

Chapter Outline

44.1 Early Developmental Stages

A. Fertilization

1. **Fertilization** requires that sperm and egg interact to form a **zygote**.
 - a. A **sperm** has three parts.
 - 1) The **head** contains a haploid nucleus covered by a caplike **acrosome** containing enzymes allowing the sperm to penetrate the egg.
 - 2) A **middle piece** contains ATP-producing mitochondria.
 - 3) The **tail** is a flagellum that allows the sperm to swim.
 - b. The plasma membrane of the egg is surrounded by the zona pellucida.
 - a. The zona pellucida is surrounded by a few layers of adhering follicular cells, collectively called the corona radiata.
 - b. These cells nourished the egg when it was in a follicle of the ovary.
2. Fertilization involves the following steps which are species-specific.
 - a. Several sperm penetrate the corona radiata and several sperm attempt to penetrate the zona pellucida.
 - b. One sperm enters the egg and their nuclei eventually fuse.
 - c. After the sperm head binds tightly to the zona pellucida, the acrosome enzymes digest form a pathway for the sperm through the zona pellucida.
 - d. The head, middle piece and usually the tail enters the egg.
 - e. Prevention of polyspermy depends on changes in the egg plasma membrane when the sperm touches the egg and depolarizes the egg plasma membrane.
 - f. As soon as plasma membranes of the sperm and egg fuse, the zona pellucida lifts away from the surface of the egg, forming a moat that prevents entrance of any other sperm.
 - g. Vitelline envelope is now fertilization envelope.

B. Embryonic Development

1. **Development** is all of the changes that occur during the life cycle of an organism.
2. An organism is an **embryo** during the first stages of development.
3. Most animals go through the same embryonic stages: zygote, morula, blastula, early and late gastrula.
4. After fertilization, a zygote undergoes **cleavage**, cell division without growth.
5. DNA replication and mitosis occur repeatedly; and the cells get smaller each division.
6. In the lancelet, the cell divisions are equal in the resulting **morula**.
7. A cavity called the **blastocoel** develops forming a hollow ball called the **blastula**.
8. **Gastrulation** is the invagination of some cells into the blastocoel to form the two of the three **primary germ layers**.
 - a. The outer layer of cells becomes **ectoderm**; ectoderm gives rise to the epidermis of the skin, the epithelial lining of the mouth and rectum, and the nervous system.
 - b. The inner layer of cells becomes the **endoderm** that gives rise to the epithelial lining of the digestive tract and the respiratory tract, associated glands of the digestive and respiratory system, and the lining of urinary bladder.
 - c. The middle **mesoderm** begins as an outpocketing of the primitive gut.
 - 1) The outpocketings grow and fuse, forming a two layered mesoderm.
 - 2) The space between them is the coelom that contains the body organs.
 - 3) The mesoderm gives rise to the skeleton, the dermis of the skin, the skeletal system, the muscular system, the excretory system, the reproductive system (including most epithelial linings), and the outer layers of respiratory and digestive systems.
10. The germ layers then develop into those future organs.

C. The Effect of Yolk

1. The amount of yolk affects how animals complete the first three stages of development (cleavage, blastulation, and gastrulation).
 2. The lancelet and frog develop quickly in water into larvae that can feed themselves.
 3. The chick provides much yolk inside a hard shell; its development continues until the chick can exist on its own.
 4. The early stages of human development resemble the chick due to our common evolutionary history.
 5. Frog embryo cells at the animal pole have little yolk; cells at the vegetal pole contain more yolk.
 6. The presence of yolk causes cells to cleave more slowly; thus cells at the animal pole are smaller.
 7. Chick cell cleavage is incomplete; only those cells lying on top of the yolk cleave and spread out over the yolk surface, in contrast to the ball-like morula of the lancelet.
 8. The frog blastocoel is formed at the animal pole only.
 - a. Those cells containing yolk do not participate in gastrulation and do not invaginate.
 - b. Instead, a slitlike blastopore is formed when the animal pole cells begin to evaginate from above.
 - c. Other pole cells move down over the yolk; the blastopore then becomes rounded.
 - d. Those yolk cells temporarily left in the region form a yolk plug.
 - e. Cells from the dorsal lip of the blastopore migrate between the ectoderm and endoderm, forming the mesoderm.
 - f. Later, splitting of the mesoderm then creates the coelom.
 9. A chick blastocoel is created when cells lift up from the yolk and leave a space between the cells and the yolk.
 - a. There is so much yolk that endoderm formation does not occur by invagination.
 - b. Instead, the upper layer of cells differentiates into ectoderm; the lower layer differentiates into endoderm.
 - c. Mesoderm arises by an invagination of cells along the edges of the longitudinal furrow in the embryo midline, called the primitive streak.
 - d. Later, a newly formed mesoderm will split to form the coelomic cavity.
- D. Neurulation and the Nervous System
1. The newly formed mesoderm cells along the main axis coalesce to form a dorsal **notochord**; it persists in lancelets but is replaced in frogs, chicks, and humans by the vertebral column.
 2. The nervous system develops from midline ectoderm located just above the notochord.
 - a. At first, the cells on dorsal surface of embryo thicken, forming the **neural plate**.
 - b. Then **neural folds** develop on either side of a **neural groove** which becomes the **neural tube** when the folds fuse.
 - c. At this point the embryo is called a **neurula**.
 - d. Later, the anterior end of the neural tube develops into the brain.
 3. Midline mesoderm cells that did not contribute to the formation of the notochord now become two longitudinal masses of tissue.
 - a. The two tissue masses become blocked off into **somites**.
 - b. The somites give rise to segmental muscles in all chordates; in vertebrates the somites also form the vertebral bones.

44.2 Developmental Processes

- A. Development requires growth, differentiation, and morphogenesis.
1. **Cellular differentiation** occurs when cells become specialized in their structure and function.
 2. **Morphogenesis** produces a change in the shape and form of a body part; this includes both early cell movement and later pattern formation.
 3. Each body cell contains a full set of chromosomes; therefore differentiation is not due to parceled out genes.
 4. Cells in the adult body are totipotent, each contains all of the instructions to form any specialized cell.
 5. Since only muscle cells produce myosin, only red blood cells produce hemoglobin, and only skin cells produce keratin, there must be differential gene expression.
 6. Two mechanisms—cytoplasmic segregation and induction—seem especially important.
- B. Cytoplasmic Segregation
1. Differentiation begins long before we can recognize specialized cell types.
 2. Eggs contain substances called maternal determinants that influence the course of development.
 3. Cytoplasmic segregation parcels out the maternal determinants as mitosis occurs and determines how the various cells of morula develop.

4. Early experiments showed the cytoplasm of a frog egg is not uniform in content.
5. After the first cleavage of a frog embryo, only a daughter cell that receives a portion of the **gray crescent** develops into a complete embryo.
6. Hans Spemann (Nobel Prize in 1935) found particular chemical signals within the gray crescent turn on the genes that control development.

C. Induction

1. As development proceeds, differentiation involves signals from neighboring cells.
2. **Induction** is the ability of one tissue to influence the development of another tissue.
3. Cell migration occurs during gastrulation; one set of cells can influence the migratory path of another set.
4. Spemann showed that the dorsal lip of a blastopore (**primary organizer**) was necessary for development.
 - a. The cells closest to the primary organizer become endoderm, those farthest away become ectoderm, and the intermediate cells became mesoderm.
 - b. A molecular concentration gradient likely acts as a signal to induce germ layer differentiation.
5. Hans Spemann and Hilde Mangold worked on the dorsal side of the embryo where the notochord and the nervous system develop.
 - a. The presumptive notochord tissue induces the formation of the nervous system when placed beneath belly ectoderm.
 - b. Warren Lewis found that a developing lens induces the optic vesicle to form the optic cup in a frog embryo.

D. Model Organisms

1. Developmental genetics has been based on work with a roundworm, the fruit fly, and the mouse.
2. As examples of major groups, these models help us understand development in general.
3. *Caenorhabditis elegans*
 - a. *Caenorhabditis elegans* is a transparent worm, 1mm long and easily raised in Petri dishes or liquid media.
 - b. It is hermaphroditic and self-fertile; therefore induced recessive mutations appear in the next generation.
 - c. Its entire genome has been sequenced.
 - d. Worm development takes only three days and an adult worm contains only 959 cells.
 - e. The destiny of each cell can be followed in specialization and **fate maps** drawn.
 - f. The anchor cell receives the most inducer to become the inner vulva; neighboring cells receive less and become the outer vulva.
 - g. Work with *C. elegans* shows that induction requires transcriptional regulation of genes in a particular sequence.
 - h. Fate maps of *C. elegans* show that 131 cells must undergo apoptosis for normal worm development.
 - i. The cell-death protein is normally inhibited; when a receptor protein binds to inactivate it, the cell-death cascade becomes active and produces proteases and nucleases to slice proteins and DNA.
4. *Drosophila melanogaster* (the fruit fly)
 - a. The first event in successful development is the establishment of the head-tail axis.
 - b. In *Drosophila* eggs, there is a greater concentration of bicoid protein at one end.
 - c. Bicoid Protein Gradient
 - 1) Bicoid means “two-tailed”; a maternal mutation causes egg to lack head and it has two tails.
 - 2) By cloning the bicoid gene and using it as a probe, mRNA was found in a gradient from anterior to posterior.
 - 3) Proteins that influence morphogenesis are **morphogens**.
 - 4) The bicoid gradient switches on the expression of segmentation genes; a gradient has a range of effects.

- d. The Segmentation Pattern
 - 1) The bicoid gradient begins a cascade of segmentation genes.
 - 2) Christiane Nusslein-Vollard and Eric Wieschaus won a Nobel Prize for discovering segmentation genes in *Drosophila*.
 - 3) By exposing flies to mutagens and then mapping mutated genes, they located segmentation abnormalities.
 - 4) The first genes activated are *gap* genes; if mutated, they cause missing blocks of segments.
 - 5) The pair-rule genes ensure 14 segments; a mutation reduces this to half.
 - 6) Segment-polarity genes cause each segment to have an anterior and posterior half.
 - 7) Morphogen gradients turn on genes because they are transcription factors that regulate which genes are active in which parts of the embryo in what order.
- e. Homeotic Genes
 - 1) **Homeotic genes** control **pattern formation** in animal morphogenesis.
 - 2) In normal fruit fly development, homeotic genes are activated after the segmentation genes.
 - 3) In 1940s, Edward Lewis has discovered homeotic genes that controlled which segment would bear antenna, legs, wings.
 - 4) Homeotic genes have been found in many organisms; they all contain the same sequence of nucleic acids called a **homeobox**.
 - 5) Because homeotic genes contain a homeobox in mammals, they are called *Hox* genes.
 - 6) Each homeobox has a **homeodomain**, a sequence of sixty amino acids.
 - 7) A homeodomain protein produced by one homeotic gene binds to and turns on the next homeotic gene, and this orderly process determines the overall pattern of the embryo.
 - 8) Homeoboxes are derived from an original nucleic acid sequence that has been conserved because of its importance in regulation of animal development.

44.3 Humans Embryonic and Fetal Development xx

- A. Development covers events from conception (**fertilization**) to birth (**parturition**).
 1. The human **gestation period** is nine months, calculated by adding 280 days to the start of last menstruation.
 2. Only about 5% of babies arrive on the forecasted date due to so many variables.
- B. Human development is divided into embryonic and fetal development.
 1. **Embryonic development** during months 1 and 2 is when the major organs are formed.
 2. **Fetal development** is during months 3–9, during which organ systems grow and mature.
- C. **Extraembryonic membranes** lie outside of embryo and protect and nourish the **embryo** and, later, the **fetus**.
 1. Evolution of extraembryonic membranes in reptiles made development on land possible.
 - a. If an embryo develops in water, the water supplies the oxygen and takes away the wastes.
 - b. The surrounding water prevents desiccation and provides a protective cushion.
 - c. For an embryo on land, these functions are performed by extraembryonic membranes.
 2. Chick extraembryonic membranes develop from extensions of germ layers, which spread over yolk.
 - a. The **chorion** lies next to the shell and carries on gas exchange.
 - b. The **amnion** contains protective amniotic fluid that bathes a developing embryo.
 - c. The **allantois** collects nitrogenous wastes.
 - d. A **yolk sac** surrounds remaining yolk that provides nourishment.
 3. Humans also have these membranes; their function is modified for internal development.
 - a. The **chorion** develops into the fetal half of the **placenta**.
 - b. A **yolk sac** is the first site of blood cell formation.
 - c. **Allantoic blood vessels** become the umbilical blood vessels.
 - d. The **amnion** surrounds the embryo and cushions it with **amniotic fluid**.
 4. Therefore, all chordate animals develop in water, either in bodies of water or within the amniotic fluid.
- D. Embryonic Development
 1. The First Week
 - a. Fertilization occurs in the upper third of the oviduct; cleavage begins as the embryo moves down this tube to the uterus.
 - b. By the time the embryo reaches the uterus on the third day, it is a **morula**.
 - c. By the fifth day, the morula is transformed into a blastocyst.
 - 1) A **blastocyst** is a hollow ball of cells, resulting from cleavage.
 - 2) The **blastocoel** is a fluid-filled cavity contained within a blastocyst.

- 3) The **trophoblast** is an outer single layer of cells, which later gives rise to the **chorion**.
 - 4) The **inner cell mass** is the mass of cells from which the embryo, and eventually the fetus, will develop.
2. The Second Week
 - a. At end of the first week, an embryo begins the process of **implantation**.
 - b. The trophoblast secretes enzymes to digest away some of the tissue and blood vessels of the uterine wall.
 - c. The trophoblast begins to secrete **human chorionic gonadotropin** causing the corpus luteum to be maintained.
 - d. As the week progresses, the inner cell mass detaches itself from the trophoblast, and two more extraembryonic membranes form: the **yolk sac** and **amnion**.
 - e. The yolk sac forms below the embryonic disk; with no nutritive function in humans, it is the site of blood cell formation.
 - f. As in chick development, a human amnion and its cavity are where the embryo (and then the fetus) develop.
 - g. In humans, amniotic fluid insulates against any thermal changes; it also cushions and protects the fetus from trauma.
 - h. Gastrulation occurs during this week resulting in the inner cell mass flattening into an **embryonic disc**.
 - 1) The embryonic disk is composed of two cell layers: the **ectoderm** above and the **endoderm** below.
 - 2) Once an embryonic disk elongates to form the **primitive streak** (similar to that found in birds), a third germ layer, the **mesoderm**, forms by invagination of the cells along the streak.
 - i. The trophoblast is reinforced by mesoderm and becomes the **chorion**.
 3. The Third Week
 - a. The nervous system is the first organ system to become visually evident.
 - 1) It appears as a thickening along the entire dorsal length of the embryo; invagination occurs as the neural folds appear.
 - 2) When the neural folds meet at the midline, the neural tube is formed.
 - 3) After the notochord is replaced by the vertebral column, the nerve cord is called the spinal cord.
 - b. The development of the heart begins in the third week and continues into the fourth.
 - 1) The right and left heart tubes fuse; the heart begins pumping blood, although the chambers are not fully formed.
 - 2) The veins enter this largely tubular heart posteriorly, and the arteries exit anteriorly.
 - 3) Later the heart twists so that all of the major vessels are located anteriorly.
 4. The Fourth and Fifth Weeks
 - a. A bridge of mesoderm (the **body stalk**) connects the caudal (tail) end of the embryo with the chorion, which has projections called **chorionic villi**.
 - b. The fourth extraembryonic membrane (the **allantois**) is contained in this stalk; its blood vessels become the umbilical blood vessels.
 - c. The head and tail then lift up, and the body stalk moves anteriorly by constriction.
 - d. Once this process is complete, the **umbilical cord** is fully formed.
 - e. **Limb buds** appear from which the arms and legs will later develop.
 - f. The head enlarges and the sense organs become more prominent.
 - g. Rudiments of the eyes, ears, and nose are evident.
 5. The Sixth Through Eighth Weeks
 - a. The developing human becomes more humanlike in appearance.
 - b. As the brain develops, the head achieves its normal relationship with the body as a neck region develops.
 - c. The nervous system is developed well enough to permit reflex actions (e.g., the startle response to touch).
 - d. At the eighth week, the embryo is about 38 mm long and weighs no more than an aspirin tablet; all organs are established.

E. The Structure and Function of the Placenta

1. Providing gas, nutrient and waste exchange, the **placenta** begins formation once the embryo is fully implanted.
2. **Chorionic villi** are treelike extensions of the chorion.
 - a. Chorionic villi project into the maternal tissues.
 - b. Later, the chorionic villi disappear in all areas except where the placenta develops.
3. By the tenth week, the placenta is fully formed and has already begun to produce progesterone and estrogen.
 - a. Due to the negative feedback control by the hypothalamus and anterior pituitary, no new follicles mature.
 - b. They maintain lining of uterus and there is no menstruation during pregnancy.
4. The chorionic villi are surrounded by maternal blood sinuses; the maternal and fetal blood do not mix.
5. Exchange of molecules between the fetal and maternal blood takes place across the walls of the chorionic villi.
6. CO₂ and wastes move across from the fetus; O₂ and nutrients flow from the maternal side.
7. The umbilical cord stretches between the placenta and the fetus.
8. Umbilical arteries transport CO₂ and other waste molecules to the placenta for disposal; the umbilical vein transports O₂ and nutrient molecules from the placenta to the rest of the fetal circulatory system.
9. Harmful chemicals can cross placenta.
 - a. This is of particular concern during the embryonic period, when various structures are first forming.
 - b. Each organ has a sensitive period during which a substance can alter the normal development.
 - c. A pregnant woman who takes thalidomide tranquilizer between days 27 and 40 is likely to have an infant born with deformed limbs; after this time period, the infant is born normal.

F. Fetal Development and Birth

1. Fetal development (months 3–9) involves an extreme increase in size; the weight multiplies 600 times.
2. The genitalia appear in the third month and gender can be identified anatomically.
3. A fetus soon acquires hair, eyebrows, eyelashes, and nails.
4. Fine, downy hair (**lanugo**) covers the limbs and trunk; it later disappears.
5. The skin grows so fast that it wrinkles; a waxy **vernix caseosa** protects the skin from the watery amniotic fluid.
6. A fetus at first only flexes its limbs; later it moves its limbs vigorously; a mother feels movements from the fourth month onward.
7. After 16 weeks, a fetal heartbeat is heard through a stethoscope.
8. A fetus born at 24 weeks may survive; the lungs are still immature and often cannot capture O₂ adequately.

G. Stages of Birth

1. When the fetal brain matures, the hypothalamus causes the pituitary to stimulate adrenal cortex so that androgens are released.
2. The placenta uses androgens as precursors for estrogens that stimulate the production of prostaglandin and oxytocin.
3. The hormones estrogen, prostaglandin, and oxytocin all cause the uterus to contract and expel the fetus.
4. The process of birth (parturition) has three stages: dilation of the cervix, birth of the baby, and expulsion of **afterbirth** (the placenta and extraembryonic membranes).