Male Reproductive System

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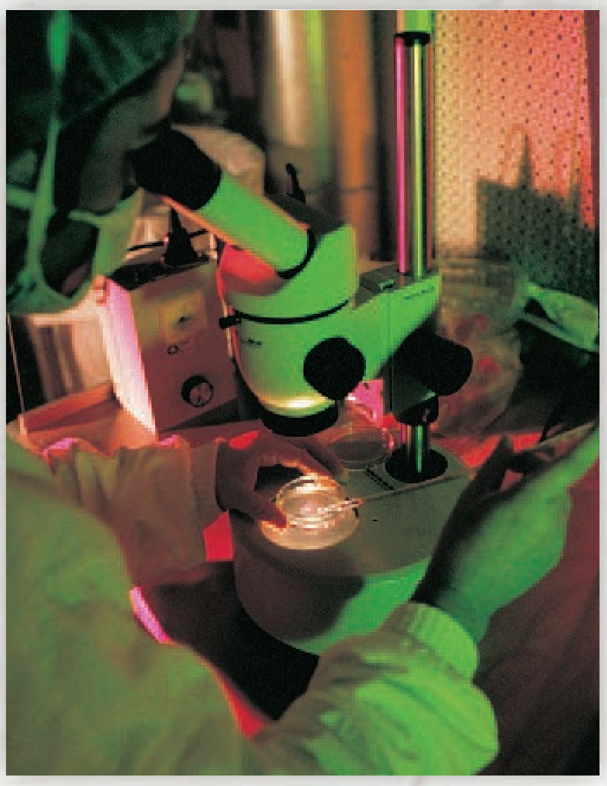


Clinical Case Study

During a routine physical exam, a 27-year-old man mentioned to his family doctor that he and his wife had been unable to conceive a child after nearly 2 years of trying. He added that his wife had taken the initiative of having a thorough gynecological evaluation in an attempt to find out what was causing the problem. Her test findings revealed no physical conditions that could be linked to infertility. Upon palpating the patient's testes, the doctor found nothing unusual. When he examined the scrotal sac above the testes, however, the doctor appeared perplexed. He informed his patient that two tubular structures, one for each testis, appeared to be absent, and that they probably had been missing since birth. During a follow-up visit, the doctor told the patient that examination of his ejaculate revealed azoospermia (no viable sperm).

Explain how the result of the semenalysis relates to the patient's physical exam findings. What are the missing structures? Does it seem peculiar that the patient is capable of producing an ejaculate? Why or why not?

FIGURE: Fertility specialists have made remarkable advancements during the past decade in treating couples with fertility problems. A semenalysis reveals the relative number of sperm (sperm count), sperm vitality, and chemical nature of the fluid medium in a sample ejaculate.

INTRODUCTION TO THE MALE REPRODUCTIVE SYSTEM

The organs of the male and female reproductive systems are adapted to produce and allow the union of gametes that contain specific genes. A random combination of the genes during sexual reproduction results in the propagation of individuals with genetic differences.

Objective 1 Explain why sexual reproduction is biologically advantageous.

Objective 2 List the functions of the male reproductive system and compare them with those of the female.

Objective 3 Distinguish between primary and secondary sex organs.

Unlike other body systems, the reproductive system is not essential for the survival of the individual; it is, however, required for the survival of the species. It is through reproduction that additional individuals of a species population are produced and the genetic code passed from one generation to the next. This can be accomplished by either asexual or sexual reproduction. But sexual reproduction, in which genes from two individuals are combined in random ways with each new generation, offers the overwhelming advantage of introducing great variability into a population. This variability of genetic constitution helps ensure that some members of a population will survive changes in the environment over evolutionary time.

The reproductive system is unique in two other respects. First, the fact that it does not become functional until it is "turned on" at puberty by the actions of sex hormones sets the reproductive system apart. By contrast, all of the other body systems are functional at birth, or shortly thereafter. Second, whereas the other organ systems of the body exhibit slight sexual differences, no other system approaches the level of dissimilarity of the reproductive system. Because sexual reproduction requires the production of two types of **gametes** (*gam′ēts*), or sex cells, the species has a male and female form, each with its own unique reproductive system. The male and female reproductive systems complement each other in their common purpose of producing offspring.

The functions of the male reproductive system are to produce the male gametes, **spermatozoa** (*sper-mat′′ŏ-zo′ă*), and to transfer them to the female through the process of *coitus* (*sexual intercourse*) or *copulation*. Another function of the male reproductive system is to produce and secrete sex hormones, which maintain the male sex organs and contribute to the male libido (sex drive). The female not only produces her own gametes (called **oocytes** [*o′ŏ-sīts*], or **ova**) and receives the sperm from the male, but her reproductive organs are specialized to provide sites for fertilization, implantation of the developing embryonic mass (the blastocyst), pregnancy, and delivery of a baby. The more complex reproductive system of the female also provides a means for nourishing the baby through the secretion of milk from the mammary glands. In addition, like in the male, another function is to produce and secrete sex hormones, which maintain the female sex organs and contribute to the female libido.

In this chapter we will consider the anatomy of the male reproductive system; the female reproductive system is the focus of chapter 21.

CHAPTER 20

Categories of Reproductive Structures

The structures of the male reproductive system can be categorized on a functional basis as follows:

- **Primary sex organs.** The primary sex organs are called *gonads;* specifically, the *testes* in the male. Gonads produce the gametes, or spermatozoa, and produce and secrete sex hormones. The secretion of male sex hormones, called *androgens,* at the appropriate times and in sufficient quantities causes the development of secondary sex organs and the expression of secondary sex characteristics.
- **Secondary sex organs.** Secondary sex organs are those structures that are essential in caring for and transporting spermatozoa. The three categories of secondary sex organs are the sperm-transporting ducts, the accessory glands, and the copulatory organ. The ducts that transport sperm include the *epididymides, ductus deferentia, ejaculatory ducts,* and *urethra.* The male accessory reproductive glands are the *seminal vesicles,* the *prostate,* and the *bulbourethral glands.* The *penis,* which contains erectile tissue, is the copulatory organ. The *scrotum* is a pouch of skin that encloses and protects the testes.
- **Secondary sex characteristics.** Secondary sex characteristics are features that are not essential for the reproductive process but are generally considered sexual attractants. In the male, they include body physique, body hair, and voice pitch.

The organs of the male reproductive system are shown in figure 20.1 and their functions are summarized in table 20.1.

Knowledge Check

1. What is the primary importance of sexual reproduction?
2. What are the functions of the male reproductive system?
3. List the organs of the male reproductive system and indicate whether they are primary or secondary sex organs.
4. With respect to the other body systems, discuss the latent (delayed) development of the reproductive system.

gamete: Gk. *gameta,* husband or wife

spermatozoa: Gk. *sperma,* seed; *zoon,* animal

androgen: Gk. *andros,* male producing

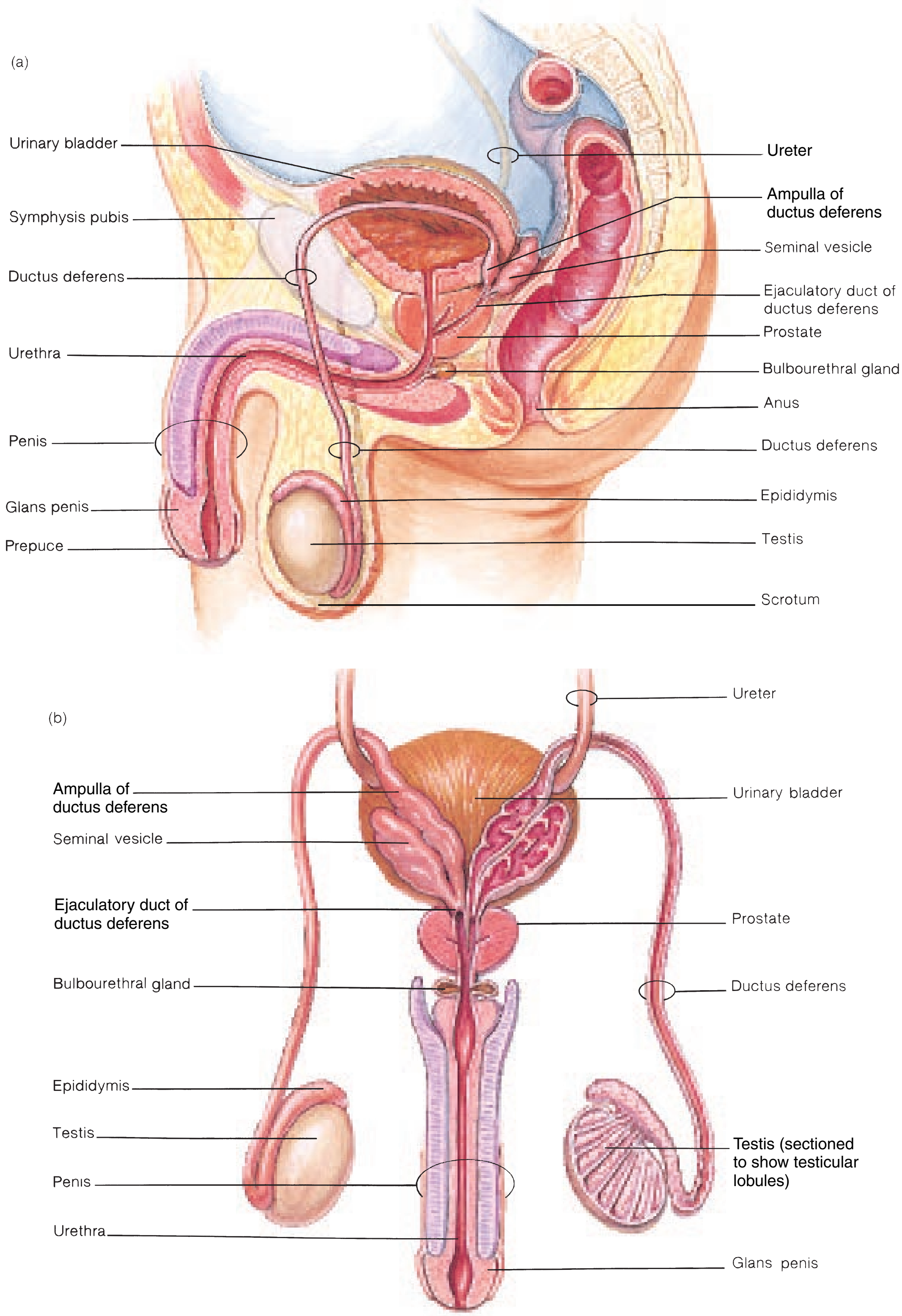


FIGURE 20.1 Organs of the male reproductive system. (*a*) a sagittal view and (*b*) a posterior view.

TABLE 20.1 Reproductive Organs of the Male

Organ(s)	Function(s)
Testes	
Seminiferous tubules	Produce spermatozoa
Interstitial cells	Secrete male sex hormones
Epididymides	Site of sperm maturation; store and convey spermatozoa to the ductus deferentia
Ductus deferentia	Store spermatozoa; convey spermatozoa to the ejaculatory ducts
Ejaculatory ducts	Receive spermatozoa and additives to produce seminal fluid
Seminal vesicles	Secrete alkaline fluid containing nutrients and prostaglandins; helps neutralize the acidic environment of the vagina
Prostate	Secretes acidic fluid that enhances motility of spermatozoa
Bulbourethral glands	Secrete fluid that lubricates the urethra and end of the penis
Scrotum	Encloses and protects the testes; helps maintain constant temperature for spermatogenesis
Penis	Conveys urine and seminal fluid to outside of body; copulatory organ

PERINEUM AND SCROTUM

The perineum is the specific portion of the pelvic region that contains the external genitalia and the anal opening. The scrotum, a pouch that supports the testes, is divided into two internal compartments by a connective tissue septum.

Objective 4 Describe the location of the perineum and distinguish between the urogenital and anal triangles.

Objective 5 Discuss the structure and function of the scrotum.

Perineum

The **perineum** (*per''ĭ-ne'um*) is a diamond-shaped region between the symphysis pubis and the coccyx (fig. 20.2). It is the muscular region of the outlet of the pelvis (see fig. 9.24). The perineum is divided into a *urogenital triangle* in front and an *anal triangle* in back. In the male perineum, the penis and scrotum are attached at the anterior portion of the urogenital triangle and the anus is located within the posterior portion of the anal triangle.

Scrotum

The saclike **scrotum** (*skro'tum*) is suspended immediately behind the base of the penis (see figs. 20.1 and 20.2). The functions of the scrotum are to support and protect the testes and to regulate their position relative to the pelvic region of the body. The soft, textured skin of the scrotum is covered with sparse hair in mature males and is darker in color than most of the other skin of the body. It also contains numerous sebaceous glands.

The external appearance of the scrotum varies at different times in the same individual as a result of the contraction and relaxation of the scrotal muscles. The **dartos** (*dar'tos*) is a layer of smooth muscle fibers in the subcutaneous tissue of the scrotum. The **cremaster** (*krĕ-mas'ter*) is a small band of skeletal muscle extending through the *spermatic cord,* a tube of fascia that also encloses the ductus deferens and testicular vessels and nerves (fig. 20.3). Both the dartos and the cremaster involuntarily contract in response to low temperatures to move the testes closer to the heat of the body in the pelvic region. The cremaster muscle is a continuation of the internal abdominal oblique muscle of the abdominal wall, which is derived as the testes descend into the scrotum. Because it is a skeletal muscle, it can be contracted voluntarily as well. When the scrotal muscles are contracted, the scrotum appears tightly wrinkled as the testes are pulled closer to the warmth of the body wall. High temperatures cause the dartos and cremaster muscles to relax and the testes to be suspended lower in the relaxed scrotum. The temperature of the testes is maintained at about 35° C (95° F), or about 3.6° F below normal body temperature, by the contraction or relaxation of the scrotal muscles. This temperature is optimal for the production and storage of spermatozoa.

Although uncommon, *male infertility* may result from an excessively high temperature of the testes over an extended period of time. Frequent hot baths or saunas may destroy sperm cells to the extent that the sperm count will be too low to enable fertilization.

The scrotum is subdivided into two longitudinal compartments by a fibrous **scrotal septum** (fig. 20.3*b*). The purpose of the scrotal septum is to compartmentalize each testis so that infection of one will generally not affect the other. In addition, the left testis is generally suspended lower in the scrotum than the right so that the two are not as likely to be compressed forcefully together. The site of the scrotal septum is apparent on the surface of the scrotum along a median longitudinal ridge called the **perineal raphe** (*ra'fe*). The perineal raphe extends forward to the undersurface of the penis and backward to the anal opening (see fig. 20.2).

The blood supply and innervation of the scrotum are extensive. The arteries that serve the scrotum are the internal pudendal branch of the internal iliac artery, the external pudendal branch of the femoral artery, and the cremasteric branch of the inferior epigastric artery. The venous drainage follows a pattern similar to that of the arteries. The scrotal nerves are primarily sensory; they include the pudendal nerves, ilioinguinal nerves, and posterior cutaneous nerves of the thigh.

dartos: Gk. *dartos*, skinned or flayed
cremaster: Gk. *cremaster*, a suspender, to hang
septum: L. septum, a partition
pudendal: L. *pudeo*, to feel ashamed
raphe: Gk. *raphe*, a seam

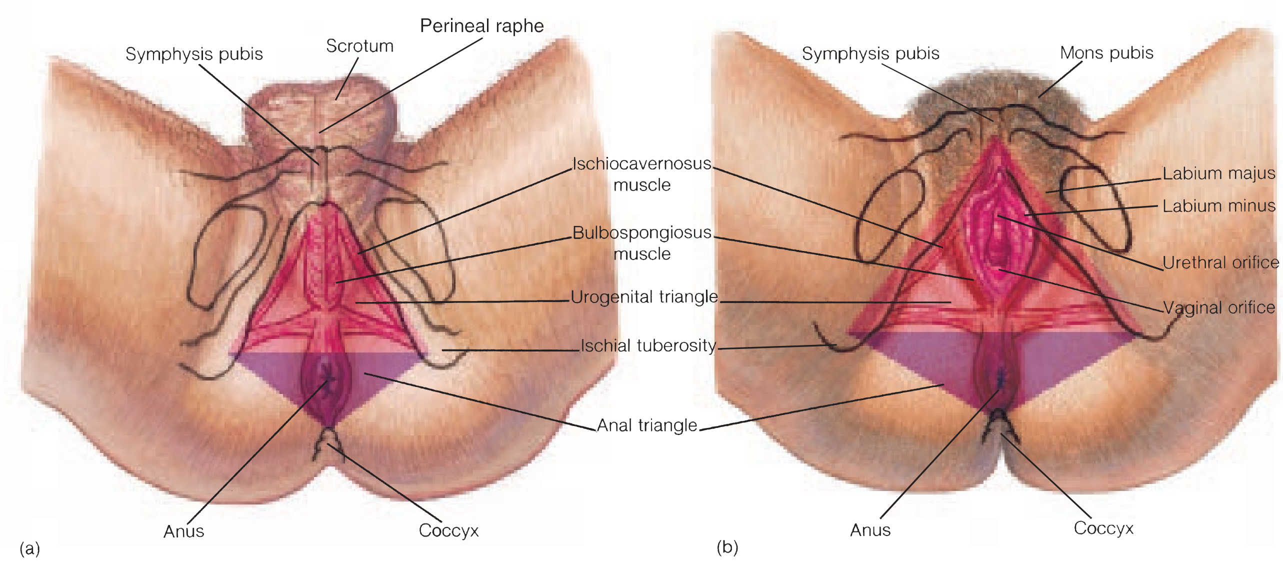


FIGURE 20.2 A superficial view of (*a*) the male perineum and (*b*) the female perineum (see chapter 21). The perineum is the region between the symphysis pubis and coccyx. It is divided into urogenital and anal triangles, indicated in red and purple respectively.

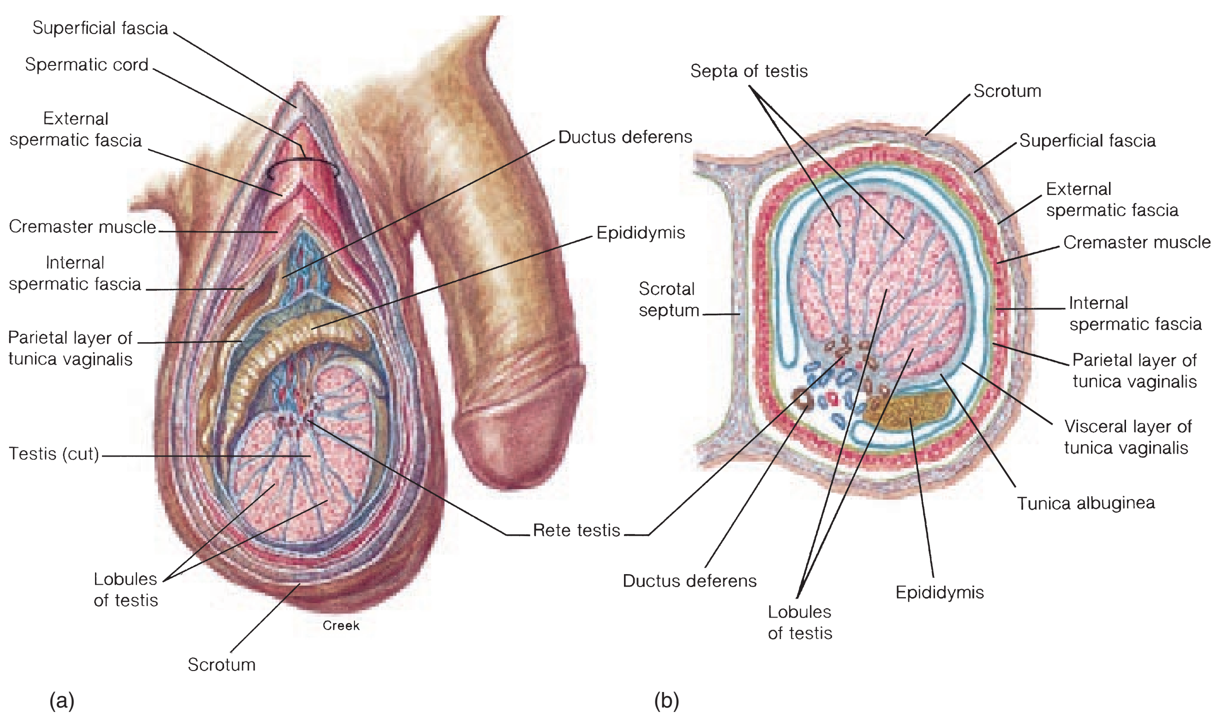


FIGURE 20.3 Structural features of a testis within the scrotum. (*a*) a longitudinal view and (*b*) a transverse view.

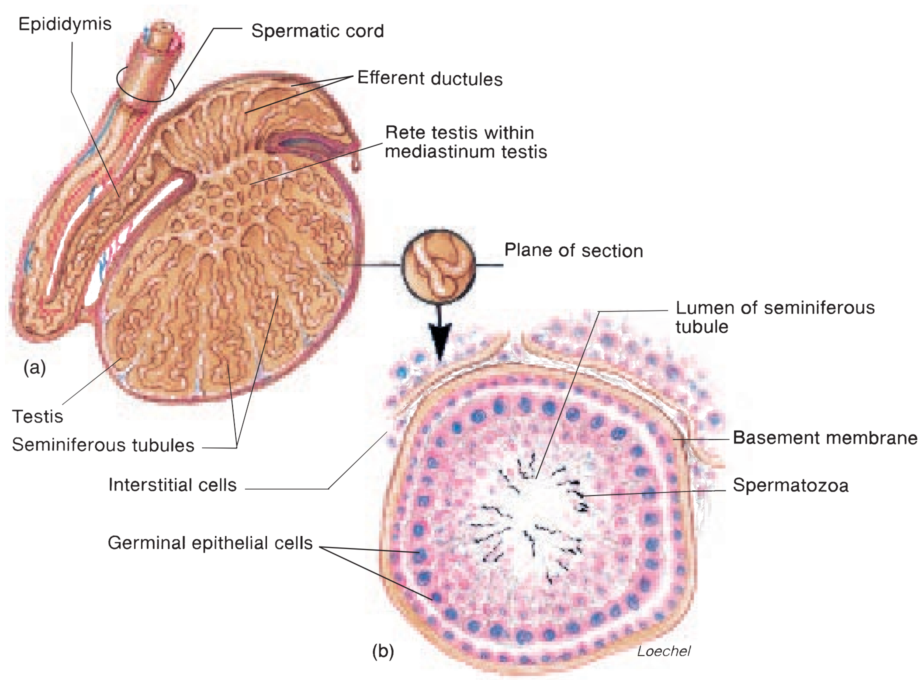


FIGURE 20.4 A diagram of the seminiferous tubules. (*a*) A sagittal section of a testis and (*b*) a transverse section of a seminiferous tubule.

Knowledge Check

5. Describe the location of the perineum.
6. Explain how the temperature of the testes is maintained. Why is it important to maintain a particular testicular temperature?
7. Describe the innervation and the blood supply to the scrotum.

TESTES

Located within the scrotum, the testes produce spermatozoa and androgens. Androgens regulate spermatogenesis and the development and functioning of the secondary sex organs.

Objective 6 Describe the location, structure, and functions of the testes.

Objective 7 Describe the effects of hormones on the growth and development of the male reproductive organs and explain how hormones are related to the development of male secondary sex characteristics.

Objective 8 List the events of spermatogenesis and distinguish between spermatogenesis and spermiogenesis.

Objective 9 Diagram the structure of a sperm cell and explain the function of each of its parts.

Structure of the Testes

The **testes** (*tes′tēz*—singular, *testis*) are paired, whitish, ovoid organs, each about 4 cm (1.5 in.) long and 2.5 cm (1 in.) in diameter. Each testis weighs between 10 and 14 g. Two tissue layers, or tunics, cover the testes. The outer **tunica vaginalis** is a thin serous sac derived from the peritoneum during the descent of the testes. The **tunica albuginea** (*al″byoo-jin′e-ă*) is a tough fibrous membrane that directly encapsulates each testis (fig. 20.3). Fibrous inward extensions of the tunica albuginea partition the testis into 250 to 300 wedge-shaped **testicular lobules.**

Each lobule of the testis contains tightly convoluted **seminiferous tubules** (fig. 20.4) that may exceed 70 cm (28 in.) in length if uncoiled. The seminiferous tubules are the functional units of the testis because it is here that *spermatogenesis*, the production of spermatozoa, occurs. Spermatozoa are produced at the rate of thousands per second—more than 100 million per day—throughout the life of a healthy, sexually mature male.

Various stages of meiosis can be observed in a section of a seminiferous tubule (see fig. 20.7*b*). The process begins as specialized germinal cells, called **spermatogonia** (*sper-mat″ŏ-go′ne-ă*), undergo meiosis to produce, in order of advancing maturity, the

tunica: L. *tunica*, a coat
vaginalis: L. *vagina*, a sheath
albuginca: L. *albus*, white
spermatogonia: Gk, *sperma*, seed; *gone*, generation

primary spermatocytes, *secondary spermatocytes*, and *spermatids* (see fig. 20.6). Forming the walls of the seminiferous tubules are **sustentacular** (Sertoli) **cells** (also called *nurse cells*) that produce and secrete nutrients for the developing spermatozoa embedded between them (see fig. 20.7*a*). The spermatozoa are formed, but not fully mature, by the time they reach the lumen of a seminiferous tubule.

Between the seminiferous tubules are specialized endocrine cells called **interstitial cells** (cells of Leydig). The function of these cells is to produce and secrete the male sex hormones. The testes are thus considered mixed exocrine and endocrine glands because they produce both spermatozoa and androgens.

Once the spermatozoa are produced, they move through the seminiferous tubules and enter a tubular network called the **rete** (*re'te*) **testis** for further maturation (fig. 20.4). Cilia are located on some of the cells of the rete testis. The spermatozoa are transported out of the testis and into the epididymis through a series of **efferent ductules.**

In all, it takes from 8 to 10 weeks for a spermatogonium to become a mature spermatozoon. In the spermatic ducts, spermatozoa can remain fertile for several months, in a state of suspended animation. If they are not ejaculated, they eventually degenerate and are absorbed into the blood.

The testes receive blood through the testicular arteries, which in turn arise from the abdominal aorta immediately below the origin of the renal arteries. The testicular veins drain the testes. The testicular vein of the right side enters directly into the inferior vena cava, whereas the testicular vein of the left side empties into the left renal vein (see fig. 16.34).

Testicular nerves innervate the testes with both motor and sensory neurons arising from the tenth thoracic segment of the spinal cord. Motor innervation is primarily through sympathetic neurons, but there is limited parasympathetic stimulation as well.

The most common cause of male infertility is a condition called *varicocele (var'i-ko-sēl)*. Varicocele occurs when one or both of the testicular veins draining from the testes becomes swollen, resulting in poor circulation in the testes. A varicocele generally occurs on the left side because the left testicular vein drains into the renal vein. The blood pressure is higher here than it is in the inferior vena cava, into which the right testicular vein empties.

Endocrine Functions of the Testes

Testosterone (tes-tos'tĕ-rōn) is by far the major androgen secreted by the adult testes. Androgens are sometimes called *anabolic steroids* because they stimulate the growth of muscles and other structures (table 20.2). Increased testosterone secretion during puberty is also required for the growth of the accessory sex organs, primarily the seminal vesicles and prostate. The removal of androgens by castration results in atrophy of these organs.

TABLE 20.2 Effect of Androgens in the Male

Category	Effect
Sex differentiation	Development and growth of the embryonic mesonephric ducts into the epididymides, ductus deferentia, seminal vesicles, and ejaculatory ducts
	Development of the urogenital sinus and tubercle into the prostate
	Development of the male external genitalia
Spermatogenesis	At puberty: Meiotic division and early maturation of spermatids
	After puberty: Maintenance of spermatogenesis
Secondary sex characteristics	Growth and maintenance of the accessory sex organs
	Growth of the penis
	Growth of facial and axillary hair
	Body growth
Anabolic effects	Protein synthesis and muscle growth
	Growth of bones
	Growth of other organs (including the larynx)
	Erythropoiesis (red blood cell formation)
Brain and behavioral effects	Increased mass of sexual nuclei; male sex drive and other aspects of male behavior

Androgens stimulate growth of the larynx (resulting in a deepening of the voice), hemoglobin synthesis (males have higher hemoglobin levels than females), and bone growth. The effect of androgens on bone growth is self-limiting, however, because androgens are ultimately responsible for the conversion of cartilage to bone in the epiphyseal plates, thus sealing the plates and preventing further lengthening of the bones.

Spermatogenesis

Spermatogenesis (*sper-mat''ŏ-jen'ĕ-sis*) is the sequence of events in the seminiferous tubules of the testes that leads to the production of spermatozoa. The germ cells that migrate from the yolk sac to the testes during early embryonic development become stem cells, or **spermatogonia,** within the outer region of the seminiferous tubules. Spermatogonia are diploid (2*n*) cells (with 46 chromosomes) that give rise to mature haploid (1*n*) gametes by a process of reductive cell division called *meiosis (mi-o'sis)*.

Meiosis occurs within the testes of males who have gone through puberty and involves two nuclear divisions, as summarized in table 20.3. During the first part of this process, the DNA duplicates (prophase I) and homologous chromosomes are separated (during anaphase I), producing two daughter cells (at

Sertoli cells: from Enrico Sertoli, Italian histologist, 1842–1910
cells of Leydig: from Franz von Leydig, German anatomist, 1821–1908
efferent ductules: L. *efferre*, to bring out; *ducere*, to lead

TABLE 20.3 **Stages of Meiosis**

Stage	Events	Stage	Events
First Meiotic Division		**Second Meiotic Division**	
Prophase I	Chromosomes appear double-stranded. The two strands, called chromatids, contain identical DNA and are joined together by a structure known as a centromere.	Prophase II	Chromosomes appear, each containing two chromatids.
	Homologous chromosomes pair up side by side.	Metaphase II	Chromosomes line up single file along equator as spindle formation is completed.
Metaphase I	Homologous chromosome pairs line up at equator; spindle apparatus is completed.	Anaphase II	Centromeres split and chromatids move to opposite poles.
Anaphase I	Homologous chromosomes separate; the two members of a homologous pair move to opposite poles.	Telophase II	Cytoplasm divides to produce two haploid cells from each of the haploid cells formed at telophase I.
Telophase I	Cytoplasm divides to produce two haploid cells.		

telophase I). Because each daughter cell contains only one of each homologous pair of chromosomes, the cells formed at the end of this *first meiotic division* contain 23 chromosomes each and are haploid (fig. 20.5). Each of the 23 chromosomes at this stage, however, consists of two strands (called *chromatids*) of identical DNA. During the *second meiotic division,* these duplicate chromatids are separated (at anaphase II), producing daughter cells (at telophase II). Meiosis of one diploid spermatogonia cell therefore produces four haploid daughter cells.

Actually, only about 1,500 stem cells migrate from the yolk sac to the embryonic testes. In order to produce many millions of spermatozoa throughout adult life, these spermatogonia duplicate themselves by mitotic division, and only one of the two cells—now called a **primary spermatocyte**—undergoes meiotic division (Fig. 20.6). In this way, spermatogenesis can occur continuously without exhausting the number of spermatogonia.

When a diploid primary spermatocyte completes the first meiotic division (at telophase I), the two haploid daughter cells thus produced are called **secondary spermatocytes.** At the end of the second meiotic division, each of the two secondary spermatocytes produces two haploid **spermatids** (*sper'mă-tidz*). One primary spermatocyte therefore produces four spermatids.

The sequence of events in spermatogenesis is reflected in the wall of the seminiferous tubule. The epithelial wall of the tubule, called the **germinal epithelium,** is indeed composed of germ cells in different stages of spermatogenesis. The spermatogonia and primary spermatocytes are located toward the outer side of the tubule, whereas the spermatids and mature spermatozoa are located on the side facing the lumen (fig. 20.7).

At the end of the second meiotic division, the four spermatids produced by the meiosis of two secondary spermatocytes are interconnected—their cytoplasm does not completely pinch off at the end of each division. The development of these interconnected spermatids into separate mature spermatozoa (a process called *spermiogenesis*) requires the participation of another type of cell in the tubules—the sustentacular (nurse) cells, or Sertoli cells.

Sustentacular (*sus''ten-tak'yŭ-lar*) **cells** are the only nongerminal cell type in the tubules. Connected by tight junctions, they form a continuous layer around the circumference of each tubule. In this way, the sustentacular cells form a *blood-testis barrier*. The molecules from the blood must pass through the cytoplasm of sustentacular cells before entering germinal cells.

In the process of *spermiogenesis* (the conversion of spermatids to spermatozoa), most of the spermatid cytoplasm is eliminated. This occurs through phagocytosis by the sustentacular cells of the "residual bodies" of cytoplasm from the spermatids. It is believed that phagocytosis of the residual bodies may transmit informational molecules from the germ cells to the sustentacular cells. The sustentacular cells, in turn, may provide molecules needed by the germ cells. It is known, for example, that the X chromosome of the germ cells is inactive during meiosis. Because this chromosome contains the genes needed to produce many essential molecules, it is believed that these molecules are provided by the sustentacular cells while meiosis is taking place.

Structure of Spermatozoa

A mature sperm cell, or **spermatozoon** (*sper-mat''ŏ-zo'on*) is a microscopic, tadpole-shaped structure approximately 0.06 mm long (fig. 20.7*c* and fig. 20.8). It consists of an oval **head** and an elongated **flagellum.** Although the head of a spermatozoon lacks mitochondria, it does contain a nucleus with 23 chromosomes. The tip of the head, called the *acrosome (ak'rŏ-sōm)*, contains

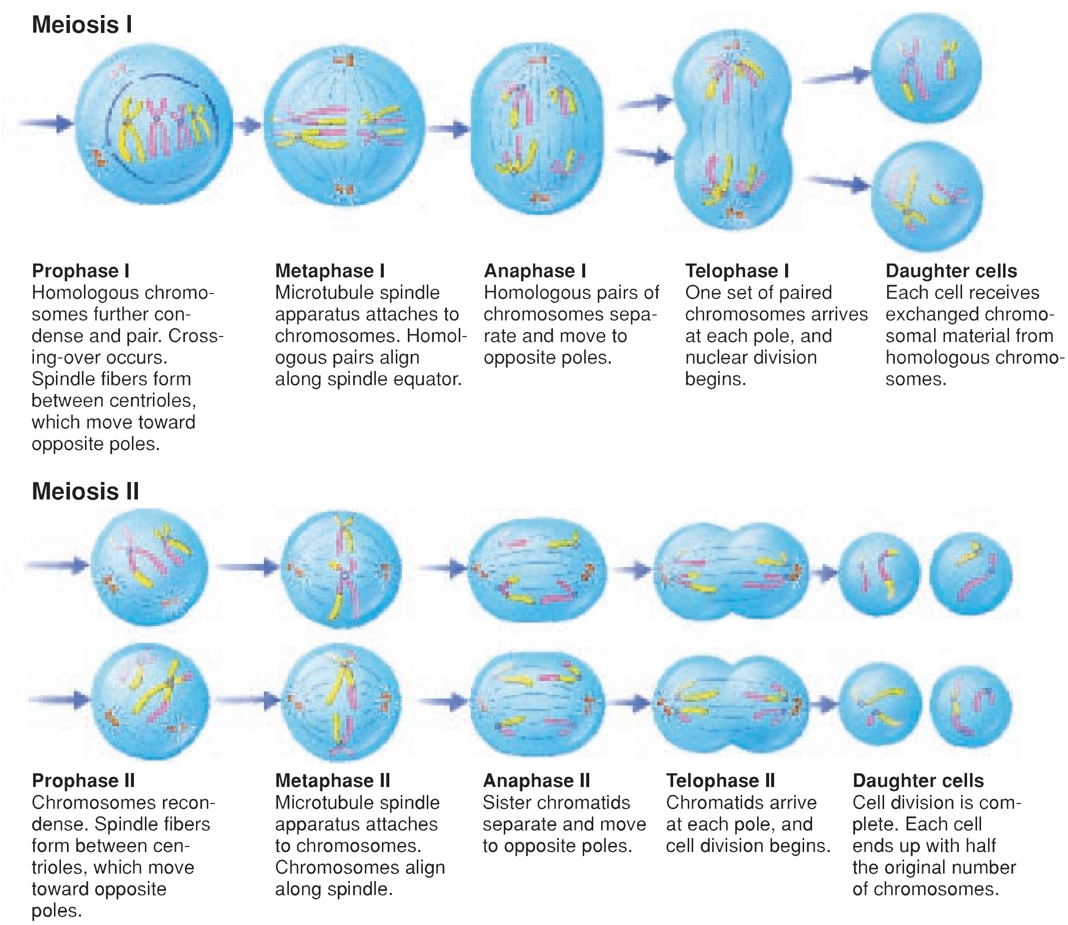


FIGURE 20.5 Meiosis, or reduction division. In the first meiotic division, the homologous chromosomes of a diploid parent cell are separated into two haploid daughter cells. Each of these chromosomes contains duplicate strands, or chromatids. In the second meiotic division, these chromatids are distributed to two new haploid daughter cells.

enzymes that help the spermatozoon penetrate the ovum. The body of the flagellum contains numerous mitochondria spiraled around a filamentous core. The mitochondria provide the energy necessary for locomotion. The flagellum propels the spermatozoon with a lashing movement. The maximum unassisted rate of spermatozoa movement is about 3 mm per hour.

Recent findings indicate that ejaculated spermatozoa (plural of spermatozoon) can survive up to 5 days at body temperature—longer than previously thought. In the average fertile male, up to 20% of these sperm cells are defective, however, and are of no value. It is not uncommon for them to have enlarged heads, dwarfed and misshapen heads, two flagella, or a flagellum that is bent. Spermatozoa such as these are unable to propel themselves adequately.

Knowledge Check

8. Describe the location and structure of the testes.
9. What are the functions of the seminiferous tubules, germinal epithelial cells, and interstitial cells?
10. Discuss the effect of testosterone on the production of sperm cells and the development of secondary sex characteristics.
11. Diagram a spermatozoon and its adjacent sustentacular cell and explain the functions of sustentacular cells in the seminiferous tubules.

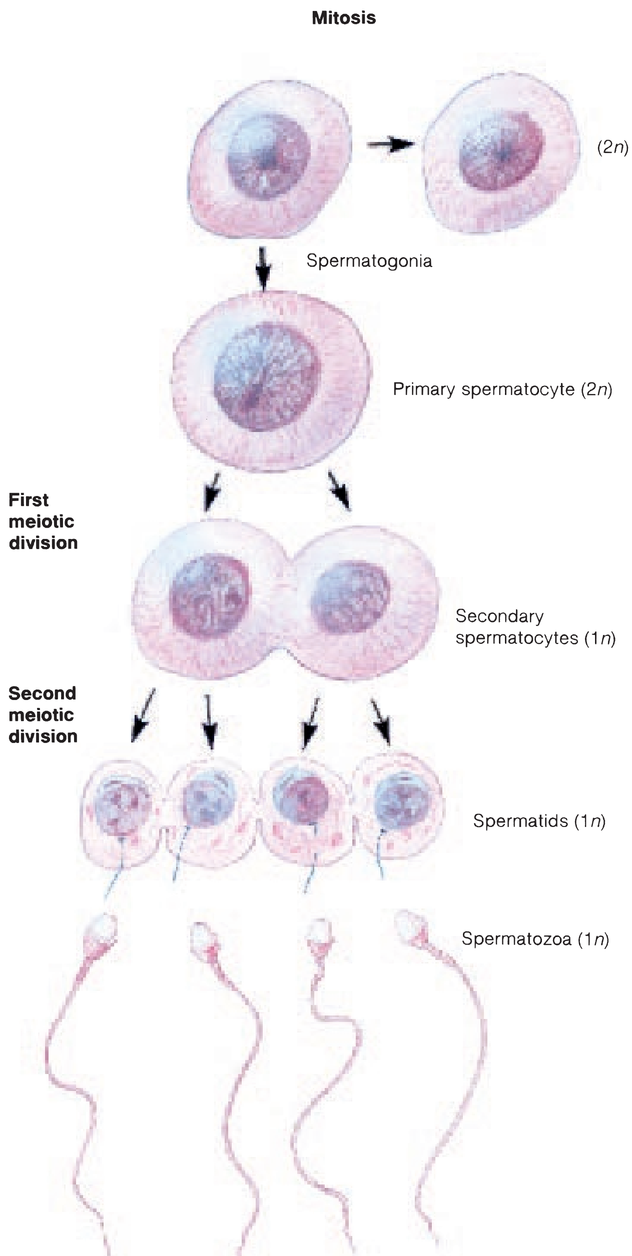


FIGURE 20.6 The process of spermatogenesis. Spermatogonia undergo mitotic division to replace themselves and produce a daughter cell that will undergo meiotic division. This cell is called a primary spermatocyte. Upon completion of the first meiotic division, the daughter cells are called secondary spermatocytes. Each of them complete a second meiotic division to form spermatids. Notice that the four spermatids produced by the meiosis of a primary spermatocyte are interconnected. Each spermatid forms a mature spermatozoon.

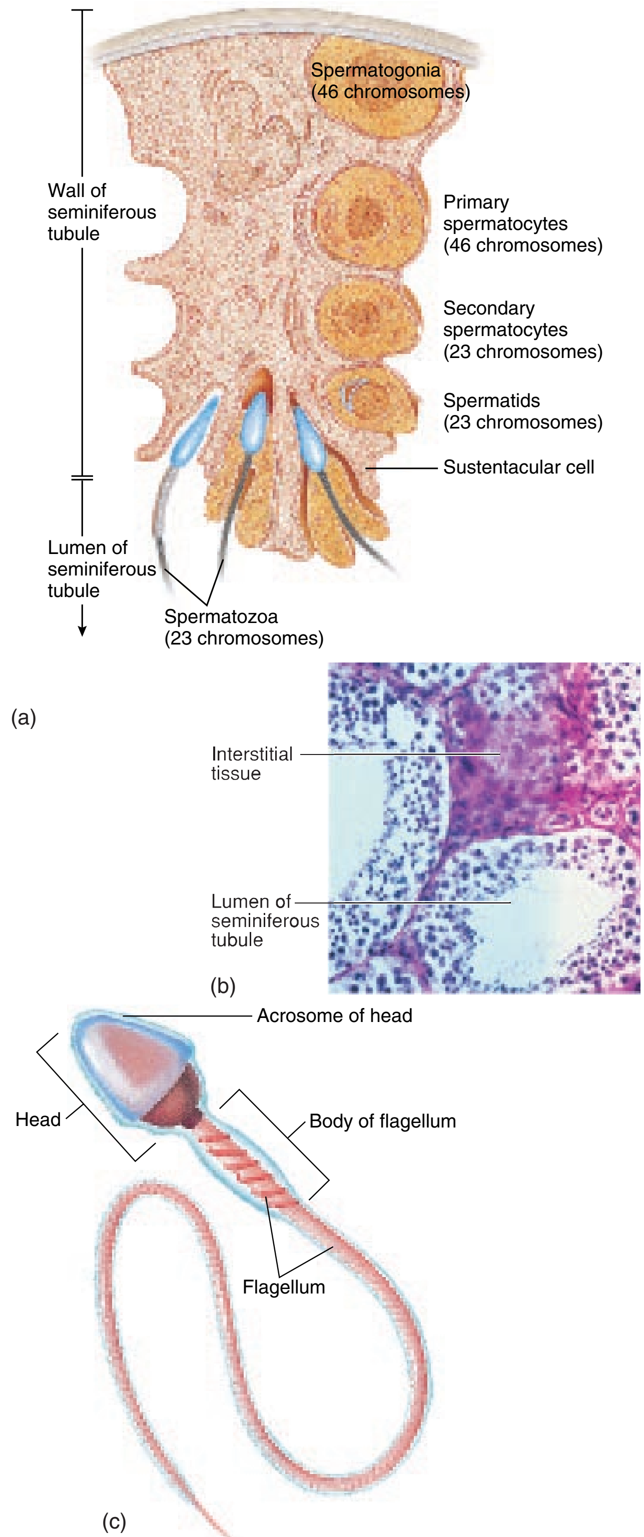


FIGURE 20.7 Seminiferous tubules and a spermatozoon. (*a*) The stages of spermatogenesis within the germinal epithelium of a seminiferous tubule, in which the relationship between sustentacular cells and developing spermatozoa is shown. (*b*) A photomicrograph of a seminiferous tubule and surrounding interstitial tissue, and (*c*) a diagram of a spermatozoon.

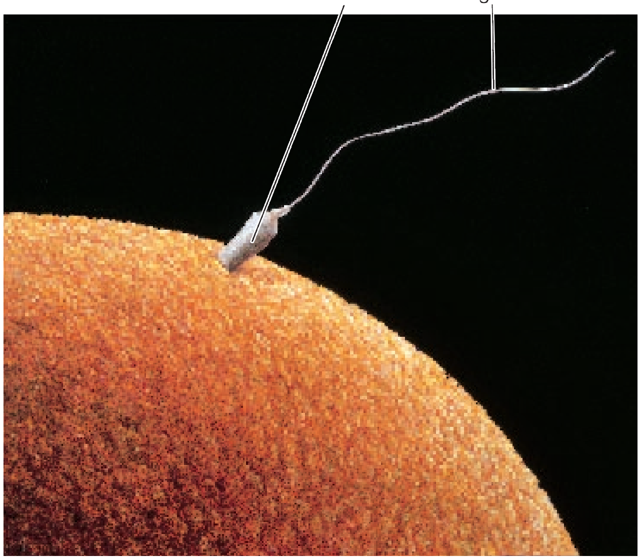


FIGURE 20.8 A scanning electron micrograph of a spermatozoon in contact with an egg.

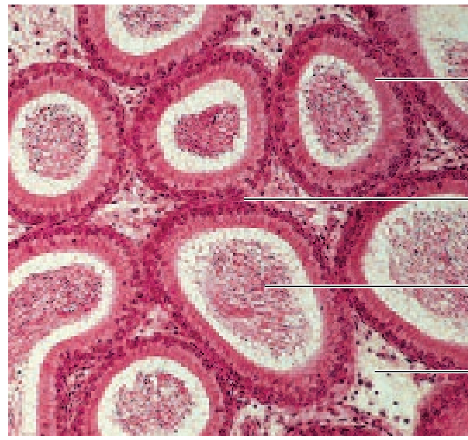


FIGURE 20.9 The histology of the epididymis showing sperm in the lumina (50×).

SPERMATIC DUCTS, ACCESSORY REPRODUCTIVE GLANDS, AND THE URETHRA

The spermatic ducts store spermatozoa and transport them from the testes to the outside of the body by way of the urethra. The accessory reproductive glands provide additives to the spermatozoa to form semen, which is discharged from the erect penis during ejaculation.

Objective 10 Describe the location and structure of each segment of the male duct system.

Objective 11 Describe the structure and contents of the spermatic cord.

Objective 12 Describe the location, structure, and functions of the ejaculatory ducts, seminal vesicles, prostate, and bulbourethral glands.

Spermatic Ducts

The spermatic ducts store spermatozoa and transport them from the testes to the urethra. The accessory reproductive glands provide additives to the spermatozoa in the formation of semen.

Epididymis

The **epididymis** (*ep″ĭ-did′ĭ-mus*—plural, *epididymides*) is an elongated organ attached to the posterior surface of the testis (see figs. 20.1 and 20.3). If it were uncoiled, it would measure 5.5 m (about 17 ft). The highly coiled, tubular *tail portion* contains spermatozoa in their final stages of maturation (fig. 20.9). The upper expanded portion is the *head*, and the tapering middle section is the *body*. The tail is continuous with the beginning portion of the ductus deferens; both store spermatozoa to be discharged during ejaculation. The time required to produce mature spermatozoa—from meiosis in the seminiferous tubules to storage in the ductus deferens—is approximately 2 months.

Ductus Deferens

The **ductus deferens** (*duk′tus def′er-enz*—plural, *ductus deferentia*) is a fibromuscular tube about 45 cm (18 in.) long and 2.5 mm thick (see fig. 20.1) that conveys spermatozoa from the epididymis to the ejaculatory duct. Also called the *vas deferens* (plural, *vasa deferentia*), it exits the scrotum as it ascends along the posterior border of the testis. From here, it penetrates the inguinal canal, enters the pelvic cavity, and passes to the side of the urinary bladder on the medial side of the ureter. The **ampulla** (*am-pool′ă*) of the ductus deferens is the terminal portion that joins the ejaculatory duct.

The histological structure of the ductus deferens includes a layer of pseudostratified ciliated columnar epithelium in contact with the tubular lumen and surrounded by three layers of tightly packed smooth muscle (fig. 20.10). Sympathetic nerves from the pelvic plexus serve the ductus deferens. Stimulation through these nerves causes peristaltic contractions of the muscular layer, which propel the stored spermatozoa toward the ejaculatory duct.

Much of the ductus deferens is located within a structure known as the **spermatic cord** (see figs. 20.3 and 20.14). The spermatic cord extends from the testis to the inguinal canal and consists of the ductus deferens, the testicular artery and venous

CHAPTER 20

deferens: L. *deferens*, conducting away
ampulla: L. *ampulla*, a two-handled bottle

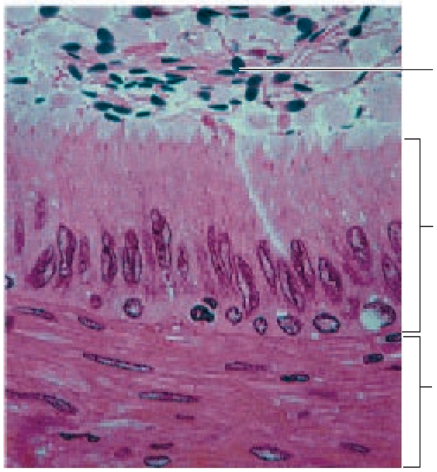


FIGURE 20.10 The histology of the ductus deferens (250×).

plexus, nerves, the cremaster muscle, lymph vessels, and connective tissue. The portion of the spermatic cord that passes anterior to the pubic bone can be easily palpated. The **inguinal** (*ing'gwĭ-nal*) **canal** is a passageway for the spermatic cord through the abdominal wall; it is a potentially weak area and a common site for development of a hernia.

Ejaculatory Duct

The ejaculatory (*ĕ-jak'yoo-lă-tor-e*) duct is about 2 cm (1 in.) long and is formed by the union of the ampulla of the ductus deferens and the duct of the seminal vesicle. The ejaculatory duct then pierces the capsule of the prostate on its posterior surface and continues through this gland (see fig. 20.1). Both ejaculatory ducts receive secretions from the seminal vesicles and then eject the spermatozoa with its additives into the prostatic urethra to be mixed with secretions from the prostate. The urethra, discussed shortly, serves as a passageway for both semen and urine. It is the terminal duct of the male duct system.

Accessory Reproductive Glands

The accessory reproductive glands of the male include the *seminal vesicles*, the *prostate*, and the *bulbourethral glands* (see fig. 20.1). The contents of the seminal vesicles and prostate are mixed with the spermatozoa during ejaculation to form *semen (seminal fluid)*. The fluid from the bulbourethral glands is released in response to sexual stimulation prior to ejaculation.

Seminal Vesicles

The paired seminal vesicles, each about 5 cm (2 in.) long, are convoluted club-shaped glands lying at the base of the urinary bladder, in front of the rectum. They secrete a sticky, slightly alkaline, yellowish substance that contributes to the motility and viability of spermatozoa. The secretion from the seminal vesicles

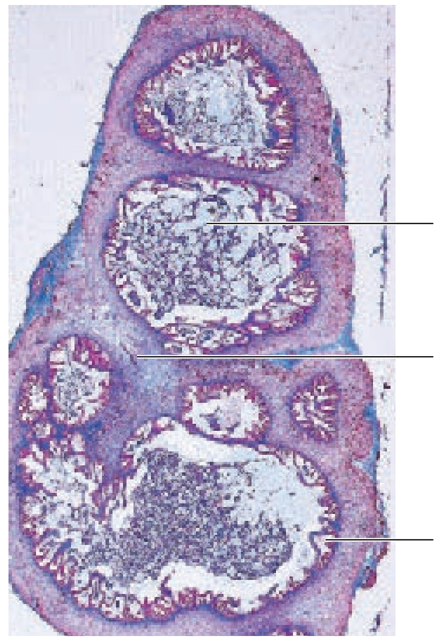


FIGURE 20.11 The histology of the seminal vesicle (10×).

contains a variety of nutrients, including fructose, that provide an energy source for the spermatozoa. It also contains citric acid, coagulation proteins, and prostaglandins. The discharge from the seminal vesicles makes up about 60% of the volume of semen.

Histologically, the seminal vesicle has an extensively coiled mucosal layer (fig. 20.11). This layer partitions the lumen into numerous intercommunicating spaces that are lined by pseudostratified columnar and cuboidal secretory epithelia (referred to as glandular epithelium).

Blood is supplied to the seminal vesicles by branches from the middle rectal arteries. The seminal vesicles are innervated by both sympathetic and parasympathetic neurons. Sympathetic stimulation causes the contents of the seminal vesicles to empty into the ejaculatory ducts on their respective sides.

Prostate

The firm prostate (*pros'tăt*) is the size and shape of a chestnut. It is about 4 cm (1.6 in.) across and 3 cm (1.2 in.) thick and lies immediately below the urinary bladder, where it surrounds the beginning portion of the urethra (see fig. 20.1). The prostate is enclosed by a fibrous capsule and divided into lobules formed by the urethra and the ejaculatory ducts that extend through the gland. The ducts from the lobules open into the urethra. Extensive bands of smooth muscle course throughout the prostate to form a meshwork that supports the glandular tissue (fig. 20.12). Contraction of the smooth muscle expels the contents from the gland and provides part of the propulsive force needed to ejaculate the semen. The thin, milky-colored prostatic secretion assists sperm cell motility as a liquefying agent, and its alkalinity

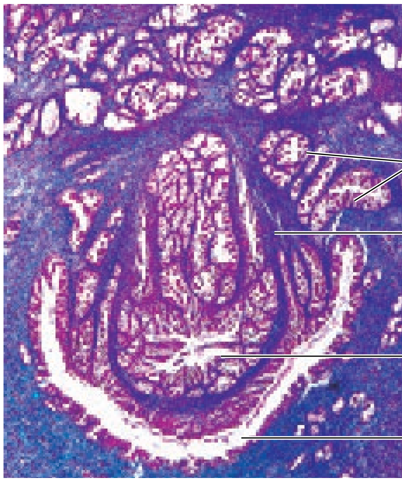


FIGURE 20.12 The histology of the prostate (50×).

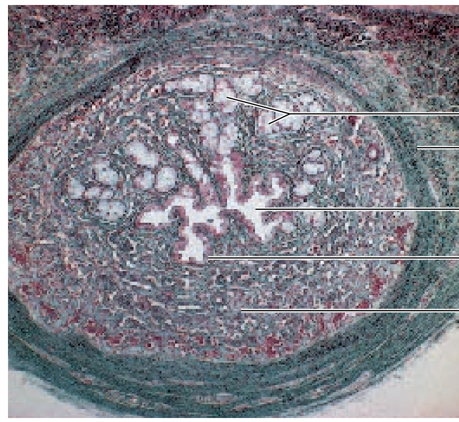


FIGURE 20.13 The histology of the urethra (10×).

protects the sperm in their passage through the acidic environment of the female vagina. The prostate also secretes the enzyme *acid phosphatase*, which is often measured clinically to assess prostate function. The discharge from the prostate makes up about 40% of the volume of the semen.

Blood is supplied to the prostate from branches of the middle rectal and inferior visceral arteries. The venous return forms the prostatic venous plexus, along with blood draining from the penis. The prostatic venous plexus drains into the internal iliac veins. The prostate has both sympathetic and parasympathetic innervation arising from the pelvic plexuses.

A routine physical examination of the male includes rectal palpation of the prostate. Enlargement or overgrowth of the glandular substance of the prostate, called *benign prostatic hypertrophy (BPH),* is relatively common in older men. It constricts the urethra, causing difficult urination. This condition may require surgery. In a *transurethral prostatic resection,* excess prostatic tissue is removed by use of a device inserted through the urethra.

Bulbourethral Glands

The paired, pea-sized, bulbourethral (Cowper's) glands are located below the prostate (see fig. 20.1). Each bulbourethral gland is about 1 cm (0.4 in.) in diameter and drains by a 2.5-cm (1-in.) duct into the urethra. Upon sexual arousal and prior to ejaculation, the bulbourethral glands are stimulated to secrete a mucoid substance that coats the lining of the urethra to neutralize the pH of the urine residue. It also lubricates the tip of the penis in preparation for coitus.

Urethra

The **urethra** of the male serves as a common tube for both the urinary and reproductive systems. However, urine and semen cannot pass through simultaneously because the nervous reflex during ejaculation automatically inhibits micturition. The male urethra is about 20 cm (8 in.) long, and S-shaped because of the shape of the penis. As described in chapter 19 (see fig. 19.15), it is divided into three regions, which are briefly reviewed here.

1. The **prostatic part of the urethra** is the 2.5-cm (1-in.) proximal portion that passes through the prostate. The prostatic urethra receives drainage from the small ducts of the prostate and the two ejaculatory ducts.
2. The **membranous part of the urethra** is the 0.5-cm (0.2-in.) portion that passes through the urogenital diaphragm. The external urethral sphincter muscle is located in this region.
3. The **spongy part of the urethra** is the longest portion, extending from the outer edge of the urogenital diaphragm to the external urethral orifice on the glans penis. About 15 cm (6 in.) long, this portion is surrounded by erectile tissue as it passes through the corpus spongiosum of the penis. The paired ducts from the bulbourethral glands attach to the spongy part of the urethra near the urogenital diaphragm.

The wall of the urethra has an inside lining of mucous membrane, composed of transitional epithelium (fig. 20.13) and surrounded by a relatively thick layer of smooth muscle tissue called the *tunica muscularis*. Specialized **urethral glands,** embedded in the urethral wall, secrete mucus into the lumen of the urethra.

Knowledge Check

12. List in order the structures through which spermatozoa pass as they travel from the testes to the urethra.
13. Differentiate between the ductus deferens and the spermatic cord.
14. Describe the structure and location of each of the accessory reproductive glands.
15. Why is the position of the prostate of clinical importance?
16. Describe the three parts of the male urethra.

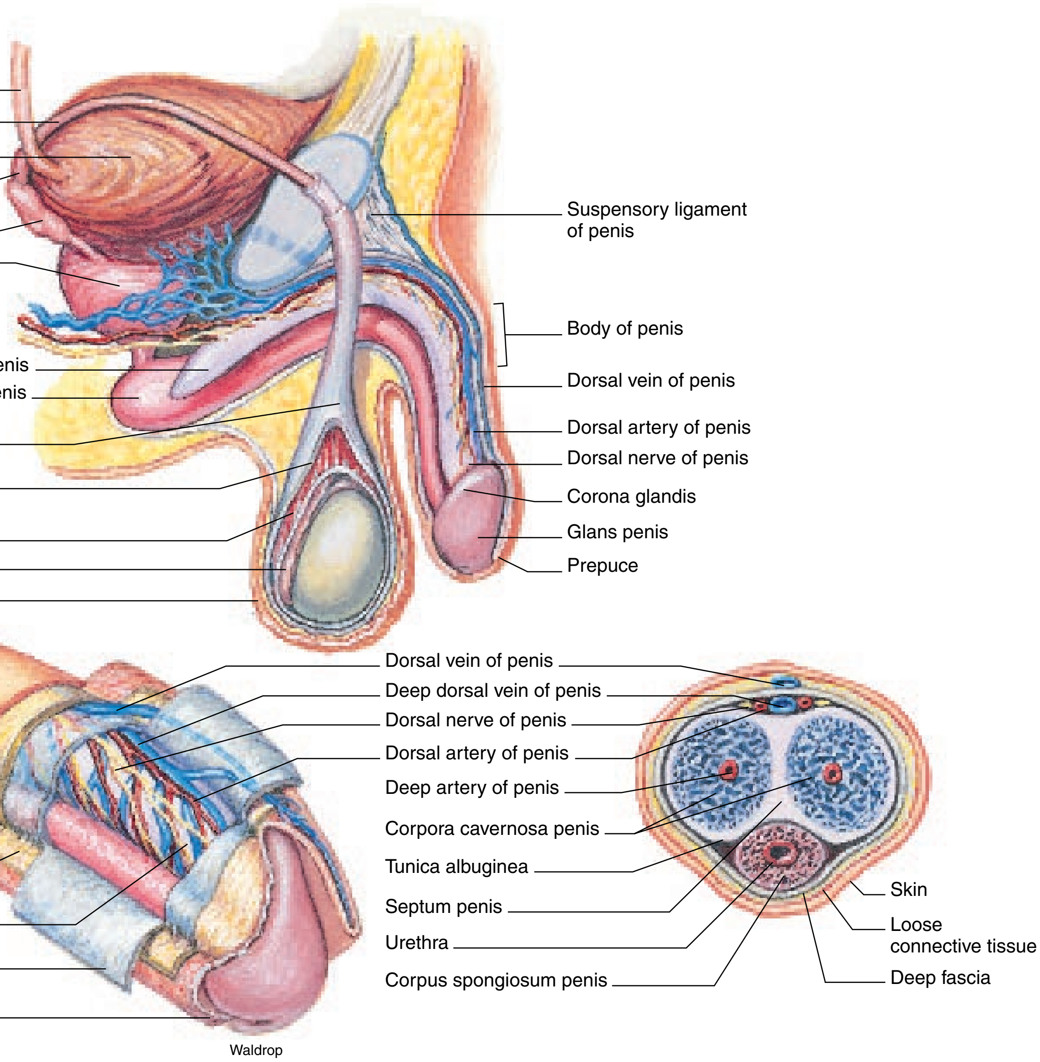


FIGURE 20.14 The structure of the penis showing the attachment, blood and nerve supply, and the arrangement of the erectile tissue.

CHAPTER 20

PENIS

The penis, containing the spongy urethra and covered with loose-fitting skin, is specialized with three columns of erectile tissue to become engorged with blood for insertion into the vagina during coitus.

Objective 13 Describe the structure and function of the penis.

The **penis** (*pe'nis*) when distended, serves as the copulatory organ of the male reproductive system. The penis and scrotum, which are suspended from the perineum, constitute the external genitalia of the male. Under the influence of sexual stimulation, the penis becomes engorged with blood. This engorgement results from the filling of intricate blood sinuses, or spaces, in the erectile tissue of the penis.

The penis is divided into a proximal attached *root,* which is attached to the pubic arch; an elongated tubular *body*, or *shaft;* and a distal cone-shaped *glans penis* (fig. 20.14). The **root of the penis** expands posteriorly to form the **bulb of the penis** and the **crus** (*krus*) **of the penis.** The bulb is positioned in the urogenital triangle of the perineum, where it is attached to the undersurface of the urogenital diaphragm and enveloped by the bulbocavernosus

crus: L. *crus*, leg, resembling a leg

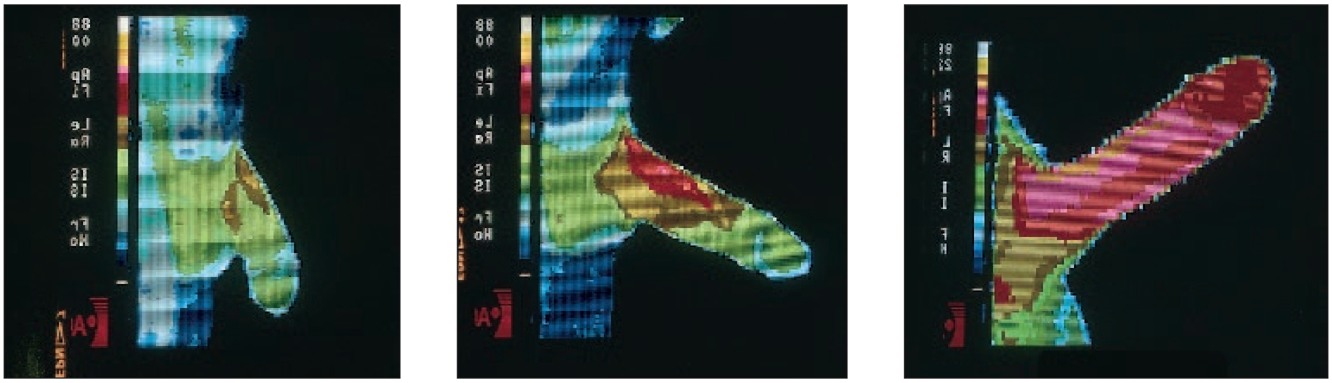


FIGURE 20.15 Thermograms of the penis showing differential heat radiation during erection. Red, yellow, and purple indicate the warmest portions; blue and green indicate the coolest.

muscle (see fig. 9.24). The crus, in turn, attaches the root of the penis to the pubic arch (ischiopubic ramus) and to the perineal membrane. The crus, which is superior to the bulb, is enveloped by the ischiocavernosus muscle.

The **body of the penis** is composed of three cylindrical columns of erectile tissue, which are bound together by fibrous tissue and covered with skin (fig. 20.14). The paired dorsally positioned masses are named the **corpora cavernosa** (*kor'por-ă kav''er-no'să*) **penis.** The fibrous tissue between the two corpora forms a **septum penis.** The **corpus spongiosum** (*spon''je-o'sum*) **penis** is ventral to the other two and surrounds the spongy urethra. The penis is flaccid when the spongelike tissue is not engorged with blood. In the sexually aroused male, it becomes firm and erect as the columns of erectile tissue fill with blood (fig. 20.15).

Trauma to the penis, testes, and scrotum is common because of their pendent (hanging) position. Because the penis and testes are extremely sensitive to pain, a male will respond reflexively to protect the groin area. Urethral injuries are more common in men than in women because of the position of the urethra in the penis. "Straddle injuries" in which the urethra and penis are forcefully compressed between a hard surface and the pubic arch, may rupture the urethra.

The **glans penis** is the cone-shaped terminal portion of the penis, which is formed from the expanded corpus spongiosum. The opening of the urethra at the tip of the glans penis is called the **urethral orifice.** The **corona glandis** is the prominent posterior ridge of the glans penis. On the undersurface of the glans penis, a vertical fold of tissue called the **frenulum** (*fren'yŭ-lum*) attaches the skin covering the penis to the glans penis.

The skin covering the penis is hairless, lacks fat cells, and is generally more darkly pigmented than the rest of the body skin. The skin of the body of the penis is loosely attached and is continuous over the glans penis as a protective retractable sheath called the **prepuce** (*pre'pyoos*), or **foreskin.** The prepuce is commonly removed from an infant on the third or fourth day after birth, or on the eighth day as part of a Jewish religious rite. This procedure is called a *circumcision*.

A *circumcision* is generally performed for hygienic purposes because the glans penis is easier to clean if exposed. A sebaceous secretion from the glans penis, called *smegma (smeg'ma),* will accumulate along the border of the corona glandis if good hygiene is not practiced. Smegma can foster bacteria that may cause infections, and therefore should be removed through washing. Cleaning the glans penis of an uncircumcised male requires retraction of the prepuce. Occasionally, a child is born with a prepuce that is too tight to permit retraction. This condition is called *phimosis (fi-mo'sis)* and necessitates circumcision.

The penis is supplied with blood on each side through the superficial external pudendal branch of the femoral artery and the internal pudendal branch of the internal iliac artery. The venous return is through a superficial median dorsal vein, which empties into the great saphenous vein in the thigh, and through the deep median vein, which empties into the prostatic plexus.

The penis has many sensory tactile receptors, especially in the glans penis, making it a highly sensitive organ. In addition, the penis has extensive motor innervation from both sympathetic and parasympathetic fibers.

Knowledge Check

17. Describe the position of the penis relative to the scrotum and accessory glands.
18. Describe the external structure of the penis and the internal arrangement of the erectile tissue.
19. Define *circumcision* and explain why this procedure is commonly performed.

cavernosa: L. *cavus*, hollow
glans: L. *glans*, acorn
corona: L. *corona*, garland, crown
frenulum: L. *frenulum*, diminutive of *frenum*, a bridle
prepuce: L. *prae*, before; *putium*, penis
phimosis: Gk. *phimosis*, a muzzling

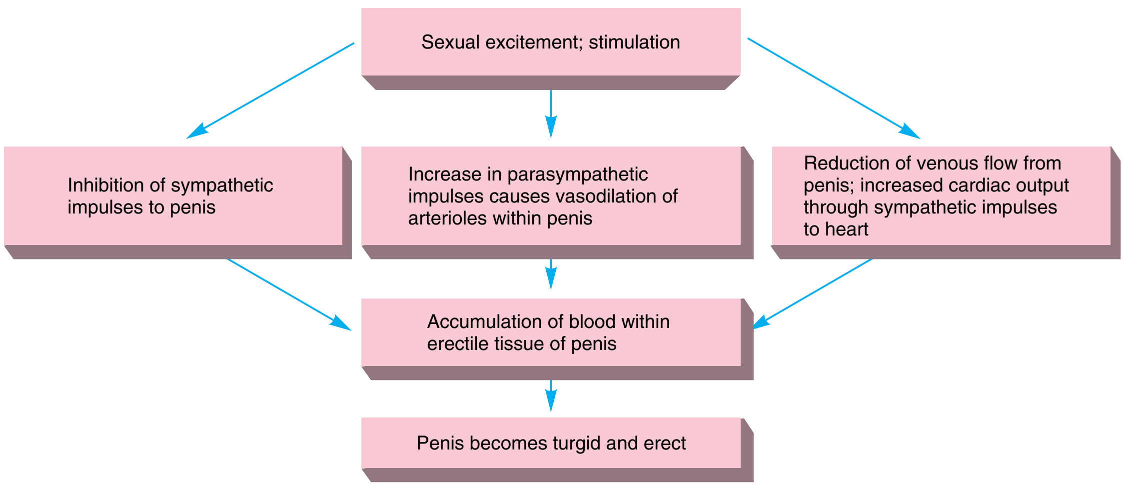


FIGURE 20.16 The mechanism of erection of the penis.

MECHANISMS OF ERECTION, EMISSION, AND EJACULATION

Erection of the penis results from parasympathetic impulses that cause vasodilation of arteries within the penis and a decrease in venous drainage. Emission and ejaculation are stimulated by sympathetic impulses, which result in the forceful expulsion of semen from the penis.

Objective 14 Distinguish between erection, emission, and ejaculation.

Objective 15 Describe the events that result in erection of the penis.

Objective 16 Explain the physiological process of ejaculation.

Objective 17 Describe the characteristic properties of semen.

Erection, emission, and ejaculation are a series of interrelated events by which semen from the male is deposited into the female vagina during coitus (sexual intercourse). *Erection* usually occurs as a male becomes sexually aroused and the erectile tissue of the penis becomes engorged with blood. *Emission* is the movement of spermatozoa from the epididymides to the ejaculatory ducts and prostatic part of the urethra (see fig. 19.15) where it is mixed with the fluid additives from the prostate and seminal vesicles to form semen (*se'men*). *Ejaculation* is the forceful expulsion of the semen (also called ejaculate or seminal fluid) from the ejaculatory ducts and urethra of the penis. Emission and ejaculation do not necessarily follow erection of the penis; they occur only if there is sufficient stimulation of the sensory receptors in the penis to elicit the ejaculatory response.

Erection of the Penis

Erection of the penis depends on the volume of blood that enters the arteries of the penis as compared to the volume that exits through venous drainage (fig. 20.15). Normally, constant sympathetic stimuli to the arterioles of the penis maintain a partial constriction of smooth muscles within the arteriole walls, so that there is an even flow of blood throughout the penis. During sexual excitement, however, parasympathetic impulses cause marked vasodilation within the arterioles of the penis, resulting in more blood entering than venous blood draining. Also, during parasympathetic stimulation there is inhibition of sympathetic impulses to arterioles of the penis. At the same time, there may be slight vasoconstriction of the dorsal vein of the penis and an increase in cardiac output. These combined events cause the spongy tissue of the corpora cavernosa and the corpus spongiosum to become distended with blood and the penis to become turgid. In this condition, the penis can be inserted into the vagina of the female and function as a copulatory organ to discharge semen.

Erection is controlled by two portions of the central nervous system—the hypothalamus in the brain and the sacral portion of the spinal cord. The hypothalamus controls conscious sexual thoughts that originate in the cerebral cortex. Nerve impulses from the hypothalamus elicit parasympathetic responses from the sacral region that cause vasodilation of the arterioles within the penis. Conscious thought is not required for an erection, however, and stimulation of the penis can cause an erection because of a reflex response in the spinal cord. This reflexive action enables an erection in a sleeping male or in an infant—perhaps from the stimulus of a diaper. The mechanism of erection of the penis is summarized in figure 20.16.

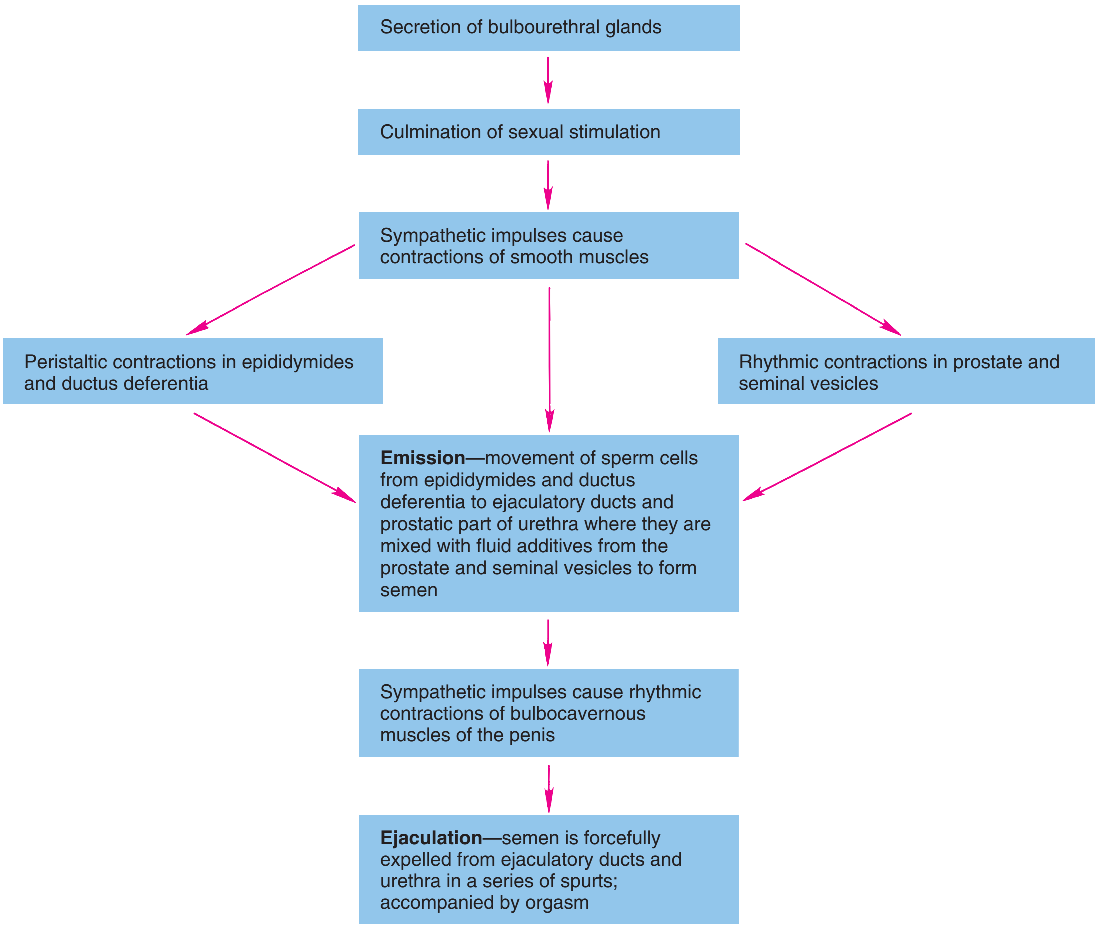


FIGURE 20.17 The mechanism of emission and ejaculation.

The penis of many mammals contain a bone called an *os penis,* or *baculum,* of a highly variable shape. The human male, having no such bone, relies exclusively on blood-filled erectile tissue to give rigidity to the penis. On average, the erect penis in an adult is 15 cm (6 in.) long and 4 cm (1.5 in.) in diameter.

Ejaculation is the expulsion of semen through the urethra of the penis. In contrast to erection, ejaculation is a response involving the sympathetic innervation of the accessory reproductive organs. Ejaculation is preceded by continued sexual stimulation, usually through activated tactile receptors in the glans penis and the skin of the body. Rhythmic friction of these structures during coitus causes sensory impulses to be transmitted to the thalamus and cerebral cortex. The first sympathetic response, which occurs prior to ejaculation, is the discharge from the bulbourethral glands. The fluid from these glands is usually discharged before penetration into the vagina and serves to lubricate the urethra and the glans penis.

Emission and Ejaculation of Semen

Emission

Continued sexual stimulation following erection of the penis causes emission (fig. 20.17). Emission is the movement of sperm cells from the epididymides to the ejaculatory ducts and the secretions of the accessory glands into the ejaculatory ducts and prostatic part of the urethra in the formation of semen. Emission occurs as sympathetic impulses from the pelvic plexus cause a rhythmic contraction of the smooth muscle of the epididymides, ductus deferentia, ejaculatory ducts, seminal vesicles, and prostate.

Ejaculation

Ejaculation immediately follows emission and is accompanied by *orgasm*—the climax of the sex act. Ejaculation occurs in a series of

TABLE 20.4 The Clinical Examination of Semen

Characteristic	Reference Value
Volume of ejaculate	1.5–5.0 ml
Sperm count	40–250 million/ml
Sperm motility	
Percentage of motile forms:	
1 hour after ejaculation	70% or more
3 hours after ejaculation	60% or more
Leukocyte count	0–2,000/ml
pH	7.2–7.8
Fructose concentration	150–600 mg/100 ml

spurts of semen from the ejaculatory ducts and the urethra. This takes place as parasympathetic impulses traveling through the pudendal nerves stimulate the bulbospongiosus muscles (see fig. 20.2) at the base of the penis and cause them to contract rhythmically. In addition, sympathetic stimulation of the smooth muscles in the urethral wall causes them to contract, helping to eject the semen.

Sexual function in the male thus requires the synergistic action (rather than antagonistic action) of the parasympathetic and sympathetic divisions of the ANS. The mechanism of emission and ejaculation is summarized in figure 20.17.

Immediately following ejaculation or a cessation of sexual stimulus, sympathetic impulses cause vasoconstriction of the arterioles within the penis, reducing the inflow of blood. At the same time, cardiac output returns to normal, as does venous return of blood from the penis. With the normal flow of blood through the penis, it returns to its flaccid condition.

Adolescent males may experience erection of the penis and spontaneous emission and ejaculation of semen during sleep. These *nocturnal emissions,* sometimes called "wet dreams," are triggered by psychic stimuli associated with dreaming. They are thought to be caused by changes in hormonal concentrations that accompany adolescent development.

Semen

Semen, also called *seminal fluid,* is the substance discharged during ejaculation (table 20.4). Generally, between 1.5 and 5.0 ml of semen are ejected during ejaculation. The bulk of the fluid (about 60%) is produced by the seminal vesicles, and the rest (about 40%) is contributed by the prostate. Spermatozoa account for less than 1% of the volume. There are usually between 60 and 150 million sperm cells per milliliter of ejaculate. In the condition of *oligospermia (ol''ĭ-go-sper'me-ă),* the male ejaculates fewer than 10 million sperm cells per milliliter and is likely to have fertility problems.

Human semen can be frozen and stored in sperm banks for future artificial insemination. In this procedure, the semen is diluted with a 10% glycerol, monosaccharide, and distilled water buffer, and frozen in liquid nitrogen. The freezing process destroys defective and abnormal sperm. For some unknown reason, however, not all human sperm is suitable for freezing.

Knowledge Check

20. Define the terms *erection, emission,* and *ejaculation.*
21. Explain the statement that male sexual function is an autonomic synergistic action.
22. Use a flow chart to explain the physiological and physical events of erection, emission, and ejaculation.
23. Describe the components of a normal ejaculate.

CLINICAL CONSIDERATIONS

Sexual dysfunction is a broad area of medical concern that includes developmental and psychogenic problems as well as conditions resulting from various diseases. Psychogenic problems of the reproductive system are extremely complex and beyond the scope of this book. Only a few of the principal developmental conditions, functional disorders, and diseases that affect the physical structure and function of the male reproductive system will be discussed here.

Developmental Problems of the Male Reproductive System

The reproductive organs of both sexes develop from similar embryonic tissue that follows a consistent pattern of formation well into the fetal period. Because an embryo has the potential to differentiate into a male or a female, developmental errors can result in various degrees of intermediate sex, or **hermaphroditism** *(her-maf' rŏ-dĭ-tiz''em).* A person with undifferentiated or ambiguous external genitalia is called a **hermaphrodite.**

True hermaphroditism—in which both male and female gonadal tissues are present in the body—is a rare anomaly. True hermaphrodites usually have a 46 XX chromosome constitution. **Male pseudohermaphroditism** occurs more frequently and generally results from hormonal influences during early fetal development. This condition is caused either by inadequate secretion of androgenic hormones or by the delayed development of the reproductive organs after the period of tissue sensitivity has passed. These individuals have a 46 XY chromosome constitution and male gonads, but the genitalia are intersexual and variable.

hermaphrodite: Gk. (mythology) *Hermaphroditos,* son of Hermes (Mercury)

The treatment of hermaphroditism varies, depending on the extent of ambiguity of the reproductive organs. Although people with this condition are sterile, they may engage in normal sexual relations following hormonal therapy and plastic surgery.

Chromosomal anomalies result from the improper separation of the chromosomes during meiosis and are usually expressed in deviations of the reproductive organs. The two most frequent chromosomal anomalies cause Turner's syndrome and Klinefelter's syndrome. **Turner's syndrome** occurs when only one X chromosome is present. About 97% of embryos lacking an X chromosome die; the remaining 3% survive and appear to be females, but their gonads, if present, are rudimentary and do not mature at puberty. A person with **Klinefelter's syndrome** has an XXY chromosome constitution, develops breasts and male genitalia, but has underdeveloped seminiferous tubules and is generally mentally retarded.

A more common developmental problem than genetic abnormalities, and fortunately less serious, is cryptorchidism. **Cryptorchidism** (*krip-tor'kĭ-diz''em*) means "hidden testis" and is characterized by the failure of one or both testes to descend into the scrotum. A cryptorchid testis is usually located along the path of descent but can be anywhere in the pelvic cavity (fig. 20.18). It occurs in about 3% of male infants and should be treated before the infant has reached the age of 5 to reduce the likelihood of infertility or other complications.

Sexual Dysfunction

Functional disorders of the male reproductive system include impotence, infertility, and sterility. **Impotence** (*im'pŏ-tens*) is the inability of a sexually mature male to achieve and maintain penile erection and/or the inability to achieve ejaculation. The causes of impotence may be physical, involving, for example, abnormalities of the penis, vascular irregularities, neurological disorders, or certain diseases. Occasionally, the cause of impotence is psychological, and the patient requires skilled counseling by a sex therapist.

Infertility is the inability of the sperm to fertilize the ovum and may involve the male or female, or both. The most common cause of male infertility is inadequate production of viable sperm. This may be due to alcoholism, dietary deficiencies, local injury, variococele, excessive heat, hormonal imbalance, or excessive exposure to radiation. Many of the causes of infertility can be treated through proper nutrition, gonadotropic hormone treatment, or microsurgery. If these treatments are not successful, it may be possible to concentrate the spermatozoa obtained

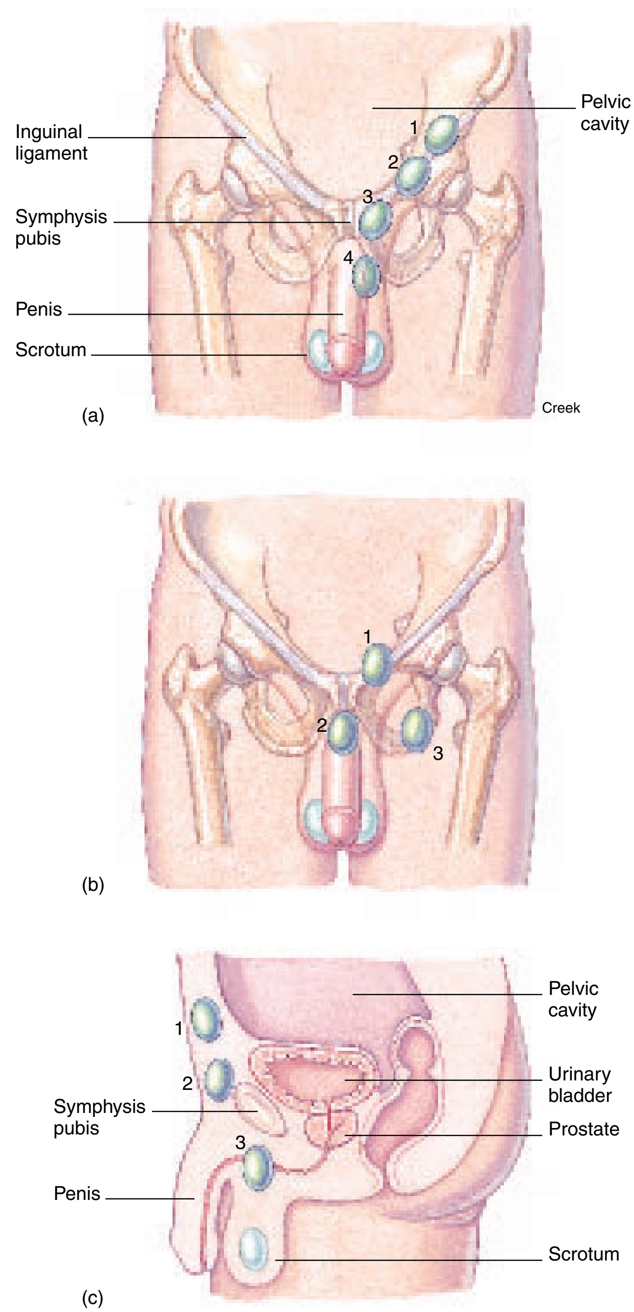


FIGURE 20.18 Cryptorchidism. (*a*) Incomplete descent of a testis may involve a region (1) in the pelvic cavity, (2) in the inguinal canal, (3) at the superficial inguinal ring, or (4) in the upper scrotum. (*b* and *c*) An ectopic testis may be (1) in the superficial fascia of the anterior pelvic wall, (2) at the root of the penis, or (3) in the perineum, in the thigh alongside the femoral vessels.

Turner's syndrome: from Henry H. Turner, American endocrinologist, 1892–1970

Klinefelter's syndrome: from Harry F. Klinefelter Jr., American physician, b. 1912

cryptorchidism: Gk. *crypto*, hidden; *orchis*, testis

impotence: L. *im*, not; *potens*, potent

Developmental Exposition

The Reproductive System

EXPLANATION

Sex Determination

Sexual identity is initiated at the moment of conception, when the *genetic sex* of the zygote (fertilized egg) is determined. The ovum is fertilized by a spermatozoon containing either an X or a Y sex chromosome. If the spermatozoon contains an X chromosome, it will pair with the X chromosome of the ovum and a female child will develop. A spermatozoon carrying a Y chromosome results in an XY combination, and a male child will develop.

Genetic sex determines whether the gonads will be testes or ovaries. If testes develop, they will produce and secrete male sex hormones during late embryonic and early fetal development and cause the secondary sex organs of the male to develop.

Embryonic Development

The male and female reproductive systems follow a similar pattern of development, with sexual distinction resulting from the influence of hormones. A significant fact of embryonic development is that the sexual organs for both male and female are derived from the same developmental tissues and are considered *homologous structures*.

The first sign of development of either the male or the female reproductive organs occurs during the fifth week as the medial aspect of each mesonephros (see chapter 19) enlarges to form the **gonadal ridge** (exhibit I). The gonadal ridge continues to grow behind the developing peritoneal membrane. By the sixth week, stringlike masses called **primary sex cords** form within the enlarging gonadal ridge. The primary sex cords in the male will eventually mature to become the seminiferous tubules. In the female, the primary sex cords will contribute to nurturing tissue of developing ova. Each gonad develops near a **mesonephric duct** and a **paramesonephric duct.** In the male embryo, each testis connects through a series of tubules to the mesonephric duct. During further development, the connecting tubules become the *seminiferous tubules*, and the mesonephric duct becomes the *efferent ductules*, *epididymis*, *ductus deferens*, *ejaculatory duct*, and *seminal vesicle*. The paramesonephric duct in the male degenerates without contributing any functional structures to the reproductive system. In the female embryo, the mesonephric duct degenerates, and the paramesonephric duct contributes greatly to structures of the female reproductive system. The distal ends of the paired paramesonephric ducts fuse to form the *uterus* and the deep portion of the *vagina*. The proximal unfused portions become the *uterine tubes*.

Externally, by the sixth week a swelling called the **genital tubercle** is apparent anterior to the small embryonic tail (future coccyx). The mesonephric and paramesonephric ducts open to the outside through the genital tubercle. The genital tubercle consists of a *glans*, a *urethral groove*, paired *urethral folds*, and paired *labioscrotal swellings* (see exhibit II). As the glans portion of the genital tubercle enlarges, it becomes known as the *phallus*. Early in fetal development (tenth through twelfth week), sexual distinction of the external genitalia becomes apparent. In the male, the phallus enlarges and develops into the *glans* of the penis. The urethral folds fuse around the urethra to form the *body* of the penis. The urethra opens at the end of the glans as the *urethral orifice*. The labioscrotal swellings fuse to form the *scrotum*, into which the testes will descend. In the female, the phallus gives rise to the *clitoris*, the urethral folds remain separated as the *labia minora*, and the labioscrotal swellings become the *labia majora*. The urethral groove is retained as a longitudinal cleft known as the *vestibule*.

Descent of the Testes

The descent of the testes from the site of development begins between the sixth and tenth week. Descent into the scrotal sac, however, does not occur until about week 28, when paired inguinal canals form in the abdominal wall to provide openings from the pelvic cavity to the scrotal sac. The process by which a testis descends is not well understood, but it seems to be associated with the shortening and differential growth of the *gubernaculum*, which is attached to the testis and extends through the inguinal canal to the wall of the scrotum (exhibit III). As the testis descends, it passes to the side of the urinary bladder and anterior to the symphysis pubis. It carries with it the ductus deferens, the testicular vessels and nerve, a portion of the internal abdominal oblique muscle, and lymph vessels. All of these structures remain attached to the testis and form what is known as the **spermatic cord** (see fig. 20.14). By the time the testis has taken its position in the scrotal sac, the gubernaculum is no more than a remnant of scarlike tissue.

During the physical examination of a neonatal male, a physician will palpate the scrotum to determine if the testes are in position. If one or both are not in the scrotal sac, it may be possible to induce descent by administering certain hormones. If this procedure does not work, surgery is necessary. The surgery is generally performed before the age of 5. Failure to correct the situation may result in sterility and possibly the development of a tumorous testis.

homologous: Gk. *homos*, the same

gubernaculum: L. *gubernaculum*, helm

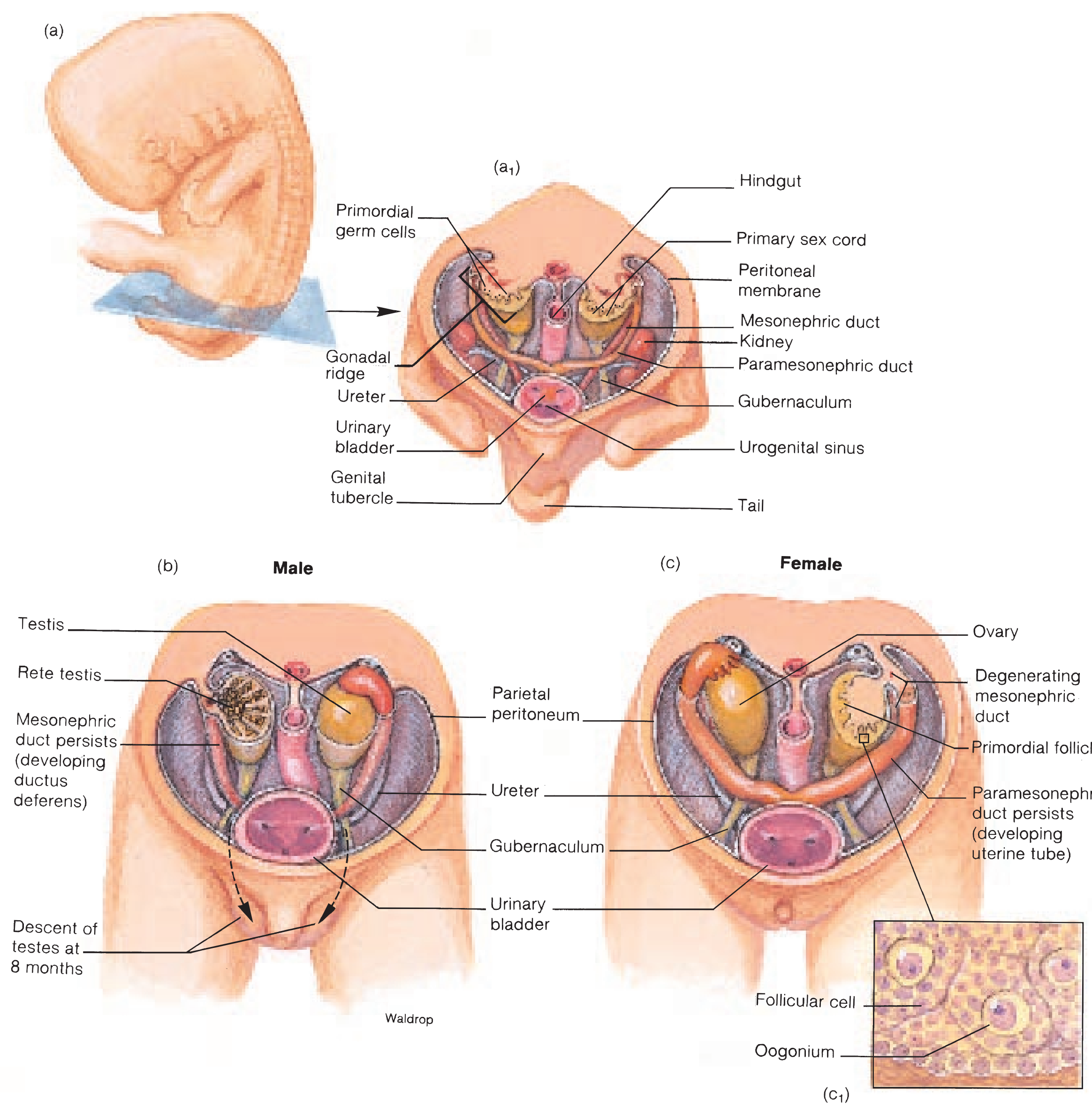


EXHIBIT I Differentiation of the male and female gonads and genital ducts. (*a*) An embryo at 6 weeks showing the positions of a transverse cut depicted in (a_1), (*b*), and (*c*). (a_1) At 6 weeks, the developing gonads (primary sex cords) are still indifferent. By 4 months, the gonads have differentiated into male (*b*) or female (*c*). The oogonia have formed within the ovaries (c_1) by 6 months.

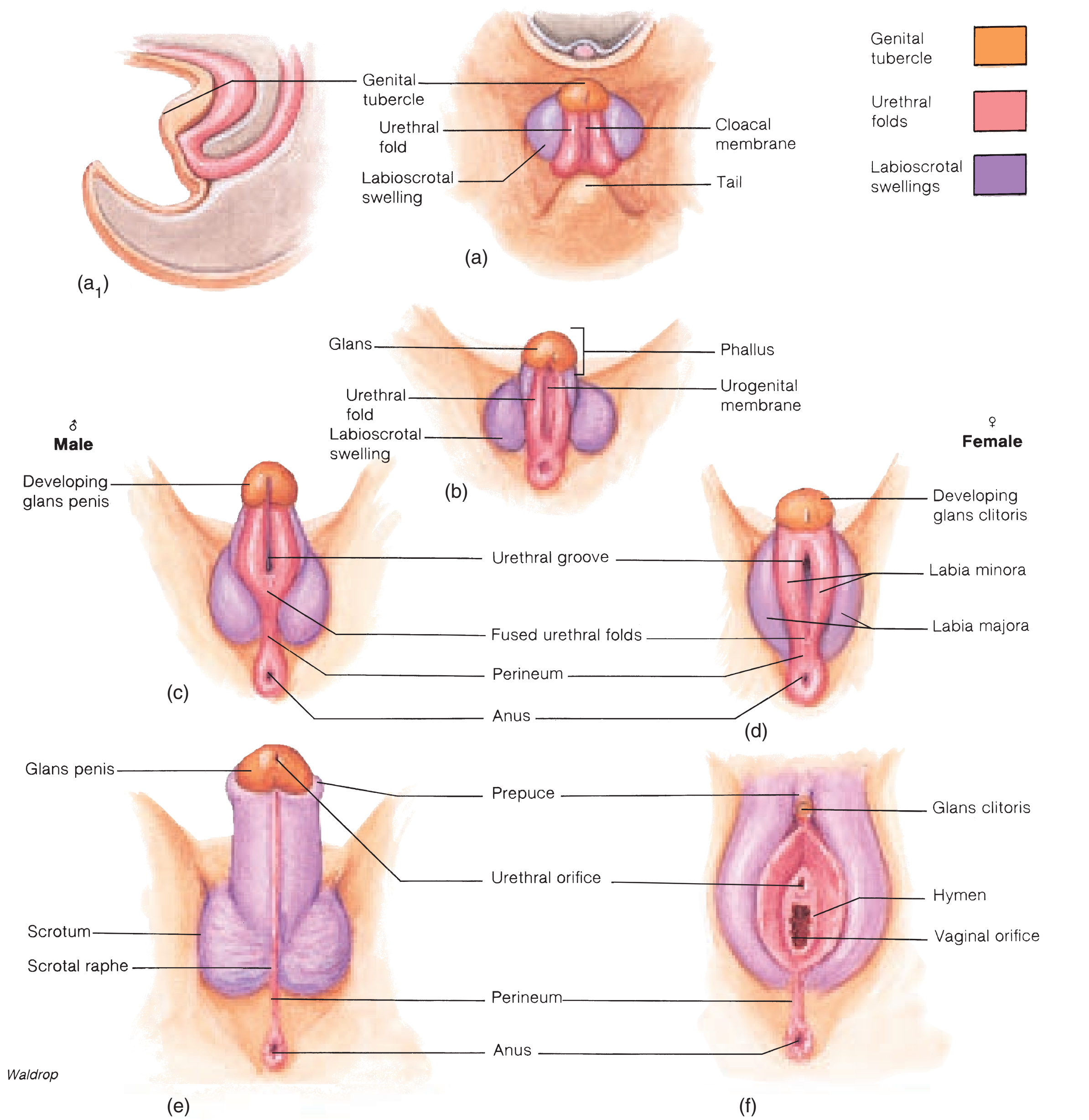
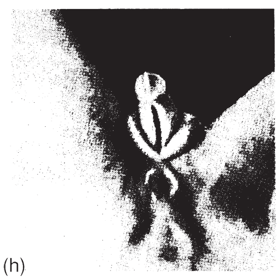


EXHIBIT II (*a*) Differentiation of the external genitalia in the male and female. (a_1) A sagittal view. At 6 weeks, the urethral fold and labioscrotal swelling are differentiated from the genital tubercle. (*b*) At 8 weeks, a distinct phallus is present during the indifferent stage. By the twelfth week, the genitalia have become distinctly male (*c*) or female (*d*), being derived from homologous structures. (*e,f*) At 16 weeks, the genitalia are formed. (*g,h*) Photographs at week 10 of male and female genitalia, respectively.

(g)



(h)

EXHIBIT II *Continued*

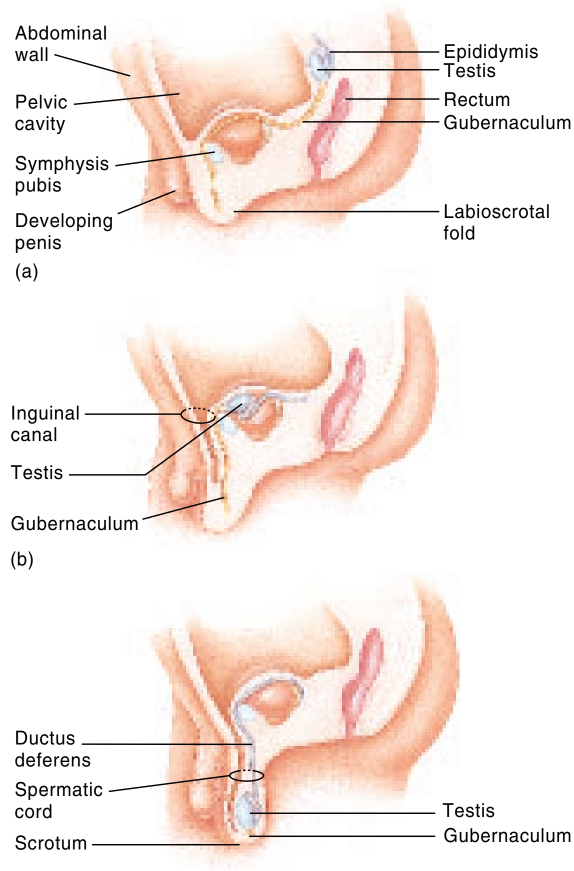


EXHIBIT III The descent of the testes. (*a*) At 10 weeks, (*b*) at 18 weeks, and (*c*) at 28 weeks. During development, each testis descends through an inguinal canal in front of the symphysis pubis and enters the scrotum.

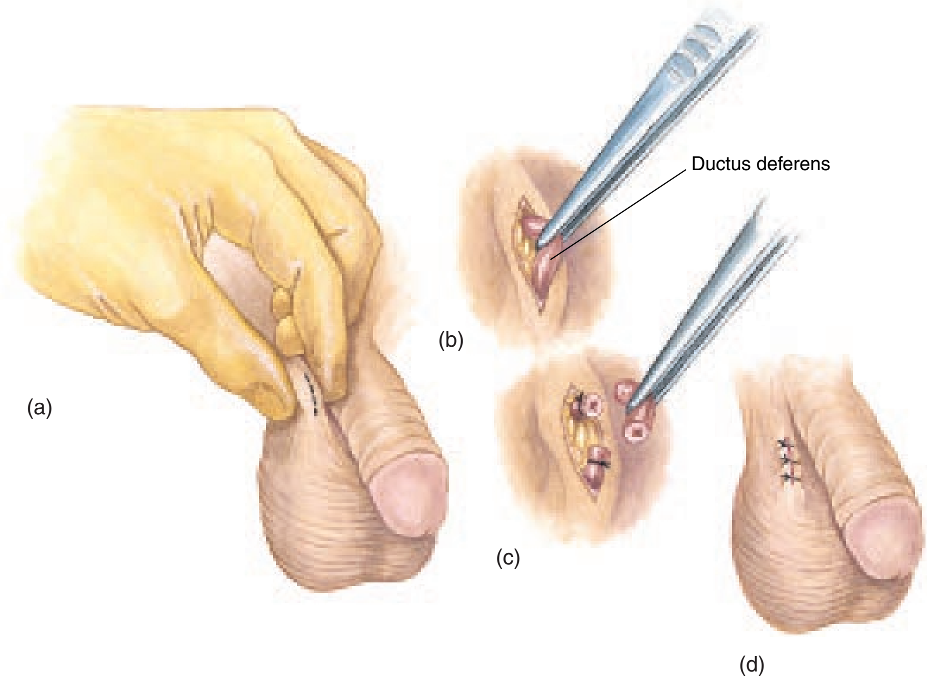


FIGURE 20.19 A simplified illustration of a vasectomy, in which a segment of the ductus deferens is tied and surgically removed through an incision in the scrotum. The procedure is then repeated on the opposite side.

through *masturbation* (in males, self-stimulation to the point of ejaculation) and use this concentrate to artificially inseminate the female.

Sterility is similar to infertility, except that it is a permanent condition. Sterility may be genetically caused, or it may be the result of degenerative changes in the seminiferous tubules (for example, mumps in a mature male may secondarily infect the testes and cause irreversible tissue damage).

Voluntary sterilization of the male in a procedure called a **vasectomy** (*vă-sek′to-me*) is a common technique of birth control. In this procedure, a small section of each ductus deferens near the epididymis is surgically removed, and the cut ends of the ducts are tied (Fig. 20.19). A vasectomy prevents transport of spermatozoa but does not directly affect the secretion of androgens, the sex drive, or ejaculation. Because sperm cells make up less than 1% of an ejaculate, even the volume is not noticeably affected.

According to the National Center for Health Statistics, there are currently 5.3 million childless infertile couples in the United States. In 40% of the cases, it is the woman's infertility that prevents conception, in 40% it is the man's. In the remaining 20%, either both partners have some abnormality, or the cause of the problem is unknown. Of those couples who seek help for infertility, only about 20% are eventually successful in producing a child.

Diseases of the Reproductive System

Sexually Transmitted Diseases

Sexually transmitted diseases (STDs) are contagious diseases that affect the reproductive systems of both the male and the female (Table 20.5). They are transmitted during sexual activity, and their frequency of occurrence in the United States is regarded by health authorities as epidemic. Commonly called *veneral diseases*, STDs have not been eradicated mainly because humans cannot develop immunity to them and because increased sexual activity increases the likelihood of infection and reinfection. Furthermore, many of the causative organisms can mutate so fast that available drug treatments are no longer effective.

Gonorrhea (*gon″ŏ-re′ă*), commonly called clap, is caused by the bacterium gonococcus, or *Neisseria gonorrhoeae*. Males with this disease suffer inflammation of the urethra, accompanied

sterility: L. *sterilis*, barren
vasectomy: L. *vas*, vessel; Gk. *ektome*, excision
venereal: L. (mythology) from *Venus*, the goddess of love
gonorrhea: L. *gonos*, seed; *rhoia*, a flow

TABLE 20.5 Sexually Transmitted Diseases

Name	Organism	Resulting Condition	Treatment
Gonorrhea	*Gonococcus* (bacterium)	Adult: sterility because of scarring of epididymides and testicular ductules (in rare cases, blood poisoning); newborn: blindness	Penicillin injections; tetracycline tablets; eye drops (silver nitrate or penicillin) in newborns as preventative
Syphilis	*Treponema pallidum* (bacterium)	Adult: gummy tumors, cardiovascular neurosyphilis; newborn: congenital syphilis (abnormalities, blindness)	Penicillin injections; tetracycline tablets
Chancroid (soft chancre)	*Hemophilus ducreyi* (bacterium)	Chancres, buboes	Tetracycline; sulfa drugs
Urethritis in males	Various microorganisms	Clear discharge	Tetracycline
Vaginitis in females	*Trichomonas* (protozoan)	Frothy white or yellow discharge	Metronidazole
	Candida albicans (yeast)	Thick, white, curdy discharge (moniliasis)	Nystatin
Acquired immune deficiency syndrome (AIDS)	Human immunodeficiency virus (HIV)	Early symptoms include extreme fatigue, weight loss, fever, diarrhea; extreme susceptibility to pneumonia, rare infections, and cancer	Azidothymidine (AZT), dideoxyinosine (ddI), and dideoxycytidine (ddC); new drugs being developed, including protease inhibitors
Chlamydia	*Chlamydia trachomatis* (bacterium)	Whitish discharge from penis or vagina; pain during urination	Tetracycline and sulfonamides
Venereal warts	Virus	Warts	Podophyllin; cautery, cryosurgery, or laser treatment
Genital herpes	Herpes simplex virus	Sores	Palliative treatment
Crabs	Arthropod	Itching	Gamma benzene hexachloride

by painful urination and frequently the discharge of pus. In females, the condition is usually asymptomatic, and therefore many women may be unsuspecting carriers of the disease. Advanced stages of gonorrhea in females may infect the uterus and the uterine tubes. A pregnant woman with gonorrhea who is not treated may transmit the bacteria to the eyes of her newborn during its passage through the birth canal, possibly causing blindness.

Syphilis (*sif'ĭ-lis*) is caused by the bacterium *Treponema pallidum*. Syphilis is less common than gonorrhea but is the more serious of the two diseases. During the *primary stage* of syphilis, a lesion called a *chancre* develops at the point where contact was made with a similar sore on an infected person. The chancre persists for 10 days to 3 months before the disease enters the *secondary stage*, which is characterized by lesions or a skin rash (fig. 20.20), accompanied by fever. This stage lasts from 2 weeks to 6 months, and the symptoms disappear of their own accord. The *tertiary stage* of untreated syphilis may occur 10 to 20 years following the primary infection. This stage is characterized by degenerative changes in various systems of the body that may lead to blindness, insanity, and death.

Acquired immune deficiency syndrome (AIDS) is a viral disease that is transmitted primarily through intimate sexual contact and through drug abuse (by sharing contaminated syringe needles). Additional information about this fatal disease, for which there is no known cure, is presented in table 20.5.

FIGURE 20.20 The secondary stages of syphilis as expressed by lesions of the skin.

chancre: Fr. *chancre*, indirectly from L. *cancer*, a crab

Disorders of the Prostate

The prostate is subject to several disorders, many of which are common in older men. The four most frequent prostatic problems are *acute prostatitis*, *chronic prostatitis*, *benign prostatic hypertrophy*, and *carcinoma of the prostate*.

Acute prostatitis is common in sexually active young men through infections acquired from a gonococcus bacterium. The symptoms of acute prostatitis are a swollen and tender prostate, painful urination, and in extreme conditions, pus dripping from the penis. It is treated with penicillin, bed rest, and increased fluid intake.

Chronic prostatitis is one of the most common afflictions of middle-aged and elderly men. The symptoms of this condition range from irritation and slight difficulty in urinating to extreme pain and urine blockage, which commonly causes secondary renal infections. In this disease, several kinds of infectious microorganisms are believed to be harbored in the prostate and are responsible for inflammations elsewhere in the body, such as in the nerves (neuritis), the joints (arthritis), the muscles (myositis), and the iris (iritis).

Benign prostatic hypertrophy (BPH) is an enlarged prostate from unknown causes. This condition occurs in nearly one-third of all males over the age of 60, and is characterized by painful and difficult urination. If the urinary bladder is not emptied completely, cystitis eventually occurs. People with cystitis may become incontinent and dribble urine continuously. Benign prostatic hypertrophy may be treated by surgical removal of portions of the gland through transurethral curetting (cutting and removal of a small section) or removal of the entire prostate, called *prostatectomy (pros″tă-tek′tŏ-me)*.

Prostatic carcinoma, cancer of the prostate, is the second leading cause of death from cancer in males in the United States. It, too, is common in males over 60 and accounts for about 25,000 deaths annually. The metastases of this cancer to the spinal column and brain are generally what kills the patient. Advanced prostatic carcinoma is treated by removal of the prostate and frequently by removal of the testes, or orchiectomy (*or″ke-ek′tŏ-me*). An orchiectomy eliminates testosterone secretion, which inhibits the growth of prostate cancer cells.

Disorders of the Testes and Scrotum

An infection in the testes is called **orchitis** (*or-ki′tis*). Orchitis may develop as the result of a primary bacterial infection or as a secondary complication of mumps contracted after puberty. If orchitis from mumps involves both testes, it usually causes sterility.

A **hydrocele** (*hi″drŏ-sēl*) is a benign fluid mass within the tunica vaginalis surrounding the testis that causes swelling of the scrotum. It is a frequent minor disorder in male infants, as well as in adults. The cause is unknown.

Clinical Case Study Answer

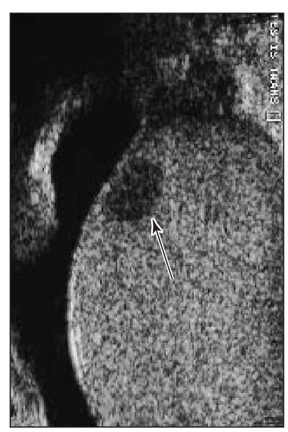
The tubular structures that are apparently absent in our patient are the ductus deferentia. This condition, known as *congenital bilateral absence of the ductus deferentia,* prevents the transport of spermatozoa from the testes to the ejaculatory ducts. This explains the absence of spermatozoa in the patient's ejaculate. His ejaculate consists only of the secretions from the seminal vesicles (which in many cases are also absent or nonfunctional in this deformity) and the prostate. Until recently, this patient's condition would have categorically prevented him from becoming a father. Microsurgical extraction of spermatozoa from the epididymides is now possible, however, and has allowed many afflicted men to father children.

CLINICAL PRACTICUM 20.1

A 29-year-old male notices a lump on his left testis during his monthly testicular self-exam. He had never felt this mass before, and so he decided to visit you, his physician. You examine the patient and feel this mass. It is smooth, nontender, and firm. The remainder of the testis has a normal texture. The epididymis is also normal. You decide that this mass needs to be further evaluated, so you order a scrotal ultrasound. This study shows a 1-cm hypoechoic oval nodule at the upper pole of the left testis (see arrow). Of note, there is a small hydrocele, a fluid collection in the scrotum.

QUESTIONS

1. Why is the testicular self-exam important?
2. This mass has an appearance that is consistent with seminoma, the most common type of testicular malignancy. Testicular malignancy generally spreads via the lymphatics. Keeping in mind that lymphatic drainage generally follows the venous drainage, where would you expect to find abnormal lymph nodes if this patient's disease has spread?
3. Why is ultrasound considered the safest way to image the scrotum?



Chapter Summary

Introduction to the Male Reproductive System (pp. 698–699)

1. The common purpose of the male and female reproductive systems is to produce offspring.
2. The functions of the male reproductive system are to produce spermatozoa, secrete androgens, and transfer spermatozoa to the reproductive system of the female.
3. Features of the male reproductive system include the primary sex organs (the testes), secondary sex organs (those that are essential for reproduction), and secondary sex characteristics (sexual attractants, expressed after puberty).

Perineum and Scrotum (pp. 700–702)

1. The saclike scrotum, located in the urogenital portion of the perineum, supports and protects the testes and regulates their position relative to the pelvic region of the body.
2. Each testis is contained within its own scrotal compartment and is separated from the other by the scrotal septum.

Testes (pp. 702–706)

1. The testes are partitioned into wedge-shaped lobules; the lobules are composed of seminiferous tubules, which produce sperm cells, and of interstitial tissue, which produces androgens.
2. Spermatogenesis occurs by meiotic division of the cells that line the seminiferous tubules.
   (a) At the end of the first meiotic division, two secondary spermatocytes have been produced.
   (b) At the end of the second meiotic division, four haploid spermatids have been produced.
3. The conversion of spermatids to spermatozoa is called spermiogenesis.
4. A sperm consists of a head and a flagellum and matures in the epididymides prior to ejaculation.
   (a) The acrosome of the head contains digestive enzymes for penetrating an ovum.
   (b) The flagellum provides undulating movement of about 3 mm per hour.

Spermatic Ducts, Accessory Reproductive Glands, and the Urethra (pp. 707–709)

1. The epididymides and the ductus deferentia are the components of the spermatic ducts.
   (a) The highly coiled epididymides are the tubular structures on the testes where spermatozoa mature and are stored.
   (b) The ductus deferentia convey spermatozoa from the epididymides to the ejaculatory ducts during emission. Each ductus deferens forms a component of the spermatic cord.
2. The seminal vesicles and prostate provide additives to the spermatozoa in the formation of semen.
   (a) The seminal vesicles are located posterior to the base of the urinary bladder; they secrete about 60% of the additive fluid of semen.
   (b) The prostate surrounds the urethra just below the urinary bladder; it secretes about 40% of the additive fluid of semen.
   (c) Spermatozoa constitute less than 1% of the volume of an ejaculate.
   (d) The small bulbourethral glands secrete fluid that serves as a lubricant for the erect penis in preparation for coitus.
3. The male urethra, which serves both the urinary and reproductive systems, is divided into prostatic, membranous, and spongy parts.

Penis (pp. 710–712)

1. The penis is specialized to become erect for insertion into the vagina during coitus.
2. The body of the penis consists of three columns of erectile tissue, the spongy urethra, and associated vessels and nerves.
3. The root of the penis is attached to the pubic arch and urogenital diaphragm.
4. The glans penis is the terminal end, which is covered with the prepuce in an uncircumcised male.

Mechanisms of Erection, Emission, and Ejaculation (pp. 712–714)

1. Erection of the penis occurs as the erectile tissue becomes engorged with blood. Emission is the movement of the spermatozoa from the epididymides to the ejaculatory ducts, and ejaculation is the forceful expulsion of semen from the ejaculatory ducts and urethra of the penis.
2. Parasympathetic stimuli to arteries in the penis cause the erectile tissue to engorge with blood as arteriole flow increases and venous drainage decreases.
3. Ejaculation is the result of sympathetic reflexes in the smooth muscles of the male reproductive organs.

Review Activities

Objective Questions

1. The perineum is
   (a) a membranous covering over the testis.
   (b) a ligamentous attachment of the penis to the symphysis pubis.
   (c) a diamond-shaped region between the symphysis pubis and the coccyx.
   (d) a fibrous sheath supporting the scrotum.
2. The dartos is a layer of smooth muscle fibers found within
   (a) the scrotum. (b) the penis.
   (c) the epididymis. (d) the prostate.
3. Which statement regarding the interstitial cells (cells of Leydig) is *true?*
   (a) They nourish spermatids.
   (b) They produce testosterone.
   (c) They produce spermatozoa.
   (d) They secrete alkaline fluid.
   (e) Both b and d are true.
4. The bulb and crus of the penis are located at
   (a) the glans penis.
   (b) the corona glandis.
   (c) the body of the penis.
   (d) the prepuce.
   (e) the root of the penis.
5. Which of the following is *not* a spermatic duct?
   (a) the epididymis
   (b) the spermatic cord

(c) the ejaculatory duct
(d) the ductus deferens

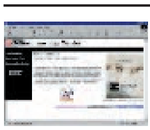
6. Spermatozoa are stored prior to emission and ejaculation in
(a) the epididymides.
(b) the seminal vesicles.
(c) the spongy urethra.
(d) the prostate.
7. Urethral glands function to
(a) secrete mucus.
(b) produce nutrients.
(c) secrete hormones.
(d) regulate spermatozoa production.
8. Which statement is *false* regarding erection of the penis?
(a) It is a parasympathetic response.
(b) It may be both a voluntary and involuntary response.
(c) It has to be followed by emission and ejaculation.
(d) It is controlled by the hypothalamus of the brain and sacral portion of the spinal cord.
9. An embryo with the genotype XY develops male accessory sex organs because of
(a) androgens.
(b) estrogens.
(c) the absence of androgens.
(d) the absence of estrogens.
10. Which of the following does *not* arise from the embryonic mesonephric duct?
(a) the epididymis
(b) the ductus deferens
(c) the seminal vesicle
(d) the prostate

Essay Questions

1. What are the functions of the male reproductive system? How do these functions compare with those of the female reproductive system?
2. Discuss how and when the genetic sex of a zygote is determined.
3. Describe the location and structure of the scrotum. Explain how the scrotal muscles regulate the position of the testes in the scrotum. Why is this important?
4. Describe the internal structure of a testis. Discuss the function of the sustentacular cells, interstitial cells, seminiferous tubules, rete testis, and efferent ductules.
5. List the structures that constitute the spermatic cord. Where is the inguinal canal? Why is the inguinal canal clinically important?
6. Diagram a spermatozoon and describe the function of each of its principal parts.
7. Describe the position, histological structure, and functions of the epididymis, ductus deferens, and ejaculatory duct.
8. Compare the seminal vesicles and the prostate in terms of location, structure, and function.
9. Describe the structure of the penis and explain the mechanisms that result in erection, emission, and ejaculation.
10. Define *semen*. How much semen is ejected during ejaculation? What does it consist of and what are its properties?
11. Comment on the significance of the indifferent stage of development with respect to developmental abnormalities of the reproductive organs.
12. Define *perineum*. Contrast the appearance of the perineum of an embryo during the indifferent stage of genital development with that of an adult male.
13. Explain what is meant by homologous structures. List the structures of the male reproductive system that form from the phallus, urethral folds, labioscrotal swellings, and the gonadal ridge.
14. Distinguish between impotence, infertility, and sterility.
15. Define *hydrocele*, *orchitis*, and *orchiectomy*. What conditions would warrant an orchiectomy?

Critical-Thinking Questions

1. Using a diagram, describe the stages of spermatogenesis. Explain why a postpubescent male can produce billions of sperm cells throughout his life without using up all of the spermatogonia.
2. The reproductive system has been described as a “nonessential” body system because it is not necessary for the survival of the individual. Upon maturation, however, the reproductive system does produce hormones that maintain adult features as well as bone structure. These hormones also influence behavior, blood composition, and metabolism. Discuss your thoughts as to whether or not the reproductive system is nonessential.
3. As a safeguard against having more children, a 40-year-old man is considering a vasectomy. This procedure involves tying and surgically removing a short section of each ductus deferens within the spermatic cord (see fig. 20.19). Will the vasectomy affect his sexual performance? Will his sexual desire be altered? What will be the components and volume of his ejaculate? Will he be sterile or infertile? What happens to spermatozoa that cannot be ejaculated?
4. If it takes only one sperm cell to fertilize an egg, why are such huge quantities expelled during ejaculation?
5. A number of pathogenic (disease-causing) organisms are transmitted through sexual activity. From the standpoint of the pathogen, why does coitus provide an ideal means of propagation?



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