22

Developmental Anatomy, Postnatal Growth, and Inheritance

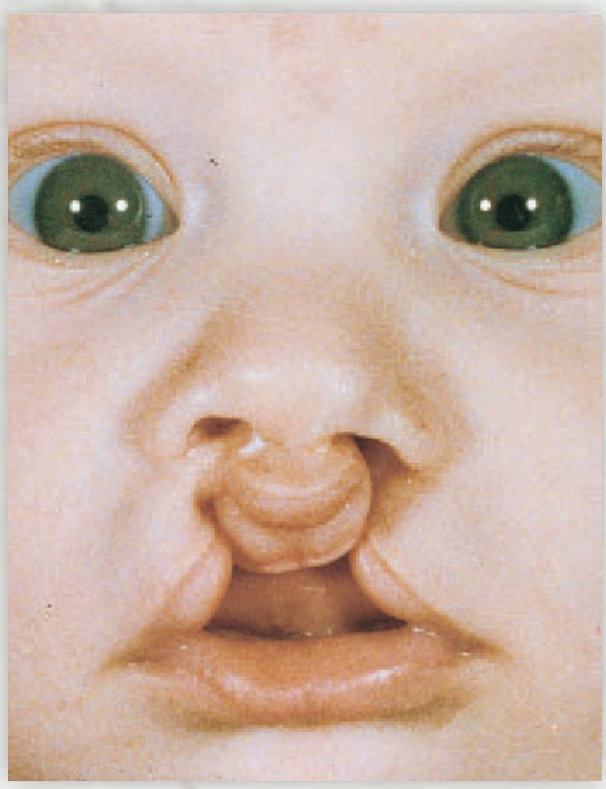

FIGURE: A cleft lip and an accompanying cleft palate are congenital disorders in which one or two sides of the upper lip and hard palate fail to fuse. Cleft lips and cleft palates can be treated very effectively with surgery.

Clinical Case Study

A 27-year-old woman gave birth to twin boys, followed by an apparently single placenta. After examining the two infants, the pediatrician informed the mother that one of them had a cleft palate but that the other was normal. She added that cleft palate could be hereditary and asked if any family members had the problem. The mother said that she knew of none. Further examination of the placenta revealed two amnions and only one chorion.

Does the presence of two amnions and one chorion indicate monozygotic or dizygotic twins? How would you account for the fact that one baby has a cleft palate, whereas the other does not?

Hints: Read the section on multiple pregnancy at the end of the chapter and carefully study figure 22.37. Can any conclusions be drawn regarding genetic similarities between the two infants? Note that identical twins are always the same gender.

FERTILIZATION

Upon fertilization of an ovum by a spermatozoon in the uterine tube, meiotic development is completed and a diploid zygote is formed.

Objective 1 Define *fertilization, capacitation,* and *morphogenesis.*

Objective 2 Describe the changes that occur in the spermatozoon and ovum prior to, during, and immediately following fertilization.

Fertilization refers to the penetration of an ovum (egg) by a spermatozoon (fig. 22.1), with the subsequent union of their genetic material. It is this event that determines a persons' gender (see p. 716) and biological inheritance. Fertilization cannot occur, however, unless certain conditions are met. First of all, an ovum must be present in the uterine tube—it can be there for at most 24 hours before it becomes incapable of undergoing fertilization. Second, large numbers of spermatozoa must be ejaculated to ensure fertilization. Although a recent study has shown that sperm cells can remain viable 5 days after ejaculation, this still leaves a "window of fertility" of only 6 days each month—the day of ovulation and the 5 days leading up to it.

As described in chapter 21, a woman usually ovulates one ovum a month, totaling about 400 during her reproductive years. Each ovulation releases an ovum that is actually a secondary oocyte arrested at metaphase of the second meiotic division. An ovum is surrounded by a thin layer of protein and polysaccharides, called the *zona pellucida*, and a layer of granulosa cells, called the *corona radiata* (fig. 22.1). These layers provide a protective shield around the ovum as it enters the uterine tube.

During coitus, a male ejaculates between 100 million and 500 million spermatozoa into the female's vagina. This tremendous number is needed because of the high fatality rate—only about 100 sperm cells survive to encounter the ovum in the uterine tube. In addition to deformed sperm cells—up to 20% in the

zona pellucida: L. *zone*, a girdle; *pellis*, skin
corona radiata: Gk. *korone*, crown; *radiata*, radiate

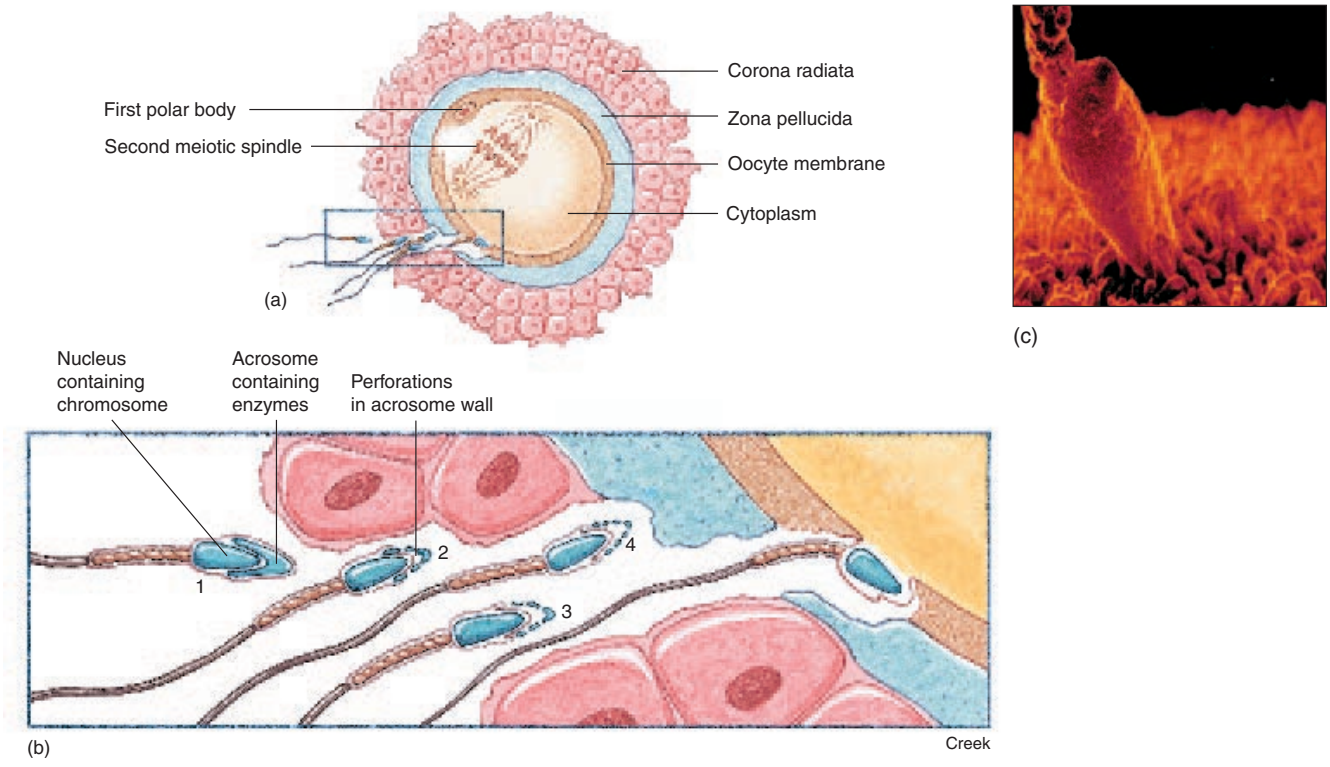

FIGURE 22.1 The process of fertilization. (*a,b*) As the head of the sperm encounters the corona radiata of the oocyte (2), digestive enzymes are released from the acrosome (3, 4), clearing a path to the oocyte membrane. When membrane of the sperm contacts the oocyte membrane (5), the membranes become continuous, and the nucleus and other contents of the sperm move into the egg cytoplasm of the oocyte. (*c*) A scanning electron micrograph of a sperm cell bound to the surface of an oocyte.

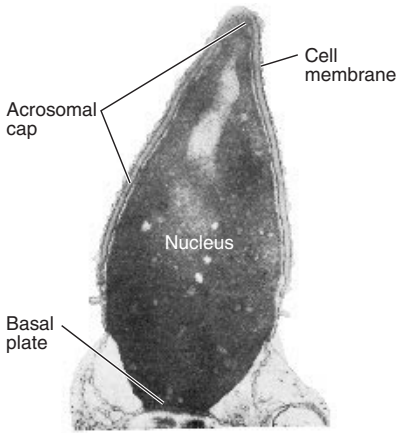

FIGURE 22.2 A transmission electron micrograph showing the head of a human spermatozoon with its nucleus and acrosome.

average fertile male—another 25% will perish as soon as they contact the vagina's acidic environment. Still others are destroyed by the woman's immune cells, which recognize them as foreign cells. Even if they manage to reach the uterine ostium (see fig. 21.12), many sperm cells will get stuck there and never make it through the uterus.

If it finally encounters an ovum, the spermatozoon must penetrate the protective corona radiata and zona pellucida for fertilization to occur. To do this, the head of each sperm cell is capped by an organelle called an **acrosome** (*ak′rŏ-sōm*) (figs. 22.1 and 22.2). The acrosome contains a trypsinlike protein-digesting enzyme and *hyaluronidase* (*hi′′ă-loo-ron′ĭ-dās*), which digests hyaluronic acid, an important constituent of connective tissue. When a spermatozoon meets an ovum in the uterine tube, an *acrosomal reaction* allows the spermatozoon to penetrate the corona radiata and the zona pellucida. A spermatozoon that comes along relatively late—after many others have undergone acrosomal reactions to expose the ovum membrane—is more likely to be the one that finally achieves penetration of the egg.

Experiments confirm that freshly ejaculated spermatozoa are infertile and must be in the female reproductive tract for at least 7 hours before they can fertilize a secondary oocyte. Their membranes must become fragile enough to permit the release of the acrosomal enzymes—a process called *capacitation*. During in vitro fertilization, capacitation is induced artificially by treating the ejaculate with a solution of gamma globulin, free serum, follicular fluid, dextran, serum dialysate, and adrenal gland extract to chemically mimic the conditions of the female reproductive tract.

acrosome: Gk. *akron*, extremity; *soma*, body
capacitation: L. *capacitas*, capable of

As soon as a spermatozoon penetrates the zona pellucida, a rapid chemical change in this layer prevents other spermatozoa from attaching to it. Therefore, only one spermatozoon is permitted to fertilize an oocyte. With the penetration of a single spermatozoon through its cell membrane, the oocyte is stimulated to complete its second meiotic division (fig. 22.3). Like the first meiotic division, the second produces one cell that contains most of the cytoplasm and one polar body. The cell containing the cytoplasm is the mature ovum, and the second polar body, like the first, ultimately fragments and disintegrates.

At fertilization, the head of the sperm cell enters the cytoplasm of the much larger ovum. Within 12 hours, the nuclear membranes in both the sperm cell and ovum disappear, and the haploid number of chromosomes (23) in the ovum is joined by the haploid number of chromosomes from the spermatozoon. A fertilized egg, or **zygote** (*zī′gōt*), containing the diploid number of chromosomes (46) is thus formed.

Within hours after conception, the structure of the body begins to form from this single fertilized egg, culminating some 38 weeks later with the birth of a baby. The transformation involved in the growth and differentiation of cells and tissues is known as **morphogenesis** (*mor′′fo-jen′ĭ-sis*), and it is through this awesome process that the organs and systems of the body are established in a functional relationship. Moreover, there are sensitive periods of morphogenesis for each organ and system, during which genetic or environmental factors may affect normal development.

Prenatal development can be divided into a *preembryonic period*, which is initiated by the fertilization of an ovum; an *embryonic period*, during which the body's organ systems are formed; and a *fetal period*, which culminates in parturition (childbirth).

Knowledge Check

1. Explain why capacitation and the acrosomal reaction of spermatozoa are necessary to accomplish fertilization of a secondary oocyte.
2. Discuss the changes that occur in a spermatozoon from the time of ejaculation to the time of fertilization. What changes occur in a secondary oocyte following ovulation to the time of fertilization?
3. Define *morphogenesis*. When does this process begin? What does it accomplish?

haploid: Gk. *haplous*, single; L. *ploideus*, multiple in form
zygote: Gk. *zygotos*, yolked, joined
diploid: Gk. *diplous*, double; L. *ploideus*, multiple in form
morphogenesis: Gk. *morphe*, form; *genesis*, beginning

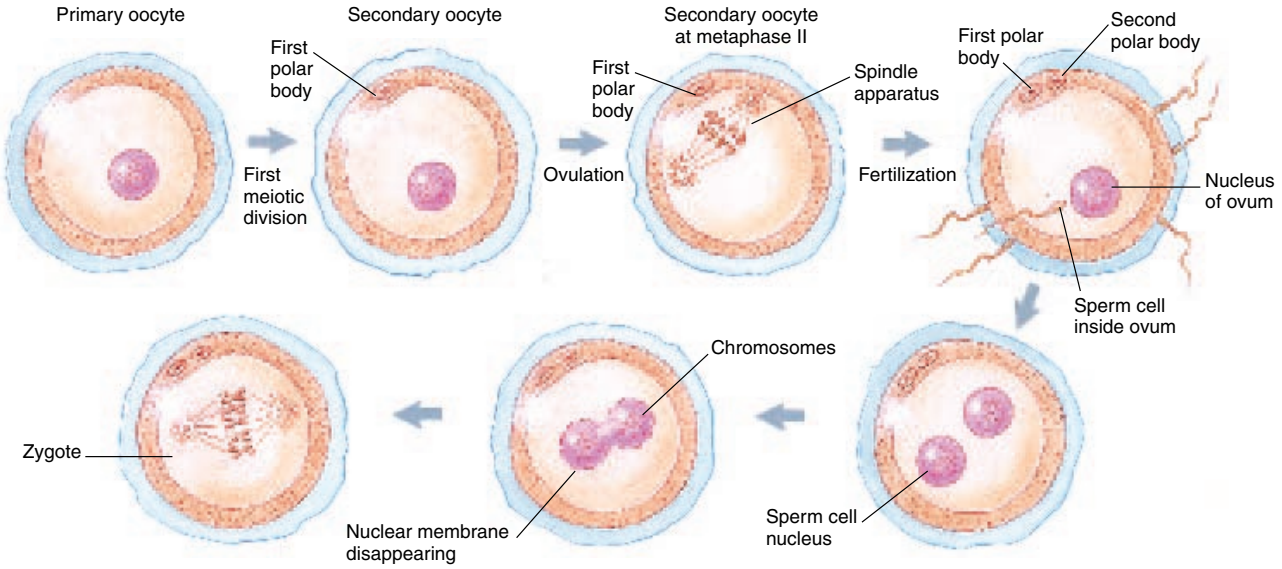

FIGURE 22.3 A secondary oocyte, arrested at metaphase II of meiosis, is released at ovulation. If this cell is fertilized, it will become a mature ovum, complete its second meiotic division, and produce a second polar body. The fertilized ovum is known as a zygote.

PREEMBRYONIC PERIOD

The events of the 2-week preembryonic period include fertilization, transportation of the zygote through the uterine tube, mitotic divisions, implantation, and the formation of primordial embryonic tissue.

Objective 3 Describe the events of preembryonic development that result in the formation of the blastocyst.

Objective 4 Discuss the role of the trophoblast in the implantation and development of the placenta.

Objective 5 Explain how the primary germ layers develop and list the structures produced by each layer.

Objective 6 Define *gestation* and explain how the parturition date is determined.

Cleavage and Formation of the Blastocyst

Within 30 hours following fertilization, the zygote undergoes a mitotic division called **cleavage.** This first division results in the formation of two identical daughter cells called *blastomeres* (fig. 22.4). Additional cleavages occur as the structure passes down the uterine tube and enters the uterus on about the third day. It is now composed of a ball of 16 or more cells called a **morula** (*mor′yŭ-lă*). Although the morula has undergone several mitotic divisions, it is not much larger than the zygote because no additional nutrients necessary for growth have been entering the cells. The morula floats freely in the uterine cavity for about 3 days. During this time, the center of the morula fills with fluid passing in from the uterine cavity. As the fluid-filled space develops within the morula, two distinct groups of cells form, and the structure becomes known as a **blastocyst** (*blas′tŏ-sist*) (fig. 22.4). The hollow, fluid-filled center of the blastocyst is called the **blastocyst cavity.** The blastocyst is composed of an outer layer of cells, known as the **trophoblast,** and an inner aggregation of cells, called the **embryoblast** (*internal cell mass)* (see fig. 22.6). With further development, the trophoblast differentiates into a structure called the **chorion** (*kor′e-on*), which will later become a portion of the placenta. The embryoblast will become the embryo. A diagrammatic summary of the ovarian cycle, fertilization, and the morphogenic events of the first week is presented in figure 22.5.

Implantation

The process of **implantation** begins between the fifth and seventh day following fertilization. This is the process by which the blastocyst embeds itself into the endometrium of the uterine wall (fig. 22.6*a*). Implantation is made possible by the secretion of *proteolytic enzymes* by the trophoblast, which digest a portion of the endometrium. The blastula sinks into the depression, and endometrial cells move back to cover the defect in the wall. At the same time, the part of the uterine wall below the implanting

morula: L. *morus,* mulberry

blastocyst: Gk. *blastos,* germ; *kystis,* bladder
trophoblast: Gk. *trophe,* nourishment; *blastos,* germ
chorion: Gk. *chorion,* membrane
implantation: L. *im,* in; *planto,* to plant

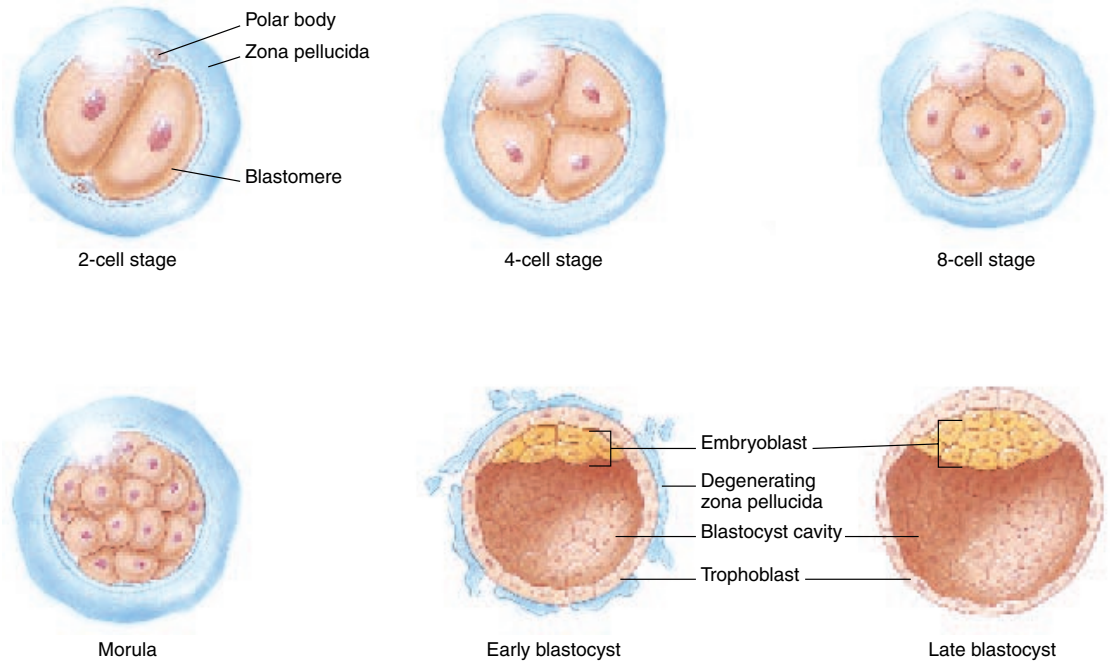

FIGURE 22.4 Sequential illustrations from the first cleavage of the zygote to the formation of the blastocyst. (Note the deterioration of the zona pellucida in the early blastocyst.)

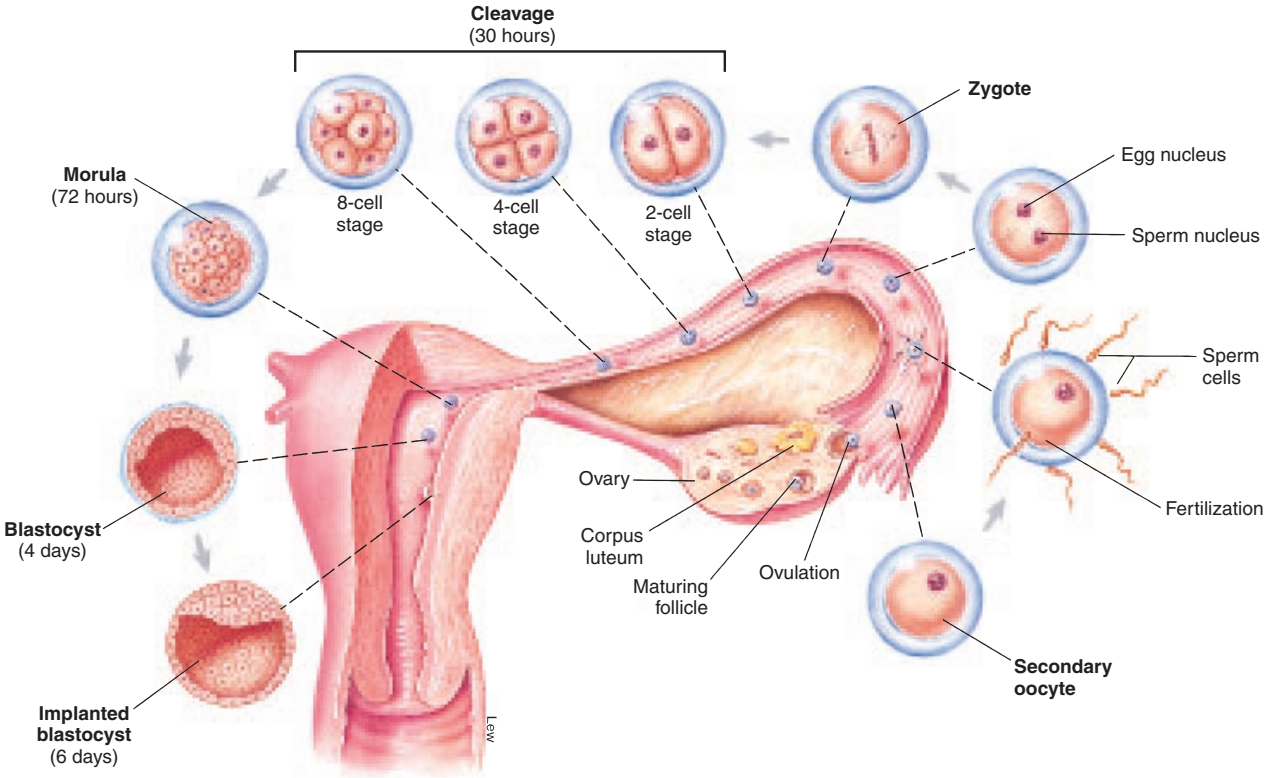

FIGURE 22.5 A diagram of the ovarian cycle, fertilization, and the events of the first week. Implantation of the blastocyst begins between the fifth and seventh day, and is generally completed by the tenth day.

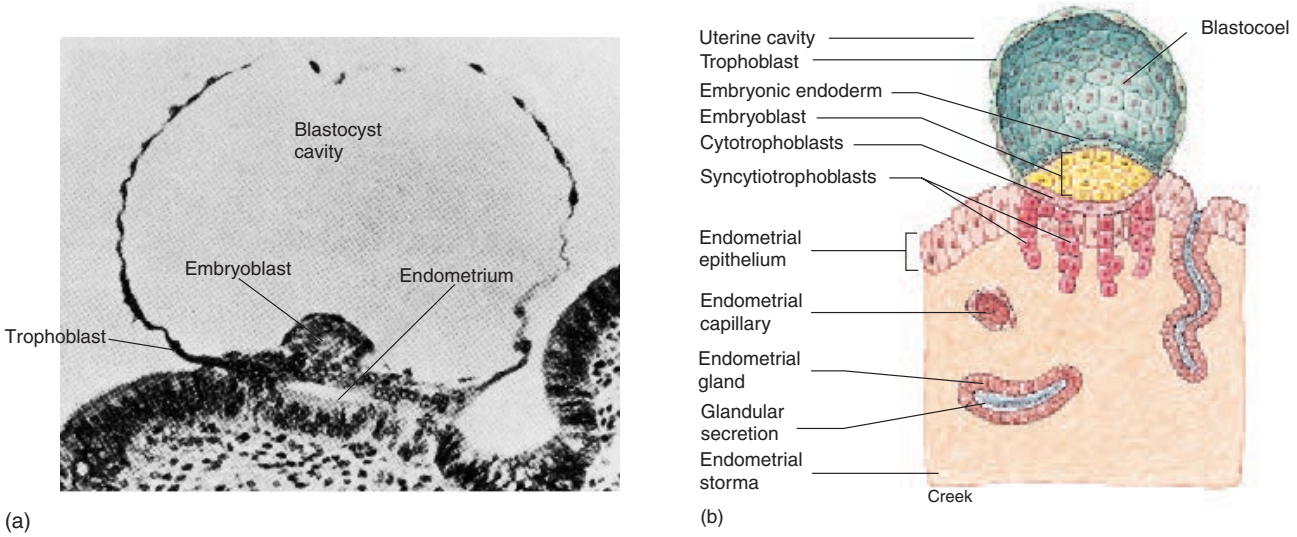

FIGURE 22.6 The blastocyst adheres to the endometrium on about the sixth day as seen in (*a*), a photomicrograph. By the seventh day (*b*), specialized syncytiotrophoblasts from the trophoblast have begun to invade the endometrium. The syncytiotrophoblasts secrete human chorionic gonadotropin (hCG) to sustain pregnancy and will eventually participate in the formation of the placenta for embryonic and fetal sustenance.

blastocyst thickens, and specialized cells of the trophoblast produce fingerlike projections, called **syncytiotrophoblasts** (*sin-sit''e-ŏ-trof'ŏ-blasts*), into the thickened area. The syncytiotrophoblasts arise from a specific portion of the trophoblast called the **cytotrophoblast** (fig. 22.6*b*), located next to the embryoblast.

The blastocyst saves itself from being aborted by secreting a hormone that indirectly prevents menstruation. Even before the sixth day when implantation begins, the syncytiotrophoblasts secrete **human chorionic gonadotropin** (*kor''e-on-ik go-nad-ŏ-tro'pin*) **(hCG).** This hormone is identical to LH in its effects, and therefore is able to maintain the corpus luteum past the time when it would otherwise regress. The secretion of estrogen and progesterone is maintained, and menstruation is normally prevented (fig. 22.7).

The secretion of hCG declines by the tenth week of pregnancy. Actually, this hormone is required only for the first 5 to 6 weeks of pregnancy because the placenta itself becomes an active steroid-secreting gland by this time. At the fifth to sixth week, the mother's corpus luteum begins to regress (even in the presence of hCG), but the placenta secretes more than sufficient amounts of steroids to maintain the endometrium and prevent menstruation.

All *pregnancy tests* assay for the presence of hCG in the blood or urine because this hormone is secreted only by the blastocyst. Because there is no other source of hCG, the presence of this hormone confirms a pregnancy. Modern pregnancy tests detect the presence of hCG by use of antibodies against hCG or by the use of cellular receptor proteins for hCG.

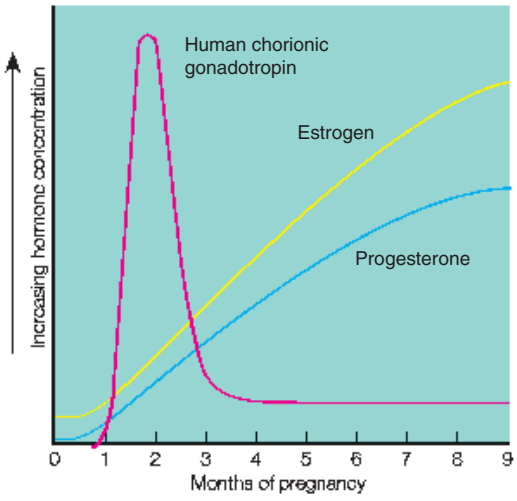

FIGURE 22.7 Human chorionic gonadotropin (hCG) is secreted by syncytiotrophoblasts during the first trimester of pregnancy. This pituitary-like hormone maintains the mother's corpus luteum for the first 5½ weeks of pregnancy. The placenta then assumes the role of estrogen and progesterone production, and the corpus luteum degenerates.

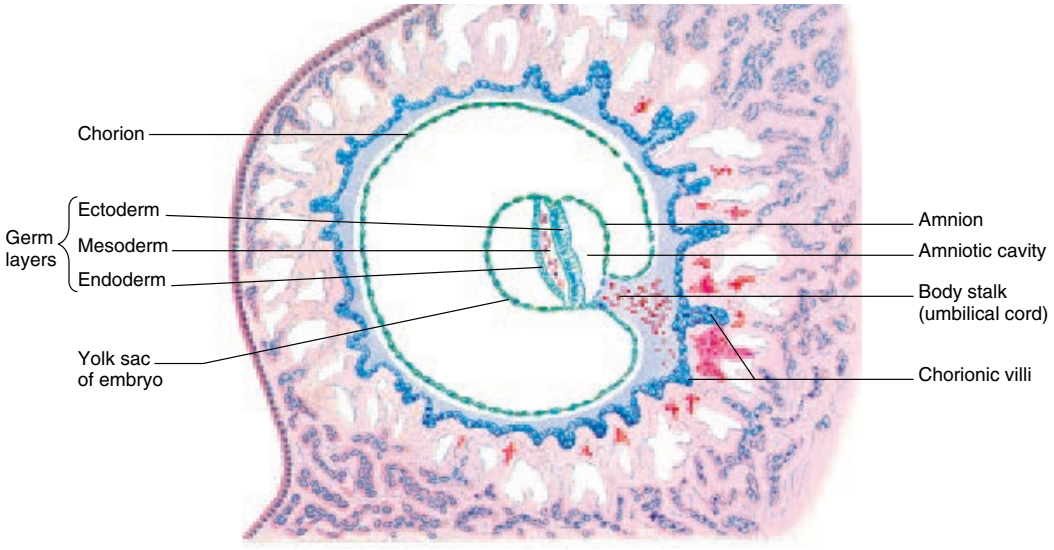

FIGURE 22.8 The completion of implantation occurs as the primary germ layers develop at the end of the second week.

TABLE 22.1 Summary of Preembryonic Development

Morphogenic Stage	Time Period	Principal Events
Zygote	24 to 30 hours following ovulation	Egg is fertilized; zygote has 23 pairs of chromosomes (diploid) from haploid sperm and haploid egg and is genetically unique
Cleavage	30 hours to third day	Mitotic divisions produce increased number of cells
Morula	Third to fourth day	Solid ball-like structure forms, composed of 16 or more cells
Blastocyst	Fifth day to end of second week	Hollow ball-like structure forms, a single layer thick; embryoblast and trophoblast form; implantation occurs; embryonic disc forms, followed by primary germ layers

Formation of the Germ Layers

As the blastocyst completes implantation during the second week of development, the embryoblast undergoes marked differentiation. A slitlike space called the **amniotic** (*am″ne-ot′ik*) **cavity** forms between the embryoblast and the trophoblast (fig. 22.8). The embryoblast flattens into the **embryonic disc** (see fig. 22.10), which consists of two layers: an upper **ectoderm,** which is closer to the amniotic cavity, and a lower **endoderm,** which borders the blastocyst cavity. A short time later, a third layer called the **mesoderm** forms between the endoderm and ectoderm. These three layers constitute the **primary germ layers** (fig. 22.8). Once they are formed, at the end of the second week, the preembryonic period is completed and the embryonic period begins.

The primary germ layers are especially significant because all of the cells and tissues of the body are derived from them. Ectodermal cells form the nervous system; the outer layer of skin (epidermis), including hair, nails, and skin glands; and portions of the sensory organs. Mesodermal cells form the skeleton, muscles, blood, reproductive organs, dermis of the skin, and connective tissue. Endodermal cells produce the lining of the GI tract, the digestive organs, the respiratory tract and lungs, and the urinary bladder and urethra.

The events of the preembryonic period are summarized in table 22.1. Refer to figure 22.9 for an illustration and a listing of the organs and body systems that derive from each of the primary germ layers.

The period of prenatal development is referred to as *gestation*. Normal gestation for humans is 9 months. Knowing this and the pattern of menstruation make it possible to determine the baby's delivery date. In a typical reproductive cycle, a woman ovulates 14 days prior to the onset of the next menstruation and is fertile for approximately 20 to 24 hours following ovulation. Adding 9 months, or 38 weeks, to the time of ovulation gives one the estimated delivery date.

ectoderm: Gk. *ecto,* outside; *derm,* skin
endoderm: Gk. *endo,* within; *derm,* skin
mesoderm: Gk. *meso,* middle; *derm,* skin

gestation: L. *gestatus,* to bear

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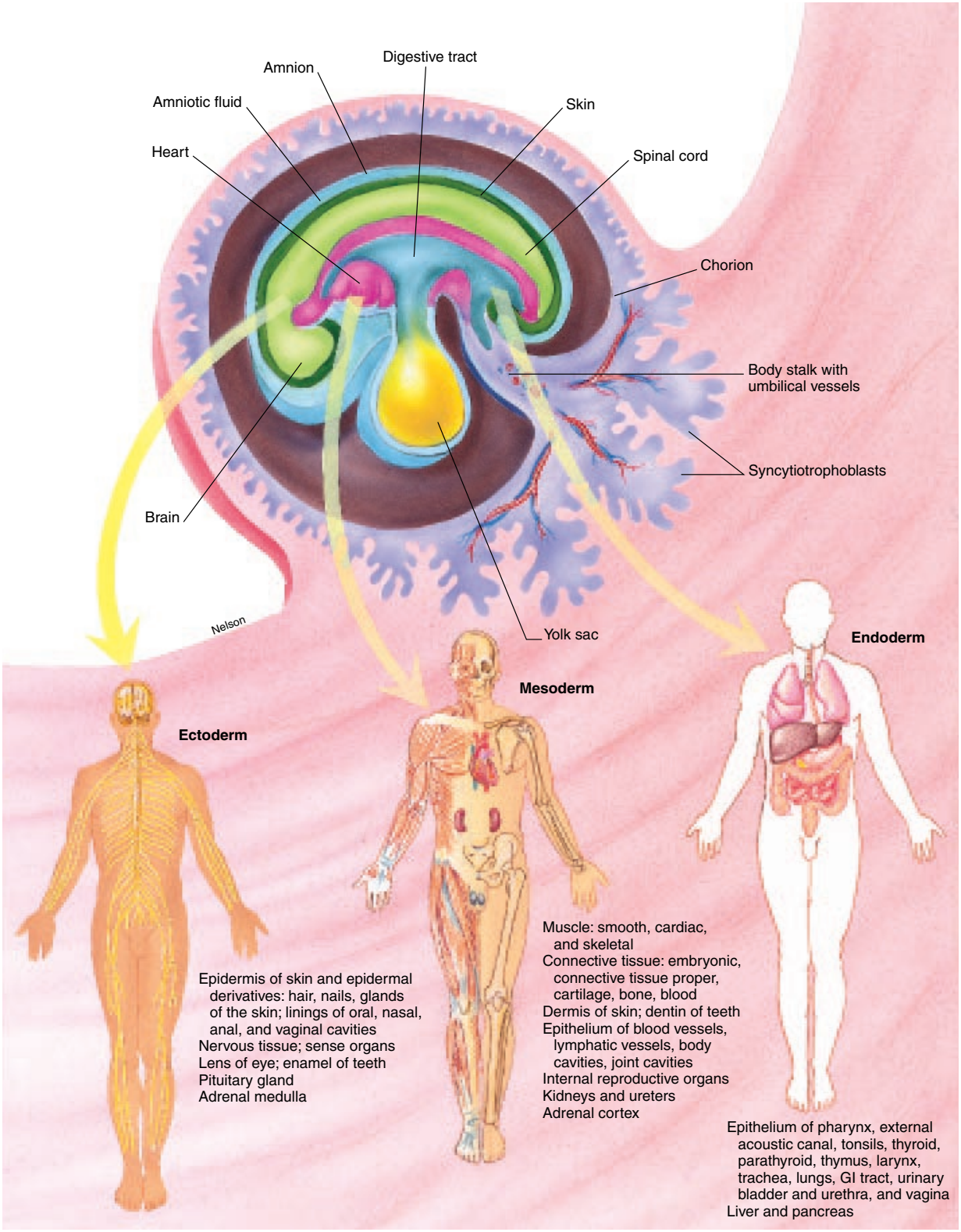


FIGURE 22.9 The body systems and the primary germ layers from which they develop.

Knowledge Check

4. List the structural characteristics of a zygote, morula, and blastocyst. Approximately when do each of these stages of the preembryonic period of development occur?
5. Discuss the process of implantation and describe the physiological events that ensure pregnancy.
6. Describe the development of the placenta.
7. List the major structures that derive from each germ layer.
8. Define *gestation*. What is the average gestation time for humans? How is the parturition date determined?

EMBRYONIC PERIOD

The events of the 6-week embryonic period include the differentiation of the germ layers into specific body organs and the formation of the placenta, the umbilical cord, and the extraembryonic membranes. Through these morphogenic events, the needs of the embryo are met.

Objective 7 Define *embryo* and describe the major events of the embryonic period of development.

Objective 8 List the embryonic needs that must be met to avoid a spontaneous abortion.

Objective 9 Describe the structure and function of each of the extraembryonic membranes.

Objective 10 Describe the development and functions of the placenta and the umbilical cord.

During the embryonic period—from the beginning of the third week to the end of the eighth week—the developing organism is correctly called an **embryo.** It is at this period that all of the body tissues and organs form, as well as the placenta, umbilical cord, and extraembryonic membranes. The term *conceptus* refers to the embryo, or to the fetus later on, and all of the extraembryonic structures—the products of conception.

Embryology is the study of the sequential changes in an organism as the various tissues, organs, and systems develop. Chick embryos are frequently studied because of the easy access through the shell and their rapid development. Mice and pig embryos are also extensively studied as mammalian models. Genetic manipulation, induction of drugs, exposure to disease, radioactive tagging or dyeing of developing tissues, and X-ray treatments are some of the commonly conducted experiments that provide information that can be applied to human development and birth defects.

During the preembryonic period of cell division and differentiation, the developing structure is self-sustaining. The embryo, however, must derive sustenance from the mother. For morphogenesis to continue, certain immediate needs must be met. These needs include (1) formation of a vascular association between the uterus of the mother and the embryo so that nutrients and oxygen can be provided and metabolic wastes and carbon dioxide can be removed; (2) establishment of a constant, protective environment around the embryo that is conducive to development; (3) establishment of a structural foundation for embryonic morphogenesis along a longitudinal axis; (4) provision for structural support for the embryo, both internally and externally; and (5) coordination of the morphogenic events through genetic expression. If these needs are not met, a spontaneous abortion will generally occur.

The first and second of these needs are provided for by extraembryonic structures; the last three are provided for intraembryonically. The extraembryonic membranes, the placenta, and the umbilical cord will be considered separately, prior to a discussion of the development of the embryo.

Serious developmental defects usually cause the embryo to be naturally aborted. About 25% of early aborted embryos have chromosomal abnormalities. Other abortions may be caused by environmental factors, such as infectious agents or teratogenic drugs (drugs that cause birth defects). In addition, an implanted embryo is regarded as foreign tissue by the immune system of the mother, and is rejected and aborted unless maternal immune responses are suppressed.

Extraembryonic Membranes

At the same time that the internal organs of the embryo are being formed, a complex system of extraembryonic membranes is also developing (fig. 22.10). The **extraembryonic membranes** are the *amnion*, *yolk sac*, *allantois*, and *chorion*. These membranes are responsible for the protection, respiration, excretion, and nutrition of the embryo and subsequent fetus. At parturition, the placenta, umbilical cord, and extraembryonic membranes separate from the fetus and are expelled from the uterus as the *afterbirth*.

Amnion

The amnion (*am′ne-on*) is a thin membrane, derived from ectoderm and mesoderm. It loosely envelops the embryo, forming an **amniotic sac** that is filled with *amniotic fluid* (fig. 22.11*b*). In later fetal development, the amnion expands to come in contact with the chorion. The development of the amnion is initiated early in the embryonic period, at which time its margin is attached to the free edge of the embryonic disc (see fig. 22.10). As the amniotic sac enlarges during the late embryonic period (at about 8 weeks), the amnion gradually sheaths the developing umbilical cord with an epithelial covering (fig. 22.12).

The buoyant amniotic fluid performs several functions for the embryo and subsequent fetus.

- It ensures symmetrical structural development and growth.
- It cushions and protects by absorbing jolts that the mother may receive.
- It helps maintain consistent pressure and temperature.
- It helps eliminate metabolic wastes.
- It permits freedom of fetal movement, which is important for skeletomuscular development and blood flow.

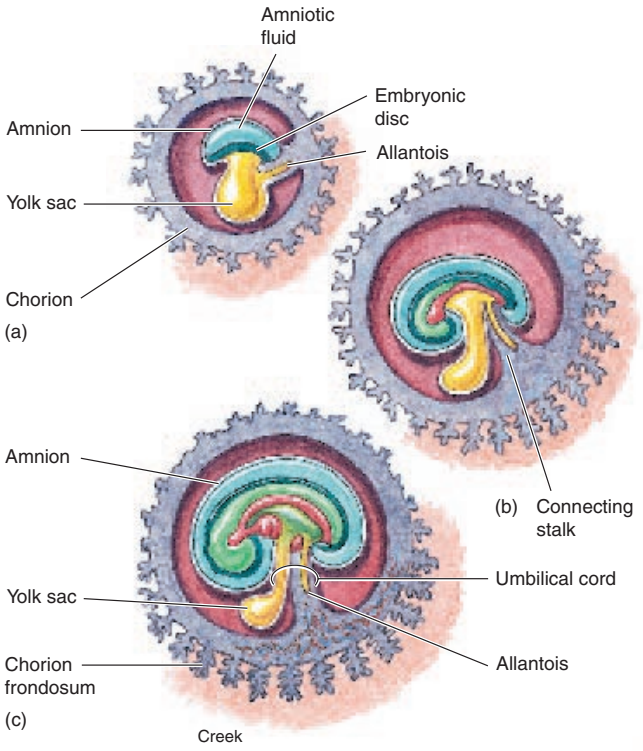


FIGURE 22.10 The formation of the extraembryonic membranes during a single week of rapid embryonic development. (*a*) At 3 weeks, (*b*) at 3½ weeks, and (*c*) at 4 weeks.

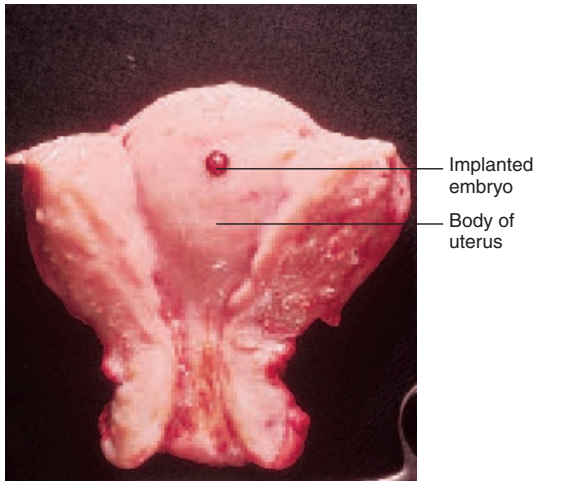
Amniotic fluid is formed initially as an isotonic fluid absorbed from the maternal blood in the endometrium surrounding the developing embryo. Later, the volume is increased and the concentration changed by urine excreted from the fetus into the amniotic sac. Amniotic fluid also contains cells that are sloughed off from the fetus, placenta, and amniotic sac. Because all of these cells are derived from the same fertilized egg, all have the same genetic composition. Many genetic abnormalities can be detected by aspirating a sample of this fluid and examining the cells obtained, in a procedure called *amniocentesis* (*am''ne-o-sen-te'sis*).

Amniocentesis (fig. 22.13) is usually performed at the fourteenth or fifteenth week of pregnancy, when the amniotic sac contains 175–225 ml of fluid. Genetic diseases, such as *Down syndrome,* or *trisomy 21* (in which there are three instead of two number–21 chromosomes), can be detected by examining chromosomes. Diseases such as *Tay-Sachs disease,* in which there is a defective enzyme involved in formation of myelin sheaths, can be detected by biochemical techniques from these fetal cells.

Amniotic fluid is normally swallowed by the fetus and absorbed in the GI tract. The fluid enters the fetal blood, and the waste products it contains enter the maternal blood in the placenta. Prior to delivery, the amnion is naturally or surgically ruptured, and the amniotic fluid (bag of waters) is released.

As the fetus grows, the amount of amniotic fluid increases. It is also continually absorbed and renewed. For the near-term baby, almost 8 liters of fluid are completely replaced each day.

Down syndrome: from John L. H. Down, English physician, 1828–96



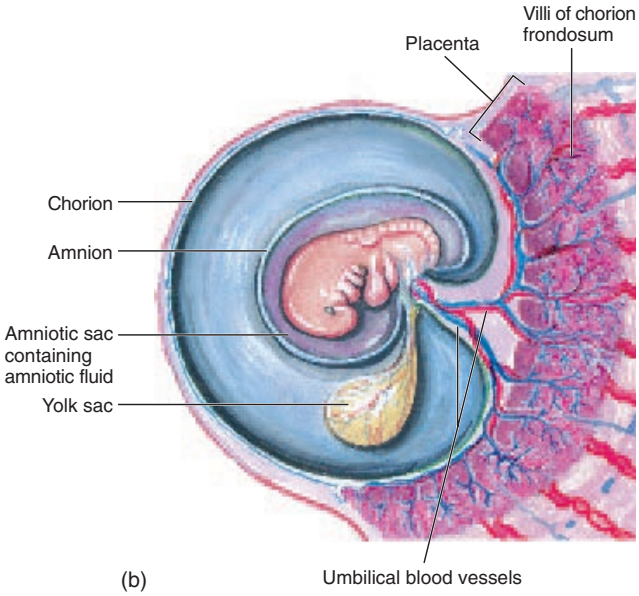


FIGURE 22.11 An implanted embryo at approximately 4½ weeks. (*a*) The interior of a uterus showing the implantation site. (*b*) The developing embryo, extraembryonic membranes, and placenta.

Yolk Sac

The yolk sac is established during the end of the second week as cells from the trophoblast form a thin *exocoelomic (ek''so-sĕ-lo'mik) membrane*. Unlike the yolk sac of many vertebrates, the

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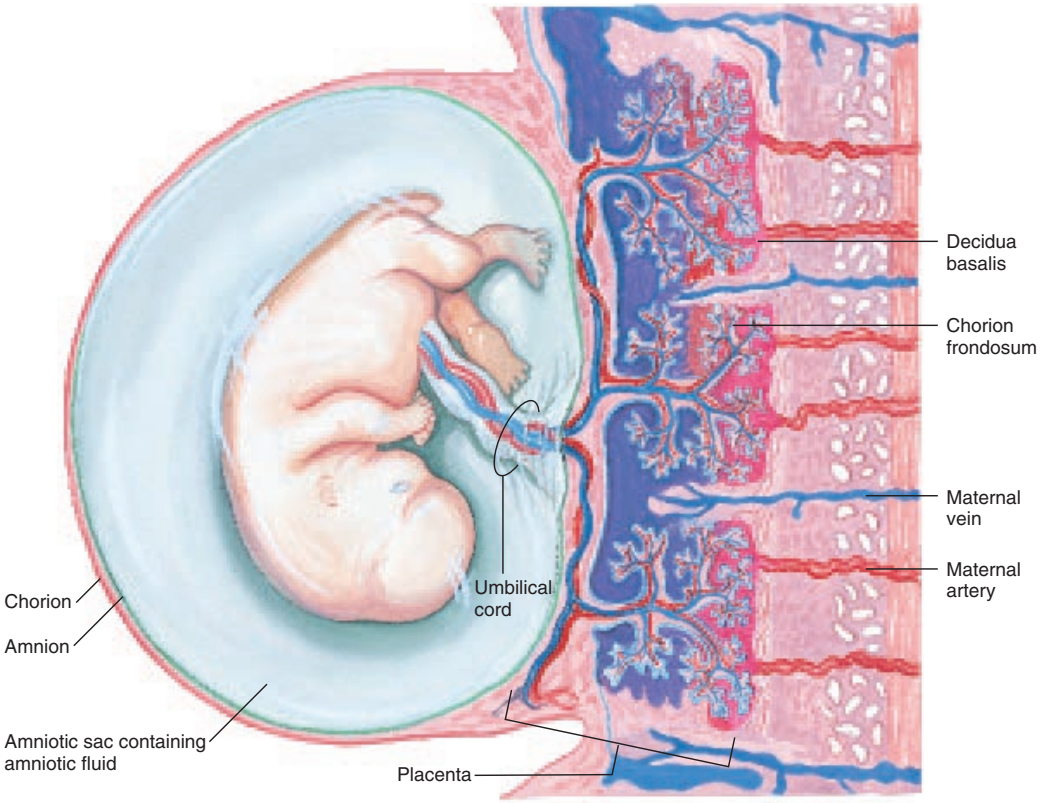


FIGURE 22.12 The embryo, extraembryonic membranes, and placenta at approximately 7 weeks of development. Blood from the embryo is carried to and from the chorion frondosum by the umbilical arteries and vein. The maternal tissue between the chorionic villi is known as the decidua basalis; this tissue, together with the villi, form the functioning placenta.

human yolk sac contains no nutritive yolk, but it is still an essential structure during early embryonic development. Attached to the underside of the embryonic disc (see figs. 22.10 and 22.11), it produces blood for the embryo until the liver forms during the sixth week. A portion of the yolk sac is also involved in the formation of the primitive gut. In addition, primordial germ cells form in the wall of the yolk sac. During the fourth week, they migrate to the developing gonads, where they become the primitive germ cells (spermatogonia or oogonia).

The stalk of the yolk sac usually detaches from the gut by the sixth week. Following this, the yolk sac gradually shrinks as pregnancy advances. Eventually, it becomes very small and serves no additional function.

Allantois

The allantois forms during the third week as a small outpouching, or diverticulum, near the base of the yolk sac (see fig. 22.10). It remains small but is involved in the formation of blood cells and gives rise to the fetal umbilical arteries and vein. It also contributes to the development of the urinary bladder.

The extraembryonic portion of the allantois degenerates during the second month. The intraembryonic portion involutes to form a thick urinary tube called the **urachus** (*yoo′ră-kus*) (see p. 690). After birth, the urachus becomes a fibrous cord called the *median umbilical ligament* that attaches to the urinary bladder.

Chorion

The chorion (*kor′e-on*) is the outermost extraembryonic membrane. It contributes to the formation of the placenta as small fingerlike extensions, called *chorionic villi*, penetrate deeply into the uterine tissue (see fig. 22.10). Initially, the entire surface of the chorion is covered with villi. But those chorionic villi on the surface toward the uterine cavity gradually degenerate, producing a smooth, bare area known as the **smooth chorion.** As this occurs, the chorionic villi associated with the uterine wall rapidly increase in number and branch out. This portion of the chorion is known

allantois: Gk. *allanto*, sausage; *iodos*, resemblance

chorion: Gk. *chorion*, external fetal membrane

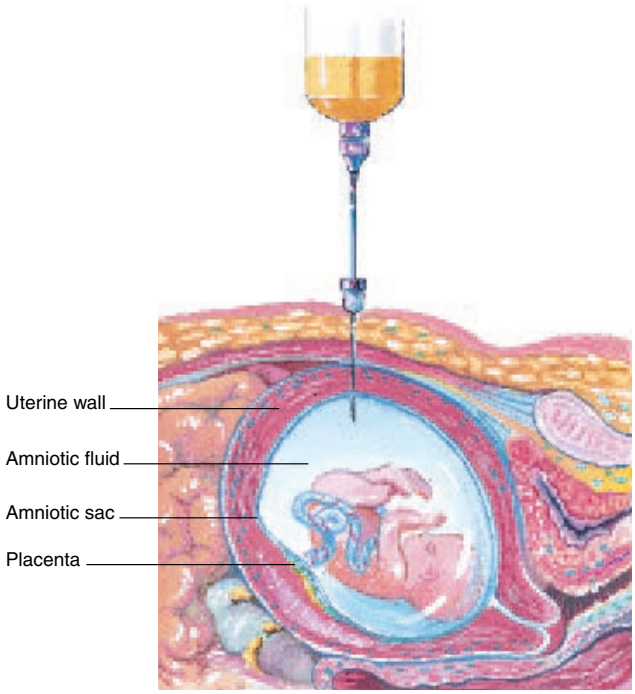


FIGURE 22.13 Amniocentesis. In this procedure, amniotic fluid containing suspended cells is withdrawn for examination. Various genetic diseases can be detected prenatally by this means.

as the **villous chorion,** or **chorion frondosum** (*fron-do'sum*). The villous chorion becomes highly vascularized with embryonic blood vessels, and as the embryonic heart begins to function, embryonic blood is pumped in close proximity to the uterine wall.

Chorionic villus biopsy is a technique used to detect genetic disorders much earlier than amniocentesis permits. In chorionic villus biopsy, a catheter is inserted through the cervix to the chorion, and a sample of chorionic villus is obtained by suction or cutting. Genetic tests can be performed directly on the villus sample, because this sample contains much larger numbers of fetal cells than does a sample of amniotic fluid. Chorionic villus biopsy can provide genetic information at 10 to 12 weeks' gestation.

Placenta

The **placenta** (*plă-sen'tă*) is a vascular structure by which an unborn child is attached to its mother's uterine wall and through which respiratory gas and metabolic exchange occurs (fig. 22.14). The placenta is formed in part from maternal tissue and in part from embryonic tissue. The embryonic portion of the placenta consists of the chorion frondosum, whereas the maternal portion is composed of the area of the uterine wall called the **decidua** (*dĕ-sid'yoo-ă*) **basalis** (see fig. 22.12), into which the chorionic villi penetrate. Blood does not flow directly between these two portions, but because their membranes are in close proximity, certain substances diffuse readily.

When fully formed, the placenta is a reddish brown oval disc with a diameter of 15 to 20 cm (6 to 8 in.) and a thickness of 2.5 cm (1 in.). It weighs between 500 and 600 g, about one-sixth as much as the fetus.

Exchange of Molecules across the Placenta

The two **umbilical arteries** deliver fetal blood to vessels within the villi of the chorion frondosum of the placenta. This blood circulates within the villi and returns to the fetus via the **umbilical vein** (fig. 22.14). Maternal blood is delivered to and drained from the cavities within the decidua basalis, which are located between the chorionic villi. In this way, maternal and fetal blood are brought close together but do not normally mix within the placenta.

The placenta serves as a site for the exchange of gases and other molecules between the maternal and fetal blood. Oxygen diffuses from mother to fetus, and carbon dioxide diffuses in the opposite direction. Nutrient molecules and waste products likewise pass between maternal and fetal blood.

The placenta has a high metabolic rate. It utilizes about one-third of all the oxygen and glucose supplied by the maternal blood. In fact, the rate of protein synthesis is actually higher in the placenta than it is in the fetal liver. Like the liver, the placenta produces a great variety of enzymes that are capable of converting biologically active molecules (such as hormones and drugs) into less active, more water-soluble forms. In this way, potentially dangerous molecules in the maternal blood are often prevented from harming the fetus.

Some substances ingested by a pregnant woman are able to pass through the placenta readily, to the detriment of the fetus. These include nicotine, heroin, and certain antidepressant drugs. Excessive nicotine will stunt the growth of the fetus; heroin can lead to fetal drug addiction; and certain antidepressants can cause respiratory problems.

Although the placenta is an effective barrier against diseases of bacterial origin, rubella and other viruses, as well as certain blood-borne bacterial diseases such as syphilis, can diffuse through the placenta and affect the fetus. During parturition, small amounts of fetal blood may pass across the placenta to the mother. If the fetus is Rh positive and the mother Rh negative, the antigens of the fetal red blood cells elicit an antibody response in the mother. In a subsequent pregnancy, the maternal antibodies then cross the placenta and cause a breakdown of fetal red blood cells—a condition called *erythroblastosis fetalis.*

Endocrine Functions of the Placenta

The placenta functions as an endocrine gland in producing both glycoprotein and steroid hormones. The glycoprotein hormones have actions similar to those of some anterior pituitary hormones. They play a key role in maintaining pregnancy and ensuring that the fetus will receive optimal nourishment.

villous: L. *villus*, tuft of hair
placenta: L. *placenta*, a flat cake

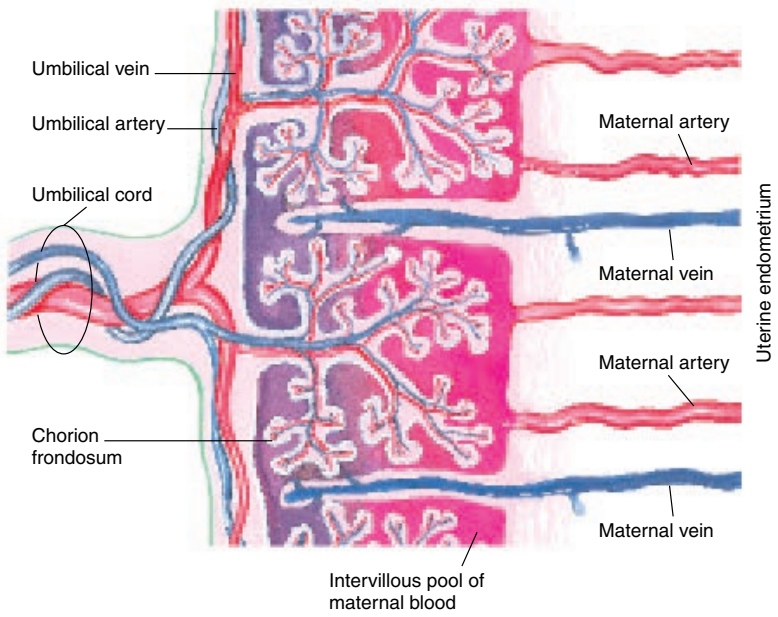


FIGURE 22.14 The circulation of blood within the placenta. Maternal blood is delivered to and drained from the spaces between the chorionic villi. Fetal blood is brought to blood vessels within the villi by branches of the umbilical arteries and is drained by branches of the umbilical vein.

TABLE 22.2 Hormones Secreted by the Placenta

Hormones	Effects
Pituitary-like Hormones	
Chorionic gonadotropin (hCG)	Similar to LH; maintains mother's corpus luteum for first 5½ weeks of pregnancy; may be involved in suppressing immunological rejection of embryo; also exhibits TSH-like activity
Chorionic somatomammotropin (hCS)	Similar to prolactin and growth hormone; in the mother, hCS promotes increased fat breakdown and fatty acid release from adipose tissue and decreased glucose use by maternal tissues (diabetic-like effects)
Sex Steroids	
Progesterone	Helps maintain endometrium during pregnancy; helps suppress gonadotropin secretion; stimulates development of alveolar tissue in mammary glands
Estrogens	Help maintain endometrium during pregnancy; help suppress gonadotropin secretion; inhibit prolactin secretion; promote uterine sensitivity to oxytocin; stimulate ductule development in mammary glands

CHAPTER 22

The placenta also converts androgens, secreted from the mother's adrenal glands, into estrogens to help protect the female embryo from becoming masculinized. In addition, the placenta secretes large amounts of *estriol*, a weak estrogen that helps to maintain the endometrium and stimulates the development of the mother's mammary glands, readying them for lactation.

The production of estriol increases tenfold during pregnancy, so that by the third trimester estriol accounts for about 90% of the estrogens excreted in the mother's urine. Because almost all of this estriol comes from the placenta (rather than from maternal tissues), measurements of urinary estriol can be used clinically to assess the health of the placenta.

The hormones secreted by the placenta and the effects they exert on their target tissues are summarized in table 22.2.

Umbilical Cord

The **umbilical** (*um-bĭlĭ-kal*) **cord** forms as the yolk sac shrinks and the amnion expands to envelop the tissues on the underside of the embryo (fig. 22.15). The umbilical cord usually attaches near the center of the placenta. When fully formed, it is between 1 and 2 cm (0.4 and 0.8 in.) in diameter and approximately 55 cm (2 ft) long. On average, the umbilical cords of male fetuses

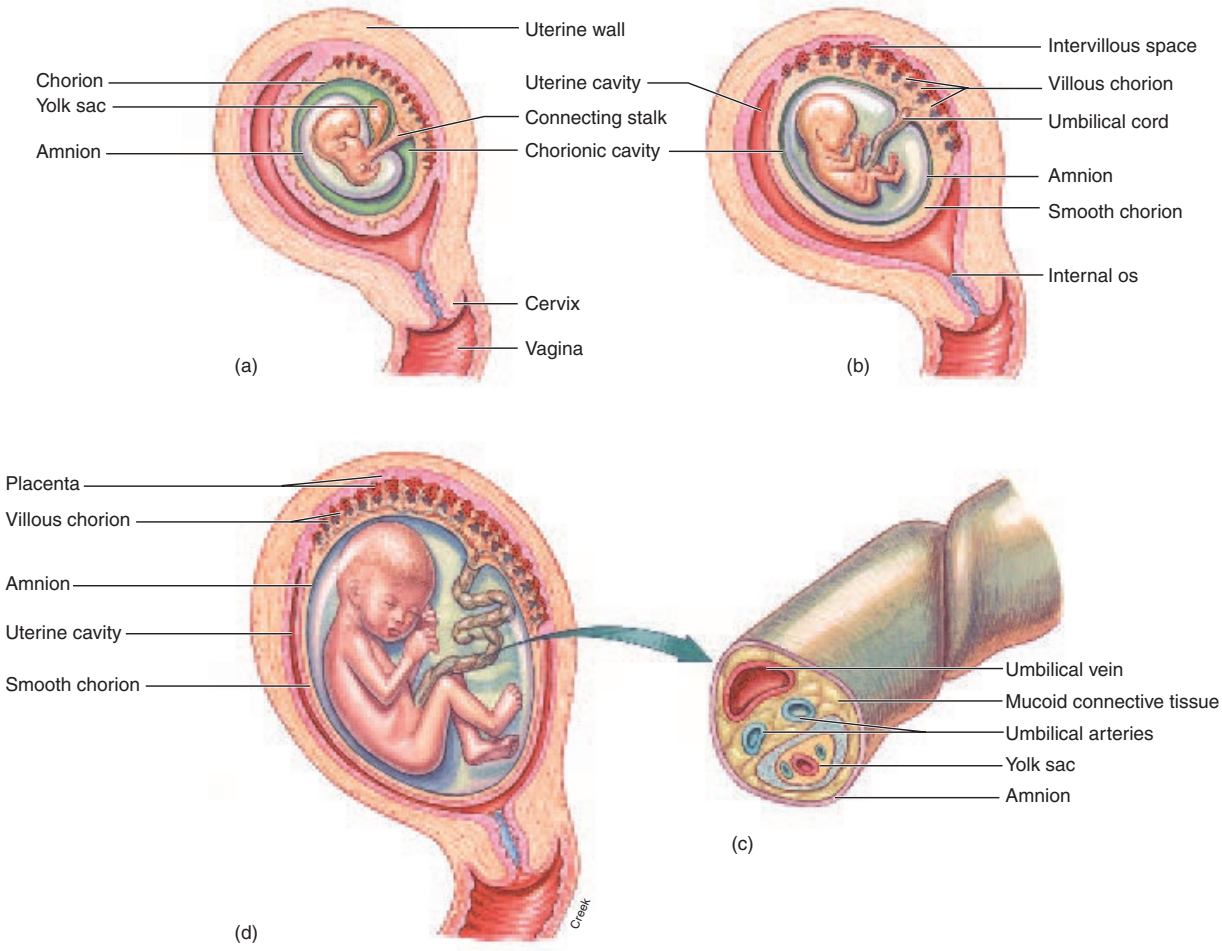


FIGURE 22.15 The formation of the umbilical cord and other extraembryonic structures as seen in sagittal sections of a gravid uterus from week 4 to week 22. (*a*) A connecting stalk forms as the developing amnion expands to surround the embryo, finally meeting ventrally. (*b*) The umbilical cord begins to take form as the amnion ensheathes the yolk sac. (*c*) A cross section of the umbilical cord showing the embryonic vessels, mucoid connective tissue, and the tubular connection to the yolk sac. (*d*) By week 22, the amnion and chorion have fused and the umbilical cord and placenta have become well-developed structures.

are approximately 5 cm (2 in.) longer than those of female fetuses. The umbilical cord contains two **umbilical arteries,** which carry deoxygenated blood from the embryo toward the placenta, and one **umbilical vein,** which carries oxygenated blood from the placenta to the embryo. These vessels are surrounded by embryonic connective tissue called **mucoid connective tissue** (Wharton's jelly).

The umbilical cord has a helical, or screwlike, form that keeps it from kinking. The spiraling occurs because the umbilical vein grows faster and longer than the umbilical arteries. In about one-fifth of all deliveries, the cord is looped once around the baby's neck. If drawn tightly, the cord may cause death or serious perinatal problems.

Wharton's jelly: from Thomas Wharton, English anatomist, 1614–73

Structural Changes in the Embryo by Week

Third Week

Early in the third week, a thick linear band called the **primitive line** (primitive streak), appears along the dorsal midline of the embryonic disc (figs. 22.10 and 22.16). Derived from mesodermal cells, the primitive line establishes a structural foundation for embryonic morphogenesis along a longitudinal axis. As the primitive line elongates, a prominent thickening called the **primitive node** appears at its cranial end (fig. 22.16). The primitive node later gives rise to the mesodermal structures of the head and to a rod of mesodermal cells called the **notochord.** The notochord forms a midline axis that is the basis of the embryonic skeleton.

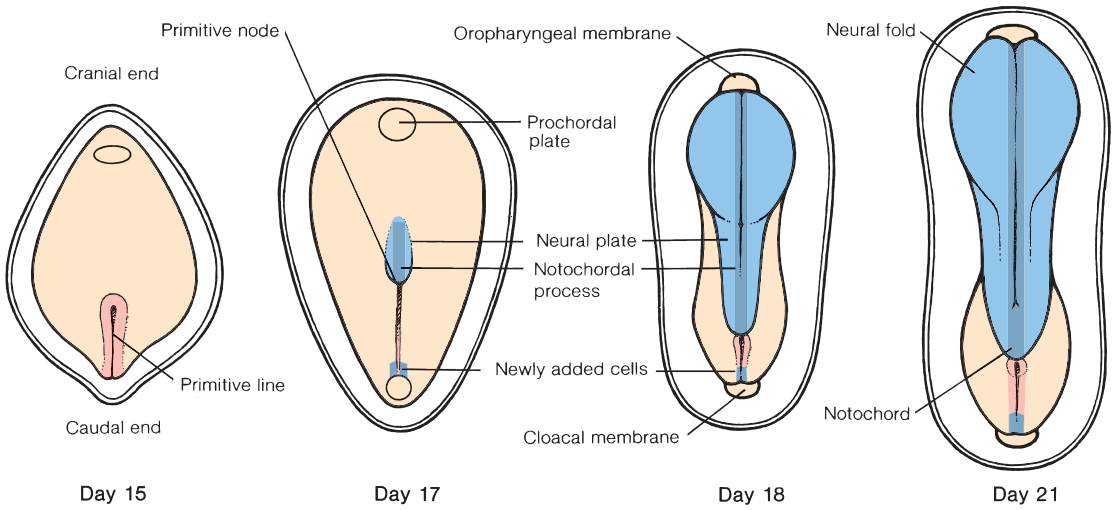


FIGURE 22.16 The appearance of the primitive line and primitive node along the embryonic disc. These progressive changes occur through the process of induction.

The primitive line also gives rise to loose embryonic connective tissue called **intraembryonic mesoderm** (mesenchyme). Mesenchyme differentiates into all the various kinds of connective tissue found in the adult. One of the earliest formed organs is the skin, which serves to support and maintain homeostasis within the embryo.

A tremendous amount of change and specialization occurs during the embryonic stage (figs. 22.17 and 22.18). The factors that cause precise sequential change from one cell or tissue type to another are not fully understood. It is known, however, that the potential for change is programmed into the genetics of each cell and that under conducive environmental conditions this change takes place. The process of developmental change is referred to as **induction.** Induction occurs when one tissue, called the *inductor tissue*, has a marked effect on an adjacent tissue, causing it to become *induced tissue*, and stimulating it to differentiate.

Fourth Week

During the fourth week of development, the embryo increases about 4 mm (0.16 in.) in length. A **connecting stalk,** which is later involved in the formation of the umbilical cord, is established from the body of the embryo to the developing placenta. By this time, the heart is already pumping blood to all parts of the embryo. The head and jaws are apparent, and the primordial tissue that will form the eyes, brain, spinal cord, lungs, and digestive organs has developed. The **superior** and **inferior limb buds** are recognizable as small swellings on the lateral body walls.

Fifth Week

Embryonic changes during the fifth week are not as extensive as those during the fourth week. The head enlarges, and the developing eyes, ears, and nasal pit become obvious. The appendages have formed from the limb buds, and paddle-shaped hand and foot plates develop.

Sixth Week

During the sixth week, the embryo is 16 to 24 mm (0.64–0.96 in.) long. The head is larger than the trunk, and the brain is undergoing marked differentiation. This is the most vulnerable period of development for many organs. An interruption at this critical time can easily cause congenital damage. The limbs are lengthened and slightly flexed, and notches appear between the **digital rays** in the hand and foot plates. The gonads are beginning to produce hormones that will influence the development of the external genitalia.

Seventh and Eighth Weeks

During the last 2 weeks of the embryonic stage, the embryo, which is now 28 to 40 mm (1.12–1.6 in.) long, has distinct human characteristics (see figs. 22.17 and 22.18). The body or-

induction: L. *inductus*, to lead in

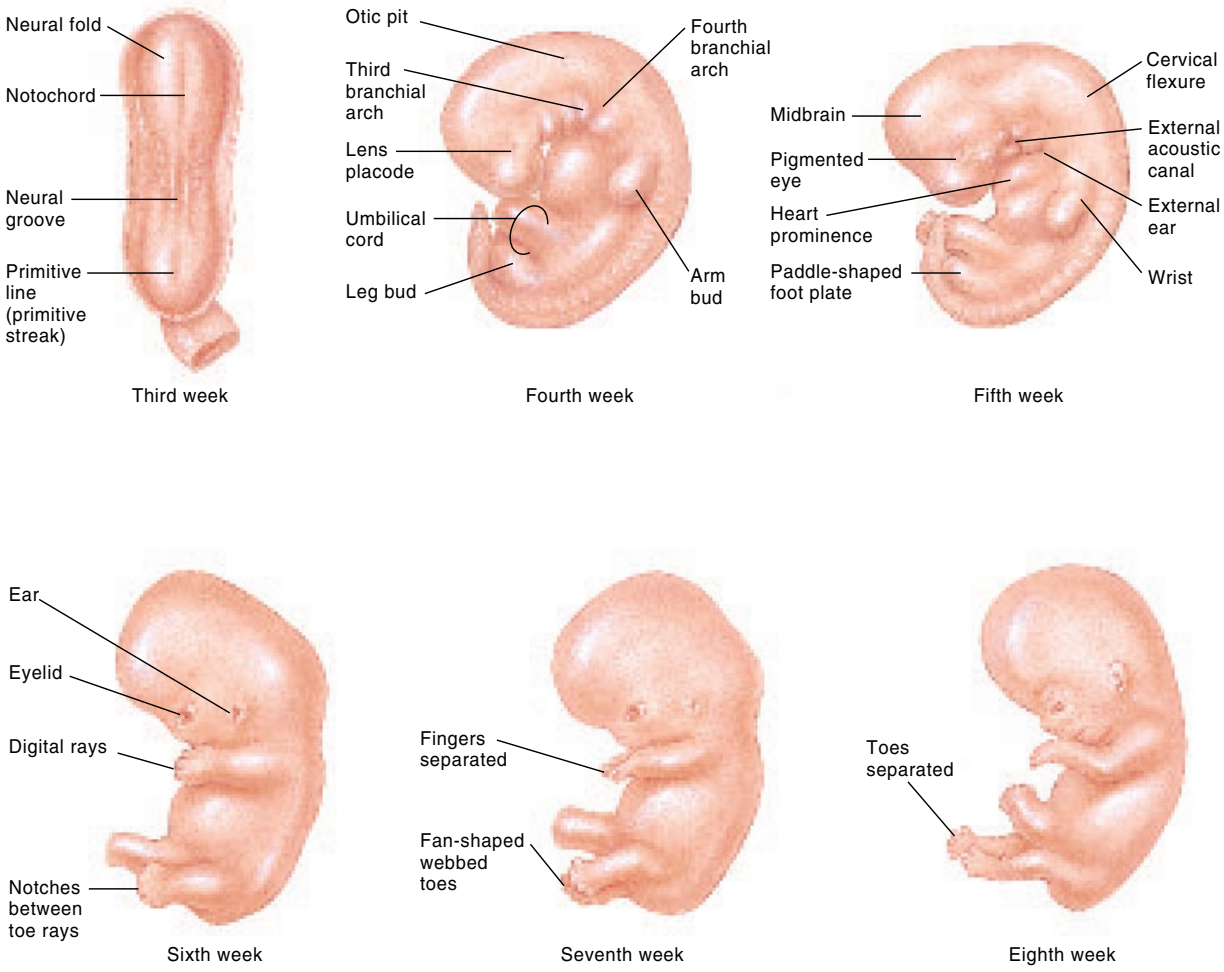


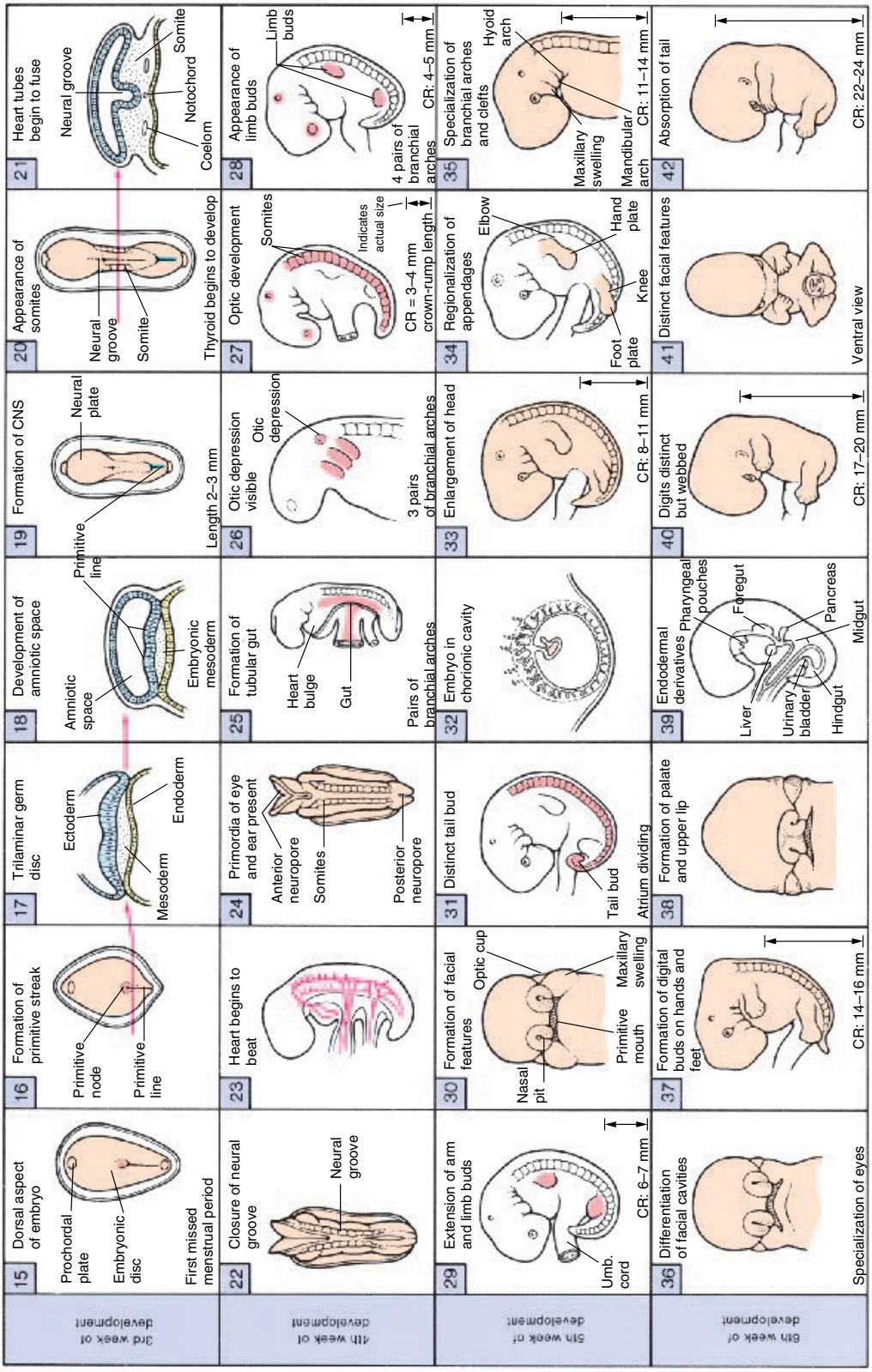
FIGURE 22.17 Structural changes in the embryo by weeks.

gans are formed, and the nervous system is starting to coordinate body activity. The neck region is apparent, and the abdomen is less prominent. The eyes are well developed, but the lids are stuck together to protect against probing fingers during muscular movement. The nostrils are developed but plugged with mucus. The external genitalia are forming but are still undifferentiated. The body systems are developed by the end of the eighth week, and from this time on the embryo is called a **fetus.**

The most precarious time of prenatal development is the embryonic period—yet, well into this period many women are still unaware that they are pregnant. For this reason, a woman should abstain from taking certain drugs (including some antibiotics) if there is even a remote chance that she is pregnant or might become pregnant in the near future.

Knowledge Check

9. Distinguish between embryo and fetus. Briefly summarize the structural changes that occur in an embryo between the fourth and eighth weeks of development.
10. Which of the five embryonic needs are met by the extraembryonic membranes?
11. Explain how each of the extraembryonic membranes is formed.
12. Identify the fetal and maternal components of the placenta and describe the blood circulation in these two components. How does gas exchange occur between mother and fetus?
13. What types of hormones are secreted by the placenta? Briefly summarize their effects.



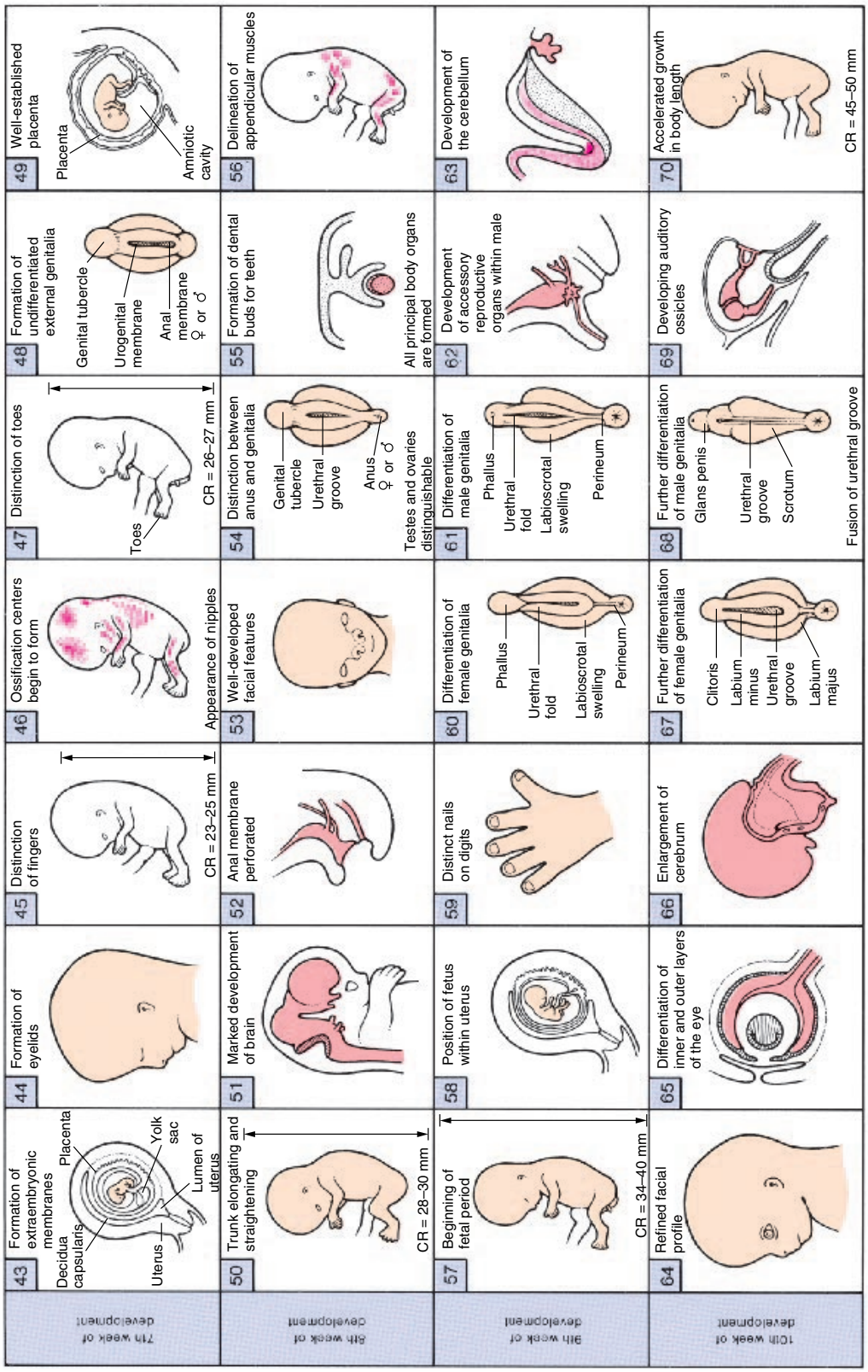


FIGURE 22.18 Major changes in embryonic and early fetal development from week 3 through week 10. (CR = crown-rump length, a straight-line measurement from the crown of the head to the developing ischium.)

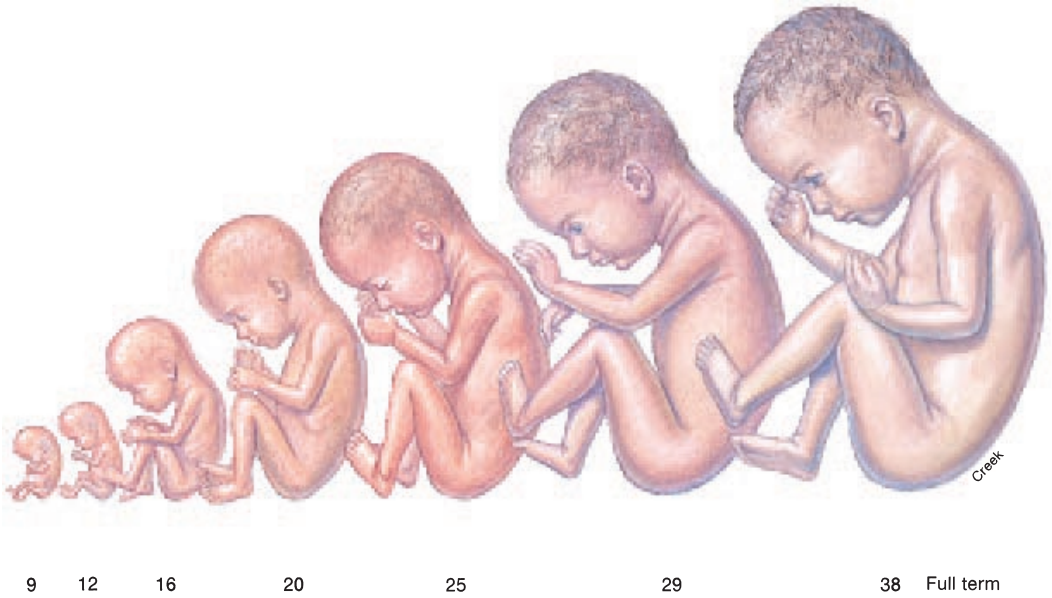


FIGURE 22.19 Changes in the external appearance of the fetus from week 9 through week 38.

FETAL PERIOD

The fetal period, beginning at week 9 and culminating at birth, is characterized by tremendous growth and the specialization of body structures.

Objective 11 Define *fetus* and discuss the major events of the fetal period of development.

Objective 12 Describe the various techniques available for examining the fetus or monitoring fetal activity.

Because most of the tissues and organs of the body form during the embryonic period, the **fetus** is recognizable as a human being at 9 weeks. The fetus is far less vulnerable than the embryo to the deforming effects of viruses, drugs, and radiation. Tissue differentiation and organ development continue during the fetal period, but to a lesser degree than before. For the most part, fetal development is primarily limited to body growth.

Structural Changes in the Fetus by Week

Changes in the external appearance of the fetus from the ninth through the thirty-eighth week are depicted in figure 22.19. A discussion of these structural changes follows.

Nine to Twelve Weeks

At the beginning of the ninth week, the head of the fetus is as large as the rest of the body. The eyes are widely spaced, and the ears are set low. Head growth slows during the next 3 weeks, whereas lengthening of the body accelerates (fig. 22.20). Ossification centers appear in most bones during the ninth week. Differentiation of the external genitalia becomes apparent at the end of the ninth week, but the genitalia are not developed to the point of sex determination until the twelfth week. By the end of the twelfth week, the fetus is 87 mm (3.5 in.) long and weighs about 45 g (1.6 oz). It can swallow, digest the fluid that passes through its system, and defecate and urinate into the amniotic fluid. Its nervous system and muscle coordination are developed to the point that it will withdraw its leg if tickled. The fetus begins inhaling through its nose but can take in only amniotic fluid.

Major structural abnormalities, which may not be predictable from genetic analysis, can often be detected by *ultrasonography* (fig. 22.21). In this procedure, organs are bombarded with sound waves that reflect back in a certain pattern determined by tissue densities. For example, sound waves bouncing off amniotic fluid will produce an image much different from that produced by sound waves bouncing off the placenta or the mother's uterus. Ultrasonography is so sensitive that it can detect a fetal heartbeat several weeks before it can be heard with a stethoscope.

Thirteen to Sixteen Weeks

By the thirteenth week, the facial features of the fetus are well formed, and epidermal structures such as eyelashes, eyebrows, hair on the head, fingernails, and nipples begin to develop. The appendages lengthen, and by the sixteenth week the skeleton is sufficiently developed to show up clearly on radiographs. During the sixteenth week, the fetal heartbeat can be heard by applying a stethoscope to the mother's abdomen. By the end of the sixteenth week, the fetus is 140 mm long (5.5 in.) and weighs about 200 g (7 oz).

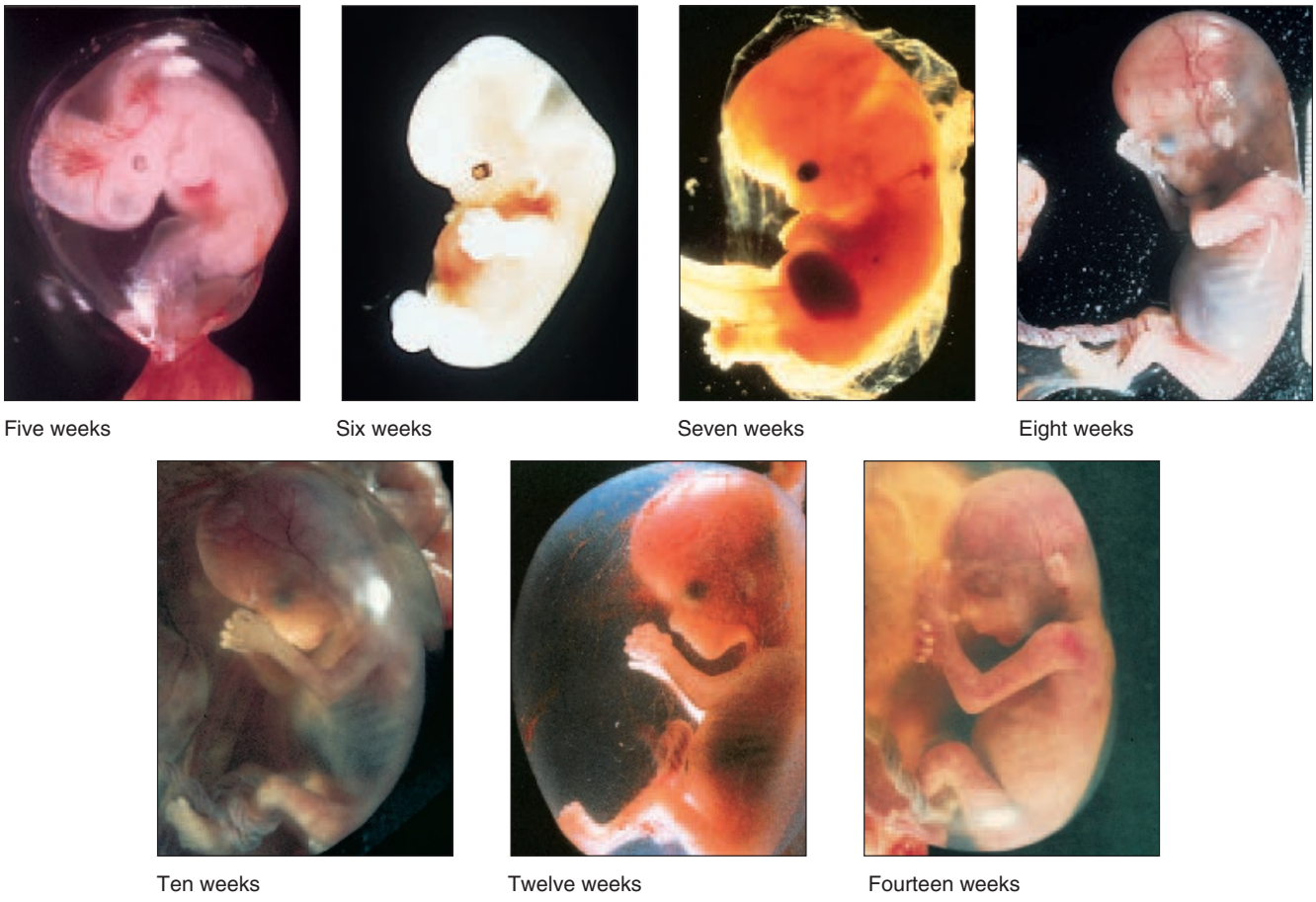


FIGURE 22.20 A photographic summary of embryonic and early fetal development.

After the sixteenth week, fetal length can be determined from radiographs. The reported length of a fetus is generally derived from a straight-line measurement from the crown of the head to the developing ischium (crown-rump length). Measurements made on an embryo prior to the fetal period, however, are not reported as crown-rump measurements but as total length.

Seventeen to Twenty Weeks

Between the seventeenth and twentieth weeks, the legs achieve their final relative proportions, and fetal movements, known as **quickening,** are commonly felt by the mother. The skin is covered with a thin, white, cheeselike material known as **vernix caseosa** (*ka″se-o′să*). It consists of fatty secretions from the sebaceous glands and dead epidermal cells. The function of vernix caseosa is to protect the fetus while it is bathed in amniotic fluid. Twenty-week-old fetuses usually have fine, silklike fetal hair called **lanugo** (*lă-noo′go*) covering the skin. Lanugo holds the vernix caseosa in place on the skin and produces a ciliary-like motion that moves amniotic fluid. It is also thought to help develop the hair follicles. A 20-week-old fetus is about 190 mm (7.5 in.) long, and it weighs about 460 g (16 oz). Because of cramped space, it develops a marked spinal flexure and is in what is commonly called the *fetal position,* with the head bent down, in contact with the flexed knees.

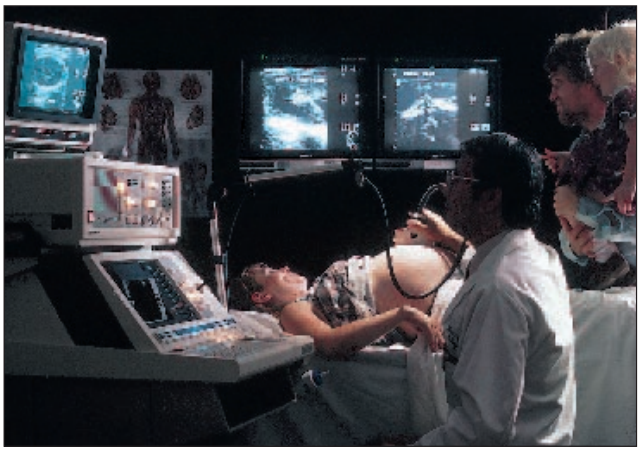
vernix caseosa: L. *vernix,* varnish; L. *caseus,* cheese
lanugo: L. *lana,* wool

Twenty-One to Twenty-Five Weeks

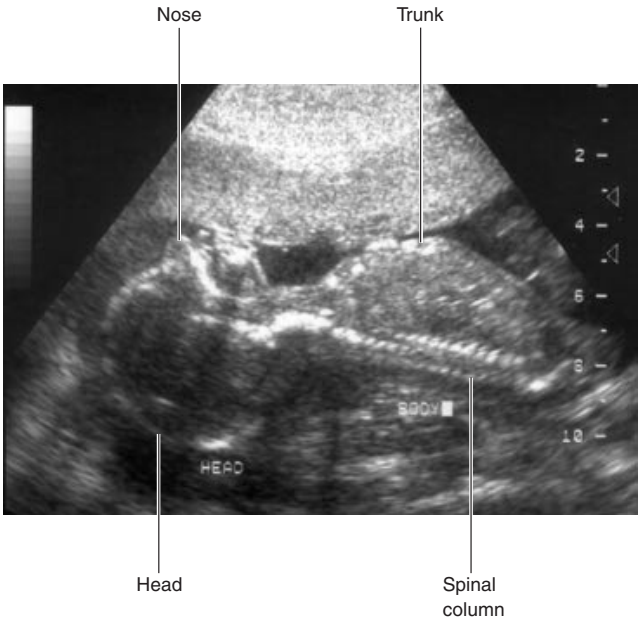
Between the twenty-first and twenty-fifth weeks, the fetus increases its weight substantially to about 900 g (32 oz). Body length increases only moderately (240 mm), however, so the weight is evenly proportioned. The skin is quite wrinkled and is translucent. Because the blood flowing in the capillaries is now visible, the skin appears pinkish.

Twenty-Six to Twenty-Nine Weeks

Toward the end of this period, the fetus will be about 275 mm (11 in.) long and will weigh about 1,300 g (46 oz). A fetus might now survive if born prematurely, but the mortality rate is high.



(a)



(b)

FIGURE 22.21 Ultrasonography. (*a*) Sound-wave vibrations are reflected from the internal tissues of a person's body. (*b*) Structures of the human fetus observed through an ultrasound scan.

Its body metabolism cannot yet maintain a constant temperature, and its respiratory muscles have not matured enough to provide a regular respiratory rate. If, however, the premature infant is put in an incubator and a respirator is used to maintain its breathing, it may survive. The eyes open during this period, and the body is well covered with lanugo. If the fetus is a male, the testes should have begun descent into the scrotum (see exhibit III, chapter 20). As the time of birth approaches, the fetus rotates to a **vertex position** in which the head is directed toward the cervix (fig. 22.22). The head repositions toward the cervix because of the shape of the uterus and because the head is the heaviest part of the body.

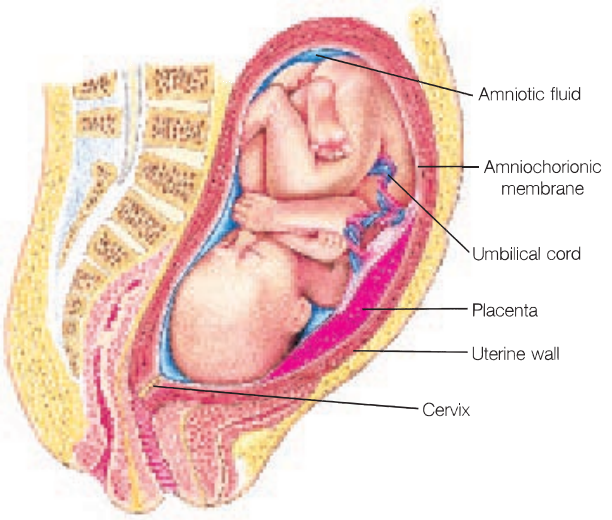


FIGURE 22.22 A fetus in vertex position. Toward the end of most pregnancies, the weight of the fetal head causes the body to rotate, positioning the head against the cervix of the uterus.

Thirty to Thirty-Eight Weeks

At the end of 38 weeks, the fetus is considered full-term. It has reached a crown-rump length of 360 mm (14 in.) and weighs about 3,400 g (7.5 lb). The average total length from crown to heel is 50 cm (20 in.). Most fetuses are plump with smooth skin because of the accumulation of subcutaneous fat. The skin is pinkish blue, even in fetuses of dark-skinned parents, because melanocytes do not produce melanin until the skin is exposed to sunlight. Lanugo is sparse and is generally found on the head and back. The chest is prominent, and the mammary area protrudes in both sexes. The external genitalia are somewhat swollen.

Knowledge Check

14. Explain why the ninth week is designated as the beginning of the fetal period of development.
15. List the approximate fetal age at which each of the following occur: (a) first detection of fetal heartbeat, (b) presence of vernix caseosa and lanugo, and (c) fetal rotation into vertex position.
16. Compare ultrasound and radiographic techniques in determining fetal development and structure.

vertex: L. *vertex*, summit

LABOR AND PARTURITION

Parturition, or childbirth, involves a sequence of events called labor. The uterine contractions of labor require the action of oxytocin, released by the posterior pituitary, and prostaglandins, produced in the uterus.

Objective 13 Describe the hormonal action that controls labor and parturition.

Objective 14 Describe the three stages of labor.

The time of prenatal development, or the time of pregnancy, is called **gestation.** In humans, the average gestation time is usually 266 days, or about 280 days from the beginning of the last menstrual period to **parturition** (*par''tyoo-rish'un*), or birth. Most fetuses are born within 10 to 15 days before or after the calculated delivery date. Parturition is accompanied by a sequence of physiological and physical events called **labor.**

The *onset of labor* is denoted by rhythmic and forceful contractions of the myometrial layer of the uterus. In *true labor*, the pains from uterine contractions occur at regular intervals and intensify as the interval between contractions shortens. A reliable indication of true labor is dilation of the cervix and a "show," or discharge, of blood-containing mucus that has accumulated in the cervical canal. In *false labor*, abdominal pain is experienced at irregular intervals, and cervical dilation and "show" are absent.

The uterine contractions of labor are stimulated by two agents: (1) **oxytocin** (*ok''sĭ-to-sin*), polypeptide hormone produced in the hypothalamus and released from the posterior pituitary, and (2) **prostaglandins** (*pros''tă-glan'dinz*), a class of fatty acids produced within the uterus itself. Labor can indeed be induced artificially by injections of oxytocin or by the insertion of prostaglandins into the vagina as a suppository.

The hormone *relaxin*, produced by the corpus luteum, may also be involved in labor and parturition. Relaxin is known to soften the symphysis pubis in preparation for parturition and is thought to also soften the cervix in preparation for dilation. It may be, however, that relaxin does not affect the uterus, but rather that progesterone and estradiol may be responsible for this effect. Further research is necessary to understand the total physiological effect of these hormones.

As illustrated in figure 22.23, labor is divided into three stages:

1. **Dilation stage.** In this period, the cervix dilates to a diameter of approximately 10 cm. Contractions are regular during this stage, and the amniotic sac ("bag of waters") generally ruptures. If the amniotic sac does not rupture spontaneously, it is broken surgically. The dilation stage generally lasts from 8 to 24 hours.
2. **Expulsion stage.** This is the period of parturition, or actual childbirth. It consists of forceful uterine contractions and abdominal compressions to expel the fetus from the uterus and through the vagina. This stage may require 30 minutes in a first pregnancy but only a few minutes in subsequent pregnancies.
3. **Placental stage.** Generally within 10 to 15 minutes after parturition, the placenta is separated from the uterine wall and expelled as the *afterbirth*. Forceful uterine contractions characterize this stage, constricting uterine blood vessels to prevent hemorrhage. In a normal delivery, blood loss does not exceed 350 ml (12 oz).

A *pudendal nerve block* may be administered during the early part of the expulsion stage to ease the trauma of delivery for the mother and to allow for an episiotomy. *Epidural anesthesia*, in which a local anesthetic is injected into the epidural space of the lumbar region of the spine, also may be used for these purposes.

Five percent of newborns are born *breech*. In a breech birth, the fetus has not rotated and the buttocks are the presenting part. The principal concern of a breech birth is the increased time and difficulty of the expulsion stage of parturition. Attempts to rotate the fetus through the use of forceps may injure the infant. If an infant cannot be delivered breech, a *cesarean (sĕ-zar'e-an) section* must be performed. A cesarean section is delivery of the fetus through an incision made into the abdominal wall and the uterus.

Knowledge Check

17. Distinguish between labor and parturition.
18. Explain the hormonal mechanisms responsible for labor and describe two techniques for inducing labor.
19. Describe the three stages of labor and state how long each stage lasts.

PERIODS OF POSTNATAL GROWTH

The course of human life after birth is seen in terms of physical and physiological changes and the attainment of maturity in the neonatal period, infancy, childhood, adolescence, and adulthood.

Objective 15 Describe the growth and development that occurs during the neonatal period, infancy, childhood, and adolescence.

Objective 16 Define *puberty* and explain how its onset is determined in males and females.

Objective 17 Define the term *adulthood* and discuss sexual dimorphism in adult humans.

gestation: L. *gestatus*, to bear

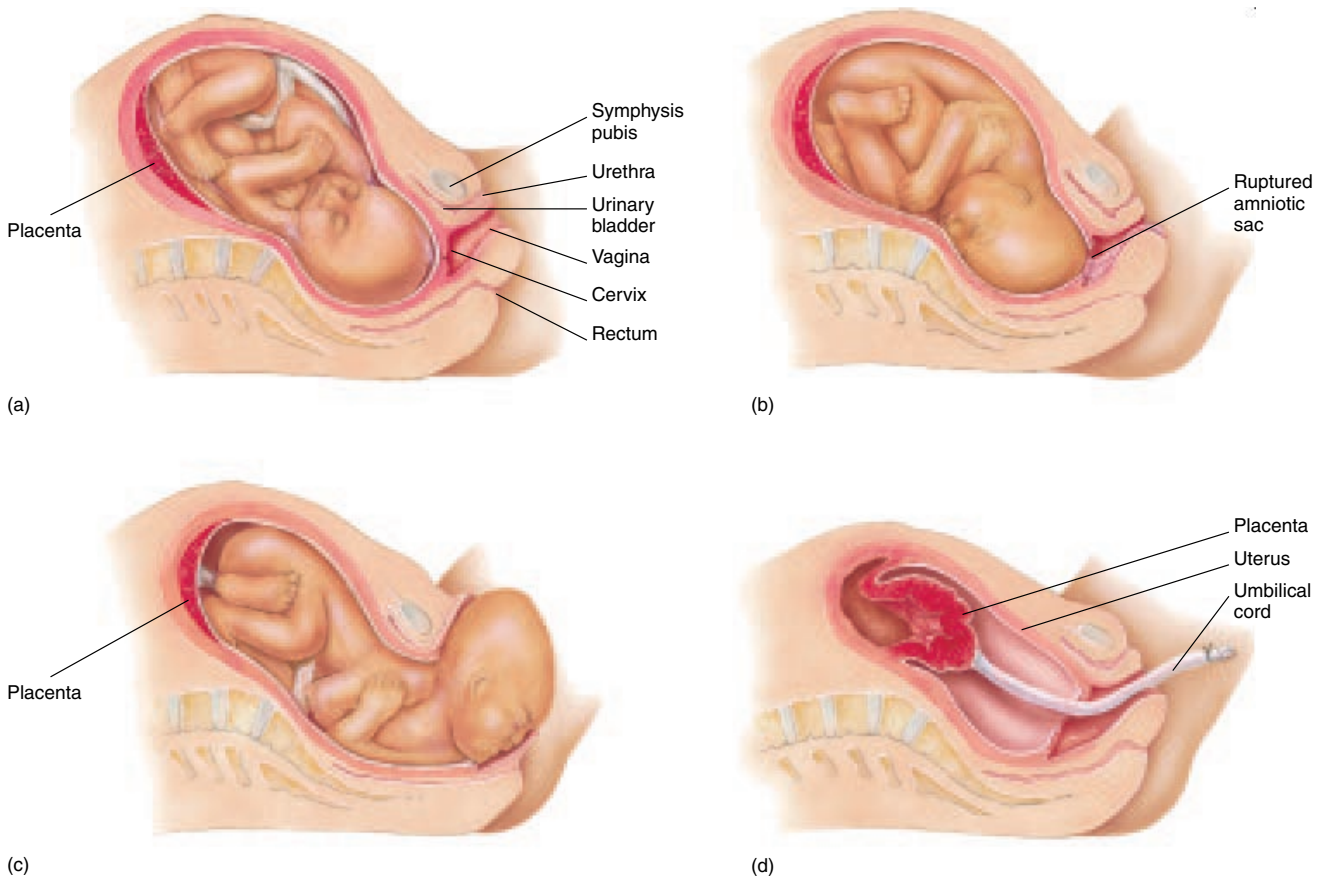


FIGURE 22.23 The stages of labor and parturition. (*a*) The position of the fetus prior to labor. (*b*) The ruptured amniotic sac during the early *dilation stage* of the cervix. (*c*) The *expulsion stage,* or period of parturition. (*d*) The *placental stage,* as the afterbirth is being expelled.

Neonatal Period

The **neonatal period** extends from birth to the end of the first month of extrauterine life. Although growth is rapid during this period, the most drastic changes are physiological. The body of a newborn must immediately adapt to major environmental changes, including thermal stress; rapid bacterial colonization of the skin, oral cavity, and GI tract; a barrage of sensory stimuli; and sudden demands on its body systems.

The most critical need of the newborn is the establishment of an adequate respiratory rate to ensure sufficient amounts of oxygen. The normal respiratory rate of a newborn is 30 to 40 respirations per minute. An adequate heart rate is also imperative. The heart of a newborn appears to be large relative to the thoracic cavity (compared to the heart of an adult) and has a rapid rate that ranges from 120 to 160 beats per minute.

neonatal: Gk. *neos*, new; *natus*, born

Most full-term newborn babies appear chubby because of the deposition of fat within adipose tissue during the last trimester of pregnancy. Dehydration is a serious threat because of the inability of the kidneys to excrete concentrated urine; large volumes of dilute urine are eliminated. Immunity is not well developed and is limited to that obtained from the mother through placental transfer. For this reason, newborns need to be guarded from exposure to infectious diseases.

Virtually all of the neurons of the nervous system are present in a newborn, but they are immature and the newborn has little coordination. Most infant behavior appears to be governed by lower cerebral centers and the spinal cord.

A newborn has many reflexes, some indicative of neuromuscular maturity and others essential for life itself. Four reflexes critical to survival are (1) the *suckling reflex*, triggered by anything that touches the newborn's lips; (2) the *rooting reflex*, which helps a baby find a nipple as it turns its head and starts to suckle in response to something that brushes its cheek; (3) the *crying reflex*, triggered by an empty stomach or other discomforts; and (4) the *breathing reflex*, apparent in a normal newborn even before the umbilical cord, with its supply of oxygen, is cut.

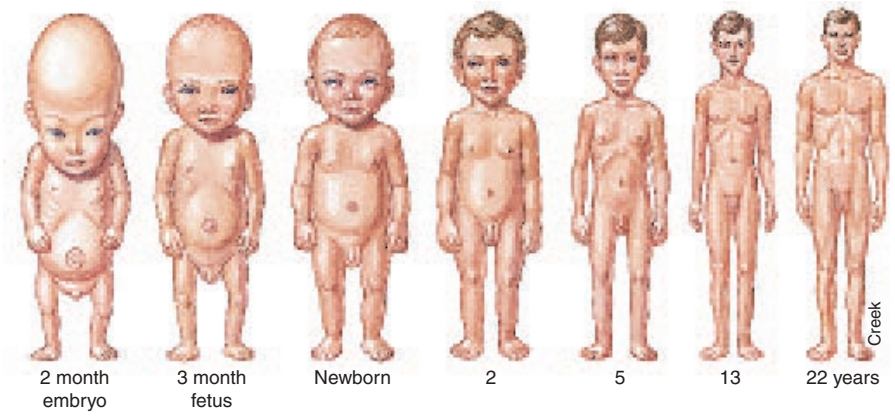


FIGURE 22.24 The relative proportions of the body from embryo to adulthood. The head of a newborn accounts for a quarter of the total body length, and the lower appendages account for about one-third. In an adult, the head constitutes about 13% of the total body length, whereas the lower appendages constitute approximately 50%.

Babies born more than 3 weeks before the due date are generally considered *premature,* but because errors are commonly made in calculating the delivery date, prematurity is defined by neonatal body weight rather than due date. Newborns weighing less than 2,500 g (5.5 lb) are considered premature. By this definition, approximately 8% of newborns in the United States are premature.

Postmature babies are those born 2 or more weeks after the due date. They frequently weigh less than they would have if they had been born at term because the placenta often becomes less efficient after a full-term pregnancy. Approximately 10% of newborns in the United States are postmature.

Infancy

The period of **infancy** follows the neonatal period and encompasses the first 2 years of life. Infancy is characterized by tremendous growth, increased coordination, and mental development.

A full-term child will generally double its birth weight by 5 months and triple it in a year. The formation of subcutaneous adipose tissue reaches its peak at about 9 months, causing the infant to appear chubby. Growth decelerates during the second year, during which time the infant gains only about 2.5 kg (5–6 lb). During the second year, the infant develops locomotor and manipulative control and gradually becomes more lean and muscular.

Body length increases during the first year by 25 to 30 cm (10 to 12 in.). There is an additional 12 cm (5 in.) of growth during the second year. The brain and circumference of the head also grow rapidly during the first year, but only moderately during the second. Head circumference increases by approximately 12 cm (5 in.) during the first year and only by an additional 2 cm during the second. The anterior fontanel (see fig. 6.13) gradually diminishes in size after 6 months and becomes effectively closed at any time from 20 to 24 months. It is the last of the fontanels to close. The brain is two-thirds of its adult size at the end of the first year and four-fifths of its adult size at the end of the second year.

By 2 years, most infants weigh approximately four times their birth weight and are 81 to 91 cm (32 to 36 in.) long. The body proportions of a 2-year-old are certainly not the same as those of an adult (fig. 22.24). Growth is a differential process, resulting in gradual changes in body proportions.

Deciduous teeth begin to erupt in most infants between 5 and 9 months. By the time they are a year old, most infants have 6 to 8 teeth. Eight more teeth erupt during the second year, making a total of 14 to 16, including the first deciduous molars and canine teeth.

The growth rates of children vary tremendously. Body lengths and weights are not always reliable indicators of normal growth and development. A more objective evaluation of a child's physical development is determined through radiographic analysis of skeletal ossification in the carpal region (fig. 22.25).

Childhood

Childhood is the period of growth and development extending from infancy to adolescence, at which time puberty begins. The duration of childhood varies because puberty begins at different ages for different people.

Childhood years are a period of relatively steady growth until preadolescence, which is characterized by a growth spurt. The average weight gain during childhood is about 3 to 3.5 kg (7 lb) per year. There is an average increase in height of 6 cm (2.5 in.) per year. The circumference of the head increases slightly—by about 3 to 4 cm (1.5 in.) during childhood—and by adolescence, the head and brain are virtually adult size.

The facial bones continue to develop during childhood (fig. 22.26). Especially significant is the enlargement of the sinuses. The first permanent teeth generally erupt during the

premature: L. *prae*, before; *maturus*, ripe
infancy: L. *in*, not; *fans*, speaking

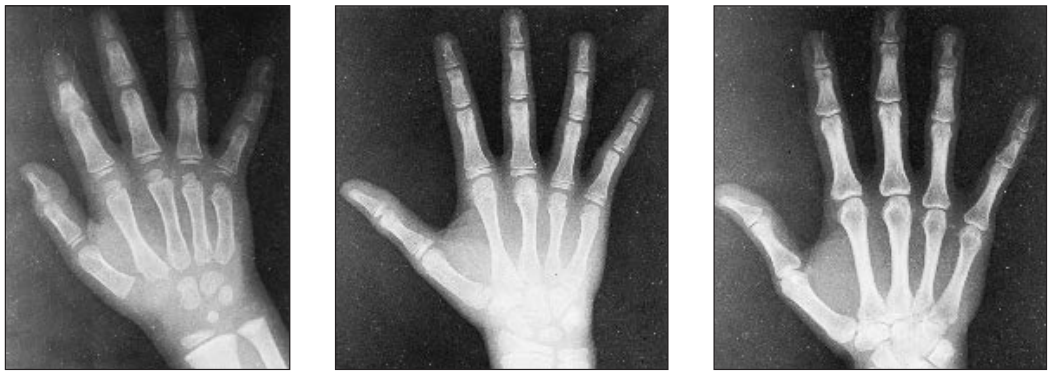


FIGURE 22.25 Radiographs of the right hand (*a*) of a child, (*b*) of an adolescent, and (*c*) of an adult.

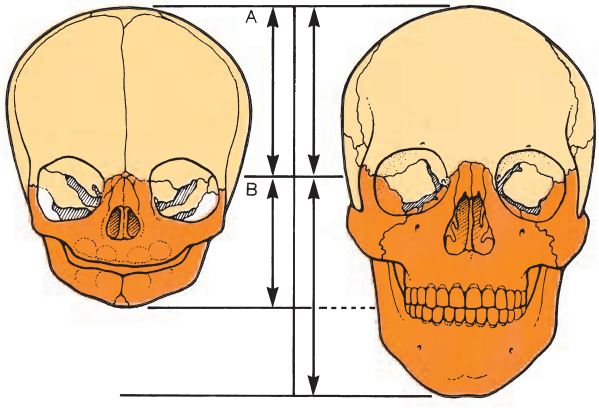


FIGURE 22.26 Growth of the skull. The height of the cranial vault (distance between planes A and B) is shown to be the same in both the infant and adult skulls. Growth of the skull occurs almost exclusively within the bones of the facial region.

seventh year, and then the deciduous teeth are shed approximately in the same sequence as they were acquired. Deciduous teeth are replaced at a rate of about four per year over the next 7 years.

Although there is an average rate of growth during childhood because of genetics, there is a wide range in what is considered normal growth. If, for example, the 8-year-olds who were among the tallest and heaviest 10% of their age group were to stop growing for a year while their classmates grew normally, they would still be taller than half their contemporaries and heavier than three-quarters of them.

During childhood, the average child becomes thinner and stronger each year as he or she grows taller. The average 10-year-old, for example, can throw a ball twice as far as the average 6-year-old. Visceral organs, particularly the heart and lungs, develop tremendously during this period, enabling a child to run faster and exercise longer.

Lymphoid tissue is at its peak of development during mid-childhood and generally exceeds the amount of such tissue in the normal adult. Children need the extra lymphoid tissue to combat childhood diseases, especially in countries where nutrition is poor and health care is minimal.

Childhood *obesity* can become a serious physical and psychological problem if not corrected. Overweight children usually exercise less and run a greater risk of contracting serious illnesses. Frequently, they are teased and rejected by classmates, which causes psychological stress. At least 5% of children in the United States can be classified as obese. Childhood obesity and adult obesity usually go hand in hand. Obesity in adults is a major health problem considering that one of five adults is at least 30% over his or her ideal, healthy weight. A controlled diet and regular exercise are fundamental in correcting obesity.

Adolescence

Adolescence is the period of growth and development between childhood and adulthood. It begins around the age of 10 in girls and the age of 12 in boys. **Adolescence** is frequently said to end at 20 years of age, but it is not clearly delineated and varies with the developmental, physical, emotional, mental, or cultural criteria that define an adult.

Puberty (*pyoo'ber-te*) is the stage of early adolescence when the secondary sex characteristics become expressed and the sexual organs become functional. **Pubescence** (*pyoo-bes'ens*) refers to the continuum of physical changes during puberty, particularly in regard to body hair. Although puberty is under hormonal control, a complex interaction of other factors, including nutrition and socioeconomic forces, has a decisive influence on the onset and duration of puberty. Thus, for both sexes there is wide individual variation.

adolescence: L. *adolescere*, to grow up
puberty: L. *pubertas*, adult form

TABLE 22.3 Sequence of Physical Development during Adolescence

Females	Age Span		Males
Growth spurt begins; breast buds and sparse pubic hair appear	10–11 yrs	11.5–13 yrs	Growth of testes and scrotum; sparse pubic hair appears; growth spurt begins; growth of penis begins
Appearance of straight, pigmented pubic hair; some deepening of voice; rapid growth of ovaries, uterus, and vagina; acidic vaginal secretion; menarche; further enlargement of breasts; kinky pubic hair; age of maximum growth	11–14 yrs	13–16 yrs	Appearance of straight, pigmented pubic hair; deepening of voice; maturation of penis, testes, scrotum, and accessory reproductive glands; ejaculation of semen; axillary hair; kinky pubic hair; sparse facial hair; age of maximum growth
Appearance of axillary hair; breasts of adult size and shape; culmination of physical growth	14–16 yrs	16–18 yrs	Increased body hair; marked vocal change; culmination of physical growth

The end result of puberty is that additional **sexually dimorphic characteristics**—traits that distinguish the sexes—are apparent. The average adult male, for example, has a deeper voice and more body hair and is taller than the average adult female. Prior to puberty, male and female children have few major structural differences aside from the general appearance of the external genitalia.

Puberty actually begins before it is physically expressed. In most instances, significant amounts of sex hormones appear in the blood of females by the age of 10 and in males by the age of 11. Sexual changes are usually thought of as the only features of puberty, but major skeletomuscular changes take place as well. During late childhood, the body proportions of the sexes are similar, males being slightly taller. Under the influence of hormones, females experience a growth spurt in early adolescence that precedes that of males by nearly 2 years. During this time, females are temporarily taller. Once puberty begins in males, the heights of both sexes equalize, and at the culmination of puberty, males are approximately 10 cm (4 in.) taller than females on the average. By the time growth is completed at the end of adolescence, males are generally 13 cm (5 in.) taller than females.

Other dimorphic differences involving skeletal structures include a broadening of the pelvic girdle in females. The muscles of males become more massive and stronger than those of females. Females acquire a thicker subcutaneous layer of the skin during adolescence, which gives them more rounded contours.

Sexual maturation during adolescence includes not only the development of the reproductive organs but the appearance of secondary sex characteristics (see fig. 2.9). The sequence of sexual maturation and expression of secondary sex characteristics for both males and females is presented in table 22.3.

In females, the first physical indication of puberty is the appearance of **breast buds,** which are swellings of the breasts and slight enlargement and pigmentation of the areolar areas. Breast buds generally appear in healthy girls at about 11 years of age, but the age may range from 9 to 13 years. Approximately 3 years are required after the appearance of breast buds for maturation of the breasts. Pubic hair usually begins to appear shortly after the breast buds become apparent, but in about one-third of all girls, sparse pubic hair appears before the breast buds. Axillary hair appears a year or two after pubic hair.

The first menstrual period, referred to as **menarche** (*mĕ-nar'ke*), generally occurs at age 13 but may occur as early as the age of 9 or as late as 17. During puberty, the vaginal secretions change from alkaline to acidic.

The onset of puberty in males varies just as much as it does in females but generally lags behind by about 1 1/2 years. The first indication of puberty in boys is growth of the testes and the appearance of sparse pubic hair at the age of 12 on the average. This is followed by growth of the penis, which continues for about 2 years, and the appearance of axillary hair. Vocal changes generally begin during early puberty but are not completed until midpuberty. Facial hair and chest hair (which may or may not be present) first appear toward the end of puberty. The mean age at which semen can be ejaculated is 13.7 years, but sufficient mature sperm for fertility are generally not produced until 14 to 16 years of age.

Adulthood

Adulthood is the final stage of human physical change. It is the period of life beyond adolescence. An adult has reached maximum physical stature as determined by genetic, nutritional, and environmental factors. Although skeletal maturity is reached in early adulthood, anatomical and physiological changes continue throughout adulthood and are part of the aging process.

Sexual dimorphism in human adults goes beyond the obvious anatomical differences. Males and females differ physiologically, metabolically, and behaviorally (psychologically and socially). Some of these differences manifest themselves prenatally and during childhood. Others are characteristics of adolescence and adulthood. It is uncertain to what extent specific dimorphisms of the sexes are genetically determined through hormonal action or influenced by environmental (including cultural) factors. It is also unclear how these governing factors are expressed in observed physical characteristics.

dimorphic: Gk. *di,* two; *morphe,* form

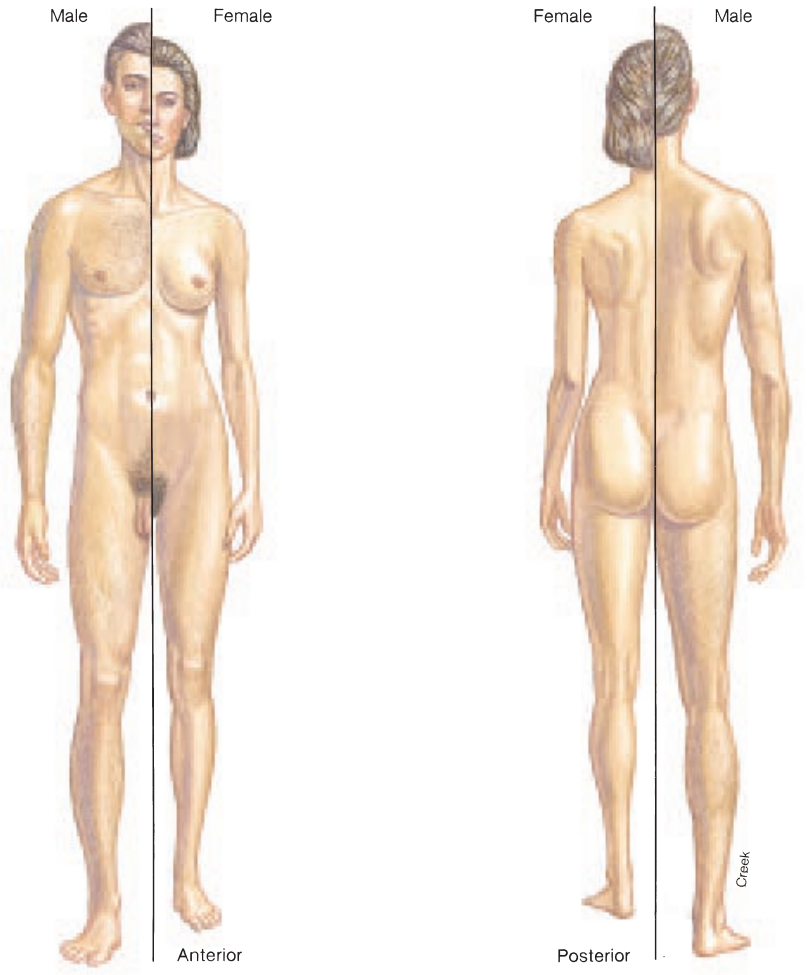


FIGURE 22.27 Relative differences in the physiques of an adult male and female. A male has proportionately longer appendages and a longer neck than a female.

The shape of the adult body is determined primarily by the skeleton and attached muscles, and also by the subcutaneous connective tissue (especially adipose tissue) and extracellular body fluids. Although the body proportions of adult males and females vary widely between individuals (fig. 22.27), adult males generally have longer appendages than females, their shoulders are broader, and their pelvises are narrower. Males also have relatively longer necks.

The general body composition of males and females can also be compared. Mean data for body composition are summarized in table 22.4. Values for total body fluid and skeletal weight are lower for adult females than for adult males. Females, however, have a higher percentage of body fat (see table 3.1). Other differences not shown in table 22.4 are that adult females have lower blood pressures, erythrocyte counts (hematocrits), basal metabolic rates, and respiratory rates than adult males. Females, however, have higher heart rates and oral temperatures.

Some of the physical and behavioral characteristics of each stage of human growth and development are summarized in table 22.5.

Physical anthropologists have long been interested in the body proportions of different racial groups. *Anthropometry* (*an''thrŏ-pom'ĭ-tre*) is the study of physical differences, particularly skeletal, between racial groups. Proportions in anthropometric studies are expressed in indices; that is, one measurement reckoned as a percentage of another measurement. The cranial index, for example, is the breadth of the skull expressed as a percentage of its length.

anthropometry: Gk. *anthropos*, human; *metron*, measure

TABLE 22.4 Body Composition of Average Adults

	Males				Females			
	Absolute		Relative (% Body Weight)		Absolute		Relative (% Body Weight)	
	Age 25	Age 65	Age 25	Age 65	Age 25	Age 65	Age 25	Age 65
Body weight	70.0 kg	70.0 kg			69.0 kg	60.0 kg		
Body fluids	41.0 liters	37.0 liters	58.9%	52.9%	30.8 liters	28.0 liters	51.3%	46.7%
Intracellular	24.0 liters	19.2 liters	34.3%	27.4%	16.6 liters	14.3 liters	27.7%	23.8%
Extracellular	17.2 liters	17.8 liters	24.6%	25.5%	14.2 liters	13.7 liters	23.6%	22.9%
Plasma volume	3,302 ml	2,940 ml	4.7%	4.2%	2,760 ml	2,462 ml	4.6%	4.1%
Lean body weight	56.3 kg	50.5 kg	80.4%	72.1%	42.0 kg	38.2 kg	70.2%	63.7%
Body fat	13.7 kg	19.5 kg	19.6%	27.9%	17.9 kg	21.8 kg	29.8%	36.3%
Skeletal weight	5.8 kg	5.7 kg	8.3%	8.1%	4.4 kg	4.2 kg	7.3%	7.0%

From K. H. Oleson, "Body Composition in Normal Adults" in *Human Body Composition*, Vol. 7:177–190. Copyright © 1965 Pergamon Press Ltd., Oxford, England.

TABLE 22.5 Summary of Postnatal Periods

Period	Time Span	Physical and Behavioral Characteristics
Neonatal period	Birth to end of fourth week	Stabilizing of body systems necessary to carry on respiration, obtain nutrients, digest nutrients, excrete wastes, regulate body temperature, and circulate blood
Infancy	End of fourth week through second year	Tremendous growth; teeth begin to erupt; muscular and nervous systems develop so that motor activities are possible; verbal communication begins
Childhood	End of infancy to puberty	Consistent growth; deciduous teeth erupt and are replaced by permanent teeth; motor control improves; urinary bladder and bowel controls are established; intellect develops rapidly
Adolescence	End of puberty to adulthood	Maturing of reproductive system; growth spurts in skeletal and muscular systems; continued development of intellect and emotional maturity
Adulthood	End of adolescence to old age	Attainment of maximum physical stature and strength; anatomical and physiological degenerative changes begin
Senescence	Old age to death	Continuing of senescence; body becomes less able to cope with diseases and physical demands; death—usually from physical disturbances in the cardiovascular system or disease processes in vital organs

A particularly standardized expression of racial differences are the indices of appendage lengths relative to sitting height. People of African ancestry, for example, have comparatively long appendages relative to sitting height; moreover, the forearm and leg are long relative to the brachium and thigh (fig. 22.28). Australian Aborigines have even longer legs proportionately than do Native Africans. People of African ancestry also have the narrowest pelvic girdle for a given shoulder width. People of Asian ancestry have relatively short appendage lengths to sitting heights. These differences provide distinct advantages and disadvantages in certain sports. Blacks have an advantage in many track events, particularly the sprints and high hurdles, whereas whites are generally adapted to distance running. Asians often excel in gymnastics and weight lifting.

Knowledge Check

20. Construct a table that lists the periods of postnatal growth from infancy through adolescence and indicate the events or characteristics of each period.
21. List four reflexes in a newborn that are critical for survival.
22. Define the terms *puberty*, *pubescence*, *sexual dimorphism*, and *menarche*. What is the average age of puberty and what brings it about?
23. Describe the physical characteristics of adulthood. Compare the body structure of an adult female to that of an adult male.

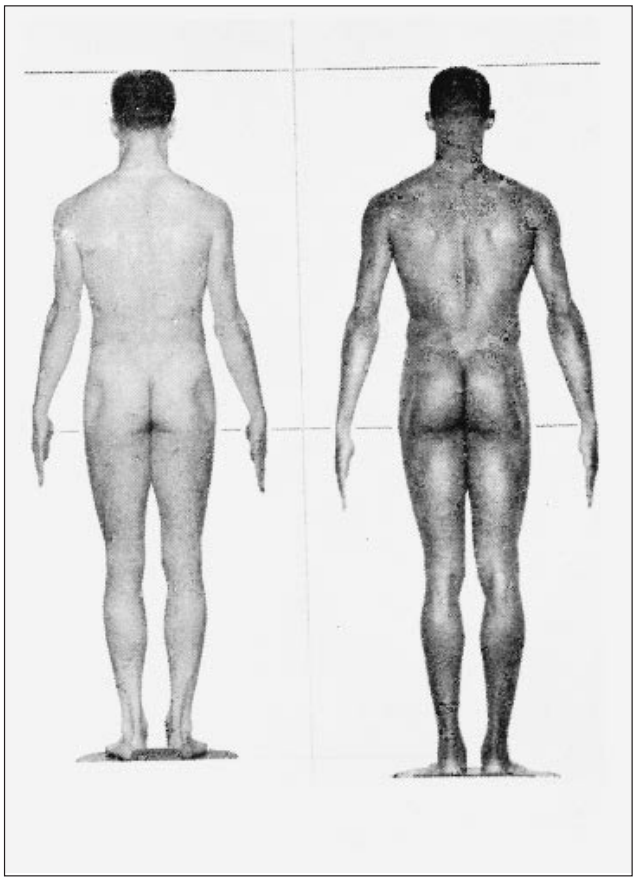


FIGURE 22.28 A comparison of Caucasian and African American physiques. The photographs of two Olympic 400-meter runners have been scaled so that both have the same sitting height.

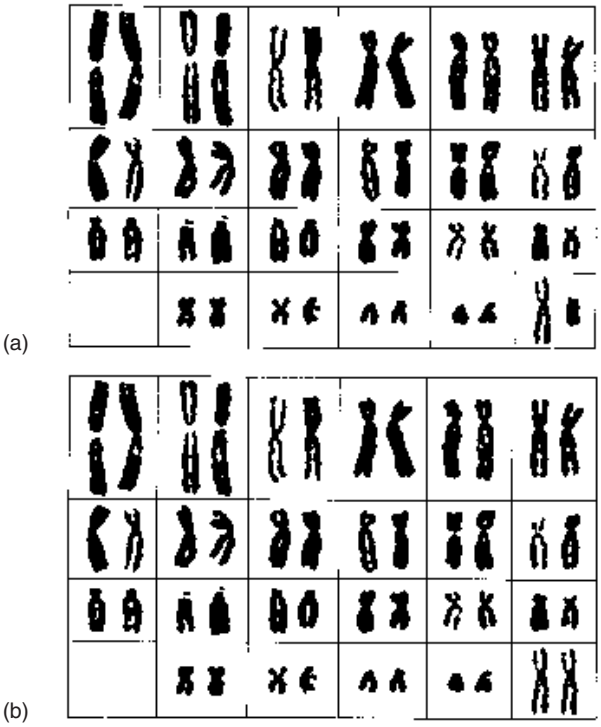


FIGURE 22.29 A karyotype of homologous pairs of chromosomes obtained from a human diploid cell. The first 22 pairs of chromosomes are called the autosomal chromosomes. The sex chromosomes are (*a*) XY for a male and (*b*) XX for a female.

INHERITANCE

Inheritance is the acquisition of characteristics or qualities by transmission from parent to offspring. Hereditary information is transmitted by genes.

Objective 18 Define *genetics.*

Objective 19 Discuss the variables that account for a person's phenotype.

Objective 20 Explain how probability is involved in predicting inheritance and use a Punnett square to illustrate selected probabilities.

Genetics is the branch of biology that deals with inheritance. Genetics and inheritance are important in anatomy and physiology because of the numerous developmental and functional disorders that have a genetic basis. Knowledge of which disorders and diseases are inherited finds practical application in genetic counseling. The genetic inheritance of an individual begins with conception.

Each zygote inherits 23 chromosomes from the mother and 23 chromosomes from the father. This does not produce 46 different chromosomes; rather, it produces 23 pairs of *homologous chromosomes*. Each member of a homologous pair, with the important exception of the sex chromosomes, looks like the other and contains similar genes (such as those coding for eye color, height, and so on). These homologous pairs of chromosomes can be **karyotyped** (photographed or illustrated) and identified, as shown in fig. 22.29. Each cell that contains 46 chromosomes (that is *diploid*) has two number-1 chromosomes, two number-2 chromosomes, and so on through chromosomes number 22. The first 22 pairs of chromosomes are called **autosomal** (*aw''tŏ-so'mal*) **chromosomes.** The twenty-third pair of chromosomes are the **sex chromosomes,** which may look different and may carry different genes. In a female these consist of two X chromosomes, whereas in a male there is one X chromosome and one Y chromosome.

Genes and Alleles

A **gene** is the portion of the DNA of a chromosome that contains the information needed to synthesize a particular protein molecule. Although each diploid cell has a pair of genes for each characteristic, these genes may be present in variant forms. Those alternative forms of a gene that affect the same characteristic but that produce different expressions of that characteristic

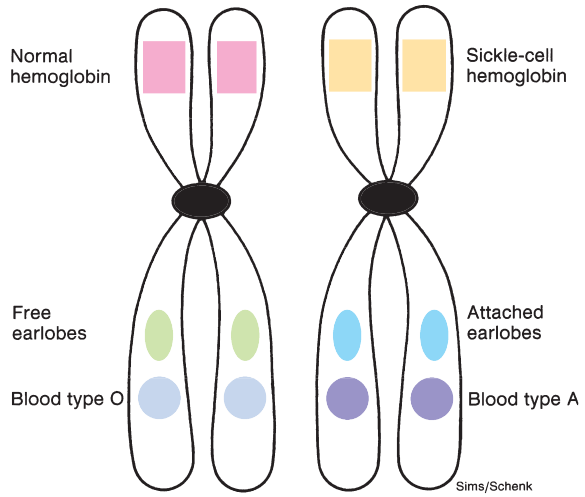


FIGURE 22.30 A pair of homologous chromosomes. Homologous chromosomes contain genes for the same characteristic at the same locus.

are called **alleles** (*ă-lēlz′*). One allele of each pair originates from the female parent and the other from the male. The shape of a person's ears, for example, is determined by the kind of allele received from each parent and how the alleles interact with one another. Alleles are always located on the same spot (called a **locus**) on homologous chromosomes (Fig. 22.30).

For any particular pair of alleles in a person, the two alleles are either identical or not identical. If the alleles are identical, the person is said to be **homozygous** (*ho′′mo-zi′gus*) for that particular characteristic. But if the two alleles are different, the person is **heterozygous** (*het′′er-o-zi′gus*) for that particular trait.

Genotype and Phenotype

A person's DNA contains a catalog of genes known as the **genotype** (*jen′ŏ-tīp*) of that person. The expression of those genes results in certain observable characteristics referred to as the **phenotype** (*fe′nŏ-tīp*).

If the alleles for a particular trait are homozygous, the characteristic expresses itself in a specific manner (two alleles for attached earlobes, for example, results in a person with attached earlobes). If the alleles for a particular trait are heterozygous, however, the allele that expresses itself and the way in which the genes for that trait interact will determine the phenotype. The allele that expresses itself is called the **dominant allele,** the one that does not is the **recessive allele.** The various combinations of dominant and recessive alleles are responsible for a person's hereditary traits (Table 22.6).

In describing genotypes, it is traditional to use letter symbols to refer to the alleles of an organism. The dominant alleles are symbolized by uppercase letters, and the recessive alleles are symbolized by lowercase. Thus, the *genotype* of a person who is homozygous for free earlobes as a result of a dominant allele is symbolized *EE;* a heterozygous pair is symbolized *Ee*. In both of these instances, the

TABLE 22.6 **Hereditary Traits in Humans Determined by Single Pairs of Dominant and Recessive Alleles**

Dominant	Recessive	Dominant	Recessive
Free earlobes	Attached earlobes	Color vision	Color blindness
Dark brown hair	All other colors	Broad lips	Thin lips
Curly hair	Straight hair	Ability to roll tongue	Lack of this ability
Pattern baldness (♂♂)	Baldness (♀♀)	Arched feet	Flat feet
Pigmented skin	Albinism	A or B blood factor	O blood factor
Brown eyes	Blue or green eyes	Rh blood factor	No Rh blood factor

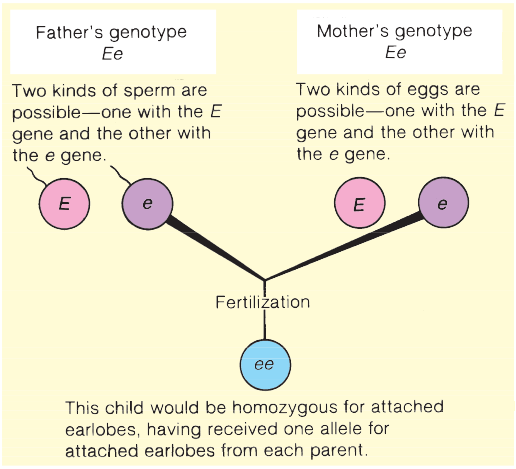


FIGURE 22.31 Inheritance of earlobe characteristics. Two parents with unattached (free) earlobes can have a child with attached earlobes.

phenotypes of the individuals would be free earlobes resulting from the presence of a dominant allele in each genotype. A person who inherited two recessive alleles for earlobes would have the genotype *ee* and would have attached earlobes.

Thus, three genotypes are possible when gene pairing involves dominant and recessive alleles. They are *homozygous dominant (EE), heterozygous (Ee),* and *homozygous recessive (ee).* Only two phenotypes are possible, however, because the dominant allele is expressed in both the homozygous dominant (*EE*) and the heterozygous (*Ee*) individuals. The recessive allele is expressed only in the homozygous recessive (*ee*) condition. Refer to figure 22.31 for an illustration of how a homozygous recessive trait may be expressed in a child of parents who are heterozygous.

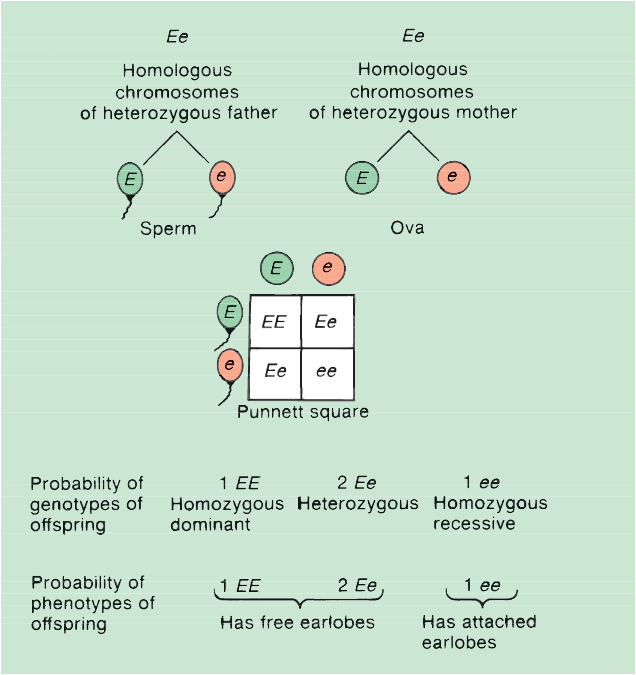


FIGURE 22.32 Use of a Punnett square to determine genotypes and phenotypes that could result from the mating of two heterozygous parents.

Probability

A **Punnett** (*pun'et*) **square** is a convenient way to express the probabilities of allele combinations for a particular inheritable trait. In constructing a Punnett square, the male gametes (spermatozoa) carrying a particular trait are placed at the side of the chart, and the female gametes (ova) at the top, as in figure 22.32. The four spaces on the chart represent the possible combinations of male and female gametes that could form zygotes. The probability of an offspring having a particular genotype is 1 in 4 (.25) for homozygous dominant and homozygous recessive and 1 in 2 (.50) for heterozygous.

A genetic study in which a single characteristic (e.g., ear shape) is followed from parents to offspring is referred to as a **monohybrid cross.** A genetic study in which two characteristics are followed from parents to offspring is referred to as a **dihybrid cross** (fig. 22.33). The term *hybrid* refers to an offspring descended from parents who have different genotypes.

Sex-linked Inheritance

Certain inherited traits are located on a sex-determining chromosome, and are thus called **sex-linked** characteristics. The allele for *red-green color blindness*, for example, is determined by a recessive allele (designated *c*) found on the X chromosome but not on the Y chromosome. Normal color vision (designated C) dominates. The ability to discriminate red from green, therefore, depends entirely on the X chromosomes. The genotype possibilities are as follows:

X^CY	Normal male
X^cY	Color-blind male
X^CX^C	Normal female
X^CX^c	Normal female carrying the recessive allele
X^cX^c	Color-blind female

In order for a female to be red-green color-blind, she must have the recessive allele on both of her X chromosomes. Her father would have to be red-green colorblind and her mother

Punnett square: from Reginald Crundall Punnett, English geneticist, 1875–1967

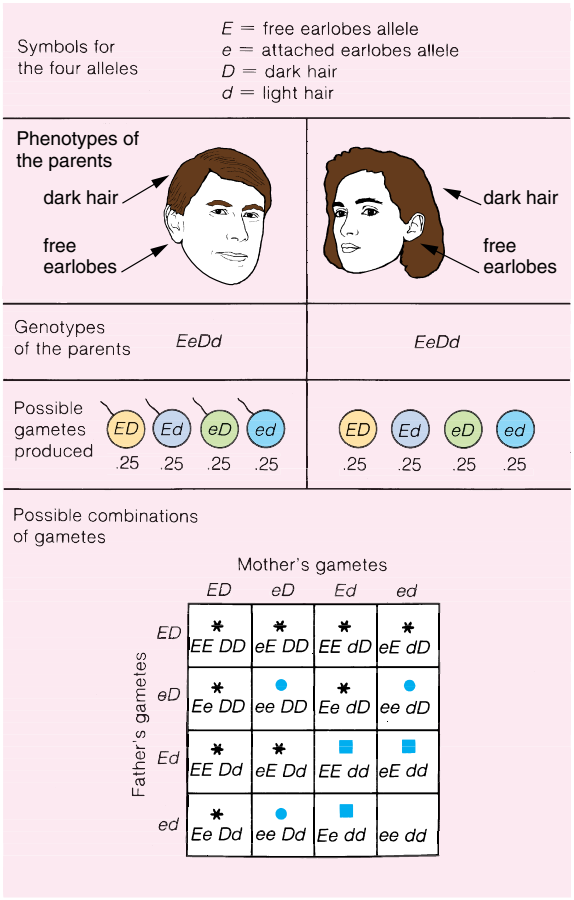


FIGURE 22.33 In a dihybrid cross, two pairs of traits are followed simultaneously. Any of the combinations of genes that have a *D* and an *E* (nine possibilities) will have free earlobes and dark hair. These are indicated with an asterisk (*). Three of the possible combinations have two alleles for attached earlobes (*ee*) and at least one allele for dark hair. They are indicated with a dot (•). Three of the combinations have free earlobes and light hair. These are indicated with a square (■). The remaining possibility has the genotype *eedd* for attached earlobes and light hair.

CHAPTER 22

would have to be a carrier for this condition. A male with only one such allele on his X chromosome, however, will show the characteristic. Because a male receives his X chromosome from his mother, the inheritance of sex-linked characteristics usually passes from mother to son.

Hemophilia is a sex-linked condition caused by a recessive allele. The blood in a person with hemophilia fails to clot or clots very slowly after an injury. If *H* represents normal clotting and *h* represents abnormal clotting, then males with X^HY will be normal and males with X^hY will be hemophiliac. Females with X^hX^h will have the disorder.

Knowledge Check

24. Define *genetics*, *genotype*, *phenotype*, *allele*, *dominant*, *recessive*, *homozygous*, and *heterozygous*.
25. List several dominant and recessive traits inherited in humans. What are some variables that determine a person's phenotype?
26. Construct a Punnett square to show the possible genotypes for color blindness of an X^cY male and an X^CX^c female.

CLINICAL CONSIDERATIONS

Pregnancy and childbirth are natural events in human biology and generally progress smoothly without complications. Prenatal development is amazingly precise, and although traumatic, childbirth for most women in the world takes place without the aid of a physician. Occasionally, however, serious complications arise, and the knowledge of an obstetrician is required. The physician's knowledge of what constitutes normal development and what factors are responsible for congenital malformations ensures the embryo and fetus every possible chance to develop normally. Many of the clinical aspects of prenatal development involve what might be referred to as applied developmental biology.

In clinical terms, gestation is frequently divided into three phases, or **trimesters,** each lasting three calendar months. By the end of the **first trimester,** all the major body systems are formed, the fetal heart can be detected, the external genitalia are developed, and the fetus is about the width of the palm of an adult's hand. During the **second trimester,** fetal quickening can be detected, epidermal features are formed, and the vital body systems are functioning. The fetus, however, still would be unlikely to survive if birth were to occur. At the end of the second trimester, fetal length is about equal to the length of an adult's hand. The fetus experiences a tremendous amount of growth and refinement in system functioning during the **third trimester.** A fetus of this age may survive if born prematurely, and of course, the chances of survival improve as the length of pregnancy approaches the natural delivery date.

Many clinical considerations are associated with prenatal development, and some of these relate directly to the female reproductive system. Other developmental problems are genetically related and will be mentioned only briefly. Of clinical concern for developmental anatomy are such topics as ectopic pregnancies, so-called test-tube babies, multiple pregnancy, fetal monitoring, and congenital defects.

Abnormal Implantation Sites

In an **ectopic** (*ek-top'ik*) **pregnancy** the blastocyst implants outside the uterus or in an abnormal site within the uterus (fig. 22.34). About 95% of the time, the ectopic location is within the uterine tube and is referred to as a **tubal pregnancy** (see fig. 21.24). Occasionally, implantation occurs near the cervix, where development of the placenta blocks the cervical opening. This condition, called **placenta previa** (*pre've-ă*), causes serious bleeding. Ectopic pregnancies will not develop normally in unfavorable locations, and the fetus seldom survives beyond the first trimester. Tubal pregnancies are terminated through medical intervention. If a tubal pregnancy is permitted to progress, the uterine tube generally ruptures, followed by hemorrhaging. Depending on the location and the stage of development (hence vascularity) of a tubal pregnancy, it may or may not be life-threatening to the woman.

In Vitro Fertilization and Artificial Implantation

Reproductive biologists have been able to fertilize a human oocyte in vitro (outside the body), culture it to the blastocyst stage, and then perform artificial implantation, leading to a full-term development and delivery. This is the so-called test-tube baby. To obtain the oocyte, a specialized laparoscope (fig. 22.35) is used to aspirate the preovulatory egg from a mature vesicular ovarian follicle. The oocyte is then placed in a suitable culture medium, where it is fertilized with spermatozoa. When the zygote reaches the blastocyst stage, it is introduced into the uterus for implantation and subsequent growth. In vitro fertilization with artificial implantation is a means of overcoming infertility problems because of damaged, blocked, or missing uterine tubes in females or low sperm counts in males.

Multiple Pregnancy

Twins occur about once in 85 pregnancies. They can develop in two ways. **Dizygotic** (*di''zi-got'ik*) (fraternal) **twins** develop from two zygotes produced by the fertilization of two oocytes by two spermatozoa in the same ovulatory cycle (fig. 22.36). **Monozygotic** (identical) **twins** form from a single zygote (fig. 22.37). Approximately one-third of twins are monozygotic.

Dizygotic twins may be of the same sex or different sexes and are not any more alike than brothers or sisters born at different times. Dizygotic twins always have two chorions and two amnions, but the chorions and the placentas may be fused.

previa: L. *previa*, appearing before or in front of

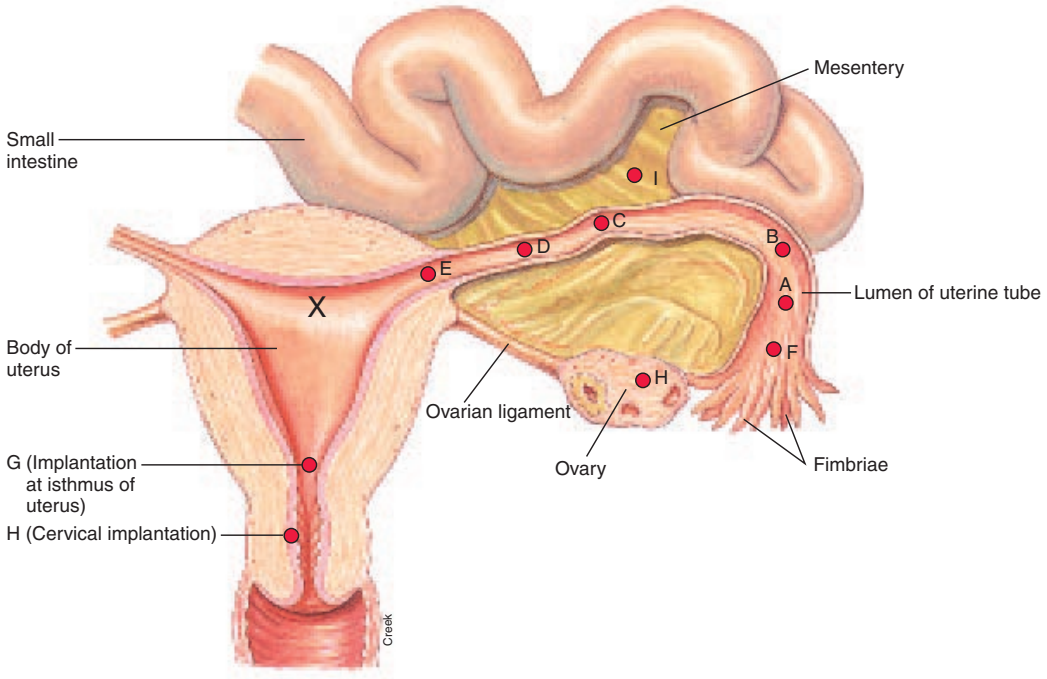


FIGURE 22.34 Sites of ectopic pregnancies. The normal implantation site is indicated by an X; the abnormal sites are indicated by letters in order of frequency of occurrence.

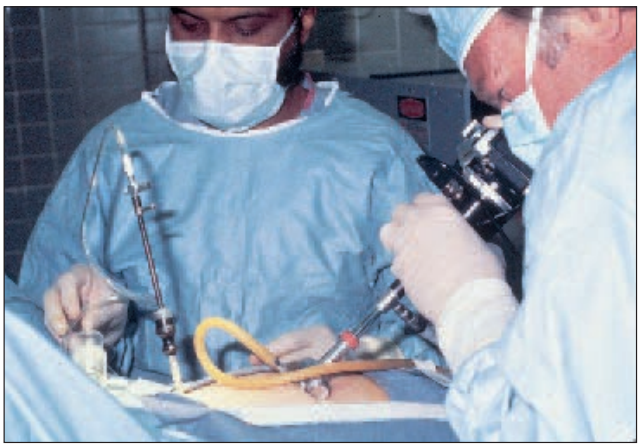


FIGURE 22.35 A laparoscope is used for various abdominal operations, including the extraction of a preovulatory ovum.

Monozygotic twins are of the same sex and are genetically identical. Any physical differences in monozygotic twins are caused by environmental factors during morphogenic development (e.g., there might be a differential vascular supply that causes slight differences to be expressed). Monozygotic twinning is usually initiated toward the end of the first week when the embryoblast divides to form two embryonic primordia. Monozygotic twins have two amnions but only one chorion and a common placenta. If the embryoblast fails to completely divide, **conjoined twins** (Siamese twins) may form.

Triplets occur about once in 7,600 pregnancies and may be (1) all from the same ovum and identical, (2) two identical and the third from another ovum, or (3) three zygotes from three different ova. Similar combinations occur in quadruplets, quintuplets, and so on.

Fetal Monitoring

Obstetrics has benefited greatly from advancements made in fetal monitoring in the last two decades. Before modern techniques became available, physicians could determine the welfare of the unborn child only by auscultation of the fetal heart and palpation of the fetus. Currently, several tests may be used to gain information about the fetus during any stage of development. Fetal conditions that can now be diagnosed and evaluated include genetic disorders, hypoxia, blood disorders, growth retardation, placental functioning, prematurity, postmaturity, and intrauterine infections. These tests also help to determine the advisability of an abortion.

Radiographs of the fetus were once commonly performed but were found harmful and have been replaced by other methods of evaluation that are safer and more informative. **Ultra-**

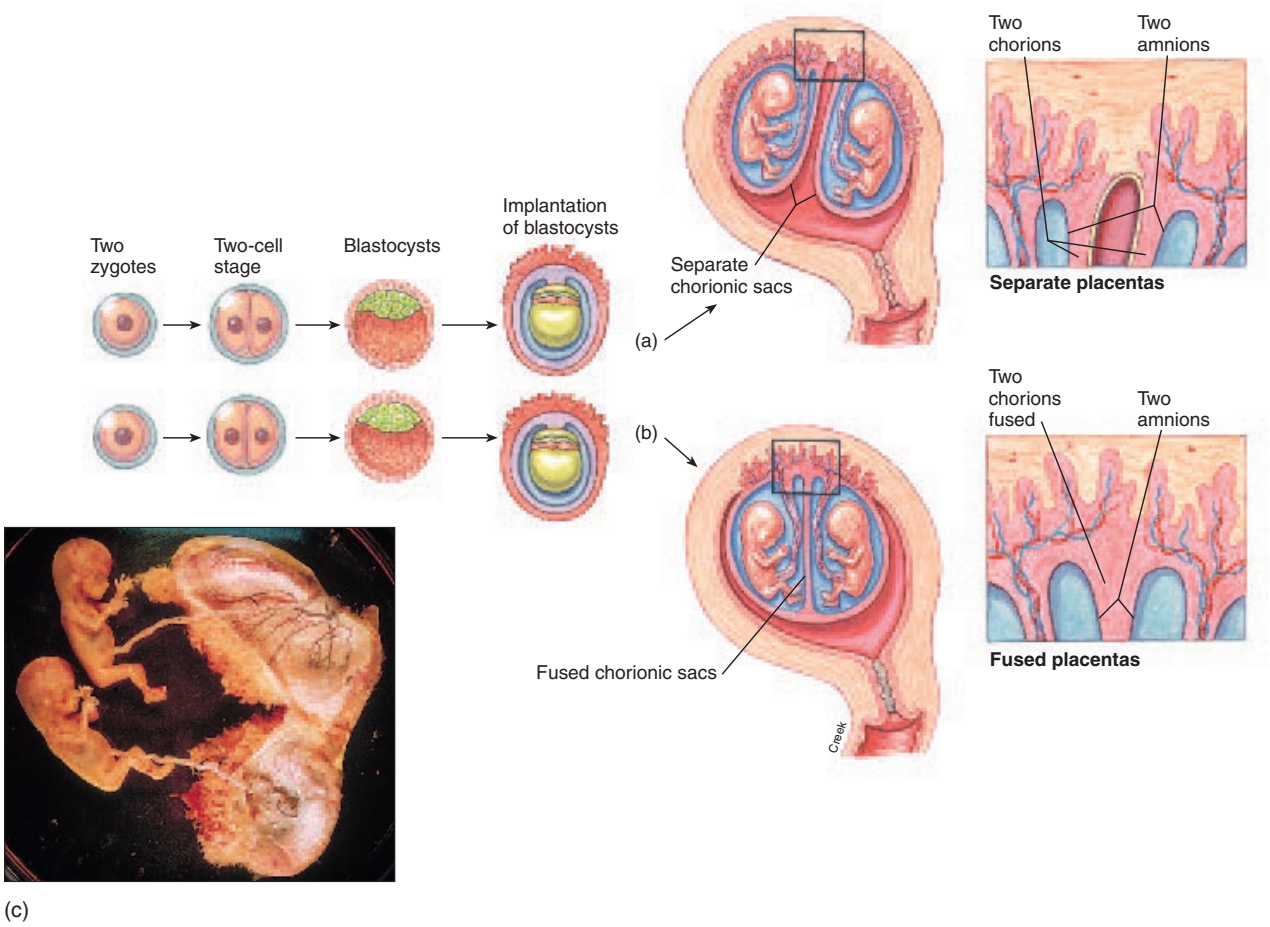


FIGURE 22.36 The formation of dizygotic twins. Twins of this type are fraternal rather than identical and may have (*a*) separate or (*b*) fused placentas. (*c*) A photograph of fraternal twins at 11 weeks.

sonography employs a mechanical vibration of high frequency to produce a safe, high-resolution (sharp) image of fetal structure (fig. 22.38). Ultrasonic imaging is a reliable way to determine pregnancy as early as 6 weeks after ovulation. It can also be used to determine fetal weight, length, and position, as well as to diagnose multiple fetuses.

Amniocentesis is a technique used to obtain a small sample of amniotic fluid so that it can be assessed genetically and biochemically (see fig. 22.13). A wide-bore needle is inserted into the amniotic sac with guidance by ultrasound, and 5–10 ml of amniotic fluid is withdrawn with a syringe. Amniocentesis is most often performed to determine fetal maturity, but it can also help predict serious disorders such as *Down syndrome* or *Gaucher's disease* (a metabolic disorder).

Fetoscopy (fig. 22.39) goes beyond amniocentesis by allowing direct examination of the fetus. Using fetoscopy, physicians scan the uterus with pulsed sound waves to locate fetal structures, the umbilical cord, and the placenta. Skin samples are taken from the head of the fetus and blood samples extracted from the placenta. The principal advantage of fetoscopy is that external features of the fetus (such as fingers, eyes, ears, mouth, and genitals) can be carefully observed. Fetoscopy is also used to determine several diseases, including hemophilia, thalassemia, and sickle-cell anemia cases, 40% of which are missed by amniocentesis.

Most hospitals are now equipped with instruments that monitor fetal heart rate and uterine contractions during labor. These instruments can detect any complication that may arise during the delivery. The procedure is called *Electronic Monitoring*

amniocentesis: Gk. *amnion*, lamb (fetal membrane); *kentesis*, puncture

fetoscopy: L. *fetus*, offspring; *skopein*, to view

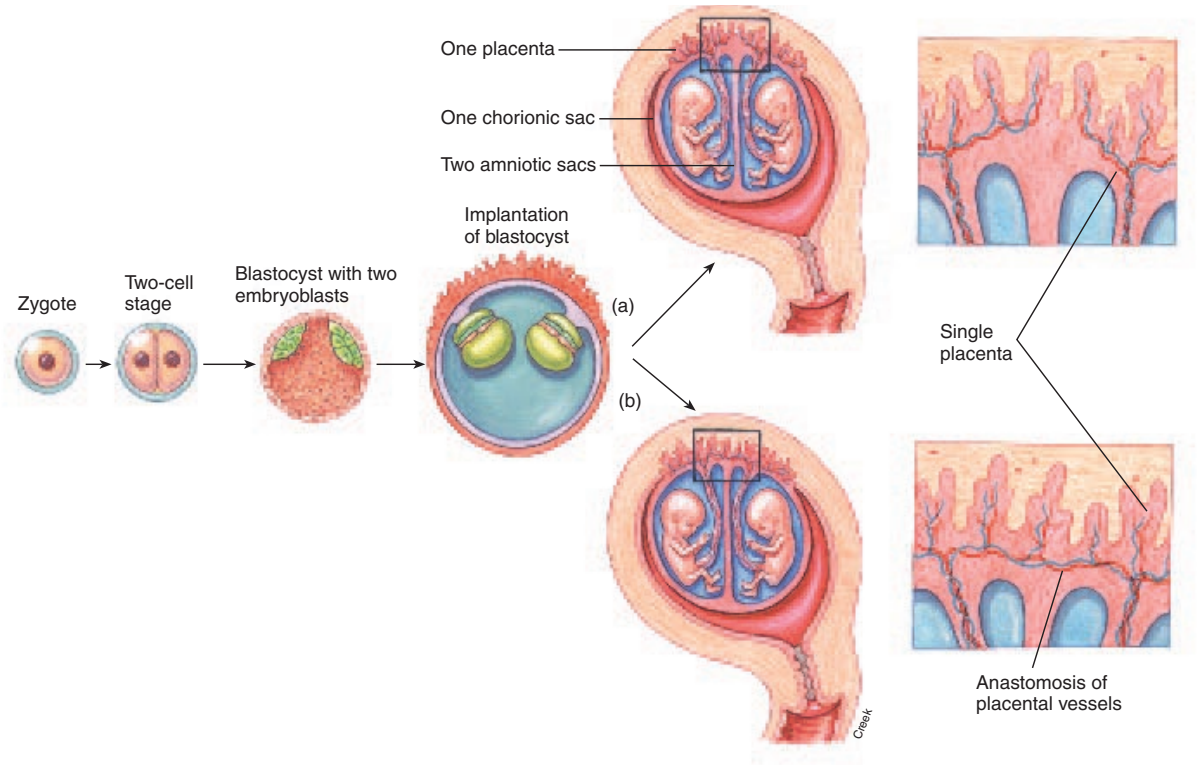


FIGURE 22.37 The formation of monozygotic twins. Twins of this type develop from a single zygote and are identical. Such twins have two amnions but only one chorion, and they share a common placenta.

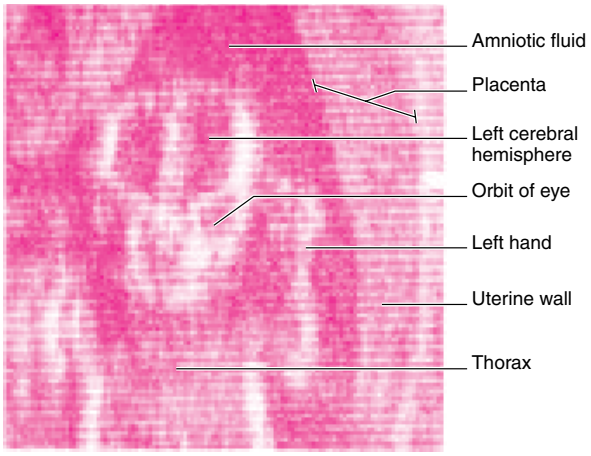


FIGURE 22.38 A color-enhanced ultrasonogram of a fetus during the third trimester. The left hand is raised, as if waving to the viewer.

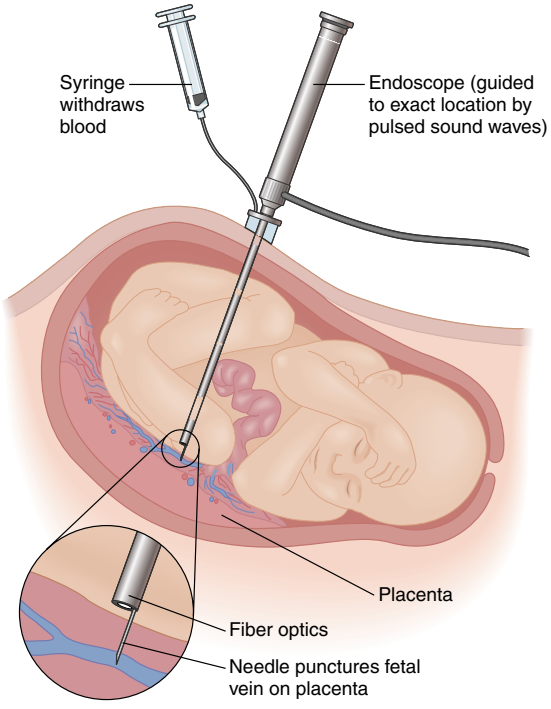


FIGURE 22.39 Fetoscopy.

CHAPTER 22

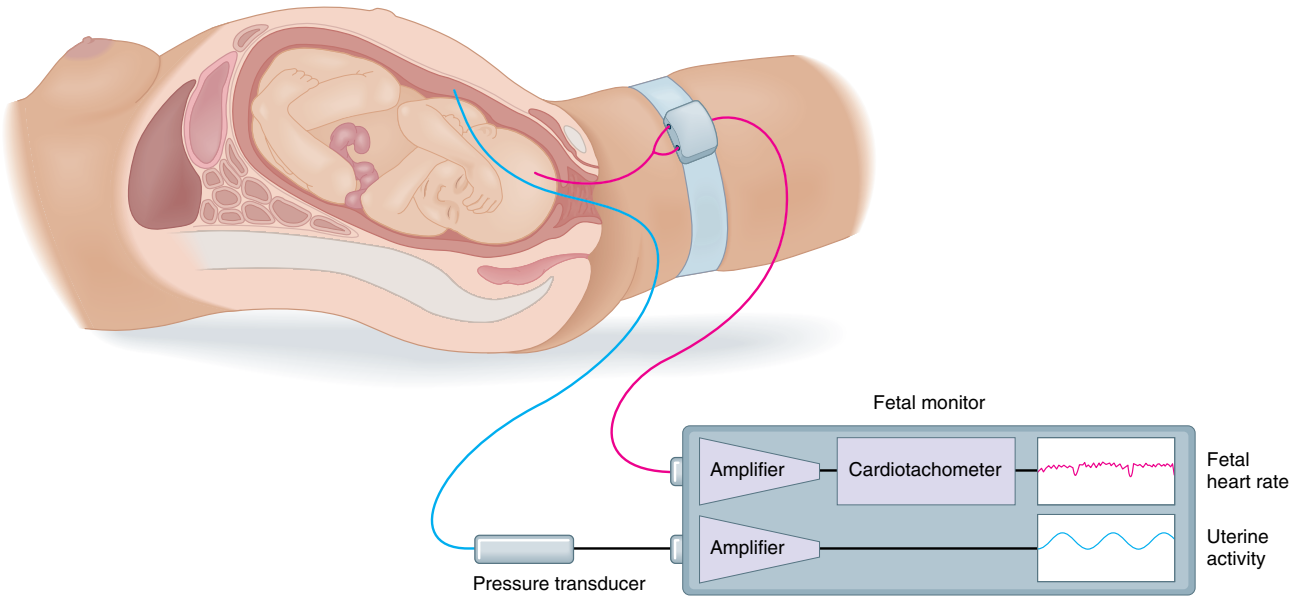


FIGURE 22.40 Monitoring the fetal heart rate and uterine contractions using an FHR–UC device.

of Fetal Heart Rate and Uterine Contractions (FHR-UC Monitoring). The extent of stress to the fetus from uterine contractions can be determined through FHR-UC monitoring (fig. 22.40). Long, arduous deliveries are taxing to both the mother and fetus. If the baby's health and vitality are presumed to be in danger because of a difficult delivery, the physician may decide to perform a cesarean section.

Congenital Defects

Major developmental problems called **congenital malformations** occur in approximately 2% of all newborn infants. They may be caused by genetic inheritance, mutation (genetic change), or environmental factors. About 15% of neonatal deaths are attributed to congenital malformations. The branch of developmental biology concerned with abnormal development and congenital malformations is called *teratology* (*tar''ă-tol'ŏ-je*). Many congenital problems have been discussed in previous chapters, in connection with the body system in which they occur.

Clinical Case Study Answer

Two amnions and one chorion in all but very unusual cases prove the twins to be monozygotic. The two infants, therefore, are genetically identical. Thus, when considering genetic disorders such as cleft palate, one would expect a high degree of concordance (both twins of a monozygotic pair exhibit a particular anomaly). Many such defects however can be present in only one twin—a consequence of nongenetic factors, such as intrauterine environment. An example would be inadequate blood supply to only one twin, resulting in a defect in that twin but not in the other.

congenital: L. *congenitus*, born with

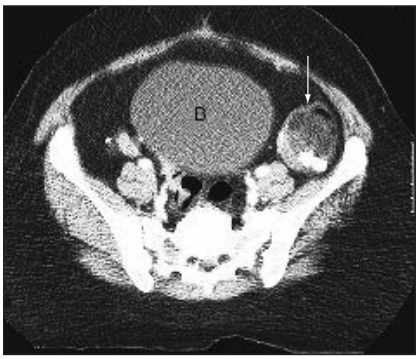
teratology: Gk. *teras*, monster; *logos*, study of

CLINICAL PRACTICUM 22.1

A 31-year-old female comes to your office for her annual gynecologic exam. She reports no menstrual abnormalities. On physical exam, you note a mass in her left adnexa (accessory component of the main organ). Because of this finding, you order a CT scan to further evaluate this area. (B = urinary bladder.)

QUESTIONS

1. What is the heterogeneous mass (arrow) seen to the left of the urinary bladder (B)?
2. What organ and cell line does this mass arise from?
3. What is the significance of this mass?



Genetic Disorders of Clinical Importance

cystic fibrosis An autosomal recessive disorder characterized by the formation of thick mucus in the lungs and pancreas that interferes with normal breathing and digestion.

familial cretinism An autosomal recessive disorder characterized by a lack of thyroid secretion because of a defect in the iodine transport mechanism. Untreated children are dwarfed, sterile, and may be mentally retarded.

galactosemia (*gă-lak''tĕ-se'me-ă*) An autosomal recessive disorder characterized by an inability to metabolize galactose, a component of milk sugar. Patients with this disorder have cataracts, damaged livers, and mental retardation.

gout An autosomal dominant disorder characterized by an accumulation of uric acid in the blood and tissue resulting from an abnormal metabolism of purines.

hepatic porphyria (*por-fĕr'e-ă*) An autosomal dominant disorder characterized by painful GI disorders and neurologic disturbances resulting from an abnormal metabolism of porphyrins.

hereditary hemochromatosis (*he''mō-kro''mă-to'sis*) A sex-influenced autosomal dominant disorder characterized by an accumulation of iron in the pancreas, liver, and heart, resulting in diabetes, cirrhosis, and heart failure.

hereditary leukomelanopathy (*loo''ko-mel''ă-nop'ă-the*) An autosomal recessive disorder characterized by decreased pigmentation in the skin, hair, and eyes and abnormal white blood cells. People with this condition are generally susceptible to infections and early deaths.

Huntington's chorea An autosomal dominant disorder characterized by uncontrolled twitching of skeletal muscles and the deterioration of mental capacities. A latent expression of this disorder allows the mutant gene to be passed to children before symptoms develop.

Marfan's syndrome An autosomal dominant disorder characterized by tremendous growth of the extremities, extreme looseness of the joints, dislocation of the lenses of the eyes, and congenital cardiovascular defects.

phenylketonuria (*fen''il-kēt''n-oor'e-ă*) (PKU) An autosomal recessive disorder characterized by an inability to metabolize the amino acid phenylalanine. It is accompanied by brain and nerve damage and mental retardation. (Newborns are routinely tested for PKU; those that are affected are placed on a diet low in phenylalanine.)

pseudohypertrophic muscular dystrophy A sex-linked recessive disorder characterized by progressive muscle atrophy. It usually begins during childhood and causes death in adolescence.

retinitis pigmentosa A sex-linked recessive disorder characterized by progressive atrophy of the retina and eventual blindness.

Tay-Sachs disease An autosomal recessive disorder characterized by a deterioration of physical and mental abilities, early blindness, and early death. It has a disproportionately high incidence in Jews of Eastern European origin.

Huntington's chorea: from George Huntington, American physician, 1850–1916

Marfan's syndrome: from Antoine Bernard-Jean Marfan, French physician 1858–1942

Chapter Summary

Fertilization (pp. 755–757)

1. Upon fertilization of a secondary oocyte by a spermatozoon in the uterine tube, meiotic development is completed and a diploid zygote is formed.
2. Morphogenesis is the sequential formation of body structures during the prenatal period of human life. The prenatal period lasts 38 weeks and is divided into a preembryonic, an embryonic, and a fetal period.
3. A capacitated spermatozoon digests its way through the zona pellucida and corona radiata of the secondary oocyte to complete the fertilization process and formation of a zygote.

Preembryonic Period (pp. 757–762)

1. Cleavage of the zygote is initiated within 30 hours and continues until a morula forms; the morula enters the uterine cavity on about the third day.
2. A hollow, fluid-filled space forms within the morula, at which point it is called a blastocyst.
3. Implantation begins between the fifth and seventh day and is enabled by the secretion of enzymes that digest a portion of the endometrium.
   (a) During implantation, the trophoblast cells secrete human chorionic gonadotropin (hCG), which prevents the breakdown of the endometrium and menstruation.
   (b) The secretion of hCG declines by the tenth week as the developed placenta secretes steroids that maintain the endometrium.
4. The embryoblast of the implanted blastocyst flattens into the embryonic disc, from which the primary germ layers of the embryo develop.
   (a) Ectoderm gives rise to the nervous system, the epidermis of the skin and epidermal derivatives, and to portions of the sensory organs.
   (b) Mesoderm gives rise to bones, muscles, blood, reproductive organs, the dermis of the skin, and connective tissue.
   (c) Endoderm gives rise to linings of the GI tract, digestive organs, the respiratory tract and lungs, and the urinary bladder and urethra.

Embryonic Period (pp. 762–771)

1. The events of the 6-week embryonic period include the differentiation of the germ layers into specific body organs and the formation of the placenta, the umbilical cord, and the extraembryonic membranes. These events make it possible for morphogenesis to continue.
2. The extraembryonic membranes include the amnion, yolk sac, allantois, and chorion.
   (a) The amnion is a thin membrane surrounding the embryo. It contains amniotic fluid that cushions and protects the embryo.
   (b) The yolk sac produces blood for the embryo.
   (c) The allantois also produces blood for the embryo and gives rise to the umbilical arteries and vein.
   (d) The chorion participates in the formation of the placenta.
3. The placenta, formed from both maternal and embryonic tissue, has a transport role in providing for the metabolic needs of the fetus and in removing its waste.
   (a) The placenta produces steroid and polypeptide hormones.
   (b) Nicotine, drugs, alcohol, and viruses can cross the placenta to the fetus.
4. The umbilical cord, containing two umbilical arteries and one umbilical vein, is formed as the amnion envelops the tissues on the underside of the embryo.
5. From the third to the eighth week, the structure of all the body organs, except the genitalia, becomes apparent.
   (a) During the third week, the primitive node forms from the primitive line, which later gives rise to the notochord and intraembryonic mesoderm.
   (b) By the end of the fourth week, the heart is beating; the primordial tissues of the eyes, brain, spinal cord, lungs, and digestive organs are properly positioned; and the superior and inferior limb buds are recognizable.
   (c) At the end of the fifth week, the sense organs are formed in the enlarged head and the appendages have developed with digital primordia evident.
   (d) During the seventh and eighth weeks, the body organs are formed, except for the genitalia, and the embryo appears distinctly human.

Fetal Period (pp. 772–774)

1. A small amount of tissue differentiation and organ development occurs during the fetal period, but for the most part fetal development is primarily limited to body growth.
2. Between weeks 9 and 12, ossification centers appear, the genitalia are formed, and the digestive, urinary, respiratory, and muscle systems show functional activity.
3. Between weeks 13 and 16, facial features are formed and the fetal heartbeat can be detected with a stethoscope.
4. During the 17-to-20-week period, quickening can be felt by the mother, and vernix caseosa and lanugo cover the skin of the fetus.
5. During the 21-to-25-week period, substantial weight gain occurs and the fetal skin becomes wrinkled and pinkish.
6. Toward the end of the 26-to-29-week period, the eyes have opened, the gonads have descended in a male, and the fetus is developed to the extent that it might survive if born prematurely.
7. At 38 weeks, the fetus is full-term; the normal gestation is 266 days.

Labor and Parturition (p. 775)

1. Labor and parturition are the culmination of gestation and require the action of oxytocin, secreted by the posterior pituitary, and prostaglandins, produced in the uterus.
2. Labor is divided into dilation, expulsion, and placental stages.

Periods of Postnatal Growth (pp. 775–782)

1. The course of human life after birth is seen in terms of physical and physiological changes and the attainment of maturity in the neonatal period, infancy, childhood, adolescence, and adulthood.
2. The neonatal period, extending from birth to the end of the fourth week, is characterized by major physiological changes.
   (a) The most critical need of the newborn is to establish adequate respiratory and heart rates. A normal respiratory rate is 30 to 40 respirations per minute, and a normal heart rate ranges from 120 to 160 beats per minute.
   (b) The four reflexes in the newborn critical to survival are the suckling reflex, the rooting reflex, the crying reflex, and the breathing reflex.
3. Infancy, extending from 4 weeks through the second year, is characterized by tremendous growth, increased coordination, and mental development.
   (a) By 2 years, most infants weigh about 4 times their birth weight and average between 32 and 36 inches in length.

(b) Growth is a differential process resulting in gradual changes from infant to adult body proportions.

4. Childhood, extending from the end of infancy to adolescence, is characterized by steady growth until preadolescence, at which time there is a marked growth spurt.
   (a) During childhood, the average child becomes thinner and stronger each year as he or she grows taller.
   (b) The fact that disease and death are relatively rare during childhood may be due to the fact that lymphoid tissue is at its peak of development at this time; it is also present in greater amounts in children than in adults.
5. Adolescence is the period of growth and development between childhood and adulthood.
   (a) Puberty is the stage of early adolescence when the secondary sex characteristics are expressed and the sex organs become functional.
   (b) The end result of puberty is the structural expression of gender, or sexual dimorphism.
   (c) Menarche generally occurs in adolescent girls at the age of 13, but it may range from 9 to 17 years. At this time, vaginal secretions change from alkaline to acid.
   (d) The first physical indications of puberty are the appearance of breast buds in females and the growth of the testes and the appearance of sparse pubic hair in males.
   (e) Although semen may be ejaculated at age 13, sufficient mature spermatozoa for fertility are not produced until 14 to 16 years of age.
6. Adulthood, the final period of human physical change, is characterized by gradual senescence as a person ages.
   (a) Although skeletal maturity is reached in early adulthood, anatomical and physiological changes continue throughout adulthood and are part of the aging process.
   (b) Sexual dimorphism in human adults is evident anatomically, physiologically, metabolically, and behaviorally.
   (c) Male and female differences in the stature, proportions, and composition of the body may become more apparent with age.

Inheritance (pp. 782–785)

1. Inheritance is the passage of hereditary traits carried on the genes of chromosomes from one generation to another.
2. Each zygote contains 22 pairs of autosomal chromosomes and 1 pair of sex chromosomes—XX in a female and XY in a male.
3. A gene is the portion of a DNA molecule that contains information for the production of one kind of protein molecule. Alleles are different forms of genes that occupy corresponding positions on homologous chromosomes.
4. The combination of genes in an individual's cells constitutes his or her genotype; the observable expression of the genotype is the person's phenotype.
   (a) Dominant alleles are symbolized by uppercase letters and recessive alleles are symbolized by lowercase letters.
   (b) The three possible genotypes are homozygous dominant, heterozygous, and homozygous recessive.
5. A Punnett square is a convenient means for expressing probability.
   (a) The probability of a particular genotype is 1 in 4 (.25) for homozygous dominant and homozygous recessive, and 1 in 2 (.50) for heterozygous.
   (b) A single trait is studied in a monohybrid cross; two traits are studied in a dihybrid cross.
6. Sex-linked traits such as color blindness and hemophilia are carried on the sex-determining chromosome.

Review Activities

Objective Questions

1. The preembryonic period is completed when
   (a) the blastocyst implants.
   (b) the placenta forms.
   (c) the blastocyst reaches the uterus.
   (d) the primary germ layers form.
2. The yolk sac produces blood for the embryo until
   (a) the heart is functional.
   (b) the kidneys are functional.
   (c) the liver is functional.
   (d) the baby is delivered.
3. Which of the following is a function of the placenta?
   (a) production of steroids and hormones
   (b) diffusion of nutrients and oxygen
   (c) production of enzymes
   (d) all of the above apply
4. The decidua basalis is
   (a) a component of the umbilical cord.
   (b) the embryonic portion of the villous chorion.
   (c) the maternal portion of the placenta.
   (d) a vascular membrane derived from the trophoblast.
5. Which of the following could diffuse across the placenta?
   (a) nicotine (c) heroin
   (b) alcohol (d) all of the above
6. During which week following conception does the embryonic heart begin pumping blood?
   (a) the fourth week
   (b) the fifth week
   (c) the sixth week
   (d) the eighth week
7. Which of the following is the period of growth from birth to the end of the fourth week?
   (a) the neonatal period
   (b) the fetal period
   (c) infancy
   (d) the suckling period
8. The normal newborn heart rate is
   (a) 70–80 beats/min.
   (b) 120–160 beats/min.
   (c) 100–120 beats/min.
   (d) 180–200 beats/min.
9. The continuum of physical change in adolescence that regulates the growth of body hair is known as
   (a) puberty.
   (b) pubal progression.
   (c) pubescence.
   (d) dimorphism.
10. Which condition is *not* characteristic of the female as compared to the male?
    (a) lower blood pressure
    (b) higher basal metabolic rate
    (c) lower red blood cell count
    (d) faster heart rate
11. The first physical indication of puberty in females is generally
    (a) alkaline vaginal secretions.
    (b) a widening pelvis.
    (c) breast buds.
    (d) axillary hair.

12. Twins that develop from two zygotes resulting from the fertilization of two ova by two spermatozoa in the same ovulatory cycle are referred to as
    (a) monozygotic. (c) dizygotic.
    (b) conjoined. (d) identical.
13. Match the genotype descriptions in the left-hand column with the correct symbols in the right-hand column.
    homozygous recessive *Bb*
    heterozygous *bb*
    homozygous dominant *BB*
14. An allele that is *not* expressed in a heterozygous genotype is called
    (a) recessive. (c) genotypic.
    (b) dominant. (d) phenotypic.
15. If the genotypes of both parents are Aa and Aa, the offspring probably will be
    (a) ½ AA and ½ *aa*.
    (b) all *Aa*.
    (c) ¼ AA, ½ *Aa*, ¼ *aa*.
    (d) ¾ AA and ¼ *aa*.

Essay Questions

1. Describe the implantation of the blastocyst into the uterine wall and the involvement of the trophoblast in the formation of the placenta.
2. Explain how the primary germ layers form. What major structures does each germ layer give rise to?
3. Explain why development is so critical during the embryonic period and list the embryonic needs that must be met for morphogenesis to continue.
4. State the approximate time period (in weeks) for the following occurrences:
   (a) appearance of the arm and leg buds.
   (b) differentiation of the external genitalia.
   (c) perception of quickening by the mother.
   (d) functioning of the embryonic heart.
   (e) initiation of bone ossification.
   (f) appearance of lanugo and vernix caseosa.
   (g) survival of fetus if born prematurely.
   (h) formation of all major body organs completed.
5. Define the term *infancy* and discuss the growth and developmental events characteristic of this period of life.
6. Define the term *childhood* and discuss the growth and developmental events characteristic of this period of life.
7. Define the term *adolescence* and discuss the role of puberty in this period of life for both males and females.
8. Distinguish between puberty and pubescence.
9. Define the term *adulthood* and describe the characteristics of this period of life.
10. List some of the structural features of adults that exemplify sexual dimorphism.
11. Define *anthropometry* and give examples of anthropometric characteristics.
12. State the features of a genetic disorder that would lead one to believe that it was a form of sex-linked inheritance.

Critical-Thinking Questions

1. Write a short paragraph about pregnancy that includes the terms *ovum*, *blastocyst*, *implantation*, *embryo*, *fetus*, *gestation*, and *parturition*.
2. If a pregnant woman had a pack-a-day cigarette habit, what predictions could you make about the health of her baby? Justify your responses.
3. The sedative thalidomide was used by thousands of pregnant women in the 1960s to alleviate their morning sickness. This drug inhibited normal limb development and resulted in tragically deformed infants with flipperlike arms and legs. At what period of prenatal development did such abnormalities originate? What lessons were learned from the thalidomide tragedy?
4. Your friend just learned that she's pregnant and she wants to name the baby either Louis or Louise. How soon can she know for sure whether she is carrying a boy or a girl? Describe the technique by which the sex can be determined in vitro.
5. Cesarean sections must be performed when a baby cannot be delivered breech. Can you think of some other reasons for a C-section?
6. Hemophilia used to be called a royal disease because it plagued many male members of the royal families of Europe and Russia. Why are female hemophiliacs rare, as their absence from royal pedigrees shows?
7. In many states, laws prohibit consanguineous marriages—those between blood relatives such as siblings or first cousins. Why is it likely that a geneticist would endorse such restrictions?

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