BIOLOGY 205/SECTION 7 DEVELOPMENT- LILJEGREN

Lecture #1
INTRODUCTION TO DEVELOPMENTAL BIOLOGY

Ppts posted by 5 pm the day before class. Lecture notes posted after class. If you come to class you will notice that some material covered is NOT posted, consider this as *bonus material* that is fair game for exams.

1. What is the study of development?

   • The process by which a fertilized egg transforms itself into a complex organism is one of the most exciting and complex mysteries in the field of biology! How does it happen?? Each of us sitting in this room developed from a single egg!

   • Developmental Biology is the study of a PROCESS whereby a single cell divides and selectively activates expression of genes to produce a complex organism composed of many cell types.

   • Ex ovo omnia=all from the egg. 1651 William Harvey proposed that all animals originate from eggs

   • What are the types of PROCESSES required?

2. A central idea of development that we will talk about many times the rest of the semester is DIFFERENTIATION: ALL CELLS HAVE THE SAME DNA, BUT DIFFERENT CELLS EXPRESS DIFFERENT GENES. This is called DIFFERENTIATION. Since different cell types express different genes, different cell types possess different cellular machinery. Different cells specialize to do different jobs. We will learn how this happens, how cells learn to activate different sets of instructions that lead to production of different proteins.

   DIVERSITY: Earth's myriad animals & plants display an incredible diversity of body plans, and yet share many conserved developmental mechanisms, evidence of their evolution from a common ancestor. Our challenge is to understand both this diversity and this unity. Interesting differences between plant and animal development will be addressed later. Giant sequoia, general sherman tree=largest tree in the world

3. This PROCESS is studied using TOOLS, many of which you have already heard about:

   a) Cell Biology - how cells are made, move, and talk to each other

   b) Genetics - what is the role of specific proteins? study the effect of mutations on developmental processes

   c) Molecular Biology - how cells selectively activate a subset of genes that will produce a unique set of cellular traits

What does this mean? You will now take your box of biological tools and use them to understand how development occurs.
Before we discuss some developmental mechanisms, let’s REVIEW THE BASICS

1. The body is made of millions to billions of cells.
   d) Each cell has a specialized task, e.g. muscle cell, nerve cell, etc.
   e) To carry out these specialized tasks, each cell has special machinery
      i. Nerve cell has machinery for transmitting electrical and chemical signals
      ii. blood cell has machinery to transport oxygen

2. Cellular machinery is largely made up of proteins
   Proteins are long chains of amino acids. Each protein molecule has evolved to carry out a particular task. For example:
      i. hemoglobin in the blood binds to and carries oxygen
      ii. actin forms filaments that make up the cytoskeleton
      iii. ribosomal proteins help make up the ribosome, the cell's protein factory
      iv. insulin is secreted by cells of the pancreas and serves as a signal to other cells.

3. Because of their different tasks, different cells contain different proteins
   While some proteins are found in all cells (actin), others are made only in specialized cells
      i. e.g. muscles make myoglobin to store oxygen for work
      ii. lymphocytes make antibodies to neutralize foreign invaders
      iii. skin cells make cytokeratin which serves as the structural element of skin and hair

4. Proteins are made up of chains or sequences of amino acids, and these amino acids are "encoded" in the cell's DNA
   a. DNA is organized in very large segments known as chromosomes, but each chromosome is a package of thousands of genes
   b. 1 gene encodes 1 protein
   c. Thus there is a myoglobin gene, an actin gene, an insulin gene etc. Genes are the instructions to make individual cellular machines.
   d. Mutations in single genes thus result in failure to produce single proteins, and mutant cells are thus lacking a particular protein machine

5. All cells have the same DNA but different cells express different genes
   a. Different sets of cellular instructions are activated in different cells, leading to the production of different proteins
      i. hemoglobin genes are only active in red blood cells
      ii. the insulin gene only in the β-cells of the pancreas
      iii. the pepsin gene only in stomach cells

6. Development occurs at an unfamiliar scale.
   • A mouse (3 inches = 7.5 cm = 750 mm) is about 100,000 times bigger than a cell- 10-30 µm = 0.01-0.03 mm
   • A gene is 10,000 times bigger than a protein, which are generally 2-10 nm long = 0.001 µm = 0.000001 mm. A gene averages 1-10µm in length (unwound DNA), but is only about 2nm wide when packaged (it is extremely folded up to fit in cell since there are 15-30,000 genes per cell).
Another way to think of this

If a mouse were the size of Chapel Hill (10 miles)
- a cell would be about the size of a basketball (8 inches),
- a gene would be on average about an inch long.

If an average protein was the size of a Volvo (10 feet):
- a cell would be the size of Chapel Hill (10 miles)
- an average gene would be about 1.5 miles long but the strand of DNA would only be a few feet wide.

DEVELOPMENTAL MECHANISMS AND THE EVOLUTION OF MULTICELLULARITY

1. Differentiation mechanisms - Two extreme models (REALITY INVOLVES BOTH!)
   a) MOSAIC DEVELOPMENT: cells become progressively committed to particular cell fates over time: there’s no looking back! In other words, cells acquire fixed identities that they then maintain without influence from neighbors; when isolated their descendants only develop into particular parts of the body. This idea is also known as autonomous specification.

   Wilhelm Roux’s experiment in 1888 illustrates this.
   Kill two of the first four cells in a frog embryo with a hot needle, and allow the remaining cells to develop.

   WHAT HAPPENS? The remaining two cells adopt the fates they would have in an intact embryo. [same results if experiment done at the 2 cell stage]

   b) "REGULATIVE" DEVELOPMENT: cells are flexible and able to adjust to alterations in their neighbors and environment; when isolated the descendants of each cell can develop into an entire organism. This idea is also known as conditional specification.

   Hans Driesch’s experiment in 1892 illustrates this.
   Separate the first four cells in a sea urchin embryo by vigorous shaking

   WHAT HAPPENS? To his surprise, rather than finding the same results as Roux. (each cell developing into a specific part, instead each regulates its fate to make an entire embryo).

   c) Most organisms combine both sources of information and develop as a combination of mosaic and regulative processes.

   For example, C. elegans: The relationship of all the cells through development can be mapped by laser ablation (removal) of a particular cell. In most cases, the rest of the animal develops normally and only the descendants of the missing cell are gone. However, in some cases the fate of the surrounding cells was altered.

2. Another way to state the basic question is of Development is: How do cells know which genes to activate as they go through development?

   Remember, different cells of the embryo will activate different genes. There are two sources of information cells can consult to decide which developmental pathway to take. These are:

   a) Information from your mother (cell)- e.g. Gene expression patterns, or Segregation of "determinants". All cells receive information from their mothers.
      i. Informational molecules (e.g. protein or mRNA).
      ii. Inherited patterns of gene expression.
iii. Information can be passed on uniformly, or can be segregated to one of the progeny cells.
   example: in worms the cells that will form the germline (to make new organisms) get P-granules and the other cells in the worm do not get P-granules. P granules are ribonucleoprotein complexes that act as translation regulators (RNA helicases, translation initiation factors). They are segregated to the posterior end of the zygote and only enter P1 cell.

b) Information from your neighbors or environment - e.g. cell-cell interactions. The essence of multicellularity = cells have neighbors, which communicate with each other. This communication can be local, via direct cell-cell contacts, or global, via diffusible molecules. Cell-cell interactions can serve to:
   i. maintain neighbors in the status quo
   ii. incite neighbors to novel behaviors.
   iii. These differences can then be transmitted to cellular offspring.
   Example: in mammals some cells clump together in balls called blood islands, then the outside cells become blood vessel cells while the inside cells become blood cells (stem cells that generate all blood cell types)

iv. Even unicellular organisms communicate!
Unicellular organisms have to sense their environment, to find food, avoid danger, and to find like individuals for sex. They have developed complicated mechanisms both to detect environmental cues and to communicate with neighbors, similar to those used by cells within a multicellular organism.

a) Yeast sex- an example of simple cell-cell communication. Baker's yeast, Saccharomyces cerevisiae, normally lives as a single cell. Haploid cells have one of two mating types, "a" or "alpha". When two cells of opposite mating types meet, mating ensues to form a diploid.
   i. Each mating type produces a different diffusible signal (a sex hormone)
   ii. This hormone is received only by cells of the opposite mating type, because only they have the correct cell surface receptors.
   iii. In response to the signal a cell alters its behavior

b) Single-celled Slime molds get it together.
Slime molds exist as single amoeboid cells, foraging on the forest floor for their bacterial prey. However, when life gets tough, the amoebae aggregate into a tiny, multicellular slug that crawls about looking for a place to sporulate. A slug contains up to 100,000 cells! When the slug reaches a favorable site, its constituent cells differentiate, some forming a foot plate, some the stalk, and some the fruiting body and the spores. When conditions improve, the spores germinate to repeat the cycle. Aggregation occurs by chemotaxis- starving cells produce the signal cyclic AMP, which binds to cell surface receptors on other amoebae, triggering them to travel toward its source.

next lecture: MODEL ORGANISMS USED TO STUDY DEVELOPMENT