Module 6

Gastrulation and the three Germ Layers

Just to have recap of what we have covered in the past modules, we have learned so far how the key players (i.e. sperms and ova) of animal development are formed by the process of gametogenesis. The haploid male and female gametes meet either outside or inside the female's body and unite during fertilization, which is not just a single event but a series of processes. The union of the two gametes activates the ovum metabolically to proceed with the next stage of development, and that is cleavage that produces a hollow ball of enormous number of cells, called the blastula.

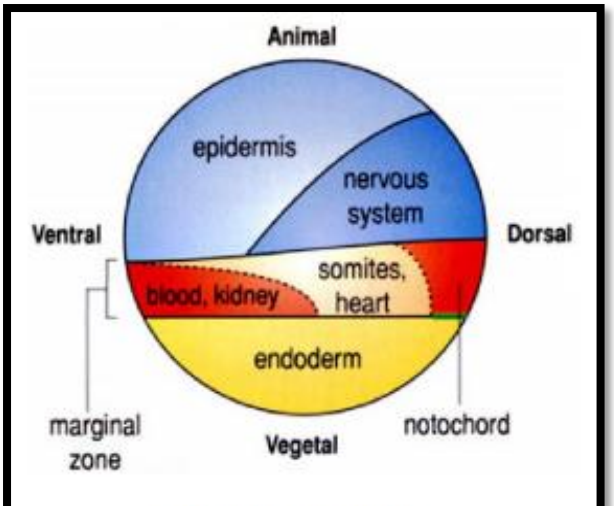
This blastula which is now consists a multitude of cells is now ready for the next stage of development, and that is the gastrula stage. This **gastrula** stage is achieved by the process of **gastrulation**. It is in the gastrula stage that the three **germ layers**, namely **ectoderm**, **endoderm** and **mesoderm** are established or positioned. And it is in these three germ layers where all the cells, tissues and organs of the future organism is derived from.

Learning Objectives: At the end of this lesson, the student should be able to:

1. Discuss how the process of gastrulation transforms the blastula into an embryo, called gastrula with three germ layers.
2. Differentiate the process of gastrulation among eggs with varying amounts of yolk.
3. Identify what organs are derived from the three germ layers and other mesenchymal cells.

Maps of the late blastula

Before we proceed to discussing gastrulation, let us go back first to the blastula stage. By the time the blastula stage ends, each region or area of the blastula is already "destined" or "fated" to become specific tissues of the developing organism. Several experiments and research have been done to establish the so-called **fate map** (Figure 1) of the blastula. Staining the different parts of the blastula makes the researcher observe which region develops into what kind of tissue. As early as in the blastula stage, the cells where the future epidermis, neural tube, blood, kidney etc. are already mapped out as can be seen in the figure shown in the next page. But are these areas where they are, their final position? The answer is NO. These cells or group of cells have to move in many ways called **morphogenetic movements** during gastrulation as we will see later.



Fate Map of Frog

Early embryologists used "vital dyes" (which would stain but not harm the cells) to follow movements of individual cells or groups of cells. The tissues to which the cells contribute would thus be labeled and visible in the adult organism. The first person to develop and use this technique to study cell fate was embryologist Walter Vogt in 1929.

http://www.macollege.in/app/webroot/uploads/department_materials/doc_102.pdf

The following text on gastrulation are lifted from Solomon, Berg & Martin (2008).

During gastrulation, the embryo begins to approximate its body plan as cells arrange themselves into three distinct **germ layers**, or embryonic tissue layers: the outermost layer, the **ectoderm;** the innermost, the **endoderm;** and the **mesoderm**, which develops between them.

Additional cell divisions take place during gastrulation, and the germ layers become established through a combination of processes, such as:

1. Many cells lose their old cell-to-cell contacts and establish new ones through cell recognition and adhesion processes involving interactions among the integrins and other plasma membrane proteins and the extracellular matrix.
2. Many cells undergo cytoskeletal changes , particularly alterations in the distribution of actin microfilaments.
3. Changes in the internal architecture of the cells allow them to change shape and/or undergo specific, directional amoeboid movements.

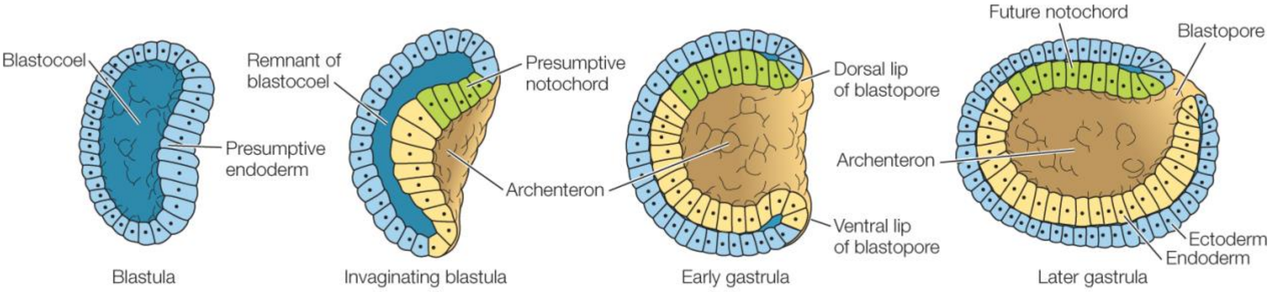
And from these movements, the locations, or positions of the cells in the late blastula stage is changed by taking up new positions in the interior of the embryo.

Each of the germ layers develops into specific parts of the embryo as we will learn later.

The varying amounts of yolk in the fertilized egg affects the gastrulation process.

Like in the cleavage stage, the amount of yolk present in the egg and its distribution also affects how the cells will move during gastrulation. For embryos with little amount of yolk such as the sea urchins and amphioxus, movement of the cells are not restricted by the yolk. Gastrulation begins when a group of cells at the vegetal pole undergoes a series of changes in shape that cause that part of the blastula wall to first flatten and then bend inward (**invaginate**). The invaginated wall eventually meets the opposite wall, obliterating the blastocoel in the process. A double-walled, cup-shaped embryo is formed.

The new cavity formed as the cells from the outer part of the blastula roll inward (**involution)** is the **archenteron** and its opening is the **blastopore (** which becomes the site of the future anus). *So, what is the group of these animals whose blastopore in the early development becomes the anus?*



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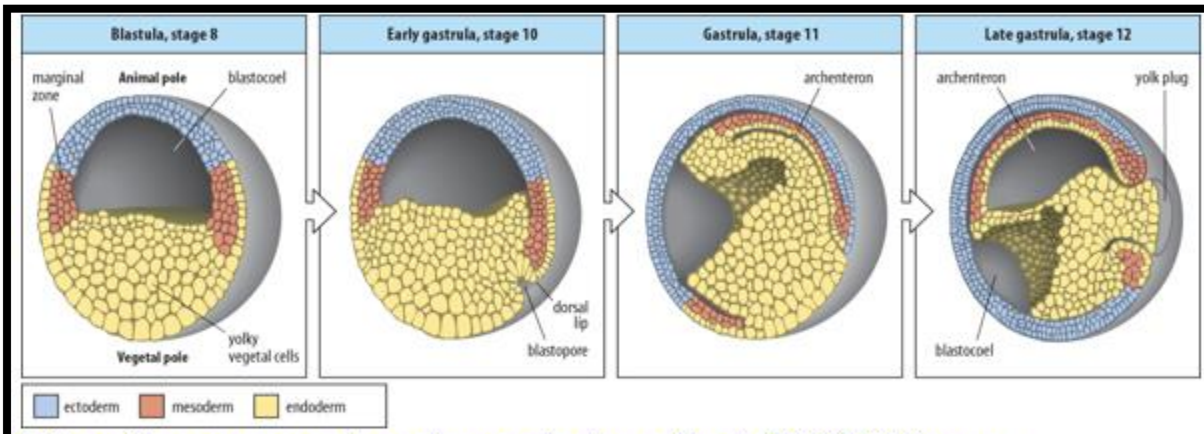
This kind of movement in echinoderms and amphioxus is not possible for amphibians because their eggs have moderately large amount of yolk. And if you can recall in the discussion of cleavage, the rate of cell division is slowed in the cells of the vegetal pole since the yolk is distributed in this region. The same way in the cells of the blastula, any inward movement of the blastula cells is also impeded by the yolk in the vegetal pole.

What happens in amphibian gastrulation? The cells from the animal pole move down the embryo surface (**epiboly**) until they reach the region of the gray crescent and move into the interior by **invagination.** This movement is made possible by the change in shape of cells , first by being flask – or bottleshaped and then sinking into the interior as they lose their remaining connections with the other cells on the surface. The spot where the cells turned inward is refereed to as the **dorsal lip of the blastopore**. As the movement inside (involution) continues, the blasto[ore becomes ring-shaped as cells lateral, and then ventral, to its dorsal lip become involved in similar movements. The yolk-filled cells fill the space enclosed by the lips of the blastopore, forming the **yolk plug.** As the new cavity archenteron enalrges as the cells roll inside, the original blastocoel is pushed until it disappears. At the end of the gastrulation process, an embryo called gastrula has the three germ layers positioned in their respective places.The colored blue cells is the **ectoderm** layer.

The figures below show the process of gastrulation in amphibian embryos and the link below it is a very short video on the gastrulation process as seen in the frog *Xenopus*.



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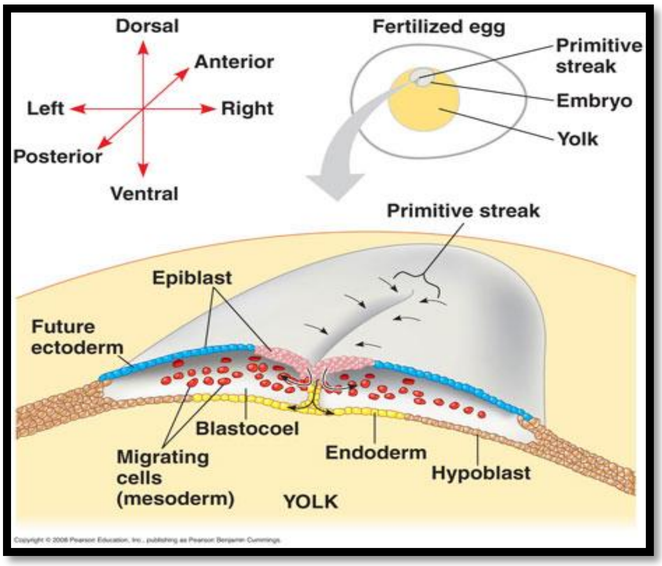
For the avian gastrulation, it is somewhat similar to the amphibian but with some differences. As you all know, the avian egg has a very massive amount of yolk that only the blastodisc is involved in the gastrulation process. Recall also,that at the time there is a blastodisc, the upper layer **epiblast**, separates from the lower layer **hypoblast**. These layers were formed by the movement called **delamination.**

The cells of the epiblast migrate toward the midline to form a thickened region known as the **primitive streak**, which elongates and narrows as it develops. At its center is a narrow furrow, the **primitive groove**. This groove is the functional equivalent of the blastopore of the echinoderm, amphioxus and amphibian embryos. The cells move inward called **ingression** at the primitive groove and remodels the original hypoblast into a final layer of hypoblast. The movement then results to loose layer mesenchymal cells between the the surface epiblast and the remodeled hypoblast. The bird embryo, however, contains no cavity homologous to the archenteron.

At the end of the gastrulation process in avian embryos, three germ layers are formed: the remaining epiblast becomes the **ectoderm**, those displacing the original hypoblsat become **endoderm**, and those in the middle, mesenchymal layer becoem **mesoderm.**



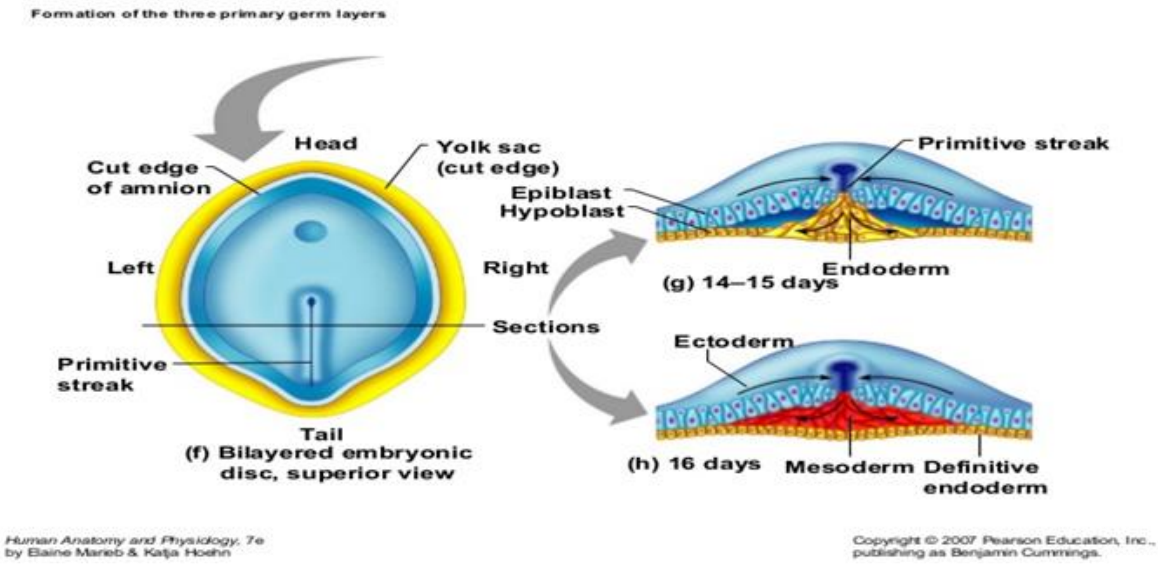
http://fig.cox.miami.edu/~cmallery/150/devel/animal_development.htm

Note the direction of the black arrows in the primitive streak and "underneath" it. These ingression movements result to the three germ layers that will give rise to the different tissues and organs of the bird.

In human embryos, the pattern of gastrulation follows the pattern seen in birds even if the mammalian egg has no yolk at all. Materials on the details of human gastrulation are scarce, therefore, extrapolation from avian and mammalian gastrulation can be reasonable working models to generalize on human gastrulation.

It is at the the start of the third week of pregnancy that gastrulation starts to happen in human embryos when implantation in the uterine wall is completed. At this time also, the four extraembryonic membranes (i.e., amnion, allantois, chorion and yolk sac) are also formed outside the embryo. These membranes will aid the embryo in mediating gas, nutrient and nitrogenous wastes exchange between the embryo and the maternal tissues.

The three germ layers originate in the epiblast. Like in birds, gastrulation is evidenced by the formation of the primitive streak and the primitive furrow where cells of the epiblast ingress inward and form the the three germ layers by the end of the gastrulation process.



the organs will go wrong and there will be no proper functioning of these organs that can affect the life of the animal in the adult stage. **As the developmental**

biologist Lewis Wolpert said about gastrulation, "It is not birth, marriage, or death, but gastrulation, which is truly the most important time of your life."

BOOK REFERENCES:

1. Carlson, B.M. 1994. Human Embryology and Developmental Biology. Mosby.
2. Carlson, B.M. 1996. Patten's Foundation of Embryology. 6th ed. McGraw Hill Book Company.
3. Solomon EP, Berg LR and Martin DW. 2008. Biology. 8th ed. Thomson Brooks/Cole.
4. Wilt, F & S. Hake. 2004. Principles of Developmental Biology. W.W. Norton & Company.

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