Section Four: Chapter 22: The Male Reproductive System

After all the amazing information presented about the human body within this text, it is clear that another remarkable aspect about the physiology of the human body is that it can completely reproduce itself! As the name indicates, the *Reproductive System* is all about re-making us. The reproduction of another human requires the **egg cell** of a woman to be fertilized by the **sperm cell** of a man, this union creates a **zygote** (which means 'union') and this is a fertilized egg cell.

In nature, when the **zygote** begins its development it continues on to become a **blastula** as it moves along in its journey toward the mother's uterus. The implantation of the developing **embryo** into the endometrium of the uterus continues developing into a **fetus** until reaching full term, being fully developed as a baby ready to be born.

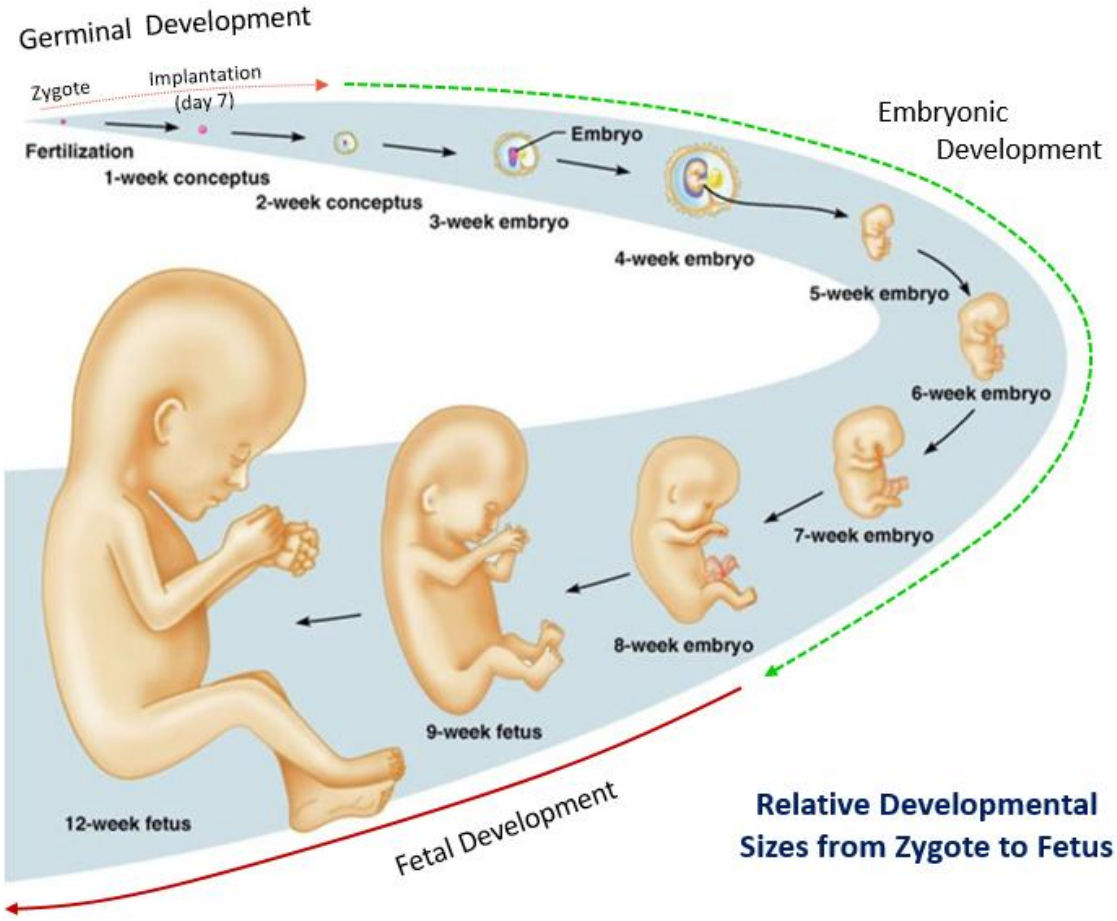


Figure 22.1 Shows the development from the fertilized egg cell called the zygote, into the blastula of dividing cells, moving to the uterus for implantation of the embryo into the endometrium for embryonic development from week 2 until week 8. At the ninth week post-conception, the fetal development period begins and culminates with the fully developed baby ready to be born at about week 40.

Brief Overview for Stages of Development during Reproduction

Although most dilettantes of birthing may believe that the duration of a pregnancy is 9 months, it is actually 40 weeks, which is about 10 months! As seen in **Figure 22.1** above, there are three stages of **prenatal development**, they are: **1) Germinal**; **2) Embryonic**; and **3) Fetal**. Prenatal development is also organized into three equal **trimesters**, which do not correspond with the three stages.

Overview of the Reproductive System

For both the male and female reproductive systems the **gonads** are the **primary reproductive structure**. Gonads are the **testes** (testicles) for men and the **ovaries** for women, see **Fig. 22.2** below.

Gonads create two important things:

1) Gametes. These are the sex cells. They are the sperm cell or spermatozoa for males, and the egg cell called the mature ovum or the primary ova for females.

2) Sex Hormones. The male sex hormones are collectively referred to as **androgens**, principally they consists of **testosterone**, and some androstenedione. There are also other hormones but they are present in much lesser amounts. The female hormones consist of two principal groups: the **estrogens**, which are estradiol (E2) and estriol (E3), and **progesterone**. Females also have testosterone, but very small amounts.

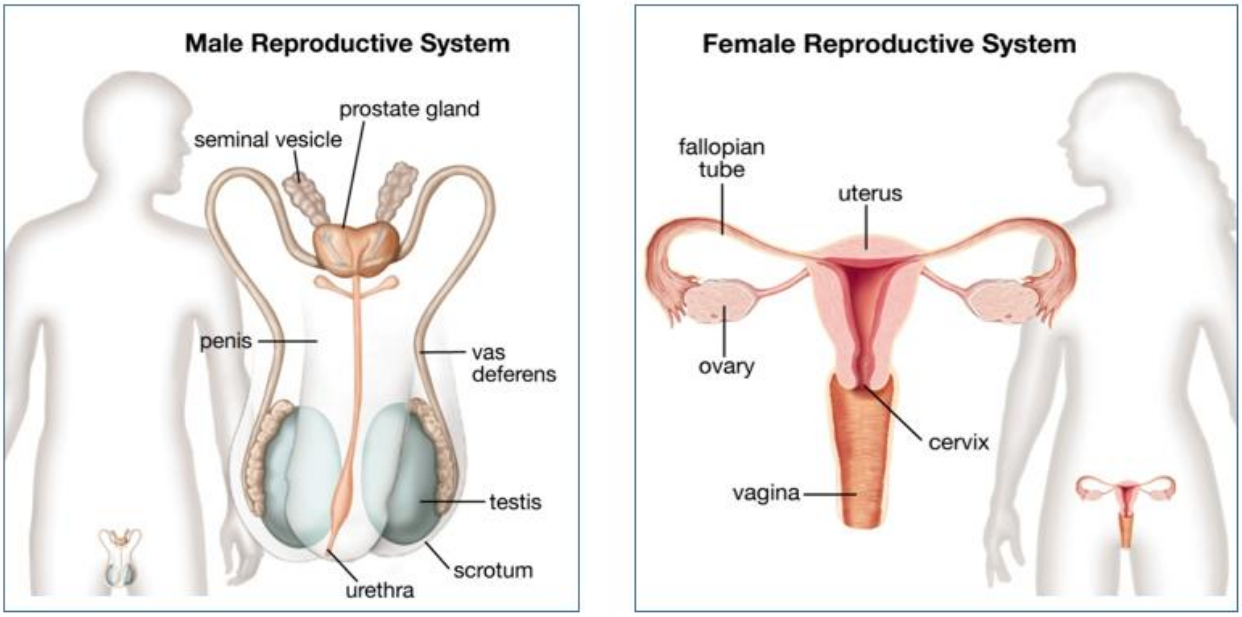


Figure 22.2 Shows the primary reproductive structures for the male (left) and female (right). The reproductive systems of each sex are centered around the gonads: The testes for the male and the ovaries for the female.

Functions of the Reproductive System

The reproductive systems for males and females are for the production, storage, nourishment and transport of functional **gametes** made by the **gonads**. We will examine the primary reproductive structure, the gonads, for males and females and describe the functions of the ducts and tracts of the reproductive systems that the gametes travel through. We will also discuss the **accessory organs** and **glands** of the reproductive systems that create the fluids and deliver the gametes to the external environment. The male and female **external genitalia** and other **secondary sexual characteristics** will be detailed. Finally, the process of **conception**, embryonic and fetal development and **parturition** (giving birth) will be discussed at the end of the female reproductive section.

The number of chromosomes in gametes (egg or sperm cells) is **haploid** which means these cells contain only 23 chromosomes, or **half** of the 46 chromosomes that all other soma (body) cells have. This is because when the egg and sperm cells unite at conception, half of the chromosomes will be provided by the mother and the other half by the father to create the full **diploid** complement of 23 pairs (46) of chromosomes for the new, genetically unique individual being created!

The Male Reproductive System

The primary function of the male reproductive system is to produce **sperm cells** and **sex hormones**, and to transport semen, which contains millions of sperm cells, into the female reproductive tract. The approach of this discussion of the reproductive systems for both sexes will be to focus on the formation and journey of the **gametes**; from their starting point in the gonads, to their journey and expulsion from the body, and ultimately to their union at conception.

The Testes

The male gonads are a pair of **testes** (singular = testis) that are housed in the **scrotum**, which is like a bag outside of the body cavity for optimal thermoregulation. They produce both sperm cells and the androgen sex hormones (such as testosterone) and are active throughout the reproductive lifespan of the male.

As seen in **Figure 22.3** below, the lobules of the testes are created by tightly coiled **seminiferous tubules** that make up most of the testicle. This is where **spermatogenesis** occurs, that is the origin and development of the sperm cells which are produced within the walls of the seminiferous tubules. Sperm exit the seminiferous tubules into the rete testis, and via the efferent (leaving) ductule, both located at the hilum (opening and exit) of the testicle, allow the developing sperm cells to flow into the **epididymis**.

The epididymis is about 20 feet in length but is extremely coiled so takes up little space positioned on top of and behind the testes. It takes about **two weeks** for sperm cells to travel through the epididymis, from the head, down the body and to the tail of the epididymis (see **Fig. 22.3**). The sperm cells continue to mature and acquire mobility as they navigate the twisting and turning 20 feet of the epididymis. Any malformed sperm cells are culled (removed) in this region. Once sperm have completed their development, they remain in the epididymis in readiness for deployment into the ductus deferens for the final leg of the journey. If the sperm is not ejaculated (released), the epididymis eventually breaks down and reabsorbs them.

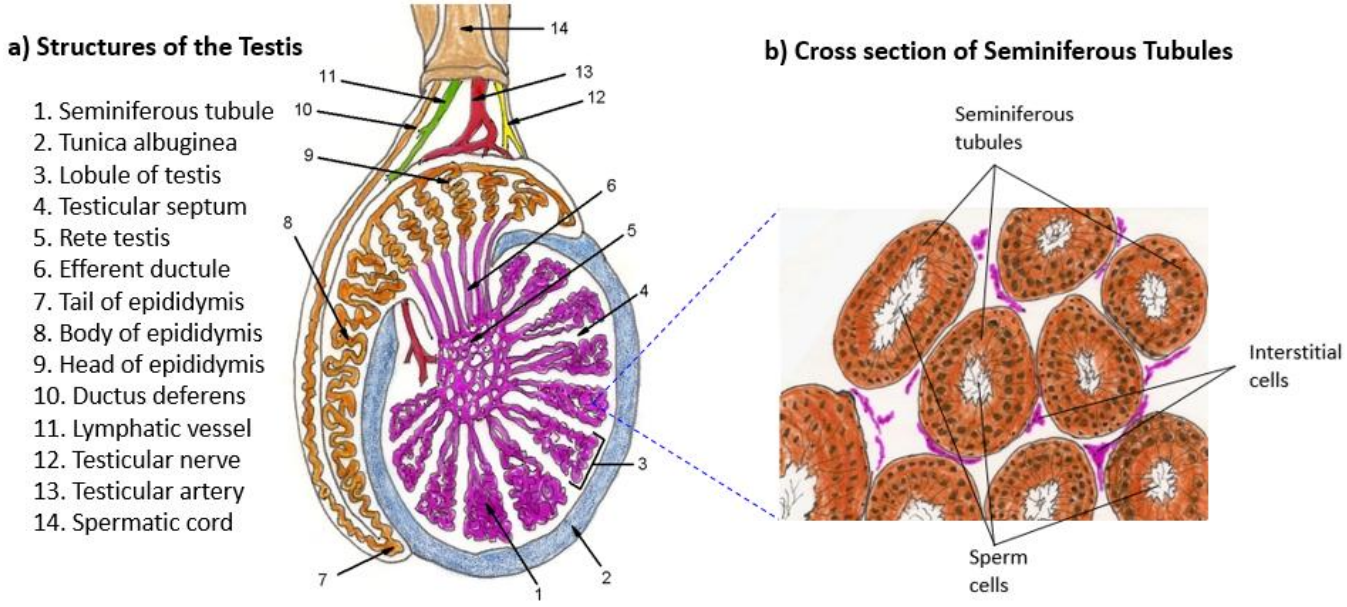


Figure 22.3 This shows **a)** a sagittal section view of a testis, with the seminiferous tubules (1) where sperm is produced and moves sequentially up the tract to the epididymis (8), where sperm mature then enter the ductus deferens (10) as it travels through the spermatic cord (14). On the right **b)** is a cross section of the seminiferous tubules, the site of spermatogenesis and the production testosterone in the interstitial cells.

During ejaculation, the smooth muscle in the walls of the where tracts mature sperm are contract and the sperm are pushed out of the tail of the epididymis into the **ductus deferens** (vas deferens). This thick, muscular tube also contracts as it travels through the spermatic cord which leads back into the body to connect with the three accessory glands that create the seminal fluid (described in detail below). Once deposited inside the female reproductive tract, the sperm cells located there have the ability to move independently toward the unfertilized egg.

Testosterone

The predominant male sex hormone is **testosterone**, a steroid hormone derived from **cholesterol** and produced by the **interstitial cells**, which are located in between the seminiferous tubules of the testes (see **Fig. 22.3 b**). The word *interstitial* means in between. These are also called the **cells of Leydig**, or can be called the **interstitial cells of Leydig** as a happy mixture between an eponym (named after a person) and a descriptive name (describing the function or location) of a structure.

During embryological development it is by the seventh week of development in the male that testosterone is secreted by the interstitial cells of Leydig, with concentrations peaking in the second trimester. This critical release of testosterone at this developmental stage denotes the start of the **anatomical** and **physiological differentiation** of the male and female sexual organs (see **Fig. 22.4** below) and much more.

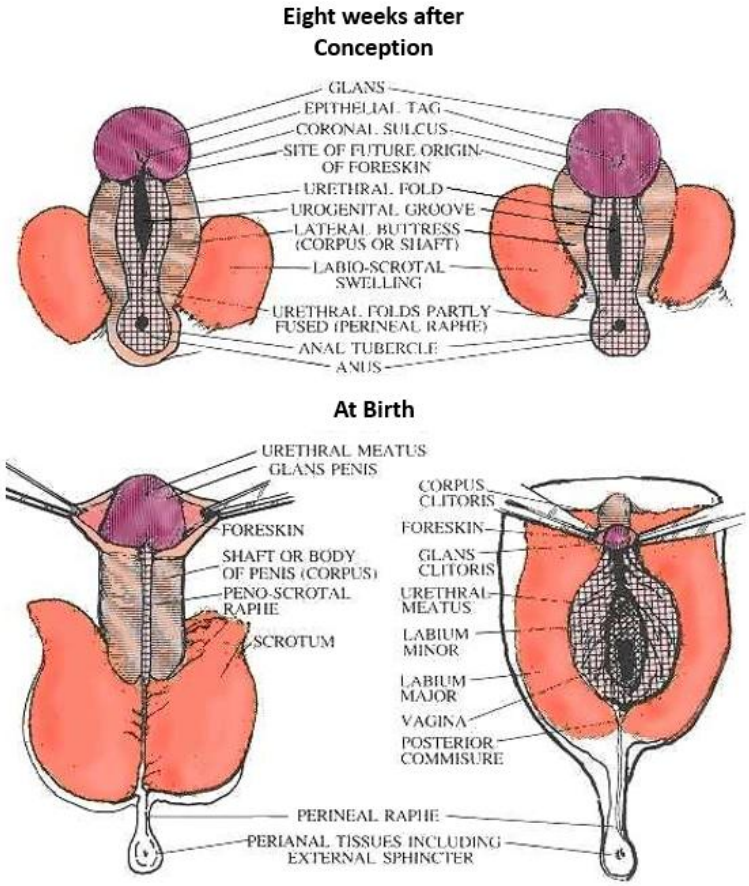


Figure 22.4 The comparison of external genitalia at eight weeks after conceptions (top panel) and immediately at birth (lower panel) shows the striking similarities in the origins of embryological development of genitalia for males (left) and females (right).

Testosterone concentrations are low until male puberty hits, when it dramatically increases. This activates the physical changes promoting the secondary sexual characteristics, and also initiates spermatogenesis.

Spermatogenesis

Spermatogenesis is the process of the production of sperms from the immature male germ cells and this begins at puberty and continues throughout a man's life.

Sperm Production Needs to be Cool!

There is a reason the testes are kept outside of the body cavity, this is because sperm production is higher and occurs more efficiently when the surrounding temperature is about 4 to 7 °F cooler than core body temperature. This is the reason the testes each sit in the **scrotum**, which is essentially an outside bag for each testicle. The skin of the scrotum contains subcutaneous **dartos muscle** which gives them their wrinkled appearance. The dartos muscle contracts and relaxes automatically to alter its surface area in response to temperature changes. In this way it helps to constantly regulate the temperature inside the scrotum to ensure they remain cooler. See **Fig. 22.5** below for the arrangement within the scrotum.

Another thermoregulation safeguard for the testes are the two **cremaster muscles** which descending from the abdominal internal oblique muscles and encircle each testis like a muscular suspender. In fact, the word cremaster means 'suspender'. In cold weather (or water), the cremaster muscles contract and elevate the testes closer to the body to retain heat. If the temperature increases, the cremaster muscles relax and drop the testes further away from the body to allowing for heat loss. The cremaster muscles also protects the testes from extrinsic trauma, as they act as a type of slender muscular shield.

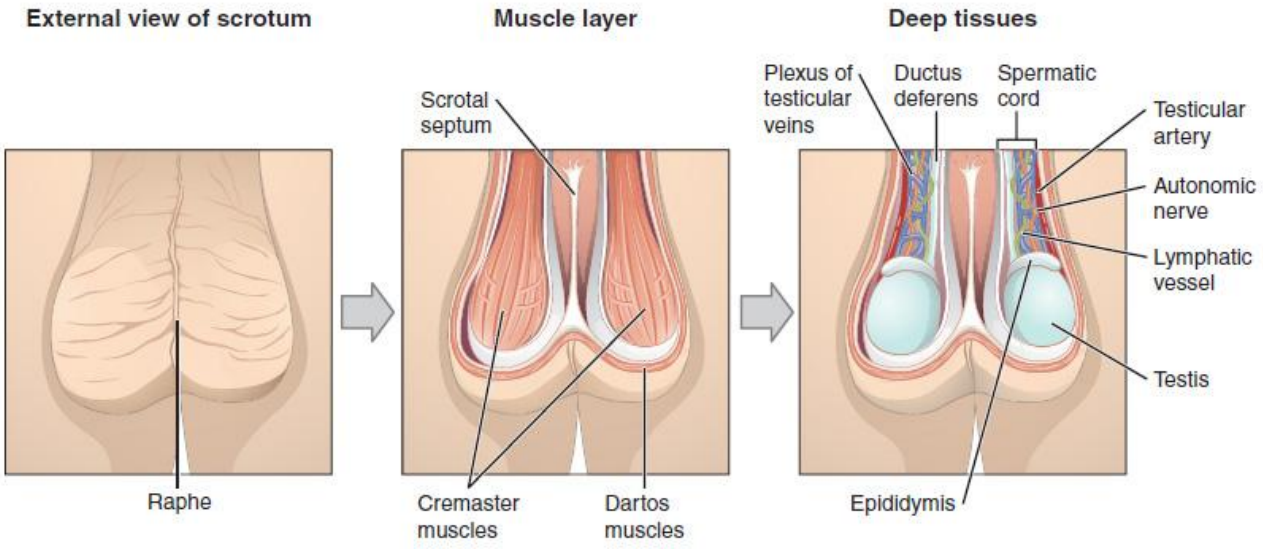


Figure 22.5 The scrotum is a bag that contains the testes. There are two different muscles, the cremaster and dartos muscles that assist in the thermoregulation of the testes. Deeper, as seen in the last frame, the spermatic cord provides access for blood and lymph vessels, nerves and the ductus deferens into and out of the testes and the abdominal cavity.

Cell Types in Seminiferous Tubules

Inside the seminiferous tubules there is stratified epithelium that lines the lumen and there are two distinct populations of cells there: **1) spermatogenic cells** that develop into spermatozoa; and **2) Sertoli cells** which are support cells that provide nutrients for the developing perm cells. These distinctions can be nicely seen in **Fig. 22.6** which depicts spermatogenesis.

Sertoli Cells

The **Sertoli cells** that act as support cells in the seminiferous tubules is an eponym (meaning named after a person) for Enrico Sertoli who described them in 1865, they can also be called **sustentacular cells** a term which means to sustain or support. These cells facilitate the development of the initial germ cells in the seminiferous tubules into **spermatozoa** (sperm cells).

They help to oversee the **spermatogenesis** that occurs in the testes. The Sertoli cells are in direct contact with the germ cells and they control the local environment within the seminiferous tubules. Regulation of spermatogenesis by follicular stimulating hormone (**FSH**) that is released from the anterior pituitary, and testosterone that is released from the interstitial cells, occurs by the actions of these hormones on Sertoli cells. It is the Sertoli cells secrete **paracrine** molecules that promote sperm production and can control whether a germ cell lives or dies. They are found all around germ cells from the peripheral basement membrane of the seminiferous tubules to the lumen.

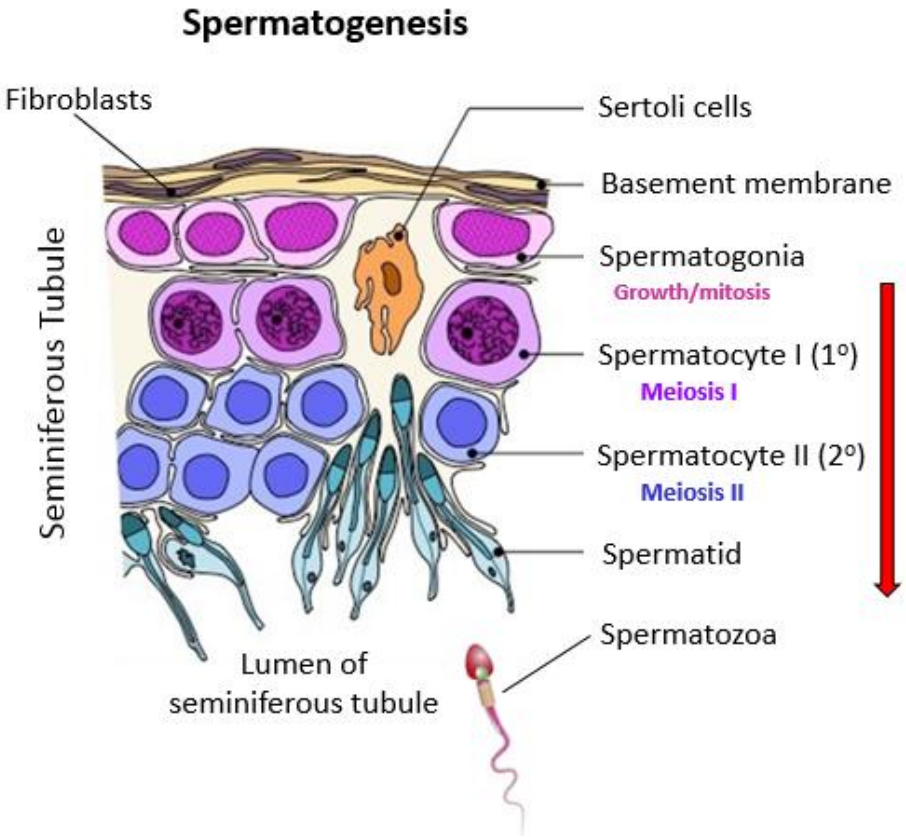


Figure 22.6 This illustration of the histology of the seminiferous tubules where spermatogenesis occurs. The spermatogonia is the stem cell of the testes and develops into the spermatocyte germ cells and finally the sperm cell. The Sertoli cells are vital support cells that guide the development of the germs cells.

Germ Cells

Moving from the periphery of the seminiferous tubules to the lumen (where the free sperm cells can flow along the seminiferous tubules) we move from the least to the most mature germs cells involved in spermatogenesis. The germ cells that are the **spermatogonia** (singular = spermatogonium) divide to produce primary and secondary spermatocytes (I and II), then they make spermatids, which finally produce formed sperm. The entire process that begins with spermatogonia and concludes with the production of sperm is called **spermatogenesis**, shown in **Fig. 22.6** above.

Spermatogenesis and Spermiogenesis

The process of **spermatogenesis** is the conversion of a diploid structure which is the first cell in **Fig. 22.6**, the **spermatogonia**, into the haploid structure of the **spermatozoa**, which is the final sperm cell in this process. The term **spermiogenesis** is the process at the very end of spermatogenesis that involves changing a haploid structure, the spermatid, into another haploid structure, the spermatozoa. The complete cycle of going from spermatogonia through to formed sperm takes approximately 64 days.

The cycle can be categorized in 5 phases:

1) The **spermatogonia** are the **stem cells** for the **germ cells** of the testis and they line the inner basement membrane of the tubule (see **Fig. 22.6** above). The process of spermatogenesis begins with **mitosis** of the diploid spermatogonia. However, the daughter cells of spermatogonia must undergo a second cellular division through the process of **meiosis**. To reduce the diploid ($2n$) set of chromosomes (46) to a haploid ($1n$) set of 23 chromosomes.

2) Two identical diploid cells result from spermatogonia mitosis. One of these cells remains a spermatogonium, and the other becomes a **primary spermatocyte** (I or 1^{o}), and moves on to the next stage in spermatogenesis.

3) The cell undergoes cell division to produce two cells with identical chromosomes, each one is a **secondary spermatocyte** (II or 2^{o}). A second round of meiotic (reduction) division occurs in both of the secondary spermatocytes, separating the chromosome pairs.

4) The process yields a total of four cells with only half of the number of chromosomes. Each of these new cells is a haploid **spermatid**.

5) The fifth and final stage of germ cell formation is the production of the **spermatozoa**, or formed sperm, which is the end result of this process.

The sperm cells are released into the lumen of the seminiferous tubules and moved along it's ducts by delicate currents of the tract, where the cells continue to develop and complete their maturation in the epididymis.

Sperm Cells

Compared to the female egg cell, which is the largest cell in the human body, sperm cells are actually quite small. What they lack in size they make up for in number. There are from about **100 to 300 million** sperm cells made each day. Contrast that to the female ovulating one oocyte per month.

Sperm have a distinctive shape (see **Fig. 22.7** below), starting with the head, mid-piece, and ending with the tail region. The head contains the enormously compact haploid nucleus with very little cytoplasm. This allows the sperm to be very small in size, the head is only 5 μm long. The **acrosome** is a structure that covers most of the head and is like a cap filled with lysosomal enzymes, which are very important in facilitating the sperms ability to participate in fertilization. Proteolytic enzymes like hyaluronidase and acrosin help sperm to penetrate the zona pellucida (meaning transparent zone), which is a protective layer surrounding the ovum. If a sperm cell contacts the ovum at just the right time (and it is never the first sperm to arrive!), the powerful enzymes help dissolve the zona pellucida and allows the sperm cell to enter the cytoplasm of the ovum, enabling the nuclei of both sex cells (the sperm and the ovum) to fuse.

The closely packed **mitochondria** fill the mid-piece of the sperm cell. This is where the ATP required for movement is produced, wherein the ATP powers the whip like flagellum, which extends from the neck and the mid-piece through the tail of the sperm, enabling it to move the entire sperm cell. The central strand of the flagellum, the axial filament (see **Fig. 22.7**), is formed from one **centriole** inside the maturing sperm cell during the final stages of spermatogenesis.

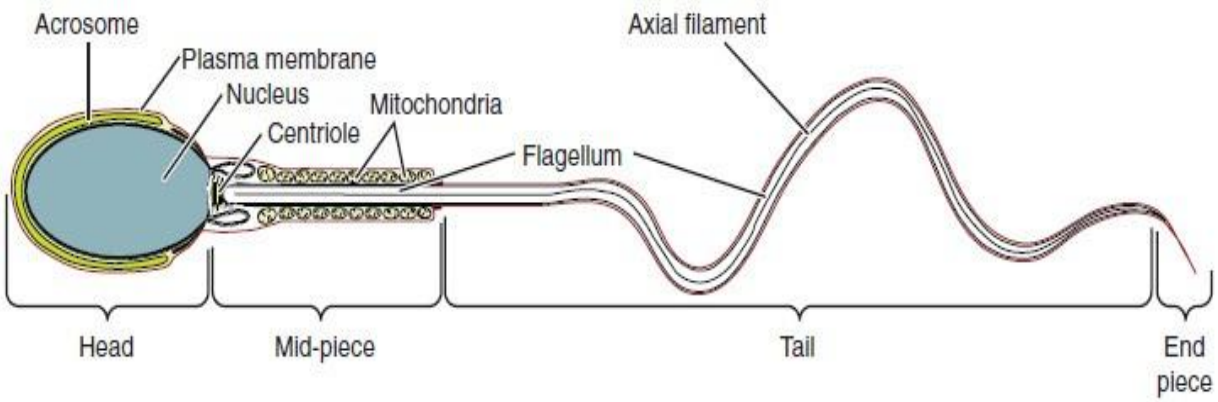


Figure 22.7 This shows the three main structures of the sperm cell: 1) the head of the sperm, which contains the nucleus, the DNA of the cell and the lysosomal enzymes; 2) the mid-piece which is packed with mitochondria to produce energy for the cell; and 3) the tail of the sperm, which moves around and around like a propeller to effectively propel the sperm cell toward the egg cell.

Other points before we move on:

- In the third trimester around the seventh month of development, the testes of male fetus each move through the abdominal musculature to descend into the scrotal cavity, which marks **descent of the testis**. The condition of cryptorchidism (crypt meaning 'hidden' and orkhid meaning 'testicle') is when both of the testes fail to descend into the scrotum prior to birth.

- Sperm counts—the total number of sperm a man produces—slowly decline after age 35

- Because the developing sperm cells are genetically different to all other cells in the body, the tight junctions between sustentacular cells create the **blood–testis barrier,** a restrictive wall-like structure that keeps substances from the blood from reaching the germ cells and at the same time, keeps surface antigens on developing germ cells from escaping into the bloodstream which could promote an autoimmune response.

The Accessory Structures and Semen

Until this point we have only discussed the development of sperm cells, but sperm requires a mixture of substances to join it in its journey outside of the body. Sperm only make ups about 5%t of the total volume of **semen** - the thick, opaque fluid that the male ejaculates. The vast majority of semen is produced by three accessory glands of the male reproductive system, they are: 1) the seminal vesicles, 2) the prostate, and 3) the bulbourethral glands.

1) Seminal Vesicles

In the earlier discussions above, we last described sperm going back into the body cavity in the ductus or vas deference (through the spermatic cord via the inguinal canal). The sperm is now ready to interconnect with the accessory structures that are within the pelvic cavity. The sperm cells enter the dilated **ampulla**

of the two ductus deferens (one form each testicle) during ejaculation where they mix with fluid from the paired **seminal vesicles**. The paired seminal vesicles are glands that make up about **60%** of the total semen volume.

The seminal vesicle fluid contains large amounts of the simple sugar **fructose** which is used by the sperm mitochondria to generate ATP to allow movement through the female reproductive tract. This fluid also contains proteins, enzymes, mucus, citric acid, fibrinogen and prostaglandins.

The **fibrinogen** facilitates in **seminal clotting** after ejaculation, helping to keep the ejaculated sperms in the female reproductive tract. **Prostaglandins** may assist by softening mucous of the cervix, and by causing reverse contractions of parts of the female reproductive tract such as the fallopian tubes, to ensure that sperm are less likely to be expelled. All of these elements help support sperm until fertilization occurs.

The fluid, now containing both sperm and seminal vesicle fluid continues to move forward into the paired **ejaculatory ducts** just beyond the ampulla and transport the seminal fluid into the prostate gland.

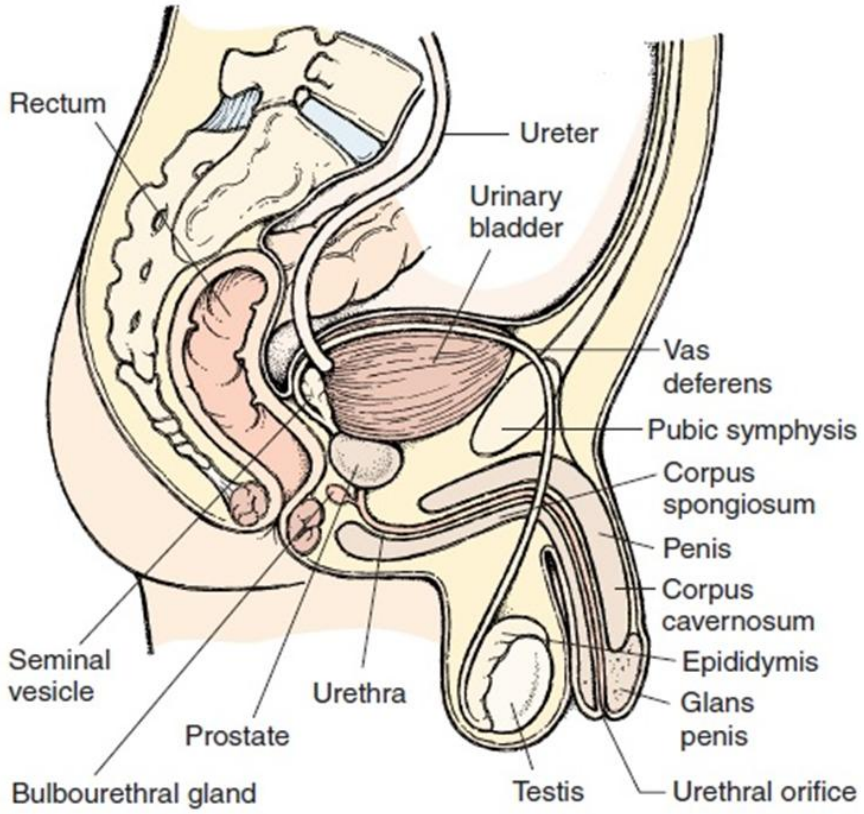


Figure 22.8 This mid-sagittal section shows the three accessory structures involved in producing semen. The sperm flowing through the vas deferens from the testis back into the body first encounters the paired seminal vesicles, then the single prostate gland, and lastly the very small paired bulbourethral glands before examining the body via the (penile) urethra.

2) Prostate Gland

The single **prostate gland** sits adjacent to the rectum, above the anal canal and at the base of the bladder (see **Fig. 22.8** above). The prostate gland surrounds the prostatic urethra (which also carries urine through the prostate). The prostate gland is about the size of a walnut, and is both glandular and muscular tissue. It contributes about 30% of the total volume of semen.

The constituents of its secretions are mainly citric acid, acid phosphatase, calcium, sodium, zinc, and potassium, protein-splitting enzymes to support the sperm cell outside of the body, and **fibrolysin**, an enzyme that dissolves the clot in semen produced by the fibrinogen contributed by the seminal vesicles. It is critical to first **coagulate** and then **de-coagulate** the semen following ejaculation.

The temporary thickening of semen helps retain it within the female reproductive tract, providing time for sperm to utilize the fructose provided by seminal vesicle secretions. When the semen regains its fluid state, sperm can then pass farther into the female reproductive tract. The prostate also excretes an alkaline (basic) fluid into semen that acts to neutralize the acidic conditions in the vaginal canal.

3) Bulbourethral Glands

The final contribution to semen is made by the very tiny paired **bulbourethral** (**Cowper's**) **glands** (see **Fig. 22.8** above). These glands release a thick, salty mucus alkaline fluid that lubricates the end of the urethra, the glans penis and the vagina, and helps to clear out any residual acidic urine from the penile urethra. This fluid usually represents about 5% of the total volume of semen. The fluid from the bulbourethral gland is released after the male becomes sexually aroused, and shortly prior to the release of the semen. It is therefore sometimes called pre-ejaculate.

The Penis

The **penis** is the male organ of copulation (sexual intercourse). It is flaccid for non-sexual actions, such as urination, and turgid and rod-like with sexual arousal. When erect, the stiffness of the organ allows it to penetrate into the vagina and deposit semen into the female reproductive tract.

The shaft of the penis surrounds the urethra. The shaft is composed of three column-like chambers of erectile tissue that span the length of the shaft. Each of the two larger lateral chambers is called a **corpus cavernosum** (plural = corpora cavernosa). Together, these make up the bulk of the penis. The **corpus spongiosum**, which can be felt as a raised ridge on the erect penis, is a smaller chamber that surrounds the spongy, or penile, urethra.

The end of the penis, called the **glans penis**, has a high concentration of nerve endings, resulting in very sensitive skin that influences the likelihood of ejaculation. The skin from the shaft extends down over the glans and forms a collar called the **prepuce** (or **foreskin**). The foreskin also contains a dense concentration of nerve endings, and both lubricate and protect the sensitive skin of the glans penis. A surgical procedure called circumcision, often performed for religious or social reasons, removes the prepuce, typically within days of birth. It is extremely painful and has no role in protection or health.

Sexual Arousal and Penile Erection

As a consequence of sexual arousal, the penis will become erect as the result of the engorgement of the tissues due to more arterial blood flowing into the penis than blood leaving in the veins. During sexual arousal, **nitric oxide** (NO) a powerful vasodilator, is released from nerves innervating blood vessels within erectile tissue of the penis, that being the paired **corpora cavernosa** and the **corpus spongiosum**.

The NO activates a signaling pathway that dilates the smooth muscles surrounding the penile arteries, and increases the blood flow to the penis. This also induces endothelial cells in the penile arterial walls to in turn secrete additional NO and perpetuate the **vasodilation**. The rapid increase in blood volume fills the erectile chambers, importantly, the increased pressure of the filled chambers compresses the thin-walled penile venules, preventing venous drainage of the penis. This creates a backlog of accumulating blood

filling the erectile tissue. The result penile erection. Depending on the flaccid dimensions of a penis, it can increase in size slightly or greatly during erection, with the average length of an erect penis measuring about 15 cm or about 6 inches.

Ejaculation
When a man is sexually stimulated, friction on the glans penis and other stimuli send signals through the nervous system that result in ejaculation. At the moment of ejaculation the walls of the **epididymis** contract and create peristaltic waves that push sperm into the **ductus deferens.** The muscles of the pelvic floor, the ductus deferens, the seminal vesicles, and the prostate gland begin to contract in a way that forces sperm and **semen** into the penile urethra. This is the onset of **orgasm** and once this has started, the man likely will continue to ejaculate and orgasm fully, with or without further stimulation.

If sexual stimulation stops before orgasm, the physical effects of the stimulation will subside and resolve. Repeated or prolonged stimulation without orgasm and ejaculation can lead to discomfort in the testes, however, any sperm that builds up and is not released by the male will be degraded by the testes. It is not unhealthy or physiologically problematic to abstain from ejaculating.

It is worth noting that a male erection can occur without conscious sexual arousal or due to mechanical stimulation or during sleep. And equally, that some men do not always have an erection when sexually aroused. Several hormones affect sexual arousal, including **testosterone**, **cortisol**, and **estradiol,** but testosterone is the best studied and understood hormone involved with sexuality, as it has a central role in sexual arousal in males, with significant effects on central arousal mechanisms.

Post-Orgasm Response
There is usually a **refractory period** after orgasm and ejaculation which is characterized by loss of erection, an abrupt decreased interest in sex and feelings of relaxation and closeness that are related to the release **oxytocin** and **prolactin**. The duration and intensity of this refractory period can vary widely.

Erectile Dysfunction
The term erectile dysfunction (ED) relates the persistent inability to achieve or maintain penile erection sufficient for satisfactory sexual performance. The main causes of erectile dysfunction include psychological and health conditions, medications, trauma and lifestyle factors. Penile erection is a complex process in which the brain, nerves, muscles and blood vessels play a major role. In addition, hormones and emotions are at work. The key issue usually relates to an inability of the NO triggered vasodilation that enables engorgement of the erectile tissues.

Functions of Testosterone
The levels of **testosterone** are critical to maintaining the healthy functioning of the male reproductive system. Continued presence of testosterone, made by the **interstitial cells** (of Leydig). In fact these cells must produce approximately 6 to 7 mg of testosterone per day.

The manufacture of androgens, including **testosterone** (testicular steroidogenesis) results in testosterone concentrations that are **100 times higher in the testes** than in the circulation. These levels are required to promote adequate spermatogenesis, and **low levels of testosterone can lead to infertility**.

Testosterone is also released into the systemic circulation and plays an important role in **muscle development**, **bone growth**, the development of secondary sexual characteristics, and maintaining a

healthy sex drive (libido). Females also make and circulate testosterone, both in the adrenal cortex and the ovaries. However, there are very low levels, and most of the testosterone in the ovaries is converted to estradiol.

Regulation of Testosterone
The control of the interstitial cells of the testes testosterone originates outside of the testes with the usual contribution form the **hypothalamus** and the **pituitary gland**. The regulation of the synthesis and secretion testosterone begins in the hypothalamus, where rhythmic pulsatile releases **gonadotropic releasing hormone** (**GnRH**) the endocrine release of hormones from the **anterior pituitary gland**.

As seen in the endocrine section, when the hypothalamus sends GnRH via the hypothalamic-hypophyseal portal system to receptors in the anterior pituitary gland, this triggers the release of **luteinizing hormone** (**LH**) and **follicular stimulating hormone** (**FSH**). These are gonadotropic hormone, meaning they stimulate the growth and development of the gonads for both men and women, so the testes and the ovaries are stimulated by both of these hormones. In men, FSH binds predominantly to the **Sertoli cells** within the seminiferous tubules to promote **spermatogenesis**, making more sperm cells.

The FSH also stimulates the Sertoli cells to produce hormones called **inhibins**, which function to inhibit FSH release from the anterior pituitary, which causes a reduction in testosterone secretion. These polypeptide hormones correlate directly with Sertoli cell function and sperm number; inhibin B can be used as a marker of spermatogenic activity. For the LH, this binds to receptors on the **interstitial cells of Leydig** in the testes and elevates the production of testosterone.

Importantly and predictably, the synthesis and secretion of both FSH and LH are principally controlled by a **negative feedback loop**. If there are low blood testosterone levels circulating, then this will stimulate the hypothalamic release of GnRH. And as we have already seen above, GnRH then stimulates the anterior pituitary to secrete LH into the bloodstream. In the testis, LH binds to LH receptors on Leydig cells and stimulates the release of testosterone.

If testosterone concentrations in the blood reach a critical threshold, testosterone itself will bind to androgen receptors on both the hypothalamus and the anterior pituitary, **inhibiting the synthesis and secretion of GnRH and LH**, respectively. When the blood concentrations of testosterone once again decline, testosterone no longer interacts with the receptors to the same degree and GnRH and LH are once again secreted, stimulating more testosterone production. This same negative feedback process occurs with **FSH** and **inhibin** to control **spermatogenesis**.

Genetic Sex, Gonadal Sex and Phenotypic Sex

Chromosomes are packages of genes found in every cell in the body. There are **23 pairs** of chromosomes (46 in total), 22 pairs of **autosomes** (of the body), and one pair of **sex chromosomes**, X Y (male) and XX (female).

The genetic sex of a person is determined by the two sex chromosomes X and Y: Males have **XY** and females have **XX**. All spermatozoa have either contribute 23X or 23Y chromosomes and all ova contribute a 23X. Therefore, the male determines the genetic sex of the offspring. In **Fig. 22.9** below is a summary illustration of all the human chromosomes and the human sex chromosomes.

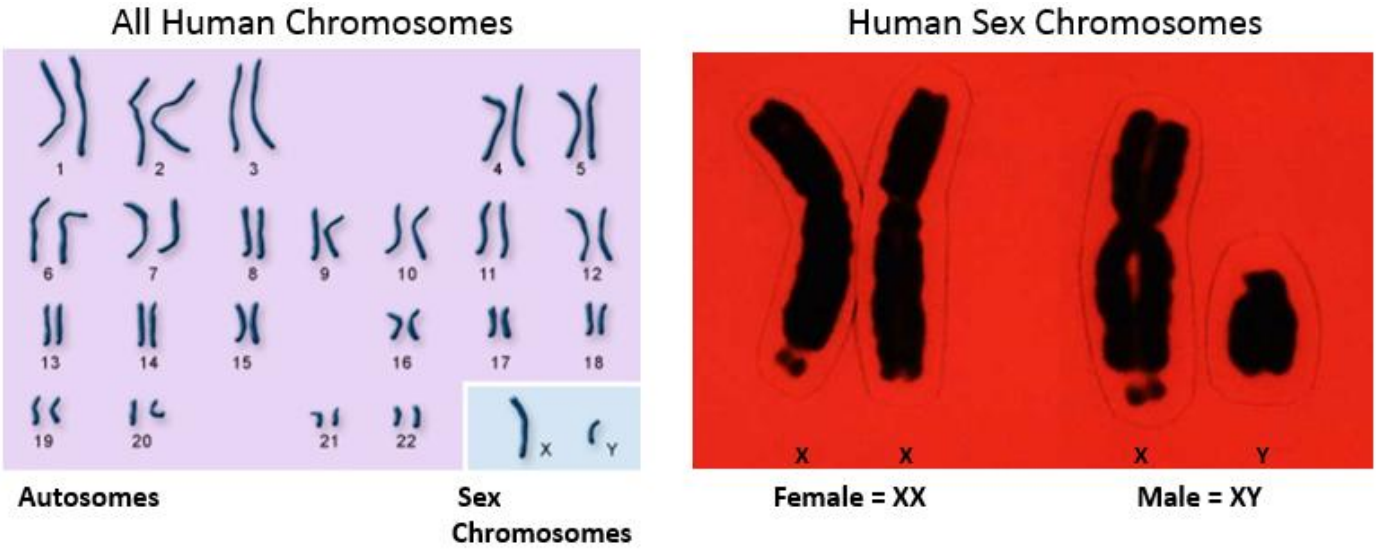


Figure 22.9 Shown at left are all 23 pairs of human chromosomes, 22 pairs are autosome, and 1 pair are the sex chromosomes. On the right, it shows the human chromosome where females have two copies of the X chromosome and males have one X and one Y chromosome. As can be seen, the X chromosome is almost three times larger than the Y chromosome, and has about 900 genes, while the Y chromosome only has about 55 genes. However, since one copy X is from the mother and the other from the father, the information on each X chromosome is not unique but redundant. The Y chromosomes, on the other hand, contains is unique information from X.

Genotype, Phenotype and Karyotype

The **phenotype** is an individual's observable traits, think 'Ph' as the F sound in the word **physical** meaning phenotype, for example height, eye color, and blood type. The **genetic** contribution to the phenotype is called the **genotype**. Some traits are determined by the genotype, while other traits are determined by environmental factors. A **karyotype** is simply a picture of a person's chromosomes.

In the developing fetus, the undifferentiated gonads to differentiate into either testes or ovaries as determined by the XY or the XX karyotype respectively. When the physiology functions as it is designed to, the differentiation of **internal** and **external genitalia** will follow from the XY or XX sex chromosomes, in other words the genotype will dictate the phenotype.

The clearest way to state how this occurs is the following: The presence of a single **Y** chromosome causes fetal undifferentiated gonads to differentiate into **testes**. If the **Y** chromosome is **absent**, testes fail to develop, and ovaries form. Phenotypic sex is determined by the formation of a male or female internal genital tract and external genitalia.

Differentiation of Internal Genitalia

During human gestation, the developing embryo (prior to the eight weeks of gestation) will have the embryonic structures that form both the male and female internal genitalia. The **Wolffian duct** gives rise to male reproductive organs, and the **Müllerian duct** gives rise to female reproductive organs (see **Fig. 22.10** below).

It is the Wolffian duct that appears first but both are generated and exists at the same time until **differentiation** occurs. This begins to occur at the eight week mark of gestation, just as the embryo becomes the fetus. At this early stage, the internal genitalia that the developing embryo have contains the rudiments of both male and female genitalia.

The **female** internal genitalia are the reproductive structures within the true pelvis, including the ovaries, uterine tubes, uterus, cervix and vagina.

The **male** internal genitalia include the testes, epididymis, ductus deferens, seminal vesicles, prostate, bulbourethral glands and ejaculatory duct.

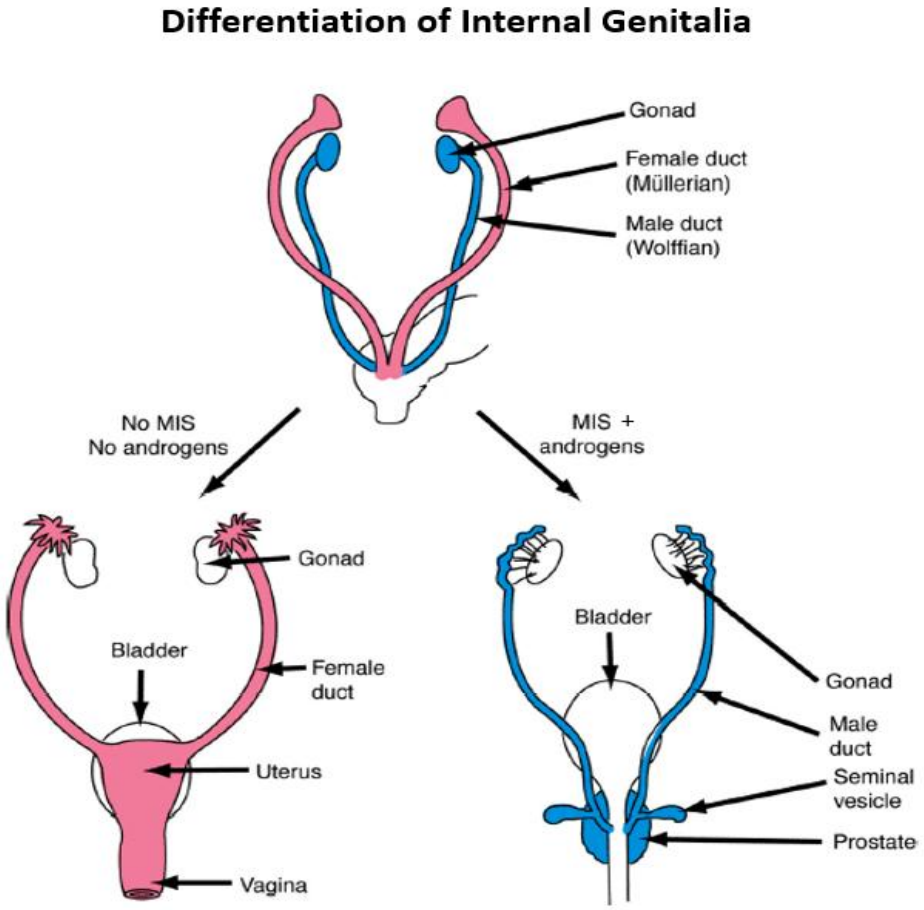


Figure 22.10 Both male and female embryos will have structures that form both the male and female internal genitalia. The Wolffian duct gives rise to male reproductive organs, and the Müllerian duct gives rise to female reproductive organs. It is the Wolffian duct that appears first but both are generated and exists at the same time until differentiation occurs.

As shown in **Figure 22.10** above, the developing fetus will have the rudiments of both male internal genitalia (the Wolffian ducts) and female internal genitalia (the Müllerian ducts). The Müllerian duct gives rise to female reproductive organs, such as the oviduct and uterus. During gestation, the Wolffian duct, which generates male reproductive organs and the kidney, is formed, and the Müllerian duct then elongates caudally along the preformed Wolffian duct.

The Male Internal Genitalia

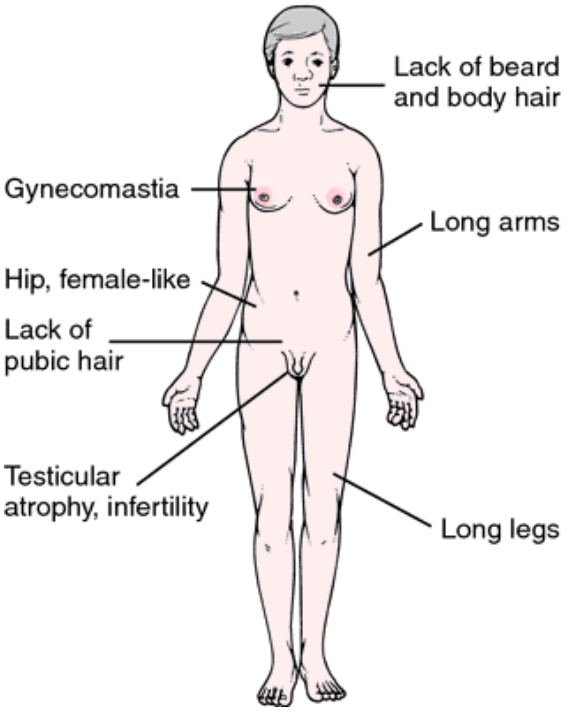
A genetically male fetus with functional testes secretes **anti-Müllerian hormone** (AMH) from **Sertoli cells** in the testes. The AMH causes regression of the Müllerian ducts and differentiation of interstitial cells (of Leydig) in the testes, which as we have already encountered then produce **testosterone** (an **androgen**) which promotes the **Wolffian duct** development into the **male internal genitalia** (see **Figure 22.10** above).

The Female Internal Genitalia

The fetal female development, like the male's, is genetically determined and occurs in the **absence** of testosterone and anti-Müllerian hormone (AMH). Without adequate levels of testosterone, there is a regression of Wolffian ducts and the establishment of **primordial follicles** that produce **estrogen**. The absence of AMH is what allows the **Müllerian ducts** to differentiate, forming **the female internal genitalia** (see **Figure 22.10** above).

Genetic Syndromes Associated with Sex Chromosomes

Klinefelter syndrome is where males are born with an extra sex chromosome, with a karyotype **XXY**. This is one of the most common male genetic abnormalities. As shown **in Fig. 22.11** at the right, males with this condition usually have characteristics of delayed puberty, small and firm testes, gynecomastia (benign enlargement of the male breast), sparse or lack of facial and body hair, lack of muscle mass, low libido, infertility, and osteoporosis.



Many of these signs and symptoms occur as a result of low testosterone because testicular growth is impaired. Therefore, testosterone therapy can prevent many of them if given around the time of puberty. Surgery may also be indicated for treatment of gynecomastia for aesthetic and psychological reasons. Infertility can be overcome, in some instances, with a procedure known as testicular sperm extraction (TESE), in which sperm are removed directly from the testicle by needle biopsy and injected into an egg to fertilize it (intracytoplasmic sperm injection [ICSI]).

Figure 22.11 To the right, shows an illustrative examples of features found in those bone with Klinefelter syndrome where males have an extra sex chromosome, with a karyotype XXY, rather than XY.

XYY Syndrome or Jacob's Syndrome

The condition of having XYY is called **Jacob's syndrome**, a not that common for males. The presence of an extra Y chromosome gives the male a karyotype of XYY - genotype is. "Super-males" often tall, high testosterone levels. Usually fertile. Males normally have one X and one Y chromosome. However, individuals with this syndrome have one X and two Y chromosomes. Affected individuals are usually very tall.

Triple-X Syndrome

Triple X syndrome is also called trisomy X, or 47, XXX, or 'fragile X syndrome'. It is a genetic disorder that affects about 1 in 1,000 females. Females normally have two X chromosomes in all cells — one X chromosome from each parent. In triple X syndrome, a female has three X chromosomes. Women with 3X chromosomes - genotype is XXX. "Super-females" or "Meta-females". Taller, long legs, slender torsos, limited fertility.

Turner's syndrome (see **Fig. 22.12**) occurs in only in females, who would normally be XX, but if a female lacks one of the X chromosomes (or it is partially missing) it results in the karyotype **X0**. This syndrome can cause some developmental problems, including short stature, webbed neck, ptosis (drooping eyelid), small lower jaw, broad chest, and arms that turn out at the elbows (cubitus valgus). It can also involve failure of the ovaries to develop, develop rudimentarily, or be absent; amenorrhea (no menstrual cycle), infertility and heart defects, such as coarctation of the aorta (deleterious narrowing of the aorta). It may also involve hypothyroidism, and skeletal deformities like kyphosis (exaggerated curvature of the vertebral column) and/or scoliosis (lateral deviation curvature of the vertebral column).

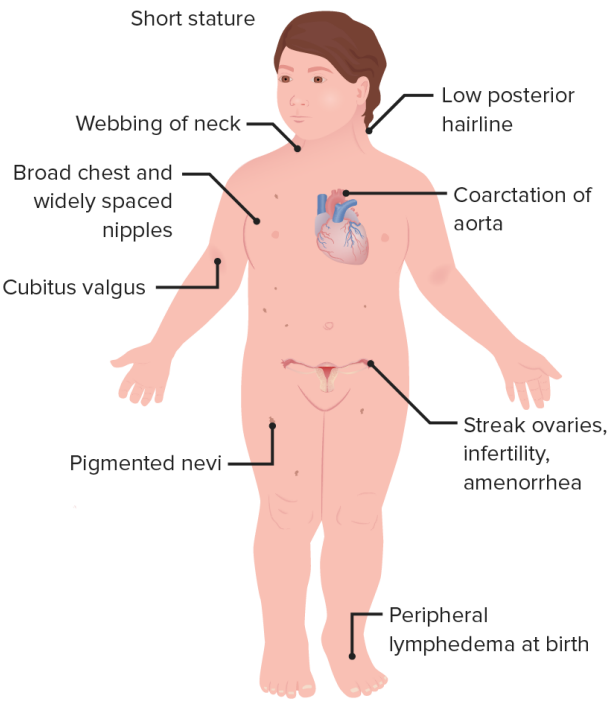


Figure 22.12 To the right, shows an illustrative example of features found in Turner syndrome of females. One person is not likely to have all of these, and there also may be other reasons for some of these conditions.

Swyer syndrome (see **Fig. 22.13** below) is a genetic condition that affects the sexual organ development, classified as a disorder of sex development (DSD). In **Swyer syndrome**, people with one X chromosome and one Y chromosome (normally present in males) are born with female external genitalia and underdeveloped gonads (ovaries or testes) known as streak gonads. This person is **chromosomally a male** but has the physical **appearance of a female**, thus the person is **genetically male** and **phenotypically female**. Those with Swyer syndrome do not have functional ovaries or testicles but have abnormal masses in their place, thus they are infertile and usually unable to carry a pregnancy. Thought to be a 'random mutation' though it's apparently possible to pass this unexpressed gene to children. This syndrome is typically diagnosed around puberty that is delayed.

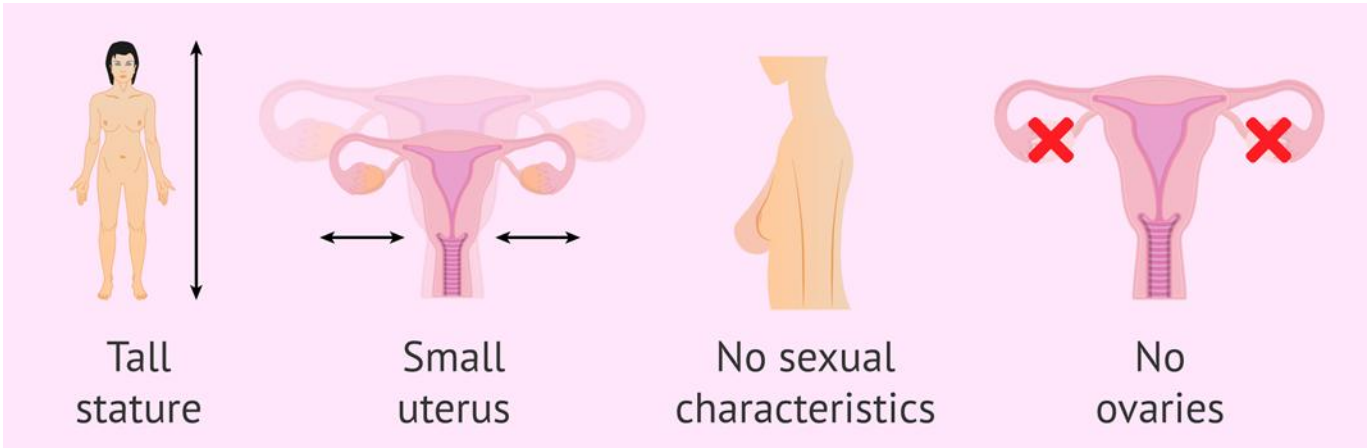


Figure 22.13 Swyer syndrome represents one phenotypic result of a failure of the gonads to develop properly, and hence is part of a class of conditions termed gonadal dysgenesis. There are many forms of gonadal dysgenesis. Swyer syndrome is an example of a condition in which an externally unambiguous female body carries dysgenetic, atypical, or abnormal gonads.

Review Questions for Chapter 22: Male Reproductive System

1. Another name for the sex cell is
- **a)** zygote
- **b)** testicle
- **c)** hormone
- **d)** gamete

2. What is the first accessory gland that a sperm passes on their way through the reproductive tract?
- **a)** Prostate
- **b)** Seminal vesicles
- **c)** Ampulla
- **d)** Epididymis
- **e)** Bulbourethral gland

3. The **gonads** in males are the _____ and the **hormone** _____ stimulates the production of_____.
- **a)** testes: LH: testosterone
- **b)** penis: FSH: sperm cells
- **c)** penis: ICSH: sperm cells
- **d)** sperm cells: ICSH: testosterone
- **e)** testes: FSH: testosterone

4. The testosterone-making cells, called interstitial cells, are located in the _____.
- **a)** spaces in between the seminiferous tubules
- **b)** seminiferous tubules
- **c)** blood stream
- **d)** anterior pituitary
- **e)** posterior pituitary

5. When at rest, the arteries supplying the erectile tissues in the penis are _____.
- **a)** relaxed, increasing blood flow
- **b)** relaxed, restricting blood flow
- **c)** constricted, restricting blood flow
- **d)** constricted, increasing blood flow

6. What structure contains the testes outside of the body and below core body temperature?
- **a)** Prostate gland
- **b)** Penis
- **c)** Urethra
- **d)** Scrotum
- **e)** Cremaster muscle

7. A fluid contains fructose, fibrinogen, and prostaglandins. What reproductive structure made it?
- **a)** The scrotum
- **b)** The Cowper's gland
- **c)** The seminal vesicles
- **d)** The prostate glands

8. The **gonadotropic** hormone _____ stimulates **interstitial cells** to make more _____.

a) FSH: testosterone
b) FSH: egg cells
c) LH: sperm cells
d) PRL: milk
e) LH: testosterone

9. Turner's syndrome is involves which of the following?

a) a genetic female who is phenotypically male
b) an XXY genotype male
c) a genetic male who is phenotypically female
d) an XXY genotype female
e) an XO genotype female

10. Which one of the following is most likely to occur in a boy during **puberty**?

a) The color of his eyes change from increases testosterone.
b) He stops being as verbal and reduces playing activities.
c) His shoulders broaden and voice deepens.
d) His voice deepens and hips widen.
e) He produces more LH and FSH to increase egg production.

Answers in Appendix B