Chapter 21

The Genetic Basis of Development

PowerPoint Lectures for
***Biology*, Seventh Edition**
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Lectures by Chris Romero

- Overview: From Single Cell to Multicellular Organism
- The application of genetic analysis and DNA technology
  - Has revolutionized the study of development

- Researchers
  - Use mutations to deduce developmental pathways
  - Have applied the concepts and tools of molecular genetics to the study of developmental biology

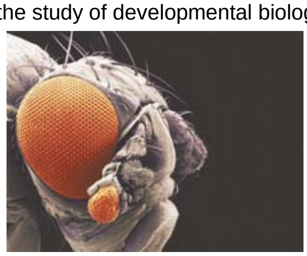


Figure 21.1

- When the primary research goal is to understand broad biological principles
  - The organism chosen for study is called a model organism

DROSOPHILA MELANOGASTER
(FRUIT FLY)

CAENORHABDITIS ELEGANS
(NEMATODE)

Figure 21.2

MUS MUSCULUS
(MOUSE)

ARABIDOPSIS THAMANA
(COMMON WALL CRESS)

DANIO RERIO
(ZEBRAFISH)

- Concept 21.1: Embryonic development involves cell division, cell differentiation, and morphogenesis
- In the embryonic development of most organisms
  - A single celled zygote gives rise to cells of many different types, each with a different structure and corresponding function

- The transformation from a zygote into an organism
  - Results from three interrelated processes: cell division, cell differentiation, and morphogenesis

Figure 21.3a, b — (a) Fertilized eggs of a frog; (b) Tadpole hatching from egg

- Through a succession of mitotic cell divisions
  - The zygote gives rise to a large number of cells
- In cell differentiation
  - Cells become specialized in structure and function
- Morphogenesis encompasses the processes
  - That give shape to the organism and its various parts

- The three processes of development overlap in time

(a) **Animal development.** Most animals go through some variation of the blastula and gastrula stages. The blastula is a sphere of cells surrounding a fluid-filled cavity. The gastrula forms when a region of the blastula folds inward, creating a tube—a rudimentary gut. Once the animal is mature, differentiation occurs in only a limited way—for the replacement of damaged or lost cells.

(b) **Plant development.** In plants with seeds, a complete embryo develops within the seed. Morphogenesis, which involves cell division and cell wall expansion rather than cell or tissue movement, occurs throughout the plant's lifetime. Apical meristems (purple) continuously arise and develop into the various plant organs as the plant grows to an indeterminate size.

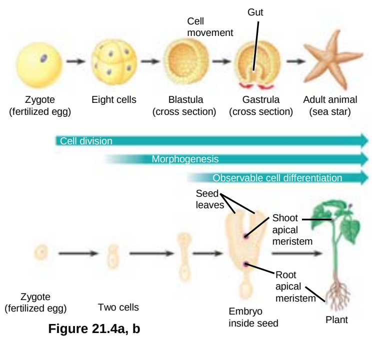


Figure 21.4a, b

- Concept 21.2: Different cell types result from differential gene expression in cells with the same DNA
- Differences between cells in a multicellular organism
  - Come almost entirely from differences in gene expression, not from differences in the cells' genomes

Evidence for Genomic Equivalence

- Many experiments support the conclusion that
  - Nearly all the cells of an organism have genomic equivalence, that is, they have the same genes

Totipotency in Plants

- One experimental approach for testing genomic equivalence
  - Is to see whether a differentiated cell can generate a whole organism

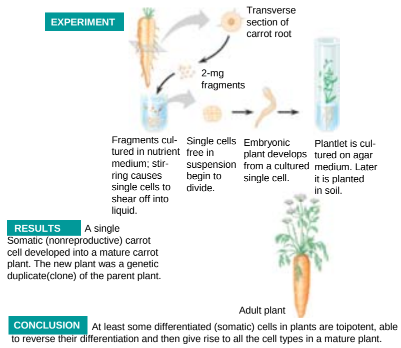


Figure 21.5

- A totipotent cell
  - Is one capable of generating a complete new organism
- Cloning
  - Is using one or more somatic cells from a multicellular organism to make another genetically identical individual

Nuclear Transplantation in Animals

- In nuclear transplantation
  - The nucleus of an unfertilized egg cell or zygote is replaced with the nucleus of a differentiated cell

- Experiments with frog embryos
  - Have shown that a transplanted nucleus can often support normal development of the egg

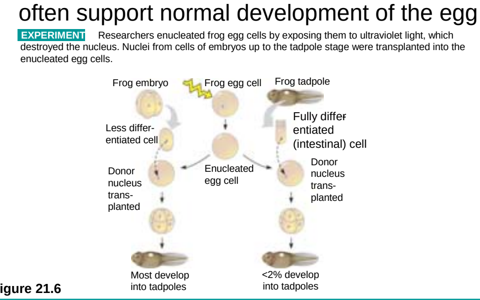


Figure 21.6

RESULTS Most of the recipient eggs developed into tadpoles when the transplanted nuclei came from cells of an early embryo, which are relatively undifferentiated cells. But with nuclei from the fully differentiated intestinal cells of a tadpole, fewer than 2% of the eggs developed into normal tadpoles, and most of the embryos died at a much earlier developmental stage.

CONCLUSION The nucleus from a differentiated frog cell can direct development of a tadpole. However, its ability to do so decreases as the donor cell becomes more differentiated, presumably because of changes in the nucleus.

- Reproductive Cloning of Mammals
- In 1997, Scottish researchers
  - Cloned a lamb from an adult sheep by nuclear transplantation

APPLICATION This method is used to produce cloned animals whose nuclear genes are identical to the donor animal supplying the nucleus.

TECHNIQUE Shown here is the procedure used to produce Dolly, the first reported case of a mammal cloned using the nucleus of a differentiated cell.

RESULTS The cloned animal is identical in appearance and genetic makeup to the donor animal supplying the nucleus, but differs from the egg cell donor and surrogate mother.

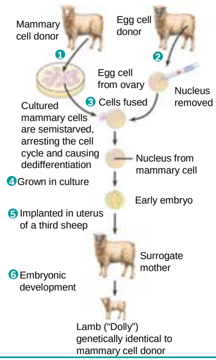


Figure 21.7

- "Copy Cat"
  - Was the first cat ever cloned

Figure 21.8

- Problems Associated with Animal Cloning
- In most nuclear transplantation studies performed thus far
  - Only a small percentage of cloned embryos develop normally to birth

The Stem Cells of Animals

- A stem cell
  - Is a relatively unspecialized cell
  - Can reproduce itself indefinitely
  - Can differentiate into specialized cells of one or more types, given appropriate conditions

- Stem cells can be isolated
  - From early embryos at the blastocyst stage

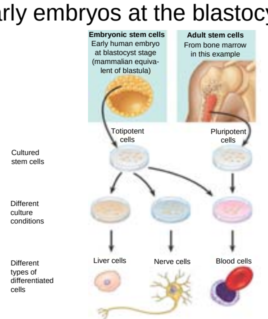


Figure 21.9

- Adult stem cells
  - Are said to be pluripotent, able to give rise to multiple but not all cell types

Transcriptional Regulation of Gene Expression During Development

- Cell determination
  - Precedes differentiation and involves the expression of genes for tissue specific proteins
- Tissue-specific proteins
  - Enable differentiated cells to carry out their specific tasks

- Determination and differentiation of muscle cells

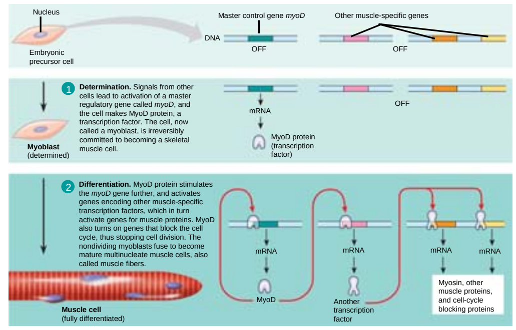
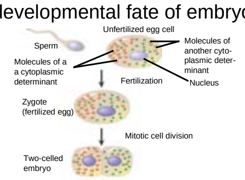


Figure 21.10

Cytoplasmic Determinants and Cell-Cell Signals in Cell Differentiation

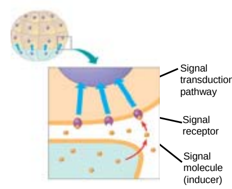
- Cytoplasmic determinants in the cytoplasm of the unfertilized egg
  - Regulate the expression of genes in the zygote that affect the developmental fate of embryonic cells



(a) Cytoplasmic determinants in the egg. The unfertilized egg cell has molecules in its cytoplasm, encoded by the mother's genes, that influence development. Many of these cytoplasmic determinants, like the two shown here, are unevenly distributed in the egg. After fertilization and mitotic division, the cell nuclei of the embryo are exposed to different sets of cytoplasmic determinants and, as a result, express different genes.

Figure 21.11a

- In the process called induction
  - Signal molecules from embryonic cells cause transcriptional changes in nearby target cells



(b) Induction by nearby cells. The cells at the bottom of the early embryo depicted here are releasing chemicals that signal nearby cells to change their gene expression.

Figure 21.11b

- Concept 21.3: Pattern formation in animals and plants results from similar genetic and cellular mechanisms
- Pattern formation
  - Is the development of a spatial organization of tissues and organs
  - Occurs continually in plants
  - Is mostly limited to embryos and juveniles in animals

- Positional information
  - Consists of molecular cues that control pattern formation
  - Tells a cell its location relative to the body's axes and to other cells

Drosophila Development: A Cascade of Gene Activations

- Pattern formation
  - Has been extensively studied in the fruit fly *Drosophila melanogaster*

The Life Cycle of Drosophila

- *Drosophila* development
  - Has been well described

- After fertilization
  - Positional information specifies the segments
  - Sequential gene expression produces regional differences in the formation of the segments

- Key developmental events in the life cycle of *Drosophila*

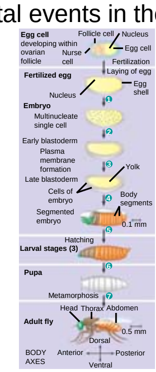


Figure 21.12

Genetic Analysis of Early Development: Scientific Inquiry

- The study of developmental mutants
  - Laid the groundwork for understanding the mechanisms of development

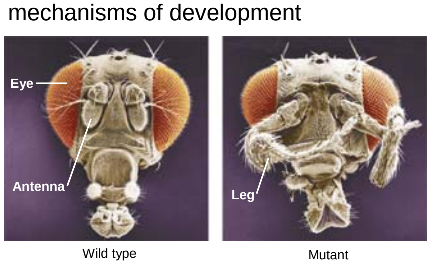
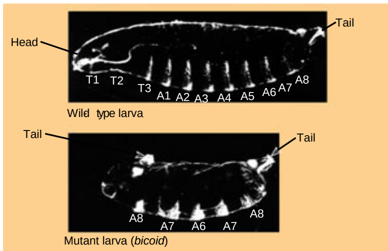


Figure 21.13

Axis Establishment

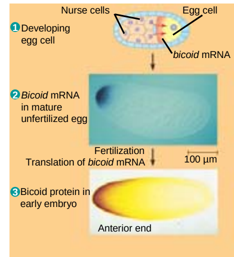
- Maternal effect genes
  - Encode for cytoplasmic determinants that initially establish the axes of the body of *Drosophila*

- Flies with the *bicoid* mutation
  - Do not develop a body axis correctly



(a) ***Drosophila*** **larvae with wild-type and** ***bicoid*** **mutant phenotypes.** A mutation in the mother's *bicoid* gene leads to tail structures at both ends (bottom larva). The numbers refer to the thoracic and abdominal segments that are present.

Figure 21.14a



(b) Gradients of ***bicoid*** **mRNA and Bicoid protein in normal egg and early embryo.**

Figure 21.14b

Segmentation Pattern

- Segmentation genes
  - Produce proteins that direct formation of segments after the embryo's major body axes are formed

Identity of Body Parts

- The anatomical identity of *Drosophila* segments
  - Is set by master regulatory genes called homeotic genes

- A summary of gene activity during *Drosophila* development

Hierarchy of Gene Activity in Early *Drosophila* Development	
Maternal effect genes (egg-polarity genes)	
↓ Gap genes	Segmentation genes of the embryo
↓ Pair-rule genes	Segmentation genes of the embryo
↓ Segment polarity genes	Segmentation genes of the embryo
↓ Homeotic genes of the embryo	
↓ Other genes of the embryo	

C. elegans: The Role of Cell Signaling

- The complete cell lineage
  - Of each cell in the nematode roundworm *C. elegans* is known

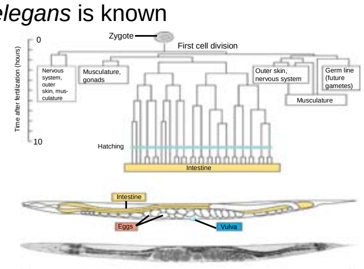
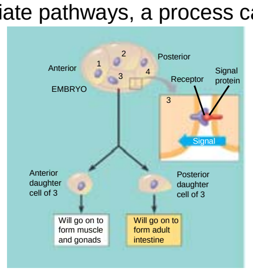


Figure 21.15

Induction

- As early as the four-cell stage in *C. elegans*
  - Cell signaling helps direct daughter cells down the appropriate pathways, a process called induction



(a) Induction of the intestinal precursor cell at the four-cell stage.

Figure 21.16a

- Induction is also critical later in nematode development
  - As the embryo passes through three larval stages prior to becoming an adult

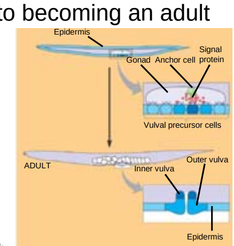


Figure 21.16b

(b) Induction of vulval cell types during larval development.

- An inducing signal produced by one cell in the embryo
  - Can initiate a chain of inductions that results in the formation of a particular organ

Programmed Cell Death (Apoptosis)

- In apoptosis
  - Cell signaling is involved in programmed cell death

Figure 21.17

- In *C. elegans*, a protein in the outer mitochondrial membrane
  - Serves as a master regulator of apoptosis

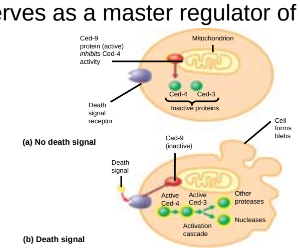


Figure 21.18a, b

- In vertebrates
  - Apoptosis is essential for normal morphogenesis of hands and feet in humans and paws in other animals

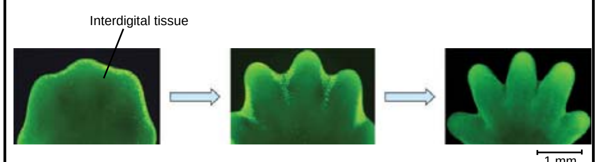


Figure 21.19

Plant Development: Cell Signaling and Transcriptional Regulation

- Thanks to DNA technology and clues from animal research
  - Plant research is now progressing rapidly

Mechanisms of Plant Development

- In general, cell lineage
  - Is much less important for pattern formation in plants than in animals
- The embryonic development of most plants
  - Occurs inside the seed

Pattern Formation in Flowers

- Floral meristems
  - Contain three cell types that affect flower development

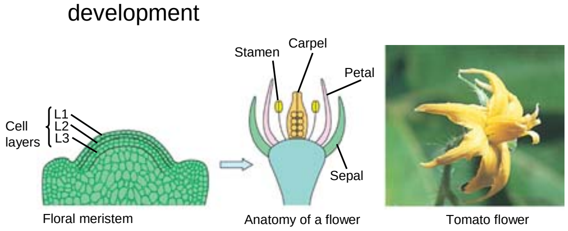


Figure 21.20

- Tomato plants with a mutant allele
  - Have been studied in order to understand the genetic mechanisms behind flower development

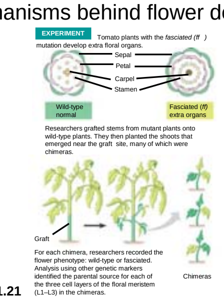
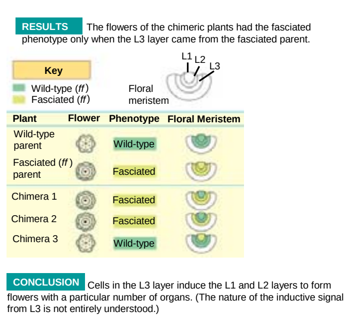


Figure 21.21



Plant	Flower	Phenotype	Floral Meristem
Wild-type parent		Wild-type	
Fasciated (*ff*) parent		Fasciated	
Chimera 1		Fasciated	
Chimera 2		Fasciated	
Chimera 3		Wild-type	

CONCLUSION Cells in the L3 layer induce the L1 and L2 layers to form flowers with a particular number of organs. (The nature of the inductive signal from L3 is not entirely understood.)

- Organ identity genes
  - Determine the type of structure that will grow from a meristem
  - Are analogous to homeotic genes in animals

Figure 21.22

- Concept 21.4: Comparative studies help explain how the evolution of development leads to morphological diversity
- Biologists in the field of evolutionary developmental biology, or “evo-devo,” as it is often called
  - Compare developmental processes of different multicellular organisms

Widespread Conservation of Developmental Genes Among Animals

- Molecular analysis of the homeotic genes in *Drosophila*
  - Has shown that they all include a sequence called a homeobox

- An identical or very similar nucleotide sequence
  - Has been discovered in the homeotic genes of both vertebrates and invertebrates

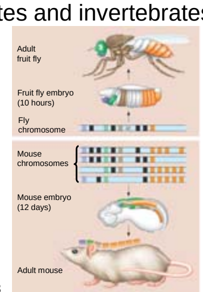


Figure 21.23

- Related genetic sequences
  - Have been found in regulatory genes of yeasts, plants, and even prokaryotes
- In addition to developmental genes
  - Many other genes involved in development are highly conserved from species to species

- In some cases
  - Small changes in regulatory sequences of particular genes can lead to major changes in body form, as in crustaceans and insects

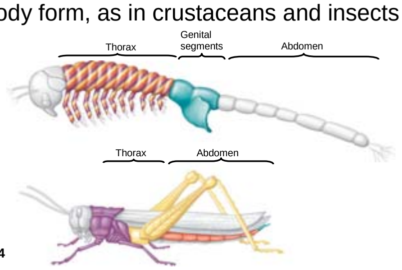


Figure 21.24

- In other cases
  - Genes with conserved sequences play different roles in the development of different species
- In plants
  - Homeobox-containing genes do not function in pattern formation as they do in animals

Comparison of Animal and Plant Development

- In both plants and animals
  - Development relies on a cascade of transcriptional regulators turning genes on or off in a finely tuned series
- But the genes that direct analogous developmental processes
  - Differ considerably in sequence in plants and animals, as a result of their remote ancestry