COMPARATIVE EMBRYOLOGY AND THE STORY OF THE FLOOD

Linda Simonetti Odhner[†]

CHAPTER 1. OVERVIEW: THE VALUE OF COMPARISON

> If teleosts [bony fish] were aided by something like human intellect and could study earth history with their own sense of values they would have no difficulty proving that their own group displays the most highly specialized and most intricate anatomy achieved by any living things, and that they are the pinnacle toward which all other efforts were directed. (Ballard 1964, 24)

Comparative embryology is the study of the development of different species of animals: their differences, their similarities, the ways they converge and diverge. Varying paths of development shed light on each other and on the underlying commonality of biological forces. Reflecting from New Church doctrine on these diverse progressions may deepen our understanding of our own spiritual states.

We know from the Writings that human physical development is a perfect image of human regeneration (AC 3570.4, 8043, 9042, TCR 583, 584, D. Wis. IV). By highlighting the uniqueness of human development and giving it a context, comparative embryology can enhance our grasp of this correspondence. When we look at an event in development and ask what its spiritual significance might be, it helps to know something of its biological significance—how it fits in with prior and subsequent events, its immediate causes and results, its function in the process of which it is a part. Correspondence does not depend so much on physical form as on use (AC 4223). Comparing the development of different species can clarify the biological significance of developmental events, and thus lead to a clearer understanding of their spiritual significance. This will become more evident as the details come to light.

[†] I wish to acknowledge, with gratitude, the research grant that the Swedenborg Scientific Association provided for this study. Address for reprints: 439 Avenue A, Horsham, PA 19044.

This series will focus primarily on the vertebrates, with a few excursions into the rest of the chordates and even the echinoderms (the earliest cell divisions in the sea urchin are remarkably similar to mammalian cleavage). Fig. 1.1 shows some different ways of dividing up the vertebrates.

In textbooks of comparative embryology, the development of amphibians—particularly frogs and salamanders—is used as a model for vertebrate development in general. There are several reasons for this. First, we know a lot about amphibian development because it is so accessible and so sporting under experimental assaults. Amphibian embryos are tough; experimenters can meddle with them in ways that would kill other species. Second, they have traits adapting them to both aquatic and terrestrial life. They are the only anamniote tetrapods; they straddle the two realms of land and water. They develop limbs and lungs as well as gills. Third, as a class they are relatively primitive and unspecialized, and so, one would think, have more in common with other vertebrates. We can learn things directly about amphibian development which can illuminate our speculations about other classes and our own species in particular.

This expedition through comparative embryology promises to be a long one—I anticipate about sixteen essays—so I would like to mention a few things which will pull everything together in a meaningful way, and give some advance notice of where we are heading.

First of all, while we look at many different gestating animals, the main focus is human development and its correspondence with human regeneration. While there is no purely biological reason to hold up human development as a standard for comparison with all other species, it can't be surpassed as a model of our progress toward the fullest humanity possible. I include my chart "Many Beginnings: Milestones in Early Human Development" (fig. 1.2) as a guide through the following nine essays—there is at least one essay for each milestone. After the tenth essay the focus shifts from the embryo as a whole to the development of different organs and systems within it. The tenth essay, "The Pharyngula: Converging Form," outlines a concept from one of my textbooks (Ballard 1964), which helps to unify some puzzling facts in comparative embryology: the idea that the forms of vertebrates in their early development

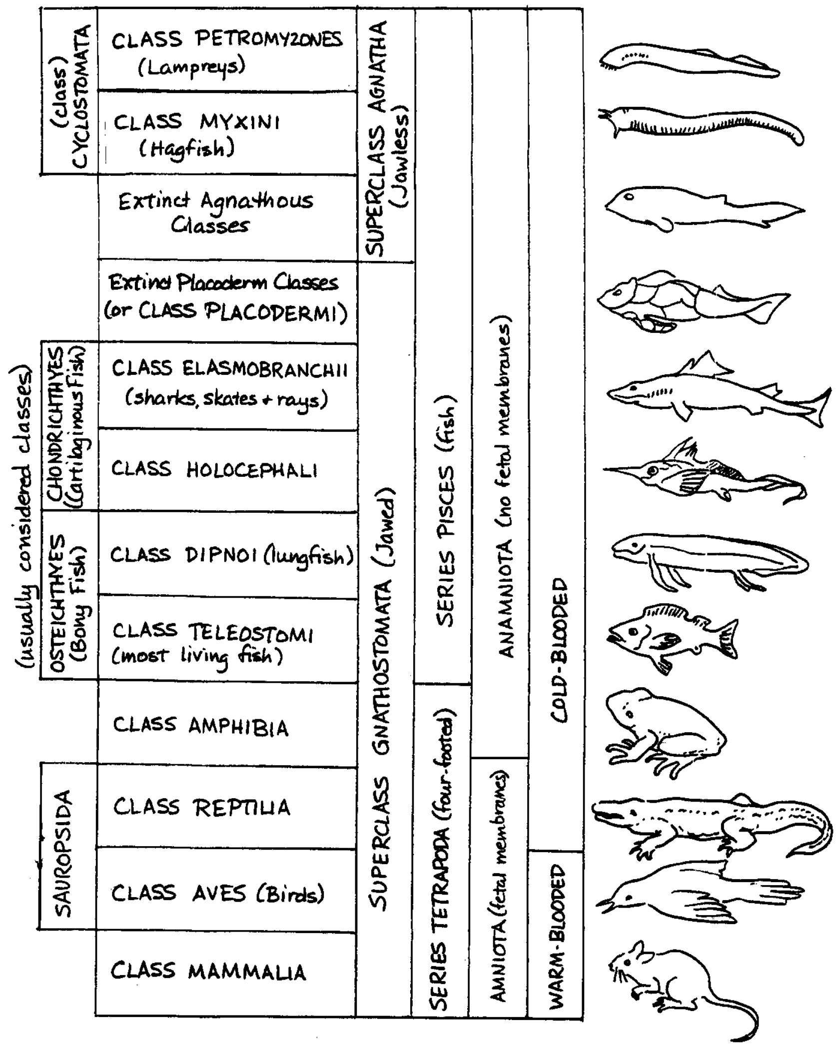


Figure 1.1: **Ways of Dividing the Vertebrates**

The full column on the left divides the vertebrates into classes; the columns on the right show different ways of dividing the whole subphylum into two categories. The partial column on the far left shows alternative (and more common) class divisions.

The scheme here follows the system Ballard (1964, pp. 11-32), a "splitter," rather than a "lumper," uses in his book. He highlights the diversity among the fishes as compared with that of the tetrapod classes, emphasizing that the Agnatha differ more from the Gnathostomes than any of the latter differ among themselves. Thus the Gnathostome/Agnatha division is the most fundamental of the ones shown on the right, and the split which probably occurred earliest in evolution.

The division into Series Tetrapoda and Series Pisces represents the contrast between land-dwelling and water-dwelling vertebrates; tetrapods are defined as having lungs or legs, usually both. The Amniote/Anamniote division turns on the mode of reproduction. Hard-shelled-egg-layers and viviparous mammals all have three fetal membranes during development: amnion, chorion and yolk sac. Many fish have yolk sacs, but never the other two membranes.

MANY BEGINNINGS: MILESTONES IN EARLY HUMAN DEVELOPMENT

SUMMARY OF DEVELOPMENTAL MILESTONES:

Milestone 0: SPERM ENTERS OOCYTE (possible "moment of conception")

- Sperm and oocyte membranes fuse
- Oocyte repels other sperm
- Oocyte nucleus undergoes FINAL MEIOTIC DIVISION
  - Second polar body ejected
  - Remaining nucleus is FEMALE PRONUCLEUS
- Sperm head swells into MALE PRONUCLEUS
- Male and female pronuclei fuse into ZYGOTE NUCLEUS
- Cell is now a ZYGOTE

stage:
FERTILIZATION
(24 hours)

Milestone 1: FIRST MITOTIC METAPHASE (My "moment of conception")

- First cell division: 2-cell stage
- Cell divisions continue as
- MORULA travels down Fallopian tube
- Cavity forms in morula as
- INNER CELL MASS is distinguished from outer layer
- BLASTOCYST enters uterus
- Zona pellucida disintegrates,
  - exposing sticky blastocyst surface

stage:
CLEAVAGE
(6 days)

Milestone 2: BLASTOCYST LANDS ON UTERINE LINING ("start of pregnancy")

- Blastocyst burrows into uterine lining
- Trophoblast invades lining,
  - begins to form PLACENTA
- Amniotic cavity forms as
  - inner cell mass becomes EMBRYONIC DISK
- ENDODERM differentiates in embryonic disk
- Extra-embryonic MESODERM and coelom form,
  - giving rise to connecting stalk
- Prechordal plate arises in endoderm

stage:
IMPLANTATION
(days 7-13)

Milestone 3: FORMATION OF PRIMITIVE STREAK (Latest point at which development can be said to begin)

- Orientation and body axis established
- ECTODERM converges on primitive streak,
  - immigrates through it,
  - forms MESODERM layer
- NOTOCHORD forms in the wake of
  - regressing primitive streak
- Cardiogenic material converges
  - at anterior end of embryo

stage:
GASTRULATION
(days 14-20)

Milestone 4: EMBRYO WITH 3 GERM LAYERS

- Notochord induces neural plate to form,
  - then neural groove, neural tube
- First mesodermal somites form
- Embryo flexes, forming gut tube and ventral wall,
  - as it rotates to face the connecting stalk,
  - which, with yolk sac, forms UMBILICAL CORD
- Heart settles below head, begins to beat
- Organ rudiments appear

stage:
NEURULATION
(days 20-28)

Milestone 5: EMBRYO IN THE ROUND (followed by pharyngula stage) converge toward a common, basic anatomy which serves as a starting point for the divergence and specialization which occur later.

In distinguishing human development from that of other species, I refer to processes that are unique to amniotes, to mammals, and to the higher primates. Not surprisingly, there are few developmental events which occur absolutely nowhere but in humans. It is more a matter of our nearer relatives sharing more traits with us, in gestation as well as in adult form.

Doctrinal unification for this project came from a somewhat unexpected source. I have tried for years, with little success, to relate embryonic development to the creation story. It seemed a logical parallel to make, yet it never led anywhere particular. The Waldorf education people have tried the same thing, without the benefit of the internal sense, and I am not satisfied with their results (Cusick 1984, 5-6). What really opens up some interesting parallels, I find, is the Noah story, particularly as it illustrates the role of temptation in regeneration. An exposition of the flood and its aftermath brings out the progress of temptation and the states which follow (AC 599-937). My study of this led to the idea, elaborated in the fifth essay of this series, that gastrulation corresponds to temptation. Some biologists consider gastrulation the true beginning of development; the Writings characterize temptation as "the true beginning of regeneration" (AC 848). I don't want to give the story away, but most of the correlations in this series, both before and after gastrulation/temptation, arose in the light of this analogy.

I wonder why I have had more success in matching developmental events with the story of the Flood than with the Creation story. It may have to do with the fact that the first chapter of Genesis deals with the regeneration of the celestial person, and the sixth and seventh chapters with the regeneration of the spiritual person; and we are spiritual rather than celestial people since the Fall. Who can say in what ways our development has changed?

Most of these essays are divided into two parts, the first dealing with the necessary scientific background and the second with doctrinal reflections on this information. A few of them swing back and forth between these two modes more than once, but I have tried to make the transitions as clear as possible.

The present work dwells more on matching spiritual and natural sequences than my previous efforts along these lines, which dealt mostly with specific structures and spiritual entities. Related to this is a greater emphasis on the very earliest stages of development—those events which come before differentiation and pattern formation and make them possible. This leads to interpretations which differ substantially from earlier ones I have made. I find this acceptable and even inevitable in the light of the following number from the Writings:

> …[T]here is an innumerable variety of all things, and there never exists one thing the same as another, and this variety is more innumerable in the truths and goods of the spiritual world, because one thing in the natural world corresponds to thousands and thousands in the spiritual world, and therefore the more interior they are, the more innumerable they are. (AC 6232.3)

CHAPTER 2. FERTILIZATION: A GROWING UNION

> So Noah, with his wife, his sons, and his sons' wives, went into the ark because of the waters of the flood. (Gen. 7:7)

> It is now clear that embryonic development does not begin with fertilization—it begins in the developing egg in the ovary. (Kirk 1975, 417)

> The term egg is best reserved for a nutritive object frequently seen on the breakfast table. (O'Rahilly, quoted in Moore 1977)

Embryology textbooks do not often speak of "the moment of conception," but rather refer to the process of fertilization, which involves a number of events and takes several hours. The changes involved have such far-reaching consequences that those who study them find it necessary to call everything by new names in an effort at clarification. It is rather difficult to follow O'Rahilly's injunction and avoid the term "egg" when discussing such matters, particularly since the term ovum is now subject to the same sort of ambiguity and hence the same lack of usefulness in describing things precisely.

The female germ cell, or ovum, often called egg, comes to this important occasion with weeks of preparation behind it. As it matures in the ovary, the ovum stores up food, information, and organization. The eggs of many species stockpile yolk as if their lives depended on it (which they do), some in a single liquid mass, like birds, and some in granules or platelets distributed through the cytoplasm, like amphibians. These differences will create variations in the course of early development.

Those eggs which contain little or no yolk may produce particularly large quantities of RNA, especially in the formation of ribosomes. The DNA of maturing eggs may take the form of "lampbrush chromosomes," with many loops pulled out for easy transcription. "By replicating the ribosomal genes so extensively, the single oocyte nucleus synthesizes in a matter of weeks a quantity of ribosomes that would otherwise take many years to produce" (Kirk 1975, 419). Ribosomes are necessary for translating genes into strings of amino acids which become proteins. The amphibian oocyte, while still nourished by the ovary, makes enough ribosomes to last until hatching, thus speeding up the vulnerable embryonic stage of development (ibid).

The sperm, in contrast to the acquisitive ovum, travels light. It carries the genetic material, fuel for the trip, and a system of locomotion, all in a streamlined shape which features a long, active tail. The Writings teach us that the human sperm carry something more, something that weighs nothing and occupies no space—a new human soul. Perhaps animal sperm carry something analagous, though lower in degree; but the commonness of parthenogenesis—the development of unfertilized eggs—complicates the picture.

The occurrence of parthenogenesis is one of the things that makes clear the independence of the two main components of fertilization, namely activation and regulation. Activation is the triggering of development in the egg, usually accomplished by the sperm, but achieved in amphibian and sea urchin eggs in the laboratory in all kinds of ridiculously simple ways: pricking with needles, changing the temperature or salt content or other chemical makeup of the surrounding medium, introducing some foreign matter into the eggs (Balinsky 1965, 124). Regulation, on the other hand, is the integration of the two sets of chromosomes into one gene-complex, and the restoration of normal mitotic function (Bodemer 1968, 54). When it occurs it helps to determine the course of development, but development can occur without it in some cases.

In fact, sperm entry can occur without regulation in those species where polyspermy is common. The first sperm that enters participates in development, while those that follow play no part in it. Most species have a mechanism which prevents additional sperm from entering after the first one (ibid., 63).

The entry of the sperm into the ovum is the first event of fertilization. In most cases the second meiotic division has not yet occurred in the female gamete, so it is technically an oocyte. In mammals, including man, it is a secondary oocyte, for the first division is complete and the first polar body has been ejected. The maturity of the egg cell at the time of fertilization differs from species to species, some being fertilized before the first division, some between the first and second, and some after the second (ibid., 64). The sperm of most species leave their tails behind when they enter the ovum, but mammal sperm bring their tails in too (ibid., 61). (See fig. 2.1 for a description of the development of the oocyte by meiosis, and fig. 2.2 for a summary of the main events of fertilization).

* * *

The formation of the first mitotic spindle in the zygote nucleus is considered to be the end of fertilization and the beginning of development. If there is any "moment of conception" this event is my choice for that honor. Since the process of human gestation has a correspondence with the spiritual life of the person after birth, I propose a parallel between birth and the first mitotic metaphase. In that case the spiritual events of gestation find an image in the physical events of fertilization. Both processes involve a growing union: in gestation, between the soul and body, and in fertilization, between sperm and ovum.

The latter union occurs in several steps: first the fusion of cell membranes, next the mingling of cytoplasm, then the joining of nuclei, and finally the combining of chromosomes in a new gene-complex. Both the male and female pronuclei travel from the surface to the center of the

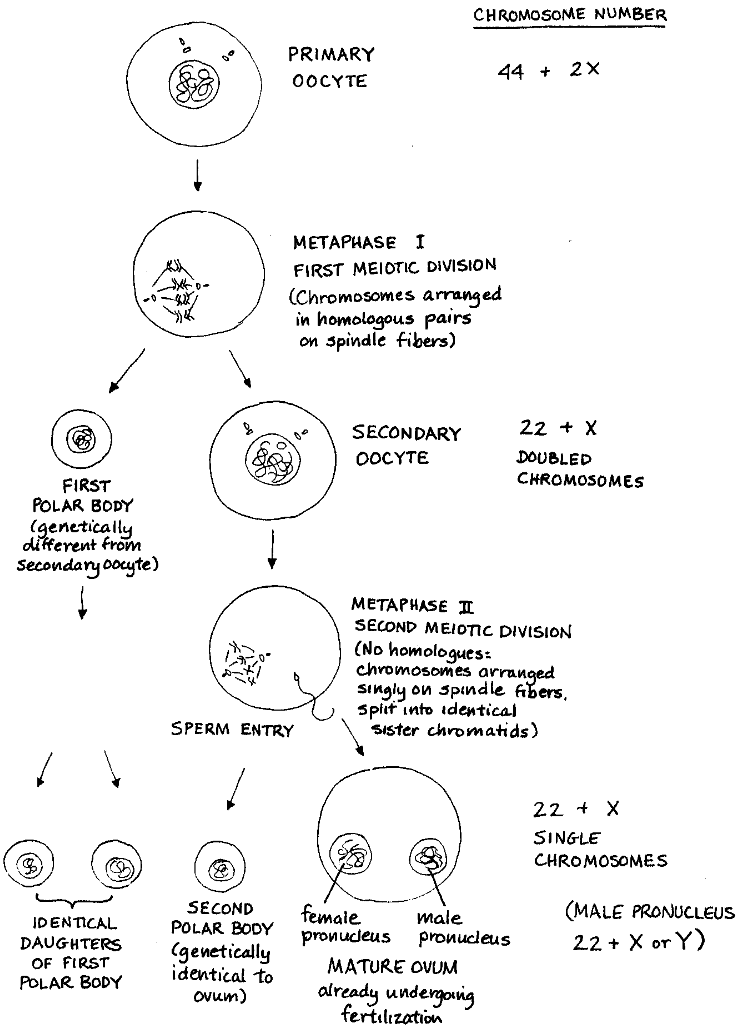


Figure 2.1: Development of the Human Oocyte

Germ cells develop from somatic cells through the process of meiosis, or reduction division, in which the number of chromosomes is halved. Two cell divisions are required for the completion of meiosis. The primordial germ cell in the female is the primary oocyte, which contains the full number of chromosomes (46) typical of somatic cells. The first meiotic division distributes one of each homologous pair of chromosomes to each daughter cell. This division begins in fetal life, is arrested at metaphase for many years, and resumes only a few weeks before ovulation occurs, in conjunction with the maturation of the follicle. It gives rise to two daughter cells, the secondary oocyte, containing most of the cytoplasm, and a small polar body. Each has 23 chromosomes, but in double form. The second and final meiotic division, which divides each of these chromosomes into its component chromatids, is not completed in the human until fertilization is under way. The second polar body is then released.

Sperm development is genetically the same, but each primary spermatocyte produces four mature sperm cells (Hamilton 1964, fig. 117; Moore 1977, fig. 2-2).

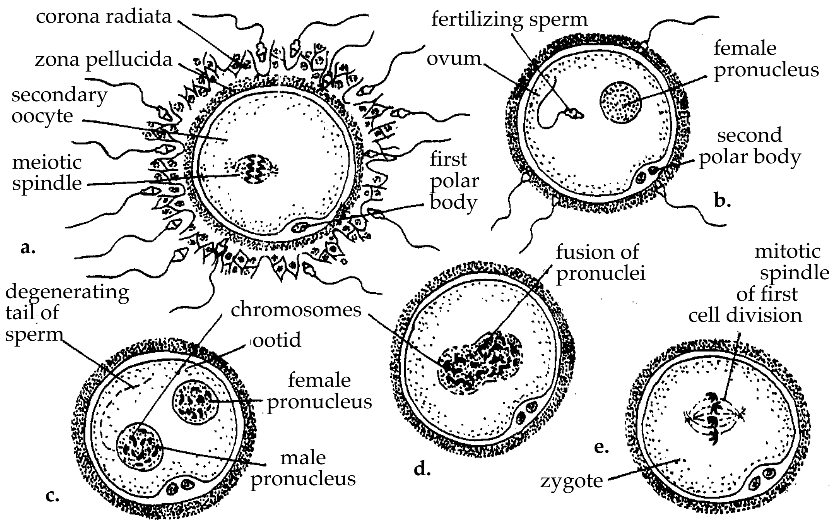


Figure 2.2: Successive unions in human fertilization

In (a), the secondary oocyte is still undergoing its final meiotic division, which is not complete until after the sperm has entered (b), and the second polar body is ejected. In (c), the sperm sheds its tail and its head enlarges to form the male pronucleus, while the female pronucleus arises from the second meiotic division of the oocyte. In (d), the pronuclei are fusing to form the nucleus of the zygote (e), in which the chromosomes double and are aligned on a mitotic spindle in preparation for the first mitotic division (Redrawn from Moore 1977, fig. 2-12).

ovum, where they join. When the male and female chromosomes first meet, each one finds its homologue and pairs off with it before they all line up in single file for the first mitosis. This pairing will not occur again (except for the union of their functions in development) until the primordial germ cells begin preparing for the meiotic divisions of the next generation (Ballard 1964, 95).

The union of the soul and body during prenatal life has its own turning points, though it too is essentially a continuum. The Writings don't give us many details about the process, though they make general statements, like "Love or the will strives unceasingly toward the human form and all things of that form" (DLW 400). However, something of the progress of the union of soul and body can be seen in the physical changes in the embryo.

The formation and functioning of each organ indicates the possibility of a fuller reception of, and thus a closer conjunction with, the inflowing soul which forms the body. The formation of the heart, beginning in the third week of development, surely channels the influx of the Lord's love into that embryonic receptacle of love which is not yet the will (see D. Wis. II.v). The formation of the brain and nervous system, which begins even earlier, solidifies the connection between soul and body which makes all influx possible. *Divine Love and Wisdom* 400 indicates a duality in the functions of heart and brain in human gestation:

> …[A]ll things of the body are formed in the womb, and they are formed by means of fibers from the brains and blood vessels from the heart, and…out of these two the tissues of all organs and viscera are made; from which it is evident that all things of man have their existence from the life of the will, which is love, from their first principles, out of the brains, through the fibers; and all things of his body out of the heart through the arteries and veins.

Is this the duality of love and wisdom or the duality of soul and body? Is it both? The duality of sperm and ovum reflects the same ambiguity.

The integration of different systems in the embryo, for example innervation of muscles so the brain can direct their actions, lays the foundation for the future union of the soul and body in the performance of uses. In a similar way the integration of the genetic materials in the zygote nucleus foreshadows their union in orchestrating embryonic development.

By the time of birth the soul is "wearing" the body much more snugly and intimately, I believe, than during the first cell divisions. Thousands of connections have been made between love's effort toward the human form and the body's form and function. The groundwork has been laid; the stage is set for the emergence of a new individual. Is this not reflected in the growing union of sperm and ovum in fertilization?

> …[T]the soul of man commences in the ovum of the mother, and is afterwards perfected in the womb and is there encompassed by a tender body, and this of such a nature that through it the soul may be able to act in a manner suited to the world into which it is born. (AC 3570.4)

CHAPTER 3. CLEAVAGE: THE FIRST SEPARATIONS

> Of clean beasts, of beasts that are unclean, of birds, and of everything that creeps on the earth, two by two they went into the ark to Noah, male and female, as God had commanded Noah. (Genesis 7:8, 9)

> If the egg has a cytoplasmic / nuclear volume ratio 10,000 times the normal ratio, the nucleus could not be expected to direct its metabolic activities very well. It is not surprising, then, to find that the metabolic activities during cleavage are not under the control of the chromosomes in the zygote. (Kirk 1975, 407)

Even more than fertilization, the cleavage stage reflects the differences in the nature of the egg from species to species, most obviously differences in the kind, amount, and distribution of yolk. The term cleavage refers to the first cell divisions after fertilization, which have several important functions. One is to bring the ratio of nuclear to cytoplasmic material up to a normal value. During cleavage genetic material is manufactured at the expense of stored food in the ovular cytoplasm. A related yet separate development is the carving up of the cytroplasm into smaller chunks, and this is where the yolk makes the biggest difference (see fig. 3.1).

The difference between determinate and indeterminate cleavage described in figure 3.1 has to do with the degree to which different parts of the uncleaved egg (zygote) are already committed to forming specific parts of the embryo. In many kinds of eggs, such as those of the mollusks, different kinds of cytoplasm can be distinguished by variation in pigment, and when certain parts of the cytoplasm are removed, the resulting embryos are abnormal, lacking predictable structures. The term mosaic describes this kind of egg. Other eggs, in contrast, are highly regulative, able to compensate for missing cytoplasm and still produce whole, normal embryos. Identical twinning in humans can result from the separation of the first two blastomeres from one another; even the first four blastomeres can sometimes give rise to four complete individuals.

In the past a strong distinction was perceived between so-called mosaic and regulative eggs, but more evidence has shown a gradation between the two. As Bodemer (1968) puts it:

TYPE OF CLEAVAGE	TYPE OF EGG	TYPE OF ANIMAL
TOTAL SUBEQUAL Blastomeres similar in size	ISOLECITHAL + OLIGOLECITHAL Little yolk, evenly distributed	many invertebrates tunicates Amphioxus marsupial + placental mammals
TOTAL UNEQUAL Blastomeres differ considerably in size	Some yolk, unevenly distributed	lampreys lungfish amphibia bats
INTERMEDIATE Blastomeres differ greatly in size; uncleaved vegetal pole forms syncytium	TELOLECITHAL much yolk, packed into one end	sturgeon, other ganoid fish
MEROBLASTIC (PARTIAL) Discoidal cleavage of cytoplasmic cap only; yolk uncleaved	Yolk in single large mass, surrounded by membrane; cytoplasmic cap at animal pole	scorpions cephalopod mollusks hagfish elasmobranchs teleosts reptiles + birds monotremes
SUPERFICIAL Nuclei travel to surface, form syncytium around yolk	CENTROLECITHAL Yolk in center, most of cytoplasm at surface	insects many other arthropods

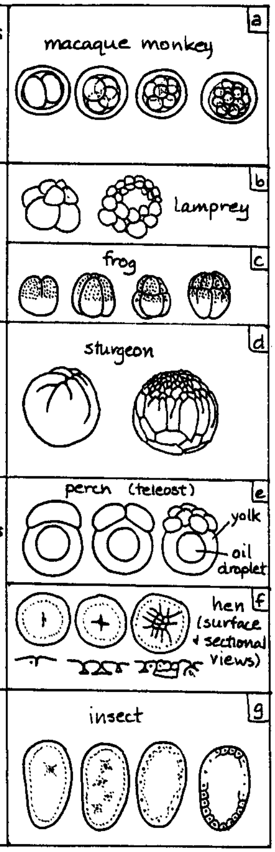


Figure 3.1: Different forms of cleavage

A table based on information from Ballard (1964), pp. 100-102. The first three types of cleavage shown—total subequal, total unequal, and intermediate—are different points on a continuum of smoothly intergrading cleavage forms, while meroblastic and superficial cleavage are distinct categories.

Another way of classifying cleavage is into determinate and indeterminate types. An intial cleavage which is indeterminate gives rise to two blastomeres, each of which has the potential to form a whole, normal embryo. A determinate cleavage produces blastomeres destined to become predetermined parts of the embryo. The degree of homogeneity in the egg cytoplasm affects this trait (Keeton 1972, pp. 559-560). The determinate/indeterminate division also reflects a continuum of conditions; all embryonic cells eventually lose their flexibility and commit themselves to specific fates, but this happens sooner in some species and later in others.

> The difference appears to be a temporal one…[T]he mosaic egg loses its flexible organization at an earlier stage of development than does the regulative egg. The prime difference…lies in the period in development during which the responsivity of the egg to environmental influences is restricted and the regions of the egg are determined to differentiate along certain lines. (p. 46)

I believe a rough correlation can be made between the degree to which an egg is regulative (flexible in its developmental response to the environment) at the time of fertilization, and the range of its possible behavioral responses after birth or hatching. The Protostomia (see fig. 3.1 above) tend to have mosaic eggs and programmed behavioral responses; the Deuterostomia, particularly the vertebrates, tend to have regulative eggs and wide repertoires of behavior. Humans have highly regulative eggs, and I suggest a possible correspondence between this labile organization in the egg and our freedom of choice, which depends on having a number of possible ways of responding to given situations.

Turning to the nature of the cell divisions themselves, it is interesting to learn that the cleavage furrows in the cytoplasm do not always occur in response to nuclear divisions already in progress. The independence of cytoplasmic from nuclear division is demonstrated by the fact that activated eggs can cleave with no nuclei at all. This may strain credibility (whoever heard of eukaryotic cell division without nuclei?), but some amphibian eggs whose nuclei have been removed have been known not only to cleave, but also to form fairly normal blastulae (Bodemer 1968, 70, 90). These enucleate blastulae cannot develop any further, however, and who can blame them? Certainly the nucleus is necessary for development to proceed. Yet it is interesting to note how independent of the nucleus cleavage turns out to be. The genetic material which has already left the nucleus at the time of fertilization is able to orchestrate the events of the cleavage stage. Experimental evidence from interspecific breeding bears this out. When the ovum of one species of amphibian is fertilized by a different species of sperm, the rate of cleavage always conforms to the maternal norm. The paternal genes make their influence known only at a later stage (ibid).

Another instance in which nuclear and cytoplasmic division don't always go together occurs in bird cleavage, where the boundary between cytoplasm and yolk consists of a syncytium—an undivided mass of cytoplasm containing many nuclei. Still another variation of cleavage occurs in copepod mollusks, where the male and female pronuclei (nuclei of the sperm and ovum) do not fuse until after the first several cleavages, simply dividing side by side within each cell (Balinsky, 124). In these cases development begins before fertilization is complete—or to put it another way, activation occurs before regulation (see previous essay).

The carving up of the zygote during cleavage does more than simply cut it into servings like a birthday cake. In addition to initiating the cellular organization that characterizes every metazoan body, it also stabilizes the arrangement of the cytoplasm, which is still essentially ovular—that is, it still derives from the organization of the egg before fertilization. This new stability makes possible the juxtaposition of different cell types, and all the fascinating processes triggered thereby, later on in development. Cleavage does not substantially change, but rather solidifies, the ovular organization of the cytoplasm.

* * *

If the beginning of the first cell division in development signifies birth (see previous essay) it follows that the cleavage stage should represent infancy (following Swedenborg's usage, I use infancy to denote the first several years of life). The Writings say, "With everybody countless genera and…species exist of intellectual concepts and desires of the will which are quite distinct and separate from one another" (AC 675). This is represented in the Noah story by all the different animals entering the Ark. The whole animal kingdom is representative of the human form. The cell divisions of the cleavage stage might symbolize the earliest distinctions among those "countless genera and species." Much of the young child's consciousness is occupied in sorting out and making sense of impressions and experiences. A little later on in *Arcana Coelestia* we find infancy described as a state progressing from general to more particular ideas (AC 848.3 quoted later). What occurs during this time is a gradual confirmation and stabilization of the personality as a whole and of individual affections and thoughts.

The increase in nuclear material suggests the storing of remnants—channels through which the Lord's blessings can flow in. The dichotomy of nucleus and cytoplasm reflects the distinction between the internal and external man. The nucleus causes and directs the activities of the cytoplasm. The fact that the cleavage stage is directed by genetic material stored in the egg before fertilization suggests that the young child does not yet direct his or her own life; much of this direction comes from the parents, and during earliest infancy from the mother.

At this stage in the human, the clump of cells is still free-floating, not yet attached to the uterus. It runs on its own limited reserves of food and a "uterine milk" secreted by the lining of the maternal womb. In a sense it has not yet come down to earth, and this might suggest the infant's association with celestial angels (AC 5342.2).

Another important event in the cleavage stage is the formation of a cavity within the clump of cells. The cavity is the blastocoel, and the surrounding cells now form the blastula, or in the case of mammals, the blastocyst. Unlike the single-layered blastulae of anamniotes, the outer layer of the mammal blastocyst does not form any part of the future embryo, but only life-support structures. The embryo will arise from an inner cell mass at one end of the blastocoel. Birds and reptiles never form a sphere of cleavage cells, but instead a blastodisc resting on the yolk mass. The distinction between the inner cell mass and the outer cells of the blastocyst resembles the child's distinguishing himself from his surroundings and realizing his separateness from the rest of the world. Animals, by their nature, don't do this to the same extent that we do.

The following passage from *Arcana Coelestia* relates not only to the cleavage stage but also to development as a whole.

> Regeneration is exactly like when a person is born as an infant. At this point he is living in the greatest obscurity, knowing virtually nothing. This being so, general ideas of things flow in first, which gradually become more definite as specific ideas are introduced into the general, and further still as yet more detailed ideas are introduced into the specific. Detailed ideas light up the general so

> that he knows not merely of their existence but also the nature of them. A similar process takes place with everyone emerging from spiritual temptation… (AC 848.3)

CHAPTER 4. IMPLANTATION: NOURISHED BY THE LORD

> And you shall take for yourself of all food that is eaten, and you shall gather it to yourself; and it shall be food for you and for them. (Genesis 6:21)

> Which third of the frog is homologous with the man? (Ballard 1964, 44)

Looking at vertebrate development in general makes it abundantly clear that the implantation stage which occurs in mammals is a detour from the usual course of development. Most species go from cleavage and blastula (or blastodisc) formation straight into gastrulation, and the entire blastula is involved in development. But the mammal embryo must establish a connection with the mother before differentiation can even begin, and the majority of the blastomeres (cleavage cells) are devoted to that connection rather than to the embryo itself. It should be emphasized that the frog blastula, though roughly similar in form, is not at all homologous (that is, equivalent) to the mammal blastocyst. Their respective paths diverge widely.

The mammal ovum is secondarily free of yolk. That is, biologists assume that the ancestors of mammals first had, and then lost, the ability to invest their eggs with yolk, since viviparity made yolk unnecessary. (I should mention here that my remarks about mammals here exclude the prototheria—the egg-laying mammals, whose eggs obviously do contain yolk.)

In mammals, the process of cleavage has depleted the reserves of energy originally stored in the egg, but fortunately the blastocyst has arrived in the uterus and is ready to touch down. As it loses the protective coating (the zona pellucida) which has surrounded it since egghood, the sticky surface of the blastocyst is exposed. The stickiness is greatest at the end with the inner cell mass, and this helps it to adhere to the uterine wall. The blastocyst then gradually erodes the uterine lining built up for its nourishment, and buries itself within that lining (fig. 4.1). At the same time a new cavity forms between the inner cell mass and the outer layer of the blastocyst, which will become the amniotic cavity; the inner cell mass, now attached to the blastocyst only at the edges, becomes the embryonic disk.

This disc soon forms two distinct layers, called endoderm and ectoderm; the endoderm faces the original blastocyst cavity, the blastocoel, and soon the whole cavity is lined with endodermal cells and is then called the yolk sac, although it never contains any yolk. Then a loose mesh of cells forms between the yolk sac endoderm and the outer layer of the blastocyst. This is the extra-embryonic mesoderm, and it soon cavitates in several places on its way to forming a single cavity, relatively quite large, called the extra-embryonic coelom (later referred to as the chorionic cavity). This cavity separates the whole complex of the embryo and its membranes into an outer capsule and an inner capsule, connected to each other by the body stalk (fig. 4.1e). This is a rather odd development, but allows some interesting maneuvers of the inner capsule a little later on (described in the seventh and eighth essays).

Meanwhile, the outer layer of the blastocyst continues to break down the uterine lining agressively, particularly at the deepest point (opposite the uterine cavity). This tissue is called the trophoblast, and it collaborates with the uterine lining to form the all-important placenta.

The whole process of human implantation seems unnecessarily complex. Why all those different layers and cavities? Implantation among the mammals differs in fascinating ways, but always involves the three fetal membranes, amnion, chorion and yolk sac, and always the formation of an embryonic disk.

The embryonic disk in mammals forms despite the fact that cleavage is fairly symmetrical and results in a spherical blastocyst. The embryonic disk is believed to be a heritage of our reptilian ancestors, in which it formed over a massive yolk. Mammals are unique in forming a spherical blastocyst followed by an embryonic disc.

* * *

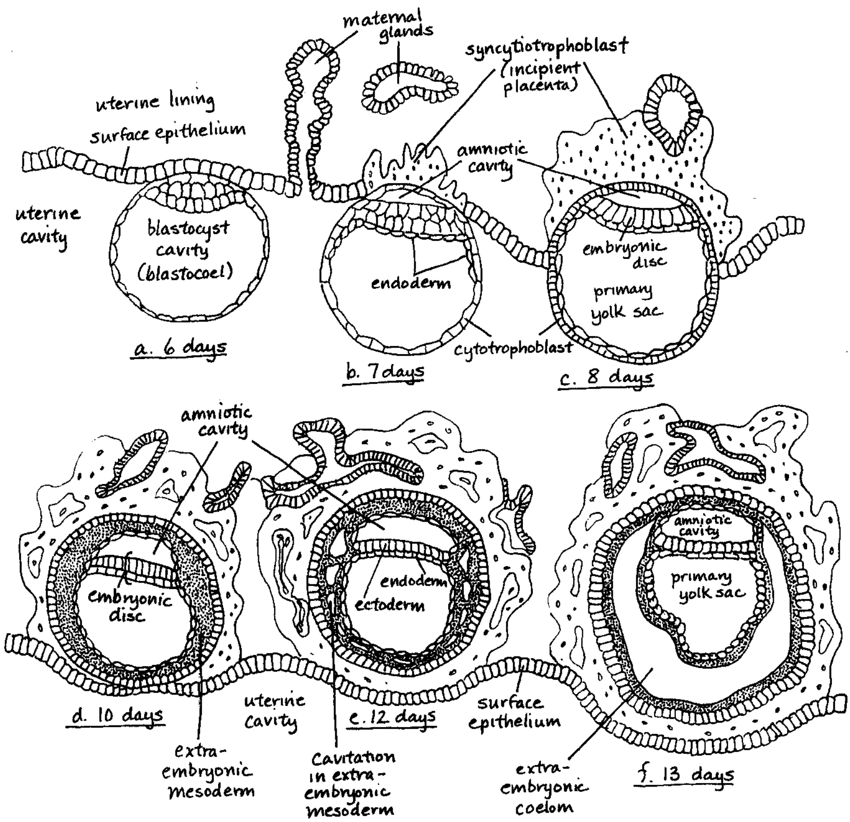


Figure 4.1: Human Implantation
In (a), the blastocyst has just made contact with the uterine lining. In (b), the syncytiotrophoblast (many nuclei; no cell walls) is invading the lining and forming the incipient placenta. Endodermal cells progressively line the blastocoel, turning it into the primary yolk sac. In (c), the amniotic cavity and embryonic disk are evident. In (d), the uterine epithelium has closed over the burrowing blastocyst, as the extra-embryonic mesoderm, originating near the tail end of the embryonic disk, grows between the outer cell layer (cytotrophoblast) and the two inner cavities (amniotic and yolk sac). (e) shows progressive cavitation and (f) the extra-embryonic coelom (Redrawn from Moore 1977, figs. 2-15, 3-1, 3-2, 3-5.).

The landing on the uterine lining is an important milestone in development; it is often considered the beginning of pregnancy, because it is the beginning of the physical link between the mother and the embryo. If cleavage represented infancy and (looking ahead) the gastrulation phase parallels adulthood and the onset of temptation, the "first contact" which begins implantation must signify an equally important milestone in childhood.

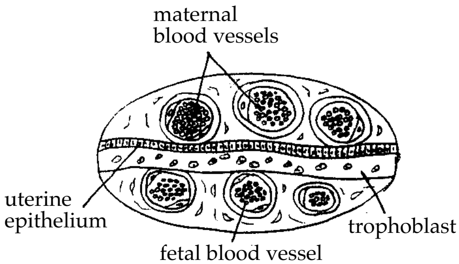
When I asked myself what that might be, the answer which suggested itself was the child's learning to read and understand the Lord's Word, which implies seeing and acknowledging the Lord as Someone separate from and outside of oneself. In infancy the child receives the Lord's life interiorly, as the nuclei are within the cells, but does not reflect on it or see it as distinct from self. Later the child learns the stories from the Word and begins to think about the Lord as another Person, and can begin to have a conscious relationship with Him. This resembles the physical relationship which the embryo embarks upon with something outside of itself—the mother, through the placenta. Through something exterior and separate, both the child and the embryo can receive interior things more fully.

This parallel leads us to ask what the correspondence of the mother, the womb, and the placenta might be. We read in *Arcana Coelestia* 9042 that carrying in the womb signifies the initiation of truth into good, and that a pregnant woman signifies the formation of good from truths. A new soul is formed in the rational as in a womb (AC 3570.4). The word placenta does not appear in Potts' Concordance, but I believe that the placenta signifies the Word—not in itself but as the person understands it, for the placenta grows along with the embryo throughout pregnancy. The placenta serves as lungs, digestive system and endocrine system for the embryo, much as the Word nourishes the person's understanding.

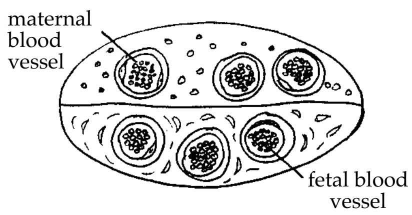
The Writings say that "the Word serves to unite heaven and earth…thus when anyone in a holy frame of mind reads the Word, a union is effected of his external man which is on earth with his internal man which is in heaven" (AC 3304.e), and that this union of earth and heaven within man makes possible his conjunction with the Lord (AC 9152.e, 9382.e). Perhaps the mother in this instance corresponds to heaven. Understanding of the Word deepens as the child grows to adulthood; first the innocent knowledge of the literal sense gives the child communication with heaven (AC 6333), and later a true understanding of it brings conjunction with the Lord: "The Lord…is present with men through the reading of the Word; but He is conjoined with him through his understanding of truth from the Word and according to it" (SS 3). This opening of the person's mind to the internal sense finds an illustration not only in the enlargement of the placenta, but also in the growing intimacy between the maternal and fetal bloodstreams as the placenta matures. The nutrients from the mother's

DIFFERENT TYPES OF PLACENTA

a. epithelio-chorial (pig)



b. endothelio-chorial (dog)



c. hemo-chorial (man)

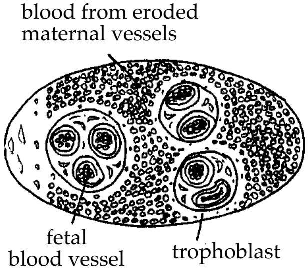


Figure 4.2: Different Types of Placenta
In the three types shown, the names refer to the maternal and fetal tissues which are in direct contact. In the pig, the epithelium of the uterine lining touches the chorionic membrane; in the dog, the endothelium of the blood vessels contacts the chorion; and in man, the chorionic villi are bathed in the maternal blood itself. Each placental type is represented at the peak of its development, when it achieves its maximum eficiency. "They all start at the epitheliochorial level. The hemoendothelial ones [in rabbits and some rodents] progress through all the other degrees of barrier reduction and only reach their final form in very late pregnancy" (Ballard 1964, pp. 207-208). So the different types of placenta also represent the different stages in the development of the last one in the series (Redrawn from Hamilton 1962, fig. 64).

blood must cross many boundaries to reach the embryo near the beginning of pregnancy, but these barriers are removed one by one (fig. 4.2), suggesting the veil of the literal sense growing more transparent to the internal sense and revealing it more fully as the person grows in understanding.

The implantation period which is so essential in insuring a food supply during the growth and differentiation which follows represents the long period of learning which precedes adulthood in humans.

> As regards the food of someone who is to be regenerated, the situation is this: Before anyone can be regenerated he must be supplied with all those things that can serve as means—the goods and delights which constitute affections as means for the will, and truths from the Lord's Word, together also with matters of a confirmatory nature from other sources, as means for the understanding. Until a person has been supplied with these he cannot be regenerated. These are what constitute his food. This explains why a person is not regenerated until he has entered adult years. (AC 677)

CHAPTER 5. GASTRULATION AS TEMPTATION

> And it came to pass after seven days that the waters of the flood were upon the earth…And the rain was on the earth forty days and forty nights. (Genesis 7:10, 12)

> It's not birth, death or marriage which is the most important event of your life, but gastrulation. (Lewis Wolpert on NOVA broadcast, "How Babies Get Made" 1988)

It's all very well to acknowledge the importance of gastrulation in embryonic development, but what exactly is gastrulation? Can a process which differs so much from species to species be precisely defined? To address this question we will begin on a descriptive level.

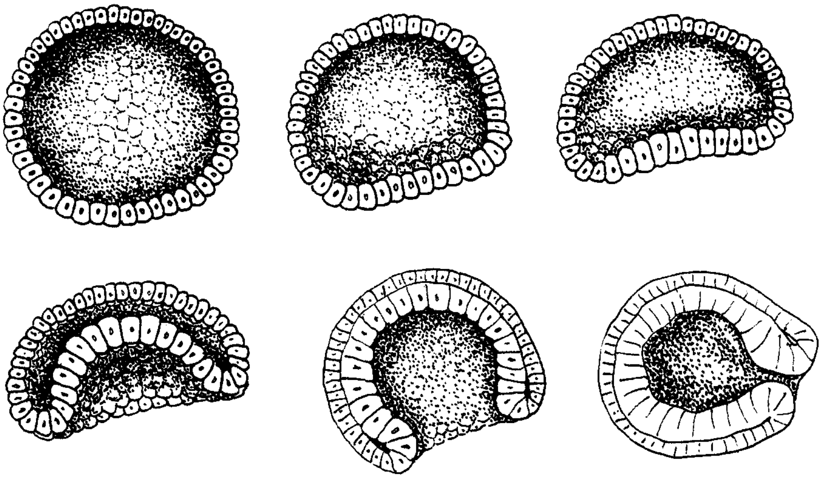


Figure 5.1: Gastrulation in Amphioxus
Note the simple, straightforward invagination of the spherical blastula into a cup-shaped structure and then into a double-walled spheroid (Redrawn from Balinsky 1965, fig. 121).

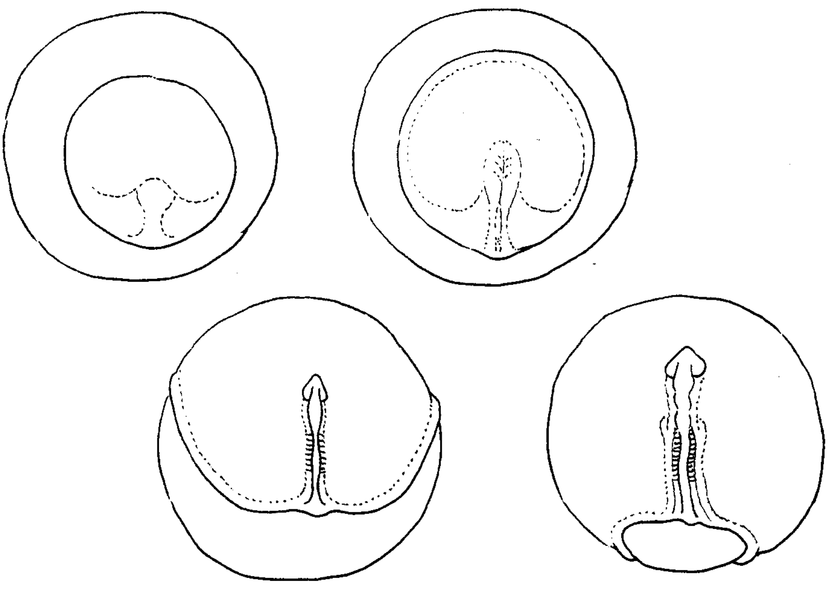


Figure 5.3: Gastrulation in Trout (Teleost Fish)
Gastrulation occurs through the edge of the blastodisk, which gradually overgrows the yolk mass as development proceeds. The yolk sac thus formed is the only fetal membrane present in fish development (Redrawn from Balinsky 1965, fig. 141).

One species that shows "typical" or "no frills" gastrulation is the amphioxus, a cephalochordate whose simple, elegant anatomy sets evolutionists to speculating about the ancestors of vertebrates. It gastrulates by forming a cuplike invagination in the spherical blastula, turning half of itself inside out and becoming a two-layered structure. The new cavity formed is the gastrocoel, or primitive gut, and its communication with the exterior is the blastopore (fig. 5.1).

The process as I've described it is pleasantly simple and straightforward, but I suspect (from my exposure to popular presentations of embryonic development) that many people harbor the idea that the vertebrates gastrulate in pretty much the same way, which is not the case at all. Everyone does it a little differently.

Amphibians begin with an approximately spherical blastula, but the blastopore gradually forms a ring which encircles the heavy, inert yolk, and then closes over it (fig. 5.2). Teleost gastrulation takes a different form (fig. 5.3), and the amniotes have worked out a completely new approach. They form an embryonic disk rather than a spherical blastula, and they gastrulate not through a simple or ring-shaped blastopore, but instead through a linear thickening called the primitive streak. Exceptions to this occur among the reptiles (turtles, for instance), but as far as I know all birds and all mammals form a primitive streak in the course of development.

The primitive streak manifests the embryo's individual identity and orientation; it determines the body axis and the head and tail ends of the future animal. The embryonic disk can form two or more primitive streaks and hence two or more embryos, but a single primitive streak always indicates a single individual.

The differences between human and bird gastrulation are subtle, and worth examining in some detail. The blastodisc of a bird lies on the surface of a relatively enormous yolk, and is composed of two layers, called epiblast and hypoblast. During gastrulation (which occurs before the egg is laid) the whole embryo is in motion with respect to the yolk. The primitive streak is a fairly stationary structure, yet composed of different cells from moment to moment, as a waterfall stays in one place while the water itself is in constant motion (fig. 5.4; Ballard, 107).

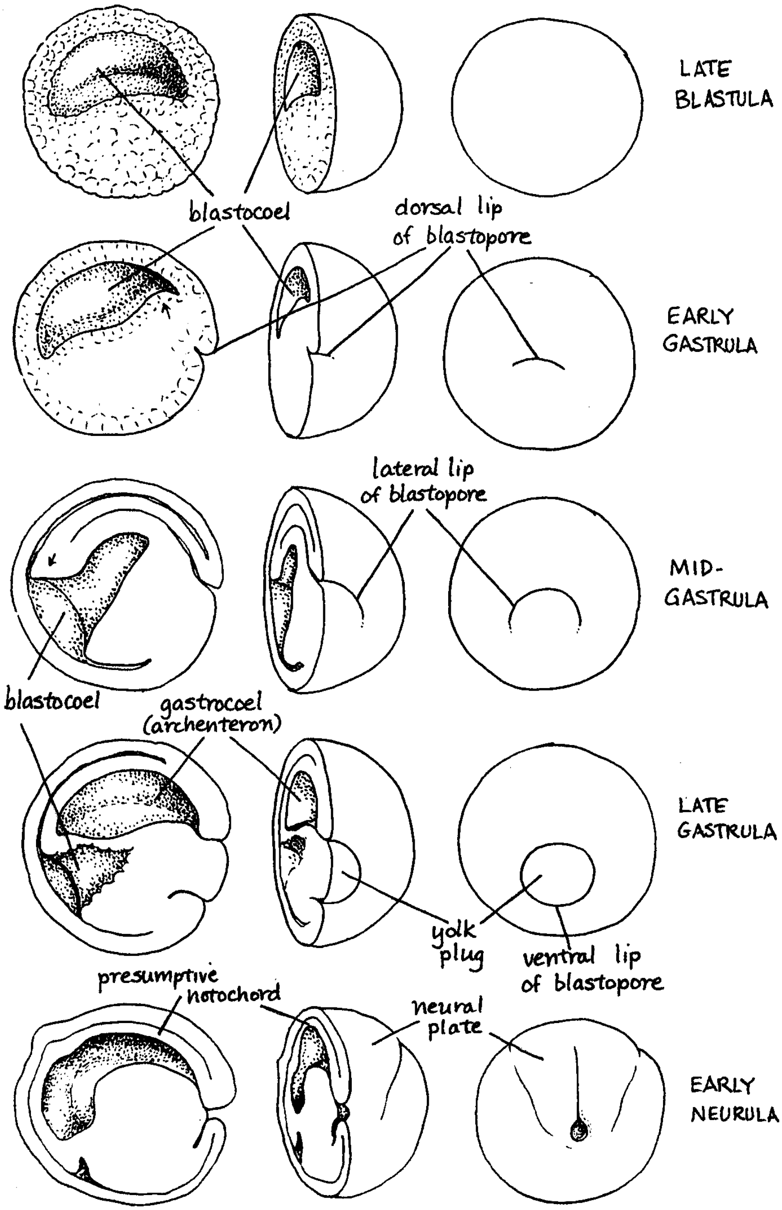


Figure 5.2: Five Stages in the Development of the Frog
The cavity which originates from the blastopore is the gastrocoel, also called archenteron or primitive gut, which replaces the blastocoel as the main cavity in the embryo. Prospective endoderm invaginates first, followed by prospective mesoderm. During neurulation (the stage following gastrulation), the endomesodermal sheet will split into two, and the mesoderm will slide between the endoderm and ectoderm. At the end of gastrulation, much of the embryonic interior is still filled with heavy, yolky cells (Modified from Balinsky 1965, figs. 127, 131, 135).

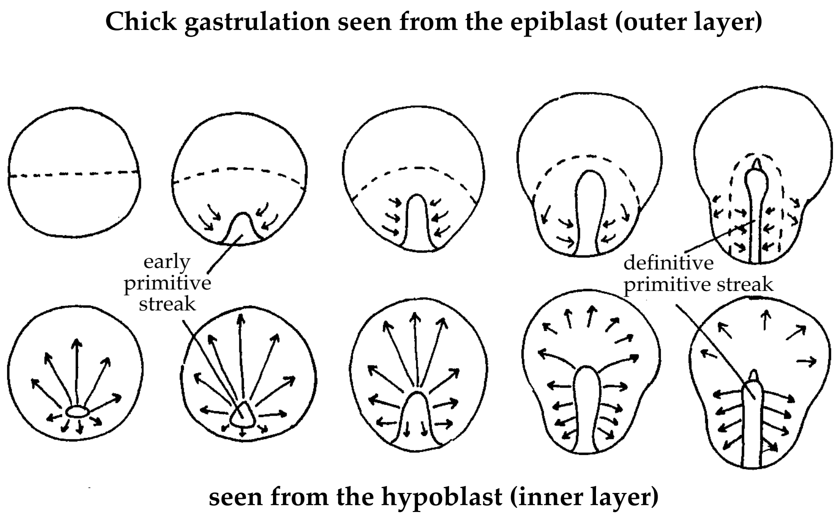


Figure 5.4: Gastrulation in the Chick
The blastodisk in the chick at the beginning of gastrulation consists of two layers, called the epiblast and hypoblast. The primitive streak forms in the upper layer, or epiblast, from the caudal half of the embryonic disk, and epiblast cells migrate through it to the lower layer, or hypoblast, pushing the original hypoblast cells to the periphery of the embryonic disk, and forming the embryonic endoderm. In the upper row, successive stages of primitive streak formation and gastrulation are shown on the epiblast side; the lower row shows what occurs simultaneously in the hypoblast. Arrows denote morphogenetic movements. After the endoderm is formed, the continued migration of epiblast through the primitive streak forms mesoderm between the other two layers (this distinction not shown in the figure). The migration pattern for mesoderm formation is similar to what occurs in mammals (Modified from Bodemer 1968, figs. 12-10, 12-14).

In humans and other mammals there is no yolk to act as a substrate for gastrulation, but rather a fluid-filled yolk sac lined with endodermal cells, The endodermal layer of the embryo is continuous with these cells, and is already in place when gastrulation begins. The endodermal layer, in fact, remains relatively stationary throughout gastrulation, serving as a substrate for it in place of the "missing" yolk. Meanwhile the upper layer of cells is in motion, part of it immigrating through the primitive streak to form the mesodermal layer between the other two, while the part that remains on top becomes ectoderm (fig. 5.5).

Looking at different forms of gastrulation makes clear that the process needs to be defined in terms of what it accomplishes, rather than how it appears externally. In all cases, gastrulation involves a lot of cell migra-

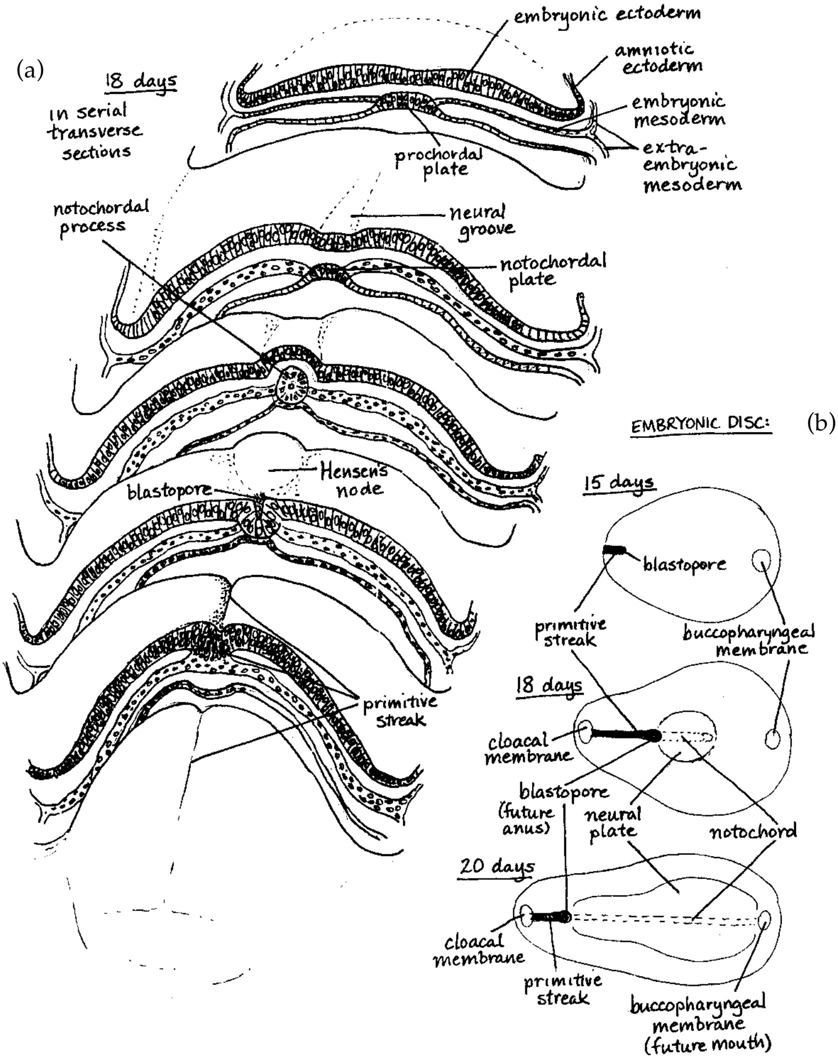


Figure 5.5: Gastrulation in Humans
In (a), an embryo in late gastrulation is divided into transverse sections. The mesoderm has already formed between the endoderm and ectoderm by migration of part of the original ectoderm through the primitive streak. Since development is most advanced at the cranial end, the sections show different stages of gastrulation at different levels of the embryo. In (b), the gastrulating embryo appears at three different ages, showing how the embryonic disk elongates, and how the primitive streak lengthens and then recedes, giving way to the developing notochord. The buccopharyngeal membrane (originally the prechordal plate) is the site of the future mouth, and the cloacal membrane is the precursor to the anus. No mesoderm forms between the ectoderm and endoderm at these two membranes, so the ectoderm and endoderm remain in contact here. Eventually the cloacal and buccopharyngeal membranes will open, allowing external access to the digestive tract. The blastopore and primitive streak recede and combine with the cloacal mebrane [(a) modified from Tuchmann-Duplessis et al. 1971, p. 26, and Hamilton 1962, figs. 53, 55; (b) redrawn from Moore 1977, fig. 4-2].

tion, reorganizes the embryo extensively (much more than cleavage and implantation do), and establishes the germ layers in their proper relationship. The three germ layers, endoderm, mesoderm, and ectoderm, are commom to all vertebrate embryos, and serve as the foundation for all the organization and differentiation which follows.

* * *

Armed with a basic understanding of gastrulation, we will now look at six different ways in which gastrulation, especially in humans, is like temptation.

1. Gastrulation is the beginning of individual development, as temptation is the beginning of individual regeneration (AC 848). Before the formation of the primitive streak, the embryonic disk still has the potential to form more than one individual. The appearance of the primitive streak, which I see as corresponding to the beginning of adulthood, indicates a commitment to the formation of a single individual. It determines the body axis and orientation in space of the embryo.

   Until adulthood, the person's identity is not strong enough to sustain temptation without being destroyed; hence the long period of preparation which comes before, when the child learns truths, receives remnants from the Lord, and begins to think independently. (See AC 677, quoted at end of previous essay). In much the same way, gastrulation cannot occur in the human embryo until its form has been stabilized and its nuclear/cytoplasmic ratio restored by cleavage, and its supply of nourishment assured by implantation and the formation of the rudimentary placenta.

2. In some species the paternal genes begin to make their influence felt during gastrulation (see essay on cleavage). The genetic information stored in the cytoplasm will carry amphibian development to the blastula stage, but for gastrulation the embryo must draw on information from the new gene-complex. (I know of no experiments indicating when this transition occurs in mammals, nor whether the

implantation stage is directed by the maternal genes only or the newly combined chromosomes.) The paternal DNA manufactures proteins before gastrulation, but they remain in the nuclei until they are drawn into the cytoplasm in preparation for gastrulation (Bodemer 1968, 70).

The substances in the nuclei of the embryonic cells are like the remnants which the Lord stores up in our internal minds in preparation for temptation. When temptation occurs, the remnants are activated, we become consciously aware of them, and through them the Lord supports us in our conflicts (AC 737). Even if the genes turn out not to function in just the same way in humans, still these truths manifest themselves in frog embryos, which also contain an image of the human form.

3. Gastrulation is a major upheaval in the life of the embryo—in fact, the most complete reorganization which the embryo ever undergoes. All the dazzling changes of appearance which occur later can't be compared with it; they are relatively local and external. It is a perilous process, too—a significant number of human embryos do not gastrulate successfully. What this reordering accomplishes is to break up the ovular order (evident in the embryo up to this time) and replace it with the most fundamental embryonic order—the three germ layers in their proper relationship. This illustrates man's transition from proprial to heavenly order during regeration.

   In gastrulation change and motion flood the embryo much as conflict and chaos flood the one undergoing temptation. During this spiritual flood evils must be broken down and modified by goods (AC 719). As the Writings say,

   > Before anything is restored to order it is very common for everything to be reduced first of all to a state of confusion resembling chaos so that things that are not compatible may be separated from one another. And once they have been separated the Lord arranges them into order. (AC 842.3)

   The migration of cells leaving their old neighbors behind and forming new patterns with previously distant cells in gastrulation beautifully embodies this bridge between the old proprium and the new.

4. The human embryo before gastrulation is a disk composed of two layers; gastrulation achieves the transition from two to three layers. This is generally true only among the amniotes; many of the lower vertebrates begin as a single-layered blastula which emerges from gastrulation with three layers, some even skipping a two-layer stage. In the Word, the number two represents conflict and three denotes rest, just as six is associated with conflict and seven with rest in the Creation story (AC 900). Therefore the progression from two to three germ layers in gastrulation might correspond to the conflict of temptation and the state of rest which comes after it.

5. The intra-embryonic mesoderm (the third germ layer) is formed in the human by gastrulation. In mammals there is mesoderm outside the embryo (extra-embryonic mesoderm) as well, but only in the higher primates is the extra-embryonic mesoderm formed first, and from a different origin than the mesoderm within the embryo.

   In my previous work I have associated the mesodermal layer with love (see Simonetti 1980 and Odhner 1985) and the extra-embryonic mesoderm with remnants of good. The mesoderm that is part of the embryo would therefore represent heavenly love which we make our own by confirming it in our lives, implanted in us by the Lord when He regenerates us by means of temptations. In a similar way the mesoderm is formed in the embryo by means of gastrulation.

6. In the human embryo the endodermal layer is relatively complete and stationary during gastrulation, and the prechordal plate arises before the primitive streak and remains separate from it. The prechordal plate in the human embryo begins as a thickening in the endoderm at the head end of the embryo, which appears just a day or two before the primitive streak. As the first indication of the embryo's orientation, it foreshadows events to come. It marks the location of the future mouth and is essential in guiding the organization of the head structures (see fig. 5.5). When the mesoderm forms a third layer between the endoderm and ectoderm, it detours around the prechordal plate area, leaving the endoderm there in contact with the ectoderm.

Most (if not all) vertebrate embryos have a prechordal plate, sometimes called prochordal plate, also known as the head organizer. In all classes other than the mammals, it begins on the outside of the embryo and migrates through the blastopore or primitive streak on its way to its proper place at the head end of the embryo on the inside. Only in the mammals does it begin in its proper place and so remain stationary, without ever approaching or associating itself with the primitive streak.

I have previously associated the endoderm with wisdom, or the understanding. Since regeneration begins in the understanding, and intellectual temptation comes before voluntary temptation (AC 670), it makes sense spiritually that the endoderm is already in place when gastrulation begins. The endoderm's independence of gastrulation, and the prechordal plate's lack of association with the primitive streak, might illustrate the separation of will and understanding without which our regeneration could not occur at all.

The prechordal plate, as the future mouth, might represent the beginning of the active acquiring and assimilation of truth. The primitive streak, as the focus of the gastrulation, could be compared with the fully adult yet unregenerate will. The formation of the endoderm is calm and straightforward compared to gastrulation, showing that "temptation of the understanding is mild compared with that of the will" (AC 734). The first state of temptation involves things of the understanding, and the second state involves things of the will (AC 755).

We have looked at six ways in which the gastrulation process in the embryo resembles the spiritual process of temptation. (Later we will explore the ways in which the results of gastrulation are like the states after temptation.) From them we can see the importance of the period of preparation which leads to the point of crisis in both cases. When gastrulation is seen as the beginning of development, all that comes before appears as a mere preliminary. Yet every part of the process is essential, and the same is true of our long childhood which prepares us for regeneration. When does life really begin? When does any process really begin? Do we consider the first steps in a progression that leads to an endpoint its beginning, or rather the time when that end actually begins to exist in use?

> "Wiping out everything from over the face of the ground" means man's proprium, which is so to speak wiped out when he is being given life…The human proprium is altogether evil and false. So long as it remains, a person is dead, but when he undergoes temptations, it is dispersed, that is, broken down and moderated by truths and goods from the Lord. In this way it is made alive and seems to be no longer present…In fact it is in no way wiped out but remains. (AC 731) ❑

Bibliography

Anthony, C. P., & Kolthoff, N. J. *Textbook of Anatomy and Physiology*. St. Louis: Mosby, 1975.

Balinsky, B. I. *Introduction to Embryology*, 2nd. ed. Philadelphia: W.B.Saunders Co., 1965.

Ballard, William W. *Comparative Anatomy and Embryology*. New York: The Ronald Press Co., 1964.

Bodemer, Charles W. *Modern Embryology*. New York: Holt, Rinehart and Winston, 1968.

Cusick, Lois. Waldorf *Parenting Handbook*, 2nd. rev. ed. Spring Valley, New York: St. George Publications, 1984.

Hamilton, W. J., J. D.Boyd, & H. W. Mossman. *Human Embryology*, 3rd ed. Baltimore: Williams & Wilkins, 1962.

Hickman, Cleveland P. *Integrated Principles of Zoology*. St. Louis: C.V.Mosby Company, 1970.

Keeton, W. T. *Biological Science*, 2nd ed. New York: Norton, 1972.

Moore, Keith L. *The Developing Human*, 2nd ed. Philadelphia: Saunders, 1977.

Odhner, L. S. "Correspondences of the Developing Human Form." *The New Philosophy* 88 (1985): 447-471.

Patten, Bradley M. *Foundations of Embryology*. New York: McGraw-Hill, 1958.

Simonetti, L. "The Human Form: Correspondences in Embryology." *The New Philosophy* (84: 1 & 2): 10-25.

Tuchmann-Duplessis, H., G. David, & P. Haegel. *Illustrated Human Embryology*, Vol. I: Embryogenesis. Trans. by Lucille S. Hurley. Paris: Masson & Co., 1971.