28. Reproductive System

This is the only system not required for the life of the individual. Rather, it is required for the continued existence of the species. The reproductive system in an individual produces, stores, nourishes, and transports either male or female gametes. The female reproductive system is also responsible for protecting, supporting, and nourishing a developing fetus.

I. Overview of Female and Male Reproductive Systems

Common elements of the two systems
Although the male and female reproductive systems have obvious differences, you will find that there are numerous similarities. Both reproductive systems include the following basic components:

A. Gonads are the primary reproductive organs—testes in males and ovaries in females. Gonads produce gametes, sperm and eggs, respectively.

B. Sex hormones are produced by the gametes. They affect sexual maturation of the body and development of the gametes.

C. Accessory reproductive organs include (1) ducts that provide passages for transport of the gametes, (2) various glands that secrete fluids required by the reproductive system, and (3) perineal structures that are important during copulation. (Perineal structures are also referred to as the external genitalia.)

II. Gametogenesis

All cells in your body, except gametes, have two copies of all your genes. These cells are called somatic cells, and they may be referred to as diploid (or 2n) to indicate the presence of two copies of the genes. Each gamete has only one copy of your genes, and gametes may be referred to as haploid (or 1n) to indicate the presence of only a single copy of each gene. In order for a new individual to form, two 1n gametes must fuse to form a 2n zygote, a process called fertilization. The zygote then divides by mitosis to form an embryo, which may eventually grow into an adult human. Gametes are produced from 2n cells via the process of meiosis, which reduces the amount of genetic material by half (2n → 1n).

III. Female Reproductive System

The major structures of the female reproductive system are shown in Fig. 28.3. The female gonads are the ovaries. The female duct system includes the uterine (or fallopian) tubes, the uterus, and the vagina. Mammary glands secrete milk to nourish a newborn child, and greater vestibular glands lubricate the vagina. Perineal structures include the labia and the clitoris.
Ovaries
Ovaries produce oocytes, secrete female sex hormones, and secrete inhibin.

Anatomy of ovaries
The ovaries are paired, oval-shaped organs about 2 cm by 3 cm in size. They are held in place on either side of the uterus by various structures made of connective tissue (Fig. 28.4). From the laboratory you should be familiar with the broad ligament and the ovarian ligament. A suspensory ligament attaches the lateral edge of the ovary to the pelvic wall.

Each ovary is encapsulated by a layer of dense connective tissue called the tunica albuginea (Fig. 28.5). The tissue of the ovary itself is divided into an outer cortex and an inner medulla.

Ovarian follicles
Eggs are produced in the cortex of each ovary (Fig. 28.5). The cortex contains many small, sac-like structures called ovarian follicles. Each follicle contains an oocyte (the egg) and one or more layers of cells that surround the oocyte:

• A primordial follicle contains a primary oocyte surrounded by a single layer of flat, squamous-like follicle cells.
• A primordial follicle may develop into a primary follicle. The flat follicle cells develop into a layer of cuboidal cells, now called granulosa cells, which secrete estrogen. The granulosa cells will multiply and form multiple layers around the oocyte.
• A secondary follicle forms from a primary follicle as a fluid-filled cavity, called an antrum, develops between layers of granulosa cells. Structures called the zona pellucida and corona radiata surround the oocyte.
• The follicle becomes a large vesicular follicle as the oocyte completes meiosis I and becomes a secondary oocyte. Eventually the vesicular follicle bulges from the surface of the ovary and releases the egg—a process called ovulation.
• After ovulation the remainder of the follicle becomes a structure called the corpus luteum. The corpus luteum secretes estrogen and progesterone in anticipation of pregnancy.
• A corpus luteum will degenerate into a clump of scar tissue called the corpus albicans.

Oogenesis and the ovarian cycle
Oogenesis begins in women before birth (Fig. 28.6). Female stem cells, called oogonia, complete mitotic divisions and differentiate into primary oocytes. The primary oocytes begin meiosis I prior to birth, but this process is not completed until after puberty.

Each month after the onset of puberty some primary oocytes continue development. One of the primary oocytes completes meiosis I and becomes a secondary oocyte. The secondary oocyte begins meiosis II, but this process stops prior to ovulation.

If the secondary oocyte is not penetrated by a sperm, then it deteriorates. If the secondary oocyte is penetrated by a sperm, then it rapidly completes meiosis II to become an ovum. The nuclei of the ovum and sperm then fuse as fertilization occurs.
From puberty to menopause

Oogenesis continues from puberty until menopause. Oocyte growth occurs in the cortex of the ovary in a process known as the ovarian cycle (Fig. 28.7). Prior to puberty, the release of gonadotropin releasing hormone (GnRH) is inhibited by low levels of estrogen released by the ovaries. With the onset of puberty, the hypothalamus becomes less sensitive to estrogen, and GnRH is released in pulses. GnRH stimulates the anterior pituitary to release luteinizing hormone (LH) and follicle-stimulating hormone (FSH). The ovarian cycle begins, and it consists of three phases:

1. The follicular phase
   At puberty, a woman’s ovaries contain about 400,000 primordial follicles, each of which contains a primary oocyte. Each month a small number of primordial follicles are activated to continue development. FSH triggers follicular cells to divide and form several layers of granulosa cells, creating primary follicles. The oocyte rapidly enlarges, and the granulosa cells produce estrogen. A few primary follicles develop into secondary follicles as granulosa cells begin secreting follicular fluid, which makes the antrum within the follicle.

   Usually a single secondary follicle makes it to the point of maturing into a vesicular follicle, which bulges from the surface of the ovary. Rising levels of LH prompt the primary oocyte to complete meiosis I, become a secondary oocyte, and enter meiosis II.

2. Ovulation
   The vesicular follicle releases the secondary oocyte in response to LH. If any other secondary or vesicular follicles have developed they degenerate. Occasionally more than one oocyte is ovulated. Does ovulation of more than one oocyte have the potential to produce fraternal twins or identical twins?

3. The luteal phase
   After ovulation, the antrum fills with clotted blood. The blood is absorbed and granulosa cells of the ruptured follicle proliferate and form a structure called the corpus luteum. The corpus luteum produces progesterone and estrogen. In the absence of fertilization, levels of progesterone and estrogen drop. The corpus luteum is destroyed by fibroblasts and becomes the corpus albicans. The ovarian cycle comes to an end. A new cycle will begin with the activation of another cluster of primordial follicles.

Uterine tubes, uterus, and vagina

Uterine tubes

After an oocyte leaves the ovary it usually enters one of two uterine tubes, also called “fallopian tubes” or “oviducts” (Fig. 28.9). The entry into the uterine tube is a funnel shaped structure called the infundibulum. The infundibulum is draped over the ovary, and it has finger-like projections called fimbriae. The uterine tube narrows as it joins the uterus; the narrow portion is called the isthmus. Fertilization of an egg by a sperm often occurs in the uterine tube.

What is an ectopic pregnancy?
**Uterus**

The uterus provides an environment for the developing embryo and fetus. The uterus can be divided into three regions (Fig. 28.9): The **body** is the major portion of the uterus, the **fundus** is the rounded part of the uterus superior to the attachment of the uterine tubes, and the **cervix** is the inferior portion of the uterus that extends into the vagina. The lumen of the uterus connects to the vagina via the **cervical canal**. The **internal os** of the canal opens to the uterus, and the **external os** of the canal opens to the vagina.

The uterine wall has a thick layer of smooth muscle, called the **myometrium**. The inner lining of the uterus is called the **endometrium**. If an embryo implants into the endometrium, then glandular and vascular tissues within the endometrium help provide nourishment for the developing embryo. The outer layer of the uterus is called the **perimetrium**; it is the visceral peritoneum of the uterus.

The endometrium has two distinct layers (Fig. 28.9c): (1) The **functional layer** changes in response to the monthly pattern of hormones. (2) The **basal layer** is the underlying layer from which a new functional layer forms each month.

**The vagina**

The vagina is a tube that leads from the uterus to the outside of the body. The wall of the vagina has three layers: an outer **adventitia**, a middle layer of smooth muscle called the **muscularis**, and an inner **mucosa**. The external opening of the vagina is called the **vaginal orifice**. Epithelial cells of the vagina secrete glycogen, which is converted to lactic acid by bacteria. The acid lowers the pH of the vagina and helps prevent infection.

Why is it that taking antibiotics can make a woman more susceptible to yeast infections?

**Uterine (menstrual) cycle and menstruation**

The **uterine cycle** (or **menstrual cycle**) is a series of changes in the endometrium that occurs in response to monthly hormonal changes. The cycle can be divided into three phases:

*The menstrual phase.* The cycle begins with the first day of **menses**, which involves degeneration of the functional layer of the endometrium. Weakened arterial vessels rupture, and blood and degenerated tissue break away from the inner wall of the uterus. This process generally lasts from one to five days, and it should be relatively painless. Painful menstruation (called **dysmenorrhea**) is generally a sign of inflammation or some other abnormal condition.

*The proliferative phase.* This phase involves proliferation of cells in the basal layer of the endometrium, which remains after menses. This results in restoration of the functional layer of the endometrium, and it is stimulated by estrogen secreted by the developing follicles.

*The secretory phase.* This phase begins as ovulation occurs. Glands in the endometrium secrete mucus rich in glycogen, which may provide a source of energy for a developing fetus. In the absence of fertilization, secretory activities decline and the cycle is repeated.
Hormones and the female reproductive cycle
Use Figs. 28.7 and 28.11 to help you understand the relationships between hormone secretion, the ovarian cycle, and the uterine cycle.

GnRH release in females varies markedly over the course of a month. Levels of GnRH increase from day zero to a peak at around day 13, then levels fall rapidly. GnRH targets the anterior pituitary where it promotes the secretion of LH and FSH, which, in turn, act on the ovaries. Both hormones, though primarily FSH, stimulate enlargement of follicles. FSH stimulates granulosa cells in the follicle to multiply and produce estrogen. LH also stimulates the production of estrogen.

The timed release of these hormones coordinates the ovarian and uterine cycles in the following manner (Fig. 28.7):
*During menses the level of FSH rises, and primary follicles develop.
*Developing follicles release estrogen. Formation of vesicular follicles causes a steep rise in estrogen secretion, roughly a week into the cycle.
*GnRH release increases in response to the estrogen, and LH secretion is stimulated. GnRH also causes a rise in FSH, although it does not rise as high as LH.
*At about day 14, levels of estrogen, LH, and FSH peak.
*High levels of LH trigger ovulation and promote progesterone secretion by the corpus luteum. Progesterone prepares and maintains the lining of the uterus.
*Levels of LH and FSH drop rapidly after ovulation. In the absence of fertilization levels of estrogen and progesterone will drop as well.
*Declines in progesterone and estrogen levels result in menses.
*If an egg is fertilized, the corpus luteum maintains estrogen and progesterone secretion. However, after 5 or 6 weeks the placenta (the interface between the uterus and fetus) begins to secrete estrogen and progesterone to maintain the pregnancy.

External genitalia
The external genitalia are often collectively referred to as the vulva (Fig. 28.12). Overlying the pubic symphysis is a layer of fatty tissue called the mons pubis. Extending posteriorly from the mons pubis are the labia majora. Medial to the labia majora are the labia minora. The labia minora surround a region called the vestibule, which contains the external urethral orifice and the vaginal orifice. Greater vestibular glands surround the vaginal orifice and release mucus to help lubricate the vagina during intercourse.

Anterior to the vestibule is the clitoris, which is the female equivalent of the penis. The clitoris is partially covered by a fold of skin called the prepuce of the clitoris. Similar to the penis, the clitoris contains corpora cavernosa, which become engorged with blood during sexual arousal.

Mammary glands
Mammary glands are present in both males and females, but they normally function only in females (Fig. 28.13). Each mammary gland lies anterior to the pectoral muscles. Slightly below the center of each is a pigmented areola; at the center of each areola is a nipple.

Each mammary gland is made of 15 to 25 lobes that radiate from the nipple. Cells within each lobe are arranged into clusters called lobules. The lobules contain smaller structures called
alveoli, which secrete milk when a woman is lactating. Milk travels from the alveoli to the nipple via lactiferous ducts.

Female sexual response
During sexual excitement, the clitoris becomes engorged with blood in a manner similar to that of the penis. Vestibular glands secrete mucus to lubricate the vagina. These processes are controlled by the parasympathetic. Orgasm in the female is accompanied by rhythmic contractions of the uterus and vagina. The events of orgasm are linked to the sympathetic nervous system.

IV. Male Reproductive System

The basic structures of the male reproductive system are shown in Fig. 28.14. The male gonads are the testes. The male duct system begins with the epididymis, which leads to the ductus deferens (or vas deferens), the ejaculatory duct, and finally the urethra. Accessory glands include the seminal vesicles, the prostate gland, and the bulbourethral glands. Perineal structures include the scrotum and the penis.

Scrotum
During early development, testes form inside the body near the kidneys. Prior to birth, the testes typically descend into the scrotum. The scrotum is a sac made of a layer of skin and an underlying layer of tissue called the superficial fascia (Fig. 28.15).

Bands of skeletal muscle, called the cremaster muscle, lie deep to the dermis of the scrotum. Contraction of the cremaster muscle pulls the testis close to the body wall. Contraction or relaxation allows regulation of temperature of the testes, which should be about 1°C cooler than core body temperature for normal sperm development.

Spermatic cords extend from the abdominopelvic cavity to the testes (Fig. 28.15). Each cord consists of fascia and muscle that enclose the ductus deferens, blood vessels, lymphatic vessels, and nerves, which lead to and from the testes. Each cord passes through the abdominal musculature through the inguinal canal, which links the scrotal cavity to the abdominopelvic cavity. Excessive force on the abdomen may push part of the intestine into the inguinal canal, resulting in an inguinal hernia.

Testes and spermatogenesis
Each testis is surrounded by an outer tunica vaginalis and an inner tunica albuginea (Fig. 28.16). Each testis is divided into compartments, called lobules. Each lobule contains a few seminiferous tubules; a single testis contains about one-half mile of seminiferous tubules. Surrounding the seminiferous tubules are interstitial cells (or Leydig cells), which produce androgens. The primary androgen secreted by the interstitial cells is testosterone.

Hormonal regulation of androgen production and sperm development
Males are sterile until puberty, which is marked by the secretion of GnRH by the hypothalamus (Fig. 28.17). GnRH’s target is the anterior pituitary, which is stimulated to release FSH and LH, similar to the case in women. FSH stimulates spermatogenesis. LH stimulates interstitial cells to produce testosterone and other androgens. Testosterone also stimulates spermatogenesis, and it
has other functions as well: It causes development of secondary sex characteristics such as deepening of the voice, reproductive organ growth, hair growth, and growth of musculature (which is the effect desired by people who abuse anabolic steroids). As levels of FSH rise, the testes secrete inhibin, a hormone that eventually inhibits FSH secretion by the pituitary.

Development of sperm: spermatogenesis and spermiogenesis
Sperm are produced in the testes via a process known as spermatogenesis (Fig. 28.18). Spermatogenesis begins in the seminiferous tubules with stem cells called spermatogonia. Spermatogonia divide by mitosis to keep replenishing the supply of spermatogonia. Some spermatogonia move on to the next stage of development by differentiating into primary spermatocytes. The primary spermatocyte undergoes the first division of meiosis, which leads to production of secondary spermatocytes. Secondary spermatocytes undergo the second division of meiosis to become spermatids. Spermatids undergo differentiation to produce spermatozoa, which are fully formed sperm. This last process of differentiation is known as spermiogenesis. Spermatozoa travel to the epididymis where they are stored. Know the various stages in spermatogenesis and the processes (underlined) that lead to each stage.

Duct system in the male reproductive tract
The epididymis leads to the ductus deferens, which leads to the ejaculatory duct and then the urethra. Be able to trace the path of sperm from the seminiferous tubules to the external urethral orifice.

Accessory glands and semen production
Sperm and fluid from the epididymis account for only about 5% of semen volume. The remainder is contributed by various accessory glands:

Seminal vesicles
Seminal vesicles produce about 60% of semen volume. The fluid secreted by the seminal vesicles has a high concentration of fructose. Why? It also contains prostaglandins, which stimulate contractions of smooth muscle along the reproductive tract. Seminal fluid is alkaline, which neutralizes the acidic environments of the urethra and the vagina. Finally, secretions of the seminal vesicles stimulate beating of sperm flagella.

B. The prostate gland produces about 20-30% of semen volume. This gland encircles the urethra as it exits the urinary bladder. Prostate fluid contains seminal plasmin, which is an antibiotic that may help prevent urinary tract infections (UTI’s). Inflammation or tumor growth of the prostate is fairly common in older men. Symptoms include pain in the lower back and painful urination.

C. The bulbourethral glands secrete thick, alkaline mucus, which also helps to neutralize acids in the urinary tract and vagina.

Semen typically contains 20-100 million sperm per milliliter of fluid, and a typical ejaculation contains 3-5 ml of semen. Greater than 60% of sperm should be swimming for good fertility.
Penis
Refer to Fig. 28.20 for a diagram of the structure of the penis. The penis and the scrotum make up the male external genitalia, and the penis is used for copulation.

The distal portion of the penis is the glans. In a circumcised male, the glans is exposed; in an uncircumcised male, the glans is covered by the foreskin (also called the prepuce). The body of the penis contains three long cylinders of erectile tissue. This tissue is porous, and as blood fills the tissue the penis becomes erect. The two dorsal portions of erectile tissue are called the corpora cavernosa, and the ventral portion is called the corpus spongiosum.

Male sexual response
Erection is caused by the dilation of blood vessels that lead to the erectile tissue. Dilation of the blood vessels is caused by the release of nitric oxide, which is stimulated by the parasympathetic nervous system.

Ejaculation is caused by the sympathetic nervous system, which causes contractions of various muscles along the male reproductive tract.