44 HUMAN REPRODUCTION AND DEVELOPMENT

Mind-Boggling Births

In December of 1998, Nkem Chukwu of Texas gave birth ahead of schedule to six girls and two boys—the first octuplets to survive premature birth (Figure 44.1).

The combined weight of the eight newborns was a bit more than 10 pounds (4.5 kilograms). Odera, the smallest, weighed less than 1 pound (20 grams). She died of heart and lung failure six days later. The others had to spend three months in the hospital before going home. Two required abdominal surgery.

Chukwu was having trouble getting pregnant, so she asked for hormone injections. The hormones caused many eggs in her ovaries to mature and be released at the same time. Chukwu chose not to reduce the number of embryos that became fertilized. The first newborn, thirteen weeks premature, was delivered naturally. Chukwu's doctor used drugs to stop labor, then surgically delivered the rest.

Over the past two decades, the incidence of multiple births has increased by almost 60 percent. The incidence of *higher order multiple births*—triplets or more—has quadrupled. What is going on?

A woman's fertility peaks in her mid-twenties. By age thirty-nine, the likelihood of natural conception declines by about half. Yet the number of first-time mothers who are more than forty years old doubled in the past decade—and many were assisted by fertility drugs, in vitro fertilization, and other reproductive interventions.

Fertility drugs are driving the increase in higher order multiple births, and they worry many doctors. Carrying more than one embryo increases the risk of miscarriage, premature delivery, or delivery by cesarean section. The newborn weight is lower and mortality rates are higher, compared to normal births. A woman carrying quintuplets runs twice the risk of miscarriage. The newborns are 90 percent more likely to develop postdelivery complications. The parents also face far more physical, emotional, and financial challenges.

The preceding chapter sketched out some principles that govern reproduction and development of animals in general. This chapter applies the principles to humans. Besides the core sections, it has many optional reference sections on topics that will directly and indirectly have a profound impact on your future. What you read may help you work through health-related problems and ethical issues concerning how we individually and collectively deal with human fertility.

So start with a premise we offered in the preceding chapter's introduction: *In nature, the function of sex is not recreational, it is the perpetuation of one's genes.* As in other mammals, human genes become packaged in gametes that start forming in a pair of gonads, or primary reproductive organs. We call them testes in males and ovaries in females. As you will see, these

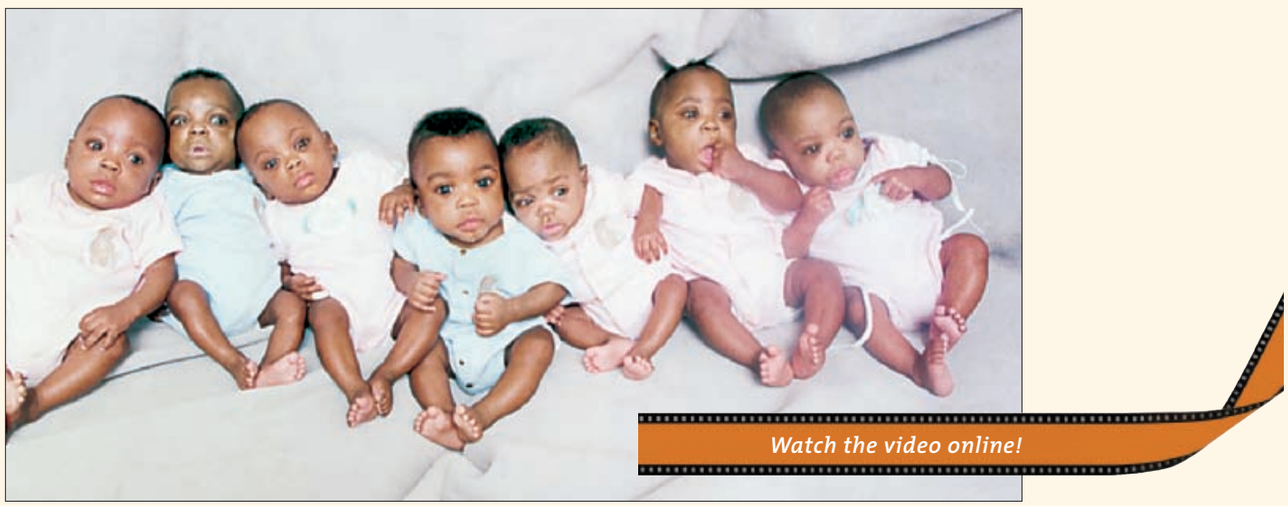
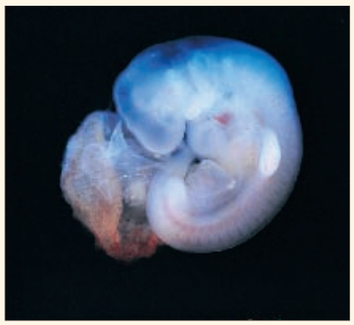


Figure 44.1 Testimony to the potency of fertility drugs—seven survivors of a set of octuplets. Besides manipulating so many other aspects of nature, humans are now manipulating their own reproduction. *Facing page*, a human embryo at an early stage of development.

IMPACTS, ISSUES



organs also secrete diverse sex hormones, which control reproductive functions as well as the development of the traits we associate with maleness and femaleness.

Remember also that early human embryos have neither male nor female traits (Section 12.5). Seven weeks after fertilization, however, a pair of ovaries start to develop in the embryos that did not inherit a Y chromosome, which carries the master gene for sex determination. Testes develop only in XY embryos. Ovaries and testes are fully formed at the time of birth. It takes about a decade for them to grow to their full size and become reproductively functional. And that is where our case study picks up.

How Would You Vote?

Fertility drugs induce multiple ovulations at the same time and increase the likelihood of high-risk multiple pregnancies. Should we restrict the use of such drugs to conditions that limit the number of embryos formed? See BiologyNow for details, then vote online.

Key Concepts

HUMAN REPRODUCTIVE SYSTEMS

The primary reproductive organs, or gonads, are sperm-producing testes in human males and oocyte-producing ovaries in females. In response to the hypothalamus and the pituitary gland, gonads release sex hormones that guide reproductive functions and the development of secondary sexual traits. Sections 44.1–44.3

THE MENSTRUAL CYCLE

From puberty onward, human females are fertile on a cyclic basis. Each month during the reproductive years, an egg is released from an ovary, and the lining of the uterus is primed for possible pregnancy. Sections 44.4, 44.5

REGARDING SEX AND PREGNANCY

Sexual intercourse leads to pregnancy, which human interventions attempt to deflect or promote. Pathogens opportunistically exploit human sexual behavior as a means of transmission to new hosts. Sections 44.6–44.8

HUMAN EMBRYONIC DEVELOPMENT

Embryonic development starts with gamete formation and proceeds through fertilization, followed by implantation of the blastocyst in the uterine lining. The embryo develops by way of cleavage, gastrulation, organ formation, and growth and tissue specialization. It forms vital connections with the mother by way of a placenta. Sections 44.9–44.13

FROM BIRTH ONWARD

Each generation starts with the birth of a new individual and extends through the reproductive years to a time of gradual aging and death. The motivation to engage in sex during the life cycle invites reflection on the gift of human life and on its consequences when multiplied by the many billions of humans now on Earth. Sections 44.14, 44.15

Links to Earlier Concepts

This chapter builds on principles of animal reproduction and development (Chapter 43). It draws on your understanding of nuclear and cytoplasmic divisions (Sections 9.3, 9.4, 10.3) and gamete formation (10.5). You may wish to review how reproductive organs form in embryos (12.5). You will revisit master genes (15.2, 17.8) and consider some effects of diet (41.8), psychoactive drug use (34.13), and smoking (40.8). You will reconsider some endocrine controls (36.3, 36.8). You will be invited to reflect on sexual behavior in medical terms (21.4, 22.2, 39.10) and from an evolutionary perspective (20.4 and the Chapter 10 introduction).

44.1 Reproductive System of Human Males

LINKS TO SECTIONS 2.7, 12.5, 33.10

A human male's genes become packaged in sperm. These male gametes form in a pair of gonads that also secrete sex hormones.

WHEN MALE GONADS FORM AND BECOME ACTIVE

Again, male gonads are called **testes** (singular, testis). Testes are the primary components of a reproductive system that also includes accessory organs, glands, and ducts (Table 44.1).

Earlier, Figure 12.8 showed how the testes start to form on the wall of an XY embryo's abdominal cavity. Before birth, they descend into the scrotum, which is a pouch of loose skin suspended below the pelvic girdle (Figure 44.2). Muscle contractions can draw the pouch closer to the main body mass, and muscle relaxation can lower it. The reflexive adjustments help keep the internal temperature suitable for sperm formation.

Packed within each testis are many small, highly coiled tubes called seminiferous tubules. Section 44.2 explains how sperm cells form and start maturing in these tubules in hormone-guided ways.

Sperm production and the emergence of secondary sexual traits start at **puberty**. This stage of postnatal development usually begins in boys between ages twelve and sixteen. Signs that it is under way include enlarging testes, growth spurts, a deepening voice, and the growth of more hair on the face, chest, armpits, and around the base of the scrotum and penis. Also, the amount and distribution of body fat and skeletal muscles undergo modification. Such secondary sexual traits do not play a direct role in reproduction.

STRUCTURE AND FUNCTION OF THE MALE REPRODUCTIVE SYSTEM

Mammalian sperm travel from testes through a series of ducts that lead into the urethra (Figure 44.3). They are not quite mature when they enter a pair of coiled, long ducts. Each duct is an epididymis, and secretions from glandular cells in its wall trigger the events that put the finishing touches on the maturing sperm cells. The last region of an epididymis stores mature sperm. During a male's reproductive years, about 100 million sperm mature every day. Unused ones are resorbed or excreted in urine.

In a sexually aroused male, smooth muscle in the walls of his reproductive organs contracts and propels mature sperm into a pair of thick-walled ducts called the vasa deferentia (singular, vas deferens). The sperm are propelled onward, through a pair of ejaculatory ducts, then into and finally out from the urethra. This last tubular duct threads vertically through the penis, the male sex organ, and opens at its tip. The urethra, remember, also functions in urinary excretion.

Sperm traveling to the urethra mix with glandular secretions and form semen, a thickened fluid that gets expelled from the penis during sexual activity. Paired seminal vesicles secrete fructose. Sperm use this sugar as an energy source. Prostaglandins secreted from the prostate gland and, to a lesser extent, seminal vesicles enter the mix. These signaling molecules may induce muscle contractions in the female reproductive tract, which may help sperm reach an egg. They also might help the sperm slip past the female's immune system, which is on guard against anything foreign.

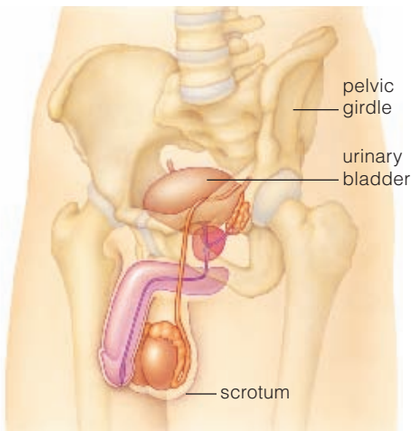
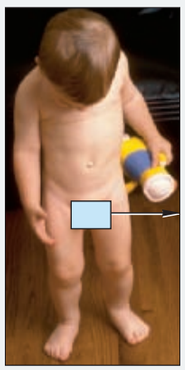


Figure 44.2 Position of the human male reproductive system relative to the pelvic girdle and urinary bladder.

Table 44.1 Organs and Accessory Components of the Human Male Reproductive System



Reproductive Organs	
Testis (2)	Sperm, sex hormone production
Epididymis (2)	Sperm maturation site and subsequent storage
Vas deferens (2)	Rapid transport of sperm
Ejaculatory duct (2)	Conduction of sperm to penis
Penis	Organ of sexual intercourse
Accessory Glands	
Seminal vesicle (2)	Secretion of large part of semen
Prostate gland	Secretion of part of semen
Bulbourethral gland (2)	Production of mucus that functions in lubrication

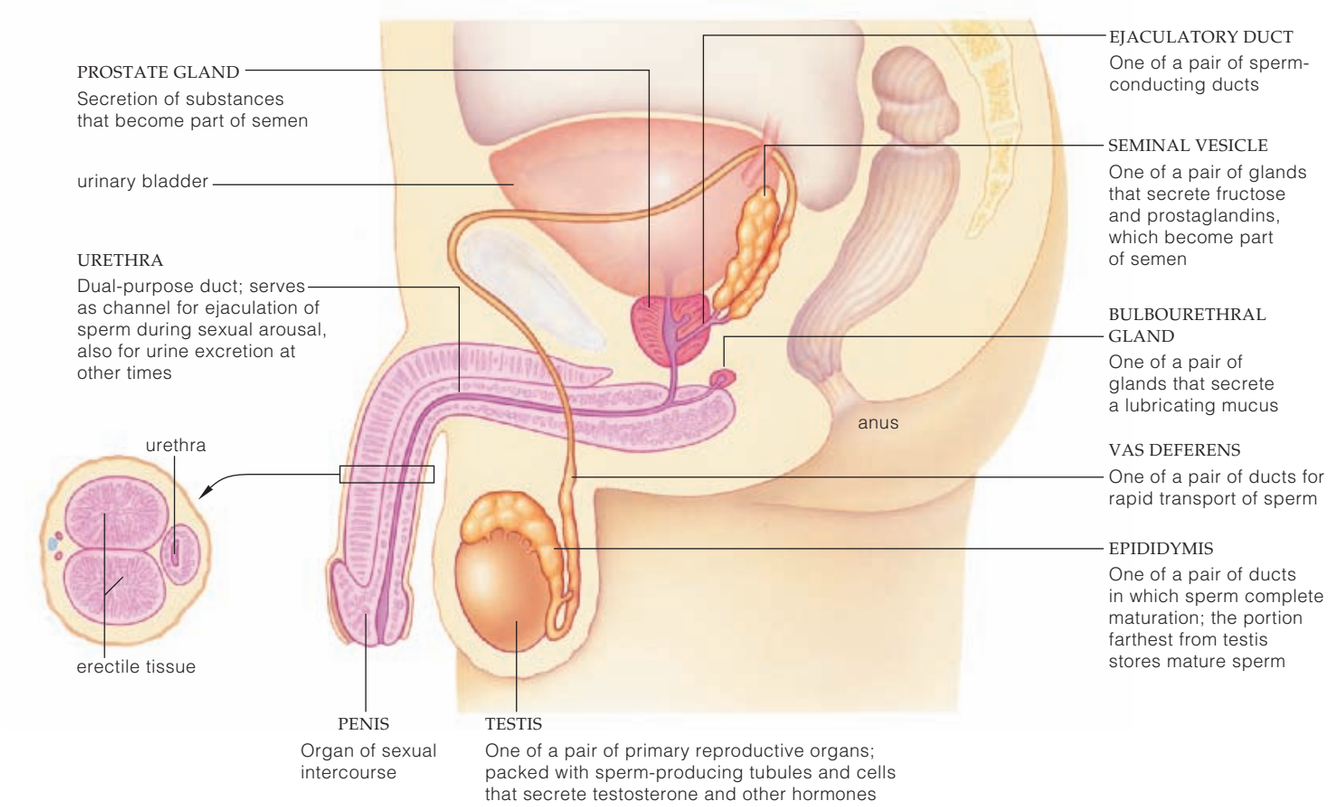


Figure 44.3 ***Animated!*** Components of the human male reproductive system and their functions.

Prostate gland secretions may also help buffer the acidic conditions in the female reproductive tract. The pH of vaginal fluid is about 3.5–4.0, but sperm swim more efficiently when the pH is 6.0. Finally, a pair of bulbourethral glands secrete mucus-rich fluid into the urethra during sexual arousal.

CANCERS OF THE PROSTATE AND TESTES

Prostate cancer is a leading cause of death among men, surpassed only by lung cancers. In 2004, more than 220,000 males were diagnosed in the United States, and about 30,000 died. In the same year, there were close to 9,000 cases of *testicular cancer*. In early stages, both cancers are painless. They might spread silently into lymph nodes of the abdomen, chest, neck, then lungs. If the cancer metastasizes, prospects are not good.

It is often said that if you examine the prostate of all the men who died of something else, you will find many who had prostate cancer and never knew it. But this might trivialize the risk. Some prostate cancers grow slowly, but other kinds now being detected in younger men often grow rapidly. Also bear in mind, heredity is a factor in prostate cancer. Other factors are advancing age, high-fat diets, exposure to toxic metals, tobacco smoking, and sedentary life-styles.

Doctors may detect prostate cancer by blood tests for increases in prostate-specific antigen (PSA) and by physical examinations. Adult males should examine their testes monthly—after a warm shower or bath—to check for enlargement, hardening, or new lumps. Treatment of testicular cancer has a high success rate; it is the easiest cancer to cure, provided it is caught before it spreads to other parts of the body.

Human males have a pair of testes. These gonads (primary reproductive organs) produce sperm. They also produce and secrete testosterone and other sex hormones.

In a duct leading out from each testis (an epidymis), sperm mature and are stored. Semen is a mix of mature sperm and noncellular secretions from a few accessory glands. During sexual arousal, it is propelled through a series of ducts. It is ejaculated from the last duct, the urethra.

44.2 Sperm Formation

LINKS TO SECTIONS 9.1, 10.5, 36.3

A type of germ cell called a spermatogonium (plural, spermatogonia) gives rise to sperm in human males. Signaling pathways that connect the hypothalamus, pituitary gland, and testes control sperm formation.

FROM GERM CELLS TO MATURE SPERM

A testis is not even as big as a golfball, yet it contains two or three coiled tubules that would stretch out 125 meters, end to end. Hundreds of wedge-shaped lobes partition the interior (Figure 44.4). Pressed against the inner wall of each tubule are many spermatogonia. These undifferentiated diploid cells divide again and again, and their newest descendants force older ones away from the wall and into the interior of the tubule. The displaced, older cells are primary spermatocytes. They receive nutrients and signals from Sertoli cells, a type of supporting cell in the seminiferous tubules.

Primary spermatocytes enter meiosis while they are being displaced—but their cytoplasm does not quite divide. Thin cytoplasmic bridges keep them connected during the nuclear divisions (Figure 44.4*c*). Molecules and ions diffuse freely across the bridges and induce all cells of each generation to mature at the same time.

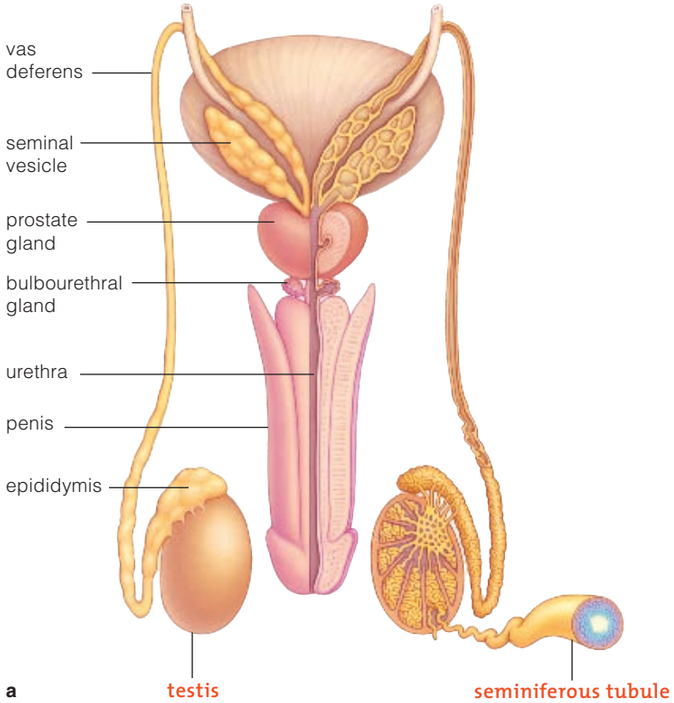
At the end of meiosis I, each cell that has formed is a secondary spermatocyte (Figure 44.4*c*). It is haploid, with chromosomes that are still duplicated. (Here you may wish to review Section 10.5.) Sister chromatids of each chromosome move apart during meiosis II, after which spermatids form. These haploid daughter cells have unduplicated chromosomes. While they mature into sperm, the cytoplasmic bridges are broken.

A mature sperm is a flagellated cell. Its flagellum, or tail, has a core of microtubules, and the midpiece above it contains mitochondria that supply energy for the tail's whiplike motions (Figure 44.4*d*). The head is packed with DNA and has an acrosome, an enzyme-containing cap. The enzymes help a sperm penetrate an oocyte by partly digesting away its outer layer.

Sperm formation takes about 100 days, from start to finish. An adult male normally produces sperm on an ongoing basis, so that many millions of cells are in different stages of development on any given day.

THE SIGNALING PATHWAYS

Four hormones—testosterone, LH, FSH, and GnRH—are part of the signaling pathways that control sperm formation. **Testosterone**, a steroid hormone, governs the structure and function of the male reproductive tract as well as the formation of sperm. It induces the development of male secondary sexual traits. It also promotes sexual and aggressive behavior. Leydig cells inside the testes secrete testosterone.



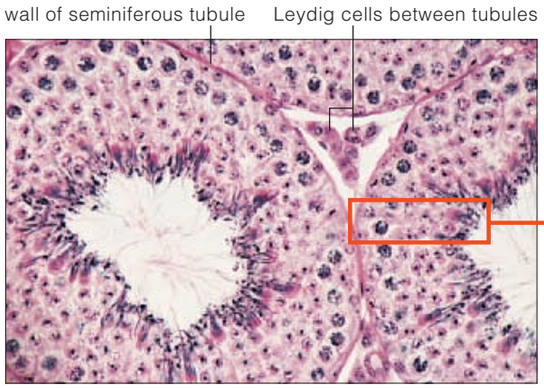


Figure 44.4 ***Animated!*** (**a**) Male reproductive tract, posterior view.

Sperm formation. (**b**) Light micrograph of cells in three adjacent seminiferous tubules, cross-section. Leydig cells occupy tissue spaces between tubules. (**c**) How sperm form, beginning with a diploid germ cell. (**d**) Structure of a mature sperm, the male gamete.

As you read in Section 36.3, the anterior lobe of the pituitary gland makes and secretes **LH** and **FSH**. (The names are abbreviations for *L*uteinizing *H*ormone and *F*ollicle-*S*timulating *H*ormone, which actually refer to their effects in ovaries, which were discovered first. It later became clear that males have them, too.)

The hypothalamus controls the secretion of all three hormones (Figure 44.5). It secretes **GnRH** when the blood levels of testosterone and other factors are low. This releasing hormone makes the anterior lobe step up its LH and FSH secretions. In turn, LH stimulates Leydig cells to secrete testosterone, which helps sperm form and mature. At puberty, the FSH binds to Sertoli cells and jump-starts sperm formation.

Figure 44.5 also shows how feedback loops to the hypothalamus can slow down testosterone secretion and sperm formation. An elevated testosterone level in blood slows the release of GnRH. When the sperm count is high, Sertoli cells release inhibin. This protein hormone induces the hypothalamus and the pituitary to decrease GnRH and FSH secretion.

Sperm formation depends on the hormones LH, FSH, and testosterone. Negative feedback loops from the testes to the hypothalamus and pituitary gland control their secretion.

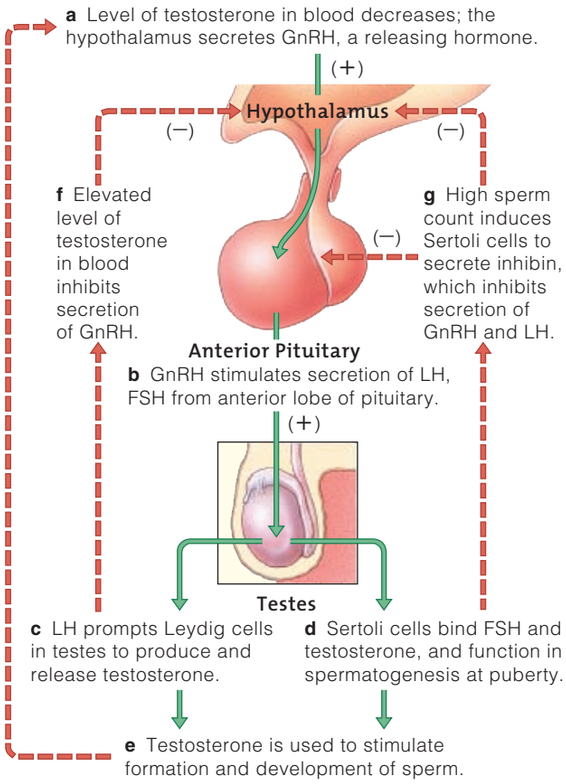
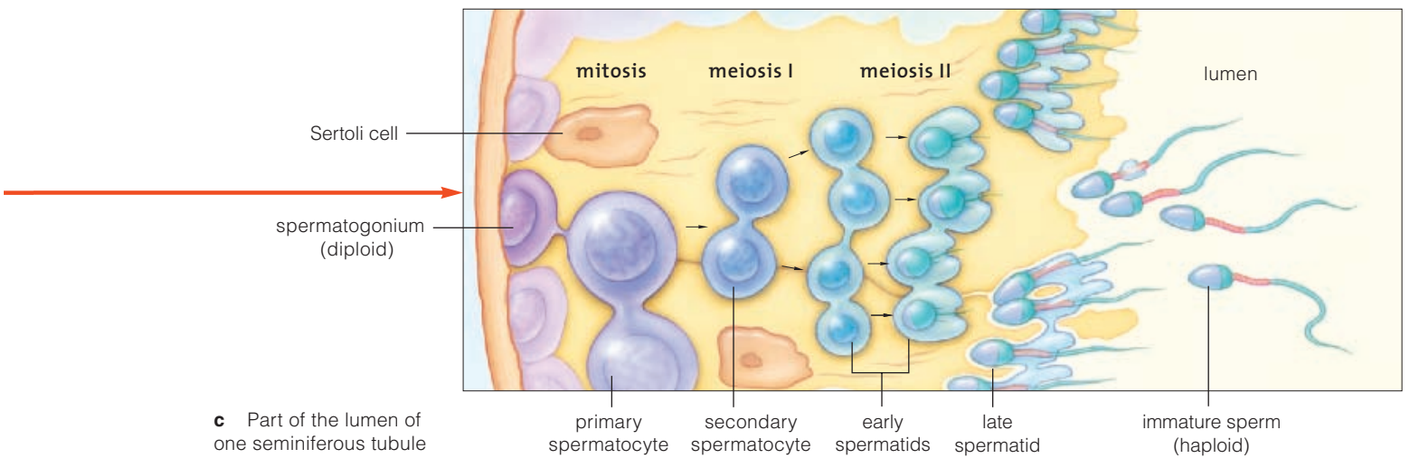
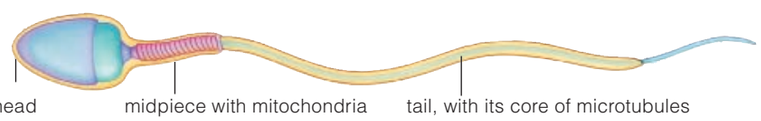


Figure 44.5 Signaling pathways in the formation and development of sperm. Negative feedback loops extend from the paired testes to the hypothalamus and the anterior lobe of the pituitary gland.



c Part of the lumen of one seminiferous tubule



d Sketch of a mature human sperm. The head consists of DNA surrounded by the acrosome.

44.3 Reproductive System of Human Females

LINKS TO SECTIONS 12.9, 36.3, 43.3

The reproductive system of human females functions in the production of gametes and sex hormones. It also has a chamber in which a new, developing individual is protected and nourished until birth.

COMPONENTS OF THE SYSTEM

Figures 44.6 and 44.7 show the reproductive system of a human female, and Table 44.2 lists their functions. The gonads are a pair of **ovaries** that produce oocytes (immature eggs) and secrete sex hormones. An ovary releases oocytes on a cyclic basis to one of a pair of oviducts, also called Fallopian tubes. Oviducts lead to the **uterus**, a hollow, pear-shaped organ. Fertilization usually occurs and a blastocyst forms in an oviduct (Section 43.3). But the blastocyst tumbles on into the uterus, where embryonic development is completed.

A thick layer of smooth muscle, the myometrium, makes up most of the uterine wall. The uterine lining, or **endometrium**, consists of connective tissues, blood vessels, and glands. The cervix, or the narrowed-down part of the uterus, connects with a muscular tube, the vagina. Mucus-secreting epithelium lines the vagina, which extends from the cervix to the body's surface. The vagina receives sperm from the male and serves as part of the birth canal.

At the body's surface are genital organs of sexual stimulation. Outermost are the labia majora, a pair of skin folds padded with adipose tissue. They enclose the labia minora, a pair of smaller folds having many blood vessels but no adipose tissue. These folds partly enclose the clitoris, a female sex organ derived from the same embryonic tissue as the male penis. Like the penis, the clitoris also has an abundance of sensory receptors and is very sensitive to sexual stimulation. The urethra opens at the body surface about midway between the vaginal opening and the clitoris.

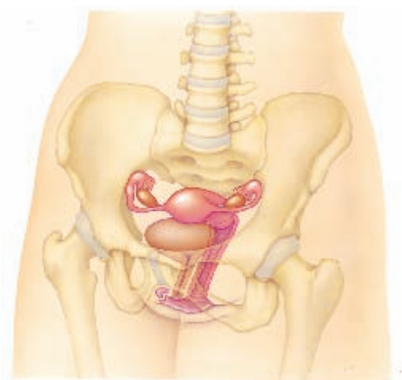


Figure 44.6 Location of the human female reproductive system relative to the pelvic girdle and urinary bladder.

OVERVIEW OF THE MENSTRUAL CYCLE

Females of most mammalian species follow an *estrous* cycle, meaning they are fertile and "in heat" (sexually receptive to males) at only certain times in the cycle. Females of humans and some other primates follow a **menstrual cycle**. They are fertile intermittently, on a cyclic basis. Their fertile periods are not synchronized with sexual receptivity. Even though they can become pregnant at only certain times in the cycle, they may be receptive to sex at any time.

The next section explains this cycle, but here is a brief overview (Table 44.3). An oocyte matures inside an ovary and is released from it, and the endometrium is primed for pregnancy. When fertilization does not occur, blood and bits of the uterine lining flow from the vagina. The flow means "there's no embryo at this time," and marks the start of a new cycle.

Table 44.2 Organs of the Human Female Reproductive Tract

Ovaries	Oocyte production and maturation, sex hormone production
Oviducts	Ducts for conducting oocyte from ovary to uterus; fertilization normally occurs here
Uterus	Chamber in which new individual develops
Cervix	Secretion of mucus that enhances sperm movement into uterus and (after fertilization) reduces embryo's risk of bacterial infection
Vagina	Organ of sexual intercourse; birth canal

Table 44.3 Events of a Menstrual Cycle Lasting Twenty-Eight Days

Phase	Events	Days of Cycle
Follicular phase	Menstruation; endometrium breaks down	1–5
	Follicle matures in ovary; endometrium rebuilds	6–13
Ovulation	Oocyte released from ovary	14
Luteal phase	Corpus luteum forms, secretes progesterone; the endometrium thickens and develops	15–28

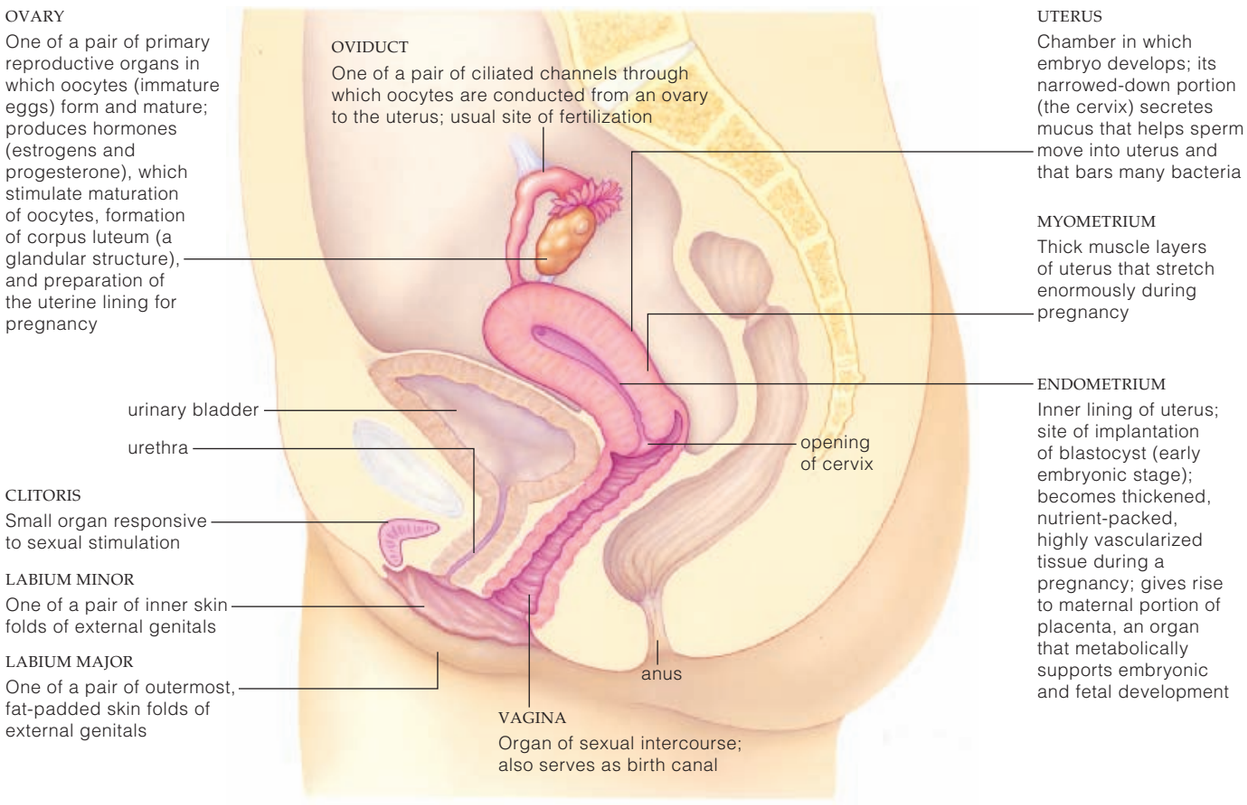


Figure 44.7 ***Animated!*** Components of the human female reproductive system and their functions.

In the cycle's *follicular* phase, menstruation occurs, the uterine lining breaks down and starts rebuilding, and an oocyte starts maturing. At **ovulation**, which is the second phase, the ovary releases an oocyte. In the *luteal* phase, a glandular structure, the **corpus luteum**, forms in an ovary. Its hormonal secretions cause the endometrium to thicken in preparation for pregnancy.

Females now enter puberty between ages ten and sixteen. Pubic hair forms, fat is deposited in breasts and around the hips, and menstrual cycles start. Each cycle lasts for twenty-eight days, on average, but it is longer or shorter for some females. Cycles usually continue until the late forties or early fifties, when sex hormone secretions start to dwindle. The decline in secretions correlates with the onset of *menopause*, the twilight of a female's reproductive capacity.

The oocytes released late in a woman's life are more vulnerable to abnormal changes in the structure and number of chromosomes when meiosis resumes inside them. Down syndrome, explained in Section 12.9, is a prime example of the potential risks.

Ten million women in the United States may suffer *endometriosis*, a disorder caused by endometrial tissue that grew outside of the uterus. Hormones still act on cells in the mislocated tissue, so menstruation, sex, and urination are painful. Scar tissue forms on ovaries or oviducts and may cause infertility. Menstrual flow that backs up through oviducts and spills into the pelvic cavity may cause the disorder. Or it may be that a few embryonic cells ended up in the wrong tissue before birth and were stimulated to grow at puberty.

Ovaries, the primary reproductive organ of human females, produce immature eggs and sex hormones. Endometrium lines the uterus, a chamber in which embryos develop.

Estrogens and progesterone guide the cyclic growth and release of oocytes from the ovary as well as the breakdown and rebuilding of the endometrium, which depends on whether pregnancy occurs. These are the key events of menstrual cycles, which start at puberty.

44.4 Preparations for Pregnancy

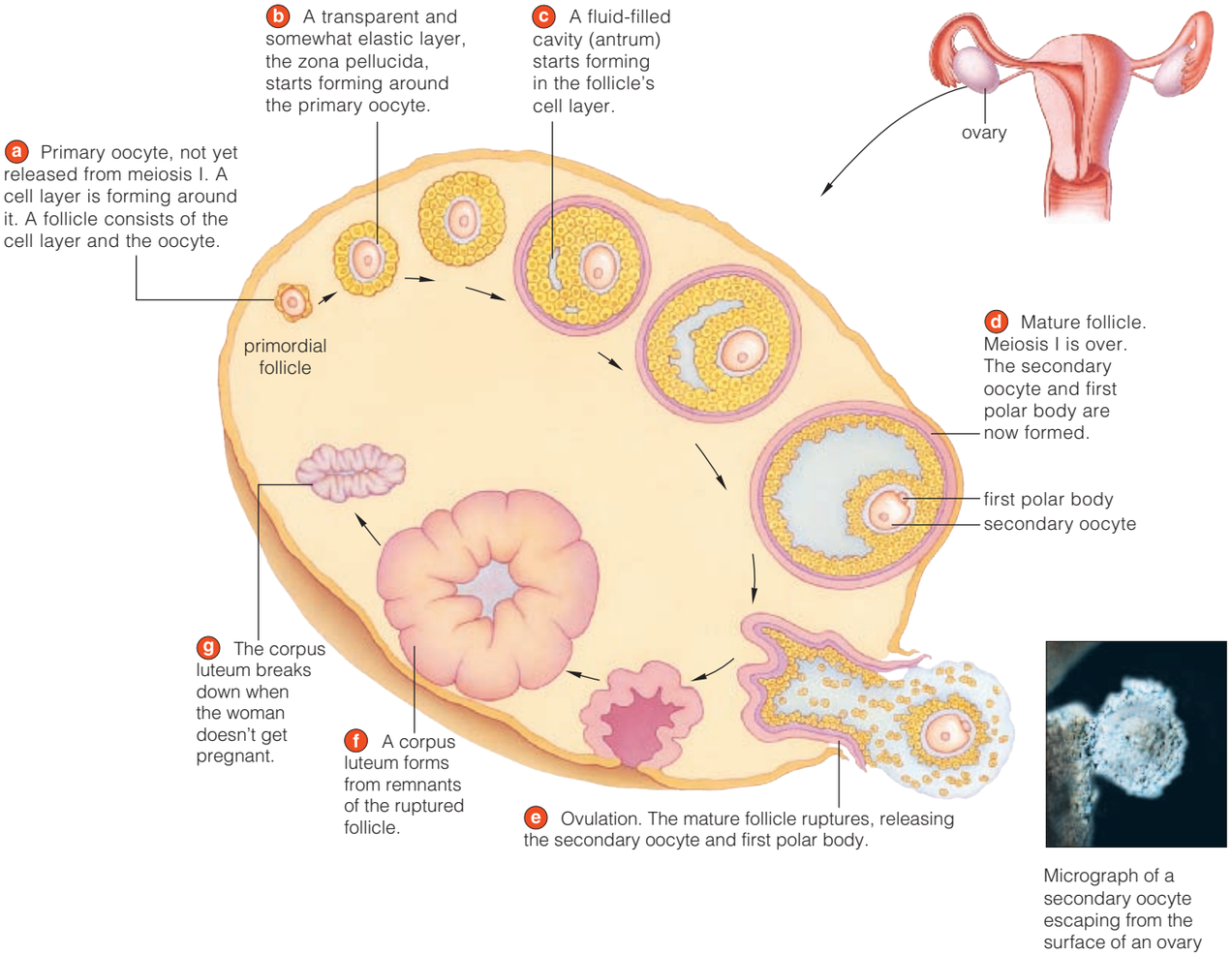
LINKS TO SECTIONS 12.5, 36.3

Even before a human female is born, germ cells in her two ovaries enter meiosis, but the nuclear division process hits a wall in prophase I. Each ovarian cell that is arrested in prophase I is a ***primary oocyte****. The only way it will finish meiosis is if a sperm fertilizes it much later in time.*

FROM PRIMARY TO SECONDARY OOCYTES

Every normal baby girl has about 2 million primary oocytes in her ovaries. By the time she is seven years old, she has about 300,000; her body has resorbed the rest. Beginning with her first menstrual cycle, meiosis resumes in one primary oocyte at a time. The primary oocyte, together with a layer of cells surrounds and nourishes it, is a primary follicle. Hormones stimulate the primary follicle to grow in size (Figure 44.8).

Eight to ten hours before being released from the ovary, the primary oocyte completes meiosis I, but its cytoplasm divides unevenly. One of the two haploid daughter cells, a **secondary oocyte**, receives most of the cytoplasm. The other cell is the first of three **polar bodies** that form by way of meiosis. It will degenerate later in the cycle. About 400 to 500 secondary oocytes will form during the reproductive years.



Micrograph of a secondary oocyte escaping from the surface of an ovary

Figure 44.8 ***Animated!*** Cyclic events in a human ovary, cross-section. The follicle does not "move around" as in this diagram, which simply shows the *sequence* of events. All of these structures form in the same place during one menstrual cycle. In the cycle's first phase, a follicle grows and matures. At ovulation, the second phase, the mature follicle ruptures and releases a secondary oocyte. In the third phase, a corpus luteum forms from the follicle's remnants.

THE SIGNALING PATHWAYS

Four kinds of hormones—FSH, LH, estrogens, and progesterones—take part in signaling pathways that control the menstrual cycle. These pathways involve feedback loops from the ovaries to the hypothalamus and the anterior pituitary gland (Figure 44.9).

Estrogens are sex hormones. Remember, they help reproductive organs form in female embryos and they maintain secondary sexual traits (Section 12.5). Also, together with **progesterone**, they stimulate oocytes to mature and prime the endometrium for pregnancy.

Just as it does in males, the hypothalamus secretes GnRH, a releasing hormone that makes the anterior pituitary step up LH and FSH secretions. In females, however, these hormones stimulate the growth of the primary oocyte and the formation of more and more cells around it. Glycoprotein molecules are deposited beneath these cells. They form a noncellular layer that is called the zona pellucida (Figure 44.8*b*).

FSH and LH collect in fluid in the follicle and prod its cells to secrete estrogens, so the levels of estrogens in blood increase. About halfway through the cycle, the pituitary responds to the increases. It secretes LH in a brief pulse. The follicle swells in response, and its wall weakens and ruptures. Fluid—and the secondary oocyte—are released. *The midcycle surge of LH triggers ovulation, the release of a secondary oocyte from the ovary.*

Estrogens released early in the cycle also stimulate growth of the endometrium and its glands, which sets the stage for pregnancy. Before the midcycle surge of LH, the follicle cells were busy secreting progesterone and estrogens. Blood vessels grew fast in the thickened endometrium. At ovulation, estrogens prompted cells of the cervical canal to release a thin, clear mucus—an ideal medium for sperm to swim through.

The midcycle LH surge that brings about ovulation also stimulates cells in the ruptured follicle to form a corpus luteum. Progesterone and estrogens secreted by this structure cause the endometrium to thicken, in preparation for pregnancy.

WHAT IF NO PREGNANCY?

All the while, the hypothalamus has been preventing other follicles in the ovary from maturing, because it has been slowing FSH secretion. When a blastocyst does not burrow into the endometrium, however, the corpus luteum lasts no more than twelve days or so. During the last days of the menstrual cycle, it secretes a prostaglandin. This local signaling molecule induces cells of the corpus luteum to self-destruct.

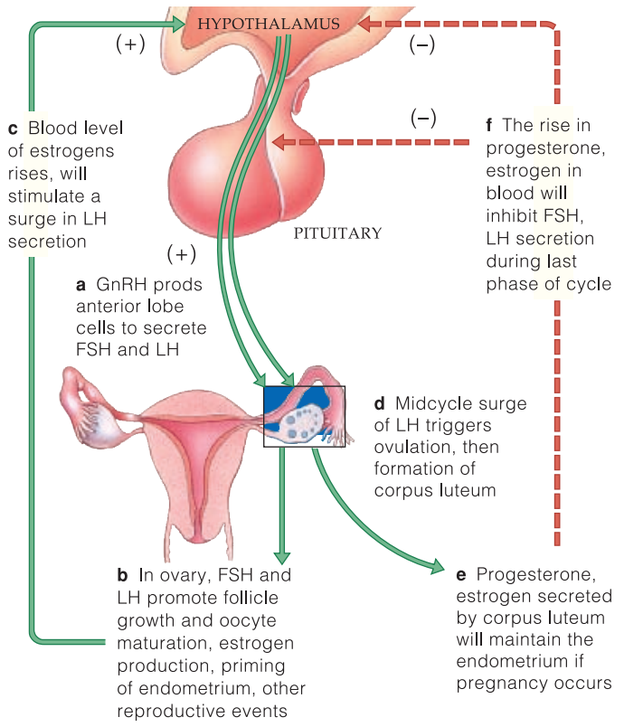


Figure 44.9 Signaling pathways that control the menstrual cycle. A positive feedback loop from an ovary to the hypothalamus (*green*) triggers ovulation. After a secondary oocyte escapes, a negative feedback loop from the ovary to the hypothalamus and pituitary gland (*red*) inhibit hormone secretions and keep another follicle from maturing until the cycle is over.

Without the corpus luteum, levels of progesterone and estrogen decline fast, and the endometrium starts to break down. Deprived of oxygen and nutrients, its blood vessels constrict and tissues die. Blood escapes as weakened capillaries rupture. Blood and sloughed endometrial tissues form a menstrual flow that lasts three to six days. Afterward, rising levels of estrogens invite the repair and growth of the endometrium.

During a menstrual cycle, FSH and LH stimulate growth of an ovarian follicle. The primary oocyte undergoes the first meiotic cell division in the oocyte. The outcome is a secondary oocyte and the first polar body.

A midcycle surge of LH triggers ovulation—the release of the secondary oocyte and the polar body from the ovary.

Feedback loops to the hypothalamus and pituitary from the ovaries and, later, the corpus luteum control cyclic changes in the function of the ovary and in the structure of the uterine lining.

44.5 Visual Summary of the Menstrual Cycle

By now, you may have come to the conclusion that the human menstrual cycle is not a simple tune on a biological banjo. It's more like a full-blown hormonal symphony! Before continuing with your reading, take a moment to review Figure 44.10. It correlates cyclic changes in the ovary and the uterus with changing concentrations of hormones that trigger the events of each menstrual cycle.

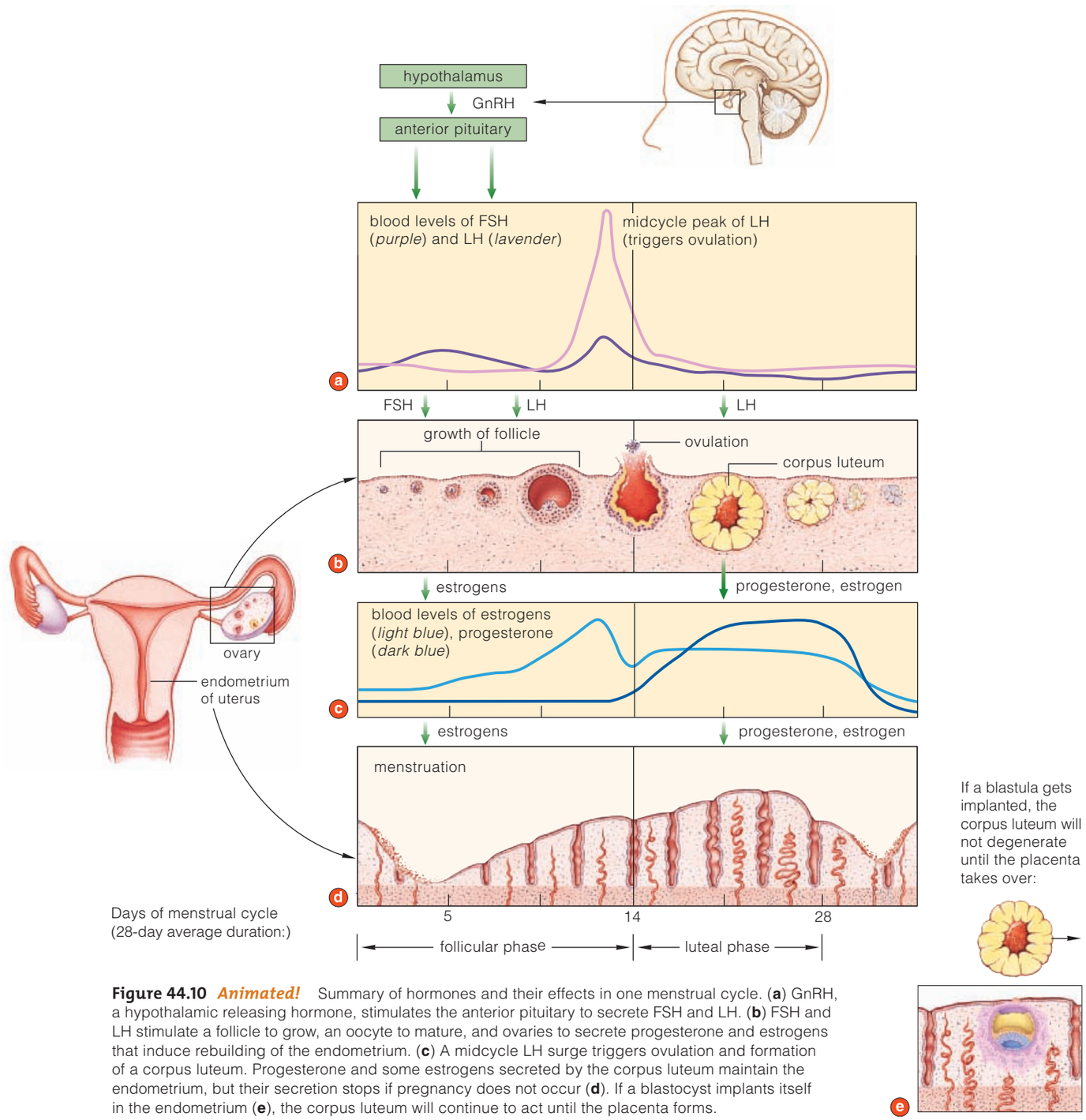


Figure 44.10 ***Animated!*** Summary of hormones and their effects in one menstrual cycle. (**a**) GnRH, a hypothalamic releasing hormone, stimulates the anterior pituitary to secrete FSH and LH. (**b**) FSH and LH stimulate a follicle to grow, an oocyte to mature, and ovaries to secrete progesterone and estrogens that induce rebuilding of the endometrium. (**c**) A midcycle LH surge triggers ovulation and formation of a corpus luteum. Progesterone and some estrogens secreted by the corpus luteum maintain the endometrium, but their secretion stops if pregnancy does not occur (**d**). If a blastocyst implants itself in the endometrium (**e**), the corpus luteum will continue to act until the placenta forms.

44.6 Pregnancy Happens

When a female and male engage in sexual intercourse, or coitus, the hormonal fog of the moment may obscure what can happen if a secondary oocyte is in an oviduct.

SEXUAL INTERCOURSE

The male sex act begins with an erection, whereby the penis stiffens and lengthens. The sex act culminates in ejaculation, the forceful expulsion of semen from the penis. As Figure 44.3 shows, the penis contains long cylinders of spongy tissue. The penis of an unaroused male stays limp because the large blood vessels that supply the spongy tissue are vasoconstricted. When a male becomes aroused, the vessels vasodilate; blood flow into the penis exceeds the amount of blood that is flowing out. Spongy tissue inside becomes engorged with blood. The penis stiffens and lengthens, which facilitates insertion into a female's vaginal canal.

Repetitive pelvic thrusting mechanically stimulates friction-activated receptors that abound at the tip of the penis. It also stimulates the female's clitoris and vaginal wall. In the male, the response is involuntary muscle contractions that force sperm-laden semen into the urethra, from which it is ejaculated.

Emotional intensity, hard breathing, strong heart pounding, and the contraction of skeletal muscles in general accompany a rhythmic throbbing of the pelvic muscles. During *orgasm*, the end of the sex act, strong sensations of physical release, warmth, and relaxation dominate. Similar sensations typify female orgasm.

You may have heard that a female will not become pregnant as long as she does not reach orgasm. Don't believe it.

FERTILIZATION

On average, an ejaculation can put 150 million to 350 million sperm in the vagina. Fertilization may occur if they arrive a few days before or after ovulation or any time in between. Less than thirty minutes after sperm arrive, contractions move them deep into the female's reproductive tract. A few hundred actually reach the upper portion of the oviduct, where eggs usually are fertilized (Figure 44.11).

Many sperm bind to the oocyte's zona pellucida. Binding triggers the release of enzymes from the cap over each sperm's head. Collectively, these digestive enzymes make a passage through the zona pellucida. Usually only one sperm enters the secondary oocyte. Only its nucleus and centrioles do not degenerate.

Remember, meiosis II was arrested in the primary oocyte. Now, upon sperm penetration, the secondary oocyte and the first polar body both complete meiosis II and cytoplasmic division. Now there is one mature egg—an **ovum** (plural, ova)—and three polar bodies. The egg nucleus fuses with the sperm nucleus (Figure 44.11*b*). Collectively, the chromosomes of both nuclei restore the diploid number for a brand new zygote.

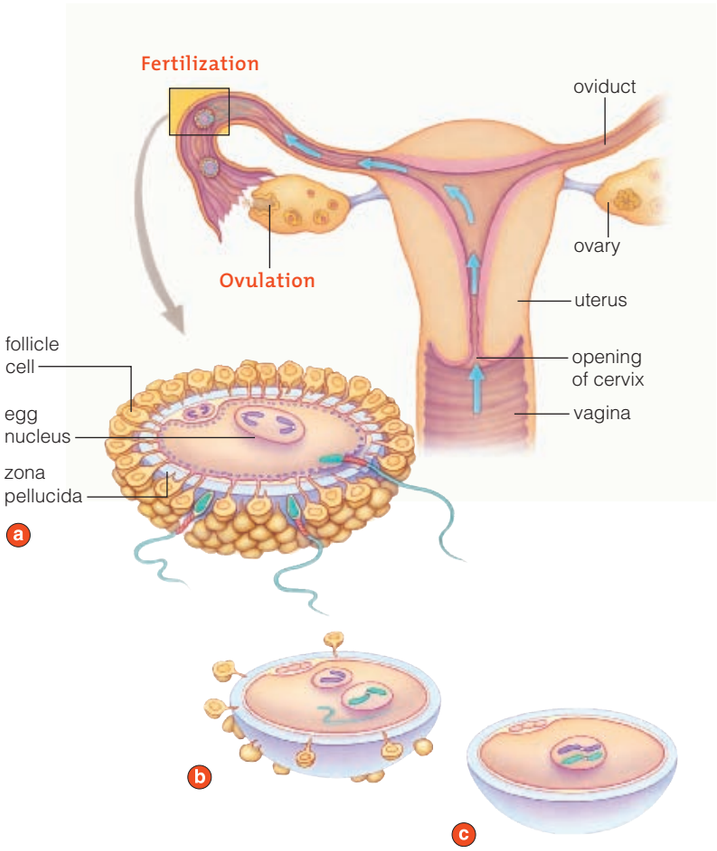


Figure 44.11 ***Animated!*** Fertilization. (**a**) Many human sperm travel rapidly from the vagina to an oviduct (*blue* arrows), where they surround a secondary oocyte. Digestive enzymes released from the cap of each sperm clear a path through the zona pellucida.

(**b**) A single sperm penetrates the secondary oocyte, which releases substances that make the zona pellucida impenetrable to the other sperm. Penetration also stimulates meiosis II of the oocyte's nucleus. (**c**) The sperm's tail degenerates; its nucleus enlarges and fuses with the nucleus of its target. Fertilization is over; a zygote has formed.

The intense physiological events that accompany coitus put sperm on a collision course with an egg.

Fertilization is over when a sperm nucleus and egg nucleus fuse. The diploid zygote that forms is the start of a new individual.

44.7 Preventing or Seeking Pregnancy

LINKS TO SECTIONS 1.7, 34.13

What options are available to those who decide to postpone, forgo, or seek pregnancy?

Fertility Control Options Let us start with the most effective way to avoid pregnancy—complete *abstinence*, or no sex at all. It takes great self-discipline to override the neural and hormonal sense of urgency associated with sex. That sexual drive, or libido, arises through interactions among the limbic system, hypothalamus, and other brain centers. It starts when the sex hormone floodgates open at puberty and peaks during the teens. The difficulty for teenagers is that the limbic system develops faster than the prefrontal cortex, through which self-discipline is exerted (Section 34.13).

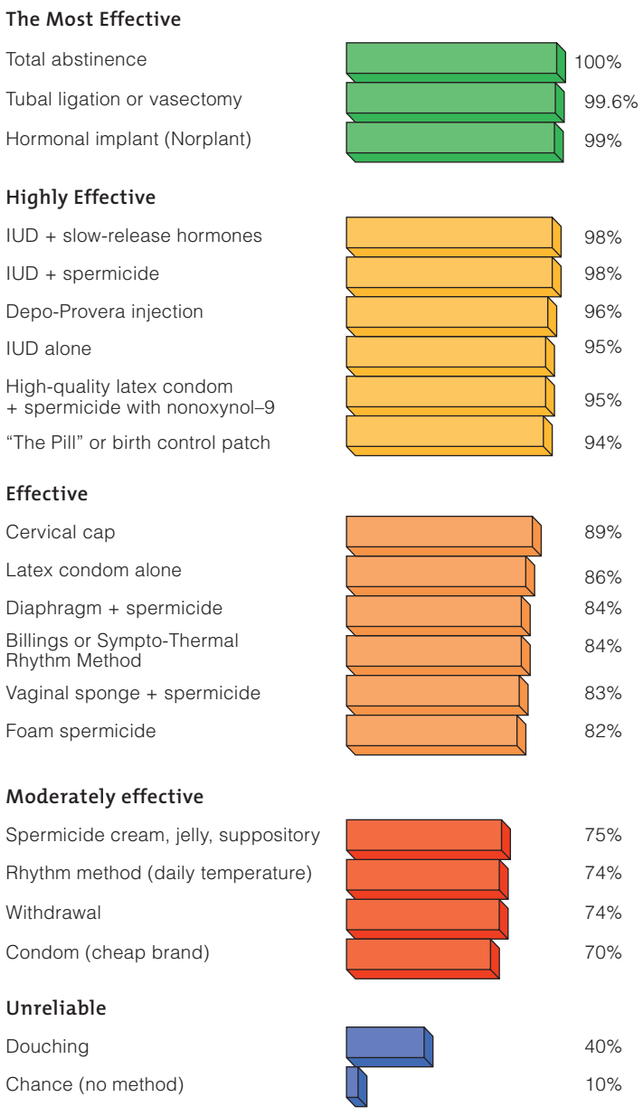


Figure 44.12 Comparison of the effectiveness of some methods of contraception. These percentages also indicate the number of unplanned pregnancies per 100 couples who use only that method of birth control for a year. For example, "94% effectiveness" for oral contraceptives means that 6 of every 100 females will still become pregnant, on average.

Different versions of the *rhythm method* are forms of abstinence; a female simply avoids sex in her fertile period. She calculates when she is fertile by recording how long her menstrual cycles last, by taking her core temperature each morning, or both. The method is inexpensive; it really costs nothing after you buy a thermometer. It does not require fittings or periodic medical checkups. Its practitioners do run a risk of pregnancy (Figure 44.12). Miscalculations are frequent. Sperm deposited in the vagina a few days before ovulation may live long enough to meet up with an egg.

Withdrawal, or removing the penis from the vagina before ejaculation, dates at least to biblical times. It requires great willpower and still may fail, because fluid released from the penis before ejaculation can contain some sperm.

Douching, or chemically rinsing the vagina right after intercourse, is too chancy. Sperm travel out of reach of the douche ninety seconds after ejaculation. Frequent douching also irritates the reproductive tract.

Controlling fertility by surgical intervention is less chancy. Males who do not want children may opt for a *vasectomy*, a procedure that requires a local anesthetic. A doctor makes a small incision in the scrotum, then cuts and ties off each vas deferens. Sperm no longer can move out of the testes and become part of semen.

A vasectomy can be reversed surgically. However, so far, only about 60 percent of those who have reversed the surgery have been able to father a child.

Tubal ligation nearly always guarantees permanent infertility. The oviducts are cauterized or cut and tied. This procedure is now more common than vasectomy. Surgical reversal is about 70 percent successful.

Less drastic fertility control methods are based on physical and chemical barriers that stop sperm from reaching an egg. *Spermicidal foam* and *spermicidal jelly* poison sperm. An applicator is used to insert either one into the vagina before sex. These products are not always reliable, but using them with a diaphragm or a condom makes them more effective.

A *diaphragm* is a flexible, dome-shaped device. It is inserted into the vagina and positioned so that it covers

the cervix before intercourse. As Figure 44.12 indicates, a diaphragm is relatively effective when first fitted by a doctor, used in conjunction with a spermicidal foam or jelly, inserted correctly each time, and left in place for a prescribed length of time.

Condoms are thin, tight-fitting sheaths worn over the penis during intercourse. Good brands may be as much as 95 percent effective when used with a spermicide. Only condoms made of latex afford protection against sexually transmitted diseases. However, even the best ones can tear or leak, at which time they become useless.

A *birth control pill* delivers synthetic estrogens and progesterone-like hormones that block maturation of oocytes and ovulation. "The Pill" reduces menstrual cramps but can cause nausea, headaches, and weight gain. With at least 50 million users, it is the most common fertility control method in the United States. When used correctly, it is at least 94 percent effective. Its use lowers the risk of ovarian cancer but increases the risk of breast, cervical, and liver cancers.

A *birth control patch* is a small, flat adhesive patch applied to skin once a week for three weeks per month. The fourth week, when the menstrual period starts, is patch-free. The patch delivers the same hormones as an oral contraceptive and blocks ovulation the same way. Like birth control pills, it is not for everyone. Some women, especially smokers, develop life-threatening blood clots and other serious cardiovascular disorders.

Progestin injections or implants block ovulation. One Depo-Provera injection is effective for three months. Norplant works for five years. Both methods are quite effective, but they may cause sporadic, heavy bleeding. Also, removing Norplant rods can be tricky.

Some women use *morning-after pills* after a condom tears, or after unprotected consensual sex or rape. One brand, Previn, is a set of two pills with hormones that suppress ovulation and block corpus luteum secretions. Morning-after pills work best when taken early but are somewhat effective up to five days after intercourse.

Regarding Abortion The methods just outlined are interventions in *fertility*, although they commonly are referred to as methods of birth control. They are meant to stop pregnancy from happening in the first place. By contrast, *abortion* is a deliberate intervention after pregnancy is under way. The word actually refers to the spontaneous as well as an induced dislodging and removal of an embryo or fetus from the uterus.

From a clinical standpoint, induced abortion usually is a rapid, relatively painless procedure that is free of complications when performed in the first three months after fertilization. The drug mifepristone (RU 486) and a prostaglandin can induce an abortion during the first nine weeks of pregnancy. Both substances bind to and block progesterone receptors in the uterus. The uterine lining, hence pregnancy, cannot be maintained.

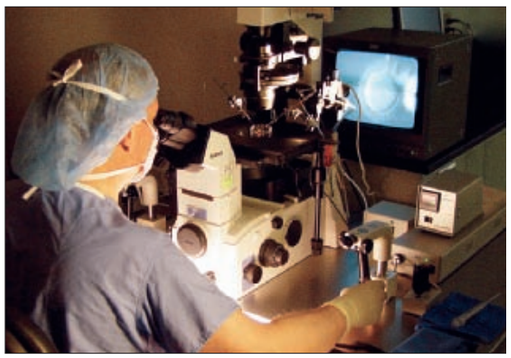


Figure 44.13 A glimpse into in vitro fertilization (IVF). A micromanipulator is used to insert a human sperm into an oocyte. The doctor is guided with the help of an image displayed on a video screen of a monitor that is attached to a microscope.

For both medical and moral reasons, the majority of people in the United States view sexually responsible behavior as being preferable to an abortion. Aborting a late-term fetus is highly controversial unless the mother's life is threatened.

Bear in mind, this textbook cannot offer you the "right" answer to a question about the morality of abortion or some other option, for reasons given in Section 1.7. It can only offer a serious explanation of how a new individual develops to help you objectively assess the biological basis of human life. Your choice of how to answer a question of what is "right" will be just that—your choice.

In Vitro Fertilization Approximately 15 percent of all couples in the United States cannot have children because of sterility or infertility. In some of the cases, hormonal imbalances stop the female from ovulating. In other cases, the male's sperm count is so low that fertilization is next to impossible.

When a couple can make normal sperm and oocytes, they sometimes seek out *in vitro fertilization*. This medical intervention promotes conception outside the body. (In vitro literally means "in glass" petri dishes or test tubes.) First the female receives injections of a hormone that stimulates oocytes into maturing. Before an oocyte can be released from an ovary, it is withdrawn and placed in a solution that simulates fluid inside the female's oviducts. Then a doctor attempts to inject a sperm into it (Figure 44.13).

When the attempt is successful, cleavage produces a tiny cluster of cells within a few days. The cluster is then transferred to the female's uterus for development.

At this writing, each attempt at in vitro fertilization costs an average of 12,000 to 17,000 dollars. When infertility (not sterility) is the problem, attempts usually fail.

Each liveborn "test-tube" baby costs health care systems between 60,000 and 100,000 dollars. A childless couple may believe no cost is too great. But many people question the cost to society in an era of increased population growth and shrinking medical coverage. Another concern is the fate of the embryonic cell clusters that are created for IVF but never used. Court battles are being waged over this issue.

44.8 Sexually Transmitted Diseases

LINKS TO SECTIONS 21.4, 22.2, 39.10

Unprotected sex exposes you to potential infection by any pathogens that your partner unknowingly may have picked up from a previous sexual partner.

CONSEQUENCES OF INFECTION

Each year, pathogens that cause **sexually transmitted diseases**, or STDs, infect about 15 million people in the United States (Table 44.4). Two-thirds of those infected are under age twenty-five. One-quarter are teenagers. Over 65 million Americans now live with an incurable STD. Treating STDs and secondary complications costs a staggering 8.4 billion dollars in an average year.

The social consequences are enormous. Females are more easily infected than males, and they develop more complications. For instance, pelvic inflammatory disease (PID), a secondary outcome of some bacterial STDs, affects about 1 million females annually. It scars the reproductive tract and can cause infertility, tubal pregnancies, and chronic pain (Figure 44.14*a*). Some fetuses acquire STDs before or during birth, then abort on their own or develop abnormally. Females commonly transmit the bacterial agent of chlamydia to newborns (Figure 44.14*b*). Type II *Herpes* virus kills 50 percent of the fetuses it infects and causes neural defects in 25 percent of the survivors.

Table 44.4 Estimated New STD Cases Per Year *

STD	U.S. Cases	Global Cases
HPV infection	5,500,000	20,000,000
Trichomoniasis	5,000,000	174,000,000
Chlamydia	3,000,000	92,000,000
Genital herpes	1,000,000	20,000,000
Gonorrhea	650,000	62,000,000
Syphilis	70,000	12,000,000
AIDS	40,000	4,900,000

* Global data on HPV and genital herpes were last compiled in 1997.

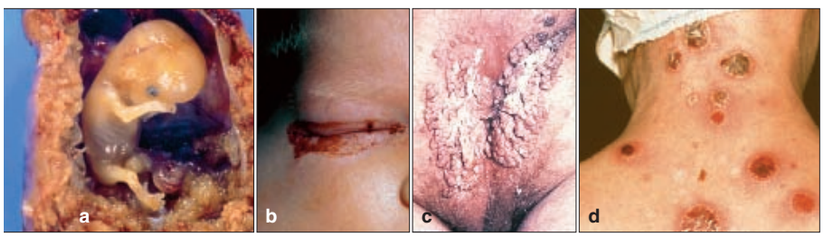


Figure 44.14 A few downsides of unsafe sex. (**a**) Tubal pregnancy. Scarring from STDs makes an embryo implant itself in an oviduct, not the uterus. Untreated tubal pregnancies can rupture an oviduct and cause bleeding, infection, and death. (**b**) One sign of a chlamydial infection transferred from a mother to her infant. (**c**) Genital warts. (**d**) Chancres typical of secondary syphilis.

MAJOR AGENTS OF STDS

HPV Infection by human papillomaviruses (HPV) is the most widespread and fastest growing STD in the United States. At least 20 million are already infected. Of about 100 HPV strains, a few cause *genital warts*. These bumpy growths form on the vagina, cervix, and external genitals, and around the anus (Figure 44.14*c*). In males, they form on the penis and scrotum. Two strains, HPV 16 and HPV 18, cause *cervical cancer*. Sexually active females should have an annual pap smear to check for any cervical changes.

Trichomoniasis *Trichomonas vaginalis*, a flagellated protozoan, causes the disease *trichomoniasis* (Section 22.2). Symptoms include vaginal soreness, itching, and a yellowish discharge. Infected males are usually symptom-free. Untreated infections damage the urinary tract, cause infertility, and invite HIV infection. A single dose of an antiprotozoal drug quickly cures an infection. To prevent reinfection, both sexual partners must be treated.

Chlamydia *Chlamydial infection* is primarily a young person's disease. Forty percent of those infected are between ages fifteen and nineteen; 1 in 10 sexually active teenage girls is infected. *Chlamydia trachomatis* causes the disease (Section 21.4). Antibiotics can quickly kill this bacterium. Most infected females are undiagnosed; they have no symptoms. Between 10 and 40 percent of those who are untreated will develop PID. In about 50 percent of infected males, symptoms include abnormal discharges from the penis and painful urination. Untreated males risk inflammation of the epididymes and infertility.

Genital Herpes About 45 million Americans have genital herpes, caused by type II *Herpes simplex* virus. Transmission to new hosts requires direct contact with active *Herpes* viruses or with sores that contain them. Mucous membranes of the mouth and genitals are vulnerable. Early symptoms are often mild or absent. Painful, small blisters may form on the vulva, cervix, urethra, or anal tissues of infected females. Blisters form on the penis and anal tissues of infected males. Within three weeks, the virus enters latency. Sores crust over and heal, but viral particles are hidden in the body.

The virus is reactivated sporadically, which causes painful sores at or near the original site of infection. Sexual intercourse, menstruation, emotional stress, or other infections trigger flare-ups. One antiviral drug, Acyclovir, decreases healing time and often the pain.

Gonorrhea The STD *gonorrhea* is caused by *Neisseria gonorrhoeae* (Figure 44.15*b*). This bacterium commonly crosses mucous membranes of the urethra, cervix, or anal canal during sexual intercourse. An infected female may notice a slight vaginal discharge or burning sensation while urinating. If the bacterium enters her oviducts, it

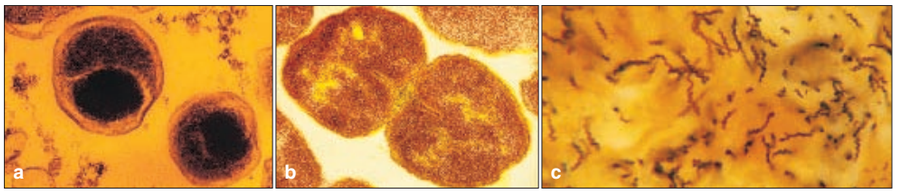


Figure 44.15 Light micrographs of bacteria that cause (**a**) chlamydia, (**b**) gonorrhea, and (**c**) syphilis.

may cause cramps, fever, vomiting, and scarring that can result in sterility. Less than a week after a male is infected, yellow pus oozes from the penis. Urination becomes more frequent and may also be painful.

Prompt treatment with antibiotics quickly cures this disease, yet it still is rampant. Many females ignore early symptoms. Also, people wrongly believe infection confers immunity. Someone can contract gonorrhea over and over again, probably because there are at least sixteen strains of *N. gonorrhoeae*. Also, use of oral contraceptives invites infection by altering vaginal pH. Populations of resident bacteria decline, so *N. gonorrhoeae* is free to move in.

Syphilis The spirochete *Treponema pallidum* causes *syphilis*, a dangerous STD (Section 21.4 and Figure 44.15*c*). Having sex with an infected partner puts this bacterium on the surface of genitals or into the cervix, vagina, or oral cavity. *T. pallidum* also slips into the body through tiny cuts. One to eight weeks later, treponemes are twisting about in a flattened, painless chancre, or localized ulcer.

This chancre is a sign of the primary stage of syphilis. It usually heals, but treponemes multiply in the spinal cord, brain, eyes, bones, joints, and mucous membranes. In an infectious secondary stage, a skin rash develops and more chancres form (Figure 44.14*d*). In about 25 percent of the cases, immune responses succeed and symptoms subside. Another 25 percent are symptom-free. In the remainder, lesions and scars appear in the skin and liver, bones, and other organs. Few treponemes form in this tertiary stage, but a host's immune system is hypersensitive to them. Chronic immune reactions may damage the brain and spinal cord and cause paralysis.

Possibly because the symptoms are so alarming, more people seek early treatment for syphilis than they do for gonorrhea. Later stages require prolonged treatment.

AIDS As you read earlier in Section 39.10, an infection by HIV, the human immunodeficiency virus, leads to *AIDS*—*A*cquired *I*mmune *D*eficiency *S*yndrome. The immune system almost always loses the battle with HIV; this is an incurable STD. There may be no outward symptoms at first. Five to ten years later, a set of chronic disorders develops. The immune system weakens, which opens the door to opportunistic infectious agents. Normally harmless bacteria already living in and on the body are the first to take advantage of lowered resistance. Then dangerous pathogens take their toll. Eventually they overwhelm the compromised immune system.

Most often, HIV spreads by way of anal, vaginal, and oral intercourse and intravenous drug use. Virus particles in blood, semen, urine, or vaginal secretions enter a new host through cuts and abrasions in the epithelial lining of the penis, vagina, rectum, or oral cavity.

Free or low-cost, confidential testing for HIV exposure is available at public health facilities. It takes a few weeks to six months or more before the body forms detectable amounts of antibodies in response to the first exposure. Anyone who tests positive for HIV can spread the virus.

Public education may help slow the spread of HIV (Figure 44.16). Most health care workers advocate safe sex, although there is confusion over what "safe" means. The use of high-quality latex condoms together with a nonoxynol–9 spermicide helps prevent viral transmission. However, as mentioned in the preceding section, this practice still carries a slight risk. Open-mouth kissing with an HIV-positive individual carries a risk. Caressing is not risky if there are no lesions or cuts where HIV-laden body fluids can enter the body. Skin lesions caused by any other sexually transmitted disease are vulnerable points of entry for the virus.

New, costly drug therapies are prolonging some lives. In the late 1990s, the rate of infection started to climb again, possibly because of a misperception that AIDS is no longer a deadly threat. But AIDS kills, and the viral agent keeps on mutating. How long today's drugs can keep a lid on deaths is anybody's guess.

Figure 44.16 NBA legend Magic Johnson, one of the torch bearers of the 2002 Winter Olympics. He was diagnosed as HIV positive in 1991. He contracted the virus through heterosexual sex, and credits his survival to AIDS drugs and informed medical care. He continues to campaign to educate others about AIDS.

44.9 Formation of the Early Embryo

LINKS TO SECTIONS 26.6, 26.9, 43.3

Nine months or so after the time of fertilization, a female gives birth. Besides taking longer to develop inside its mother, the new individual will require more intense care for a much longer time compared to other primates.

Pregnancy lasts an average of thirty-eight weeks from the time of fertilization. It takes about one week for a blastocyst to form. All major organs form during the *embryonic* period—the third to the end of the eighth week of pregnancy. When this period ends, the new individual is called a **fetus**. It has distinctly human features. In the *fetal* period, from the start of the ninth week until birth, organs grow and become specialized. We often refer to the first three months of pregnancy as the first trimester. The second trimester extends from the start of the fourth month to the end of the sixth, and the third trimester ends at birth.

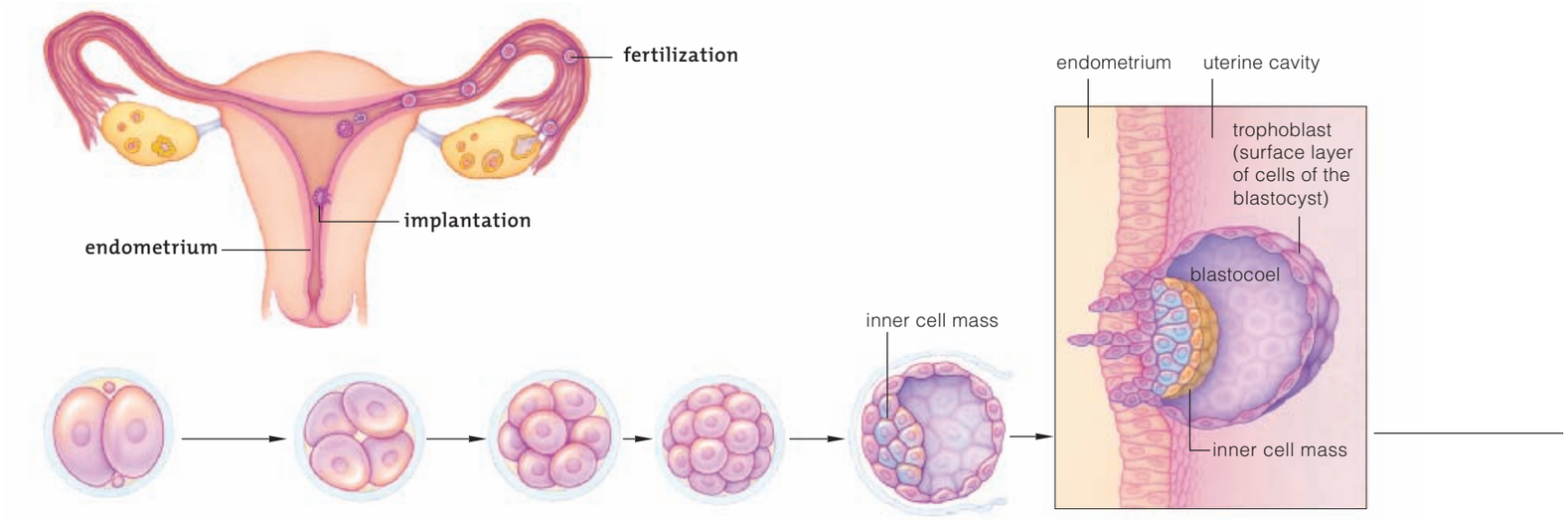
CLEAVAGE AND IMPLANTATION

Three to four days after fertilization, the zygote has already started cleavage. Some of its genes are being expressed, because the early cuts need their products (Section 14.3). At the eight-cell stage, the cells huddle into a ball. A human blastocyst forms by the fifth day. It consists of a trophoblast (an outer layer of cells), a cavity filled with their secretions (a blastocoel), and an inner cell mass (Figure 44.17*d*). One or two days later, **implantation** is under way. The blastocyst adheres to the uterine lining. It invades the mother's tissues and forms connections that will metabolically support the pregnancy. By now, the inner cell mass has become two flattened layers of cells in the shape of a disk. This embryonic disk will give rise to the embryo proper.

EXTRAEMBRYONIC MEMBRANES

As implantation continues, membranes start to form outside the embryo. First, a fluid-filled *amniotic* cavity opens up between the embryonic disk and part of the blastocyst surface (Figure 44.17*f*). Many cells migrate around the wall of the cavity and form the **amnion**, a membrane that will enclose the embryo. Fluid in the cavity will function as a buoyant cradle in which an embryo can grow, move freely, and be protected from abrupt temperature changes and mechanical impacts.

As the amnion forms, other cells migrate around the inner wall of the blastocyst, forming a lining that



a DAYS 1–2. The first cleavage furrow extends between the two polar bodies. Later cuts are angled, so cells become asymmetrically arranged. Until the eight-cell stage forms, they are loosely organized, with space between them.

b DAY 3. After the third cleavage, cells abruptly huddle into a compacted ball, which tight junctions among the outer cells stabilize. Gap junctions formed along the interior cells enhance intercellular communication.

c DAY 4. By 96 hours there is a ball of sixteen to thirty-two cells shaped like a mulberry. It is a morula (after *morum*, Latin for mulberry). Cells of the surface layer will function in implantation and will give rise to a membrane, the chorion.

d DAY 5. A blastocoel (fluid-filled cavity) forms in the morula as a result of surface cell secretions. By the thirty-two-cell stage, differentiation is occurring in an inner cell mass that will give rise to the embryo proper. This embryonic stage is the blastocyst.

e DAYS 6–7. Some of the blastocyst's surface cells attach themselves to the endometrium and start to burrow into it. Implantation has started.

becomes a **yolk sac**. This extraembryonic membrane speaks of the evolution of land vertebrates. For most animals that produce shelled eggs, the yolk sac holds nutritive yolk. In humans, one portion of the yolk sac becomes a site of blood cell formation. Another will give rise to germ cells, the forerunners of gametes.

Before a blastocyst is fully implanted, spaces open in maternal tissues and become filled with blood that seeps in from ruptured capillaries. In the blastocyst, a new cavity opens up around the amnion and yolk sac. The lining of the cavity becomes the **chorion**, a third membrane that balloons like fingers of many rubber gloves into maternal tissues. It will become part of the spongy, blood-engorged tissue called the placenta.

After the blastocyst is implanted, an outpouching of the yolk sac will become the fourth extraembryonic membrane—the **allantois**. The allantois has different roles in different groups. Among reptiles, birds, and some mammals, it serves in respiration and in storing metabolic wastes. In humans, the urinary bladder and blood vessels for a placenta form from it (Table 44.5).

The blastocyst itself stops menstruation. Cells of the blastocyst secrete a hormone called human chorionic gonadotropin, or HCG. This hormone stimulates the corpus luteum to continue secreting progesterone and estrogens (Figure 44.10). It does so until the placenta takes over secretion of HCG about eleven weeks later. By the start of the third week, HCG may be detected in samplings of the mother's blood or urine. At-home *pregnancy tests* have a treated "dipstick" that changes color when urine contains this pregnancy hormone.

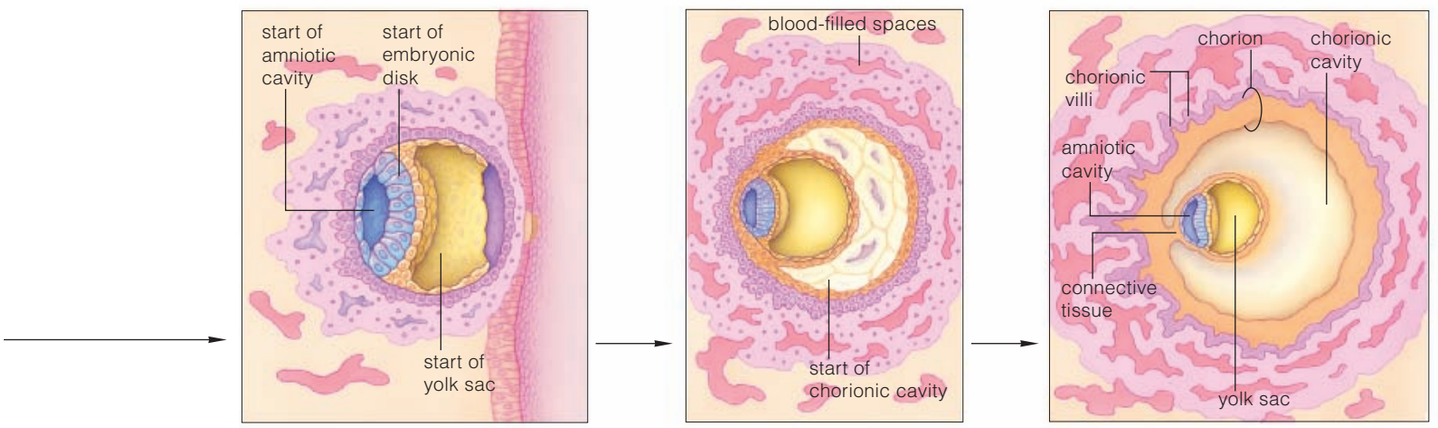
Table 44.5 Human Extraembryonic Membranes

Amnion	Encloses, protects embryo in a fluid-filled, buoyant cavity
Yolk sac	Becomes site of red blood cell formation; germ cell source
Chorion	Lines amnion and yolk sac, becomes part of placenta
Allantois	Source of urinary bladder and blood vessels for placenta

Cleavage of the human zygote produces a cluster of cells that develops into the blastocyst that implants itself in the endometrium six or seven days after fertilization.

Projections from the blastocyst's surface invade maternal tissues, and connections start to form that in time will metabolically support the developing embryo.

Some parts of the blastocyst give rise to an amnion, yolk sac, chorion, and allantois. These extraembryonic membranes serve different functions. Together they are vital for the structural and functional development of the embryo.



f **DAYS 10–11**. The yolk sac, embryonic disk, and amniotic cavity have started to form from parts of the blastocyst.

g **DAY 12**. Blood-filled spaces form in maternal tissue. The chorionic cavity starts to form.

h **DAY 14**. A connecting stalk has formed between the embryonic disk and chorion. Chorionic villi, which will be features of a placenta, start to form.

Figure 44.17 ***Animated!*** From fertilization through implantation. A blastocyst forms, and its inner cell mass will give rise to a disk-shaped early embryo. Three extraembryonic membranes (the amnion, chorion, and yolk sac) start forming. A fourth membrane (allantois) forms after the blastocyst is implanted.

44.10 Emergence of the Vertebrate Body Plan

LINKS TO SECTIONS 15.1, 15.3, 17.8, 43.2, 43.4

By the time a female misses a first menstrual period after fertilization, cleavage is over. Gastrulation is under way.

Gastrulation, recall, is the stage when cell divisions, migrations, and rearrangements give rise to primary tissue layers (Section 43.4). The inner cell mass has been developing much as it did in reptilian ancestors of mammals. But the blastomeres are now arranged as a flattened, two-layered embryonic disk. That disk is reminiscent of the one that forms in the yolky eggs of living reptiles and birds (Figure 44.18*a*).

By now, the embryonic disk is surrounded by the amnion and chorion—except where a stalk joins it to the chorion wall. The yolk sac lining has formed from one of the two layers. The other layer now starts to become the embryo proper. A depression appears on the disk and its sides begin to thicken. Figure 44.18*a* shows this *primitive streak*. The next day, it lengthens and thickens more. Its appearance marks the onset of gastrulation. It defines the anterior–posterior axis and, in time, the bilateral symmetry of the embryo.

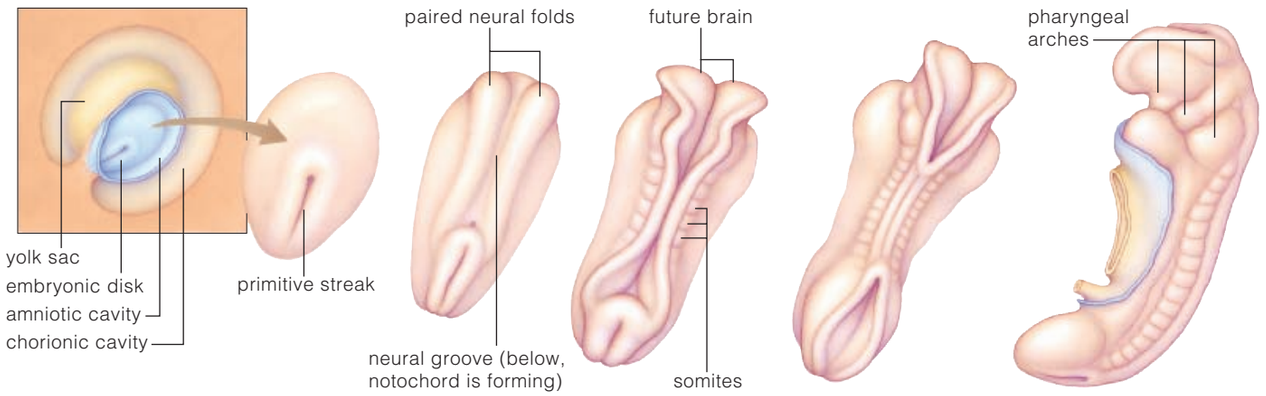
Endoderm and mesoderm form from cells that are migrating inward along this axis. Pattern formation starts. Embryonic inductions and interactions among classes of master genes map out the basic body plan, as they do in all vertebrates. Tissues and organs form in orderly steps according to predictable patterns.

For example, by the eighteenth day, the embryonic disk has two folds that will merge into a neural tube, the start of the spinal cord and brain (Figure 44.18*b*). Some mesoderm folds into a tube that develops into a notochord. The vertebrate notochord is no more than a structural model; bony segments form on it. In *spina bifida*, the neural tube, and one or more vertebrae do not form properly, and the spinal cord, its coverings, or both may protrude from the vertebral column.

Toward the end of the third week, multiple paired segments form from some mesoderm. These **somites** are embryonic sources of most bones, skeletal muscles of the head and trunk, and the dermis overlying these body parts (Section 43.2). Pharyngeal arches start to form; they will contribute to the pharynx, larynx, and the face, neck, mouth, and nose (Figure 44.18*c*). Small spaces open up in certain parts of the mesoderm. In time, they will interconnect as a coelomic cavity.

The basic vertebrate body plan emerges early in the development of the new individual.

A primitive streak, neural tube, somites, and pharyngeal arches form during the embryonic period of all vertebrates. Formation of the primitive streak establishes the body's anterior–posterior axis and its bilateral symmetry.



a **DAY 15.** A faint band appears around a depression along the axis of the embryonic disk. This is the primitive streak, and it marks the onset of gastrulation in vertebrate embryos.

b **DAYS 18–23.** Organs start to form through cell divisions, cell migrations, tissue folding, and other events of morphogenesis. Neural folds will merge to form the neural tube. Somites (bumps of mesoderm) appear near the embryo's dorsal surface. They will give rise to most of the skeleton's axial portion, skeletal muscles, and much of the dermis.

c **DAYS 24–25.** By now, some embryonic cells have given rise to pharyngeal arches. These will contribute to the formation of the face, neck, mouth, nasal cavities, larynx, and pharynx.

Figure 44.18 Hallmarks of the embryonic period of humans and other vertebrates. A primitive streak and then a notochord form. Neural folds, somites, and pharyngeal arches form later. (**a**,**b**) Dorsal views of the embryo's back. (**c**) Side view.

44.11 Why Is the Placenta So Important?

Even before the embryonic period starts, the uterus has been interacting with extraembryonic membranes in ways that will sustain the embryo's rapid growth.

By the third week, tiny fingerlike projections from the chorion have grown into the maternal blood that has pooled in the endometrial spaces. These projections are chorionic villi. They enhance the rate of exchange of substances between the mother and the embryo. The villi are functional components of the placenta.

The **placenta** is a blood-engorged organ composed of the uterine lining and extraembryonic membranes. At full term, it will make up about one-fourth of the inner surface of the uterus (Figure 44.19).

A placenta is the body's way of sustaining the new individual while allowing its blood vessels to develop separately from the mother's blood vessels. Oxygen and vital nutrients diffuse out of the maternal blood vessels, across the placenta's blood-filled spaces, then into embryonic blood vessels. The vessels converge in an umbilical cord, the lifeline between the placenta and the new individual. Carbon dioxide and other wastes diffuse in the other direction. The mother's lungs and kidneys dispose of the wastes (Section 40.5).

LINK TO SECTION 40.5

After the third month, the placenta itself takes over the task of maintaining the uterine lining. It starts to secrete the sex hormones progesterone and estrogens.

The placenta is a blood-engorged organ of endometrial and extraembryonic membranes. It allows the new individual to take up oxygen and nutrients from the mother and give up wastes to her. It does so while allowing embryonic blood vessels to develop separately from the mother's.

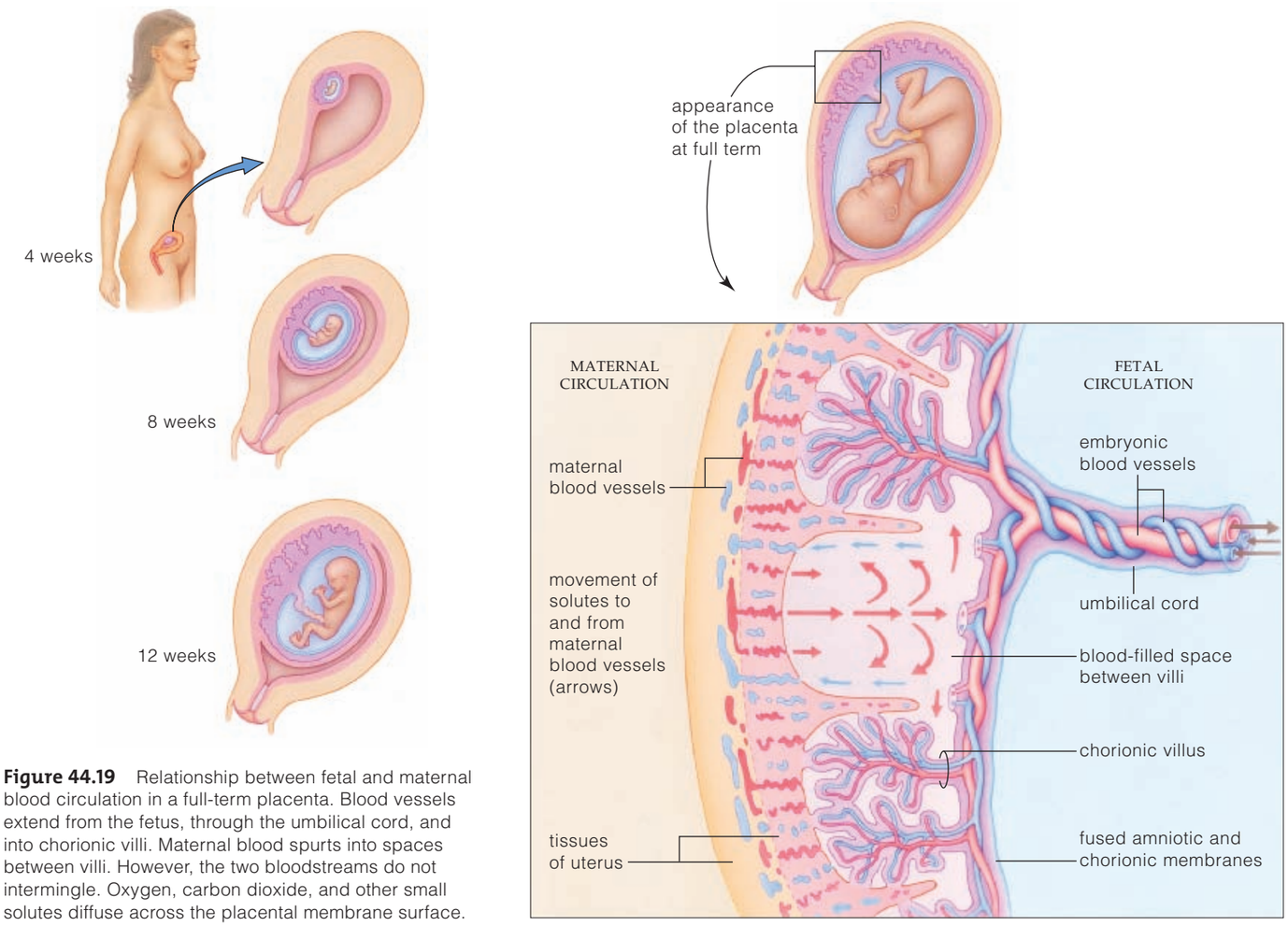


Figure 44.19 Relationship between fetal and maternal blood circulation in a full-term placenta. Blood vessels extend from the fetus, through the umbilical cord, and into chorionic villi. Maternal blood spurts into spaces between villi. However, the two bloodstreams do not intermingle. Oxygen, carbon dioxide, and other small solutes diffuse across the placental membrane surface.

44.12 Emergence of Distinctly Human Features

LINKS TO SECTIONS 9.4, 12.5, 28.5

Early on, a human embryo—with its gill arches and long tail—has a distinctly vertebrate appearance. The tail soon disappears, and by the beginning of the fetal period, the developing individual has distinctly human features.

When the fourth week ends, the embryo is 500 times its starting size. Weeks five and six are the boundary between the embryonic and fetal periods. Now growth slows as details of organs fill in. Limbs form; toes and fingers are sculpted from paddles. The umbilical cord develops, and so does an intricate circulatory system. Growth of the all-important head now surpasses that of all other regions (Figure 44.20). Reproductive organs start forming, as explained in Section 12.5. At the end of the eighth week, the individual is no longer just "a vertebrate." Its features define it as a human fetus.

In the second trimester, as developing nerves and muscles connect up, reflexive movements begin. Legs

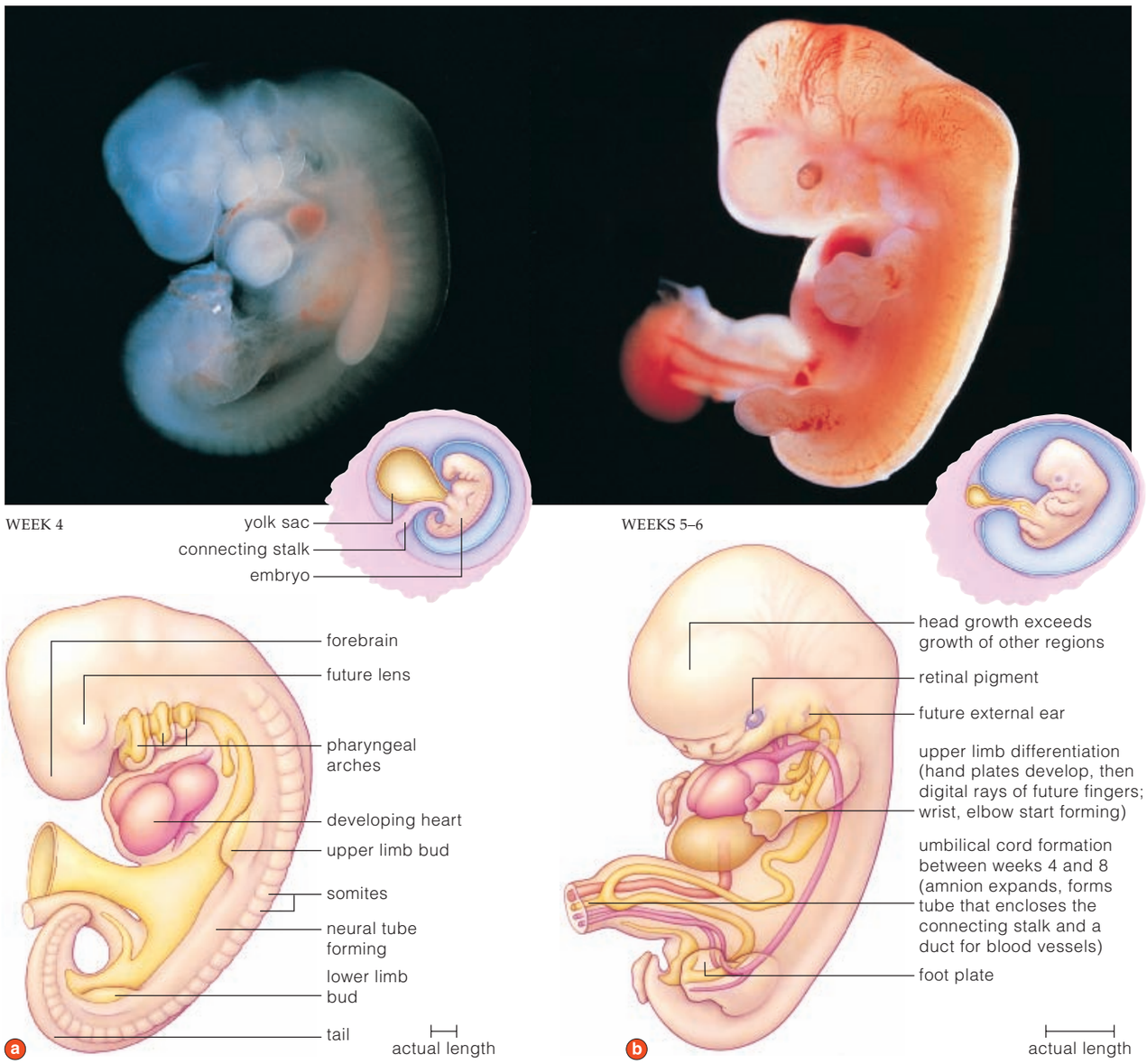
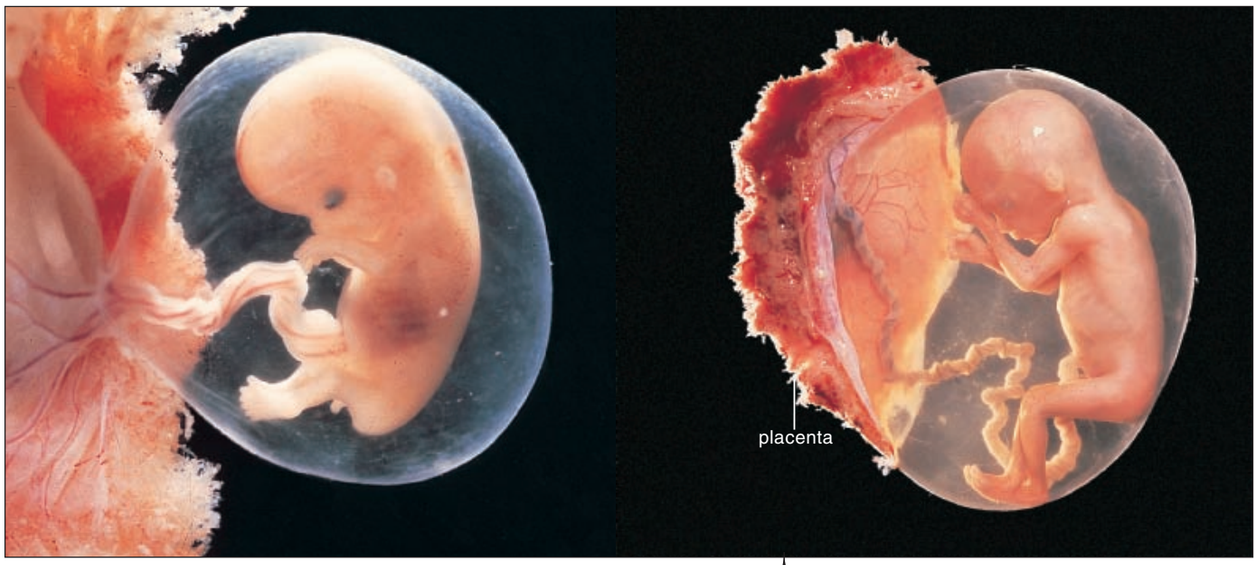


Figure 44.20 Human embryo at successive stages of development.

kick, arms wave about, and fingers grasp. The fetus frowns, squints, puckers its lips, sucks, and hiccups. When the fetus is five months old, its heartbeat can be heard clearly through a stethoscope positioned on the mother's abdomen. The mother can sense movements of fetal arms and legs.

By now, soft, fetal hair (the lanugo) covers the skin; most will be shed before birth. A thick, cheesy coating protects the wrinkled, reddish skin from abrasion. In the sixth month, delicate eyelids and eyelashes form. Eyes open during the seventh month, the start of the final trimester. By this time all portions of the brain have formed and have begun to function.

In the fetal period, the primary tissues that formed in the early embryo become sculpted in ways that transform this vertebrate embryo into one with distinctly human features.



WEEK 8

final week of embryonic period; embryo looks distinctly human compared to other vertebrate embryos

upper and lower limbs well formed; fingers and then toes have separated

primordial tissues of all internal, external structures now developed

tail has become stubby

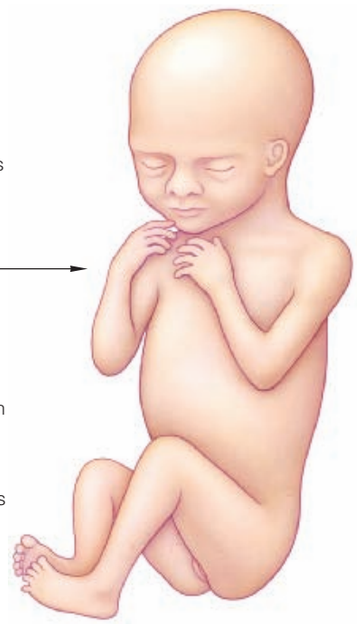
c actual length

WEEK 16
Length: 16 centimeters (6.4 inches)
Weight: 200 grams (7 ounces)

WEEK 29
Length: 27.5 centimeters (11 inches)
Weight: 1,300 grams (46 ounces)

WEEK 38 (full term)
Length: 50 centimeters (20 inches)
Weight: 3,400 grams (7.5 pounds)

During fetal period, length measurement extends from crown to heel (for embryos, it is the longest measurable dimension, as from crown to rump).



d

44.13 Mother as Provider, Protector, Potential Threat

LINKS TO SECTIONS 18.5, 34.13, 40.5, 41.8

Each pregnant female is committing much of her body's resources to the growth and development of a brand-new individual. From fertilization until birth, her future child is at the mercy of her diet, health habits, and life-style.

NUTRITIONAL CONSIDERATIONS

When a mother-to-be eats a well-balanced diet, her embryo gets all the proteins, carbohydrates, and lipids it requires for growth and development (Section 41.8). However, her own body's demands for vitamins and minerals increase as the placenta preferentially absorbs them for the fetus from her blood. Medically supervised increases in her uptake of B-complex vitamins before and during early pregnancy reduce the embryo's risk of severe neural tube defects. Folate (folic acid) is especially important in this regard.

Dietary deficiencies adversely affect many developing organs. For example, the brain expands most in the weeks just before and after birth. Poor nutrition during this span may impair intelligence and other functions later in life.

A pregnant female must eat enough to gain twenty to twenty-five pounds, on average. If she does not, her newborn may be seriously underweight, at greater risk of postdelivery complications and, in time, impaired brain function.

INFECTIOUS DISEASES

Remember, IgG antibodies in a pregnant female's blood cross the placenta and protect the embryo or fetus from all but the most serious bacterial infections (Section 39.5). Some viral diseases are dangerous in the first six weeks after fertilization, a crucial time of organ formation.

Suppose the female contracts *rubella* (German measles) in this critical period. There is a 50 percent chance that some organs will not form properly. For instance, if she is infected while embryonic ears are forming, her newborn may be deaf (Figure 44.21). If she is infected at any time from the fourth month of pregnancy onward, this particular disease will have no notable effect. A female may avoid the risk entirely by getting vaccinated against the virus before pregnancy.

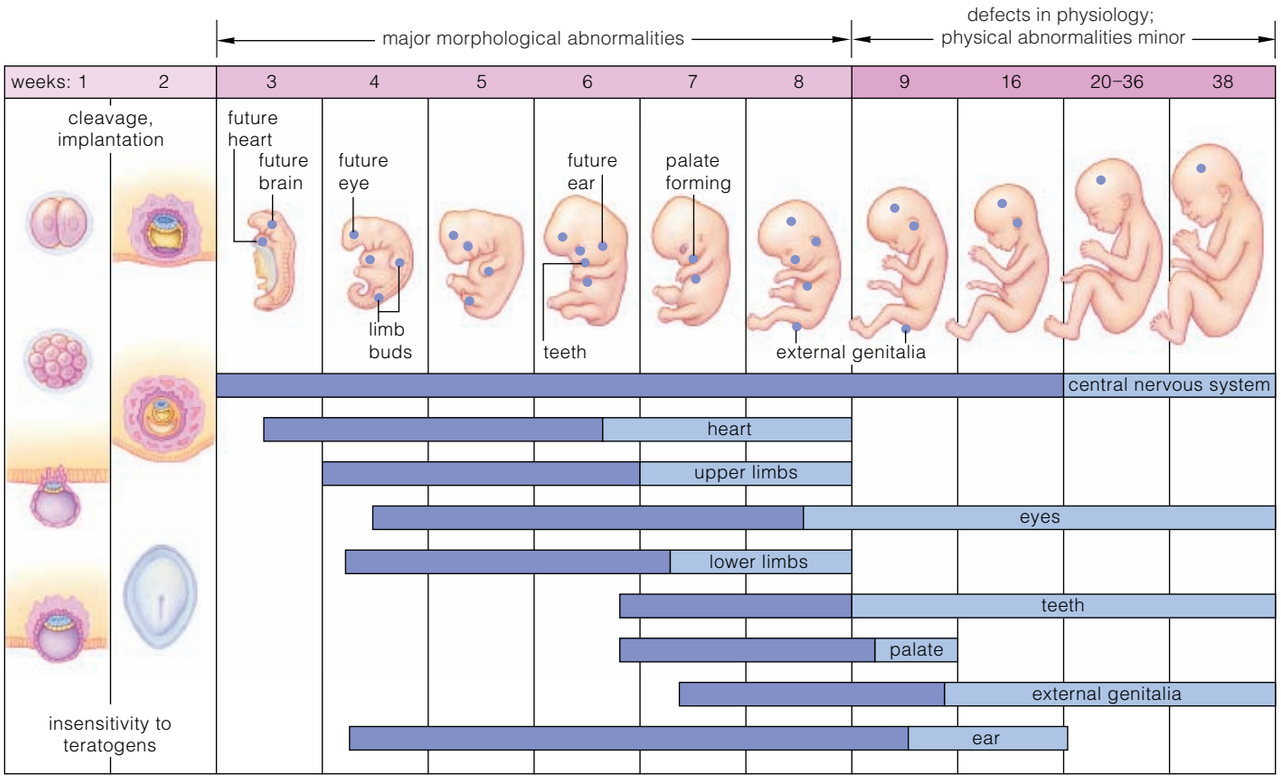


Figure 44.21 Teratogen sensitivity. Teratogens are drugs, infectious agents, and environmental factors that invite embryonic or fetal deformities, usually after organs form. They adversely affect growth, tissue remodeling, and tissue resorption. *Dark blue* signifies the highly sensitive period; *light blue* signifies periods of less severe sensitivity to teratogens. For example, the upper limbs are most sensitive to damage during weeks 4 through 6, and somewhat sensitive during weeks 7 and 8.

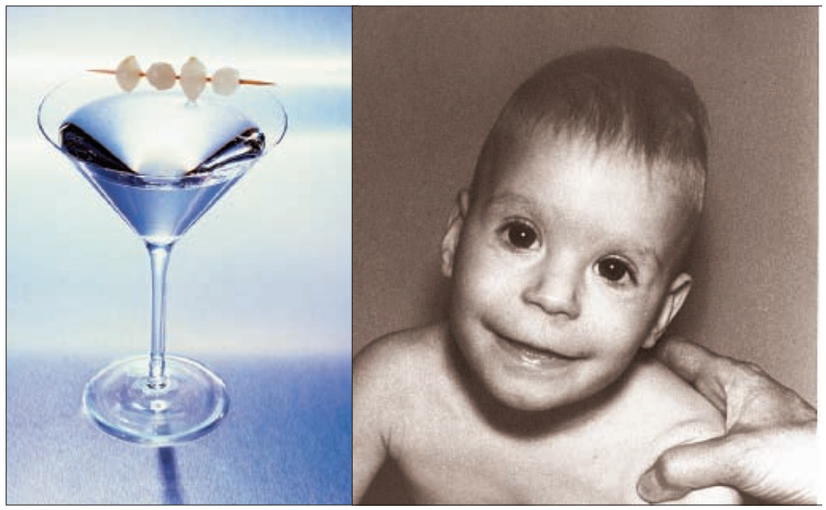


Figure 44.22 An infant with fetal alcohol syndrome—FAS. The obvious symptoms are low and prominently positioned ears, improperly formed cheekbones, and an abnormally wide, smooth upper lip. Growth-related complications and abnormalities of the nervous system can be expected.

FAS cases are grossly underdiagnosed, misdiagnosed, and underreported. Part of the problem is that medical schools do not always train doctors to recognize FAS symptoms. Patients of child-bearing age should be screened for alcohol use, just as they are for glucose levels and other indicators of health.

ALCOHOL, TOBACCO, AND OTHER DRUGS

Alcohol Remember the introduction to Chapter 6? Alcohol passes freely across cell membranes. It also passes freely across the placenta. When a pregnant female drinks, her developing embryo or fetus will quickly absorb alcohol. Excessive intake invites *fetal alcohol syndrome* (FAS).

Symptoms of this disorder include reduced brain size, mental impairment, facial deformities, a small head, slow growth, possible heart problems, and poor coordination (Figure 44.22). In some parts of the United States, the average incidence of FAS is as high as 1.5 cases per 1,000 live births. The damage is permanent; children affected by FAS never do catch up, physically or mentally.

Even moderate drinking during pregnancy may have negative effects. One study indicated that even a single episode of high alcohol intake can induce apoptosis in neurons of the developing brain. Increasingly, doctors are urging total abstinence from alcohol during pregnancy.

Tobacco Smoking or exposure to secondhand smoke increases the risk of miscarriage and adversely affects fetal growth and development. Remember, carbon monoxide in smoke outcompetes oxygen for binding sites on hemoglobin (Section 40.5), so the embryo or fetus cannot get enough oxygen. Nicotine levels in amniotic fluid actually can be higher than those in the mother's blood.

Smoking any tobacco regularly during pregnancy results in underweight newborns. This happens even when the female's weight, nutrition, and other key variables match those of pregnant nonsmokers. Tobacco smoke adversely affects nutrition as well. In one study, pregnant females who smoked lowered the blood concentration of vitamin C for themselves *and* for their fetuses, even when intake of that vitamin matched the intake of a control group.

The effects may be long term. Researchers tracked a group of children born in the same week for seven years. More children of smokers died of postdelivery complications. Those that survived were smaller, had twice as many heart defects. By age seven, they were nearly half a year behind children of nonsmokers in their "reading age."

Cocaine A pregnant female who uses cocaine of any kind increases the likelihood of miscarriage and premature delivery. As Section 34.13 explains, cocaine is a psychoactive drug, and it disrupts the development of the fetal nervous system. A child of a cocaine addict is likely to be abnormally small and irritable early in life. Some studies indicate that prenatal exposure to cocaine has long-term negative effects on intelligence and behavior.

Prescription Drugs Pregnant women should not take any drugs except under medical supervision. To underscore this point, the tranquilizer *thalidomide* was routinely prescribed in Europe. Infants of some of the women who used it during the first trimester had severely deformed arms and legs, or none at all. This drug has been withdrawn from the market. But other tranquilizers, sedatives, and barbiturates are still being prescribed, and they may cause some less severe damage. Certain *anti-acne drugs* might invite facial and cranial deformities.

Depression during pregnancy is not uncommon and may put the fetus at risk. A mother who does not feel like eating or otherwise taking care of herself can compromise fetal development. To avoid such problems, some pregnant women are treated with antidepressants. So far, research suggests that these drugs do not increase the miscarriage rate, slow fetal growth, or increase the incidence of birth defects. However, the infants of women who used the drugs right up to the time of delivery apparently can show some withdrawal symptoms.

A final note: Teenagers are much less likely than older women to receive timely prenatal care and are more likely to smoke during pregnancy. Because of these and other factors, the babies born to teenagers are more likely to be premature. They are at greater risk of serious and long-term illness, of delays in postnatal developments, and of dying in the first year of life (Section 18.5).

44.14 Birth and Postnatal Development

LINKS TO SECTIONS 26.10, 35.9, 36.8, 43.6, 43.7

Human growth and development continue as the newborn embarks on a course of extended dependency and learning. As with all mammals, its early survival depends on nutritious milk, typically provided by the mother.

GIVING BIRTH

A fetus born too prematurely (before 22 weeks) will not survive. The risk also is great for births before 28 weeks, mainly because the lungs have not developed enough. The risk starts to drop after this. By 36 weeks, the survival rate is 95 percent. A fetus born between 36 and 38 weeks still has some trouble breathing and maintaining a core temperature even with the best of medical care. On average, the most favorable birthing time is 38 weeks after fertilization.

The properties of the cervix change as a fetus nears full term. Until now, the firm wall of the cervix has helped keep the fetus from prematurely slipping out of the uterus. Its connective tissue weakens in the last weeks of pregnancy. The crosslinks between collagen fibers loosen, the cervix becomes thinner, softer, and more flexible. These structural changes will allow it to stretch enough to permit the expulsion of the fetus.

The birth process is known as labor. Typically, the amnion ruptures right before birth, so amniotic fluid drains from the vagina. The cervical canal dilates and the fetus can move out of the uterus, then through the vagina and into the outside world (Figure 44.23).

Remember the hormone **oxytocin**? It causes smooth muscle inside the uterine wall to contract during labor. When the fetus was nearing full term, it "dropped," or shifted downward, so its head touched the cervix. Receptors in the cervix sensed the mechanical pressure and signaled the hypothalamus, which induced the posterior lobe of the pituitary to secrete oxytocin.

Binding of oxytocin to smooth muscle now causes an increase in the strength of contractions, which puts more mechanical pressure on the cervix. More of the hormone is secreted. And so, in a **positive feedback cycle**, the stretching causes oxytocin secretion, which causes more stretching, and so on until the fetus is expelled and there is no more mechanical pressure on the cervix. Intravenous injections of synthetic oxytocin can be given to induce or increase contractions.

The strong contractions also detach and expel the placenta from the uterus, as the afterbirth. They help stop bleeding at the site where the placenta attached to the wall of the uterus. They constrict blood vessels at the ruptured attachment site, so the umbilical cord can be cut and tied off. A few days after shriveling up, the cord's stump has become the navel.

Corticotropin-releasing hormone (CRH) affects the timing of labor, and it might contribute to *postpartum depression*. The hypothalamus makes this hormone in all humans, but the placenta also produces it. During pregnancy, its blood level may increase three times. CRH stimulates the adrenal cortex to secrete **cortisol** (Sections 36.8 and 36.9). This hormone might help the mother-to-be cope with the extraordinary physical and emotional strains of pregnancy and labor.

During pregnancy, a high blood level of cortisol can suppress CRH production by the hypothalamus. After the placenta is expelled, the CRH level briefly plummets. The decline commonly triggers a short-term depression that may continue until the hypothalamus resumes its normal production of CRH.

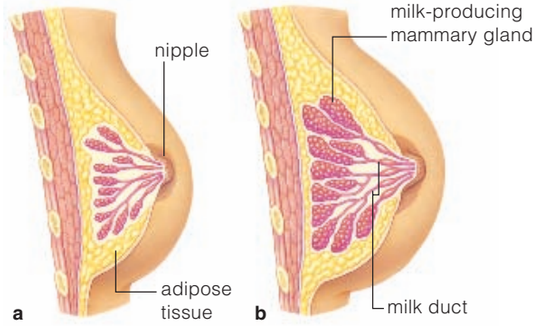


Figure 44.24 (**a**) Breast of a human female who is not pregnant. (**b**) Breast of a lactating female.

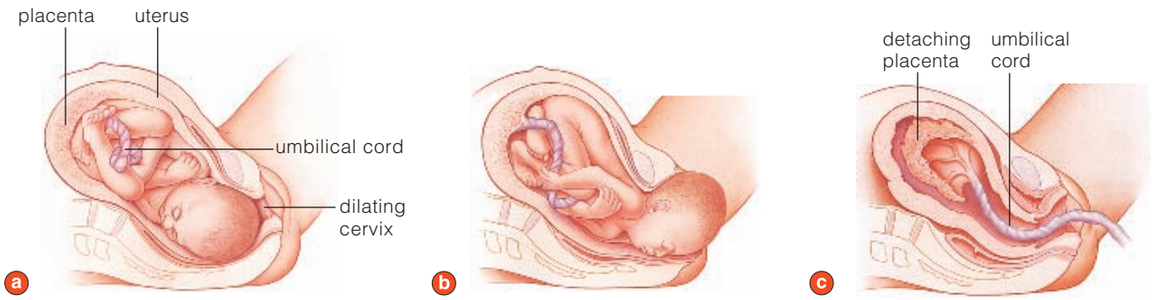


Figure 44.23 Expulsion of (**a**,**b**) a human fetus and (**c**) afterbirth during labor. Afterbirth consists of the placenta, tissue fluid, and blood.

NOURISHING THE NEWBORN

Once the lifeline to the mother is severed, a newborn enters the extended time of dependency and learning that is typical of all primates (Section 26.10 and page 461). Its early survival requires an ongoing supply of milk or its nutritional equivalent. **Lactation**, or milk production, occurs in mammary glands in a mother's breasts (Figure 44.24). Before pregnancy, breast tissue is largely adipose tissue and a system of undeveloped ducts. Their size depends on how much fat they hold, not on milk-producing capacity. During pregnancy, estrogens and progesterone stimulate development of a glandular system for milk production.

For the first few days after birth, mammary glands produce a fluid rich in proteins and lactose. **Prolactin**, a hormone that calls for synthesis of enzymes used in milk production, is secreted by the mother's anterior pituitary (Section 36.3). When the newborn suckles, the pituitary releases oxytocin, which triggers muscle contractions that force fluid into milk ducts. It also causes uterine contractions that help shrink this birth chamber back to its pre-pregnancy size.

Besides being nutrient-rich, human breast milk has immunoglobulins that enhance resistance to infection. Some other components stimulate growth of bacterial symbionts in the infant gut. However, alcohol, drugs, mercury, and other toxins in a mother's body also can be secreted in milk. As during pregnancy, a nursing mother should tailor her life-style and diet.

POSTNATAL DEVELOPMENT

As is the case for many species, humans change in size and proportion until they reach sexual maturity. Figure 44.25 shows a few of the proportional changes during the life cycle. Table 44.6 defines the prenatal ("before birth") and postnatal ("after birth") stages.

Postnatal growth is most rapid between the years thirteen and nineteen. Not until adulthood are bones fully mature. Long after the adults have put the new generation on a path toward sexual reproduction and development, they gradually age and then pass on in a natural turn of events in the life cycle (Sections 43.6 and 43.7). Selection has favored the perpetuation of genes, not morphological immortality.

The human life cycle flows naturally from the time of birth, growth, and development, to production of the individual's own offspring, and on through aging to the time of death.

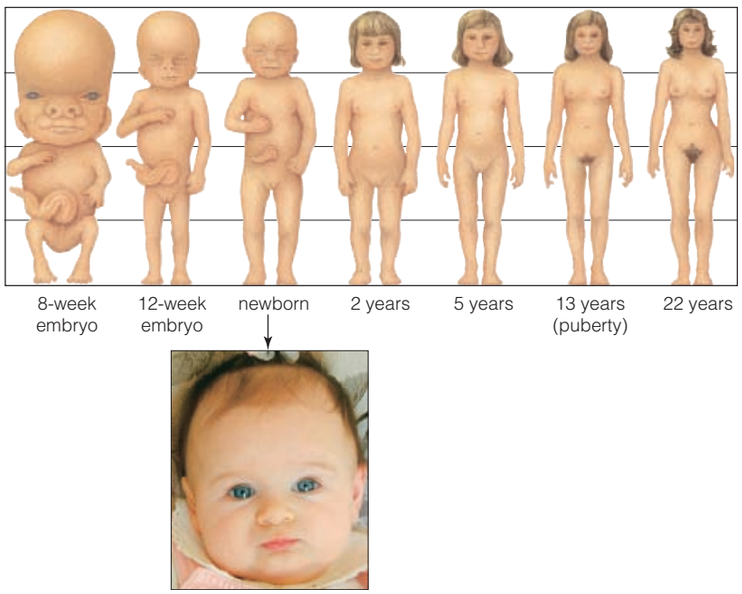


Figure 44.25 Observable, proportional changes in the human body during prenatal and postnatal periods of development. Changes in overall physical appearance are slow but noticeable until the teenage years. For example, compared to an embryo, the legs of teenagers are longer and the trunk shorter, so the head is proportionally smaller. Correlate these drawings with the stages in Table 44.6.

Table 44.6 Stages of Human Development

Prenatal period	
Zygote	Single cell resulting from fusion of sperm nucleus and egg nucleus at fertilization.
Morula	Solid ball of cells produced by cleavages.
Blastocyst (blastula)	Ball of cells with surface layer, fluid-filled cavity, and inner cell mass.
Embryo	All developmental stages from two weeks after fertilization until end of eighth week.
Fetus	All developmental stages from ninth week to birth (about 38 weeks after fertilization).
Postnatal period	
Newborn	Individual during the first two weeks after birth.
Infant	Individual from two weeks to about fifteen months after birth.
Child	Individual from infancy to about ten or twelve years.
Pubescent	Individual at puberty; secondary sexual traits develop; girls between 10 and 15 years, boys between 12 and 16 years.
Adolescent	Individual from puberty until about 3 or 4 years later; physical, mental, emotional maturation.
Adult	Early adulthood (between 18 and 25 years); bone formation and growth finished. Changes proceed slowly after this.
Old age	Aging processes result in expected tissue deterioration.

44.15 On Human Fertility

FOCUS ON BIOETHICS

LINK TO SECTION 20.4

The motivation to engage in sex during the life cycle has been evolving for hundreds of millions of years. A few centuries of moral arguments for self-control have not suppressed it. How will we reconcile our biological past with the need for a stabilized cultural present?

In this chapter, you tracked the transformation of a human zygote into an adult. That transformation raises profound questions. *When, precisely, does development begin?* As you have seen, major developmental events unfold even before fertilization. *When does life begin?* During her lifetime, a female may produce as many as 500 eggs, all of which are alive. With one ejaculation, a male may release a quarter of a billion sperm, all of which are alive. Before one sperm and one egg merge by chance and establish the genetic makeup of a new individual, they are as much alive as any other form of life.

It is scarcely tenable, then, to say that life begins at fertilization. *Life began more than 3.8 billion years ago—and each gamete, each zygote, and each sexually mature individual is but a fleeting stage in the continuation of that beginning.*

This greater perspective on life cannot diminish the meaning of conception. It is no small thing to entrust a new individual with the gift of life, wrapped in the unique evolutionary threads of our species and handed down through an immense sweep of time.

Yet how can we reconcile the marvel of individual birth with the astounding birth rate for our species? About 14,800 newborns are entering the world every hour. By the time you go to bed tonight, there may be 356,000 more—about as many as there are in Cincinnati. In less than four months, there may 36,800,000 more—about as many as there are now in the entire state of California.

Human population growth is outstripping resources. Many millions already face the horrors of starvation. Living where we do, few of us know what it means to give birth to a child, to give it the gift of life, and have no food to keep it alive.

And how can we reconcile the marvel of birth with the reality of unwanted pregnancies? In the United States, about half of all pregnancies are unintended, and half of those—750,000 to 1 million annually—end in abortion. Complex biological and social factors contribute to sexual behavior. Many teenagers have reported that they were not mature enough or willing to accept responsibility for sexual behavior that has unintended consequences. Far more adult women around the world say they simply have no resources to raise a child, or one more child. In 2004 alone, close to 46 million chose abortions.

Whether and how fertility should be controlled is a volatile issue. We return to this issue in the next chapter, in the context of principles that govern the growth and stability of all populations.

http://biology.brookscole.com/starr11

Summary

Sections 44.1–44.3 The human reproduction system consists of a pair of primary reproductive organs, or gonads, and accessory organs and ducts. Gonads produce gametes, the packages that perpetuate one's genes. They also produce sex hormones that orchestrate reproductive function and the development of gender-specific secondary sexual traits.

The male gonads are testes. Leading away from each is an epididymis, vas deferens, and ejaculatory duct in which sperm successively finish maturing, are stored, and then are rapidly transported to the urethra that opens onto the surface of the tip of the penis.

Sperm are mixed with secretions from two seminal vesicles, a bulbourethral gland, and a prostate gland to form semen, a thick fluid that is expelled from the penis during sexual activity.

Feedback loops from the testes to the hypothalamus and pituitary gland govern secretion of GnRH, LH, FSH, and testosterone, which control sperm formation and male reproductive function. Testosterone, which Leydig cells in testes secrete, promotes development of male secondary sexual traits as well.

Each sperm is a flagellated cell. Its head is packed with DNA and has an enzyme-filled cap. Sertoli cells in the testes nourish them as they mature.

The female gonads are ovaries. Other reproductive organs are a pair of oviducts (Fallopian tubes) that form a channel to the uterus, a muscular chamber in which embryos develop. The cervix, a narrowed neck of the uterus, opens to the vagina, the organ of sexual intercourse as well as the birth canal.

BiologyNow

Learn about the reproductive system of the human male with the animation on BiologyNow.

See how sperm form with the animation on BiologyNow.

Learn about the reproductive system of the human female with the animation on BiologyNow.

Sections 44.4, 44.5 A menstrual cycle is a recurring cycle of fertility during the reproductive years. A human female cycle is monthly. Feedback loops from the ovaries to the hypothalamus and anterior lobe of the pituitary gland control the cycle's three phases:

Follicular phase. The hypothalamus secretes GnRH, which stimulates the anterior pituitary to secrete FSH and LH. These sex hormones act on a follicle: a primary oocyte, arrested in meiosis I, and a cell layer around it. The follicle matures and secretes estrogens that stimulate the endometrium, the lining of the uterine chamber, to thicken in preparation for pregnancy. The oocyte finishes meiosis I. Cytoplasmic division follows and results in a large secondary oocyte and one polar body, which quickly degenerates.

Ovulatory phase. A midcycle surge of LH triggers the release of the secondary oocyte from the ovary. This event is called ovulation.

Luteal phase. After ovulation, a glandular structure, the corpus luteum, forms from remnants of the follicle. It secretes progesterone and some estrogen that prime the endometrium for fertilization. If fertilization occurs, the corpus luteum will be maintained until a placenta forms. If fertilization does not occur, the corpus luteum will degenerate. The endometrium will break down and get sloughed off with blood, and a new cycle will begin.

BiologyNow

Observe the cyclic changes in an ovary with the animation on BiologyNow.

Learn about the effects of hormones on the menstrual cycle with the animation on BiologyNow.

Section 44.6 As a sperm penetrates it, a secondary oocyte is stimulated to complete meiosis II; cytoplasmic division results in one mature egg (ovum) and two polar bodies. Fertilization is complete when the egg nucleus fuses with the sperm nucleus to form a zygote.

BiologyNow

See what happens during fertilization with the animation on BiologyNow.

Sections 44.7, 44.8 Humans prevent pregnancy by abstinence, surgery, physical or chemical barriers, or manipulations of female sex hormones. Unsafe sex and other behaviors promote the spread of pathogens that cause sexually transmitted diseases, or STDs.

BiologyNow

Read the InfoTrac article "Genital Herpes: A Hidden Epidemic," Linda Bren, FDA Consumer, *March–April 2002.*

Section 44.9 After fertilization, cleavage begins and transforms the zygote into a blastocyst, which implants itself in the endometrium. HCG, a hormone the blastocyst secretes, stimulates the corpus luteum to keep on maintaining the endometrium. Gastrulation starts with the formation of ectoderm, endoderm, and mesoderm. Four extraembryonic membranes also form:

The *amnion* becomes a fluid-filled sac around the embryo, which it protects from drying out, mechanical shock, and abrupt temperature changes.

In most shelled eggs, a *yolk sac* stores nutritive yolk. In humans, part of the sac becomes a major site of blood formation. Some of its cells give rise to germ cells that later give rise to sperm or eggs.

The *chorion*, a protective membrane, encloses the embryo and the other extraembryonic membranes. It becomes a major component of the placenta.

In humans, blood vessels for the placenta arise from the *allantois*, as does the urinary bladder.

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Observe early human development with the animation on BiologyNow.

Section 44.10 The anterior–posterior body axis forms in the gastrula. The gastrula's neural disk gives rise to the neural tube, the forerunner of the brain and spinal cord. Somites are paired bumps of mesoderm that give rise to skeletal muscles, bones, and the overlying dermis.

Sections 44.11–44.13 A blood-engorged organ, the placenta, gradually forms from endometrial tissue and extraembryonic membranes. It permits embryonic blood vessels to develop independently of the mother's but also allows oxygen, nutrients, and wastes to diffuse between them. To some extent, the placenta serves as a protective barrier for the fetus. But it cannot protect the fetus from harmful effects of the mother's nutritional deficiencies, infections, intake of prescription drugs, illegal drugs, alcohol, and cigarette smoke.

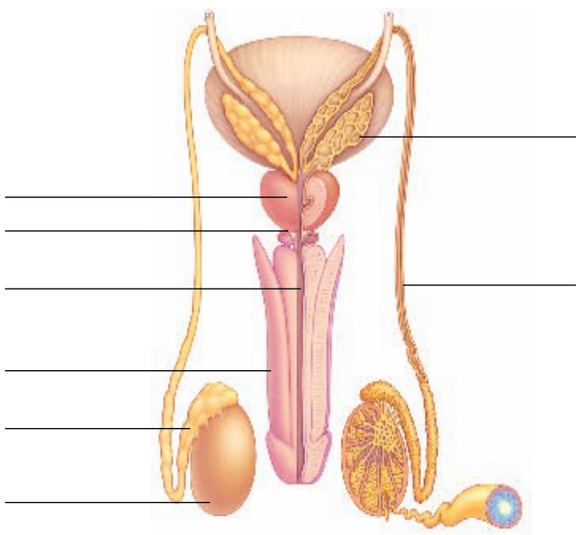
The embryo has distinctly human features by the end of the eighth week of pregnancy and thereafter is called a fetus. A mother's health, nutrition, and life-style affect fetal growth and development.

Section 44.14 During labor, uterine contractions expel the fetus and afterbirth. Hormones trigger labor, the maturation of mammary glands, and milk flow. Most development and growth are over by adulthood.

Self-Quiz

Answers in Appendix II

1. Label all of the parts of the human male reproductive system and check to see that you can state their functions:



2. Label all of the parts of the human female reproductive system and check to see that you can state their functions:

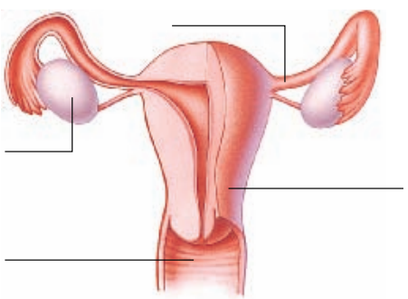


Figure 44.26 Identical twins Sabra and Nina, who started life as the same zygote. The first two blastomeres that formed at cleavage, the inner cell mass, or some other early stage split and gave rise to two genetically identical individuals.

3. Meiotic divisions of _____ produce mature sperm.
   a. Leydig cells
   b. Sertoli cells
   c. both a and b
   d. neither a nor b

4. During a menstrual cycle, a midcycle surge of _____ triggers ovulation.
   a. estrogens b. progesterone c. LH d. FSH

5. The corpus luteum secretes _____ .
   a. LH b. FSH c. progesterone d. prolactin

6. Which of the following is (are) caused by bacteria?
   a. chlamydia
   b. gonorrhea
   c. genital warts
   d. trichomoniasis
   e. a and b
   f. c and d

7. A _____ implants in the lining of the uterus.
   a. zygote b. gastrula c. blastocyst d. fetus

8. Which of the following puts human developmental stages in the correct order?
   a. zygote, blastocyst, embryo, fetus
   b. zygote, embryo, blastocyst, fetus
   c. zygote, embryo, fetus, blastocyst
   d. blastocyst, zygote, embryo, fetus

9. A human ovum is a(an) _____ .
   a. immature ooocyte
   b. primary oocyte
   c. secondary oocyte
   d. tertiary oocyte

10. The _____ , a fluid-filled sac, surrounds and protects an embryo and keeps it from drying out.
   a. yolk sac b. allantois c. amnion d. chorion

11. At full term, a placenta _____ .
   a. is composed of extraembryonic membranes alone
   b. directly connects maternal and fetal blood vessels
   c. keeps maternal and fetal blood vessels separated

12. (A) _____form(s) in all vertebrate embryos.
   a. neural tube
   b. somites
   c. pharyngeal arches
   d. primitive streak
   e. a through c
   f. a through d

13. Distinctly human features emerge in the embryo by the end of the _____ week after fertilization.
   a. second
   b. third
   c. fourth
   d. fifth
   e. eighth
   f. sixteenth

14. Match each term with the most suitable description.

____ testis	a. maternal and fetal tissues
____ cervix	b. stores mature sperm
____ placenta	c. produces testosterone
____ vagina	d. produces estrogen and progesterone
____ ovary	e. usual site of fertilization
____ oviduct	f. lining of uterus
____ epididymis	g. birth canal
____ endometrium	h. entrance to uterus

Additional questions are available on Biology Now™

Critical Thinking

1. A male erection occurs when blood flows into the penis faster than it flows out. Signals from the nervous system cause nerve endings in the penis to release nitric oxide, a neurotransmitter. When nitric oxide binds to receptors on postsynaptic cells in the organ's spongy tissue, it activates an enzyme that catalyzes production of cGMP (short for cyclic guanine monophosphate). The cGMP causes blood vessels to vasodilate, which lets more blood flow in. When all else is working smoothly, an erection occurs.

   Erectile dysfunction is being treated with drugs such as sildenafil, sold under the brand name Viagra, which target PDE–5 (short for phosphodiesterase–5). This liver enzyme converts cGMP to inactive form. Sketch out a simple flow chart that shows the normal action of nitric oxide, cGMP, and PDE–5 and identify where sildenafil acts.

2. Drugs that inhibit signals of sympathetic neurons may be prescribed for males who have high blood pressure. How might such drugs interfere with sexual behavior?

3. On rare occasions, Leydig cells form tumors in young boys, and the testes secrete as much as 1,000 times the normal amount of testosterone. The boys grow up much shorter than would otherwise be expected. Explain why, and also speculate on what other symptoms may develop.

4. *Identical twins* form when an embryo splits, most often between the third and eighth day following fertilization. Worldwide, the birth rate of identical twins is about 4 in every 1,000, with no significant difference among ethnic groups. Because identical twins arise from the same fertilized egg, they have the same genotype and look much the same (Figure 44.26).

   Fraternal twins, which are nonidentical genetically, arise when two oocytes mature, are released, and become fertilized at the same time. Such twins run in families. The incidence varies among ethnic groups and is highest among blacks and lowest in Asians. The variation might be an outcome of differences in gene products that affect the FSH level in blood.

   Explain how a high FSH level in blood would increase the likelihood of fraternal twins. In addition, explain why variation in FSH levels would not affect the incidence of identical twins.

5. By UNICEF estimates, each year 110,000 people are born with abnormalities as a result of rubella infections. Major symptoms of *congenital rubella syndrome,* or CRS, are deafness, blindness, mental impairment, and heart problems. A fetus is at risk if a nonvaccinated female is infected during the first trimester, but not later. Review the developmental events that unfold during pregnancy and explain why this is the case.

6. Given what you have read about where a human embryo develops, explain why a tubal pregnancy, as shown in Figure 44.14*a*, must be surgically terminated.

7. In the United States, teenage pregnancies as well as STD infections are rampant. Suppose the office of the Surgeon General requests your participation in a task force that will recommend practices that might reduce the incidence of teenage pregnancies and STD infections. What practices might have the most success? Would they provoke enthusiasm or resistance among teenagers in your community? Among adults? Explain why.

VII Principles of Ecology

Two organisms—a fox in the shadows cast by a snow-dusted spruce tree. What are the consequences of their interactions with each other, with other kinds of organisms, and with their environment? By the end of this last unit, you might find worlds within worlds in such photographs.