60

Vertebrate Development

Concept Outline

60.1 Fertilization is the initial event in development.

Stages of Development. Fertilization of an egg cell by a sperm occurs in three stages: penetration, activation of the egg cell, and fusion of the two haploid nuclei.

60.2 Cell cleavage and the formation of a blastula set the stage for later development.

Cell Cleavage Patterns. The cytoplasm of the zygote is divided into smaller cells by a mitotic cell division in a process called cleavage.

60.3 Gastrulation forms the three germ layers of the embryo.

The Process of Gastrulation. Cells of the blastula invaginate and involute to produce an outer ectoderm, an inner endoderm layer, and a third layer, the mesoderm.

60.4 Body architecture is determined during the next stages of embryonic development.

Developmental Processes during Neurulation. The mesoderm of chordates forms a notochord, and the overlying ectoderm rolls to produce a neural tube.
How Cells Communicate during Development. Cell-to-cell contact plays a major role in selecting the paths along which cells develop.
Embryonic Development and Vertebrate Evolution. The embryonic development of a mammal includes stages that are characteristic of more primitive vertebrates.
Extraembryonic Membranes. Embryonic cells form several membranes outside of the embryo that provide protection, nourishment, and gas exchange for the embryo.

60.5 Human development is divided into trimesters.

First Trimester. A blastocyst implants into the mother's endometrium, and the formation of body organs begins during the third and fourth week.
Second and Third Trimesters. All of the major organs of the body form during the first trimester and so further growth and development take place during this time.
Birth and Postnatal Development. Birth occurs as a result of uterine contractions; the human brain continues to grow significantly after birth.

FIGURE 60.1
Development is the process that determines an organism's form and function. A human fetus at 18 weeks is not yet halfway through the 38 weeks—about 9 months—it will spend within its mother, but it has already developed many distinct behaviors, such as the sucking reflex that is so important to survival after birth.

Reproduction in all but a few vertebrates unites two haploid gametes to form a single diploid cell called a zygote. The zygote develops by a process of cell division and differentiation into a complex multicellular organism, composed of many different tissues and organs (figure 60.1). Although the process of development is a continuous series of events with some of the details varying among different vertebrate groups, we will examine vertebrate development in six stages. In this chapter, we will consider the stages of development and conclude with a description of the events that occur during human development.

Stages of Development

In vertebrates, as in all sexual animals, the first step in development is the union of male and female gametes, a process called **fertilization.** Fertilization is typically external in fish and amphibians, which reproduce in water, and internal in all other vertebrates. In internal fertilization, small, motile sperm are introduced into the female reproductive tract during mating. The sperm swim up the reproductive tract until they encounter a mature egg or oocyte in an oviduct, where fertilization occurs. Fertilization consists of three stages: penetration, activation, and fusion.

Penetration

As described in chapter 59, the secondary oocyte is released from a fully developed Graafian follicle at ovulation. It is surrounded by the same layer of small granulosa cells that surrounded it within the follicle (figure 60.2). Between the granulosa cells and the egg's plasma membrane is a glyco-

protein layer called the zona pellucida. The head of each sperm is capped by an organelle called the acrosome, which contains glycoprotein-digesting enzymes. These enzymes become exposed as the sperm begin to work their way into the layer of granulosa cells, and the activity of the enzymes enables the sperm to tunnel their way through the zona pellucida to the egg's plasma membrane. In sea urchins, egg cytoplasm bulges out at this point, engulfing the head of the sperm and permitting the sperm nucleus to enter the cytoplasm of the egg (figure 60.3).

Activation

The series of events initiated by sperm penetration are collectively called egg activation. In some frogs, reptiles, and birds, more than one sperm may penetrate the egg, but only one is successful in fertilizing it. In mammals, by contrast, the penetration of the first sperm initiates changes in the egg membrane that prevent the entry of other sperm. As the sperm makes contact with the oocyte membrane, there is a change in the membrane potential (see chapter 54
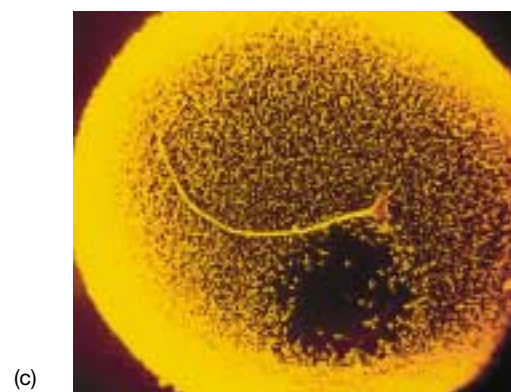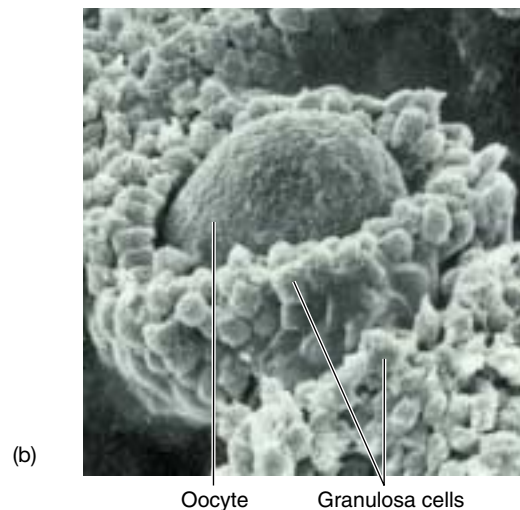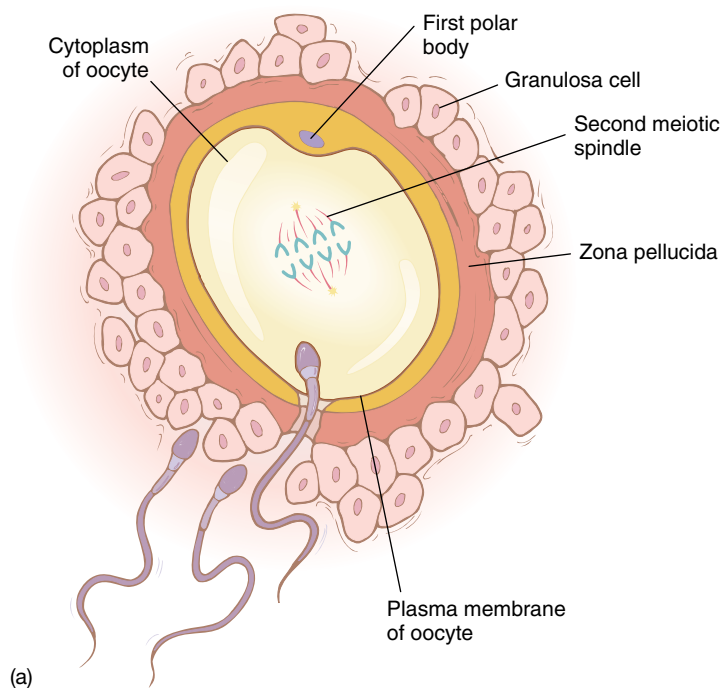

(a)

(b)

(c)

FIGURE 60.2
Mammalian reproductive cells. (*a*) A sperm must penetrate a layer of granulosa cells and then a layer of glycoprotein called the zona pellucida, before it reaches the oocyte membrane. This penetration is aided by digestive enzymes in the acrosome of the sperm. These scanning electron micrographs show (*b*) a human oocyte (90×) surrounded by numerous granulosa cells, and (*c*) a human sperm on an egg (3000×).
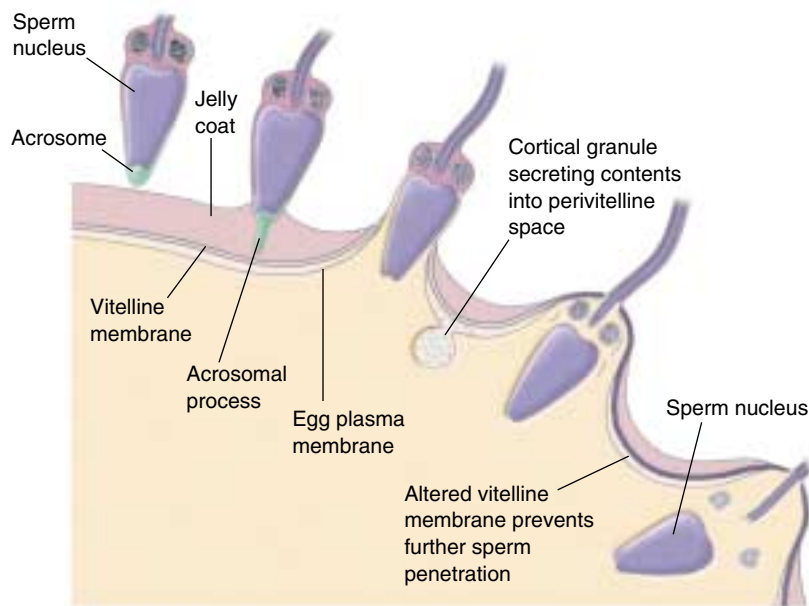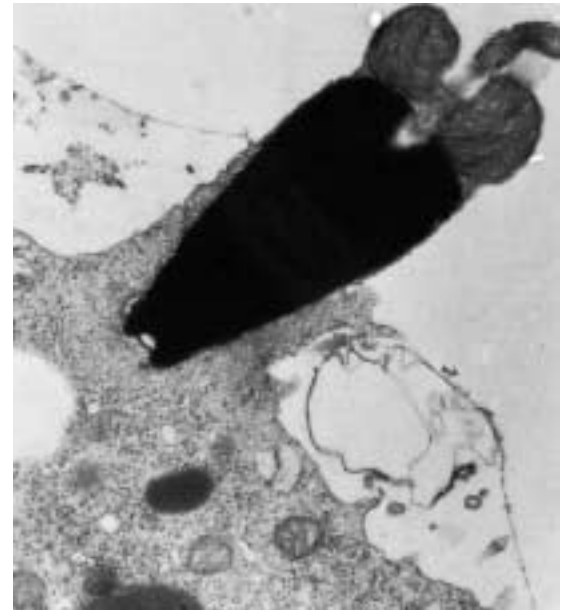
FIGURE 60.3
Sperm penetration of a sea urchin egg. (*a*) The stages of penetration. (*b*) An electron micrograph (50,000×) of penetration. Penetration in both invertebrate and vertebrate eggs is similar.

for discussion of membrane potential) that prevents other sperm from fusing with the oocyte membrane. In addition to these changes, sperm penetration can have three other effects on the egg. First, in mammals it stimulates the chromosomes in the egg nucleus to complete the second meiotic division, producing two egg nuclei. One of these nuclei is extruded from the egg as a second polar body (see chapter 59), leaving a single haploid egg nucleus within the egg.

Second, sperm penetration in some animals triggers movements of the egg cytoplasm around the point of sperm entry. These movements ultimately establish the bilateral symmetry of the developing animal. In frogs, for example, sperm penetration causes an outer pigmented cap of egg cytoplasm to rotate toward the point of entry, uncovering a gray crescent of interior cytoplasm opposite the point of penetration (figure 60.4). The position of the gray crescent determines the orientation of the first cell division. A line drawn between the point of sperm entry and the gray crescent would bisect the right and left halves of the future adult. Third, activation is characterized by a sharp increase in protein synthesis and an increase in metabolic activity in general. Experiments demonstrate that the protein synthesis in the activated oocyte is coded by mRNA that was previously produced and already present in the cytoplasm of the unfertilized egg cell.

In some vertebrates, it is possible to activate an egg without the entry of a sperm, simply by pricking the egg membrane. An egg that is activated in this way may go on to develop parthenogenetically. A few kinds of amphibians, fish, and reptiles rely entirely on parthenogenetic reproduction in nature, as we mentioned in chapter 59.
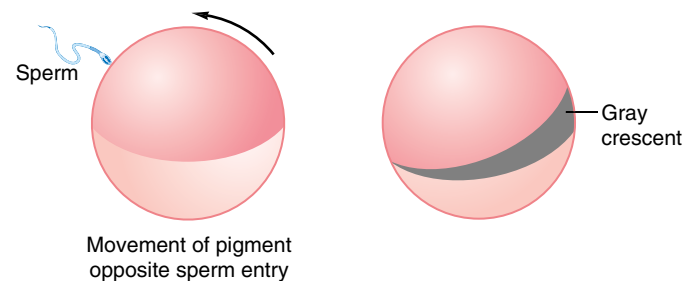

FIGURE 60.4
Gray crescent formation in frog eggs. The gray crescent appears opposite the point of penetration by the sperm.

Nuclei Fusion

The third stage of fertilization is the fusion of the entering sperm nucleus with the haploid egg nucleus to form the diploid nucleus of the zygote. This fusion is triggered by the activation of the egg. If a sperm nucleus is microinjected into an egg without activating the egg, the two nuclei will not fuse. The nature of the signals that are exchanged between the two nuclei, or sent from one to the other, is not known.

The three stages of fertilization are penetration, activation, and nuclei fusion. Penetration initiates a complex series of developmental events, including major movements of cytoplasm, which eventually lead to the fusion of the egg and sperm nuclei.

Cell Cleavage Patterns

Following fertilization, the second major event in vertebrate reproduction is the rapid division of the zygote into a larger and larger number of smaller and smaller cells (table 60.1). This period of division, called cleavage, is not accompanied by an increase in the overall size of the embryo. The resulting tightly packed mass of about 32 cells is called a **morula,** and each individual cell in the morula is referred to as a **blastomere.** As the blastomeres continue to divide, they secrete a fluid into the center of the morula. Eventually, a hollow ball of 500 to 2000 cells, the **blastula,** is formed. The fluid-filled cavity within the blastula is known as the *blastocoel.*

The pattern of cleavage division is influenced by the presence and location of yolk, which is abundant in the eggs of many vertebrates (figure 60.5). As we discussed in the previous chapter, vertebrates have embraced a variety of reproductive strategies involving different patterns of yolk utilization.

Primitive Chordates

When eggs contain little or no yolk, cleavage occurs throughout the whole egg (figure 60.6). This pattern of cleavage, called holoblastic cleavage, was characteristic of the ancestors of the vertebrates and is still seen in groups such as the lancelets and agnathans. In these animals, holoblastic cleavage results in the formation of a symmetrical blastula composed of cells of approximately equal size.

Amphibians and Advanced Fish

The eggs of bony fish and frogs contain much more cytoplasmic yolk in one hemisphere than the other. Because yolk-rich cells divide much more slowly than those that have little yolk, holoblastic cleavage in these eggs results in a very asymmetrical blastula (figure 60.7), with large cells containing a lot of yolk at one pole and a concentrated mass of small cells containing very little yolk at the other. In these blastulas, the pole that is rich in yolk is called the vegetal pole, while the pole that is relatively poor in yolk is called the animal pole.
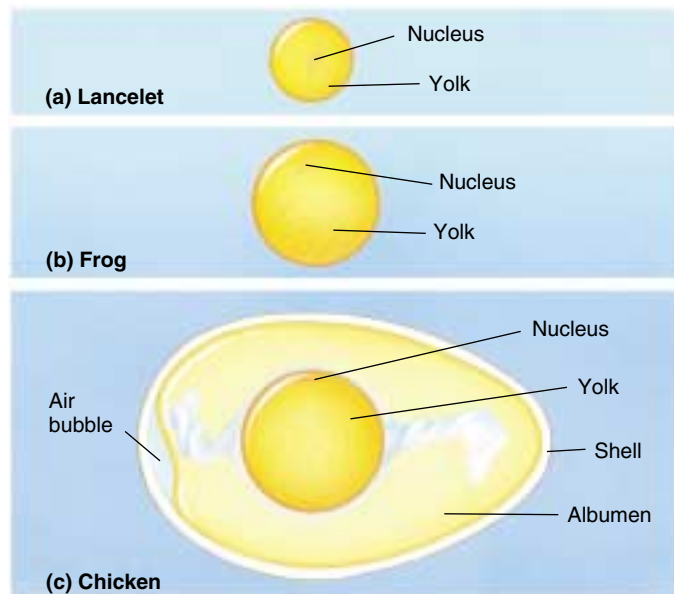

FIGURE 60.5
Yolk distribution in three kinds of eggs. (*a*) In the lancelet, a primitive chordate, the egg consists of a central nucleus surrounded by a small amount of yolk. (*b*) In a frog egg there is much more yolk, and the nucleus is displaced toward one pole. (*c*) Bird eggs are complexly organized, with the nucleus just under the surface of a large, central yolk.
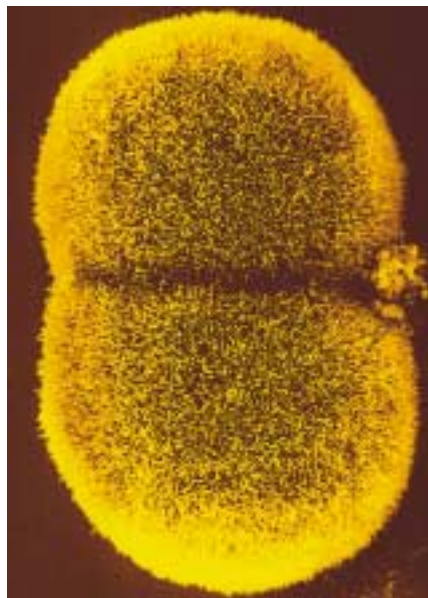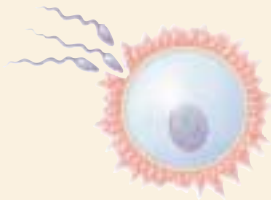

FIGURE 60.6
Holoblastic cleavage (3000×). In this type of cleavage, cell division occurs throughout the entire egg.
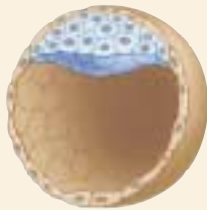

FIGURE 60.7
Dividing frog eggs. The closest cells in this photo (those near the animal pole) divide faster and are smaller than those near the vegetal pole.

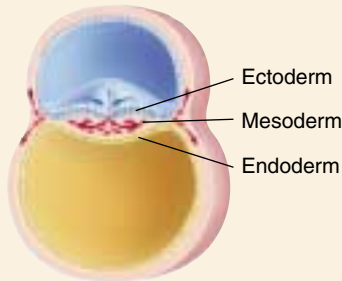**Table 60.1   Stages of Vertebrate Development (Mammal)**

	Stage	Description
	Fertilization	The haploid male and female gametes fuse to form a diploid zygote.
	Cleavage	The zygote rapidly divides into many cells, with no overall increase in size. These divisions affect future development, since different cells receive different portions of the egg cytoplasm and, hence, different regulatory signals.
Ectoderm Mesoderm Endoderm	Gastrulation	The cells of the embryo move, forming three primary cell layers: ectoderm, mesoderm, and endoderm.
Neural groove Notochord	Neurulation	In all chordates, the first organ to form is the notochord; second is the dorsal nerve cord.
Neural crest Neural tube Notochord	Neural crest cell formation	During neurulation, the neural crest is produced as the neural tube is formed. The neural crest gives rise to several uniquely vertebrate structures.
	Organogenesis	Cells from the three primary layers combine in various ways to produce the organs of the body.
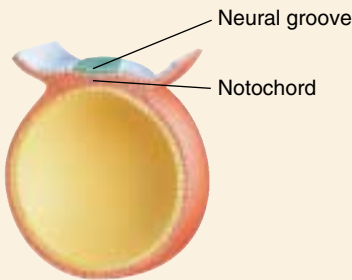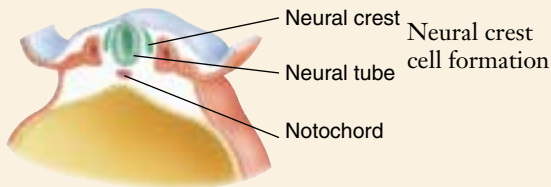
Reptiles and Birds

The eggs produced by reptiles, birds, and some fish are composed almost entirely of yolk, with a small amount of cytoplasm concentrated at one pole. Cleavage in these eggs occurs only in the tiny disc of polar cytoplasm, called the blastodisc, that lies astride the large ball of yolk material. This type of cleavage pattern is called meroblastic cleavage (figure 60.8). The resulting embryo is not spherical, but rather has the form of a thin cap perched on the yolk.

Mammals

Mammalian eggs are in many ways similar to the reptilian eggs from which they evolved, except that they contain very little yolk. Because cleavage is not impeded by yolk in mammalian eggs, it is holoblastic, forming a ball of cells surrounding a blastocoel. However, an inner cell mass is concentrated at one pole (figure 60.9). This inner cell mass is analogous to the blastodisc of reptiles and birds, and it goes on to form the developing embryo. The outer sphere of cells, called a trophoblast, is analogous to the cells that form the membranes underlying the tough outer shell of the reptilian egg. These cells have changed during the course of mammalian evolution to carry out a very different function: part of the trophoblast enters the endometrium (the epithelial lining of the uterus) and contributes to the placenta, the organ that permits exchanges between the fetal and maternal bloods. While part of the placenta is composed of fetal tissue (the trophoblast), part is composed of the modified endometrial tissue (called the *decidua basalis*) of the mother's uterus. The placenta will be discussed in more detail in a later section.

The Blastula

Viewed from the outside, the blastula looks like a simple ball of cells all resembling each other. In many animals, this appearance is misleading, as unequal distribution of developmental signals from the egg produces some degree of mosaic development, so that the cells are already committed to different developmental paths. In mammals, however, it appears that all of the blastomeres receive equivalent sets of signals, and body form is determined by cell-cell interactions. In a mammalian blastula, called a *blastocyst*, each cell is in contact with a different set of neighboring cells, and these interactions with neighboring cells are a major factor influencing the developmental fate of each cell. This positional information is of particular importance in the orientation of mammalian embryos, setting up different patterns of development along three embryonic axes: anterior-posterior, dorsal-ventral, and proximal-distal.

For a short period of time, just before they implant in the uterus, the cells of the mammalian blastocyst have the power to develop into many of the 210 different types of
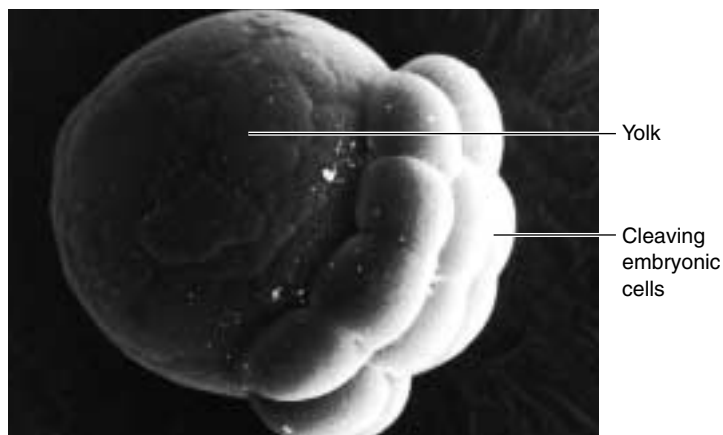

FIGURE 60.8
Meroblastic cleavage (400×). In this type of cleavage, only a portion of the egg actively divides to form a mass of cells.
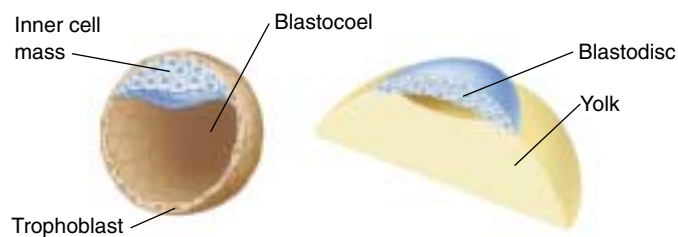

FIGURE 60.9
The embryos of mammals and birds are more similar than they seem. (*a*) A mammalian blastula is composed of a sphere of cells, the trophoblast, surrounding a cavity, the blastocoel, and an inner cell mass. (*b*) An avian (bird) blastula consists of a cap of cells, the blastodisc, resting atop a large yolk mass. The blastodisc will form an upper and a lower layer with a compressed blastocoel in between.

cells in the body—and probably all of them. Biologists have long sought to grow these cells, called *embryonic stem cells*, in tissue culture, as such stem cells might in principle be used to produce tissues for human transplant operations. Injected into a patient, for example, they might be able to respond to local signals and produce new tissue (see chapter 19). The first success in growing stem cells in culture was reported in 1998, when researchers isolated cells from the inner cell mass of human blastocysts and successfully grew them in tissue culture. These stem cells continue to grow and divide in culture indefinitely, unlike ordinary body cells, which divide only 50 or so times and then die.

A series of rapid cell divisions called cleavage transforms the zygote into a hollow ball of cells, the blastula. The cleavage pattern is influenced by the amount of yolk and its distribution in the egg.

The Process of Gastrulation

The first visible results of cytoplasmic distribution and cell position within the blastula can be seen immediately after the completion of cleavage. Certain groups of cells **invaginate** (dent inward) and **involute** (roll inward) from the surface of the blastula in a carefully orchestrated activity called **gastrulation.** The events of gastrulation determine the basic developmental pattern of the vertebrate embryo. By the end of gastrulation, the cells of the embryo have rearranged into three primary **germ layers: ectoderm, mesoderm,** and **endoderm.** The cells in each layer have very different developmental fates. In general, the ectoderm is destined to form the epidermis and neural tissue; the mesoderm gives rise to connective tissue, skeleton, muscle, and vascular elements; and the endoderm forms the lining of the gut and its derivatives (table 60.2).

How is cell movement during gastrulation brought about? Apparently, migrating cells creep over stationary cells by means of actin filament contractions that change the shapes of the migrating cells affecting an invagination of blastula tissue. Each cell that moves possesses particular cell surface polysaccharides, which adhere to similar polysaccharides on the surfaces of the other moving cells. This interaction between cell surface molecules enables the migrating cells to adhere to one another and move as a single mass (see chapter 7).

Just as the pattern of cleavage divisions in different groups of vertebrates depends heavily on the amount and distribution of yolk in the egg, so the pattern of gastrulation among vertebrate groups depends on the shape of the blastulas produced during cleavage.

Table 60.2	Developmental Fates of the Primary Cell Layers
Ectoderm	Epidermis, central nervous system, sense organs, neural crest
Mesoderm	Skeleton, muscles, blood vessels, heart, gonads
Endoderm	Lining of digestive and respiratory tracts; liver, pancreas

Gastrulation in Primitive Chordates

In primitive chordates such as lancelets, which develop from symmetrical blastulas, gastrulation begins as the surface of the blastula invaginates into the blastocoel. About half of the blastula's cells move into the interior of the blastula, forming a structure that looks something like an indented tennis ball. Eventually, the inward-moving wall of cells pushes up against the opposite side of the blastula and then stops moving. The resulting two-layered, cup-shaped embryo is the gastrula (figure 60.10). The hollow structure resulting from the invagination is called the archenteron, and it is the progenitor of the gut. The opening of the archenteron, the future anus, is known as the blastopore.

This process produces an embryo with two cell layers: an outer ectoderm and an inner endoderm. Soon afterward, a third cell layer, the mesoderm, forms between the ectoderm and endoderm. In lancelets, the mesoderm forms from pouches that pinch off the endoderm. The appearance of these three primary cell layers sets the stage for all subsequent tissue and organ differentiation.

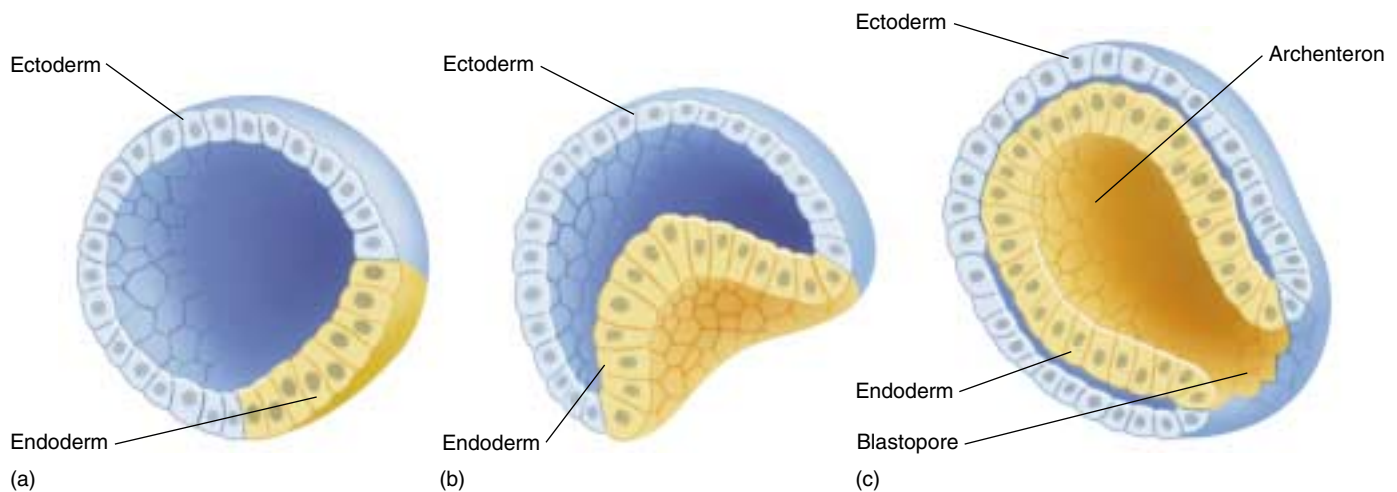**FIGURE 60.10**
Gastrulation in a lancelet. In these chordates, the endoderm is formed by invagination of surface cells (*a*, *b*). This produces the primitive gut, or archenteron (*c*). Mesoderm will later be formed from pouches off the endoderm.

Gastrulation in Most Aquatic Vertebrates

In the blastulas of amphibians and those aquatic vertebrates with asymmetrical yolk distribution, the yolk-laden cells of the vegetal pole are fewer and much larger than the yolk-free cells of the animal pole. Consequently, gastrulation is more complex than it is in the lancelets. First, a layer of surface cells invaginates to form a small, crescent-shaped slit where the blastopore will soon be located. Next, cells from the animal pole involute over the dorsal lip of the blastopore (figure 60.11), at the same location as the gray crescent of the fertilized egg (see figure 60.4). As in the lancelets, the involuting cell layer eventually presses against the inner surface of the opposite side of the embryo, eliminating the blastocoel and producing an archenteron with a blastopore. In this case, however, the blastopore is filled with yolk-rich cells, forming the yolk plug. The outer layer of cells resulting from these movements is the ectoderm, and the inner layer is the endoderm. Other cells that involute over the dorsal lip and ventral lip (the two lips of the blastopore that are separated by the yolk plug) migrate between the ectoderm and endoderm to form the third germ layer, the mesoderm (figure 60.11).
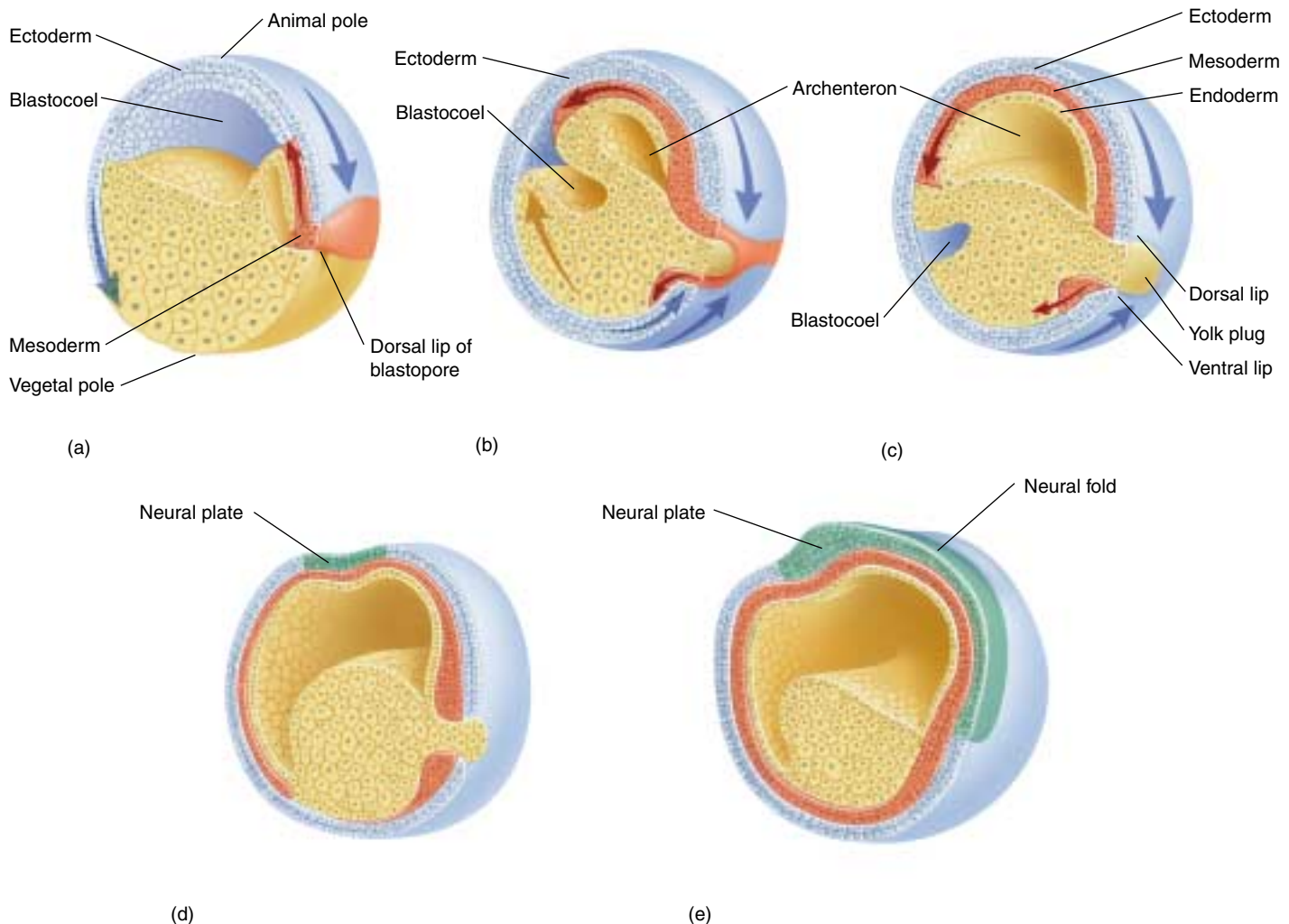
FIGURE 60.11
Frog gastrulation. (*a*) A layer of cells from the animal pole moves toward the yolk cells ultimately involuting through the dorsal lip of the blastopore. (*b*) Cells in the dorsal lip zone then involute into the hollow interior, or blastocoel, eventually pressing against the far wall. The three primary tissues (ectoderm, mesoderm, and endoderm) become distinguished. Ectoderm is shown in blue, mesoderm in red, and endoderm in yellow. (*c*) The movement of cells in the dorsal lip creates a new internal cavity, the archenteron, which opens to the outside through the plug of yolk remaining at the point of invagination. (*d*) The neural plate later forms from ectoderm. (*e*) This will next form a neural groove and then a neural tube as the embryo begins the process of neurulation. The cells of the neural ectoderm are shown in green.

Gastrulation in Reptiles, Birds, and Mammals

In the blastodisc of a bird or reptile and the inner cell mass of a mammal, the developing embryo is a small cap of cells rather than a sphere. No yolk separates the two sides of the embryo, and, as a result, the lower cell layer is able to differentiate into endoderm and the upper layer into ectoderm without cell movement. Just after these two primary cell layers form, the mesoderm arises by invagination and involution of cells from the upper layer. The surface cells begin moving to the midline where they involute and migrate laterally to form a mesodermal layer between the ectoderm and endoderm. A furrow along the longitudinal midline marks the site of this involution (figures 60.12 and 60.13). This furrow, analogous to an elongated blastopore, is called the **primitive streak.**

Gastrulation in lancelets involves the formation of ectoderm and endoderm by the invagination of the blastula, and the mesoderm layer forms from pouches pinched from the endoderm. In those vertebrates with extensive amounts of yolk, gastrulation requires the involution of surface cells into a blastopore or primitive streak, and the mesoderm is derived from some of these involuted cells.
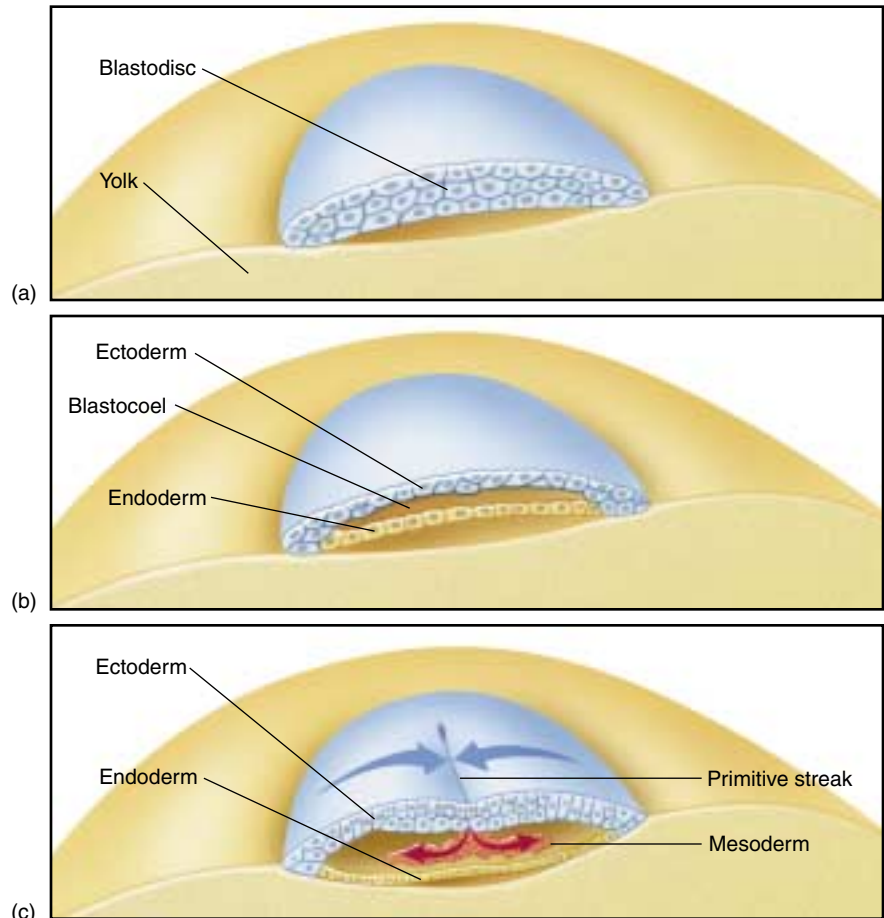
FIGURE 60.12
Gastrulation in birds. The upper layer of the blastodisc (*a*) differentiates into ectoderm, the lower layer into endoderm (*b*). Among the cells that migrate into the interior through the dorsal primitive streak are future mesodermal cells (*c*).
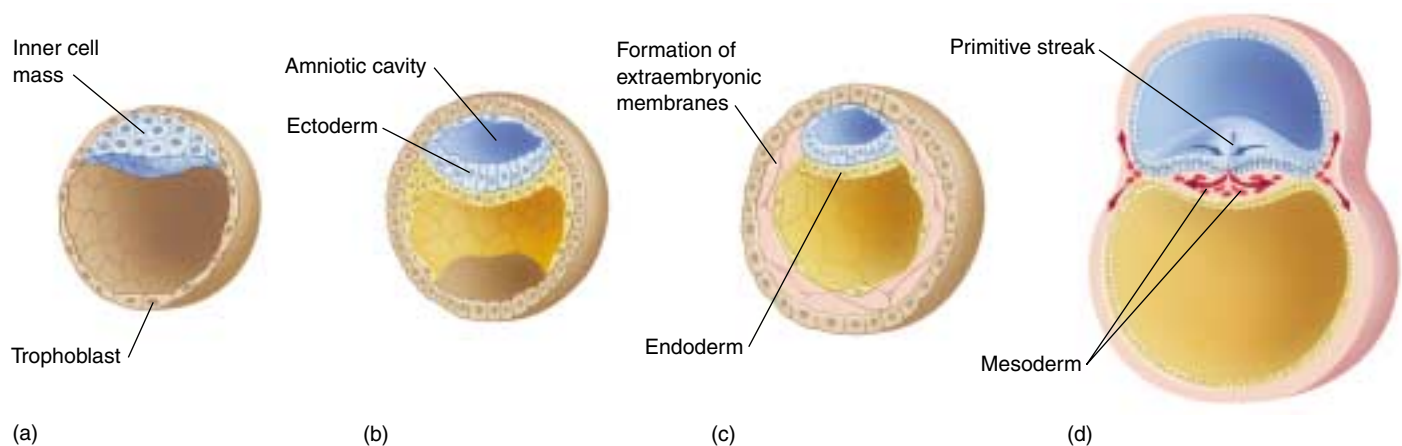
FIGURE 60.13
Mammalian gastrulation. (*a*) The amniotic cavity forms within the inner cell mass and its base. Layers of ectoderm and endoderm differentiate (*b* and *c*) as in the avian blastodisc. (*d*) A primitive streak develops, through which cells destined to become mesoderm migrate into the interior, again reminiscent of gastrulation in birds. The trophoblast has now moved further away from the embryo and begins to play a role in forming the placenta.

60.4 Body architecture is determined during the next stages of embryonic development.

Developmental Processes during Neurulation

During the next step in vertebrate development, the three primary cell layers begin their transformation into the body's tissues and organs. The process of tissue differentiation begins with the formation of two morphological features found only in chordates, the **notochord** and the hollow dorsal nerve cord. This development of the dorsal nerve cord is called **neurulation.**

The notochord is first visible soon after gastrulation is complete, forming from mesoderm along the dorsal midline of the embryo. It is a flexible rod located along the dorsal midline in the embryos of all chordates, although its function is replaced by the vertebral column when it develops from mesoderm in the vertebrates. After the notochord has been laid down, a layer of ectodermal cells situated above the notochord invaginates, forming a long crease, the **neural groove,** down the long axis of the embryo. The edges of the neural groove then move toward each other and fuse, creating a long hollow cylinder, the **neural tube** (figure 60.14), which runs beneath the surface of the embryo's back. The neural tube later differentiates into the spinal cord and brain.

The dorsal lip of the blastopore induces the formation of a notochord, and the presence of the notochord induces the overlying ectoderm to differentiate into the neural tube. The process of induction, when one embryonic region of cells influences the development of an adjacent region by changing its developmental pathway, was discussed in chapter 17 and is further examined in the next section.

While the neural tube is forming from ectoderm, the rest of the basic architecture of the body is being determined rapidly by changes in the mesoderm. On either side of the developing notochord, segmented blocks of mesoderm tissue called **somites** form; more somites are added as development continues. Ultimately, the somites give rise to the muscles, vertebrae, and connective tissues. The mesoderm in the head region does not separate into discrete somites but remains connected as **somitomeres** and form the striated muscles of the face, jaws, and throat. Some body organs, including the kidneys, adrenal glands, and gonads, develop within another strip of mesoderm that runs alongside the somites. The remainder of the mesoderm moves out and around the endoderm and eventually surrounds it completely. As a result of this movement, the mesoderm becomes separated into two layers. The outer layer is associated with the body wall and the inner layer is associated with the gut. Between these two layers of mesoderm is the coelom (see chapter 45), which becomes the body cavity of the adult.

The Neural Crest

Neurulation occurs in all chordates, and the process in a lancelet is much the same as it is in a human. However, in vertebrates, just before the neural groove closes to form the neural tube, its edges pinch off, forming a small strip of cells, the **neural crest,** which becomes incorporated into the roof of the neural tube (figure 60.14). The cells of the neural crest later move to the sides of the developing embryo. The appearance of the neural crest was a key event in the evolution of the vertebrates because neural crest cells, after migrating to different parts of the embryo, ultimately develop into the structures characteristic of (though not necessarily unique to) the vertebrate body.

The differentiation of neural crest cells depends on their location. At the anterior end of the embryo, they merge

Neural plate
Neural fold
Ectoderm
Notochord
Mesoderm
Endoderm
Archenteron
(a)

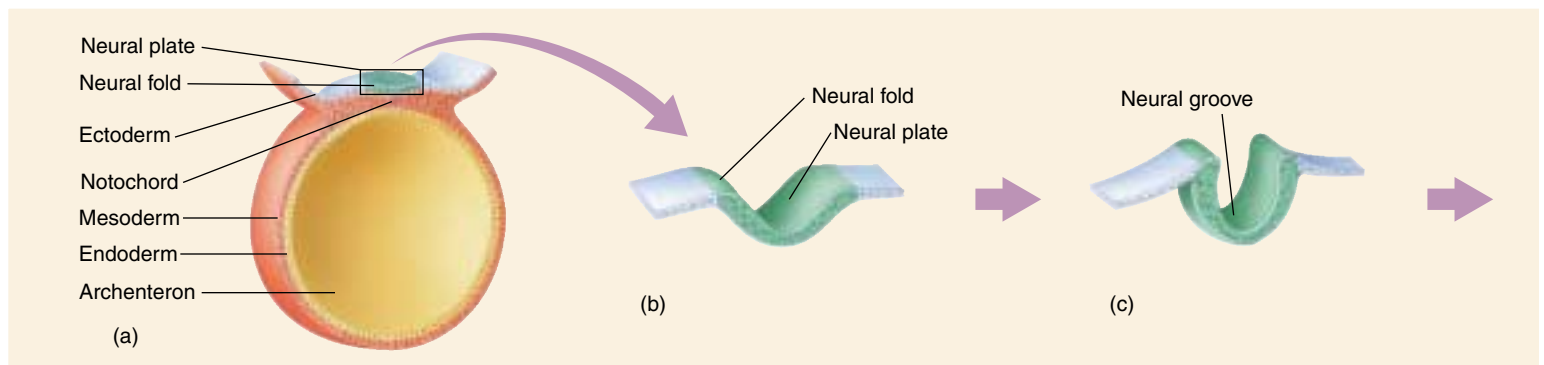Neural fold
Neural plate
(b)

Neural groove
(c)

FIGURE 60.14
Mammalian neural tube formation. (*a*) The neural tube forms above the notochord when (*b*) cells of the neural plate fold together to form the (*c*) neural groove.

with the anterior portion of the brain, the forebrain. Nearby clusters of ectodermal cells associated with the neural crest cells thicken into **placodes,** which are distinct from neural crest cells although they arise from similar cellular interactions. Placodes subsequently develop into parts of the sense organs in the head. The neural crest and associated placodes exist in two lateral strips, which is why the vertebrate sense organs that develop from them are paired.

Neural crest cells located in more posterior positions have very different developmental fates. These cells migrate away from the neural tube to other locations in the head and trunk, where they form connections between the neural tube and the surrounding tissues. At these new locations, they contribute to the development of a variety of structures that are particularly characteristic of the vertebrates, several of which are discussed below. The migration of neural crest cells is unique in that it is not simply a change in the relative positions of cells, such as that seen in gastrulation. Instead, neural crest cells actually pass through other tissues.

The Gill Chamber

Primitive chordates such as lancelets are filter-feeders, using the rapid beating of cilia to draw water into their bodies through slits in their pharynx. These pharyngeal slits evolved into the vertebrate gill chamber, a structure that provides a greatly improved means of respiration. The evolution of the gill chamber was certainly a key event in the transition from filter-feeding to active predation.

In the development of the gill chamber, some of the neural crest cells form cartilaginous bars between the embryonic pharyngeal slits. Other neural crest cells induce portions of the mesoderm to form muscles along the cartilage, while still others form neurons that carry impulses between the nerve cord and these muscles. A major blood vessel called the aortic arch passes through each of the embryonic bars. Lined by still more neural crest cells, these bars, with their internal blood supply, become highly branched and form the gills of the adult.

Because the stiff bars of the gill chamber can be bent inward by powerful muscles controlled by nerves, the whole structure is a very efficient pump that drives water past the gills. The gills themselves act as highly efficient oxygen exchangers, greatly increasing the respiratory capacity of the animals that possess them.

Elaboration of the Nervous System

Some neural crest cells migrate ventrally toward the notochord and form sensory neurons in the dorsal root ganglia (see chapter 54). Others become specialized as Schwann cells, which insulate nerve fibers and permit the rapid conduction of nerve impulses. Still others form the autonomic ganglia and the adrenal medulla. Cells in the adrenal medulla secrete epinephrine when stimulated by the sympathetic division of the autonomic nervous system during the fight-or-flight reaction. The similarity in the chemical nature of the hormone epinephrine and the neurotransmitter norepinephrine, released by sympathetic neurons, is understandable—both adrenal medullary cells and sympathetic neurons derive from the neural crest.

Sensory Organs and Skull

A variety of sense organs develop from the placodes. Included among them are the olfactory (smell) and lateral line (primitive hearing) organs discussed in chapter 55. Neural crest cells contribute to tooth development and to some of the facial and cranial bones of the skull.

> The appearance of the neural crest in the developing embryo marked the beginning of the first truly vertebrate phase of development, as many of the structures characteristic of vertebrates derive directly or indirectly from neural crest cells.

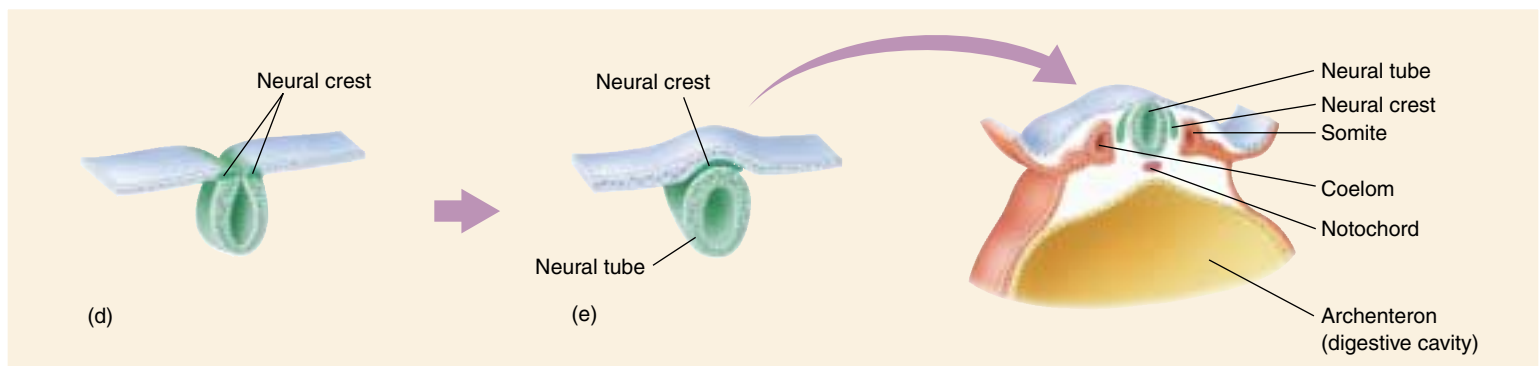**FIGURE 60.14 (continued)**
(*d*) The neural groove eventually closes to form a hollow tube. (*e*) As the tube closes, some of the cells from the dorsal margin of the neural tube differentiate into the neural crest, which is characteristic of vertebrates.

How Cells Communicate during Development

In the process of vertebrate development, the relative position of particular cell layers determines, to a large extent, the organs that develop from them. By now, you may have wondered how these cell layers know where they are. For example, when cells of the ectoderm situated above the developing notochord give rise to the neural groove, how do these cells know they are above the notochord?

The solution to this puzzle is one of the outstanding accomplishments of experimental embryology, the study of how embryos form. The great German biologist Hans Spemann and his student Hilde Mangold solved it early in this century. In their investigation they removed cells from the dorsal lip of an amphibian blastula and transplanted them to a different location on another blastula (figure 60.15). (The dorsal lip region of amphibian blastu-las develops from the grey crescent zone and is the site of origin of those mesoderm cells that later produce the notochord.) The new location corresponded to that of the animal's belly. What happened? The embryo developed *two* notochords, a normal dorsal one and a second one along its belly!

By using genetically different donor and host blastulas, Spemann and Mangold were able to show that the notochord produced by transplanting dorsal lip cells contained host cells as well as transplanted ones. The transplanted dorsal lip cells had acted as **organizers** (see also chapter 17) of notochord development. As such, these cells stimulated a developmental program in the belly cells of the embryos in which they were transplanted: the development of the notochord. The belly cells clearly contained this developmental program but would not have expressed it in the normal course of their development. The transplantation of the dorsal lip cells caused them to do so.
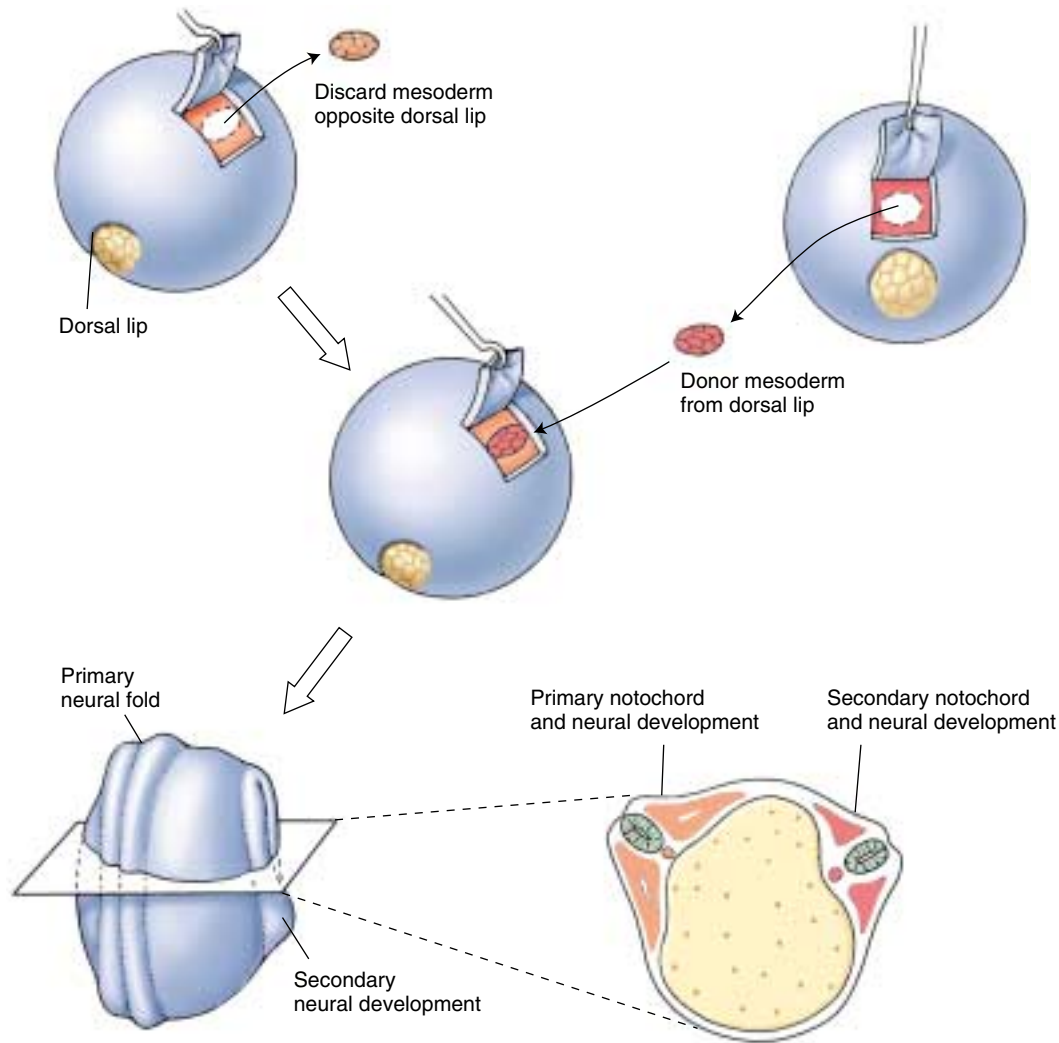

FIGURE 60.15
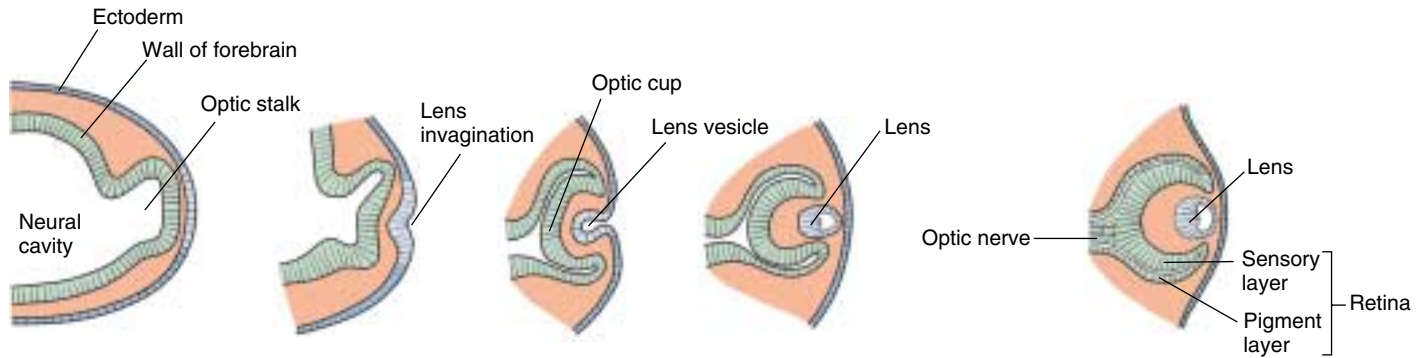**Spemann and Mangold's dorsal lip transplant experiment.**

FIGURE 60.16
Development of the eye by induction. An extension of the optic stalk grows until it contacts ectoderm, which induces a section of the ectoderm to pinch off and form the lens. Other structures of the eye develop from the optic stalk.

These cells had indeed induced the ectoderm cells of the belly to form a notochord. This phenomenon as a whole is known as **induction.**

The process of induction that Spemann discovered appears to be the basic mode of development in vertebrates. Inductions between the three primary tissue types—ectoderm, mesoderm, and endoderm—are referred to as **primary inductions.** Inductions between tissues that have already been differentiated are called **secondary inductions.** The differentiation of the central nervous system during neurulation by the interaction of dorsal ectoderm and dorsal mesoderm to form the neural tube is an example of primary induction. In contrast, the differentiation of the lens of the vertebrate eye from ectoderm by interaction with tissue from the central nervous system is an example of secondary induction.

The eye develops as an extension of the forebrain, a stalk that grows outward until it comes into contact with the epidermis (figure 60.16). At a point directly above the growing stalk, a layer of the epidermis pinches off, forming a transparent lens. When the optic stalks of the two eyes have just started to project from the brain and the lenses have not yet formed, one of the budding stalks can be removed and transplanted to a region underneath a different epidermis, such as that of the belly. When Spemann performed this critical experiment, a lens still formed, this time from belly epidermis cells in the region above where the budding stalk had been transplanted.

What is the nature of the inducing signal that passes from one tissue to the other? If one imposes a nonporous barrier, such as a layer of cellophane, between the inducer and the target tissue, no induction takes place. In contrast, a porous filter, through which proteins can pass, does permit induction to occur. The induction process was discussed in detail in chapter 17. In brief, the inducer cells produce a protein factor that binds to the cells of the target tissue, initiating changes in gene expression.

The Nature of Developmental Decisions

All of the cells of the body, with the exception of a few specialized ones that have lost their nuclei, have an entire complement of genetic information. Despite the fact that all of its cells are genetically identical, an adult vertebrate contains hundreds of cell types, each expressing various aspects of the total genetic information for that individual. What factors determine which genes are to be expressed in a particular cell and which are not to be? In a liver cell, what mechanism keeps the genetic information that specifies nerve cell characteristics turned off? Does the differentiation of that particular cell into a liver cell entail the physical loss of the information specifying other cell types? No, it does not—but cells progressively lose the capacity to *express* ever-larger portions of their genomes. *Development is a process of progressive restriction of gene expression.*

Some cells become **determined** quite early in development. For example, all of the egg cells of the human female are set aside very early in the life of the embryo, yet some of these cells will not achieve differentiation into functional oocytes for more than 40 years. To a large degree, a cell's location in the developing embryo determines its fate. By changing a cell's location, an experimenter can alter its developmental destiny. However, this is only true up to a certain point in the cell's development. At some stage, every cell's ultimate fate becomes fixed, a process referred to as **commitment.** Commitment is not irreversible (entire individuals can be cloned from an individual specialized cell, as recounted in chapter 17), but rarely if ever reverses under ordinary circumstances.

When a cell is "determined," it is possible to predict its developmental fate; when a cell is "committed," that developmental fate cannot be altered. Determination often occurs very early in development, commitment somewhat later.

Embryonic Development and Vertebrate Evolution

The primitive chordates that gave rise to vertebrates were initially slow-moving, filter-feeding animals with relatively low metabolic rates. Many of the unique vertebrate adaptations that contribute to their varied ecological roles involve structures that arise from neural crest cells. The vertebrates became fast-swimming predators with much higher metabolic rates. This accelerated metabolism permitted a greater level of activity than was possible among the more primitive chordates. Other evolutionary changes associated with the derivatives of the neural crest provided better detection of prey, a greatly improved ability to orient spatially during prey capture, and the means to respond quickly to sensory information. The evolution of the neural crest and of the structures derived from it were thus crucial steps in the evolution of the vertebrates (figure 60.17).

Ontogeny Recapitulates Phylogeny

The patterns of development in the vertebrate groups that evolved most recently reflect in many ways the simpler patterns occurring among earlier forms. Thus, mammalian development and bird development are elaborations of reptile development, which is an elaboration of amphibian development, and so forth (figure 60.18). During the development of a mammalian embryo, traces can be seen of appendages and organs that are apparently relics of more primitive chordates. For example, at certain stages a human embryo possesses pharyngeal slits, which occur in all chordates and are homologous to the gill slits of fish. At later stages, a human embryo also has a tail.

In a sense, the patterns of development in chordate groups has built up in incremental steps over the evolutionary history of those groups. The developmental instructions for each new form seem to have been layered on top of the previous instructions, contributing addi-
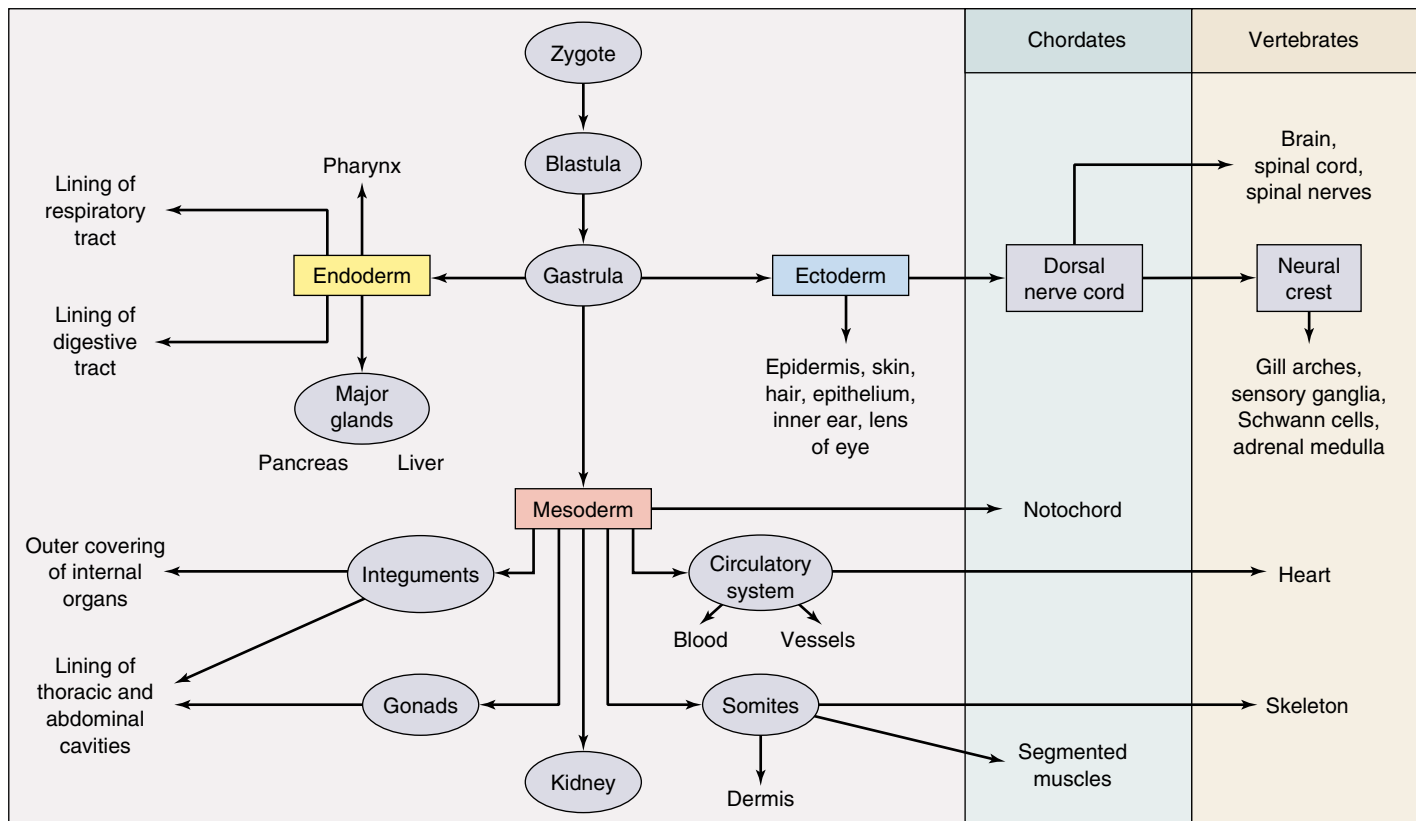

FIGURE 60.17
Derivation of the major tissue types. The three germ layers that form during gastrulation give rise to all organs and tissues in the body, but the neural crest cells that form from ectodermal tissue give rise to structures that are prevalent in the vertebrate animal such as gill arches and Schwann cells.
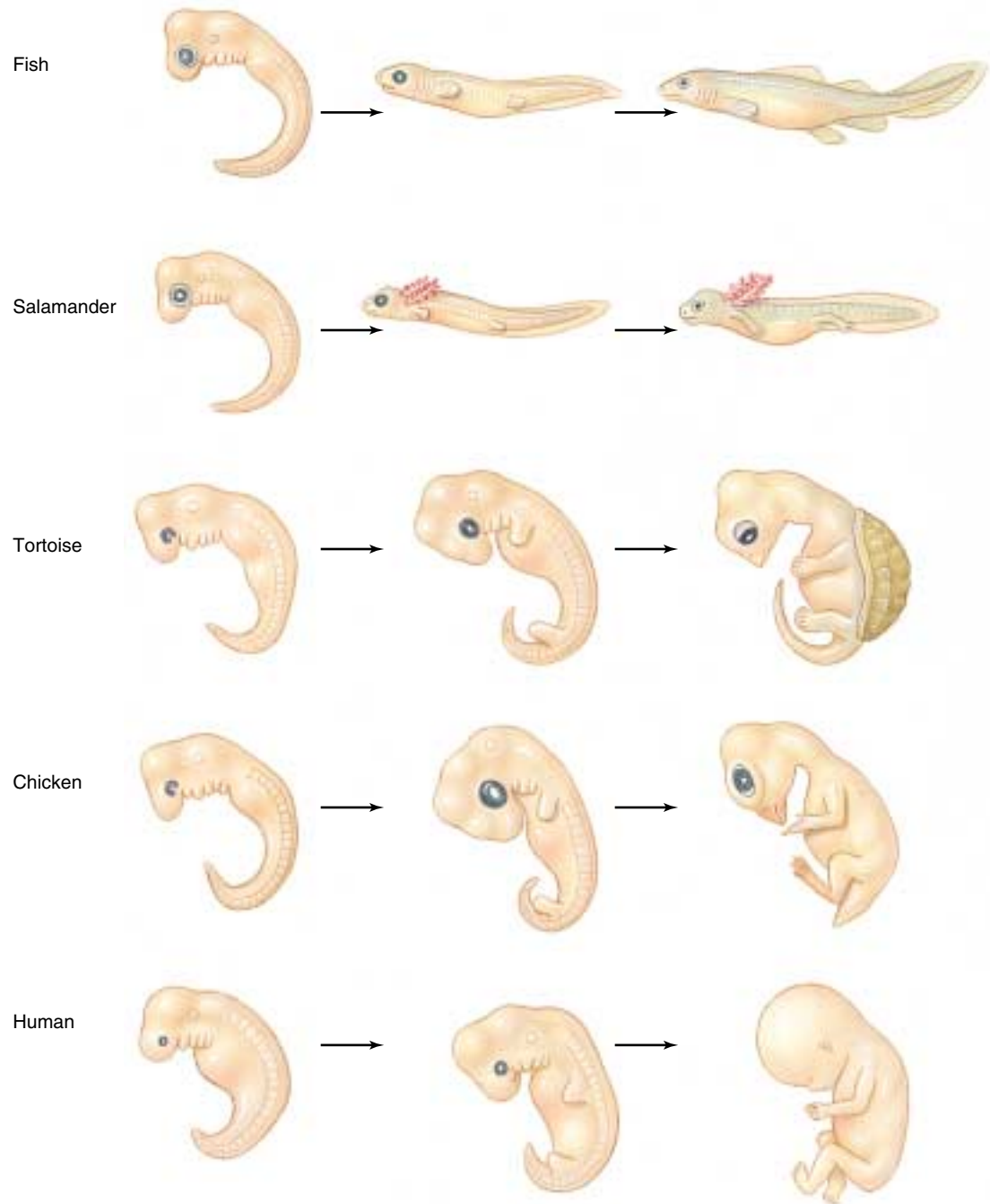
FIGURE 60.18 Embryonic development of vertebrates. Notice that the early embryonic stages of these vertebrates bear a striking resemblance to each other, even though the individuals are from different classes (fish, amphibians, reptiles, birds, and mammals). All vertebrates start out with an enlarged head region, gill slits, and a tail regardless of whether these characteristics are retained in the adults.

Fish

Salamander

Tortoise

Chicken

Human

tional steps in the developmental journey. This hypothesis, proposed in the nineteenth century by Ernst Haeckel, is referred to as the "biogenic law." It is usually stated as an aphorism: *ontogeny recapitulates phylogeny;* that is, embryological development (ontogeny) involves the same progression of changes that have occurred during evolution (phylogeny). However, the biogenic law is not literally true when stated in this way because embryonic stages are not reflections of *adult* ancestors. Instead, the embryonic stages of a particular vertebrate often reflect the *embryonic* stages of that vertebrate's ancestors. Thus, the

pharyngeal slits of a mammalian embryo are *not* like the gill slits its ancestors had *when they were adults.* Rather, they are like the pharyngeal slits its ancestors had *when they were embryos.*

Vertebrates seem to have evolved largely by the addition of new instructions to the developmental program. Development of a mammal thus proceeds through a series of stages, and the earlier stages are unchanged from those that occur in the development of more primitive vertebrates.

Extraembryonic Membranes

As an adaptation to terrestrial life, the embryos of reptiles, birds, and mammals develop within a fluid-filled **amniotic membrane** (see chapter 48). The amniotic membrane and several other membranes form from embryonic cells but are located outside of the body of the embryo. For this reason, they are known as **extraembryonic membranes.** The extraembryonic membranes, later to become the **fetal membranes,** include the amnion, chorion, yolk sac, and allantois.

In birds, the **amnion** and **chorion** arise from two folds that grow to completely surround the embryo (figure 60.19). The amnion is the inner membrane that surrounds the embryo and suspends it in *amniotic fluid*, thereby mimicking the aquatic environments of fish and amphibian embryos. The chorion is located next to the eggshell and is separated from the other membranes by a cavity, the *extraembryonic coelom*. The **yolk sac** plays a critical role in the nutrition of bird and reptile embryos; it is also present in mammals, though it does not nourish the embryo. The **allantois** is derived as an outpouching of the gut and serves to store the uric acid excreted in the urine of birds. During development, the allantois of a bird embryo expands to form a sac that eventually fuses with the overlying chorion, just under the eggshell. The fusion of the allantois and chorion form a functioning unit in which embryonic blood vessels, carried in the allantois, are brought close to the porous eggshell for gas exchange. The allantois is thus the functioning "lung" of a bird embryo.

In mammals, the embryonic cells form an inner cell mass that will become the body of the embryo and a layer of surrounding cells called the trophoblast (see figure 60.9). The trophoblast implants into the endometrial lining of its mother's uterus and becomes the chorionic membrane (figure 60.20). The part of the chorion in contact with endometrial tissue contributes to the placenta, as is described in more detail in the next section. The allantois in mammals contributes blood vessels to the structure that will become the umbilical cord, so that fetal blood can be delivered to the placenta for gas exchange.

> The extraembryonic membranes include the yolk sac, amnion, chorion, and allantois. These are derived from embryonic cells and function in a variety of ways to support embryonic development.
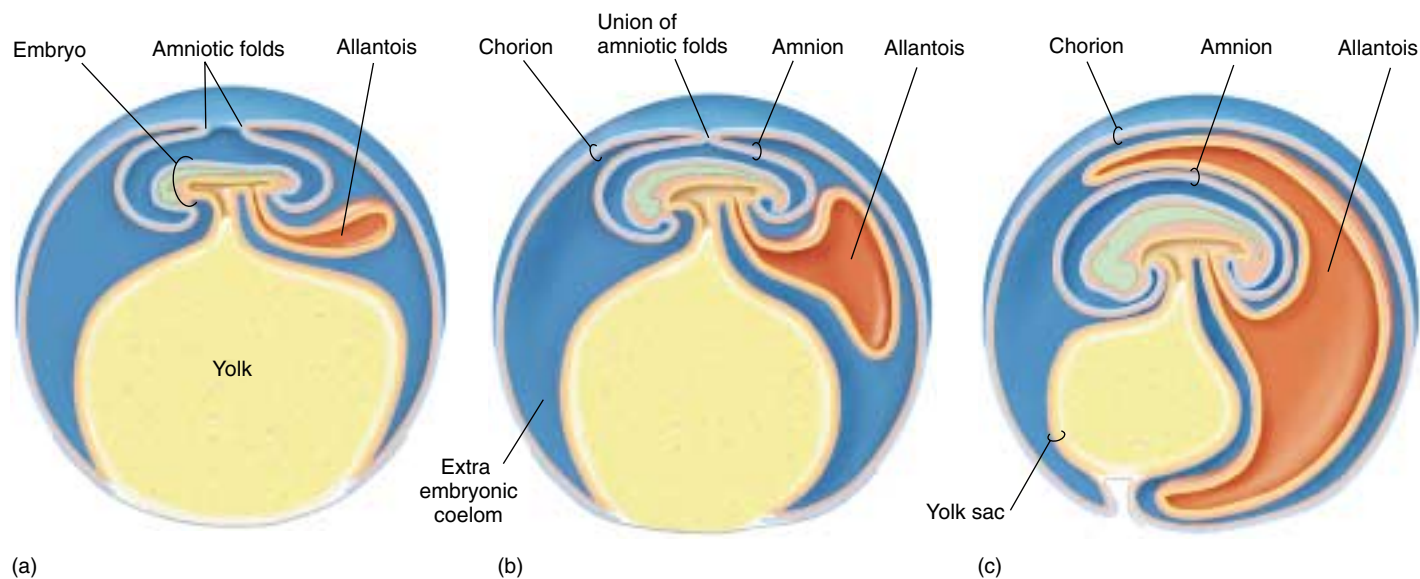

(a) (b) (c)

FIGURE 60.19
The extraembryonic membranes of a chick embryo. The membranes begin as amniotic folds from the embryo (*a*) that unite (*b*) to form a separate amnion and chorion (*c*). The allantois continues to grow until it will eventually unite with the chorion just under the eggshell.

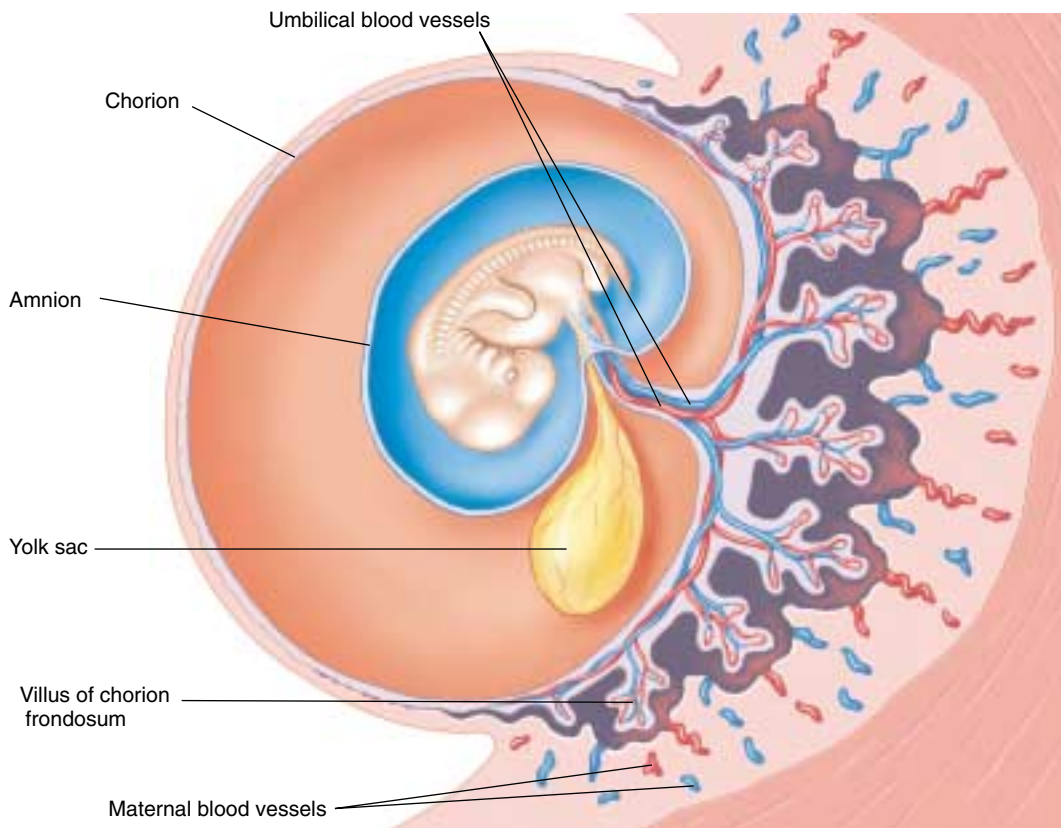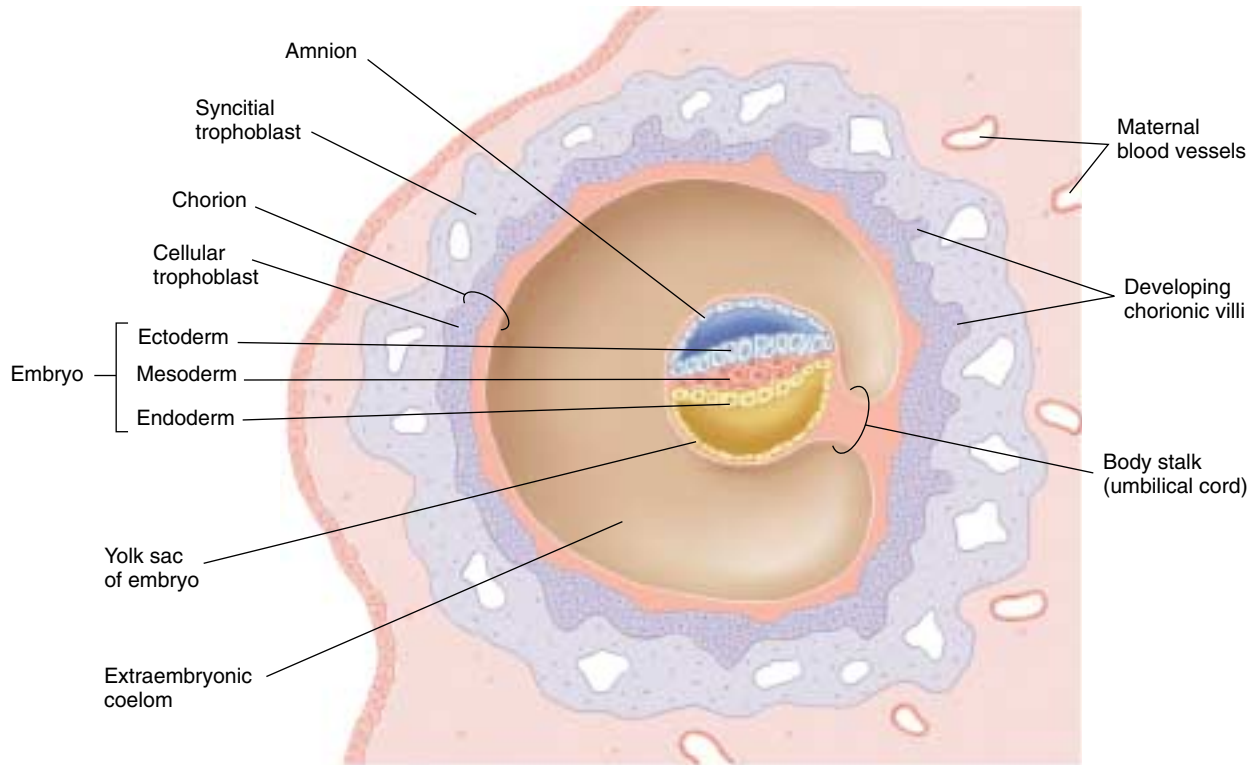**FIGURE 60.20**
The extraembryonic membranes of a mammalian embryo. (*a*) After the embryo implants into the mother's endometrium (6–7 days after fertilization), the trophoblast becomes the chorion, and the yolk sac and amnion are produced. (*b*) The chorion develops extensions, called villi, that interdigitate with surrounding endometrial tissue. The embryo is encased within an amniotic sac.

First Trimester

The development of the human embryo shows its evolutionary origins. Without an evolutionary perspective, we would be unable to account for the fact that human development proceeds in much the same way as development in a bird. In both animals, the embryo develops from a flattened collection of cells—the blastodisc in birds or the inner cell mass in humans. While the blastodisc of a bird is flattened because it is pressed against a mass of yolk, the inner cell mass of a human is flat despite the absence of a yolk mass. In humans as well as in birds, a primitive streak forms and gives rise to the three primary germ layers. Human development, from fertilization to birth, takes an average of 266 days. This time is commonly divided into three periods, called trimesters.

The First Month

About 30 hours after fertilization, the zygote undergoes its first cleavage; the second cleavage occurs about 30 hours after that. By the time the embryo reaches the uterus (6–7 days after fertilization), it is a blastula, which in mammals is referred to as a blastocyst. As we mentioned earlier, the
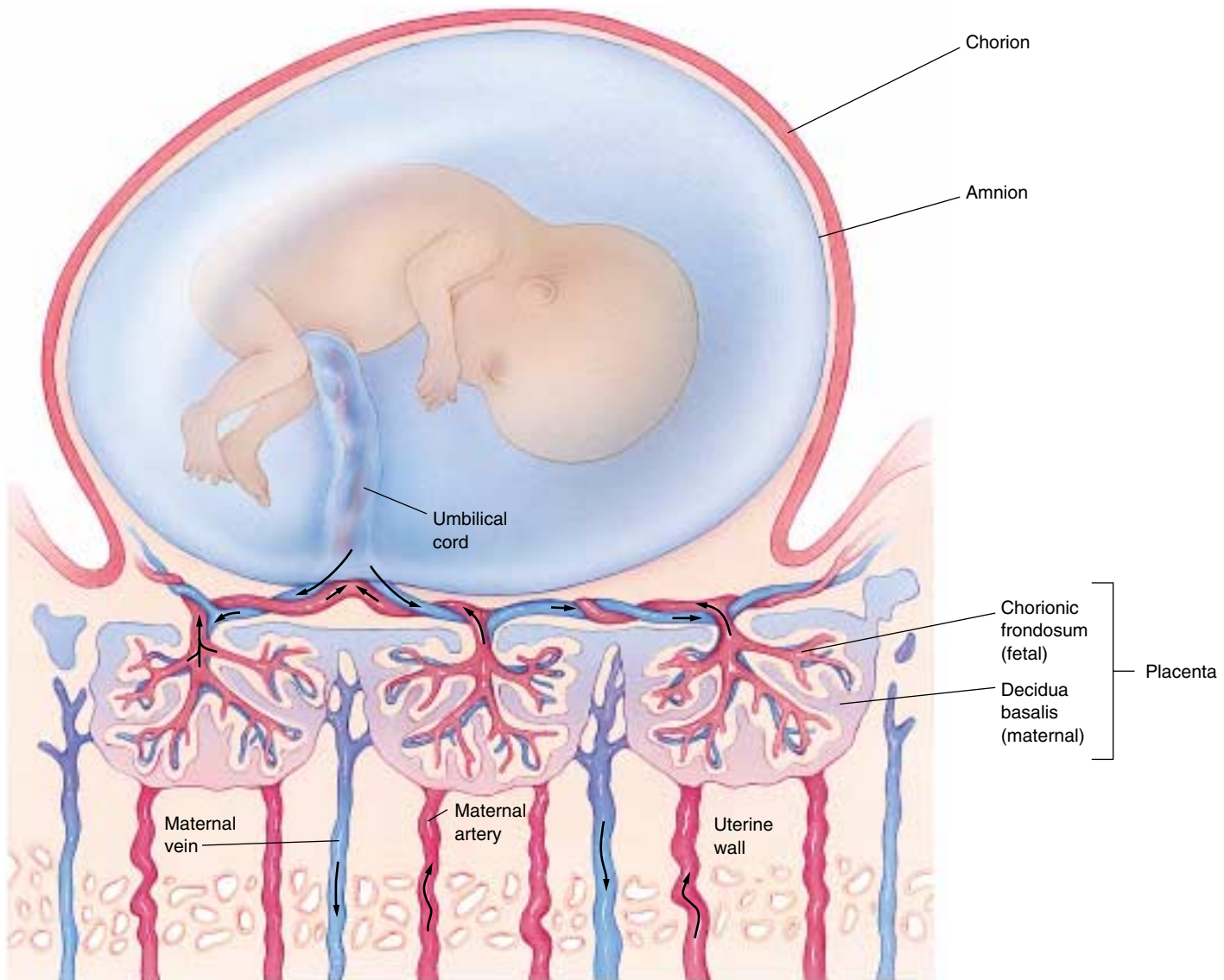
FIGURE 60.21
Structure of the placenta. The placenta contains a fetal component, the chorionic frondosum, and a maternal component, the decidua basalis. Deoxygenated fetal blood from the umbilical arteries (shown in blue) enters the placenta, where it picks up oxygen and nutrients from the mother's blood. Oxygenated fetal blood returns in the umbilical vein (shown in red) to the fetus, where it picks up oxygen and nutrients from the mother's blood.

blastocyst consists of an inner cell mass, which will become the body of the embryo, and a surrounding layer of trophoblast cells (see figure 60.9). The blastocyst begins to grow rapidly and initiates the formation of the amnion and the chorion. The blastocyst digests its way into the endometrial lining of the uterus in the process known as implantation.

During the second week after fertilization, the developing chorion forms branched extensions, the *chorionic frondosum* (fetal placenta) that protrude into the endometrium (figure 60.21). These extensions induce the surrounding endometrial tissue to undergo changes and become the *decidua basalis* (maternal placenta). Together, the chorionic frondosum and decidua basalis form a single functioning unit, the placenta (figure 60.22). Within the placenta, the mother's blood and the blood of the embryo come into close proximity but do not mix (see figure 60.21). Oxygen can thus diffuse from the mother to the embryo, and carbon dioxide can diffuse in the opposite direction. In addition to exchanging gases, the placenta provides nourishment for the embryo, detoxifies certain molecules that may pass into the embryonic circulation, and secretes hormones. Certain substances such as alcohol, drugs, and antibiotics are not stopped by the placenta and pass from the mother's bloodstream to the fetus.

One of the hormones released by the placenta is human chorionic gonadotropin (hCG), which was discussed in chapter 59. This hormone is secreted by the trophoblast cells even before they become the chorion, and is the hormone assayed in pregnancy tests. Because its action is almost identical to that of luteinizing hormone (LH), hCG maintains the mother's corpus luteum. The corpus luteum, in turn, continues to secrete estradiol and progesterone, thereby preventing menstruation and further ovulations.

Gastrulation also takes place in the second week after fertilization. The primitive streak can be seen on the surface of the embryo, and the three germ layers (ectoderm, mesoderm, and endoderm) are differentiated.

In the third week, neurulation occurs. This stage is marked by the formation of the neural tube along the dorsal axis of the embryo, as well as by the appearance of the first somites, which give rise to the muscles, vertebrae, and connective tissues. By the end of the week, over a dozen somites are evident, and the blood vessels and gut have begun to develop. At this point, the embryo is about 2 millimeters long.

Organogenesis (the formation of body organs) begins during the fourth week (figure 60.23*a*). The eyes form. The tubular heart develops its four chambers and starts to pulsate rhythmically, as it will for the rest of the individual's life. At 70 beats per minute, the heart is destined to beat more than 2.5 billion times during a lifetime of 70 years. Over 30 pairs of somites are visible by the end of the fourth week, and the arm and leg buds have begun to form. The embryo has increased in length to about 5 millimeters. Although the developmental scenario is now far advanced,

FIGURE 60.22
Placenta and fetus at seven weeks.

many women are unaware they are pregnant at this stage.

Early pregnancy is a very critical time in development because the proper course of events can be interrupted easily. In the 1960s, for example, many pregnant women took the tranquilizer thalidomide to minimize the discomforts associated with early pregnancy. Unfortunately, this drug had not been adequately tested. It interferes with limb bud development, and its widespread use resulted in many deformed babies. Organogenesis may also be disrupted during the first and second months of pregnancy if the mother contracts rubella (German measles). Most spontaneous abortions occur during this period.

The Second Month

Morphogenesis (the formation of shape) takes place during the second month (figure 60.23*b*). The miniature limbs of the embryo assume their adult shapes. The arms, legs, knees, elbows, fingers, and toes can all be seen—as well as a short bony tail! The bones of the embryonic tail, an evolutionary reminder of our past, later fuse to form the coccyx. Within the abdominal cavity, the major organs, including the liver, pancreas, and gallbladder, become evident. By the end of the second month, the embryo has grown to about 25 millimeters in length, weighs about one gram, and begins to look distinctly human.

(a)   (b)

FIGURE 60.23
The developing human. (*a*) Four weeks, (*b*) seven weeks, (*c*) three months, and (*d*) four months.

The Third Month

The nervous system and sense organs develop during the third month, and the arms and legs start to move (figure 60.23*c*). The embryo begins to show facial expressions and carries out primitive reflexes such as the startle reflex and sucking. The eighth week marks the transition from embryo to fetus. At this time, all of the major organs of the body have been established. What remains of development is essentially growth.

At around 10 weeks, the secretion of human chorionic gonadotropin (hCG) by the placenta declines, and the corpus luteum regresses as a result. However, menstruation does not occur because the placenta itself secretes estradiol and progesterone (figure 60.24). In fact, the amounts of these two hormones secreted by the placenta far exceed the amounts that are ever secreted by the ovaries. The high levels of estradiol and progesterone in the blood during pregnancy continue to inhibit the release of FSH and LH, thereby preventing ovulation. They also help maintain the uterus and eventually prepare it for labor and delivery, and they stimulate the development of the mammary glands in preparation for lactation after delivery.
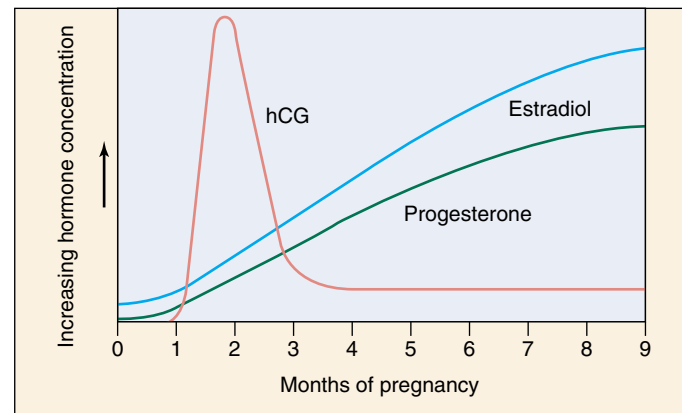
FIGURE 60.24
Hormonal secretion by the placenta. The placenta secretes chorionic gonadotropin (hCG) for 10 weeks. Thereafter, it secretes increasing amounts of estradiol and progesterone.

> The embryo implants into the endometrium, differentiates the germ layers, forms the extraembryonic membranes, and undergoes organogenesis during the first month and morphogenesis during the second month.

(c)

(d)

Second and Third Trimesters

The second and third trimesters are characterized by the tremendous growth and development required for the viability of the baby after its birth.

Second Trimester

Bones actively enlarge during the fourth month (figure 60.23*d*), and by the end of the month, the mother can feel the baby kicking. During the fifth month, the head and body grow a covering of fine hair. This hair, called **lanugo,** is another evolutionary relict but is lost later in development. By the end of the fifth month, the rapid heartbeat of the fetus can be heard with a stethoscope, although it can also be detected as early as 10 weeks with a fetal monitor. The fetus has grown to about 175 millimeters in length and attained a weight of about 225 grams. Growth begins in earnest in the sixth month; by the end of that month, the baby weighs 600 grams (1.3 lbs) and is over 300 millimeters (1 ft) long. However, most of its prebirth growth is still to come. The baby cannot yet survive outside the uterus without special medical intervention.

Third Trimester

The third trimester is predominantly a period of growth rather than development. The weight of the fetus doubles several times, but this increase in bulk is not the only kind of growth that occurs. Most of the major nerve tracts in the brain, as well as many new neurons (nerve cells), are formed during this period. The developing brain produces neurons at an average rate estimated at more than 250,000 per minute! Neurological growth is far from complete at the end of the third trimester, when birth takes place. If the fetus remained in the uterus until its neurological development was complete, it would grow too large for safe delivery through the pelvis. Instead, the infant is born as soon as the probability of its survival is high, and its brain continues to develop and produce new neurons for months after birth.

The critical stages of human development take place quite early, and the following six months are essentially a period of growth. The growth of the brain is not yet complete, however, by the end of the third trimester, and must be completed postnatally.

Birth and Postnatal Development

In some mammals, changing hormone levels in the developing fetus initiate the process of birth. The fetuses of these mammals have an extra layer of cells in their adrenal cortex, called a fetal zone. Before birth, the fetal pituitary gland secretes corticotropin, which stimulates the fetal zone to secrete steroid hormones. These corticosteroids then induce the uterus of the mother to manufacture prostaglandins, which trigger powerful contractions of the uterine smooth muscles.

The adrenal glands of human fetuses lack a fetal zone, and human birth does not seem to be initiated by this mechanism. In a human, the uterus releases prostaglandins, possibly as a result of the high levels of estradiol secreted by the placenta. Estradiol also stimulates the uterus to produce more oxytocin receptors, and as a result, the uterus becomes increasingly sensitive to oxytocin. Prostaglandins begin the uterine contractions, but then sensory feedback from the uterus stimulates the release of oxytocin from the mother's posterior pituitary gland. Working together, oxytocin and prostaglandins further stimulate uterine contractions, forcing the fetus downward (figure 60.25). Initially, only a few contractions occur each hour, but the rate eventually increases to one contraction every two to three minutes. Finally, strong contractions, aided by the mother's pushing, expel the fetus, which is now a newborn baby.

After birth, continuing uterine contractions expel the placenta and associated membranes, collectively called the afterbirth. The umbilical cord is still attached to the baby, and to free the newborn, a doctor or midwife clamps and cuts the cord. Blood clotting and contraction of muscles in the cord prevent excessive bleeding.

Nursing

Milk production, or lactation, occurs in the alveoli of mammary glands when they are stimulated by the anterior pituitary hormone, prolactin. Milk from the alveoli is secreted into a series of alveolar ducts, which are surrounded by smooth muscle and lead to the nipple (figure 60.26). During pregnancy, high levels of progesterone stimulate the development of the mammary alveoli, and high levels of estradiol stimulate the development of the alveolar ducts. However, estradiol blocks the actions of prolactin on the
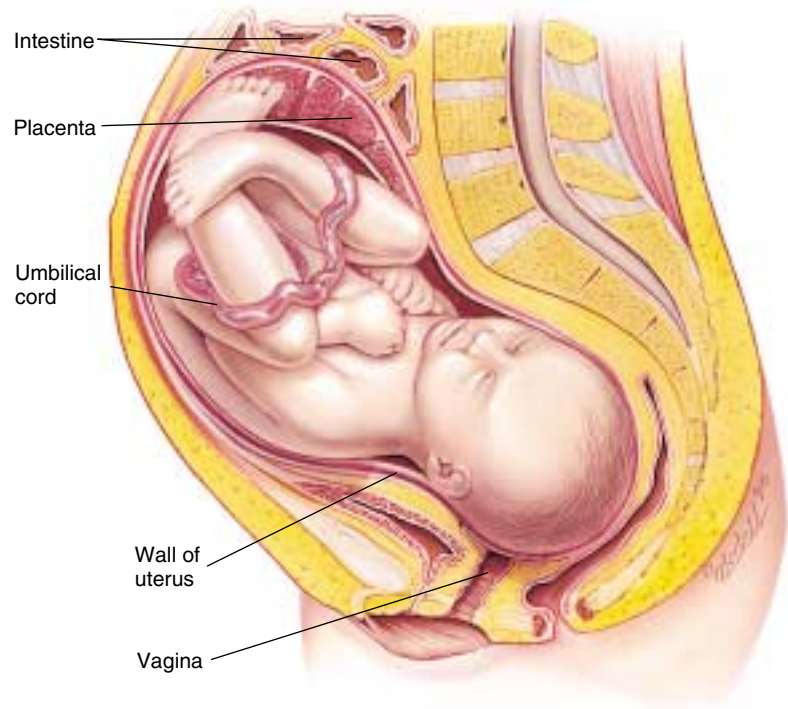

FIGURE 60.25
Position of the fetus just before birth. A developing fetus is a major addition to a woman's anatomy. The stomach and intestines are pushed far up, and there is often considerable discomfort from pressure on the lower back. In a natural delivery, the fetus exits through the vagina, which must dilate (expand) considerably to permit passage.
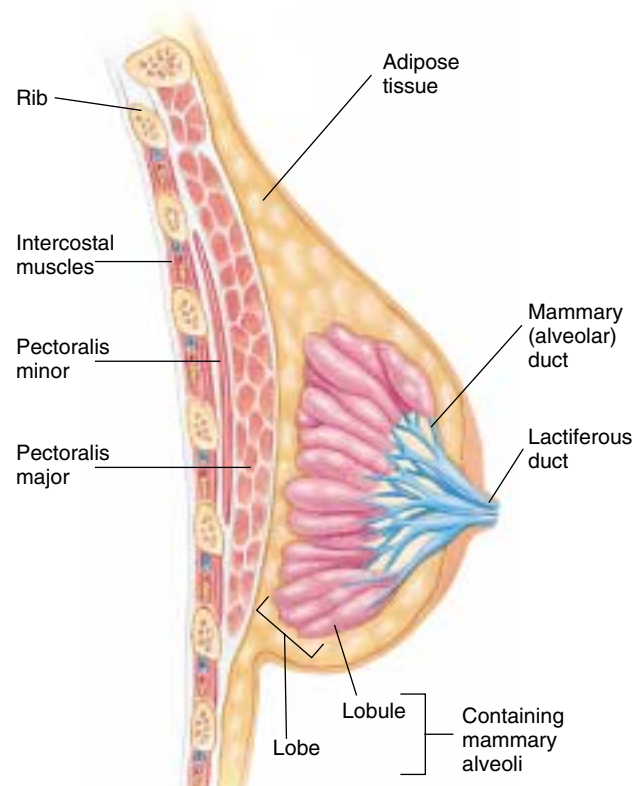

FIGURE 60.26
A sagittal section of a mammary gland. The mammary alveoli produce milk in response to stimulation by prolactin, and milk is ejected through the lactiferous duct in response to stimulation by oxytocin.

mammary glands, and it inhibits prolactin secretion by promoting the release of prolactin-inhibiting hormone from the hypothalamus. During pregnancy, therefore, the mammary glands are prepared for lactation but prevented from lactating.

When the placenta is discharged after birth, the concentrations of estradiol and progesterone in the mother's blood decline rapidly. This decline allows the anterior pituitary gland to secrete prolactin, which stimulates the mammary alveoli to produce milk. Sensory impulses associated with the baby's suckling trigger the posterior pituitary gland to release oxytocin. Oxytocin stimulates contraction of the smooth muscle surrounding the alveolar ducts, thus causing milk to be ejected by the breast. This pathway is known as the milk-ejection reflex. The secretion of oxytocin during lactation also causes some uterine contractions, as it did during labor. These contractions help to restore the tone of uterine muscles in mothers who are breastfeeding.

The first milk produced after birth is a yellowish fluid called colostrum, which is both nutritious and rich in maternal antibodies. Milk synthesis begins about three days following the birth and is referred to as when milk "comes in." Many mothers nurse for a year or longer. During this period, important pair-bonding occurs between the mother and child. When nursing stops, the accumulation of milk in the breasts signals the brain to stop prolactin secretion, and milk production ceases.

Postnatal Development

Growth of the infant continues rapidly after birth. Babies typically double their birth weight within two months. Because different organs grow at different rates and cease growing at different times, the body proportions of infants are different from those of adults. The head, for example, is disproportionately large in newborns, but after birth it grows more slowly than the rest of the body. Such a pattern of growth, in which different components grow at different rates, is referred to as allometric growth.

In most mammals, brain growth is mainly a fetal phenomenon. In chimpanzees, for instance, the brain and the cerebral portion of the skull grow very little after birth, while the bones of the jaw continue to grow. As a result, the head of an adult chimpanzee looks very different from that of a fetal chimpanzee (figure 60.27). In human infants, on the other hand, the brain and cerebral skull grow at the same rate as the jaw. Therefore, the jaw-skull proportions do not change after birth, and the head of a human adult looks very similar to that of a human fetus. It is primarily for this reason that an early human fetus seems so remarkably adultlike. The fact that the human brain continues to grow significantly for the first few years of postnatal life means that adequate nutrition and a rich, safe environment are particularly crucial during this period for the full development of the person's intellectual potential.
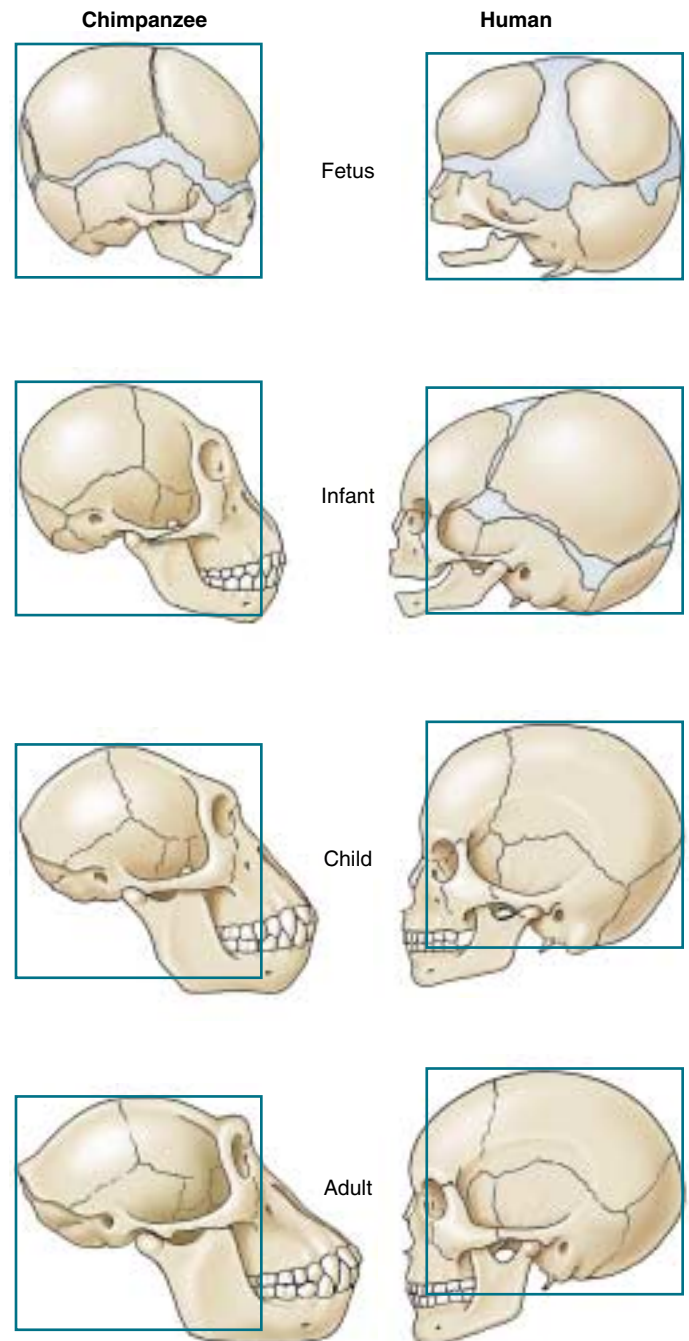

Chimpanzee   Human

Fetus

Infant

Child

Adult

FIGURE 60.27
Allometric growth. In young chimpanzees, the jaw grows at a faster rate than the rest of the head. As a result, the adult chimpanzee head shape differs greatly from its head shape as a newborn. In humans, the difference in growth between the jaw and the rest of the head is much smaller, and the adult head shape is similar to that of the newborn.

Birth occurs in response to uterine contractions stimulated by oxytocin and prostaglandins. Lactation is stimulated by prostaglandin, but the milk-ejection reflex requires the action of oxytocin.

Summary	*Questions*	*Media Resources*

60.1 Fertilization is the initial event in development.

- Fertilization is the union of an egg and a sperm to form a zygote. It is accomplished externally in most fish and amphibians, and internally in all other vertebrates.
- The three stages of fertilization are (1) penetration, (2) activation, and (3) fusion.

1. What are the three stages of fertilization, and what happens during each stage?

- Fertilization

60.2 Cell cleavage and the formation of a blastula set the stage for later development.

- Cleavage is the rapid division of the newly formed zygote into a mass of cells, without any increase in overall size.
- The cleavages produce a hollow ball of cells, called the blastula.

2. What is the difference between holoblastic cleavage and meroblastic cleavage? What is responsible for an embryo undergoing one or the other type of cleavage?

- Early development
- Preembryonic development

60.3 Gastrulation forms the three germ layers of the embryo.

- During gastrulation, cells in the blastula change their relative positions, forming the three primary cell layers: ectoderm, mesoderm, and endoderm.
- In eggs with moderate or large amounts of yolk, cells involute down and around the yolk, through a blastopore or primitive streak to form the three germ layers.

3. What is an archenteron, and during what developmental stage does it form? What is the future fate of this opening in vertebrates?

4. How is gastrulation in amphibians different from that in lancelets?

- Cell differentation

60.4 Body architecture is determined during the next stages of embryonic development.

- Neurulation involves the formation of a structure found only in chordates, the notochord and dorsal hollow nerve cord.
- The formation of the neural crest is the first developmental event unique to vertebrates. Most of the distinctive structures associated with vertebrates are derived from the neural crest.

5. What structure unique to chordates forms during neurulation?

6. What are the functions of the amnion, chorion, and allantois in birds and mammals?

- Art Activity: Human extra-embryonic membranes

- Embryonic and fetal development

60.5 Human development is divided into trimesters.

- Most of the critical events in human development occur in the first month of pregnancy. Cleavage occurs during the first week, gastrulation during the second week, neurulation during the third week, and organogenesis during the fourth week.
- The second and third months of human development are devoted to morphogenesis and to the elaboration of the nervous system and sensory organs.
- During the last six months before birth, the human fetus grows considerably, and the brain produces large numbers of neurons and establishes major nerve tracts.

7. How does the placenta prevent menstruation during the first two months of pregnancy?

8. At what time during human pregnancy does organogenesis occur?

9. Is neurological growth complete at birth?

10. What hormone stimulates lactation (milk production)? What hormone stimulates milk ejection from the breast?

- Bioethics Case Study: Critically ill newborns

- Human development
- Pregnancy
- Postnatal period