Unit

2B

Chapter 10

Production of gametes

Figure 10.1 Sperm and an egg

Unit content

Body systems

Reproductive systems are specialised for gamete production and fertilisation.

Reproductive systems:

- structure and function of the male and female reproductive systems
- spermatogenesis and oogenesis.

The survival of any species depends on reproduction, and the human species is no exception. To ensure the continuation of our species, some members must produce new individuals to replace those that inevitably die.

Humans reproduce sexually—a process involving the joining together of male and female sex cells. These sex cells, called **gametes**, are produced in specialised sex organs, termed **gonads**. The fusion of a male gamete and a female gamete at **fertilisation** results in a single cell, called a **zygote**, from which the new individual develops.

The gonads are the **primary sex organs**; they produce the gametes. Other organs are essential for reproduction; they store the gametes, bring them together for fertilisation and support the developing baby. These are the **secondary sex organs**.

The reproductive system of humans is different from the other systems of the body because the organs making up the system in the male are quite unlike those of the female.

Male reproductive system

The male gonads consist of two testicles or **testes**. Within each the male gametes, **spermatozoa** (or **sperm**), are produced. The testes are held and supported in a skin-covered pouch called the **scrotum** (see Fig. 10.2). The scrotum appears to be a single pouch of skin, but internally it is divided into two sacs, each containing a single testis. Production and development of sperm requires a temperature that is about 2 °C lower than the normal body temperature. Therefore, to allow sperm production to take

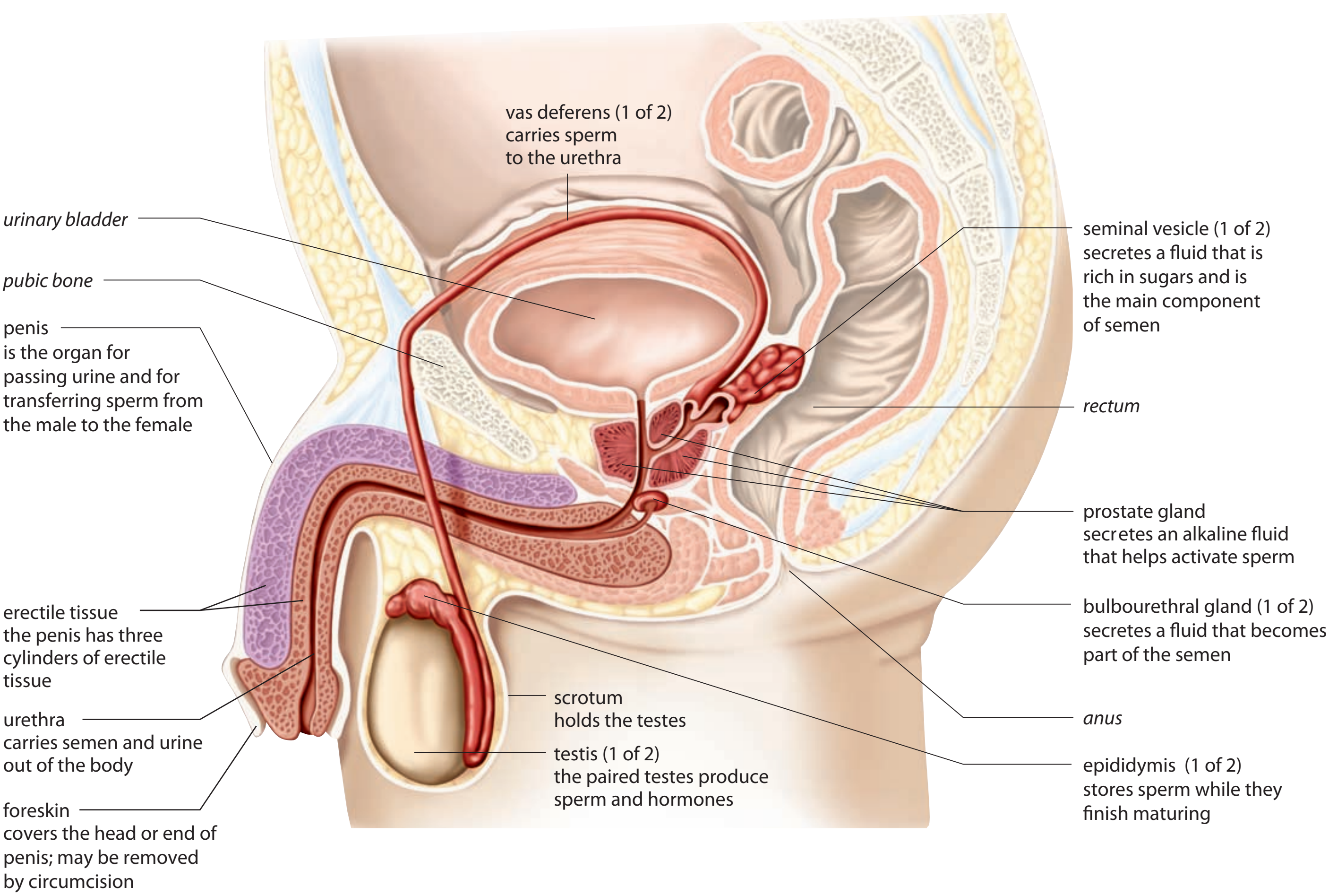


Figure 10.2 The male reproductive system

place, the testes lie outside the body cavity in the scrotum. With exposure to cold, contraction of smooth muscle fibres in the wall of the scrotum moves the testes closer to the body, where the temperature is slightly higher. If necessary, the same muscles can relax, moving the testes away from the body to keep them cooler.

Each testis is oval in shape, approximately 4.5 cm long, 2.5 cm wide and 3 cm thick. Internally they are divided into between 200 and 300 **lobules**, or compartments, filled with fine tubes called **seminiferous tubules**. The tubules are lined with cells that produce the male gametes. The seminiferous tubules in each compartment of the testis join together to form a short, straight tubule. These straight tubules eventually join into ducts, which leave the testis and enter a structure called the epididymis (Fig. 10.3).

Between the seminiferous tubules are clusters of **interstitial cells** that secrete the male hormone, testosterone. The role of testosterone will be discussed in Chapter 11.

The **epididymis** is a highly folded tubule that fits against the rear surface of each testis (Fig. 10.3). Sperm from the testis enter the tubule of the epididymis. If the tubule were unravelled, it would be about 5–6 m in length, allowing plenty of space for the storage of sperm. Sperm may be stored here for up to a month, during which time they mature.

The tubule of the epididymis continues to become the **vas deferens** (or sperm duct), which carries the sperm away from the testis. The vas deferens extends upwards from the testis, passes into the abdominal cavity and crosses the upper surface of the bladder. It then turns downward, looping behind the bladder (Fig. 10.2). Under the bladder, the two vasa deferentia (plural form), one from each testis, join the tube that leaves the bladder. This tube, the **urethra**, runs through the penis and is a duct for transporting both urine and sperm to the exterior.

For transfer into a female's body, and to reach the egg for fertilisation, the sperm must be in a liquid. This liquid, the **semen** (or **seminal fluid**), nourishes and aids the transport of sperm. It is a mixture of secretions from three glands—the seminal vesicles, prostate and bulbourethral glands (see Fig. 10.2).

(a)

(b)

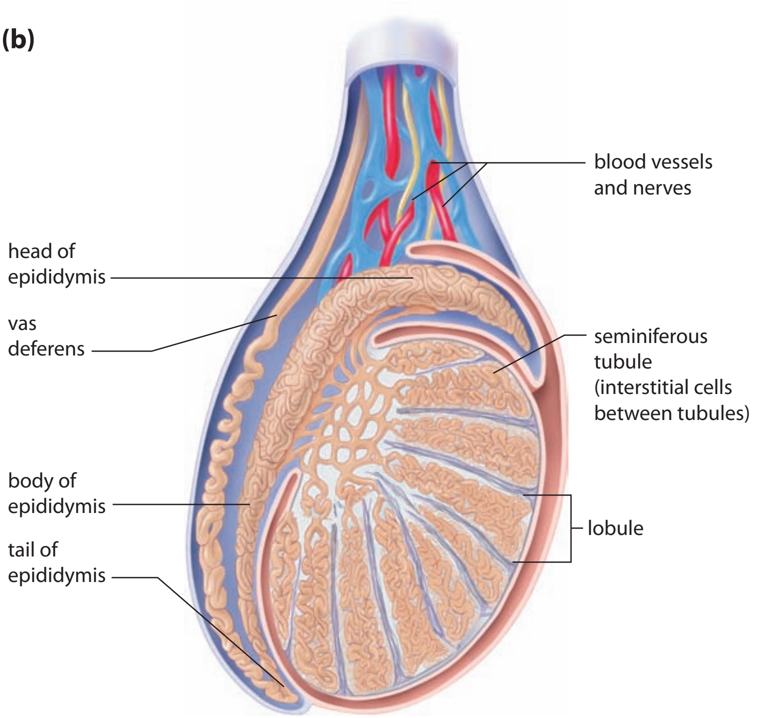


Figure 10.3 **(a)** The testis and associated structures shown life size. **(b)** Section through a testis, showing the system of tubules

1. The **seminal vesicles** are a pair of pouch-like organs about 5 cm in length located behind the urinary bladder. They secrete a thick fluid that is rich in sugars and makes up about 60% of the volume of semen.
2. The **prostate gland** is where the two vasa deferentia join the urethra. It is a single gland, shaped like a doughnut, which surrounds the urethra just below the bladder. It secretes a thin, milky, alkaline fluid that also becomes part of the semen.
3. The **bulbourethral glands**, also known as **Cowper's glands**, are two small yellow glands each about the size of a pea. They are located beneath the prostate on either side of the urethra. They secrete clear mucus, which is carried to the urethra by a duct from each gland. This secretion acts as a lubricant, and much of it precedes the emission of the seminal fluid, with only a small amount included in the semen.

The urethra carries sperm and semen through the penis to a slit-like opening at the tip. In reproduction the penis is used to transfer sperm from the male to the vagina of the female.

The penis contains connective tissue that has a very rich blood supply. This **erectile tissue** has a large number of sponge-like spaces, which fill with blood during sexual arousal. This causes the penis to enlarge, stiffen and become erect. It is only when the penis is erect that it can be successfully introduced into the vagina.

EXTENSION

The head of the penis is covered in loose skin called the **foreskin**. Removal of the foreskin is an operation called **circumcision**. It was once a widespread practice in Australia but is now rarely performed.

Find out:

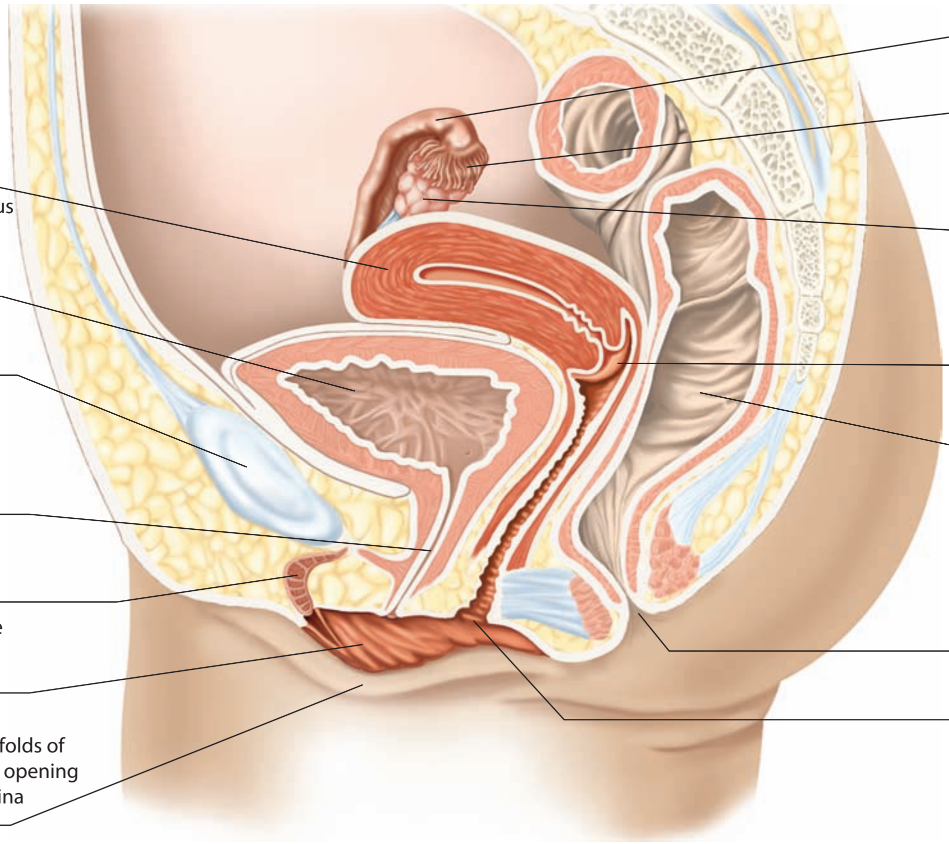
- why circumcision used to be a common practice and the advantages claimed for it
- the evidence put forward that uncircumcised men, or their partners, are more likely to suffer from certain forms of cancer or sexually transmitted infections
- any disadvantages associated with circumcision and why most medical practitioners are now opposed to the practice
- if circumcision has links with specific cultures or particular religious beliefs.

Female reproductive system

The primary sex organs of the female are the two ovaries. The **ovaries** are the female gonads; in them the female gametes, the **ova** (or **eggs**), are produced. Each ovary is an almond-shaped gland about 3 cm in length and, unlike the testis, is located completely within the body. One ovary is located on each side of the abdominal cavity, supported by ligaments (Fig. 10.4).

Each ovary is composed of a mass of connective tissue called the **stroma**. This is surrounded by a layer of cells containing numerous **germ cells**. Each germ cell is enclosed in a **follicle**, and at any one time there are numerous follicles in various stages of development. (How these germ cells develop into ova is discussed later in this chapter.) As a follicle matures, it moves to the surface of the ovary and ruptures. The egg is expelled into the funnel-like opening of the **uterine tube**. There are two uterine

(a)



(b)

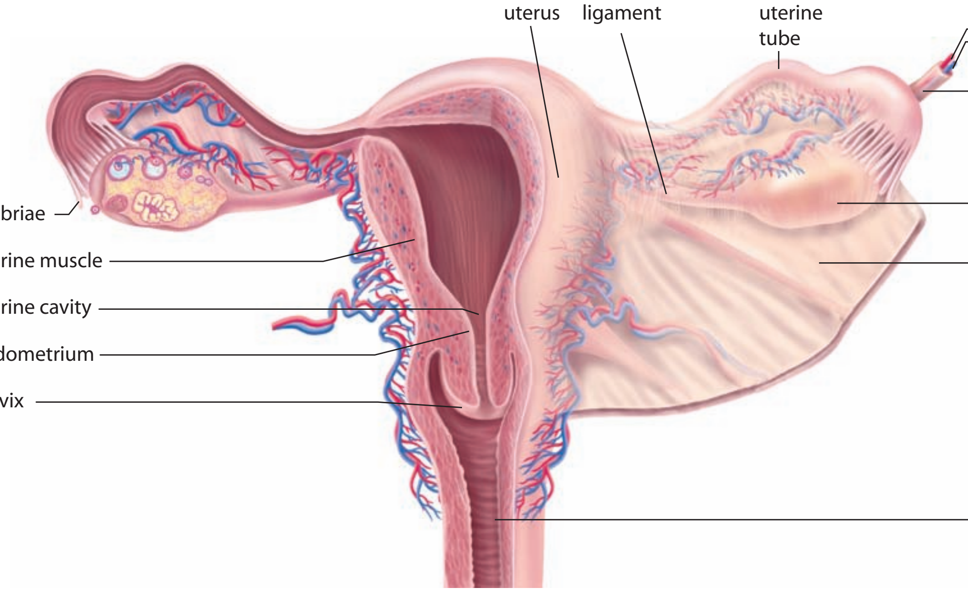


Figure 10.4 The female reproductive system as viewed **(a)** from the side showing the position of the internal organs and **(b)** from the front with the organs on the left side of the diagram cut away to show their internal structure

tubes (also called **Fallopian tubes** or oviducts), one extending from each ovary. They carry the egg from an ovary to the uterus (Fig. 10.4). The funnel-like opening near the ovary is fringed with finger-like projections that appear to just touch the surface of the ovary. These projections, called **fimbriae**, help to guide the egg into the uterine tube. A ciliated epithelium lines the tube, and beating cilia carry the egg towards the uterus. Contraction of smooth muscles of the wall of the uterine tube also aids this movement of the egg.

The **uterus** (sometimes called the **womb**) is a single, hollow, pear-shaped organ situated behind the urinary bladder and in front of the rectum. It is held in position in the pelvic cavity by broad ligaments (Fig. 10.4). The ligaments do not hold the uterus tightly in place. It has limited movement, so its position can vary slightly. Normally it is tipped forward over the bladder, but variation may occur depending on how full the urinary bladder or the rectum is. The wall of the uterus is made up mainly of smooth muscle, with a soft mucous membrane lining called the **endometrium**. The uterus has a major role to play in protecting and nourishing the developing foetus during pregnancy (see Chapter 12).

At the lower end of the uterus is the **cervix**, or neck of the uterus. The cervix protrudes into the **vagina**, a canal leading to the outside of the body (Fig. 10.4). The vagina is a muscular structure lined with mucous membranes, and is capable of considerable stretching. It is around 10 cm in length and receives the penis of the male during sexual intercourse. During childbirth, the vagina becomes greatly enlarged to form the birth canal. The external opening of the vagina is partially covered by a fold of tissue called the **hymen**. This is stretched and usually torn when sexual intercourse occurs for the first time, but it may be torn by other means. The hymen may also remain in place after sexual intercourse, so its presence or absence is *not* a reliable sign of virginity.

The vagina opens to the exterior in a region termed the **vulva**, which is made up of the external genital organs of the female—the labia majora, the labia minora, and the clitoris (Fig. 10.5).

The **labia majora** are two fleshy folds of skin, made up of fat and fibrous tissue, containing a large number of glands that produce an oily secretion. Their outer surfaces are pigmented and, after puberty, covered in hair. The inner surfaces are smooth, lack hair, and are moist from the oily secretions. Beneath and between the labia majora are two smaller folds of skin, pinkish in colour, without fat, and lacking in pubic hair, the **labia minora**. They surround the space into which the urethra and vagina open. At their upper end the labia minora surround the clitoris, a structure equivalent to the penis of the male. The **clitoris** contains erectile tissue, blood vessels and nerves. It is very sensitive to touch, becoming engorged with blood when stimulated.

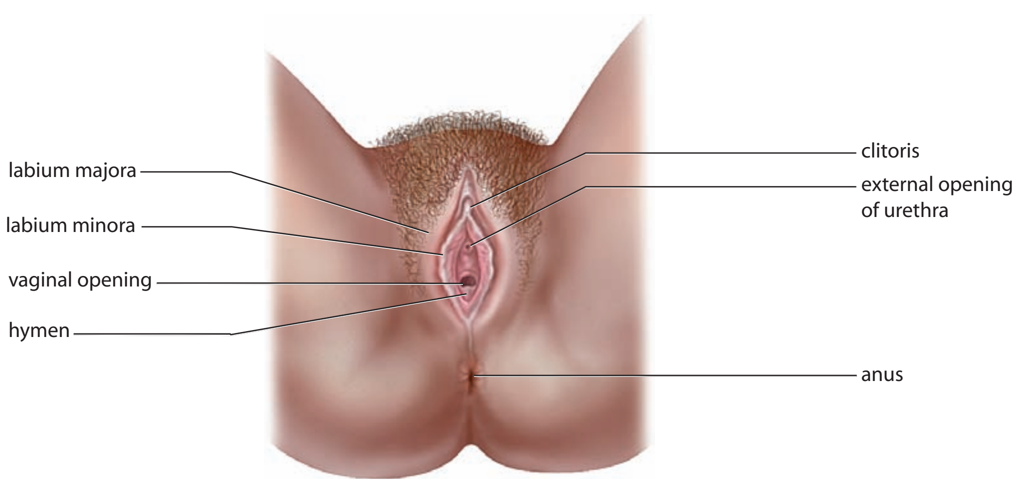


Figure 10.5 External genital organs of the female

The production of gametes

The male and female reproductive systems are specialised for the production of the male and female sex cells, or **gametes**. A male gamete and a female gamete join at fertilisation to form a new cell, the zygote. From the zygote develops the multicelled organism. Thus, offspring produced sexually originate from the cells of both the male and the female parent. Sexual reproduction, then, is a cellular event. It involves a sex cell from the male, a **spermatozoon** (sperm), fusing with a sex cell from the female, an **ovum** (egg). These sex cells, therefore, must have only half the chromosome number of body cells. The process of cell division that produces cells with half the normal number of chromosomes, or the haploid number, is called **meiosis**. Meiosis was described in Chapter 5. It takes place in the sex organs of sexually reproducing organisms.

Following meiosis, the new cells develop into the gametes, the sperm or eggs. Gamete development, from meiosis to mature gametes, is called **gametogenesis**. There are two types of gametogenesis: formation of spermatozoa in the testis is called **spermatogenesis** and formation of ova in the ovary is called **oogenesis**.

Spermatogenesis

Spermatogenesis occurs inside the seminiferous tubules of each testis (Fig. 10.2). The seminiferous tubules are lined with immature cells called **spermatogonia**, or sperm mother cells, which contain the diploid number (Table 10.1) of chromosomes. At puberty, the spermatogonia begin dividing by *mitosis* and in so doing provide a continuous source of new cells for the production of spermatozoa. Some of the daughter cells from the spermatogonia are pushed inward towards the centre of the tubule, where they undergo a period of growth. These enlarged cells are called **primary spermatocytes**. Primary spermatocytes—like spermatogonia—are diploid, and undergo the first stage of *meiosis* to produce **secondary spermatocytes** (Fig. 10.6). These cells are haploid. The second meiotic division divides each secondary spermatocyte into two **spermatids**. Thus, four haploid spermatids are formed by meiosis from one diploid spermatogonium.

View an animation of spermatogenesis at http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter28/animation_spermatogenesis_quiz_1_.html

The final stage of spermatogenesis occurs when the spermatids mature into spermatozoa (sperm). During this time much of the cytoplasm of the cell is lost and a tail containing contractile material forms. The maturing spermatozoa are nourished during this stage by special cells that extend from the outer portion of the seminiferous tubule into the centre (Fig. 10.7). The entire process of spermatogenesis, from spermatogonium to spermatozoa, takes about 72 days and occurs continuously after puberty.

Human sperm are microscopic, being only about 0.06 mm long. Each is made up of a head, neck, middle piece and tail (Fig. 10.8). The tail is capable of violent swimming motions to propel the cell forward. The head consists almost entirely of the nuclear material, with a fluid-filled vesicle at its tip. In the fluid are enzymes, which are important if the sperm reaches an egg. The enzymes break down the layer of cells surrounding the egg so that fertilisation can occur. The middle piece contains mitochondria, where respiration takes place to provide the sperm with energy for

Table 10.1 Haploid and diploid defined

Term	Definition
Diploid	The number of chromosomes present in the body (or somatic) cells of an individual (2*n*)
Haploid	The number of chromosomes present in the gametes (*n*)

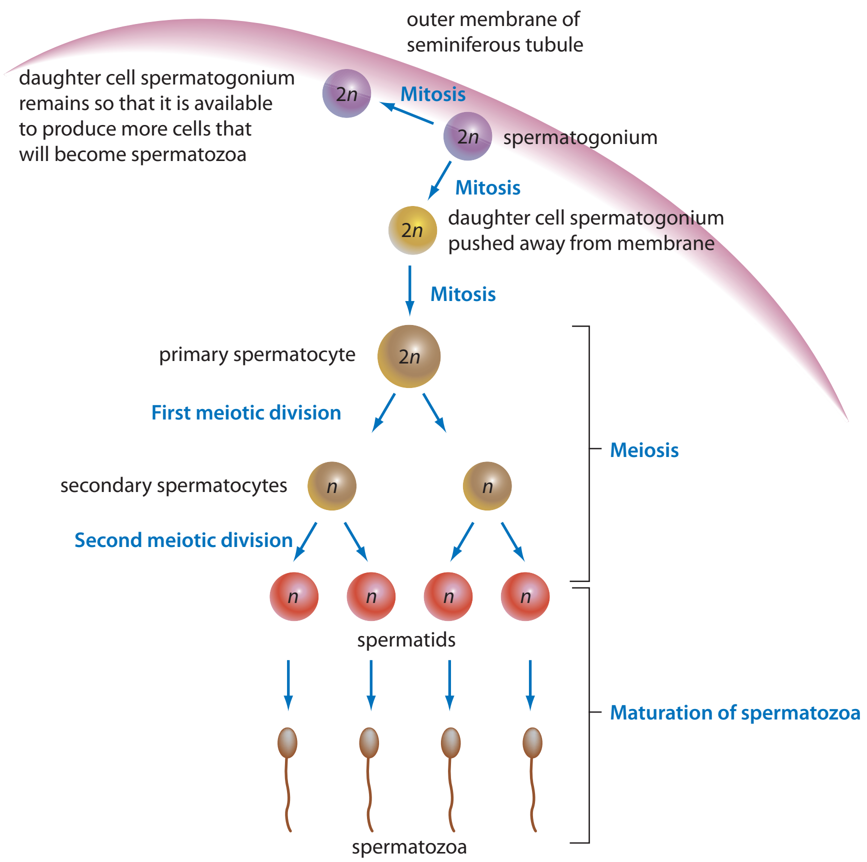


Figure 10.6 Spermatogenesis

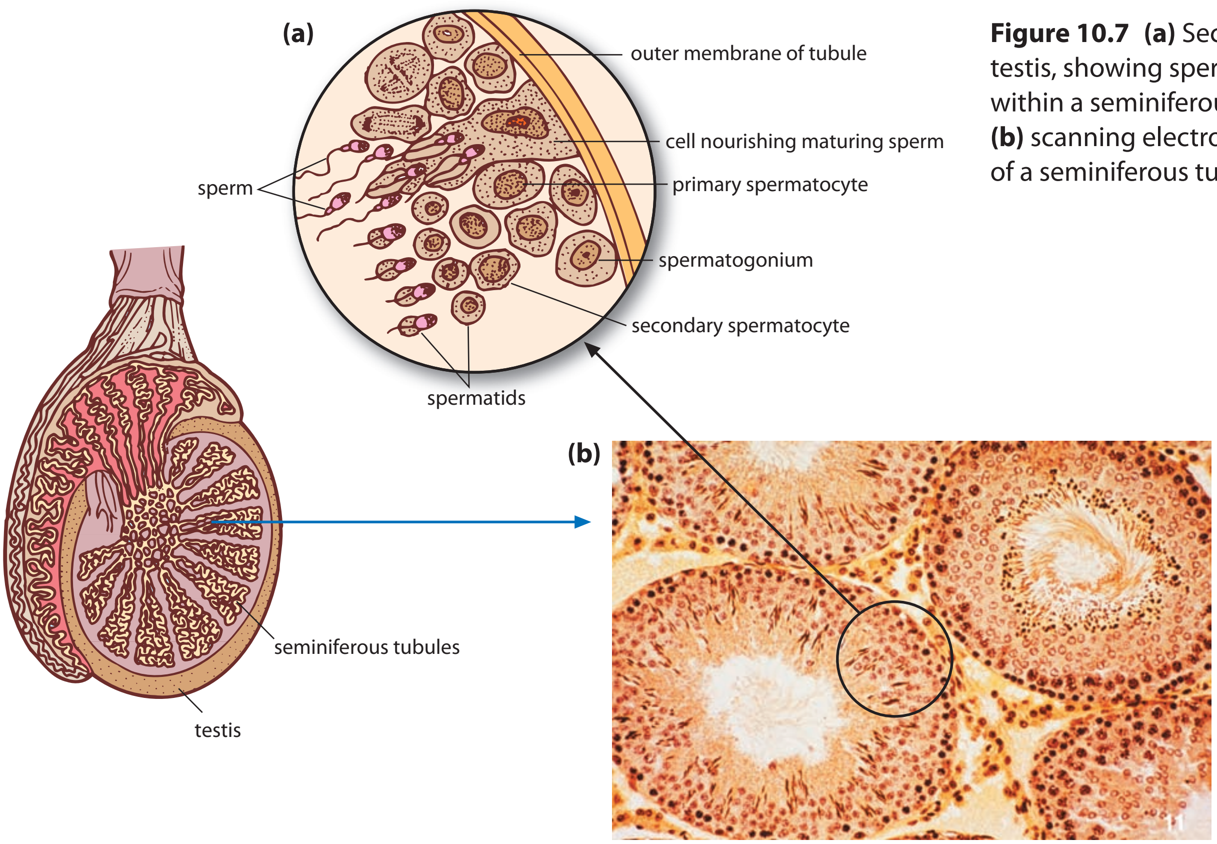


Figure 10.7 **(a)** Section of testis, showing spermatogenesis within a seminiferous tubule; **(b)** scanning electron micrograph of a seminiferous tubule

(a)

(b)

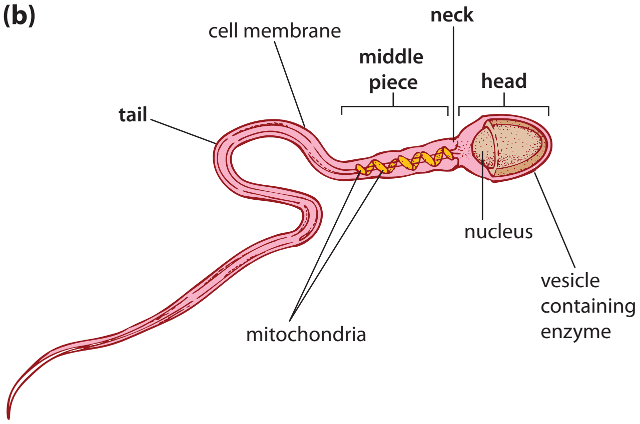


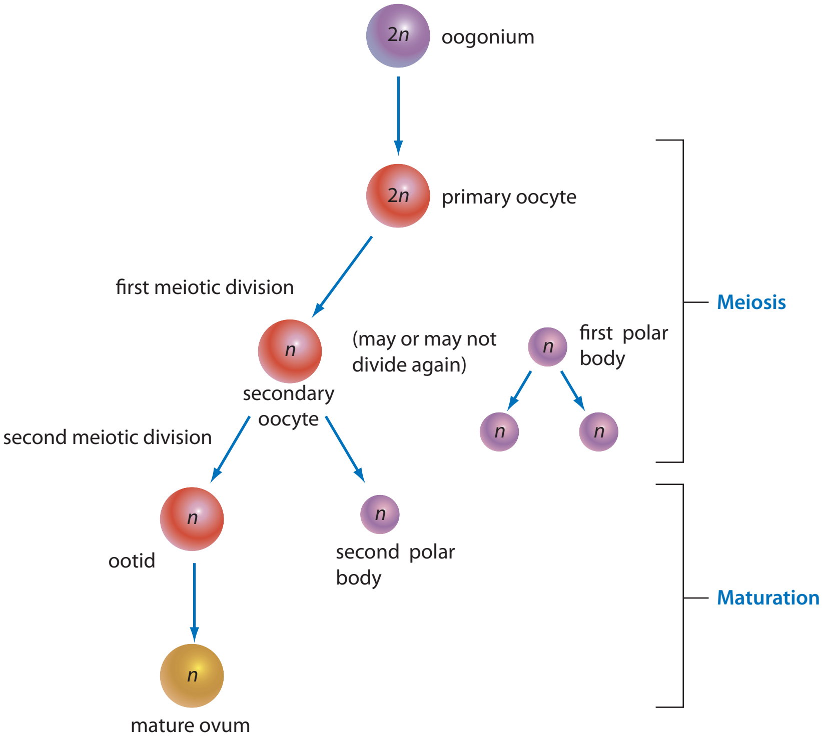
Figure 10.8 Spermatozoa: **(a)** scanning electron micrograph of human spermatozoa; **(b)** diagrammatic structure

movement (see Chapter 4). Around the mitochondria there is a thin layer of cytoplasm. Because there is so little cytoplasm, sperm have a short survival period and receive their nourishment from the semen in which they are suspended.

Oogenesis

The production of ova within the ovaries is called **oogenesis** (Fig. 10.9). With only a few exceptions, the events are essentially the same as spermatogenesis. Oogenesis also involves both meiosis and maturation.

Figure 10.9 Oogenesis



Before a female baby is born, millions of egg mother cells, or **oogonia**, develop in the ovaries. These cells are diploid and divide by mitosis to produce the cells that will eventually develop into ova. By the time of birth, each ovary contains several hundred thousand oogonia, which have undergone a growth phase to become **primary oocytes**. The primary oocytes begin prophase of the first meiotic division but the process stops at this point, so at birth they are still in the first prophase. Each of these primary oocytes is surrounded by a single layer of cells, forming a **primary follicle** (see Fig. 11.2 on page 147).

At puberty the process of follicle growth and maturation begins. As a follicle matures, the primary oocyte contained within it completes the stages of the first division of meiosis, producing two haploid cells. These cells are of unequal size. The larger one receives half the chromosomes but nearly all the cytoplasm, and is called a **secondary oocyte**. The smaller cell receives the other half of the chromosomes but very little cytoplasm, and is called the **first polar body**.

The secondary oocyte immediately commences the second division of meiosis but stops at metaphase. At this stage ovulation occurs: the follicle ruptures, expelling the secondary oocyte along with its polar body (Fig. 10.9). The secondary oocyte enters the uterine tube and, if penetrated by a spermatozoon, meiosis is quickly completed. The second division of meiosis also produces two cells of unequal size, both haploid. The larger one develops into an ovum, or mature egg. The smaller cell is the **second polar body**. The first polar body may also undergo a second meiotic division to produce two additional polar bodies. All polar bodies disintegrate. Thus, in the female, oogenesis produces a single ovum from each primary oocyte; while in the male, spermatogenesis produces four sperm from each primary spermatocyte.

Working scientifically

Activity 10.1 The male reproductive system

The reproductive systems of most mammals are similar in structure and function. Examination of the reproductive structures of the male rat will help you to understand the human reproductive system.

Your teacher may ask you to dissect a rat yourself, may demonstrate the dissection, or may refer you to a video or photographs for this activity.

You will need (if doing the dissection yourself)

A male rat; dissecting board; dissecting instruments; string; hand lens or magnifying glass; disposable gloves

What to do

Your teacher will demonstrate how to tie the rat firmly to the dissecting board.

1. Identify the external features of the rat that are associated with reproduction—the scrotum containing the testes, the penis and the opening of the urethra at the tip of the penis.
2. Follow your teacher's instructions to open one of the scrotal sacs to reveal the testis. This will involve cutting through the skin around the base of the penis and continuing the cut down through the middle of one of the scrotal sacs. Use a blunt probe to gently lift the testis clear of the scrotal sac.

3. You will now be able to identify the vas deferens and the epididymis, as well as the testis. Use a hand lens, or magnifying glass, to see the seminiferous tubules inside the testis and the tubules that make up the epididymis. (See Fig. 10.10.)

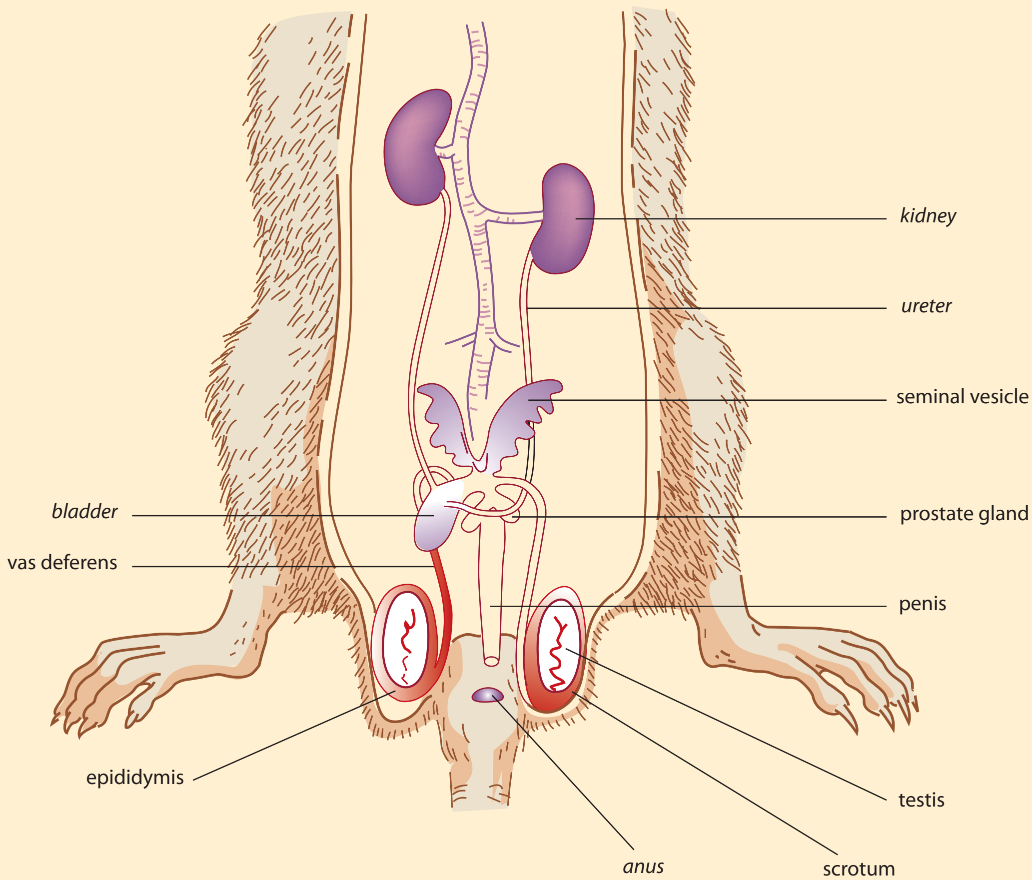


Figure 10.10 The male rat showing the reproductive system (the alimentary canal has been removed)

4. Clear the skin away from the rear portion of the belly of the rat. Tracing the vas deferens forward, cut through the wall of the rat's abdomen so that you can see where it enters the body cavity.
5. Identify the urinary bladder. If the rat is not preserved, this will appear as a semi-transparent bag containing clear fluid. Near the bladder the two vasa deferentia, one from each testis, join together to form the urethra.
6. Near the point where the vasa deferentia join you will be able to see two white, elongated glands with a crinkly appearance. These are the seminal vesicles. The prostate gland, although present in the rat, is very difficult to see.

Studying your observations

1. Draw a diagram of your dissection, labelling all the structures that you have identified.
2. On your diagram use arrows to show the path of the sperm and semen during ejaculation.
3. List any differences between the reproductive structures of a male rat and a male human.

Activity 10.2 The female reproductive system

As with the male, there is much to be learned by looking at the reproductive structures of the female rat. There are, however, a number of important differences between female rats and humans.

This activity can be done in conjunction with Activity 10.1 so that the male and female reproductive systems can be compared. As with that activity, your teacher may ask you to dissect a rat yourself, may demonstrate the dissection, or may refer you to a video or photographs for this activity.

You will need (if doing the dissection yourself)

A female rat; dissecting board; dissecting instruments; string; hand lens or magnifying glass; disposable gloves

What to do

Your teacher will demonstrate how to tie the rat firmly to the dissecting board.

1. Identify the external features of the rat that are associated with reproduction—the genital opening and the mammary glands. In addition, locate the urethra and the anus. Fig. 10.11 may help with your identification.

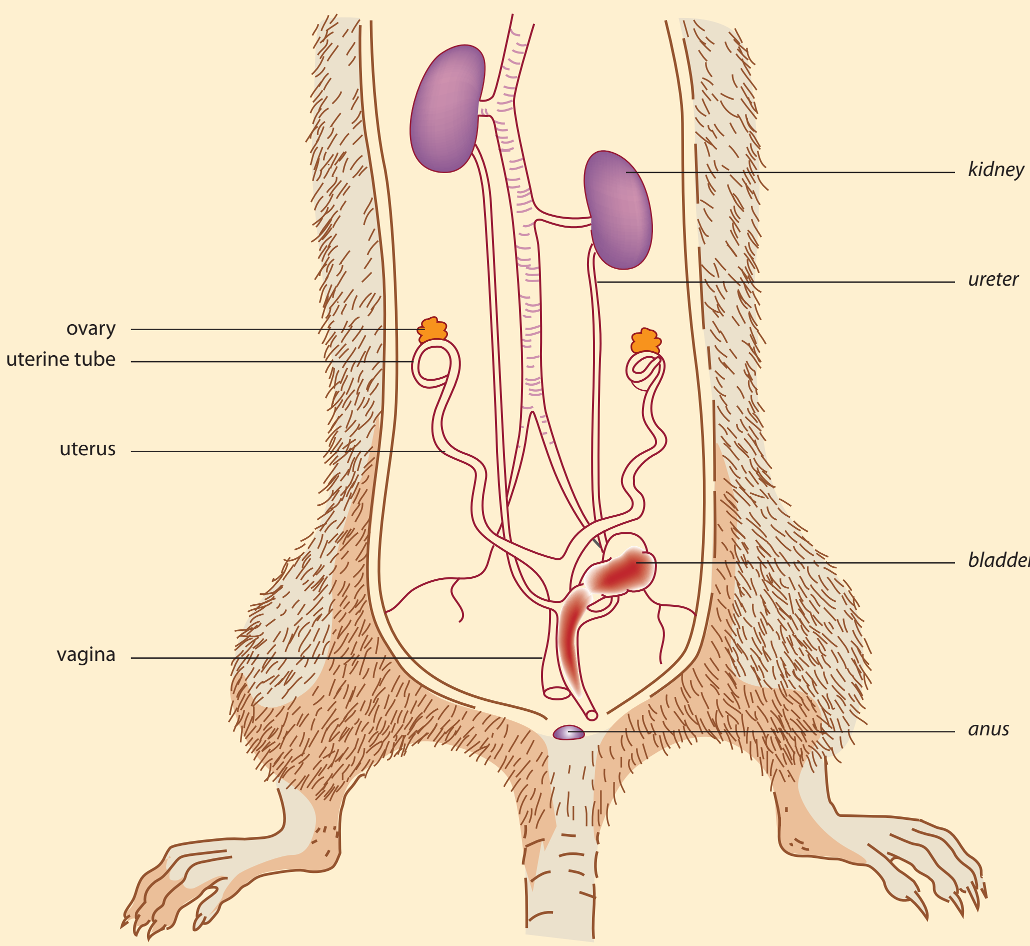


Figure 10.11 The female rat showing the reproductive system (the alimentary canal has been removed)

2. Count the number of nipples on the underside of the abdomen.
3. Follow your teacher's instructions to open the body cavity to reveal the reproductive organs. There may be some fat associated with these organs but do not try to remove it. You may just need to displace it so the reproductive organs can be easily observed.
4. Locate the vagina.
5. Locate the two uteri that extend from the vagina up each side of the body cavity.
6. At the anterior (front) end of each uterus is a very short uterine tube that you will find difficult to identify.
7. At the end of each uterus is a small, round, orange coloured structure. This is the ovary.
8. It may help to insert a blunt seeker into the vagina to trace the pathway sperm would take.
9. Identify the urinary bladder. If the rat is not preserved, this will appear as a semi-transparent bag containing clear fluid.

Studying your observations

1. Draw a diagram of your dissection, labelling all the structures that you have identified.
2. On your diagram use arrows to show the path an egg would take after ovulation.
3. Use a different coloured pencil to show the path that you think the sperm and semen would take after they have been deposited in the vagina.
4. List any differences between the reproductive structures of a female rat and a female human.
5. Of the differences you have noted, which ones are related to the rat having a number of offspring at one time?

REVIEW QUESTIONS

1. Draw a diagram of the male reproductive system and label the testis, scrotum, penis, vas deferens, seminiferous tubules, urethra, prostate gland, bulbourethral glands and seminal vesicles.
2. What are the primary sex organs of the male? What are their functions?
3. Explain the reason for the location of the testes in the scrotum.
4. Describe the internal structure of a testis, and include in your answer the location of sperm production.
5. List the glands that secrete seminal fluid and describe the function of each.
6. Draw a diagram of the female reproductive system and label the ovary, uterus, uterine tubes, fimbriae, cervix, vagina, endometrium, labia and clitoris.
7. **(a)** Outline the events that take place in spermatogenesis and oogenesis.
   (b) List the differences between the two processes.
8. **(a)** What are gametes?
   (b) Draw a sperm and identify the main parts.
9. **(a)** Describe the functions of the vagina.
   (b) List the parts of the vulva, and the functions of each.

APPLY YOUR KNOWLEDGE

1. Why is reproduction necessary for the human species? Is it necessary for all members of a species to reproduce? Give reasons for your answer.
2. Draw a diagram to illustrate the life cycle of the human species. Include in your diagram the gametes, zygote, embryo, child and adult. Indicate where fertilisation occurs, and show which parts of the cycle are haploid and which are diploid.
3. The location of the testes within a scrotum makes them vulnerable to damage. What advantages are there for the testes in such a location? Describe how the scrotum provides such advantages.
4. The seminiferous tubules are highly coiled, and if they were stretched out would be about 800 m in length. Why is such a great length required in the tubules? List as many advantages as you can to support your answer.
5. **(a)** It has been found that men who regularly wear tight-fitting underwear may produce fewer sperm and have reduced sperm quality. Suggest why this may be so.
   (b) If a man uses a laptop computer on his lap for long periods is it possible that his sperm production could be affected? Explain.