Chapter 47.

Development

What’s the most complex problem in biology?
The most complex problem

How to get from here to there

Development: cellular level

- Cell division
- Differentiation
  - cells become specialized in structure & function
    - if each kind of cell has the same genes, how can they be so different
    - shutting off of genes = loss of totipotency
- Morphogenesis
  - “creation of form” = give organism shape
  - basic body plan
    - polarity
      - one end is different than the other
    - symmetry
      - left & right side of body mirror each other
    - asymmetry
      - pssst, look at your hand…
Development: step-by-step

- Gamete formation
- Fertilization
- Cleavage (cell division, mitosis)
- Gastrulation (morphogenesis)
- Organ formation (differentiation)
- Growth & tissue formation (differentiation)

Model organisms
Fertilization

- Joining of egg nucleus & sperm nucleus
  - how does sperm get through egg cell membrane?
  - how to protect against fertilization by multiple sperm
  - how is the rest of development triggered?

- Only sperm nucleus enters egg cell
  - sea urchin
- Whole sperm enters egg cell
  - mammals
Blocking polyspermy

- Triggers opening of Na\(^+\) channels in egg cell membrane
  - depolarizes membrane
  - "fast block" to polyspermy

- Triggers signal transduction pathway
  - release of Ca\(^++\) from ER causes cascade reaction across egg
  - "fertilization envelope" forms like bubble around egg
  - "slow block" to polyspermy
“Fast block” to polyspermy
- Release of Na+ causes depolarization wave reaction across egg membrane

Cleavage: start of multicellularity
- Repeated mitotic divisions of zygote
  - may be unequal divisions of cytoplasm
    - cleavage pattern determined by amount of yolk in egg
    - leaves different contents in each cell
    - seals development fate of each cell & its descendants
  - vegetal pole = yolk-rich end
  - animal pole = nearest the nucleus
Egg $\rightarrow$ zygote $\rightarrow$ morula

Cell signaling
- Regulating the expression of genes that affect the developmental fate of the cell
Egg → morula → blastula

- **Blastula formation**
  - successive divisions result in a **blastula**
  - hollow single-layered sphere enclosing a space, the blastocoel
Gray crescent

- In amphibians
  - establishes anterior-posterior body axes
- In mammals
  - polarity may be established by the entry of the sperm into the egg

Importance of cytoplasmic determinants
Also proof of retention of full genetic composition after mitosis
Early embryonic stages

- **Morula**
  - solid ball stage

- **Blastula**
  - hollow fluid-filled ball stage
    - by the time human embryo reaches uterus

- **Gastrula**
  - development of primitive digestive tract (gut) & tissue layers

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Gastrulation

- zygote $\rightarrow$ blastula $\rightarrow$ gastrula

How you looked as a blastula...
Gastrulation

- zygote → blastula → gastrula
- rearranges the blastula to form a 3-layered embryo with a primitive gut

- blastopore: forms at sperm penetration point
- archenteron: forms endoderm embryonic gut
- mesoderm
- endoderm
- blastoderm
- primary mesoderm
- ectoderm
- tissue formation
- dorsal lip: organizing center for development

- animal pole
- vegetal pole
- ingression
- secondary mesoderm

2004-2005 AP Biology
Primary tissue or “germ” layers

- **ectoderm**
  - external surfaces: skin
    - epidermis (skin); nails, hair & glands; tooth enamel; eye lens; epithelial lining of nose, mouth & rectum; nervous system

- **endoderm**
  - internal lining
    - epithelial lining of digestive tract & respiratory systems; reproductive system & urinary tract; digestive organs

- **mesoderm**
  - middle tissues: muscle, blood & bone
    - notochord; skeletal, muscular, circulatory, lymphatic, excretory & reproductive systems; lining of body cavity

Basic body plan

- **Archenteron becomes embryonic gut**
  - mouth at one end
  - anus at the other

- **Protostomes**
  - “1st mouth”
  - blastopore = mouth
  - invertebrates

- **Deuterostomes**
  - “2nd mouth”
  - blastopore = anus
  - echinoderms & vertebrates
**Dorsal lip**

- **Organizer:** grafting the dorsal lip of one embryo onto the ventral surface of another embryo results in the development of a second notochord & neural tube at the site of the graft.

**Morphogenesis**

- Organization of differentiated cells into tissues & organs
- Cell migration
  - by changes in shape
    - cells fold inward as pockets by changing shape
  - Cell movements
    - cells move by pseudopods projecting from the cell body
  - Signals from cues
    - guided by following chemical gradients
    - respond to adhesive cues from recognition proteins on adjacent cells
Cell signaling

- Regulating the expression of genes that affect the developmental fate of the cell

Gastrulation

- Cells change size & shape: sheets of cells expand & fold inward & outward

Changes in cell shape involve reorganization of the cytoskeleton
Gastrulation

- Cells move by pseudopods

Organ development

- Organ development begins with the formation of:
  - neural tube
    - future spinal cord & brain
  - notochord
    - primitive skeleton, replaced by vertebrate spinal column
  - somites
    - bands of tissue that will become muscles & bones
Coelom
- Body cavity formed between layers of mesoderm
  - in which the digestive tract & other internal organs are suspended

Acoelomates
- flatworms

Pseudocoelomates
- roundworms, nematodes

Coelomates
- mollusca, annelida, arthropoda, echinodermata, & chordata
Coelomates

- **Mollusca**
  - snails, clams
- **Annelida**
  - segmented worms
- **Arthropoda**
  - spiders & insects
- **Echinodermata**
  - marine, starfish, sea urchins
- **Chordata**
  - vertebrates
Neural tube development

- Neural tube & notochord
  - embryonic structures that will become spinal chord & vertebrae

Apoptosis

- Programmed cell death
  - Sculpts body parts
  - Genetically programmed elimination of tissues & cells that were used for only short periods in the embryo or adult
    - human embryos develop with webs between toes & fingers, but they are not born that way!
**Apoptosis**

(a) Process of apoptosis

(b) Model for the molecular basis of apoptosis in nematode development

**Stem cells**

Early human embryo at blastocyst stage

(mammalian equivalent of blastula)

Embryonic stem cells

OR

Bone marrow
(for example)

Adult stem cells

pluripotent cells

Liver cells

Nerve cells

Heart muscle cells
Homeotic genes

- Mutations to homeotic genes produce flies with such strange traits as legs growing from the head in place of antennae.
- Structures characteristic of a particular part of the animal arise in wrong place

antennapedia flies
Homeobox DNA

- Master control genes evolved early
- Conserved for hundreds of millions of years
- Homologous homeobox genes in fruit flies & vertebrates
  - kept their chromosomal arrangement

Evolutionary Constraints on Development

- Basic body plans of the major animal groups have not changed due to a limited number of homeotic genes (master genes)
- These genes have imposed limits
  - taxonomic / evolutionary
  - physical
  - architectural