Animal Development

Chapter 47

Brief History of Developmental Ideas

- As recently as the 18th century, the prevailing theory was a notion called *preformation*: the idea that the egg or sperm contains an embryo—a preformed, miniature infant, or "***homunculus***"—that simply becomes larger during development."
  - Homunculi do not exist.
  - Nevertheless, many aspects of development are already in place in the eggs of many species.

- **Aristotle** proposed the idea of ***epigenesis*** 2,000 years earlier.
  - The idea was that an animal forms gradually over time from a relatively formless egg
  - At the time this was also conjecture
    - As was the idea of *preformation*
  - ***Epigenesis*** is now a theory that has much support
    - Such theories like this one, gravity, plate tectonics, evolution, and the idea that the Earth revolves around the sun are often considered "facts" although some people dispute every one of these "theories" despite overwhelming amounts of verifiable evidence.

Embryonic Development

- Starts after Fertilization
- Embryonic Development includes three stages
  - Cleavage
  - Gastrulation
  - Organogenesis
- Ends at Birth

Fertilization

- Many species require fertilization before an embryo can develop.
  - This primarily true for sexually reproducing species.
  - Parthenogenesis is the development of embryos without fertilization.
- Sperm and egg must meet and their nuclear DNA combines.
  - Sperm and egg are both haploid (n)
  - The resulting zygote is diploid (2n)

- At the tip of the head of a sperm is a vesicle called an ***acrosome***.
  - Contains hydrolytic enzymes
  - Enzymes release when the sperm meets the egg
    - Enzymes digest the ***zona pellucida*** in the eggs (in mammals)
    - ***zona pellucida*** is an extracellular protective matrix
  - Once through the zona pellucida, the plasma membranes of the sperm and egg meet and combine
    - Protein molecules on the sperm join the receptor proteins on the plasma membrane and unlock it.
    - The nucleus of the sperm is then injected into the egg cell and a chain reaction occurs
    - The egg's membrane quickly depolarizes, which prevents additional sperm from entering the egg
      - This *fast block to polyspermy* occurs in many animals, but <u>not</u> in mammals
- In mammals, the cortical reaction causes a hardening of the ***zona pellucida***
  - This is the ***Slow Block to Polyspermy***
    - Requires several minutes to complete
- The nucleus of the sperm and the egg eventually combine to form a diploid zygote and fertilization is completed

Embryonic Development Begins Cleavage

- Cleavage patterns differ between different groups of animals depending on their evolutionary relationship.
  - The ***zygote*** (one large cell) divides into several smaller cells called ***blastomeres***.
    - Each blastomeres has its own nucleus
  - The first five to seven divisions result in the ***Morula***, a simple ball of blastomeres cells.
- ***Meroblastic*** cleavage
  - In a frog embryo (and most other vertebrates), initial cleavage events are incomplete
    - the cleavage planes go through the animal pole but do not immediately extend all the way through the vegetal pole before the next cleavage event occurs.
- ***Holoblastic*** cleavage, in contrast, is the complete division of eggs having little yolk
  - As in sea urchins and mammals
- A fluid-filled cavity forms within the ball (Morula). This cavity is called the ***Blastocoel***
  - The Morula becomes a ***Blastula*** when the blastocoel is fully formed.

- A ***blastula*** is a hollow ball of cells about the same size as the original zygote
  - Further development of the Blastula differs between groups of species.

- Yolk is generally concentrated at one side of the egg
  - This side is called the ***vegetal pole***
- The opposite side of the egg is called the ***animal pole***.
    - The vegetal pole is often colored yellow in textbooks
    - The animal pole is often colored grey in textbooks

- Eventually the cleavage goes all the way through the vegetal pole, but the resulting ***blastomeres*** are larger in the vegetal pole than in the animal pole.
- Unequal cell division generates more cells in the vegetal pole than in the animal pole.
- The ***Blastocoel*** develops in the animal pole (most vertebrate animals)
  - In mammals and other animals that have relatively little yolk, there is no polarity of the cell and the ***blastocoel*** is centrally located.

Gastrulation

- After the first few cell divisions (cleavage), there is a dramatic rearrangement of cells of the blastula to form a three-layered embryo with a primitive gut.
  - This process is called ***Gastrulation***
  - We'll use the sea urchin as an example for describing Gastrulation

- Gastrulation begins at the vegetal pole in a sea urchin
  - A few cells detatch from the blastula wall and move into the ***blastocoel***
  - These cells are called ***mesenchyme*** cells
  - The remaining cells near the vegetal pole flatten and form the ***vegetal plate***

- The vegetal plate buckles inward (invaginates), forming a blind-ended tube called the ***archenteron***
  - This is the primitive gut
- The hole leading to this primitive gut is called the ***blastopore***
  - This becomes the anus in sea urchins (and other ***deuterostomes***, including humans)

- When the archenterone reaches the other side of the cell, it fuses and creates an opening that will become the animal's mouth (in ***deuterostomes***)

- In ***Protostomes*** the ***blastopore*** becomes the mouth and the second opening becomes the anus.

- **Germ Layers**
  Three germ layers (embryonic tissues) are created during ***gastrulation***
  - ***Ectoderm***
    - the cells that remain on the outside of the gastrula
  - ***Mesoderm***
    - the cells that detach and move into the blastocoel
  - ***Endoderm***
    - the cells that invaginate from the vegetal plate to become the primitive gut (archenteron)

Organogensis

- Various regions of the three embryonic germ layers develop into the rudiments of organs during the process of organogenesis.
- The development of the ***neural tube*** which forms from the ectoderm in chordates is an example
  - Certain cells within the mesoderm separate from the other mesodermal tissue and become the notochord (above the blastocoel).
  - The notochord cells release chemical signals that cause the ectoderm tissue above it to specialize into a neural plate.
  - The neural plate buckles inward as it grows and eventually rolls into a tube.
  - This tube is called the neural tube and runs from the anterior to the posterior.
  - The neural tube will become the central nervous system, including the brain and spinal cord.

Amniotes

- All vertebrates require an aquatic environment during development.
- Fish & Amphibians lay their eggs in water and do not need any special structures.
- Vertebrates that have evolved to inhabit terrestrial habitats (Reptiles and Mammals) also evolved structures that allow their embryos to remain wet.
  - Two of these structures exist today…
    - The shelled egg of reptiles (and a few mammals, monotremes)
    - The Uterus of placental mammals
  - Within the shell or uterus, the embryos of these animals are surrounded by fluid within a sac called an ***amnion***

- **Reptiles and Mammals are Amniotes**
- Within an egg, several embryonic membranes protect the embryo
  - **Amnion** – protect the embryo by holding fluid, preventing dehydration and cushions mechanical shock
  - **Chorion** – exchanges gases between the embryo and the surrounding environment
  - **Yolk Sac** – contains a stockpile of nutrients stored for the growing embryo
  - **Allantois** – functions as a disposal sac for certain metabolic wastes. Also helps exchange gases along with the chorion

- Mammals have the same structures.
  - In mammals, the ***chorion*** completely surrounds the embryo and other extraembryonic membranes and functions in gas exchange.
  - The ***amnion*** is a sac that is filled with fluid (***amniotic fluid***) which helps keep the embryo wet and protects it.
    - This fluid is the "water" that breaks in the early stages of child birth
  - Below the developing embryo is another fluid filled cavity lined with a membrane. This is the ***yolk sac***, which in most mammals, contains no yolk.
  - The ***allantois*** is incorporated into the umbilical cord and functions in nutrient and gas exchange.