostate gland. Fifteen to 30 small ducts from the prostate gland and the two ejaculatory ducts empty into the prostatic urethra. The **membranous urethra** is the shortest part of the urethra and extends from the prostate gland through the perineum, which is part of the muscular floor of the pelvis. The **spongy urethra,** also called the **penile** (pē′nīl) **urethra,** is by far the longest part of the urethra and extends from the membranous urethra through the length of the penis. In rare cases, the penis does not develop completely. In these cases the urethra may open to the exterior along the inferior surface of the penis (see hypospadia, chapter 29, page 1081). Stratified columnar epithelium lines most of the urethra, but transitional epithelium is in the prostatic urethra near the bladder, and stratified squamous epithelium is near the opening of the spongy urethra to the outside. Several minute mucus-secreting **urethral glands** empty into the urethra.

5. *Where, specifically, are sperm cells produced in the testis? Describe the process of sperm cell formation. Explain the structure and function of the blood–testes barrier.*
6. *Describe and give the function of the parts of a mature sperm cell.*
7. *Name all the ducts the sperm cells traverse to go from their site of production to the outside.*
8. *Where do sperm cells undergo maturation?*
9. *Name the parts of the spermatic cord. Describe the location of the superficial and deep inguinal rings.*
10. *Distinguish between the prostatic, membranous, and spongy parts of the male urethra.*

Penis

Objective

- *Describe the parts of the penis.*

The **penis** contains three columns of erectile tissue (see figure 28.6), and engorgement of this erectile tissue with blood causes the penis to enlarge and become firm, a process called **erection**. The penis is the male organ of copulation through which sperm cells are transferred from the male to the female. Two of the erectile columns form the dorsum and sides of the penis and are called the **corpora cavernosa** (kōr′pōr-ă kav-er-nos′ă). The third column, the **corpus spongiosum** (kōr′pŭs spŭn′jē-ō′sŭm), forms the ventral portion of the penis and it expands to form a cap, the **glans penis,** over the distal end of the penis. The spongy urethra passes through the corpus spongiosum, penetrates the glans penis, and opens as the **external urethral orifice.** At the base of the penis, the corpus spongiosum expands to form the **bulb of the penis,** and each corpus cavernosum expands to form a **crus** (kroos; pl. crura, kroo′ră) **of the penis.** Together, these structures constitute the **root of the penis** and the crura attach the penis to the coxae.

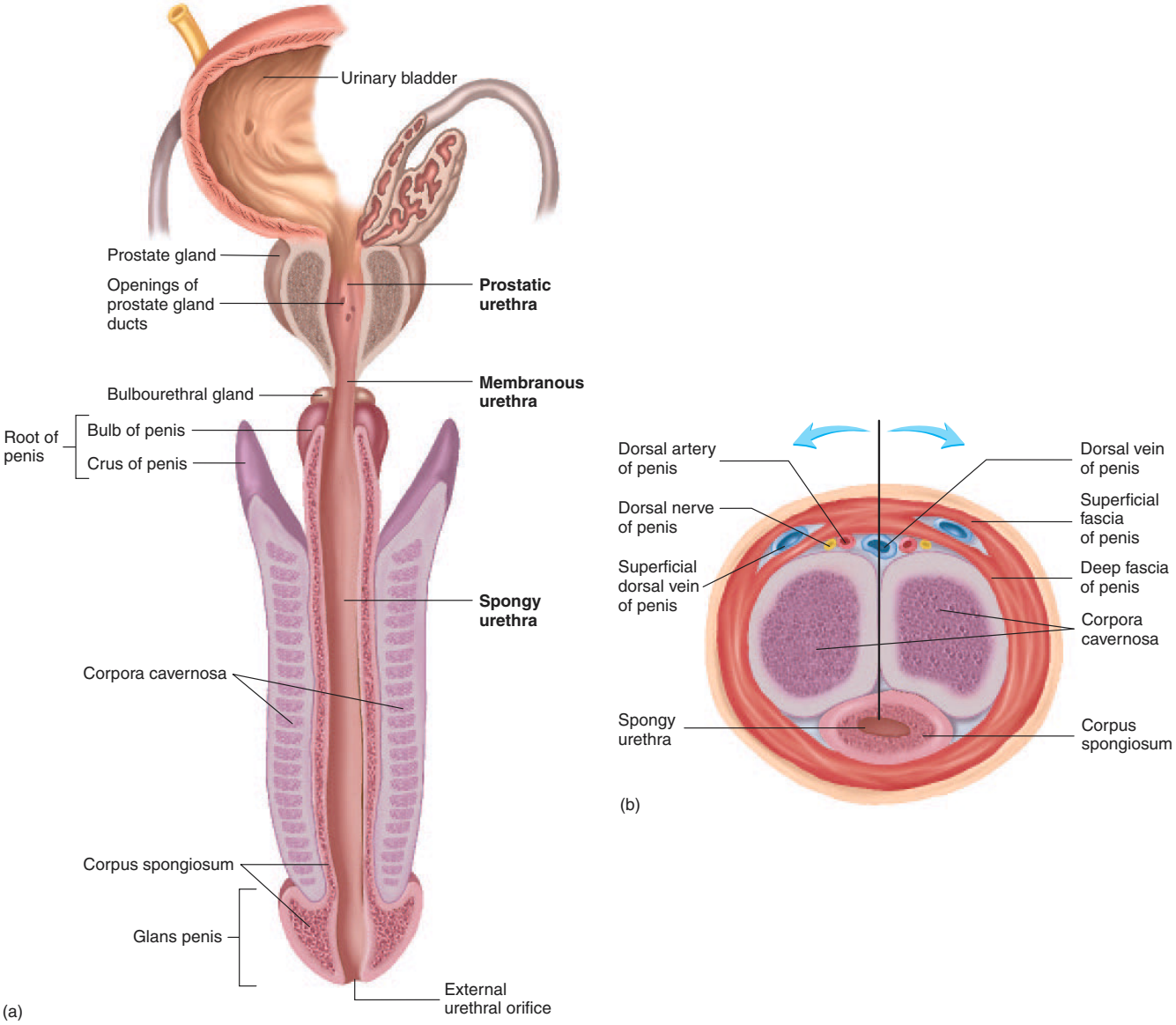


Figure 28.6 Penis

(*a*) Sagittal section through the spongy or penile urethra laid open and viewed from above. The prostate is also cut open to show the prostatic urethra. (*b*) Cross section of the penis showing principal nerves, arteries, and veins along the dorsum of the penis. The *line* and *arrows* depict the manner in which (*a*) is cut and laid open.

Skin is loosely attached to the connective tissue that surrounds the erectile columns in the shaft of the penis. The skin is firmly attached at the base of the glans penis, and a thinner layer of skin tightly covers the glans penis. The skin of the penis, especially the glans penis, is well supplied with sensory receptors. A loose fold of skin called the **prepuce** (prē′poos), or **foreskin,** covers the glans penis.

Circumcision

Circumcision (ser-kŭm-sizh′ŭn) is accomplished by surgically removing the prepuce, usually near the time of birth. Compelling medical reasons for circumcision do not appear to exist. Uncircumcised males have a higher incidence of penile cancer, but the underlying cause appears to be related to chronic infections and poor hygiene. In those few cases in which the prepuce is "too tight" to be moved over the glans penis, circumcision can be necessary to avoid chronic infections and maintain normal circulation.

The primary nerves, arteries, and veins of the penis pass along its dorsal surface (see figure 28.6*b*). Dorsal arteries, with dorsal nerves lateral to them, are found on either side of a single, midline dorsal vein. Additional deep arteries lie within the corpora cavernosa.

Accessory Glands

Objective

- ***Name the male accessory glands, state where they empty into the duct system, and describe their secretions.***

Seminal Vesicles

The **seminal vesicles** (sem′i-năl ves′i-klz) are sac-shaped glands located next to the ampullae of the ductus deferentia (see figure 28.5). Each gland is about 5 cm long and tapers into a short duct that joins the ductus deferens to form the ejaculatory duct. The seminal vesicles have a capsule containing fibrous connective tissue and smooth muscle cells.

Prostate Gland

The **prostate** (pros′tāt; one standing before) **gland** consists of both glandular and muscular tissue and is about the size and shape of a walnut; that is, about 4 cm long and 2 cm wide. It is dorsal to the symphysis pubis at the base of the urinary bladder, where it surrounds the prostatic urethra and the two ejaculatory ducts (see figure 28.1). The gland is composed of a fibrous connective tissue capsule containing distinct smooth muscle cells and numerous fibrous partitions, also containing smooth muscle, that radiate inward toward the urethra. Covering these muscular partitions is a layer of columnar epithelial cells that form saccular dilations into which the columnar cells secrete prostatic fluid. Fifteen to 30 small prostatic ducts carry these secretions into the prostatic urethra.

Cancer of the Prostate

Cancer of the prostate is the second-most common cause of cancer deaths in men in the United States, fewer than from lung cancer and more than from colon cancer. A prostate-specific antigen (PSA) increases in the circulatory system of most men who have prostatic cancer. A blood sample can be taken and an assay performed to test for the presence of the antigen. If the concentration of the antigen in the blood has increased, an examination for prostatic cancer is highly recommended. Because of its prevalence in men older than 50, an annual or biannual analysis for prostatic cancer should be done.

Some debate accompanies the treatment for prostatic cancer. Cancer of the prostate in relatively young men and large tumors in all men generally require treatment; however, treatment in elderly men is controversial. Some evidence suggests that elderly men with small tumors in the prostate are likely to die of causes unrelated to prostatic cancer, even if they receive no treatment. Treatment for prostatic cancer includes radiation, chemotherapy, and surgery. Surgery can result in incontinence and it generally results in the inability to sustain an erection, although new, more successful surgical techniques have been developed.

P R E D I C T 1

The prostate gland can enlarge for several reasons, including infections, tumor, and old age. The detection of enlargement or changes in the prostate is an important way to detect prostatic cancer. Suggest a way other than surgery that the prostate gland can be examined by palpation for any abnormal changes.

Bulbourethral Glands

The **bulbourethral** (bŭl′bō-ū-rē′thrăl) **glands** are a pair of small glands located near the membranous part of the urethra (see figures 28.1 and 28.5). In young males, each is about the size of a pea, but they decrease in size with age and are almost impossible to see in old men. Each bulbourethral gland is a compound mucous gland (see chapter 4). The small ducts of each gland unite to form a single duct. The single duct from each bulbourethral gland then enters the spongy urethra at the base of the penis.

Secretions

Semen (sē′men) is a composite of sperm cells and secretions from the male reproductive glands. The seminal vesicles produce about 60% of the fluid, the prostate gland contributes about 30%, the testes contribute 5%, and the bulbourethral glands contribute 5%. **Emission** is the discharge of semen into the prostatic urethra. **Ejaculation** is the forceful expulsion of semen from the urethra caused by the contraction of the urethra, the skeletal muscles in the floor of the pelvis, and the muscles at the base of the penis.

The bulbourethral glands and urethral mucous glands produce a mucous secretion just before ejaculation. This mucus lubricates the urethra, neutralizes the contents of the normally acidic spongy urethra, provides a small amount of lubrication during intercourse, and helps reduce vaginal acidity.

Testicular secretions include sperm cells, a small amount of fluid, and metabolic by-products. The thick, mucuslike secretions of the seminal vesicles contain large amounts of fructose and other nutrients that nourish the sperm cells. The seminal vesicle secretions also contain fibrinogen, which is involved in a weak coagulation reaction of the semen after ejaculation, and prostaglandins, which can cause uterine contractions.

The thin, milky secretions of the prostate have a rather high pH and; with secretions of the seminal vesicles, bulborurethral glands, and urethral mucous glands; help to neutralize the acidic urethra. The secretions of the prostate and seminal vesicles also help neutralize the acidic secretions of the testes, and those of the vagina. The prostatic secretions are also important in the transient coagulation of semen because they contain clotting factors that convert fibrinogen from the seminal vesicles to fibrin, resulting in coagulation. The coagulated material keeps the semen as a single, sticky mass for a few minutes after ejaculation, and then fibrinolysin from the prostate causes the coagulum to dissolve, thereby releasing the sperm cells to make their way up the female reproductive tract.

P R E D I C T 2

Explain a possible reason for having the coagulation reaction.

Before ejaculation, the ductus deferens begins to contract rhythmically to propel sperm cells and testicular fluid from the tail of the epididymis to the ampulla of the ductus deferens. Contractions of the ampullae, seminal vesicles, and ejaculatory ducts cause the sperm cells, testicular secretions, and seminal fluid to move into the prostatic urethra, where they mix with prostatic secretions released as a result of contractions of the prostate gland.

Normal sperm cell counts in the semen range from 75–400 million sperm cells per milliliter of semen, and a normal ejaculation usually consists of about 2–5 mL of semen. Most of the sperm cells (millions) are expended in moving the general group of sperm cells through the female reproductive system. Enzymes carried in the acrosomal cap of each sperm cell help to digest a path through the mucoid fluids of the female reproductive tract and through materials surrounding the oocyte. Once the acrosomal fluid is depleted from a sperm cell, the sperm cell is no longer capable of fertilization.

11. *Describe the erectile tissue of the penis. Define the terms glans penis, crus, bulb, and prepuce.*
12. *State where the seminal vesicles, prostate gland, and bulbourethral glands empty into the male reproductive duct system.*
13. *Define the terms emission and ejaculation.*
14. *Define the term semen. Describe the contribution to semen of the accessory sex glands. What is the function of each secretion?*

Physiology of Male Reproduction

Objectives

- *List the hormones that influence the male reproductive system, and explain how reproductive hormone secretions are regulated.*
- *Describe the effects of testosterone.*
- *Explain the role of psychic stimulation, tactile stimulation, and the parasympathetic and parasympathetic divisions of the ANS in the male sex act.*

Normal function of the male reproductive system depends on both hormonal and neural mechanisms. Hormones are primarily responsible for the development of reproductive structures and maintenance of their functional capacities, development of secondary sexual characteristics, control of sperm cell formation, and influencing sexual behavior. Neural mechanisms are primarily involved in sexual behavior and controlling the sexual act.

Regulation of Sex Hormone Secretion

Hormonal mechanisms that influence the male reproductive system involve the hypothalamus, the pituitary gland, and the testes (figure 28.7). A small peptide hormone called **gonadotropin-releasing hormone (GnRH)** or **luteinizing hormone-releasing hormone (LHRH)** is released from neurons in the hypothalamus. GnRH passes through the hypothalamohypophyseal portal system to the anterior pituitary gland (see chapter 18). In response to GnRH, cells within the anterior pituitary gland secrete two hormones referred to as **gonadotropins** (gō′nad-ō-trō′pinz, gon′ă-dō-trō′pinz) because they influence the function of the **gonads** (gō′nadz; the testes or ovaries).

The two gonadotropins are **luteinizing hormone (LH)** and **follicle-stimulating hormone (FSH).** They are named for their functions in females, but they also perform important functions in males. LH in males is sometimes called **interstitial cell-stimulating hormone (ICSH).** LH binds to the interstitial cells in the testes and causes them to increase their rate of testosterone synthesis and secretion. FSH binds primarily to sustentacular cells in the seminiferous tubules and promotes sperm cell development. Both gonadotropins bind to specific receptor molecules on the membranes of the cells that they influence, and cyclic adenosine monophosphate is an important intracellular mediator in those cells.

For GnRH to stimulate the secretion of large quantities of LH and FSH, the anterior pituitary must be exposed to a series of brief increases and decreases in GnRH. Chronically elevated GnRH levels

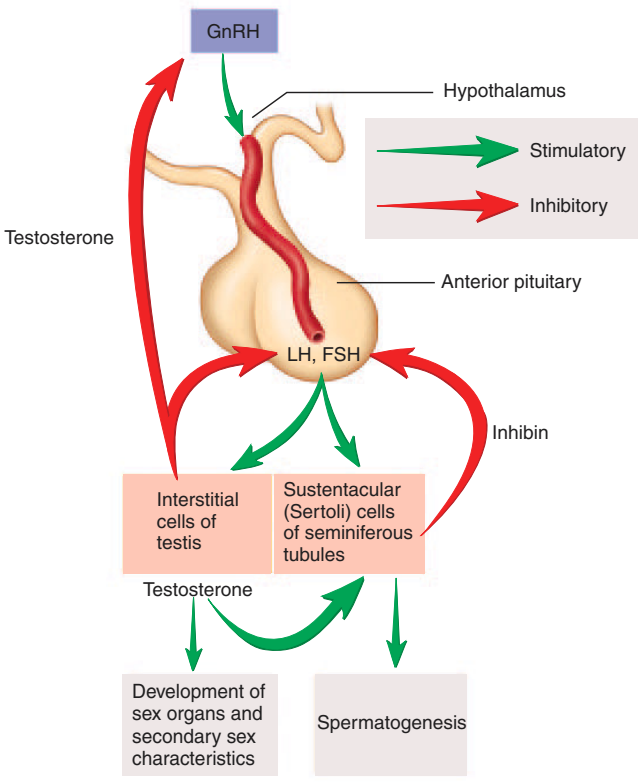


Figure 28.7 Regulation of Reproductive Hormone Secretion in Males

GnRH from the hypothalamus stimulates the secretion of LH and FSH from the anterior pituitary. LH and FSH stimulate spermatogenesis, secretion of testosterone, and secretion of inhibin in the testes. Testosterone has a negative-feedback effect on the hypothalamus and pituitary to reduce LH and FSH secretion, whereas inhibin specifically inhibits FSH secretion. Testosterone has a stimulatory effect on the sex organs, secondary sex characteristics, and the sustentacular (Sertoli) cells.

Clinical Focus Male Infertility

Infertility (in-fer-til′i-tē) is reduced or diminished fertility. The most common cause of infertility in males is a low sperm cell count. If the sperm cell count drops to below 20 million sperm cells per milliliter, the male is usually infertile.

A decreased sperm cell count can occur because of damage to the testes as a result of trauma, radiation, cryptorchidism, or infections like mumps. Reduced sperm cell counts can result from inadequate secretion of luteinizing hormone and follicle-stimulating hormone, which can be caused by hypothyroidism, trauma to the hypothalamus, infarctions of the hypothalamus or anterior pituitary gland, and tumors. Decreased testosterone secretion also reduces the sperm cell count. Some reports suggest that the average sperm count has decreased substantially since the end of World War II (1945) although there is some controversy about the accuracy of these reports. It's speculated that certain synthetic chemicals are responsible.

Fertility is reduced if the sperm cell count is normal but sperm cell structure is abnormal. Abnormal sperm cell structure can be due to chromosomal abnormalities or genetic factors. Reduced sperm cell motility also results in infertility. A major cause of reduced sperm cell motility is antisperm antibodies produced by the immune system, which bind to sperm cells.

Fertility can sometimes be achieved by collecting several ejaculations, concentrating the sperm cells, followed by their introduction into the female's reproductive tract, a process called **artificial insemination** (in-sem-i-nā′shŭn).

in the blood cause the anterior pituitary cells to become insensitive to stimulation by GnRH molecules, and little LH or FSH is secreted.

GnRH Pulses and Infertility

GnRH can be produced synthetically, and if administered in small amounts in frequent pulses or surges, it can be useful in treating males who are infertile. GnRH can also inhibit reproduction because chronic administration of it can sufficiently reduce LH and FSH levels to prevent sperm cell production in males or ovulation in females.

Testosterone is the major male hormone secreted by the testes. It's classified as an **androgen** (*andros* is Greek for male human being) because it stimulates the development of male reproductive structures (see chapter 29) and male secondary sexual characteristics. The testes secrete other androgens, but they are produced in smaller concentrations and are less potent than testosterone. In addition, the testes secrete small amounts of estrogen and progesterone.

Testosterone has a major influence on many tissues. It plays an essential role in the embryonic development of reproductive structures, their further development during puberty, the development of secondary sexual characteristics during puberty, the maintenance of sperm cell production, and the regulation of gonadotropin secretion. It also influences behavior.

Inside of some target tissue cells, an enzyme converts testosterone to dihydrotestosterone. In these cells, dihydrotestosterone is the active hormone. The scrotum and penis are examples. If the enzyme is not active, these structures don't fully develop normally. In other target tissue cells, an enzyme converts testosterone to estrogen, and estrogen is the active hormone. Some brain cells convert testosterone to estrogen and, in these cells, estrogen may be the active hormone responsible for some aspects of male sexual behavior.

The sustentacular cells of the testes secrete a polypeptide hormone called **inhibin** (in-hib′in). Inhibin inhibits FSH secretion from the anterior pituitary.

Puberty

A gonadotropin-like hormone called **human chorionic** (kō-rē-on′ik) **gonadotropin (HCG),** which the placenta secretes, stimulates the synthesis and secretion of testosterone by the fetal testes before birth. After birth, however, no source of stimulation is present, and the testes of the newborn baby atrophy slightly and secrete only small amounts of testosterone until puberty, which normally begins when a boy is 12–14 years old.

Puberty (pū′ber-tē) is the age at which individuals become capable of sexual reproduction. Before puberty, small amounts of testosterone and other androgens in males inhibit GnRH release from the hypothalamus. At puberty, the hypothalamus becomes much less sensitive to the inhibitory effect of androgens, and the rate of GnRH secretion increases, leading to increased LH and FSH release. Elevated FSH levels promote sperm cell formation, and elevated LH levels cause the interstitial cells to secrete larger amounts of testosterone. Testosterone still has a negative-feedback effect on GnRH secretion after puberty but is not capable of completely suppressing it.

Effects of Testosterone

Testosterone is by far the major androgen in males. Nearly all of the androgens, including testosterone, are produced by the interstitial cells, with small amounts produced by the adrenal cortex and possibly by the sustentacular cells. Testosterone causes the enlargement and differentiation of the male genitals and reproductive duct system, is necessary for sperm cell formation, and is required for the descent of the testes near the end of fetal development. Testosterone stimulates hair growth in the following regions: (1) the pubic area and extending up the linea alba, (2) the legs, (3) the chest, (4) the axillary region, (5) the face, and (6) occasionally, the back. It causes vellus hair to be converted to terminal hair, which are more pigmented and coarser.

Male Pattern Baldness

Some men have a genetic tendency called **male pattern baldness,** which develops in response to testosterone and other androgens. When testosterone levels increase at puberty, the density of hair on the top of the head begins to decrease. Baldness usually reaches its maximum rate of development when the individual is in the third or fourth decade of life.

Testosterone also causes the texture of the skin to become rougher or coarser. The quantity of melanin in the skin also increases, making the skin darker. Testosterone increases the rate of secretion from the sebaceous glands, especially in the region of the face, frequently resulting near the time of puberty in the development of acne. Beginning near the time of puberty, testosterone also causes hypertrophy of the larynx. The structural changes can first result in a voice that's difficult to control, but ultimately the voice reaches its normal masculine quality.

Testosterone has a general stimulatory effect on metabolism so that males have a slightly higher metabolic rate than females. The red blood cell count is increased by nearly 20% as a result of the effects of testosterone on erythropoietin production. Testosterone also has a minor mineralocorticoid-like effect, causing the retention of sodium in the body and, consequently, an increase in the volume of body fluids. Testosterone promotes protein synthesis in most tissues of the body; as a result, skeletal muscle mass increases at puberty. The average percentage of the body weight composed of skeletal muscle is greater for males than for females because of the effect of androgens.

Synthetic Androgens and Muscle Mass

Some athletes, especially weightlifters, ingest synthetic androgens in an attempt to increase muscle mass. The side effects of the large doses of androgens are often substantial and include testicular atrophy, kidney damage, liver damage, heart attacks, and strokes. Administration of synthetic androgens is highly discouraged by the medical profession and is a violation of the rules of most athletic organizations.

Testosterone causes rapid bone growth and increases the deposition of calcium in bone, resulting in an increase in height. The growth in height is limited, however, because testosterone also causes early closure of the epiphyseal plates of long bones (see chapter 6). Males who mature sexually at an earlier age grow rapidly but reach their maximum height earlier. Males who mature sexually at a later age do not exhibit a rapid period of growth, but they grow for a longer period and can become taller than those who mature sexually at an earlier age.

Male Sexual Behavior and the Male Sex Act

Testosterone is required to initiate and maintain male sexual behavior. Testosterone enters cells within the hypothalamus and the surrounding areas of the brain and influences their function, resulting in sexual behavior. Male sexual behavior may depend, in part, however, on the conversion of testosterone to other steroids, such as estrogen, in the cells of the brain.

The blood levels of testosterone remain relatively constant throughout the lifetime of a male from puberty until about 40 years of age. Thereafter, the levels slowly decline to about 20% of this value by 80 years of age, causing a slow decrease in sex drive and fertility.

The male sex act is a complex series of reflexes that result in erection of the penis, secretion of mucus into the urethra, emission, and ejaculation. Sensations that are normally interpreted as pleasurable occur during the male sexual act and result in a climactic sensation, **orgasm** (ōr′gazm), associated with ejaculation. After ejaculation, a phase called **resolution** occurs, in which the penis becomes flaccid, an overall feeling of satisfaction exists, and the male is unable to achieve erection and a second ejaculation for many minutes to many hours or longer.

Sensory Action Potentials and Integration

Action potentials are conducted by sensory neurons from the genitals through the pudendal nerve to the sacral region of the spinal cord, where reflexes that result in the male sexual act are integrated. Action potentials travel from the spinal cord to the cerebrum to produce conscious sexual sensations.

Rhythmic massage of the penis, especially the glans penis, provides an extremely important source of sensory action potentials that initiate erection and ejaculation. Sensory action potentials, produced in surrounding tissues, such as the scrotum and the anal, perineal, and pubic regions, reinforce sexual sensations. Engorgement of the prostate and seminal vesicles with secretions of the urethra, urinary bladder, ductus deferens, and testes also cause sexual sensations. In some cases, mild irritation, such as from an infection, can cause sexual sensations.

Psychic stimuli, such as sight, sound, odor, or thoughts, have a major effect on sexual reflexes. Thinking sexual thoughts or dreaming about erotic events tends to reinforce stimuli that trigger sexual reflexes like erection and ejaculation. Ejaculation while sleeping is a relatively common event in young males and is thought to be triggered by psychic stimuli associated with dreaming. Psychic stimuli can also inhibit the sexual act, and thoughts that are not sexual in nature tend to decrease the effectiveness of the male sexual act. The inability to concentrate on sexual sensations is one of the causes of **impotence** (im′pŏ-tens), the inability to achieve or maintain an erection and to accomplish the male sexual act. Impotence can also be caused by nerve damage, such as can result from prostate surgery, or restricted circulation.

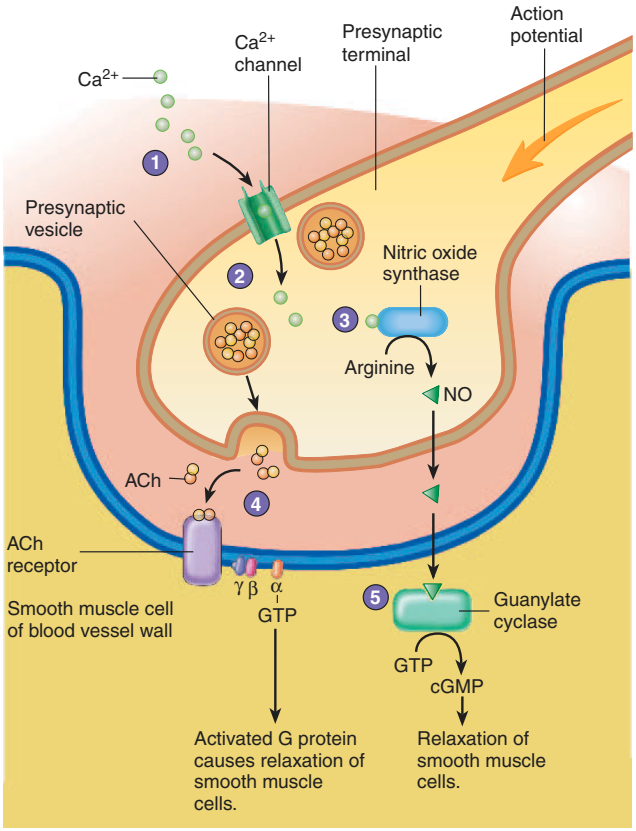
Action potentials from the cerebrum that reinforce the sacral reflexes are not absolutely required for the culmination of the male sexual act, and the male sexual act can occasionally be accomplished by males who have suffered spinal cord injuries superior to the sacral region.

Erection, Emission, and Ejaculation

When **erection** (ē-rek′shŭn) occurs, the penis becomes enlarged and rigid. Erection is the first major component of the male sexual act. Action potentials travel from the spinal cord through the pudendal nerve to the arteries that supply blood to the erectile tissues. The

nerve fibers release acetylcholine as well as **nitric oxide** (NO) as neurotransmitter substances. Acetylcholine binds to muscarinic receptors and activates a G-protein mechanism that causes smooth muscle relaxation. NO diffuses into the smooth muscle cells of blood vessels and combines with the enzyme guanylate cyclase, which converts guanosine triphosphate (GTP) to cyclic guanosine monophosphate (cGMP). The cGMP causes smooth muscle cells to relax and blood vessels to dilate (figure 28.8). At the same time, other arteries of the penis constrict to shunt blood to the erectile tissues. As a consequence, blood fills the sinusoids of the erectile tissue and compresses the veins. Because venous outflow is partially occluded, the blood pressure in the sinusoids causes inflation and rigidity of the erectile tissue. Nerve action potentials that result in erection come from parasympathetic centers (S2–S4) or sympathetic centers (T2–L1) in the spinal cord. Normally, the parasympathetic centers are more important, but in cases of damage to the sacral region of the spinal cord, it's possible for erection to occur through the sympathetic system.

Parasympathetic action potentials also cause the mucous glands within the penile urethra and the bulbourethral glands at the base of the penis to secrete mucus.



1. Action potentials in parasympathetic neurons cause voltage-gated Ca^{2+} channels to open and Ca^{2+} diffuse into the presynaptic terminals.
2. Ca^{2+} initiate the release of acetylcholine (ACh) from presynaptic vesicles.
3. Ca^{2+} also activate nitric oxide synthase, which promotes the synthesis of nitric oxide (NO) from arginine.
4. ACh binds to ACh receptors on the smooth muscle cells and activates a G protein mechanism. The activated G protein causes the relaxation of smooth muscle cells and erection of the penis.
5. NO binds to guanylate cyclase enzymes and activates them. The activated enzymes convert GTP to cGMP, which causes relaxation of the smooth muscle cells and erection of the penis.

Process Figure 28.8 Neural Control of Erection

Erectile Dysfunction

Failure to achieve erections, **erectile dysfunction (ED),** can be a major source of frustration for some men and can contribute to disharmony in relationships. ED can be due to reduced testosterone secretion, which can result from hypothalamic, pituitary, or testicular complications. In other cases, ED can be due to defective stimulation of the erectile tissue by nerve fibers or reduced response of the blood vessels to neural stimulation. Erection can be achieved in some people by oral medication, such as sildenafil (Viagra), or by the injection of specific drugs into the base of the penis, which function to increase blood flow into the sinusoids of the erectile tissue of the penis, resulting in erection for many minutes. Viagra blocks the activity of the enzyme that converts cGMP to GMP. Consequently, it allows cGMP to accumulate in smooth muscle cells in the arteries of erectile tissues and causes them to relax. Although Viagra is effective in causing or enhancing erection in males, its action is not specific to erectile tissue of the penis. It causes vasodilation in other tissues and can increase the workload of the heart.

Emission (ē-mish′ŭn) is the accumulation of sperm cells and secretions of the prostate gland and seminal vesicles in the urethra. Sympathetic centers (T12–L1) in the spinal cord, which are stimulated as the level of sexual tension increases, control emission. Sympathetic action potentials cause peristaltic contractions of the reproductive ducts and stimulate the seminal vesicles and the prostate gland to release their secretions. Consequently, semen accumulates in the prostatic urethra and produces sensory action potentials that pass through the pudendal nerves to the spinal cord. Integration of these action potentials results in both sympathetic and somatic motor output. Sympathetic action potentials cause constriction of the internal sphincter of the urinary bladder so that semen and urine are not mixed. Somatic motor action potentials are sent to the skeletal muscles of the urogenital diaphragm and the base of the penis, causing several rhythmic contractions that force the semen out of the urethra. The movement of semen out of the urethra is called **ejaculation** (ē-jak-ū-lā′shŭn). In addition, an increase in muscle tension occurs throughout the body.

15. *Where are GnRH, FSH, LH, and inhibin produced? What effects do they produce?*
16. *What changes in hormone production occur at puberty?*
17. *Where is testosterone produced? Describe the effects of testosterone on the embryo, during puberty, and on the adult male.*
18. *What effects do psychic, tactile, parasympathetic, and sympathetic stimulation have on the male sex act?*

Anatomy of the Female Reproductive System

Objectives

- ***Describe the anatomy and histology of the ovaries.***
- ***Discuss the development of the follicle and the oocyte, the process of ovulation, and fertilization.***
- ***Name and describe the parts of the uterine tube, uterus, vagina, external genitalia, perineum, and mammae.***

The female reproductive organs consist of the ovaries, uterine tubes, uterus, vagina, external genital organs, and mammary glands. The internal reproductive organs of the female (figures 28.9 and 28.10) are within the pelvis between the urinary bladder and the rectum. The uterus and the vagina are in the midline, with the ovaries to each side of the uterus. A group of ligaments holds the internal reproductive organs in place. The most conspicuous is the **broad ligament,** an extension of the peritoneum that spreads out on both sides of the uterus and to which the ovaries and uterine tubes are attached.

Ovaries

The two **ovaries** (ō′var-ēz) are small organs about 2–3.5 cm long and 1–1.5 cm wide (see figure 28.10). A peritoneal fold called the **mesovarium** (mez′ō-vā′rē-ŭm; mesentery of the ovary) attaches each ovary to the posterior surface of the broad ligament. Two other ligaments are associated with the ovary: the **suspensory ligament,** which extends from the mesovarium to the body wall, and the **ovarian ligament,** which attaches the ovary to the superior margin of the uterus. The ovarian arteries, veins, and nerves traverse the suspensory ligament and enter the ovary through the mesovarium.

Ovarian Histology

The visceral peritoneum covering the surface of the ovary is called the **ovarian,** or **germinal, epithelium.** The term germinal epithelium exists because it was once thought to produce oocytes. Immediately below the epithelium is a layer of dense fibrous connective tissue, the **tunica albuginea** (al-bū-jin′ē-ă). The more dense outer part of the ovary is called the **cortex** and a looser inner part is called the **medulla** (figure 28.11). Blood vessels, lymphatic vessels, and nerves from the mesovarium enter the medulla. Numerous small vesicles called ovarian follicles, each of which contains an **oocyte** (ō′ō-sīt), are distributed throughout the cortex.

Follicle and Oocyte Development

Oogenesis (ō-ō-jen′ĕ-sis) is the production of a secondary oocyte within the ovaries. By the fourth month of prenatal life, the ovaries may contain 5 million **oogonia** (ō-ō-gō′nē-ă), the cells from which

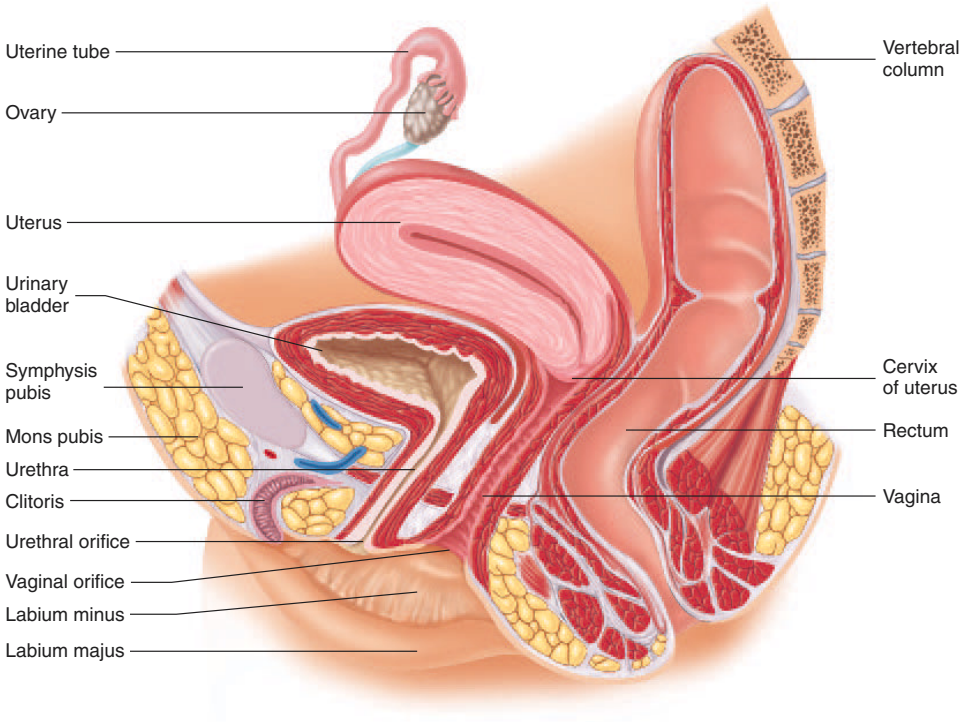


Figure 28.9 Sagittal Section of the Female Pelvis

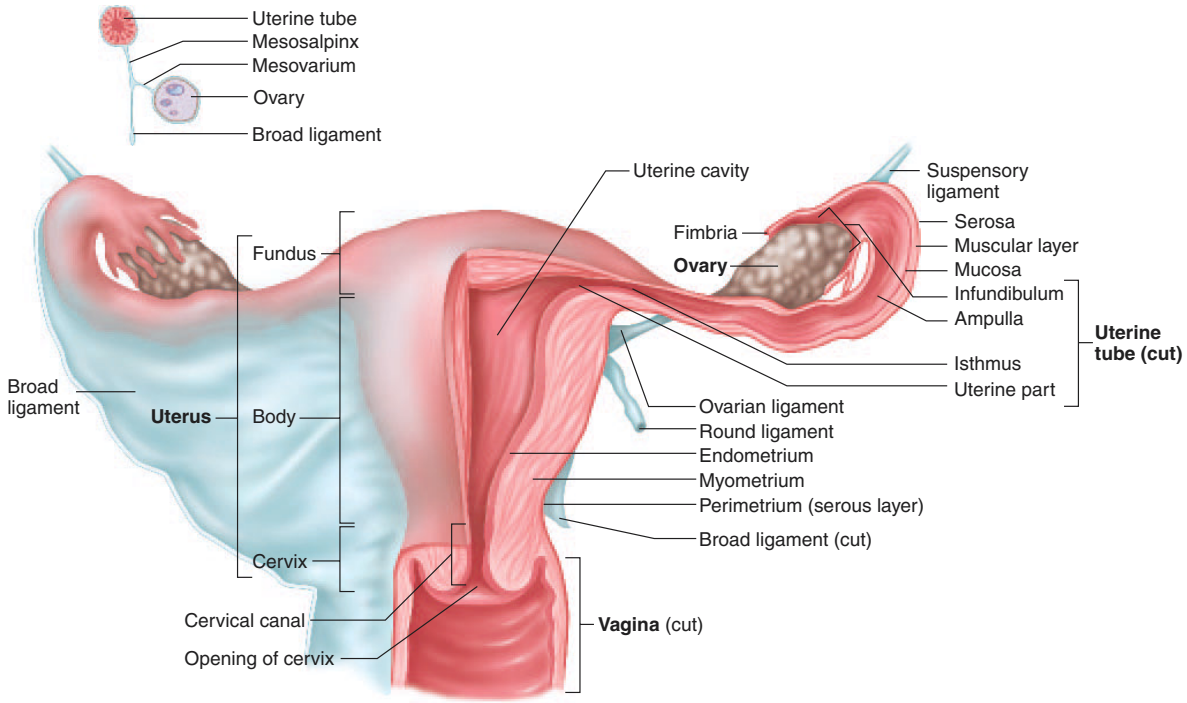


Figure 28.10 Uterus, Vagina, Uterine Tubes, Ovaries, and Supporting Ligaments

Anterior view of the uterus, uterine tubes, and associated ligaments. The uterus and uterine tubes are cut in section (on the left side), and the vagina is cut to show the internal anatomy. The inset shows the relationships between the ovary, uterine tube, and the ligaments that suspend them in the pelvic cavity.

oocytes develop. By the time of birth, many of the oogonia have degenerated, and those remaining have begun meiosis. Meiosis stops, however, during the first meiotic division at a stage called prophase I (see figure 28.13). The cell at this stage is called a **primary oocyte,** and at birth about 2 million of them are present. The primary oocyte is surrounded by a single layer of flat cells called **granulosa** (gran-ū-lō′să) **cells,** and the structure is called a **primordial follicle.** From birth to puberty, the number of primordial follicles declines to around 300,000–400,000; of these only about 400 continue oogenesis and are released from the ovary. At puberty, the cyclical secretion of FSH stimulates the further development of a small number of primordial follicles. The primordial follicle is converted to a **primary follicle** when the oocyte enlarges and the single layer of granulosa cells first becomes enlarged and cuboidal (see figure 28.11 and figure 28.12). Subsequently, several layers of granulosa cells form, and a layer of clear material is deposited around the primary oocyte called the **zona pellucida** (zō′nă pe-loo′si-dă).

Some of the primary follicles continue development and become **secondary follicles.** The granulosa cells multiply and form an increasing number of layers around the oocyte. Irregular small spaces called **vesicles,** which are fluid-filled, form among the granulosa cells. As the secondary follicle enlarges, surrounding cells are molded around it to form the **theca** (thē′kă), or **capsule.** Two layers of thecae can be recognized around the secondary follicle: the vascular **theca interna** and the fibrous **theca externa** (see figure 28.11).

The secondary follicle continues to enlarge, and, when the fluid-filled vesicles fuse to form a single fluid-filled chamber called the **antrum** (an′trŭm), the follicle is called the **mature,** or **graafian** (graf′ē-ăn), **follicle.** The antrum progressively increases in size and fills with additional fluid, and the follicle forms a lump on the surface of the ovary after reaching its maximum size (see figure 28.11).

As the antrum forms, it's filled with fluid produced by the granulosa cells. The oocyte is pushed off to one side of the follicle and lies in a mass of follicular cells called the **cumulus mass,** or **cumulus oophorus** (kū′mū-lŭs ō-of′ōr-ŭs; see figure 28.11). The innermost cells of this mass resemble a crown radiating from the oocyte and are thus called the **corona radiata.**

Usually, only one graafian follicle reaches the most advanced stages of development and is ovulated. The other follicles degenerate. In a mature follicle, just before ovulation, the primary oocyte completes the first meiotic division to produce a **secondary oocyte**

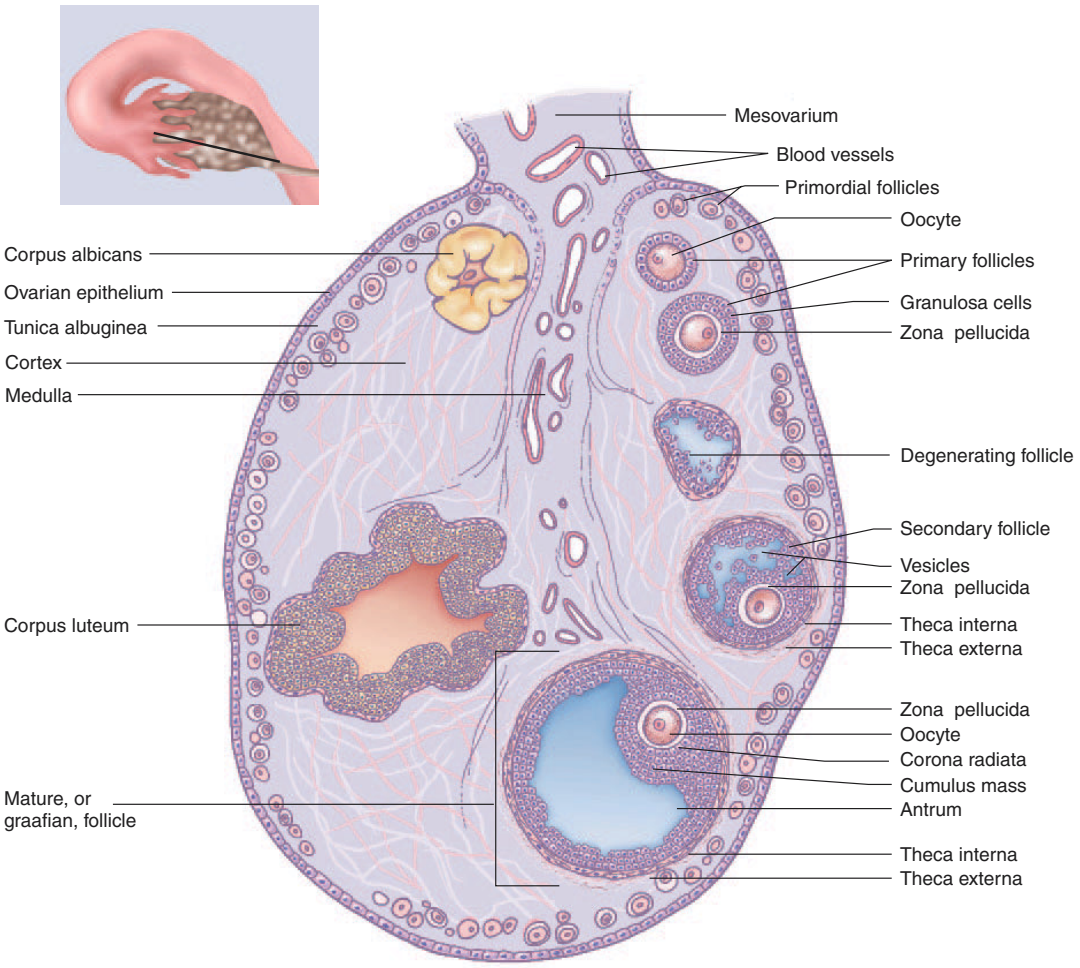


Figure 28.11 Histology of the Ovary

The ovary is sectioned to illustrate its internal structure (inset shows plane of section). Ovarian follicles from each major stage of development are present.

and a **polar body** (figure 28.13). Division of the cytoplasm is unequal, and most of it goes to the secondary oocyte, whereas the polar body receives very little. The secondary oocyte begins the second meiotic division, which stops in metaphase II.

Ovulation

As the mature follicle continues to swell, it can be seen on the surface of the ovary as a tight, translucent blister. The follicular cells secrete a thinner fluid than previously and at an increased rate so that the follicle swells more rapidly than can be accommodated by follicular growth. As a result, the granulosa cells and theca become very thin over the area exposed to the ovarian surface.

The mature follicle expands and ruptures, forcing a small amount of blood and follicular fluid out of the vesicle. Shortly after this initial burst of fluid, the secondary oocyte, surrounded by the cumulus mass and the zona pellucida, escapes from the follicle. The release of the secondary oocyte is called **ovulation** (ov′ū-lā′shŭn, ō′vū-lā′shŭn).

During ovulation, development of the secondary oocyte has stopped at metaphase II. If sperm cell penetration doesn't occur, the secondary oocyte never completes this second division and simply degenerates and passes out of the system. Continuation of the second meiotic division is triggered by **fertilization,** the entry of a sperm cell into the secondary oocyte. Once the sperm cell penetrates the secondary oocyte, the second meiotic division is completed, and a second polar body is formed. The fertilized oocyte is now called a **zygote** (zī′gōt; see figure 28.13).

Fate of the Follicle

After ovulation, the follicle still has an important function. It becomes transformed into a glandular structure called the **corpus luteum** (kōr′pŭs loo′tē-ŭm; yellow body), which has a convoluted

1. The primordial follicle consists of an oocyte surrounded by a single layer of squamous granulosa cells.

2. A primordial follicle becomes a primary follicle as the granulosa cells become enlarged and cuboidal.

3. The primary follicle enlarges. Granulosa cells form more than one layer of cells. The zona pellucida forms around the oocyte.

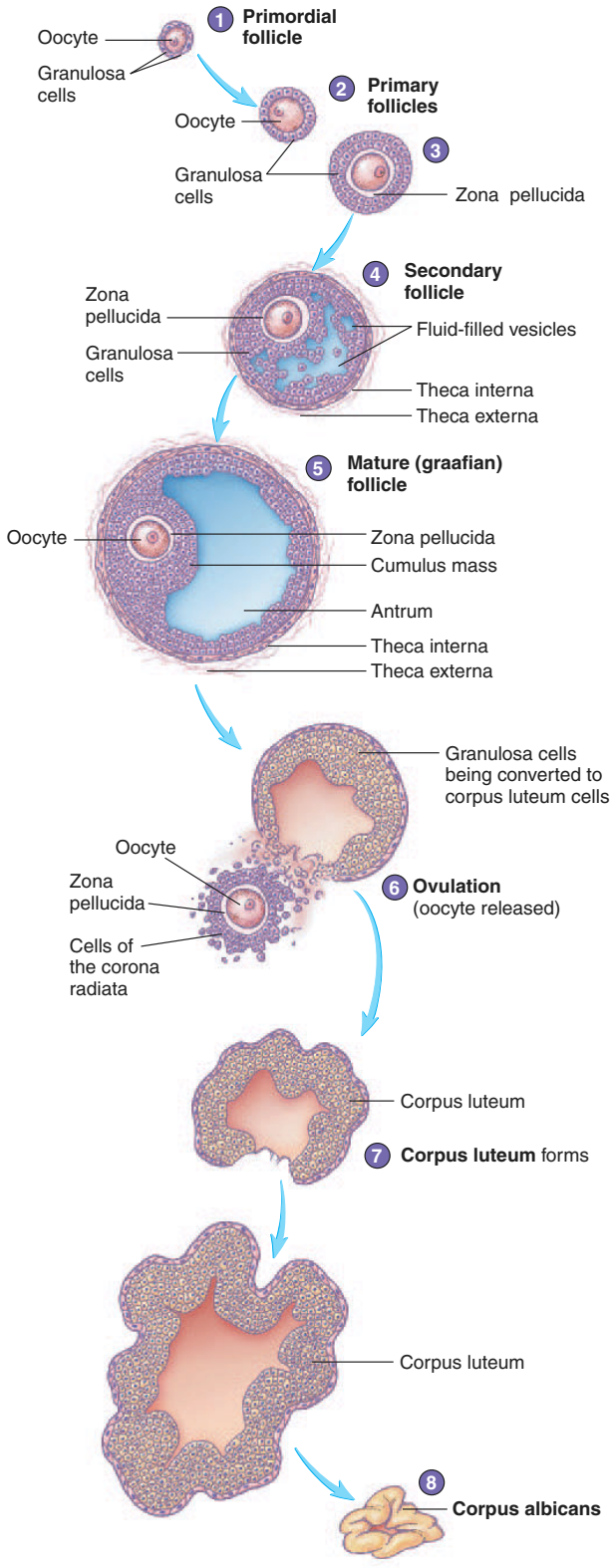
4. A secondary follicle forms when fluid-filled vesicles (spaces) develop among the granulosa cells and a well-developed theca becomes apparent around the granulosa cells.

5. A mature follicle forms when the fluid-filled vesicles form a single antrum. When a follicle becomes fully mature, it is enlarged to its maximum size, a large antrum is present, and the oocyte is located in the cumulus mass.

6. During ovulation the oocyte is released from the follicle, along with some surrounding granulosa cells of the cumulus mass called the corona radiata.

7. Following ovulation, the granulosa cells divide rapidly and enlarge to form the corpus luteum.

8. When the corpus luteum degenerates, it forms the corpus albicans.



Process Figure 28.12 Maturation of the Follicle and Oocyte

1. Oogonia are the cells from which oocytes arise. The oogonia divide by mitosis to produce other oogonia and primary oocytes.

2. Five million oogonia may be produced by the 4th month of prenatal life. Primary oocytes begin the first meiotic division but stop at prophase I. All of the primary oocytes remain in this state until puberty.

3. The first meiotic division is completed in a single mature follicle just before ovulation during each menstrual cycle. A secondary oocyte and the first polar body result from the unequal division of the cytoplasm.

4. The secondary oocyte begins the second meiotic division but stops at metaphase II.

5. The second meiotic division is completed after ovulation and after a sperm cell unites with the secondary oocyte. A secondary oocyte and a second polar body are formed.

6. Fertilization is completed after the nuclei of the secondary oocyte and the sperm cell unite. The resulting cell is called a zygote.

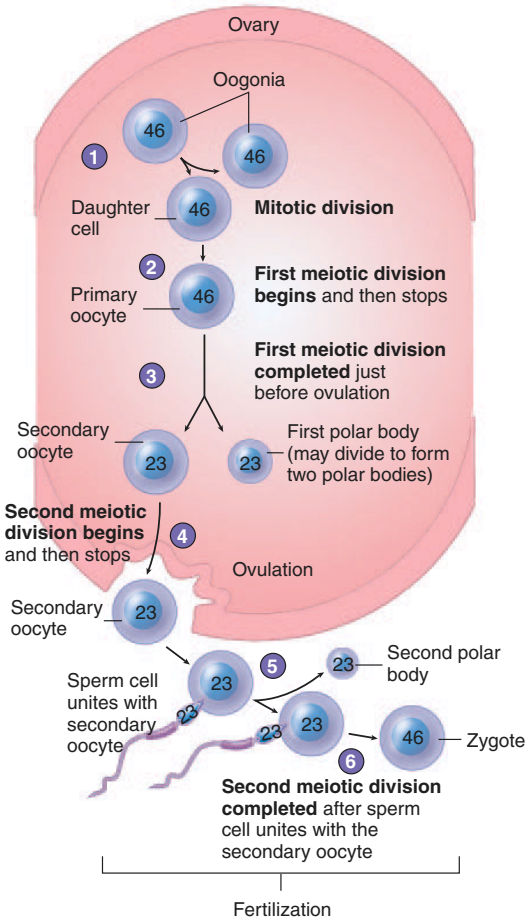


Figure 28.13 Maturation and Fertilization of the Oocyte

The primary oocyte undergoes meiosis and gives off the first polar body to become a secondary oocyte just before ovulation. Sperm cell penetration initiates the completion of the second meiotic division and the expulsion of a second polar body. The nuclei of the oocyte and the sperm cell unite. Fertilization results in the formation of a zygote.

appearance as a result of its collapse after ovulation (see figure 28.12). The granulosa cells and the theca interna, now called **luteal cells,** enlarge and begin to secrete hormones—progesterone and smaller amounts of estrogen.

If pregnancy occurs, the corpus luteum enlarges and remains throughout pregnancy as the **corpus luteum of pregnancy.** If pregnancy does not occur, the corpus luteum remains functional for about 10–12 days and then begins to degenerate. Progesterone and estrogen secretion decreases, and connective tissue cells become enlarged and clear, giving the whole structure a whitish color; it is, therefore, called the **corpus albicans** (al′bĭ-kanz; white body). The corpus albicans continues to shrink and eventually disappears after several months or even years.

19. *Name and describe the ligaments that hold the ovaries in place.*
20. *Describe the coverings and structure of the ovary.*
21. *Starting with the oogonia, describe the development and production of a mature follicle that contains a secondary oocyte.*
22. *Describe the process of ovulation.*
23. *What is the corpus luteum? What happens to the corpus luteum if fertilization occurs? If fertilization does not occur?*

Uterine Tubes

Two **uterine tubes,** also called **fallopian** (fa-lō′pē-an) **tubes,** or **oviducts** (ō′vi-dŭkts), are present. There is a uterine tube on each side of the uterus associated with an ovary (see figure 28.10). Each tube is located along the superior margin of the broad ligament. The part of the broad ligament most directly associated with the uterine tube is called the **mesosalpinx** (mez′ō-sal′pinks; mesothelium of the trumpet-shaped uterine tube).

The uterine tube opens directly into the peritoneal cavity to receive the oocyte from the ovary. It expands to form the **infundibulum** (in-fŭn-dib′ū-lŭm; funnel), and long, thin processes called **fimbriae** (fim′brē-ē; fringe) surround the opening of the infundibulum. The inner surfaces of the fimbriae consist of a ciliated mucous membrane.

The part of the uterine tube that is nearest the infundibulum is called the **ampulla.** It's the widest and longest part of the tube and accounts for about 7.5–8 cm of the total 10 cm length of the tube. The part of the uterine tube nearest the uterus, the **isthmus,** is much narrower and has thicker walls than does the ampulla. The **uterine,** or **intramural, part** of the tube passes through the uterine wall and ends in a very small uterine opening.

The wall of each uterine tube consists of three layers (see figure 28.10). The outer **serosa** is formed by the peritoneum, the middle **muscular layer** consists of longitudinal and circular smooth muscle cells, and the inner **mucosa** consists of a mucous membrane of simple ciliated columnar epithelium. The mucosa is arranged into numerous longitudinal folds.

The mucosa of the uterine tubes provides nutrients for the oocyte, or, if fertilization has occurred, to the developing embryonic mass (see chapter 29) as it passes through the uterine tube. The ciliated epithelium helps move the small amount of fluid and the oocyte, or the developing embryonic mass, through the uterine tubes.

Uterus

The **uterus** (ū′ter-ŭs) is the size and shape of a medium-sized pear and is about 7.5 cm long and 5 cm wide (see figures 28.9 and 28.10). It's slightly flattened anteroposteriorly and is oriented in the pelvic cavity with the larger, rounded part, the **fundus** (fŭn′dŭs; bottom of a rounded flask), directed superiorly and the narrower part, the **cervix** (ser′viks; neck), directed inferiorly. The main part of the uterus, the **body,** is between the fundus and the cervix. A slight constriction called the **isthmus** marks the junction of the cervix and the body. Internally, the uterine cavity continues as the **cervical canal,** which opens through the **ostium** into the vagina.

Cancer of the Cervix

Cancer of the cervix is a relatively common type of cancer of the reproductive organs in females and fortunately can be detected and successfully treated. Early in the development of cervical cancer, the cells of the cervix change in a characteristic way. This change can be observed by taking a cell sample and examining the cells microscopically. The most common technique is to obtain a **Papanicolaou (Pap) smear,** which is named after a U.S. physician, of Greek origin, who developed the technique. Pap smears have a reliability of 90% for detecting cervical cancer.

The major ligaments holding the uterus in place are the **broad ligament,** the **round ligaments,** (see figure 28.10) and the **uterosacral ligaments.** The broad ligament is a peritoneal fold extending from the lateral margin of the uterus to the wall of the pelvis on either side. It also ensheaths the ovaries and the uterine tubes. The round ligaments extend from the uterus through the inguinal canals to the labia majora of the external genitalia, and the uterosacral ligaments attach the lateral wall of the uterus to the sacrum. Normally, the uterus is anteverted, meaning that the body of the uterus is tipped slightly anteriorly. In some women, the uterus is retroverted, or tipped posteriorly. In addition to the ligaments, skeletal muscles of the pelvic floor provide much support inferiorly to the uterus. If these muscles are weakened (e.g., in childbirth), the uterus can extend inferiorly into the vagina, a condition called a **prolapsed uterus.**

The uterine wall is composed of three layers: perimetrium (serous), myometrium, and endometrium (see figure 28.10). The **perimetrium** (per-i-mē′trē-ŭm), or **serous layer,** of the uterus is the peritoneum that covers the uterus. The next layer, just deep to the perimetrium, is the **myometrium** (mī′ō-mē′trē-ŭm), or **muscular layer,** which consists of a thick layer of smooth muscle. The myometrium accounts for the bulk of the uterine wall and is the thickest layer of smooth muscle in the body. In the cervix, the muscular layer contains less muscle and more dense connective tissue. The cervix is, therefore, more rigid and less contractile than the rest of the uterus. The innermost layer of the uterus is the **endometrium** (en′dō-mē′trē-ŭm), or **mucous membrane.** The endometrium consists of a simple columnar epithelial lining and a connective tissue, the lamina propria. Simple tubular glands are scattered about the lamina propria and open through the epithelium into the uterine cavity. The endometrium consists of two layers: a thin, deep **basal layer,** which is the deepest part of the lamina propria and is continuous with the myometrium; and a thicker, superficial **functional layer,** which consists of most of the lamina propria and the endothelium, and lines the cavity itself. The functional layer is so named because it undergoes changes and sloughing during the female menstrual cycle.

Columnar epithelial cells line the cervical canal, which contains **cervical mucous glands.** The mucus fills the cervical canal and acts as a barrier to substances that could pass from the vagina into the uterus. Near the time of ovulation the consistency of the mucus changes, making the passage of sperm cells from the vagina into the uterus easier.

Vagina

The **vagina** (vă-jī′nă) is a tube about 10 cm long that extends from the uterus to the outside of the body (see figure 28.10). The vagina is the female organ of copulation, functioning to receive the penis during intercourse, and it allows menstrual flow and childbirth. Longitudinal ridges called **columns** extend the length of the anterior and posterior vaginal walls, and several transverse ridges called **rugae** (roo′gē) extend between the anterior and posterior columns. The superior, domed part of the vagina, the **fornix** (fōr′niks; domed), is attached to the sides of the cervix so that a part of the cervix extends into the vagina.

The wall of the vagina consists of an outer muscular layer and an inner mucous membrane. The muscular layer is smooth muscle that allows the vagina to increase in size to accommodate the penis during intercourse and to stretch greatly during childbirth. The mucous membrane is moist stratified squamous

epithelium that forms a protective surface layer. The vaginal mucous membrane releases most of the lubricating secretions produced by the female during intercourse.

A thin mucous membrane called the **hymen** (hī′men) covers the **vaginal opening,** or **orifice.** Sometimes, the hymen completely closes the vaginal opening (a condition called imperforate hymen), and it must be removed to allow menstrual flow. More commonly, the hymen is perforated by one or several holes. The openings in the hymen are usually greatly enlarged during the first sexual intercourse. In addition, the hymen can be perforated or torn at some earlier time in a young woman's life, such as during strenuous physical exercise. Thus, the absence of an intact hymen doesn't necessarily indicate that a woman has had sexual intercourse, as was once thought.

24. *Describe the structures of the uterine tube. How are they involved in moving the oocyte or the zygote?*
25. *Name the parts of the uterus. Describe the layers of the uterine wall.*
26. *Describe the major ligaments holding the uterus in place.*
27. *Where is the vagina located? Describe the layers of the vaginal wall. What are rugae and columns? What is the hymen?*

External Genitalia

The external female genitalia, also referred to as the **vulva** (vŭl′vă) or **pudendum** (pū-den′dŭm), consist of the vestibule and its surrounding structures (figure 28.14). The **vestibule** (ves′ti-bool) is the space into which the vagina opens posteriorly and the urethra opens anteriorly. A pair of thin, longitudinal skin folds called the **labia** (lā′bē-ă; lips) **minora** (sing., labium minus) form borders on each side of the vestibule. A small erectile structure called the **clitoris** (klit′ō-ris) is located in the anterior margin of the vestibule.

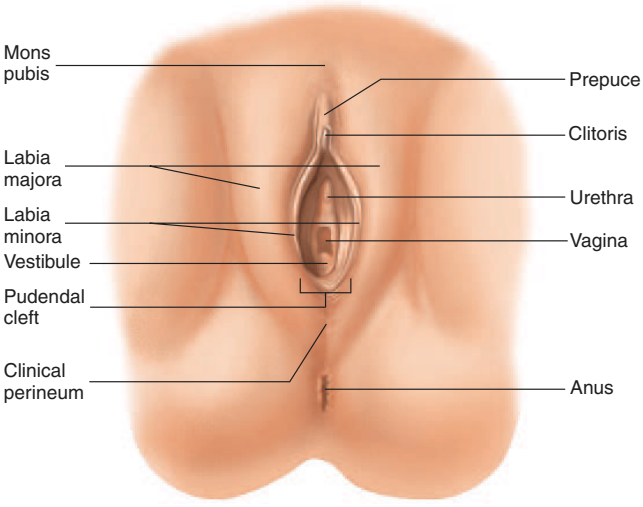


Figure 28.14 Female External Genitalia

Anteriorly, the two labia minora unite over the clitoris to form a fold of skin called the **prepuce.**

The clitoris is usually less than 2 cm in length and consists of a shaft and a distal glans. It's well supplied with sensory receptors and functions to initiate and intensify levels of sexual tension. The clitoris contains two erectile structures, the **corpora cavernosa,** each of which expands at the base end of the clitoris to form the **crus of the clitoris** and attaches the clitoris to the coxae. The corpora cavernosa of the clitoris are comparable to the corpora cavernosa of the penis, and they become engorged with blood as a result of sexual excitement. In most women, this engorgement results in an increase in the diameter, but not the length, of the clitoris. With increased diameter, the clitoris makes better contact with the prepuce and surrounding tissues and is more easily stimulated.

Erectile tissue that corresponds to the corpus spongiosum of the male lies deep to and on the lateral margins of the vestibular floor on either side of the vaginal orifice. Each erectile body is called a **bulb of the vestibule.** Like other erectile tissue, it becomes engorged with blood and is more sensitive during sexual arousal. Expansion of the bulbs causes narrowing of the vaginal orifice and produces better contact of the vagina with the penis during intercourse.

On each side of the vestibule, between the vaginal opening and the labia minora, is an opening of the duct of the **greater vestibular gland.** Additional small mucous glands, the **lesser vestibular glands,** or **paraurethral glands,** are located near the clitoris and urethral opening. They produce a lubricating fluid that helps to maintain the moistness of the vestibule.

Lateral to the labia minora are two prominent, rounded folds of skin called the **labia majora.** Subcutaneous fat is primarily responsible for the prominence of the labia majora. The two labia majora unite anteriorly in an elevation over the symphysis pubis called the **mons pubis** (monz; mound; pū′bis). The lateral surfaces of the labia majora and the surface of the mons pubis are covered with coarse hair. The medial surfaces are covered with numerous sebaceous and sweat glands. The space between the labia majora is called the **pudendal** (pū-den′dăl) **cleft.** Most of the time, the labia majora are in contact with each other across the midline, closing the pudendal cleft and concealing the deeper structures within the vestibule.

Perineum

The **perineum,** as in the male, is divided into two triangles by the superficial and deep transverse perineal muscles (figure 28.15). The anterior, urogenital triangle contains the external genitalia, and the posterior, anal triangle contains the anal opening. The region between the vagina and the anus is the **clinical perineum.** The skin and muscle of this region can tear during childbirth. To prevent such tearing, an incision called an **episiotomy** (e-piz-ē-ot′ō-mē, e-pis-ē-ot′ō-mē) is sometimes made in the clinical perineum. This clean, straight incision is easier to repair than a tear would be. Alternatively, allowing the perineum to stretch slowly during the delivery may prevent tearing, thereby making an episiotomy unnecessary.

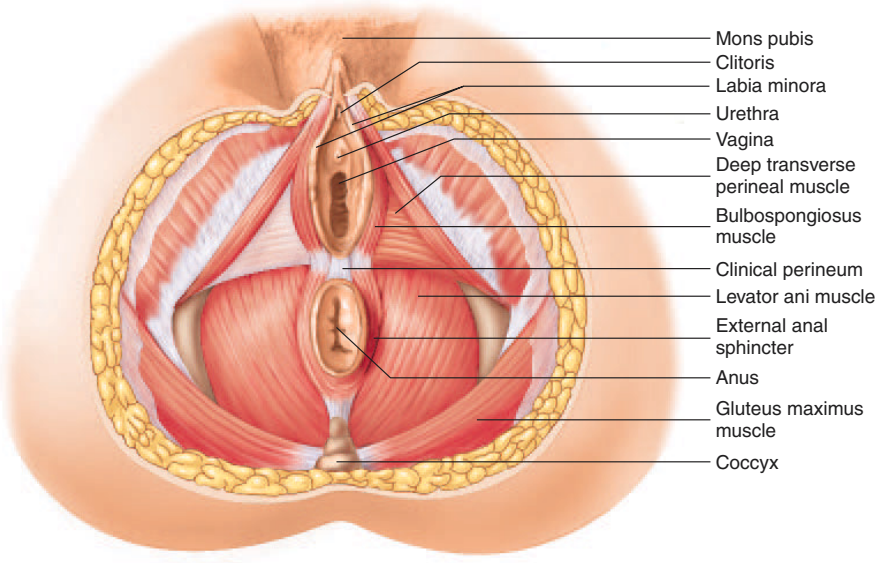


Figure 28.15 Inferior View of the Female Perineum

Mammary Glands

The **mammary glands** are the organs of milk production and are located within the **mammae** (mam′ē), or **breasts** (figure 28.16). The mammary glands are modified sweat glands. Externally, the breasts of both males and females have a raised **nipple** surrounded by a circular, pigmented **areola** (ă-rē′ō-lă). The areolae normally have a slightly bumpy surface caused by the presence of rudimentary mammary glands, called **areolar glands,** just below the surface. Secretions from these glands protect the nipple and the areola from chafing during nursing.

In prepubescent children, the general structure of the breasts is similar, and both males and females possess a rudimentary glandular system, which consists mainly of ducts with sparse alveoli. The female breasts begin to enlarge during puberty, primarily under the influence of estrogen and progesterone. Increased sensitivity or pain in the breasts often accompanies this enlargement. Males often experience these same sensations during early puberty, and their breasts can even develop slight swellings; however, these symptoms usually disappear fairly quickly. On rare occasions, the breasts of a male become enlarged, a condition called **gynecomastia** (gī′nĕ-kō-mas′tē-ă).

Each adult female mammary gland usually consists of 15–20 glandular **lobes** covered by a considerable amount of adipose tissue. It is primarily this superficial fat that gives the breast its form. The lobes of each mammary gland form a conical mass, with the nipple located at the apex. Each lobe possesses a single **lactiferous** (lak-tif′er-ŭs; milk-producing) **duct,** which opens independently of other lactiferous ducts on the surface of the nipple. Just deep to the surface, each lactiferous duct enlarges to form a small, spindle-shaped **lactiferous sinus,** which accumulates milk during milk production. The lactiferous duct supplying a lobe subdivides to

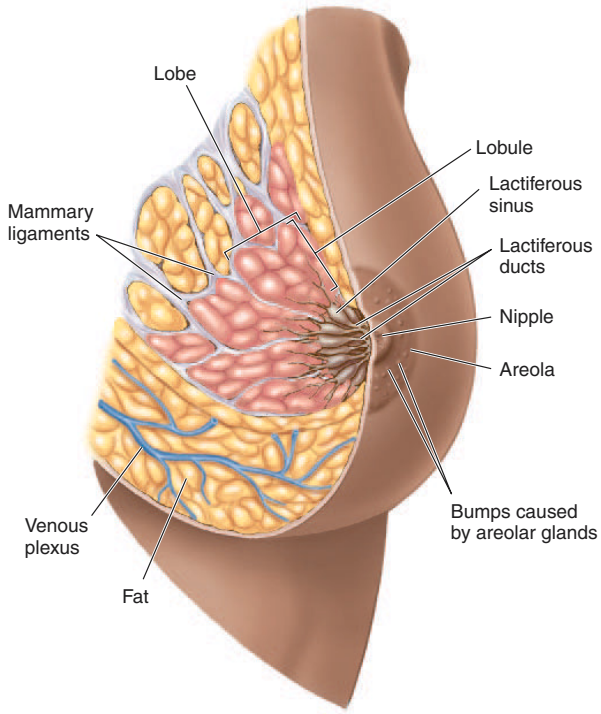


Figure 28.16 Anatomy of the Breast

The section illustrates the blood supply, the mammary glands, and the duct system.

form smaller ducts, each of which supplies a **lobule.** Within a lobule, the ducts branch and become even smaller. In the milk-producing breast, the ends of these small ducts expand to form secretory sacs called **alveoli.**

A group of **mammary,** or **Cooper's, ligaments** support and hold the breasts in place. These ligaments extend from the fascia over the pectoralis major muscles to the skin over the mammary glands and prevent the breasts from excessive sagging. In older adults, however, these ligaments weaken and elongate, allowing the breasts to sag to a greater extent than when the person was younger.

The nipples are very sensitive to tactile stimulation and contain smooth muscle cells that contract, causing the nipple to become erect in response to stimulation. These smooth muscle cells respond, like other erectile tissues, during sexual arousal.

28. *What are the vulva, pudendum, and vestibule?*
29. *What erectile tissue is in the clitoris and bulb of the vestibule? What is the function of the clitoris and bulb of the vestibule?*
30. *Describe the labia minora, the prepuce, the labia majora, the pudendal cleft, and the mons pubis.*
31. *Where are the greater and lesser vestibular glands located? What is their function?*
32. *Define the term perineum. What is the anterior clinical perineum? Define and give the purpose of an episiotomy.*
33. *Describe the route taken by a drop of milk from its site of production to the outside of the body. What are Cooper's ligaments?*

Fibrocystic Changes and Cancer of the Breast

Fibrocystic changes in the breast are benign changes. They include the formation of fluid filled cysts, hyperplasia of the duct system of the breast, and deposition of fibrous connective tissue. These changes occur in approximately 10% of women who are less than 21 years of age, 25% of women in their reproductive years, and 50% of women who are postmenopausal. The cause of the condition is not known. Major manifestations are breast pain, especially during the luteal phase of the menstrual cycle and continuing until menstruation. Some evidence suggest that some women with certain types of duct hyperplasia, when associated with a family history of breast cancer, have an increased likelihood of developing breast cancer.

Cancer of the breast is a serious, often fatal disease in women. Risk factors include a family history of breast cancer, early menarche, late menopause, obesity, radiation of the chest, abnormal cells in fibrocystic disease, and hormone replacement therapy. The use of mammography and regular self-examination of the breast can help in early detection and effective treatment of breast cancer. Women who have inherited specific gene mutations have increased risk of breast cancer. Prophylactic removal of the breasts in women who are identified, based on genetic analysis, as likely to develop breast cancer may result in a longer life expectancy for these women.

Physiology of Female Reproduction

Objective

- *Explain the timetable for the typical menstrual cycle.*

As in the male, female reproduction is under the control of hormonal and nervous regulation. Development of the female reproductive organs and normal function depend on a number of hormones in the body.

Puberty

During puberty, females experience their first episode of menstrual bleeding, which is called **menarche** (me-nar′kē), which generally begins between 11 and 13 years of age and is generally completed by 16 years of age. The vagina, uterus, uterine tubes, and external genitalia begin to enlarge. Fat is deposited in the breasts and around the hips, causing them to enlarge and assume an adult form. The ducts of the breasts develop, pubic and axillary hair grows, and the voice changes, although this is a more subtle change than in males. Development of sexual drive is also associated with puberty.

Elevated rates of estrogen and progesterone secretion by the ovaries are primarily responsible for the changes associated with puberty. Before puberty, estrogen and progesterone are secreted in very small amounts. LH and FSH levels also remain very low. The low secretory rates are due to a lack of GnRH released from the hypothalamus. At puberty, not only are GnRH, LH, and FSH secreted in greater quantities than before puberty, but the adult pattern is established in which a cyclic pattern of FSH and LH secretion occurs. The cyclic secretion of LH and FSH, ovulation, the monthly changes in secretion of estrogen and progesterone, and the resultant changes in the uterus characterize the menstrual cycle.

Menstrual Cycle

The term **menstrual** (men′stroo-ăl) **cycle** technically refers to the cyclic changes that occur in sexually mature, nonpregnant females and culminate in menses. Typically, the menstrual cycle is about 28 days long, although it can be as short as 18 days in some women and as long as 40 days in others (figure 28.17 and table 28.2). The term **menses** (men′sēz) is derived from a Latin word meaning month. It is a period of mild hemorrhage, which occurs approximately once each month, during which the uterine epithelium is sloughed and expelled from the uterus. **Menstruation** (men-stroo-ā′shŭn) is the discharge of the blood and elements of the uterine mucous membrane. Although the term *menstrual cycle* refers specifically to changes that occur in the uterus, several other cyclic changes are associated with it, and the term is often used to refer to all of the cyclic events that occur in the female reproductive system. These changes include the cyclic changes in hormone secretion, in the ovary, and in the uterus.

The first day of menses is day 1 of the menstrual cycle, and menses typically lasts 4–5 days. Ovulation occurs on about day 14 of a 28-day menstrual cycle, although the timing of ovulation varies from individual to individual and varies within a single individual from one menstrual cycle to the next. The time between

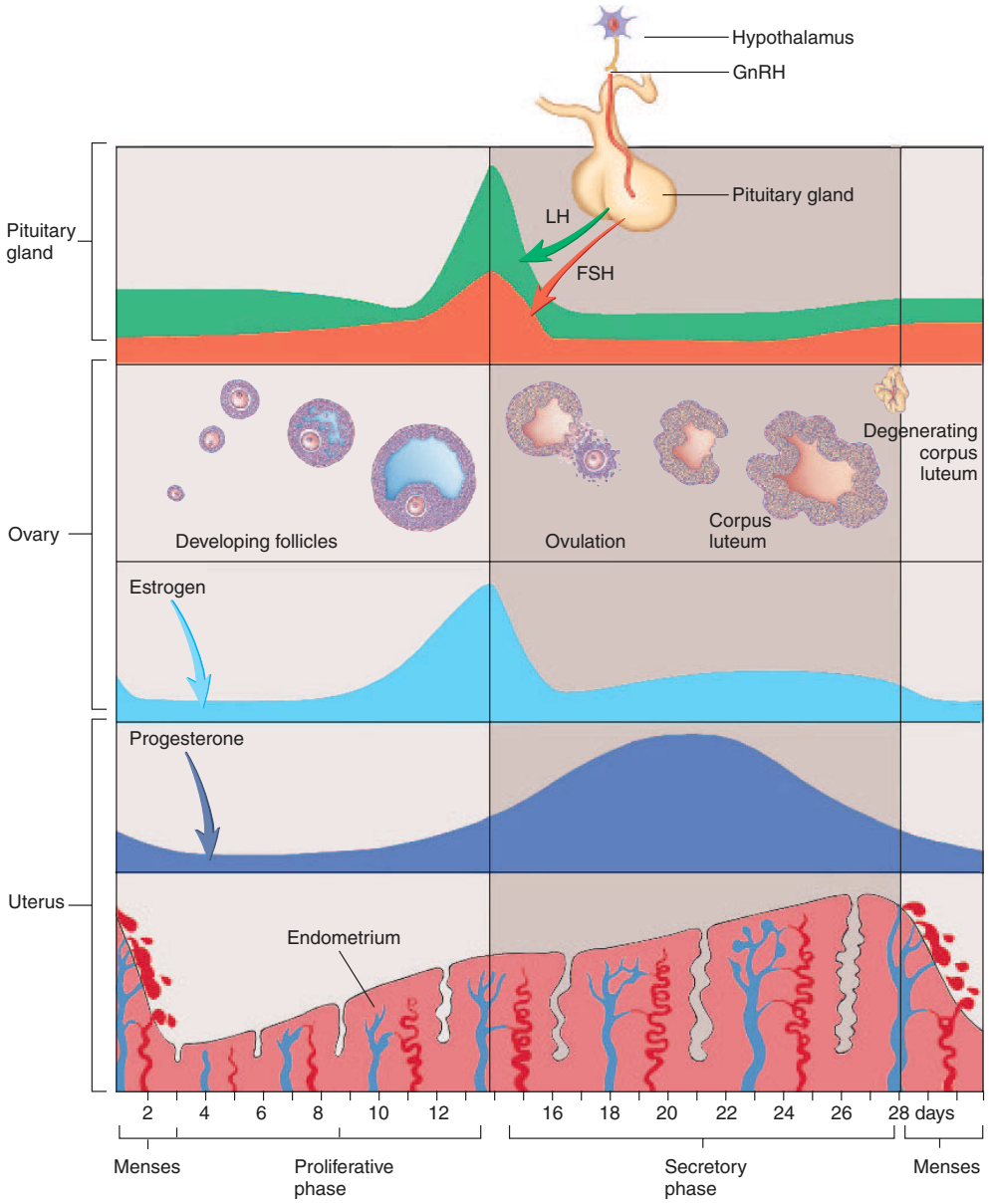


Figure 28.17 The Menstrual Cycle

The various lines depict the changes in blood hormone levels, the development of the follicles, and the changes in the endometrium during the cycle.

ovulation, on day 14, and the next menses is typically 14 days. The time between the first day of menses and the day of ovulation is more variable than the time between ovulation and the next menses. The time between the ending of menses and ovulation is called the **follicular phase,** because of the rapid development of ovarian follicles, or the **proliferative phase,** because of the rapid proliferation of the uterine mucosa. The period after ovulation and before the next menses is called the **luteal phase,** because of the existence of the corpus luteum, or the **secretory phase,** because of maturation of and secretion by uterine glands.

- *34. What is menarche? What other changes occur at puberty?*
- *35. For a typical menstrual cycle, which day is the first day of menses? Which day is ovulation, usually?*

Table 28.2 The Menstrual Cycle

Menses	Proliferative Phase	Ovulation	Secretory Phase
Pituitary Hormones			
LH levels are low and remain low; FSH increases somewhat.	LH and FSH levels begin to increase rapidly in response to increases in estrogen near the end of the proliferative phase.	Increasing levels of LH trigger ovulation. Ovulation generally occurs after LH levels have reached their peak. FSH reaches a peak about the time of ovulation and initiates development of follicles that may complete maturation during a later cycle.	LH and FSH levels decline to low levels following ovulation and remain at low levels during the secretory phase in response to increases in estrogen and progesterone.
Developing Follicles			
FSH secreted during menses causes several follicles to begin to enlarge.	Several follicles continue to enlarge. As they enlarge, they begin to secrete estrogen. In addition, many of them degenerate. Only one of the follicles becomes a mature follicle that is capable of ovulating by the end of the proliferative phase.	Normally, a single follicle reaches maturity and ovulates in response to LH. The oocyte and some cumulus cells are released during ovulation.	Following ovulation, the granulosa cells of the ovulated follicle change to luteal cells and begin secreting large amounts of progesterone and some estrogen.
Estrogen			
The ovarian follicles secrete very little estrogen.	Near the end of the proliferative phase, the enlarging follicles begin to secrete increasing amounts of estrogen. The estrogen causes the pituitary gland to secrete increasing quantities of LH and smaller quantities of FSH. The positive-feedback relationship between estrogen and LH results in rapidly increasing LH and estrogen levels several days prior to ovulation. The rapid increase in LH triggers ovulation.	Estrogen, secreted by developing follicles, reaches a peak at ovulation.	Following ovulation, estrogen levels decline. After the luteal cells have been established, smaller amounts of estrogen are secreted by the corpus luteum.
Progesterone			
The ovarian follicles secrete very little progesterone.	Progesterone levels are low during the proliferative phase.	Progesterone levels are low.	Following ovulation, progesterone levels increase due to the secretion of progesterone by the corpus luteum. Progesterone levels remain high throughout the secretory phase and fall rapidly just before menses unless pregnancy occurs.
Uterine Endometrium			
The endometrium of the uterus undergoes necrosis and is eliminated in the menstrual fluid during menses. The necrosis is a result of decreasing progesterone concentrations near the end of the proliferative phase.	In response to estrogen, endometrial cells of the uterus undergo rapid cell division and proliferate rapidly. In addition, the number of progesterone receptors in the endometrial cells increases in response to estrogen.	Ovulation occurs over a short time, and it signals the end of the proliferative phase, as estrogen levels decline, and the onset of the secretory phase, as the progesterone levels begin to increase.	Progesterone causes the endometrial cells to enlarge and secrete a small amount of fluid. The endometrium continues to thicken throughout the secretory phase. Near the end of the secretory phase, declining progesterone levels allow the spiral arteries of the endometrium to constrict, causing ischemia, and the endometrium becomes necrotic unless pregnancy occurs.

Ovarian Cycle

Objectives

- *Describe the phases of the ovarian and uterine cycles.*
- *List the hormones of the female reproductive system, and explain how reproductive hormones are regulated.*
- *Discuss the effects of the ovarian hormones on the uterus.*

The **ovarian cycle** specifically refers to the events that occur in a regular fashion in the ovaries of sexually mature, nonpregnant women during the menstrual cycle. The hypothalamus and anterior pituitary release hormones that control these events. FSH from the anterior pituitary is primarily responsible for initiating the development of primary follicles, and as many as 25 begin to mature during each menstrual cycle. The follicles that start to develop in response to FSH may not ovulate during the same menstrual cycle in which they begin to mature, but they may ovulate one or two cycles later.

Although several follicles begin to mature during each cycle, normally only one is ovulated. The remaining follicles degenerate. Larger and more mature follicles appear to secrete estrogen and other substances that have an inhibitory effect on other less mature follicles.

Early in the menstrual cycle, the release of GnRH from the hypothalamus increases, and sensitivity of the anterior pituitary to GnRH increases. These changes stimulate the production and release of a small amount of FSH and LH by the anterior pituitary.

FSH and LH stimulate follicular growth and maturation and an increase in estradiol secretion by the developing follicles. FSH exerts its main effect on the granulosa cells, and LH exerts its initial effect on the cells of the theca interna and later on the granulosa cells.

LH stimulates the theca interna cells to produce androgens, which diffuse from these cells to the granulosa cells. FSH stimulates the granulosa cells to convert androgens to estrogen. In addition, FSH gradually increases LH receptors in the granulosa cells, and estrogen produced by the granulosa cells increases LH receptors in the theca interna cells. After LH receptors in the granulosa cells have increased, LH stimulates the cells to produce some progesterone, which diffuses from the granulosa cells to the theca interna cells, where it is converted to androgens. Thus, the production of androgens by the theca interna cells increases, and the conversion of androgens to estrogen by the granulosa cells is responsible for a gradual increase in estrogen secretion by these cells throughout the follicular phase, even though only a small increase in LH secretion occurs. FSH levels actually decrease during the follicular phase because developing follicles produce inhibin, and inhibin has a negative-feedback effect on FSH secretion.

As estrogen levels begin to increase in the follicular phase, they have a negative-feedback effect on the secretion of LH and FSH by the anterior pituitary. The gradual increase in estrogen levels, especially late in the follicular phase, begins to have a positive-feedback effect on LH and FSH release from the anterior pituitary. The sustained increase in estrogen is necessary for the development of the positive feedback effect. In response to this positive-feedback effect, LH and FSH secretion increase rapidly and in large amounts just before ovulation (figure 28.18). The increase in blood levels of both LH and FSH is called the **LH surge,** and the increase in FSH is called the **FSH surge.** The LH surge occurs several hours earlier and to a greater degree than the FSH surge, and the LH surge can last up to 24 hours.

The LH surge initiates ovulation and causes the ovulated follicle to become the corpus luteum. FSH can make the follicle more sensitive to the influence of LH by stimulating the synthesis of additional LH receptors in the follicles and by stimulating the development of follicles that may ovulate during later ovarian cycles.

The LH surge causes the primary oocyte to complete the first meiotic division just before or during the process of ovulation. Also, the LH surge triggers several events that are very much like inflammation in the mature follicle and that result in ovulation. The follicle becomes edematous, proteolytic enzymes cause the degeneration of the ovarian tissue around the follicle, the follicle ruptures, and the oocyte and some surrounding cells are slowly extruded from the ovary.

Shortly after ovulation, production of estrogen by the follicle decreases, and production of progesterone increases as granulosa cells are converted to corpus luteum cells. After the corpus luteum forms, progesterone levels become much higher than before ovulation, and some estrogen is produced also. The increased progesterone and estrogen have a negative-feedback effect on GnRH release from the hypothalamus. As a result, LH and FSH release from the anterior pituitary decreases. Estrogen and progesterone cause down-regulation of GnRH receptors in the anterior pituitary, and the anterior pituitary cells become less sensitive to GnRH. Because of the decreased secretion of GnRH and decreased sensitivity of the anterior pituitary to GnRH, the rate of LH and FSH secretion declines to very low levels after ovulation (see figures 28.17 and 28.18).

If fertilization of the ovulated oocyte does take place, the developing embryonic mass begins to secrete the LH-like substance **human chorionic gonadotropin (HCG),** which keeps the corpus luteum from degenerating. As a result, blood levels of estrogen and progesterone do not decrease, and menses does not occur. If fertilization does not occur, HCG is not produced. The cells of the corpus luteum begin to atrophy after day 25 or 26, and the blood levels of estrogen and progesterone decrease rapidly, which results in menses.

36. *Describe the events of the ovarian cycle. What role do FSH and LH play in the ovarian cycle?*
37. *Describe how the cyclic increase and decrease in FSH and LH is produced.*
38. *Where is HCG produced, and what effect does it have on the ovary?*

PREDICT 3

Predict the effect on the ovarian cycle of administering a relatively large amount of estrogen and progesterone just before the preovulatory LH surge. Also predict the consequences of continually administering high concentrations of GnRH.

Uterine Cycle

The term **uterine cycle** refers to changes that occur primarily in the endometrium of the uterus during the menstrual cycle (see figure 28.17). Other, more subtle changes also occur in the vagina and other structures during the menstrual cycle. Cyclic secretions of estrogen and progesterone are the primary cause of these changes.

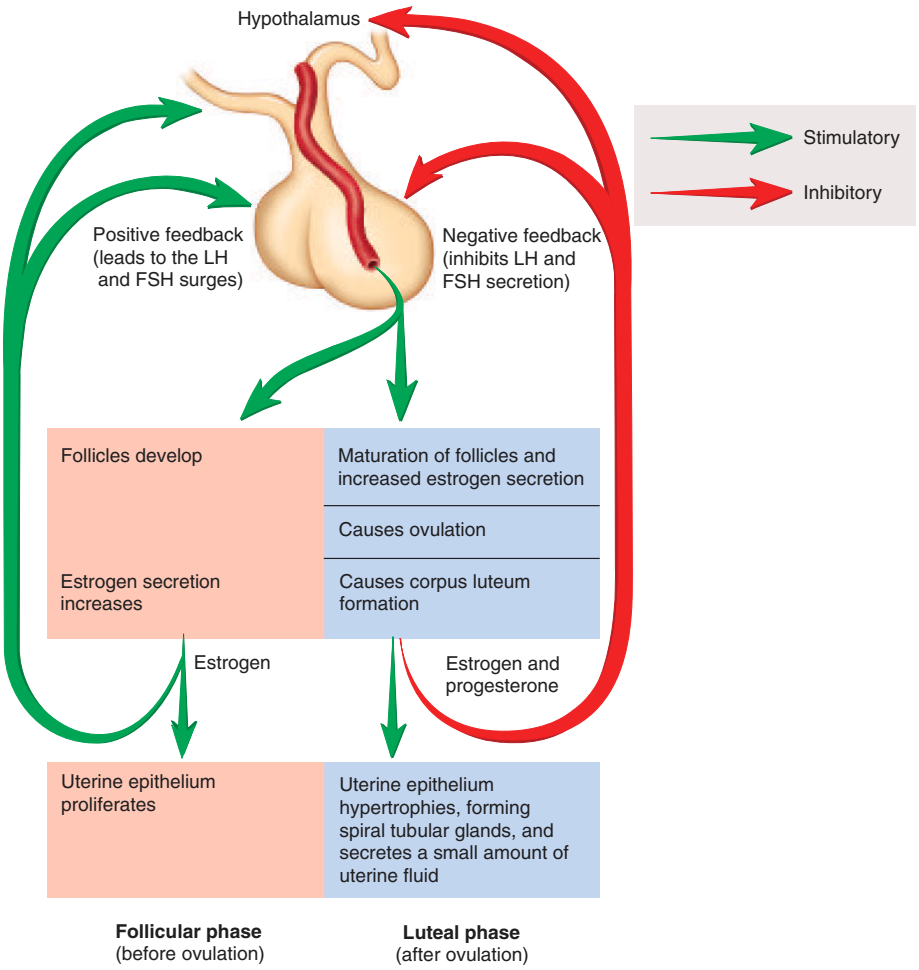


Figure 28.18 Regulation of Hormone Secretion during the Menstrual Cycle

The regulation of hormone secretion from the anterior pituitary and the ovary during the menstrual cycle before and after ovulation is depicted. Before ovulation there is an increase in FSH secretion which stimulates follicles to develop and estrogen secretion. Estrogen causes the endometrium to proliferate and the hypothalamus to increase LH secretion, which results in the LH surge prior to ovulation. The LH surge causes a follicle to mature and ovulate. The corpus luteum develops and secretes progesterone and some estrogen. The progesterone causes hypertrophy of the endometrium and has a negative feedback effect on LH and FSH secretion. The corpus luteum continues to secrete progesterone for approximately 12 days after ovulation.

The endometrium of the uterus begins to proliferate after menses. The remaining epithelial cells rapidly divide and replace the cells of the functional layer that were sloughed during the last menses. A relatively uniform layer of low cuboidal endometrial cells is produced. It later becomes columnar, and is folded to form tubular **spiral glands.** Blood vessels called **spiral arteries** project through the delicate connective tissue that separates the individual spiral glands to supply nutrients to the endometrial cells. After ovulation, the endometrium becomes thicker, and the spiral glands develop to a greater extent and begin to secrete small amounts of a fluid rich in glycogen. Approximately 7 days after ovulation, or about day 21 of the menstrual cycle, the endometrium is prepared to receive the developing embryonic mass, if fertilization has occurred. If the developing embryonic mass arrives in the uterus too early or too late, the endometrium does not provide a suitable environment for it.

Estrogen causes the endometrial cells and, to a lesser degree, the myometrial cells to proliferate. It also makes the uterine tissue more sensitive to progesterone by stimulating the synthesis of progesterone receptor molecules within the uterine cells. After ovulation, progesterone from the corpus luteum binds to the progesterone receptors, resulting in cellular hypertrophy in the endometrium and myometrium and causing the endometrial cells to become secretory. Estrogen increases the tendency of the smooth muscle cells of the uterus to contract in response to stimuli, but progesterone inhibits smooth muscle contractions. When progesterone levels increase while estrogen levels are low, contractions of the uterine smooth muscle are reduced.

P R E D I C T 4

Predict the effect on the endometrium of maintaining high progesterone levels in the circulatory system including the period of time during which estrogen normally increases following menstruation.

If pregnancy does not occur by day 24 or 25, progesterone and estrogen levels decline to low levels as the corpus luteum degenerates. As a consequence, the uterine lining also begins to degenerate. The spiral arteries constrict in a rhythmic pattern for longer and longer periods as progesterone levels fall. As a result, all but the basal parts of the spiral glands become ischemic and then necrotic. As the cells become necrotic, they slough into the uterine lumen. The necrotic endometrium, mucous secretions, and a small amount of blood released from the spiral arteries make up the menstrual fluid. Decreases in progesterone levels and increases in inflammatory substances that stimulate myometrial smooth muscle cells cause uterine contractions that expel the menstrual fluid from the uterus through the cervix and into the vagina.

39. Name the stages of the uterine cycle, and describe the events that take place in each stage. What are the effects of estrogen and progesterone on the uterus?

Female Sexual Behavior and the Female Sex Act

Objective

- *Describe the role of the nervous system in the femalesex act.*

Sexual drive in females, like sexual drive in males, depends on hormones. The adrenal gland and other tissues, such as the liver, convert steroids like progesterone to androgens. Androgens and possibly estrogens affect cells in the brain, especially in the hypothalamus, and influence sexual behavior. Androgens and estrogen alone don't control sexual drive, however. For example, sexual drive cannot be predictably increased simply by injecting these hormones into healthy women or men. Psychologic factors also affect sexual behavior. For example, after removal of the ovaries or after menopause, many women report having an increased sex drive because they no longer fear pregnancy.

The neural pathways, both sensory and motor, involved in controlling sexual responses are the same for males and females. Sensory action potentials are conducted from the genitals to the sacral region of the spinal cord, where reflexes that govern sexual responses are integrated. Ascending pathways, primarily the spinothalamic tracts (see chapter 14), conduct sensory information through the spinal cord to the brain, and descending pathways conduct action potentials back to the sacrum. As a result, cerebral influences modulate the sacral reflexes. Motor action potentials are conducted from the spinal cord to the reproductive organs by both parasympathetic and sympathetic nerve fibers and to skeletal muscles by the somatic motor nerve fibers.

During sexual excitement, erectile tissue within the clitoris and around the vaginal opening becomes engorged with blood as a result of parasympathetic stimulation. The nipples of the breast often become erect as well. The mucous glands within the vestibule, especially the vestibular glands, secrete small amounts of mucus. Large amounts of mucuslike fluid are also extruded into the vagina through its wall, although no well-developed mucous glands are within the vaginal wall. These secretions provide lubrication that allows for easy entry of the penis into the vagina and easy movement of the penis during intercourse. Tactile stimulation of the female's genitals that occurs during sexual intercourse along with psychologic stimuli, normally triggers an orgasm. The vaginal, uterine, and perineal muscles contract rhythmically, and muscle tension increases throughout much of the body. After the sexual act a period of resolution characterized by an overall sense of satisfaction and relaxation occurs. The female can be receptive to further stimulation and can experience successive orgasms. Although orgasm is a pleasurable component of sexual intercourse, it's not necessary for females to experience an orgasm for fertilization to occur.

Menstrual Cramps, PMS, and Amenorrhea

Menstrual cramps are the result of strong myometrial contractions that occur before and during menstruation. The cramps can result from excessive prostaglandin secretion. Sloughing of the endometrium of the uterus results in an inflammation in the endometrial layer of the uterus, and prostaglandins are produced as part of the inflammatory process. Progesterone inhibits sloughing of the endometrium and contractions of uterine smooth muscle. Estrogen stimulates sloughing of the endometrium because it increases uterine smooth muscle contractions. In some women, menstrual cramps are extremely uncomfortable. Many women can alleviate painful menstruation by taking nonsterioidal anti-inflammatory drugs (NSAIDs), such as aspirin or ibuprofen, which inhibit prostaglandin biosynthesis, just before the onset of menstruation. These treatments, however, are not effective in treating all painful menstruation, especially when the causes of pain are more complicated than inflammation associated with normal menstruation, such as from tumors of the myometrium or obstruction of the cervical canal.

A topic of continuing research concerns **premenstrual syndrome (PMS).** Some women suffer from severe changes in mood that often result in aggression and other socially unacceptable behaviors prior to menses. It has been hypothesized that hormonal changes associated with the menstrual cycle trigger these mood changes. Some women appear to have been successfully treated with steroid hormones. This treatment however doesn't appear to be effective for everyone with the condition. Similarly, reducing caffeine, alcohol, sugar, and animal fat consumption helps some women. It's unclear how many women are affected by PMS. It's a controversial condition, because a precise definition of the premenstrual period is not well established, the symptoms of the condition vary among individuals and are not easily monitored, and its precise cause and the physiologic mechanisms for the condition are unknown. Whether all women diagnosed as having PMS are suffering from the same condition is unclear. Improvements in defining symptoms associated with PMS and specifically identifying individuals exhibiting characteristics of depression have resulted in improved treatment.

The absence of a menstrual cycle is called **amenorrhea** (ă-men-ō-rē'ă). If the pituitary gland doesn't function properly because of abnormal development, the woman will not begin to menstruate at puberty. This condition is called **primary amenorrhea.** In contrast, if a

woman has had normal menstrual cycles and later stops menstruating, the condition is called **secondary amenorrhea.** One cause of secondary amenorrhea is anorexia, a condition in which lack of food causes the hypothalamus to decrease GnRH secretion to levels so low that the menstrual cycle cannot occur. Female athletes or ballet dancers who have rigorous training schedules have a high frequency of secondary amenorrhea. The physical stress that can be coupled with an inadequate food intake also results in very low GnRH secretion. Increased food intake, for anorexic women, and reduced training, for women who exercise intensely, generally restores normal hormone secretion and normal menstrual cycles.

Secondary amenorrhea can result from pituitary tumors that decrease FSH and LH secretion, or from a lack of GnRH secretion from the hypothalamus. Head trauma and tumors that affect the hypothalamus can result in lack of GnRH secretion.

Secondary amenorrhea can result from a lack of normal hormone secretion from the ovaries, which can be caused by autoimmune diseases that attack the ovary or by polycystic ovarian disease, in which cysts in the ovary produce large amounts of androgen that are converted to estrogens by other tissues in the body. The increased estrogen prevents the normal cycle of FSH and LH secretion required for ovulation to occur. Other hormone-secreting tumors of the ovary can also disrupt the normal menstrual cycle and result in amenorrhea.

40. When must intercourse take place for fertilization to occur? Is an orgasm required for fertilization to occur?

Female Fertility and Pregnancy

Objective

- ***Explain what happens to the ovaries and the uterus if fertilization occurs and if it doesn't occur.***

After the sperm cells are ejaculated into the vagina during sexual intercourse, they are transported through the cervix, the body of the uterus, and the uterine tubes to the ampulla (figure 28.19). The forces responsible for the movement of sperm cells through the female reproductive tract involve the swimming ability of the sperm cells and, possibly, muscular contractions of the uterus and the uterine tubes. During sexual intercourse, oxytocin is released from the posterior pituitary of the female, and the semen introduced into the vagina contains prostaglandins. Both of these hormones stimulate smooth muscle contractions in the uterus and uterine tubes.

While passing through the vagina, uterus, and uterine tubes, the sperm cells undergo **capacitation** (kă-pas′i-tā′shŭn), a process that enables them to release acrosomal enzymes, which allow penetration of the cervical mucus, cumulus mass cells, and the oocyte plasma membrane.

The oocyte can be fertilized for up to 24 hours after ovulation, and some sperm cells remain viable in the female reproductive tract for up to 6 days although most of them have degenerated after 24 hours. For fertilization to occur successfully, sexual intercourse must, therefore, occur between 5 days before and 1 day after ovulation.

One sperm cell enters the secondary oocyte, and fertilization occurs (see chapter 29). For the next several days, a sequence of cell divisions occurs while the developing cells pass through the uterine tube to the uterus. By 7 or 8 days after ovulation, which is day 21 or 22 of the average menstrual cycle, the endometrium of the uterus is prepared for implantation. Estrogen and progesterone have caused it to reach its maximum thickness and secretory activity, and the developing embryonic mass begins to implant. The outer layer of the developing embryonic mass, the **trophoblast** (trof′ō-blast, trō′fō-blast), secretes proteolytic enzymes that digest the cells of the thickened endometrium (see chapter 29), and the mass digests its way into the endometrium.

Ectopic Pregnancy

An ectopic pregnancy results if implantation occurs anywhere other than in the uterine cavity. The most common site of ectopic pregnancy is the uterine tube. Implantation in the uterine tube eventually is fatal to the fetus and can cause the tube to rupture. The possibility of hemorrhage makes ectopic pregnancy dangerous to the mother. In rare cases, implantation can occur in the mesenteries of the abdominal cavity, and the fetus can develop normally but must be delivered by caesarean section.

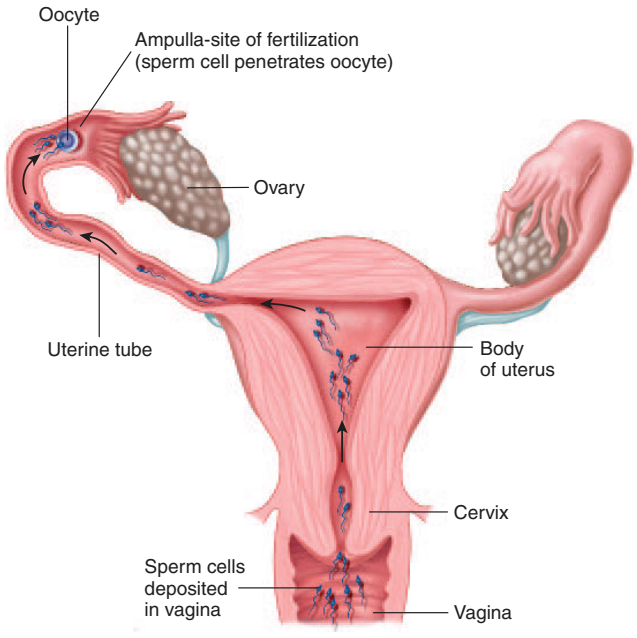


Figure 28.19 Sperm Cell Movement

Sperm cells are deposited in the vagina as part of the semen when the male ejaculates. Sperm cells pass through the cervix, the body of the uterus, and the uterine tube. Fertilization normally occurs when the oocyte is in the upper one-third of the uterine tube (the ampulla).

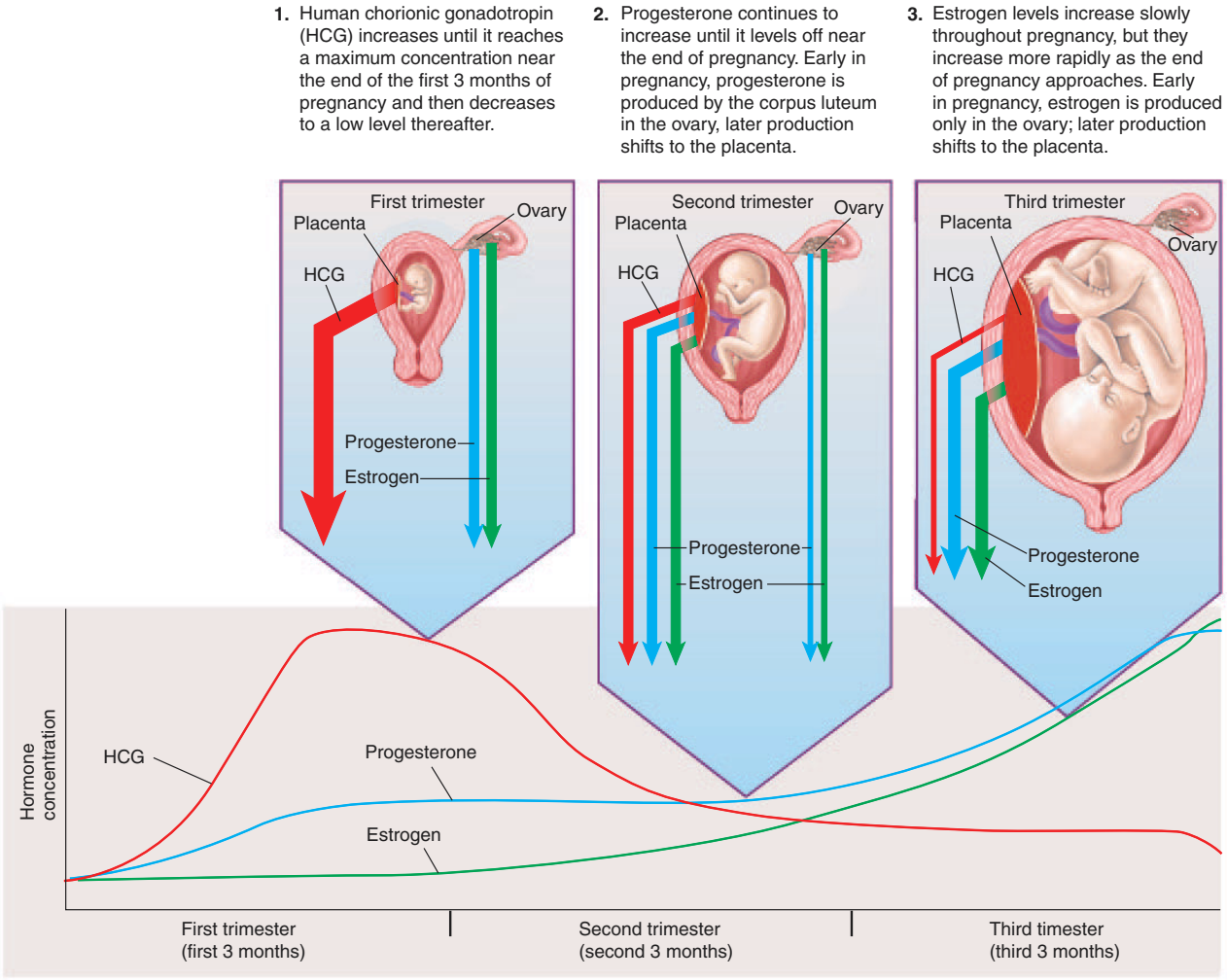


Figure 28.20 **Changes in Hormone Concentration During Pregnancy**

HCG, progesterone, and estrogens are secreted from the placenta during pregnancy. Early in pregnancy estrogen and progesterone are secreted by the ovary. During midpregnancy there is a shift toward estrogen and progesterone secretion by the placenta. Late in pregnancy these two hormones are secreted by the placenta.

The trophoblast secretes HCG, which is transported in the blood to the ovary and causes the corpus luteum to remain functional. As a consequence, both estrogen and progesterone levels continue to increase rather than decrease. The secretion of HCG increases rapidly and reaches a peak about 8–9 weeks after fertilization. Subsequently, HCG levels in the circulatory system decline to a lower level by 16 weeks and remain at a relatively constant level throughout the remainder of pregnancy. Detection of HCG excreted in the urine is the basis for some pregnancy tests.

The estrogen and progesterone secreted by the corpus luteum are essential for the maintenance of pregnancy. After the **placenta** (plă-sen′tă) forms from the trophoblast and uterine tissue, however, it also begins to secrete estrogen and progesterone. By the time the first 3 months of pregnancy are complete, the corpus luteum is no longer needed to maintain pregnancy, the placenta has become an endocrine gland that secretes sufficient quantities of estrogen and progesterone to maintain pregnancy. Estrogen and progesterone levels increase in the woman's blood throughout pregnancy (figure 28.20).

41. What is capacitation of sperm cells?

Clinical Focus Control of Pregnancy

Many methods are used to prevent or terminate pregnancy (figure B), including methods that prevent fertilization (contraception), prevent implantation of the developing embryo (IUDs), or remove the implanted embryo or fetus (abortion). Many of these techniques are quite effective when done properly and used consistently (table A).

Behavorial Methods

Abstinence, or refraining from sexual intercourse, is a sure way to prevent pregnancy when practiced consistently. It's not an effective method when used only occasionally.

Coitus (kō′i-tŭs) **interruptus** is removal of the penis from the vagina just before ejaculation. This is a very unreliable method of preventing pregnancy, because it requires perfect awareness and willingness to withdraw the penis at the correct time. It also ignores the fact that some sperm cells are found in preejaculatory emissions.

Periodic abstinence, the **natural family planning method,** or the **rhythm method** requires abstaining from sexual intercourse near the time of ovulation. A major factor in the success of this method is the ability to predict accurately the time of ovulation. Although the rhythm method provides some protection against becoming pregnant, it has a relatively high rate of failure, resulting from both the inability to predict the time of ovulation and the failure to abstain around the time of ovulation.

Barrier Methods

A **condom** (kon′dom) is a sheath of animal membrane, rubber, or latex. Placed over the erect penis, it is a barrier device, because the semen is collected within the condom instead of within the vagina. Condoms also provide protection against sexually transmitted diseases. A **vaginal condom** also acts as a barrier device. The vaginal condom can be placed into the vagina by the woman before sexual intercourse.

Methods to prevent sperm cells from reaching the oocyte once they are in the vagina include use of a diaphragm, a cervical cap, and spermicidal agents. The diaphragm and cervical cap are flexible plastic or rubber domes that are placed over the cervix within the vagina, where they prevent passage of sperm cells from the vagina through the cervical canal of the uterus. The diaphragm is larger than the cervical cap. The most commonly used **spermicidal agents** are foams or creams that kill the sperm cells. They are inserted into the vagina before sexual intercourse. When used in combination, a condom and foam or cream are much more effective than when they are used alone. A **spermicidal douche** (doosh) is a stream of fluid containing a chemical toxic to sperm cells that is injected into the vagina. The stream of fluid removes and kills sperm cells. Spermicidal douches used alone are not very effective.

Lactation

Lactation (lak-tā′shŭn) prevents the menstrual cycle for a few months after childbirth. Action potentials sent to the hypothalamus in response to suckling that cause the release of oxytocin and prolactin also inhibit FSH and LH release from the anterior pituitary. Lactation, therefore, prevents the development of ovarian follicles and ovulation. Despite continual lactation, the ovarian and uterine cycles eventually resume. Because ovulation occurs before menstruation, relying on lactation to prevent pregnancy is not consistently effective.

Chemical Methods

Synthetic estrogen and progesterone in **oral contraceptives** (birth-control pills) effectively suppress fertility in females. These substances may have more than one action, but they reduce LH and FSH release from the anterior pituitary. Estrogen and progesterone are present in high enough concentrations to have a negative-feedback effect on the pituitary, which prevents the large increase in LH and FSH secretion that triggers ovulation. Over the years, the dose of

Table A Effectiveness of Various Methods for Preventing Pregnancy

Technique	Effectiveness When Used Properly (%)	Actual Effectiveness (%)
Abortion	100	Unknown
Sterilization	100	99.9
Combination (estrogens and progesterones) pill	99.9	98
Intrauterine device	98	98
Minipill (low dose of estrogens and progesterones)	99	97
Condom plus spermicide	99	96
Condom alone	97	90
Diaphragm plus spermicide	97	85
Foam	97	80
Rhythm	97	70

estrogen and progesterone in birth-control pills has been reduced. The current lower-dose birth-control pills have fewer side effects than earlier dosages. An increased risk of heart attack or stroke exists in women using oral contraceptives who smoke or have a history of hypertension or coagulation disorders. For most women, the pill is effective and has a minimum frequency of complications, until at least age 35.

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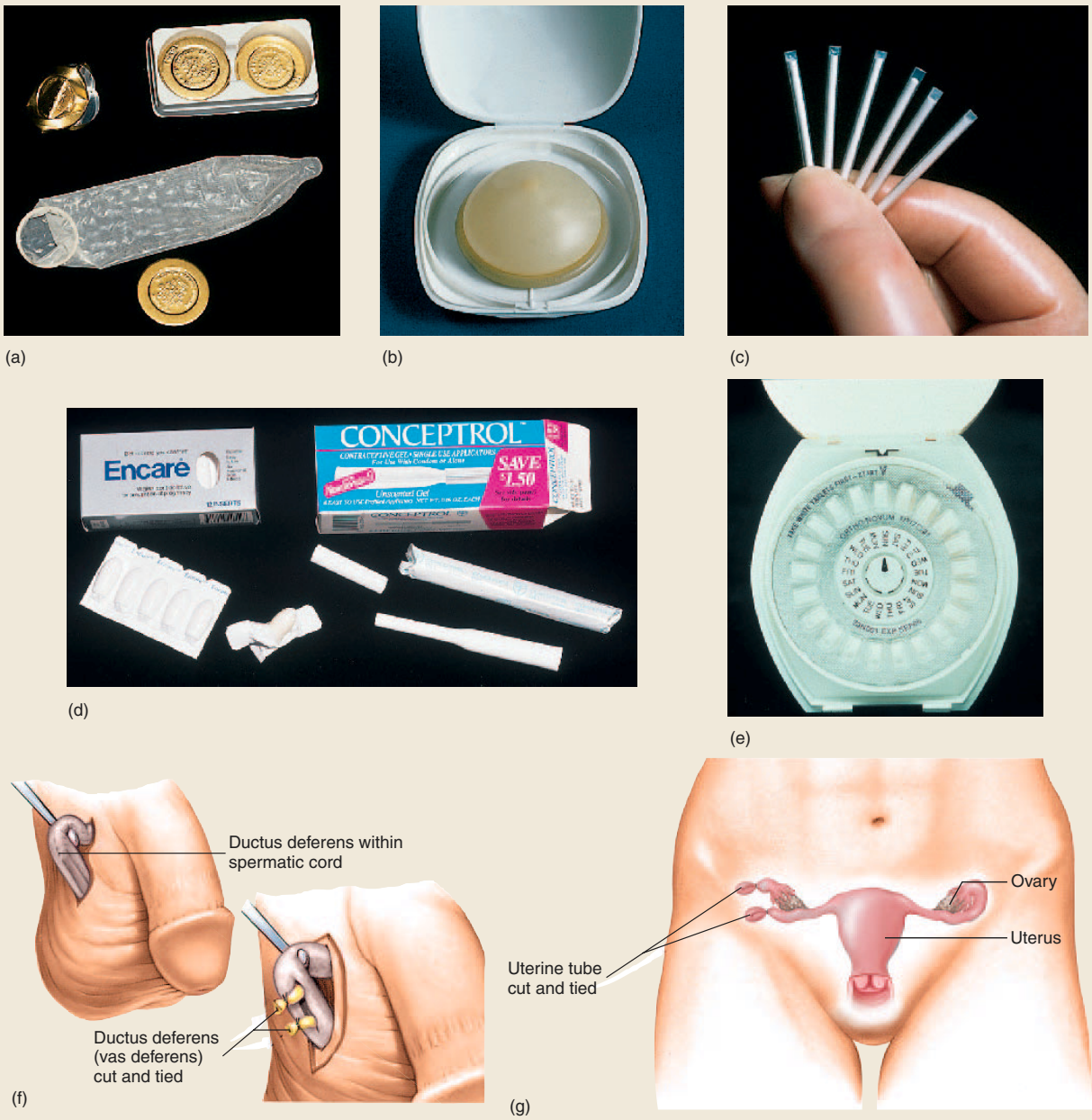

Figure B Contraceptive Devices and Techniques

(*a*) Condom. (*b*) Diaphragm used with spermicidal jelly. (*c*) Norplant system. (*d*) Spermicidal foam. (*e*) Oral contraceptives. (*f*) Vasectomy. (*g*) Tubal ligation.

Continued

Progesterone-like chemicals, such as medroxy progesterone (Depo-Provera), which are injected intramuscularly and slowly released into the circulatory system, can act as effective contraceptives. Injected progesterone-like chemicals can provide protection from pregnancy for up to 3 months, depending on the amount injected. A thin silastic tube containing these chemicals, such as the Norplant system, can be implanted beneath the skin, usually in the upper arm, from which they are slowly released into the circulatory system. The implants can be effective for up to 5 years. Menstruation does not normally occur in women using these techniques while the progesterone levels are elevated.

Advantages of injected and implanted progesterone-like contraceptives over other chemical methods of birth control are that they don't require taking pills on a daily basis. The long-term effects of injected and implanted progesterone-like chemicals have not been as thoroughly studied as the long-term effects of birth-control pills have, and they are still being evaluated.

Mifepristone (RU486) blocks the action of progesterone. It causes the endometrium of the uterus to slough off and to be expelled from the uterus as it does at the time of menstruation. Because it blocks progesterone receptors, the endometrium undergoes changes similar to those caused by decreasing progesterone levels. It is, therefore, used to induce menstruation and reduce the possibility of implantation when sexual intercourse has occurred near the time of ovulation. It can also be used to terminate pregnancies. **Morning-after pills,** similar in composition to birth-control pills, are available. Doubling the number of birth-control pills after sexual intercourse within 3 days and again after 12 more hours is sometimes recommended. This or similar techniques can be used after intercourse but they are only about 75% effective. The elevated estrogen and progesterone levels may inhibit the preovulatory LH surge in some cases, it may alter the rate of transport of the fertilized ovum from the uterine tube to the uterus, or it may inhibit implantation. The precise effect of the elevated estrogen and progesterone-like substances depends on the stage of menstrual cycle when they are taken.

Surgical Methods

Vasectomy (va-sek′tō-mē) is a common method used to render males permanently incapable of fertilization without affecting the performance of the sex act. Vasectomy is a surgical procedure used to cut and tie the ductus deferens from each testis within the scrotal sac. This procedure prevents sperm cells from passing through the ductus deferens and becoming part of the ejaculate. Because such a small volume of ejaculate comes from the testis and epididymis, vasectomy has little effect on the volume of the ejaculated semen. The sperm cells are reabsorbed in the epididymis.

A common method of permanent birth control in females is **tubal ligation** (lī-gā′shŭn), a procedure in which the uterine tubes are tied and cut or clamped through an incision made through the wall of the abdomen. This procedure closes off the pathway between the sperm cells and the oocyte. **Laparoscopy** (lap-ă-ros′kŏ-pē), a procedure in which a special instrument is inserted into the abdomen through a small incision, is commonly used so that only small openings are required to perform the operation.

In some cases, pregnancies are terminated by surgical procedures called **abortions.** The most common method for performing abortions is the insertion of an instrument through the cervix into the uterus. The instrument scrapes the endometrial surface while a strong suction is applied. The endometrium and the embedded embryo are disrupted and sucked out of the uterus. This technique is normally used only in pregnancies that have progressed less than 3 months.

Prevention of Implantation

Intrauterine devices (IUDs) are inserted into the uterus through the cervix to prevent normal implantation of the developing embryonic mass within the endometrium. Some early IUD designs produced serious side effects, such as perforation of the uterus, and, as a result, many IUDs have been removed from the market. Data indicate, however, that IUDs are effective in preventing pregnancy.

Menopause

Objective

- ***Define the term menopause, and describe the changes that occur because of it.***

When a female is 40–50 years old, menstrual cycles become less regular, and ovulation often does not occur. Eventually menstrual cycles stop completely. The cessation of menstrual cycles is called **menopause** (men′ō-pawz). The time from the onset of irregular cycles to their complete cessation, which is often 3 to 5 years, is called the **female climacteric** (klī-mak′ter-ik, klī-mak-ter′ik) or **perimenopause.**

Menopause is associated with changes in the ovary. The number of follicles remaining in the ovaries of menopausal women is small. In addition, the follicles that remain become less sensitive to stimulation by LH and FSH, even though these hormone levels are elevated. As the ovaries become less responsive to stimulation by FSH and LH, fewer mature follicles and corpora lutea are produced. Gradual morphologic changes occur in the female in response to the reduced amount of estrogen and progesterone produced by the ovaries (table 28.3).

A variety of symptoms occur in some females during the climacteric, including "hot flashes," irritability, fatigue, anxiety, and occasionally severe emotional disturbances. Some data indicate an increased risk of heart disease for the first few years after the

Clinical Focus Causes of Female Infertility

Causes of infertility in females include malfunctions of the uterine tubes, reduced hormone secretion from the pituitary or ovary, and interruption of implantation.

Adhesions from pelvic inflammatory conditions caused by a variety of infections can cause blockage of one or both uterine tubes and is a relatively common cause of infertility in women.

Reduced ovulation can result from inadequate secretion of LH and FSH, which can be caused by hypothyroidism, trauma to the hypothalamus, infarctions of the hypothalamus or anterior pituitary gland, and tumors.

Interruption of implantation may result from uterine tumors or conditions causing abnormal ovarian hormone secretion. For example, premature degeneration of the corpus luteum causes progesterone levels to decline and menses to occur. If the corpus luteum degenerates before the placenta begins to secrete progesterone, the endometrium and the developing embryonic mass degenerate and are eliminated from the uterus. The conditions that result in secondary amenorrhea also reduce fertility (see section on menstrual problems earlier in the chapter).

Endometriosis (en′dō-mē-trē-ō′sis), a condition in which endometrial tissue is found in abnormal locations, reduces fertility. Generally, endometriosis is thought to result from some endometrial cells passing from the uterus through the uterine tubes into the pelvic cavity. The endometrial cells invade the peritoneum of the pelvic cavity. Because the endometrium is sensitive to estrogen and progesterone, periodic inflammation of the areas where the endometrial cells have invaded occurs. Endometriosis is a cause of abdominal pain associated with menstruation and it can reduce fertility.

Table 28.3 Possible Changes Caused by Decreased Ovarian Hormone Secretion in Postmenopausal Women

Affected Structures and Functions	Changes
Menstrual cycle	Five to 7 years before menopause, the cycle becomes more irregular; finally, the number of cycles in which ovulation does not occur increases, and corpora lutea do not develop
Uterine tubes	Little change
Uterus	Irregular menstruation is gradually followed by no menstruation; chance of cystic glandular hypertrophy of the endometrium increases; the endometrium finally atrophies, and the uterus becomes smaller
Vagina and external genitalia	Dermis and epithelial lining become thinner; vulva becomes thinner and less elastic; labia majora become smaller; pubic hair decreases; vaginal epithelium produces less glycogen; vaginal pH increases; reduced secretion leads to dryness; the vagina is more easily inflamed and infected
Skin	Epidermis becomes thinner; melanin synthesis increases
Cardiovascular system	Hypertension and atherosclerosis occur more frequently
Vasomotor instability	Hot flashes and increased sweating are correlated with vasodilation of cutaneous blood vessels; hot flashes are not caused by abnormal FSH and LH secretion but are related to decreased estrogen levels
Sex drive	Temporary changes, such as either decreases or increases in sex drive, are often associated with the onset of menopause
Fertility	Fertility begins to decline approximately 10 years before the onset of menopause; by age 50, almost all oocytes and follicles are lost; loss is gradual, and no increased follicular degeneration is associated with the onset of menopause

beginning of menopause. Many of these symptoms can be treated successfully by administering small amounts of estrogen and then gradually decreasing the treatment over time or by providing psychologic counseling. It appears that administering estrogen following menopause also helps to prevent osteoporosis. Although estrogen therapy has been successful, in many women it prolongs symptoms associated with menopause. Some potential side effects of estrogen therapy are of concern, such as a small increase in the possibility for the development of breast and uterine cancer.

42. *Define the terms menopause and female climacteric. What causes these changes, and what symptoms commonly occur?*

Effects of Aging on the Reproductive System

Objective

- *Discuss age-related changes in males and females.*

Age-Related Changes in Males

Several age-related changes occur in the male reproductive system. In some, but not all men, there is an age-related decrease in the size and the weight of the testes. There's an associated decrease in the number of interstitial cells and a thinning of the wall of the

Clinical Focus Infectious Diseases

Sexually Transmitted Diseases

Sexually transmitted diseases (STDs) are a class of infectious diseases spread by intimate sexual contact between individuals. These diseases include the major venereal diseases nongonococcal urethritis, trichomoniasis, gonorrhea, genital herpes, genital warts, syphilis, and acquired immunodeficiency syndrome.

Nongonococcal urethritis refers to any inflammation of the urethra that's not caused by gonorrhea. Factors like trauma or passage of a nonsterile catheter through the urethra can cause this condition, but many cases are acquired through sexual contact. In most cases, the bacterium *Chlamydia trachomatis* is responsible, but other bacteria may be involved. *Chlamydia trachomatis* infection is one of the most common sexually transmitted diseases. It often is unrecognized in people who have it and is responsible for many cases of pelvic inflammatory disease. Left untreated, it can also result in sterility, but antibiotics are usually effective in curing the condition.

Trichomonas vaginalis is a protozoan commonly found in the vagina of females and the urethra of males. If the normal acidity of the vagina is disturbed, *Trichomonas* can grow rapidly. *Trichomonas* infection is more common in females than in males because the vagina provides a suitable environment in which these organisms can survive. The rapid growth of these organisms results in inflammation and a greenish yellow discharge characterized by a foul odor.

Gonorrhea (gon-ō-rē′ă) is caused by the bacterium *Neisseria gonorrhoeae*. The organisms attach to the epithelial cells of the vagina or to the male urethra. The invasion of bacteria establishes an inflammatory response in which pus is formed. Males become aware of a gonorrheal infection by painful urination and the discharge of pus-containing material from the urethra. Symptoms appear within a few days to a week. Recovery may eventually occur without complication, but, when complications do occur, they can be serious. The urethra can become partially blocked, or sterility can result from blockage of reproductive ducts with scar tissue. In some cases, other organ systems, such as the heart, meninges of the brain, or joints, may become infected. In females, the early stages of infection may pass unnoticed, but the infection can lead to pelvic inflammatory disease. Gonorrheal eye infections may occur in newborn children of females with gonorrheal infections. Antibiotics are usually effective in treating gonorrheal infections, and the immune system often successfully combats gonorrheal infections in untreated individuals.

Genital herpes (her′pēz) is a viral infection usually caused by herpes simplex type 2. Lesions appear after an incubation period of about 1 week and cause a burning sensation. After this, blisterlike areas of inflammation appear. In males and females, urination can be painful, and walking or sitting can be unpleasant, depending on the location of the lesions. The blisterlike areas heal in about 2 weeks. The lesions may reoccur. The viruses exist in a latent condition in nerve cells and may produce inflamed lesions on the genitals in response to factors like menstruation, emotional stress, or illness. If active lesions are present in the mother's vagina or external genitalia, a caesarean delivery is performed to prevent newborns from becoming infected with the herpesvirus. Because genital herpes is caused by a virus, no effective antibiotic cure for it is available.

seminiferous tubules. These changes may be secondary to a decrease in blood flow to the testes or due to a gradual decrease in sex hormone production. There is a decrease in the rate of sperm cell production and an increase in the number of abnormal sperm cells. However, sperm cell production doesn't stop, and it remains adequate for fertility for most men.

Age-related changes become obvious in the prostate gland by 40 years of age. By 60 years of age there is a clear decrease in blood flow, an increased thickness in the epithelial cell lining of the prostate gland, and a decrease in functional smooth muscle cells in the wall of the prostate. The changes in the prostate gland do not decrease fertility. There's a substantial increase in the incidence of benign prostatic hypertrophy that can create difficulty in urination because it compresses the prostatic urethra. A significant number of men older than 60 years of age (approximately 15%) require medical treatment for benign prostatic hypertrophy. By 80 years this number is 50%. Before 50 years of age prostatic cancer is rare. After 55 years of age it's the third leading cause of death from cancer in men. Enlargement of the prostate because of prostatic cancer can also create difficulty in urination.

Impotence increases in men with age. By 60 years of age approximately 15% of men have difficulty with impotence and by 80 years of age it is 50%. There's an increase in fibrous connective tissue in the erectile tissue of the penis, which, by the time males are 60 years of age, generally decreases the speed of erection.

Although there's great variation among males, many exhibit a decrease in the frequency of sexual activity and a decrease in sexual performance. Psychological changes, age-related changes in the nervous system, and decreased blood flow explain some of the decrease. Many exhibit decreased sexual activity because of the side effects of medications taken for other conditions.

Genital warts also result from a viral infection (human papillomavirus) and are quite contagious. This disease is common, and its frequency is increasing. Genital warts can also be transmitted from infected mothers to their infants. Genital warts vary from separate, small, warty growths to large cauliflower-like clusters. The lesions are usually not painful, but they can cause painful intercourse, and they bleed easily. For women who have genital warts, an increased risk exists of developing cervical cancer. Treatments for genital warts include topical agents, cryosurgery, or other surgical methods.

Syphilis (sif′i-lis) is caused by the bacterium *Treponema pallidum,* which can be spread by sexual contact of all kinds. Syphilis exhibits an incubation period from 2 weeks to several months. The disease progresses through several recognized stages. In the primary stage, the initial symptom is a small, hard-based **chancre** (shan′ker), or sore, that usually appears at the site of infection. Several weeks after the primary stage, the disease enters the secondary stage, characterized mainly by skin rashes and mild fever. The symptoms of secondary syphilis usually subside after a few weeks, and the disease enters a latent period in which no symptoms are present. In less than half the cases, a tertiary stage develops after many years. In the tertiary stage, many lesions develop that can cause extensive tissue damage and can lead to paralysis, insanity, and even death. Syphilis can be passed on to newborns by an infected mother. Damage to mental development and other neurologic symptoms are among the more serious consequences. Females who have syphilis in the latent phase are most likely to have babies who are infected. Antibiotics are used to treat syphilis, although some strains are very resistant to certain antibiotics.

Acquired immunodeficiency syndrome (AIDS) is caused by infection with the human immunodeficiency virus (HIV), which appears to ultimately result in destruction of the immune system (see chapter 22). The most common mechanisms of transmission of the virus are through sexual contact with a person infected with HIV and through sharing needles with an infected person during the administration of illicit drugs. Although transmission did occur during the early 1980s through tainted blood products, screening techniques now make the transmission of HIV through blood transfusions very rare. Some rare cases of transmission of HIV through accidental needle- sticks in hospitals and other health care facilities have been documented. No evidence exists that casual contact with a person who has AIDS or who is infected with HIV results in transmission of the disease. Transmission appears to require exposure to body fluids of an infected person in a way that allows HIV into the interior of another person. Normal casual contact, including touching an HIV-infected person, doesn't increase the risk of infection.

Other Infectious Diseases

Pelvic inflammatory disease (PID) is a bacterial infection of the female pelvic organs. It usually involves the uterus, uterine tubes, or ovaries. A vaginal or uterine infection may spread throughout the pelvis. Gonorrhea and chlamydia are the most common causes of PID; however, other bacteria can be involved. Early symptoms of PID include increased vaginal discharge and pelvic pain. Early treatment with antibiotics can stop the spread of PID, but lack of treatment results in a life-threatening infection. PID can also lead to sterility.

Age-Related Changes in Females

The most significant age-related change in females is menopause. By age 50 few viable follicles remain in the ovaries. As a result, there's a decrease in the estrogen and progesterone produced by the ovaries.

The uterus decreases in size and the endometrium decreases in thickness. The time between menstruations becomes irregular and longer. Finally menstruations stop. As the uterus decreases in size, it tips posteriorly and assumes a lower position in the pelvic cavity. Occasionally, uterine prolapse, in which the ligaments of the uterus allow it to descend and protrude into the vagina, occurs. Within 15 years after menopause, the uterus is 50% of its original size.

The vaginal wall becomes thinner and less elastic. There is less lubrication of the vagina and the epithelial lining is more fragile. An increased tendency occurs for vaginal infections. Vaginal contractions, during intercourse, decrease and the vagina narrows with age. In healthy females, sexual excitement requires greater time to develop, the peak levels of sexual activity are lower, and return to the resting state occurs more quickly.

Approximately 10% of all women will have breast cancer. The increase is most rapid between 45 and 65 years of age, and the incidence is greater for those who have a history of breast cancer in their families than for those who do not. Cancer of the endometrium and cancer of the uterine cervix increases between 50 and 65 years of age. Ovarian cancer increases in frequency in older women, and it's the second most common cancer of the reproductive system in older women.

- *43. What are the age-related changes that occur in the prostate gland?*
- *44. What are some of the long-term effects of menopause?*

Systems Pathology

Benign Uterine Tumors

Mrs. M had four children and was 43 years old. She noticed that menstruation was becoming gradually more severe and lasting up to several days longer each time it started. After she menstruated almost continuously for 2 months, she made an appointment with her physician, who performed a pelvic examination, including tests for conditions like cervical cancer and uterine cancer. Palpation of the uterus indicated the presence of enlarged masses in Mrs. M's uterus. The results of a dilation and curettage (D&C—dilation of the cervix and scraping [curettage] of the endometrium to remove growths or other abnormal tissues) indicated that Mrs. M suffered from leiomyomas, or fibroid tumors of the uterus.

Background Information

Uterine **leiomyomas** (lī′ō-mī-ō′măs; figure C), also called uterine fibroids, are enlarged masses of smooth muscle in the myometrium, and they are one of the most common disorders of the uterus. They are the most frequent tumor in women, affecting one of every four. Three-fourths of the women with this condition, however, experience no symptoms. The enlarged mass compresses the uterine lining (endometrium), resulting in ischemia and inflammation and in frequent and severe menstruations. Abdominal cramping because of strong uterine contractions can be present. Constant menstruation is a

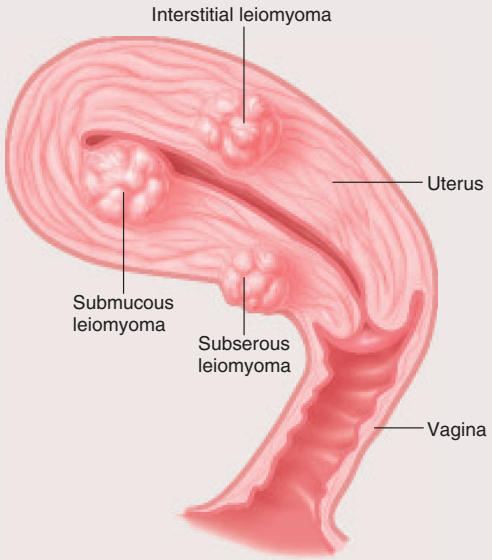

Figure C Leiomyomas or Fibroid Tumors

Leiomyomas, or fibroid tumors, are enlarged masses of smooth muscle. They are located near the mucosa (submucous), within the myometrium (interstitial), or near the serosa (subserous).

S U M M A R Y

The male reproductive system produces sperm cells and transfers them to the female. The female reproductive system produces the oocyte and nurtures the developing child.

Anatomy of the Male Reproductive System (p. 1017)

Scrotum

1. The scrotum is a two-chambered sac that contains the testes.
2. The dartos and cremaster muscles help to regulate testicular temperature.

Perineum

The perineum is the diamond-shaped area between the thighs and consists of a urogenital triangle and an anal triangle.

Testes

1. The tunica albuginea is the outer connective tissue capsule of the testes.
2. The testes are divided by septa into compartments that contain the seminiferous tubules and the interstitial cells.
3. The seminiferous tubules become straight to form the tubuli recti which lead to the rete testis. The rete testis opens into the efferent ductules of the epididymis.
4. During development, the testes pass from the abdominal cavity through the inguinal canal to the scrotum.

Sperm Cell Development

1. Sperm cells (spermatozoa) are produced in the seminiferous tubules.
2. Spermatogonia divide (mitosis) to form primary spermatocytes.
3. Primary spermatocytes divide (first division of meiosis) to form secondary spermatocytes, which divide (second division of meiosis) to form spermatids.
4. Spermatids develop an acrosome and a flagellum to become sperm cells.
5. Sertoli cells nourish the sperm cells, form a blood–testes barrier, and produce hormones.

Ducts

1. Efferent ductules extend from the testes to the head of the epididymis.
2. The epididymis is a coiled tube system located on the testis that is the site of sperm cell maturation. It consists of a head, body, and tail.
3. The ductus deferens passes from the epididymis into the abdominal cavity.

System Interactions Effect of Leiomyomas on Other Systems

System	Interaction
Integumentary	If anemia does not develop, skin appearance is normal, but if anemia does develop, the skin can appear pale because of the reduced hemoglobin in red blood cells. The continual loss of blood often results in iron-deficiency anemia. The hemoglobin concentration of blood and the hematocrit are, therefore, reduced.
Muscular	If anemia develops and is severe, muscle weakness may result because of the reduced ability of the cardiovascular system to deliver adequate oxygen to muscles.
Skeletal	The rate of red blood cell synthesis in the red bone marrow increases.
Digestive	An enlarged tumor can put pressure on the rectum or sigmoid colon, resulting in constipation.
Cardiovascular	A chronic loss of blood as in prolonged menstruation over many months to years frequently results in iron-deficiency anemia. Manifestations of anemia include reduced hematocrit, reduced hemoglobin concentration, smaller-than-normal red blood cells (microcytic anemia), and increased heart rate.
Respiratory	Because of anemia, the oxygen-carrying capacity of the blood is reduced. Increased respiration during physical exertion and rapid fatigue are likely to occur if anemia develops.
Urinary	The kidneys increase erythropoietin secretion in response to the loss of red blood cells. The erythropoietin increases red blood cell synthesis in red bone marrow. An enlarged tumor can put pressure on the urinary bladder, resulting in increased frequency of and painful urination.

frequent manifestation of these tumors, and it is one of the most common reasons why women elect to have the uterus removed, a procedure called a **hysterectomy** (his-ter-ek′tō-mē).

P R E D I C T 5

When discussing her condition with her mother, Mrs. M discovered that her mother recalled frequent menstruations that were irregular and prolonged when she was in her late forties. Her mother did not have a hysterectomy, and in a few years the frequency of menstruation began to gradually subside. Explain.

4. The ductus deferens and the seminal vesicle join to form the ejaculatory duct.
5. The prostatic urethra extends from the urinary bladder to join with the ejaculatory ducts to form the membranous urethra.
6. The membranous urethra extends through the urogenital diaphragm and becomes the spongy urethra, which continues through the penis.
7. The spermatic cord consists of the ductus deferens, blood and lymphatic vessels, nerves, and remnants of the process vaginalis. Coverings of the spermatic cord consist of the cremaster muscle, external fascia, and internal fascia.
8. The spermatic cord passes through the inguinal canal into the abdominal cavity.

Penis

1. The penis consists of erectile tissue.
   - The two corpora cavernosa form the dorsum and the sides of the penis.
   - The corpus spongiosum forms the ventral part and the glans penis.
2. The bulb of the penis and the crura form the root of the penis and the crura attaches the penis to the coxae.
3. The prepuce covers the glans penis.

Accessory Glands

1. The seminal vesicles empty into the ejaculatory ducts.
2. The prostate gland consists of glandular and muscular tissue and empties into the prostatic urethra.
3. The bulbourethral glands are compound mucous glands that empty into the spongy urethra.
4. Secretions
   - Semen is a mixture of gland secretions and sperm cells.
   - The bulbourethral glands and the urethral mucous glands produce mucus, which neutralizes the acidic pH of the urethra.
   - The testicular secretions contain sperm cells.
   - The seminal vesicle fluid contains fructose and fibrinogen.
   - The prostate secretions make the seminal fluid more pH-neutral. Clotting factors activate fibrinogen, and fibrinolysin breaks down fibrin.

Physiology of Male Reproduction (p. 1028)

Regulation of Sex Hormone Secretion

1. GnRH is produced in the hypothalamus and released in surges.
2. GnRH stimulates LH and FSH release from the anterior pituitary.
   - LH stimulates the interstitial cells to produce testosterone.
   - FSH stimulates sperm cell formation.
3. Inhibin, produced by sustentacular cells, inhibits FSH secretion.

Puberty

1. Before puberty, small amounts of testosterone inhibit GnRH release.
2. During puberty, testosterone does not completely suppress GnRH release, resulting in increased production of FSH, LH, and testosterone.

Effects of Testosterone

1. Interstitial cells, the adrenal cortex, and possibly the sustentacular cells produce testosterone.
2. Testosterone causes the development of male sex organs in the embryo and stimulates the descent of the testes.
3. Testosterone causes enlargement of the genitals and is necessary for sperm cell formation.
4. Other effects of testosterone
   - Hair growth stimulation (pubic area, axilla, and beard) and inhibition (male pattern baldness)
   - Enlargement of the larynx and deepening of the voice
   - Increased skin thickness and melanin and sebum production
   - Increased protein synthesis (muscle), bone growth, blood cell synthesis, and blood volume
   - Increased metabolic rate

Male Sexual Behavior and the Male Sex Act

1. Testosterone is required for normal sex drive.
2. Stimulation of the sexual act can be tactile or psychologic.
3. Afferent action potentials pass through the pudendal nerve to the sacral region of the spinal cord.
4. Parasympathetic stimulation
   - Erection is due to vasodilation of the blood vessels that supply the erectile tissue.
   - The glands of the urethra and the bulbourethral glands produce mucus.
5. Sympathetic stimulation causes erection, emission, and ejaculation.

Anatomy of the Female Reproductive System (p. 1032)

Ovaries

1. The broad ligament, the mesovarium, the suspensory ligaments, and the ovarian ligaments hold the ovaries in place.
2. The peritoneum (ovarian epithelium) and the tunica albuginea form the surface of the ovaries.
3. The ovary is divided into a cortex (contains follicles) and a medulla (receives blood and lymph vessels and nerves).
4. Follicle and oocyte development
   - Oogonia proliferate and become primary oocytes that are in prophase I of meiosis.
   - Primary follicles are primary oocytes surrounded by granulosa cells.
   - During puberty, primary follicles become secondary follicles.
   - The primary oocytes continue meiosis to metaphase II and become secondary oocytes surrounded by the zona pellucida. The center of the follicle fills with fluid to form the antrum, the granulosa cells increase in number, and theca cells form around the secondary follicle.
   - Graafian follicles are enlarged secondary follicles at the surface of the ovary.
5. Ovulation
   - The follicle swells and ruptures, and the secondary oocyte is released from the ovary.
   - The second meiotic division is completed when the secondary oocyte unites with a sperm cell to form a zygote.
6. Fate of the follicle
   - The graafian follicle becomes the corpus luteum.
   - If fertilization occurs, the corpus luteum persists. If no fertilization occurs, it becomes the corpus albicans.

Uterine Tubes

1. The mesosalpinx holds the uterine tubes.
2. The uterine tubes transport the oocyte or zygote from the ovary to the uterus.
3. Structures
   - The ovarian end of the uterine tube is expanded as the infundibulum. The opening of the infundibulum is the ostium, which is surrounded by fimbriae.
   - The infundibulum connects to the ampulla, which narrows to become the isthmus. The isthmus becomes the uterine part of the uterine tube and passes through the uterus.
4. The uterine tube consists of an outer serosa, a middle muscular layer, and an inner mucosa with simple ciliated columnar epithelium.
5. Movement of the oocyte
   - Cilia move the oocyte over the fimbriae surface into the infundibulum.
   - Peristaltic contractions and cilia move the oocyte within the uterine tube.
   - Fertilization occurs in the ampulla, where the zygote remains for several days.

Uterus

1. The uterus consists of the body, the isthmus, and the cervix. The uterine cavity and the cervical canal are the spaces formed by the uterus.
2. The uterus is held in place by the broad, round, and uterosacral ligaments.
3. The wall of the uterus consists of the perimetrium (serous membrane), the myometrium (smooth muscle), and the endometrium (mucous membrane).

Vagina

1. The vagina connects the uterus (cervix) to the vestibule.
2. The vagina consists of a layer of smooth muscle and an inner lining of moist stratified squamous epithelium.
3. The vagina is folded into rugae and longitudinal folds.
4. The hymen covers the vestibular opening of the vagina.

External Genitalia

1. The vulva, or pudendum, comprises the external genitalia.
2. The vestibule is the space into which the vagina and the urethra open.
3. Erectile tissue
   - The two corpora cavernosa form the clitoris.
   - The corpora spongiosa form the bulbs of the vestibule.
4. The labia minora are folds that cover the vestibule and form the prepuce.
5. The greater and lesser vestibular glands produce a mucous fluid.
6. When closed, the labia majora cover the labia minora.
   - The pudendal cleft is a space between the labia majora.
   - The mons pubis is an elevated fat deposit superior to the labia majora.

Perineum

The clinical perineum is the region between the vagina and the anus.

Mammary Glands

1. The mammary glands are modified sweat glands located in the breasts.
   - The mammary glands consist of glandular lobes and adipose tissue.
   - The lobes consist of lobules that are divided into alveoli.
   - The lobes connect to the nipple through the lactiferous ducts.
   - The areola surround the nipple.
2. Cooper's ligaments support the breasts.

Physiology of Female Reproduction (p. 1040)

Puberty

1. Puberty begins with the first menstrual bleeding (menarche).
2. Puberty begins when GnRH levels increase.

Menstrual Cycle

1. Ovarian cycle
   - FSH initiates development of the primary follicles.
   - The follicles secrete a substance that inhibits the development of other follicles.
   - LH stimulates ovulation and completion of the first meiotic division by the primary oocyte.
   - The LH surge stimulates the formation of the corpus luteum. If fertilization occurs, HCG stimulates the corpus luteum to persist. If fertilization does not occur, the corpus luteum becomes the corpus albicans.
2. A positive-feedback mechanism causes FSH and LH levels to increase near the time of ovulation.
   - Estrogen produced by the theca cells of the follicle stimulates GnRH secretion.
   - GnRH stimulates FSH and LH, which stimulate more estrogen secretion, and so on.
   - Inhibition of GnRH levels causes FSH and LH levels to decrease after ovulation. Inhibition is due to the high levels of estrogen and progesterone produced by the corpus luteum.
3. Uterine cycle
   - Menses (day 1 to days 4 or 5). The spiral arteries constrict, and endometrial cells die. The menstrual fluid is composed of sloughed cells, secretions, and blood.
   - Proliferation phase (day 5 to day 14). Epithelial cells multiply and form glands, and the spiral arteries supply the glands.
   - Secretory phase (day 15 to day 28). The endometrium becomes thicker, and the endometrial glands secrete.
   - Estrogen stimulates proliferation of the endometrium and synthesis of progesterone receptors.
   - Increased progesterone levels cause hypertrophy of the endometrium, stimulate gland secretion, and inhibit uterine contractions. Decreased progesterone levels cause the spiral arteries to constrict and start menses.

Female Sexual Behavior and the Female Sex Act

1. Female sex drive is partially influenced by androgens (produced by the adrenal gland) and steroids (produced by the ovaries).
2. Parasympathetic effects
   - The erectile tissue of the clitoris and the bulbs of the vestibule become filled with blood.
   - The vestibular glands secrete mucus, and the vagina extrudes a mucuslike substance.

Female Fertility and Pregnancy

1. Intercourse must take place 3 days before to 1 day after ovulation if fertilization is to occur.
2. Sperm cell transport to the ampulla depends on the ability of the sperm cells to swim and possibly on contractions of the uterus and the uterine tubes.
3. Implantation of the developing embryonic mass into the uterine wall occurs when the uterus is most receptive.
4. Estrogen and progesterone secreted first by the corpus luteum and later by the placenta are essential for the maintenance of pregnancy.

Menopause

The female climacteric begins with irregular menstrual cycles and ends with menopause, the cessation of the menstrual cycle.

Effects of Aging on the Reproductive System (p. 1051)

Age-Related Changes in Males

1. There is an age-related decrease in the size and weight of the testes, decrease in the number of interstitial cells, thinning of the seminiferous tubule wall, and a decrease in sperm production. Sperm cell production is still adequate for fertilization.
2. The prostate gland enlarges, and there is an age-related increase in prostatic cancer.
3. Impotence is age-related and there is a gradual decrease in sexual activity.

Age-Related Changes in Females

1. The most significant age-related change in females is menopause.
2. The uterus decreases in size and the vaginal wall thins.
3. There is an age-related increase in breast, uterine, and ovarian cancer.

REVIEW AND COMPREHENSION

1. If an adult male walked into a swimming pool of cold water, which of these muscles would be expected to contract?
   a. cremaster muscle
   b. dartos muscle
   c. gubernaculum
   d. prepuce muscle
   e. both a and b
2. Testosterone is produced in the
   a. Interstitial cells.
   b. seminiferous tubules of the testes.
   c. anterior lobe of the pituitary.
   d. sperm cells.
3. Early in development (4 months after fertilization), the testes
   a. are found in the peritoneal cavity.
   b. move through the inguinal canal.
   c. produce a membrane that becomes the scrotum.
   d. produce sperm cells.
   e. all of the above.
4. The site of spermatogenesis in the male is the
   a. ductus deferens.
   b. seminiferous tubules.
   c. epididymis.
   d. rete testis.
   e. efferent ductule.
5. The location of final maturation and storage of sperm cells before their ejaculation is the
   a. seminal vesicles.
   b. seminiferous tubules.
   c. glans penis.
   d. epididymis.
   e. sperm bank.

6. Given these structures:
   1. ductus deferens
   2. efferent ductule
   3. epididymis
   4. ejaculatory duct
   5. rete testis

   Choose the arrangement that lists the structures in the order a sperm cell passes through them from the seminiferous tubules to the urethra.
   a. 2,3,5,4,1
   b. 2,5,3,4,1
   c. 3,2,4,1,5
   d. 3,4,2,1,5
   e. 5,2,3,1,4
7. Concerning the penis,
   a. the membranous urethra passes through the corpora cavernosa.
   b. the glans penis is formed by the corpus spongiosum.
   c. the penis contains four columns of erectile tissue.
   d. the crus of the penis is part of the corpus spongiosum.
   e. the bulb of the penis is covered by the prepuce.
8. Given these glands:
   1. prostate gland
   2. bulbourethral gland
   3. seminal vesicle

   Choose the arrangement that is in the order the glands contribute their secretions to the formation of semen.
   a. 1,2,3
   b. 2,1,3
   c. 2,3,1
   d. 3,1,2
   e. 3,2,1
9. Which of these glands is correctly matched with the function of its secretions?
   a. bulbourethral gland—neutralizes acidic contents of the urethra
   b. seminal vesicles—contain large amounts of fructose, which nourishes the sperm cells
   c. prostate gland—contains clotting factors that cause coagulation of the semen
   d. all of the above
10. LH in the male stimulates
    a. development of the seminiferous tubules.
    b. spermatogenesis.
    c. testosterone production.
    d. both a and b.
    e. all of the above.
11. Which of these factors causes a decrease in GnRH release?
    a. decreased inhibin
    b. increased testosterone
    c. decreased FSH
    d. decreased LH
12. In the male, before puberty
    a. FSH levels are higher than after puberty.
    b. LH levels are higher than after puberty.
    c. GnRH release is inhibited by testosterone.
    d. all of the above.
13. Testosterone
    a. stimulates the development of terminal hairs.
    b. decreases red blood cell count.
    c. prevents closure of the epiphyseal plate.
    d. decreases blood volume.
    e. all of the above.
14. Which of these is consistent with erection of the penis?
    a. parasympathetic stimulation
    b. dilation of arterioles
    c. engorgement of sinusoids with blood
    d. occlusion of veins
    e. all of the above
15. The first polar body
    a. is normally formed before fertilization.
    b. is normally formed after fertilization.
    c. normally receives most of the cytoplasm.
    d. is larger than an oocyte.
    e. both a and b.
16. After ovulation the mature follicle collapses, taking on a yellowish appearance to become the
    a. degenerating follicle.
    b. corpus luteum.
    c. corpus albicans.
    d. tunica albuginea.
    e. cumulus mass.
17. The ampulla of the uterine tube
    a. is the opening of the uterine tube into the uterus.
    b. has long, thin projections called the ostium.
    c. is connected to the isthmus of the uterine tube.
    d. is lined with ciliated columnar epithelium.
18. The layer of the uterus that undergoes the greatest change during the menstrual cycle is the
    a. perimetrium.
    b. hymen.
    c. endometrium.
    d. myometrium.
    e. broad ligament.
19. The vagina
    a. consists of skeletal muscle.
    b. has ridges called rugae.
    c. is lined with simple squamous epithelium.
    d. all of the above.
20. During sexual excitement, which of these structures fills with blood and causes the vaginal opening to narrow?
    a. bulb of the vestibule
    b. clitoris
    c. mons pubis
    d. labia majora
    e. prepuce
21. Given these vestibular-perineal structures:
    1. vaginal opening
    2. clitoris
    3. urethral opening
    4. anus

    Choose the arrangement that lists the structures in their proper order from the anterior to the posterior aspect.
    a. 2,3,1,4
    b. 2,4,3,1
    c. 3,1,2,4
    d. 3,1,4,2
    e. 4,2,3,1
22. Concerning the breasts,
    a. lactiferous ducts open on the areola.
    b. each lactiferous duct supplies an alveolus.
    c. they are attached to the pectoralis major muscles by mammary ligaments.
    d. even before puberty, the female breast is quite different from the male breast.

23. The major secretory product of the mature follicle is
    a. estrogen.
    b. progesterone.
    c. LH.
    d. FSH.
    e. relaxin.
24. In the average adult female, ovulation occurs at day _____ of the menstrual cycle.
    a. 1
    b. 7
    c. 14
    d. 21
    e. 28
25. Which of these processes or phases in the monthly reproductive cycle of the human female occur at the same time?
    a. maximal LH secretion and menstruation
    b. early follicular development and the secretory phase of the uterus
    c. regression of the corpus luteum and an increase in ovarian progesterone secretion
    d. ovulation and menstruation
    e. proliferation stage of the uterus and increased estrogen production
26. During the secretory phase of the menstrual cycle, one would normally expect
    a. the highest levels of estrogen that occur during the menstrual cycle.
    b. the mature follicle to be present in the ovary.
    c. an increase in the thickness of the endometrium.
    d. both a and b.
    e. all of the above.
27. The cause of menses in the menstrual cycle appears to be
    a. increased progesterone secretion from the ovary, which produces blood clotting.
    b. increased estrogen secretion from the ovary, which stimulates the muscles of the uterus to contract.
    c. decreased progesterone secretion by the ovary.
    d. decreased production of oxytocin, causing the muscles of the uterus to relax.
28. After fertilization the successful development of a mature, full-term fetus depends upon the
    a. release of human chorionic gonadotropin (HCG) by the developing placenta.
    b. production of estrogen and progesterone by the placental tissues.
    c. maintenance of the corpus luteum for all 9 months.
    d. both a and b.
    e. all of the above.
29. A woman with a 28-day menstrual cycle is most likely to become pregnant as a result of coitus on days
    a. 1–3.
    b. 5–8.
    c. 9–14.
    d. 15–20.
    e. 21–28.
30. Menopause
    a. develops when follicles become less responsive to FSH and LH.
    b. results from elevated estrogen levels in 40- to 50-year-old women.
    c. occurs because too many follicles develop during each cycle.
    d. results when follicles develop but contain no oocytes.
    e. occurs because FSH and LH levels decline.

Answers in Appendix F

CRITICAL THINKING

1. If an adult male were castrated, what would happen to the levels of GnRH, FSH, LH, and testosterone in his blood? What effect would these hormonal changes have on sexual characteristics and behavior?
2. If a 9-year-old boy were castrated, what would happen to the levels of GnRH, FSH, LH, and testosterone in his blood? What effect would these hormonal changes have on sexual characteristics and behavior?
3. Suppose you want to produce a birth-control pill for men. On the basis of what you know about the male hormone system, what do you want the pill to do? Discuss any possible side effects that could be produced by your pill.
4. If the ovaries are removed from a postmenopausal woman, what happens to the levels of GnRH, FSH, LH, estrogen, and progesterone in her blood? What symptoms do you expect to observe?
5. During the secretory phase of the menstrual cycle, you normally expect
    a. the highest levels of progesterone that occur during the menstrual cycle.
    b. a follicle present in the ovary that is ready to undergo ovulation.
    c. that the endometrium reaches its greatest degree of development.
    d. both a and b.
    e. both a and c.
6. If the ovaries are removed from a 20-year-old female, what happens to the levels of GnRH, FSH, LH, estrogen, and progesterone in her blood? What side effects do these hormonal changes have on her sexual characteristics and behavior?
7. A study divides healthy adult females into two groups (A and B). Both groups are composed of females who have been sexually active for at least 2 years and are not pregnant at the beginning of the experiment. The subjects weigh about the same amount, and none smokes cigarettes, although some do drink alcohol occasionally. Group A women receive a placebo in the form of a sugar pill each morning during their menstrual cycles. Group B women receive a pill containing estrogen and progesterone each morning of their menstrual cycles. Then plasma LH levels are measured before, during, and after ovulation. The results are as follows:

Group	4 Days Before Ovulation	The Day of Ovulation	4 Days After Ovulation
A	18 mg/100 mL	300 mg/100 mL	17 mg/100 mL
B	21 mg/100 mL	157 mg/100 mL	15 mg/100 mL

   The number of pregnancies in group A was 37/100 females/year. The number of pregnancies in group B was 1.5/100 females/year. What conclusion can you reach on the basis of these data? Explain the mechanism involved.
8. A woman who is taking birth-control pills that consist of only progesterone experiences the hot flash symptoms of menopause. Explain why.
9. GnRH can be used to treat some women who want to have children but have not been able to get pregnant. Explain why it's critical to administer the correct concentration of GnRH at the right time during the menstrual cycle.

Answers in Appendix G

ANSWERS TO PREDICT QUESTIONS

1. The prostate gland is anterior to the wall of the rectum. A finger inserted into the rectum can palpate the prostate gland through the rectal wall.
2. Coagulation may help keep the sperm cells within the female reproductive tract, thereby increasing the likelihood of fertilization.
3. If administered before the preovulatory LH surge, estrogen stimulates the hypothalamus to secrete GnRH. Estrogen and progesterone, in large amounts, inhibit GnRH and LH releases. A large amount of estrogen and progesterone administered at this time should, therefore, reduce the surge of LH. Continual administration of high levels of GnRH causes anterior pituitary cells to become insensitive to GnRH. Thus, LH and FSH levels remain low, and the ovarian cycle stops.
4. High progesterone levels after menses inhibit GnRH secretion from the hypothalamus and, therefore, FSH and LH secretion from the anterior pituitary. Without FSH and LH, the events of the ovarian cycle, including estrogen production, are inhibited. Because estrogen causes proliferation of the endometrium, thickening of the endometrium is not expected. Also, estrogen increases the synthesis of uterine progesterone receptors, and without estrogen the secretory response of the endometrium to the elevated progesterone is inhibited.
5. Mrs. M's mother could have had leiomyomas also, although, without direct data from medical examinations, one cannot be certain. If that were the cause of her irregular menstruations, they may have become less frequent as Mrs. M's mother experienced menopause. During menopause, the uterus gradually becomes smaller, and eventually the cyclic changes in the endometrial lining cease. If the leiomyomas were relatively mild, the onset of menopause could explain the gradual disappearance of the irregular and prolonged menstruations. (*Note:* If the tumors are large, constant and severe menstruations are likely even if regular menstrual cycles stop due to menopause.)