Summary: Reproduction and Embryonic Development

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Contents

1 The nature of asexual reproduction

Reproduction, or "the creation of new individuals from existing ones" is essential to the continuation of life over the lifespan of an organism. **Asexual reproduction** is one permutation of the two types of reproduction: sexual reproduction and asexual reproduction. In contrast to *sexual* reproduction, *asexual* reproduction poses no stipulations as to genetic diversity, nor the ability of a parent organism to find a mate: an organism may reproduce without sex via budding, fission, or the process of fragmentation and regeneration, for example.

Advantages	Disadvantages
Allows animals that live in isolation to produce offspring	Produces genetically uniform populations
Perpetuates a particular genotype precisely and rapidly	

Table 1: Advantages and disadvantages associated with asexual reproduction

2 The nature of sexual reproduction

Sexual reproduction, or "the creation of genetically unique offspring by the fusion of two haploid sex cells (gametes), orming a diploid zygote" is an alternative pathway to "reproduction" in organisms where the **fertilization** of **gamete** cells—sex cells with n chromosomes—is the desired mode of reproduction. In organisms where the mode of reproduction involves such fertilization, there exist two types of gametes:

- **Sperm**, the male gamete: travels by means of a flagellum

  and the

- **Egg**, the female gamete: is not self-propelled

The fusion of the two aforementioned cells leads to the formation of a **zygote**, which develops into a new individual.

In contrast with asexual reproduction, sexual reproduction increases genetic diversity in the resulting population through random fertilization and meiosis. The combination of these randomization factors results in the principal force of natural selection: genetic variability.

While the aspect of variability associated with sexual reproduction might be attractive for various mobile species, for isolated or immobile organisms, sexual reproduction is implausible, as it requires a mate with which to procreate. This inconvenience is addressed by the development of **hermaphroditism**, or the existence of both female and male reproductive systems in a single organism—"perfect" flowers with both stamens and carpels, are an example of such a development. The development of hermaphroditism can be seen as advantageous, as it allows for animals to reproduce with respect to environmental conditions.

Even with respect to sexual reproduction, there exist two separate development of reproductive mechanisms: **reproduction by external fertilization** wherein gametes are released into and fuse in the environment, and **reproduction by internal fertilization** wherein sperm are deposited in or near the female reproductive tract.

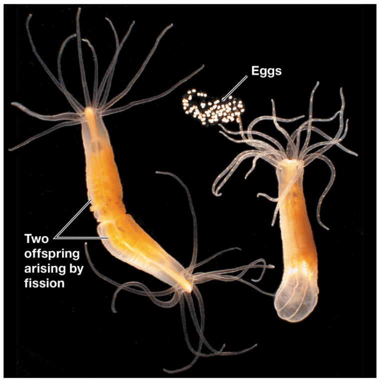

Figure 1: The utilization of both asexual and sexual reproduction in the hydra.

3 The human female reproductive system

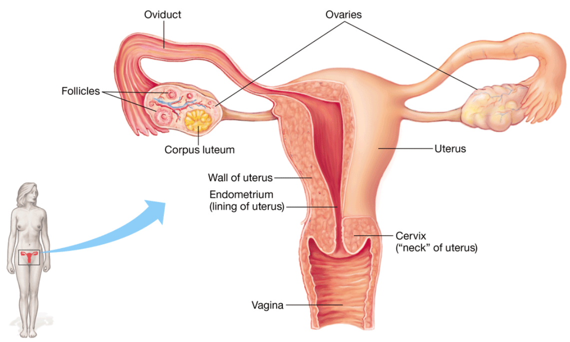

Figure 2: A diagram of the female human reproductive system.

The **ovaries** are the gamete-producing organs in the female reproductive system, and can be described as having a "bumpy" surface—caused by the **follicles** that both produce estrogen and enclose a developing egg cell.

In the process of **ovulation**, a female will release an immature egg via the cilia lining the **oviduct**, or *fallopian tube*— after starting puberty, of course— as a result of the maturation of a follicle, every 28 days. In addition, after having matured and formed the **corpus luteum**, a follicle will begin to release progestrone, alongside additional estrogen, complementing the maintainence of the uterine lining. This process usually ceases near the age of 50.

With consideration to the above structural definitions, the following statements regarding the development of a zygote, and the eventual birth of a human fetus can be made:

1. When ovulation occurs, if sperm are present in the upper part of the oviduct, fertilization may occur.
2. After fertilization occurs, the zygote should continuously divide as it traverses the oviduct, eventually becoming an embryo.
3. In the **uterus**—the site of pregnancy[1]—, an **embryo** will be deposited in the inner lining of the uterus **endometrium**.
4. After implantation, the embryo will complete development until the 8th week of pregnancy, when the developing human will, henceforth, be referred to as a **fetus**.
5. After continued development of the fetus, the **vagina** will serve as the canal through which the baby is born. The vagina is separated from the uterus by the **cervix**—the "neck" of the uterus.

In addition to each of the aforementioned structures utilized in embryonic and fetal development, various external structures collectively referred to as the **vulva** provide functionality in copulation[2]:

- In sexual intercourse, the **vagina** serves as a repository for sperm, and is guarded by the **labia minora** and **labia majora**.
- Though it does not provide additional *necessary* functionality in reproduction, the **clitoris**—an erectile organ consisting of a short shaft, followed by the **prepuce**, a small hood of highly sensitive skin—does serve a purpose in reproduction in that it evokes a highly presurable sensation when stimulated. As do the vagina and th elabia minor, this organ enlarges during sexual activity as a result of increased concentration of blood in the area.

4 The human male reproductive system

As is the case with many other mammals, the natural temperature of the human body presents a challenge for the proper development of sperm cells within the **testes**—the male gonads. That is, in humans, the most desirable temperature for sperm development is approximately 2°C less than the normal human body

[1] In rare cases, an **ectopic pregnancy** may commence, where an embryo implants itself in the oviduct, potentially rupturing surrounding tissues.

[2] The **hymen** could be categorized as one such structure, but provides little functionality in reproduction, and is ruptured in vigorous physical activity or intercourse.

temperature of 36.5–37.5°C. In humans, the **scrotum** solves this dilemma by keeping sperm-forming cells within the acceptable temperature range.

After a sufficient volume of sperm cells have been produced in the testes, sperm leave the gonads through the **epididymis**, where sperm cells will continue to develop until **ejaculation**. Once the muscular contractions necessary for ejaculation to occur take place, the sperm will leave the epididymis via the **vas deferens**, and travel upward around the bladder, where the vans deferens joins with the **seminal vesicle**. Finally, sperm will be conveyed via the urethera. Thus, it follows that, in contrast with the female reproductive system, the male reproductive system is directly related and physically connected to the uninary system. This entire process is controlled by FSH and LH hormones, and, by extension, the hypothalamus. The former of the aforementioned hormones, FSH stimulates sperm production, while LH promotes androgen secretion.

However, the important distinction between sperm and nourishing fluid contained in semen must be made: **grandular secretions** are produced by the **prostate gland**, and are initially separate from sperm. Alongside **alkaline mucus** produced by the **bulbourethral glands** and sperm, these fluids comprise **semen**, the fluid ejaculated from the penis during orgasm.

As does the female reproductive system, the male reproductive system consists of various external structures:

- The **scrotum**: stores sperm at a suitable temperature
- The **penis**: similarly to the clitoris, this organ is composed of erectile tissue forming a shaft, supporting a sensitive glans, and is engorged during sexual arrousal[3]

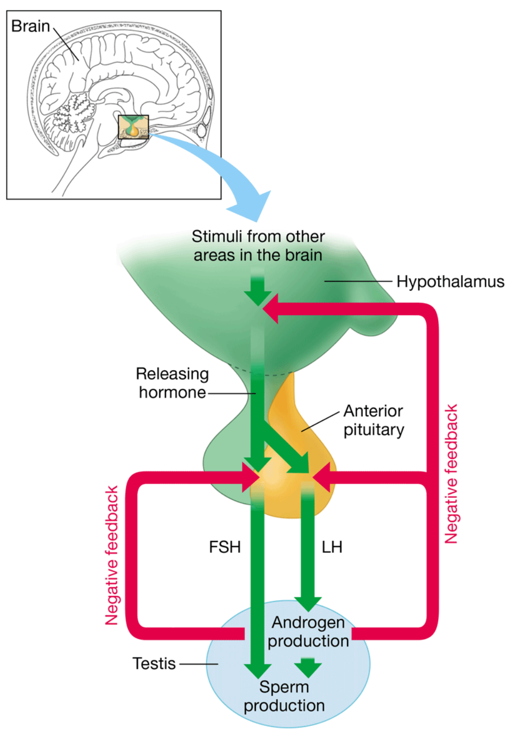

Figure 3: Hormonal control of the testis by the hypothalamus

5 The production of gametes via meiosis

[3]In individuals with **erectile dysfunction (ED)**, or a tendency to **impotence**, engorement of the penis is made improbable. This condition can result from drug use, alcohol, or psychological problems.

Both egg and sperm cells must be produced through the procedure of meiosis, or **gametogenesis**.

5.1 Spermatogenesis

Spermatogenesis, or the formation and development of sperm cells, necessitates the conversion of initially diploid cells ($2n$) in the outer walls of the coiled seminiferous tubules of the testis to secondary haploid spermatocytes ($n = 23$). In human males, this process takes approximately 10 weeks to complete, and is usually continuous through the entirety of a male's adult life.

5.2 Oogenesis

As is the case in spermatogenesis, in oogenesis, the majority of gamete production and development takes place in the respective gonad—the ovary. However, in contrast to that which was demonstrated by the male reproductive system, the female reproductive system does not produce gametes "on-demand"—that is, the gametes are produced on a regular basis, each 28 days, on the basis of the release of a follicle- stimulating hormone (FSH). This process is, in part, reminiscent of sperm production, as it is ultimately riggered by the hypothalamus. However, these two mechanisms do, of course, differ in the fact that:

1. Oogenesis occurs in a cyclic fashion, while spermatogenesis will be triggered by sexual stimulation
2. Oogenesis is only carried out between puberty and menopause, while spermatogenesis usually lasts the entirety of a male's adult life
3. Naturally, oogenesis produces far less gamete cells than spermatogenesis, simply due to the mechanical stipulations of human sexual reproduction

The end result of each of these processes is, of course, a haploid gamete cell.

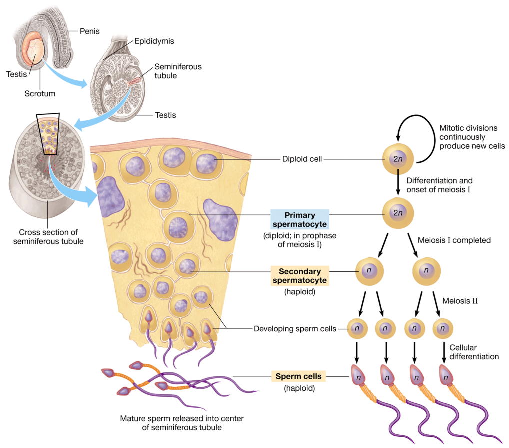

Figure 4: The production of gametes in a human female (spermatogenesis).

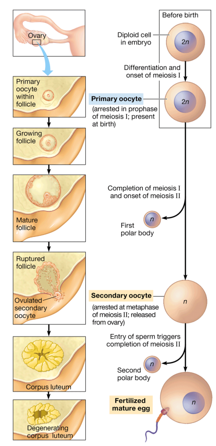

Figure 5: The production of gametes in a human female (oogenesis).

6 The female mammalian reproductive cycle is coordinated by hormone secretion

6.1 Important distinctions between mammalian reproductive cycle subprocesses.

The female mammalian reproductive cycle can be divided into two distinct subproceesses: the *ovarian* cycle and the *menstrual* cycle.

Figure 6: The production of gamete cells in a human female (oogenesis).

The former of these processes deals exclusively with the production of gamete cells, while the latter deals with the preparation of the female reproductive system for the potential implantation of an embryo. Messaging via the exchange of hormones between these processes allows for the production of gamete cells with respect to a uterine lining conducive to the growth of an embryo. More specifically, LH and FSH hormones act to mediate this synchronization effect.

6.2 Overview: The female mammalian reproductive cycle

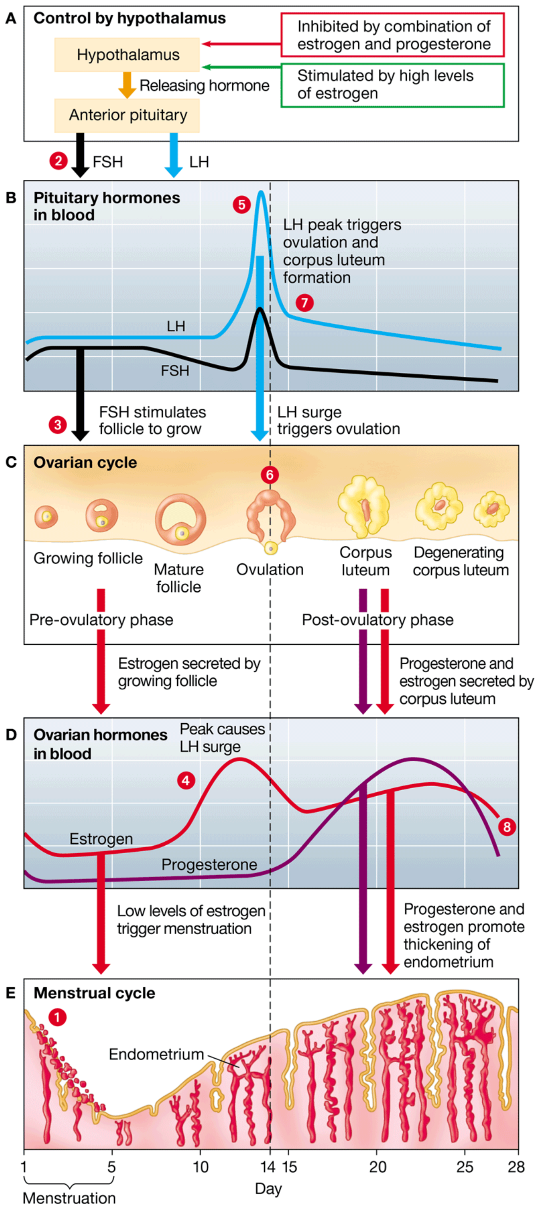

Figure 7: The reproductive cycle of the human female.

With respect to the discharge of ovules from the ovaries, the ovarian and menstrual cyclese can be separated into two distinct parts:

- The pre-ovulatory phase: the period in which a follicle begins growth
- The post-ovutory phase: the period in which the follicle has become a corpus luteum

Typically, when accounting for each of these "parts" of the reproductive cycle, the following sequence of structural events takes place:

1. **Menstruation**: for 3–5 days, the endometrium is in a breakdown process, resulting in uterine bleeding. This even occurs at the same time as the pre-ovulatory phase of the ovarian cycle.
2. The endometrium begins to regrow.
3. After 20–25 days, if the embryo has not implanted itself in the uterine lining, the ovarian and menstrual cycles restart.

FSH, LH, progesterone and estrogen are the primary hormones responsible for synchronizing the ovarian and menstrual cycles. The functions of each of the aforementioned hormones in coordinating the reproductive cycle are as follows:

- **FSH**, or follicle-stimulating hormone: prompts the growth of a follicle in the ovaries. In other words, this hormone kicks off the ovarian cycle
  - Follicles produced as a result of the secretion of FSH themselves secrete estrogen, preventing bloodstream concentration of FSH and LH low during the pre-ovulatory phase
- **Estrogen**: As the period of ovulation approaches and the size of the follicle continues to increase, estrogen levels increase dramatically. This results in the secretion of FSH and LH en masse.
- **LH**: stimulates the completion of meiosis I, marking the production of the secondary oocyte, when the follicle is ruptured.
  - Encourages estrogen secretion by the corpus luteum.
- **Estrogen and progesterone**: signals to the hypothalamus that FSH and LH level ought to drop, preventing a secondary follicle from developing. This effect experiences gradual decay, until the end of the post-ovulatory phase, at which point an embryo should have been implanted into the uterus. In other words, the decay of this effect marks the beginning of the next reproductive cycle.

7 The mechanics of fertilization

Fertilization is, of course, the first step in the development of an embryo— that is to say, the fusion of two haploid cells from two different individuals is required in order for the normal pathway of embryo development to ensue.

It is needless to say that the action of fertilization is not inherently probabilistic: each actor—the sperm cell and the egg cell— participating in the conjoinment of genetics posess certain properties that make fertilizatiion possible. The sperm cell, for example, is composed of a plasma-membrane enclosed haploid nucleus, an **acrosome** containing enzymes that help penetrate the surface of the egg cell, a flagellum tail, and mitochondria.

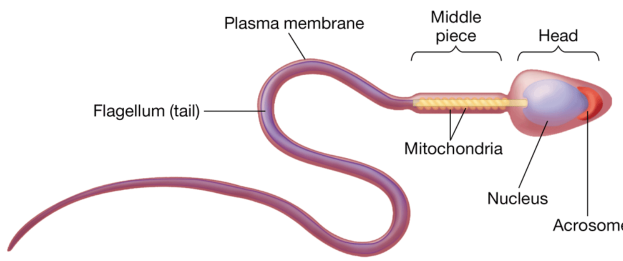

Figure 8: The structure of a human sperm cell.

With consideration to the biological theme of correlation between structure and function, it follows that the components found in a typical sperm cell serve some purpose in fertilization. Thus, one must turn to the natural process of fertilization itself:

1. The sperm cell traverses the uterus, and, eventually, the fallopian tubes, utilizing its mitochondria and flagellum tail
2. A sperm cell binds to an egg cell
3. The plasma membrane of the cell that will be fertilized becomes impenetrable
4. The vitelline layer of the egg becomes impenetrable
5. The fusion of the egg and the sperm nuclei is complete
6. DNA synthesis begins
7. The zygote divides

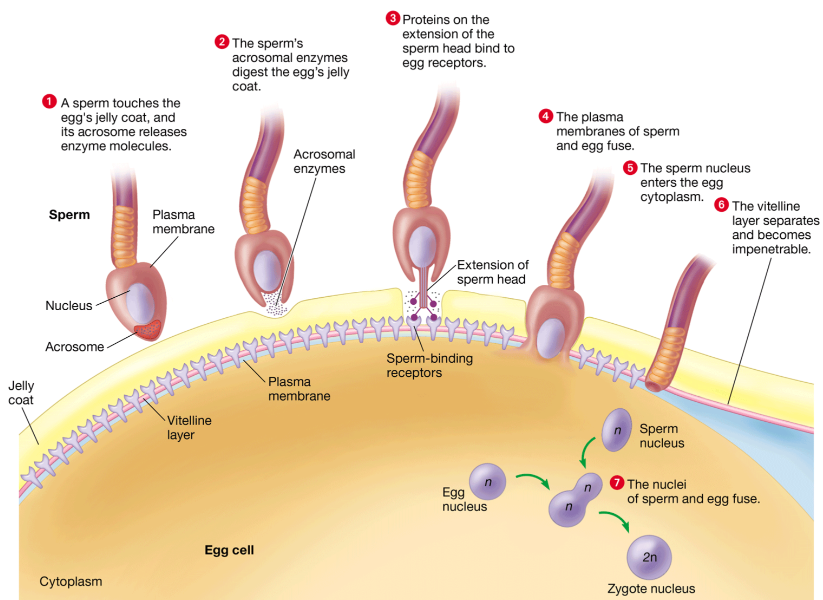

Figure 9: The process of fertilization in a sea urchin

8 The mechanics of cleavage

Cleavage is defined as the first stage in a series of carefully controllled cell divisions and specialization ultimately leading to the maturation of an organism. More specifically, cleavage is the stage during which rapid successive divisions of a zygote lead to the production of a "multicellular ball." Or, in other words, the completion of this process results in the transformation of the zygote into an embryo.

It should be noted that, at this point in development, the zygote cell divides simply for the sake of dividing—that is, division is not performed with the intention of producing differentiated, or specific *types* of cells. Furthermore, the zygote does not produce many new proteins at this point, and simply seeks to sustain division by feeding off nutrients stored in the containing egg. Yet, with consideration to the non-expansionist manner of development at this stage in maturation, it remains true that this action of "division" is less akin to traditional mitosis, and bears more resemblance to the simple action of *partition*—new cells are not significantly larger than—or even comparable in size, for that matter, with consideration to—the source cell.

Typically cleavage takes approximately 4 hours to complete in a frog, and 4 days to complete in a human.

One notable development that arises about the completion of cleavage is the formation of the **blastocoel**—a fluid-filled cavitiy located in the center of the embryo. After the completion of cleavage, this cavity transforms into a **blastula**, a hollow ball of undifferentiated cells that pose quite promising therapeutic use cases.

9 The mechanics of gastrulation

Gastrulation, the second phase of embryonic development, is perhaps best likened to a blueprinting phase of maturation—that is, cells are arranged in a manner that is conducive to the efficient formation of further organs and tissues. This "wireframing / blueprinting" action results in the formation of a **gastrula**, or a three-layer stage. The three stages comprising the gastrula can be defined as such:

- **Ectoderm**: the outer layer of the gastrula—likened to the epidermis of the adult skin, the epithelial lining of the mouth and rectum, the sense receptors in the epidermis, the cornea and lens of the eye, and the nervous system
- **Endoderm**: represents the digestive tract of an embryo—likened to the epithelial lining of both an adult digestive tract and respiratory system, the liver, the pancreas, the thyroid, the parathyroids, the thymus, the lining of the urethera, the urinary bladder, and the reproductive system
- **Mesoderm**: lies between the two aforementioned "sections" of the embryonic developmental stage—akin to the skeletal, muscular, circulatory, excretory, and reproductive systems

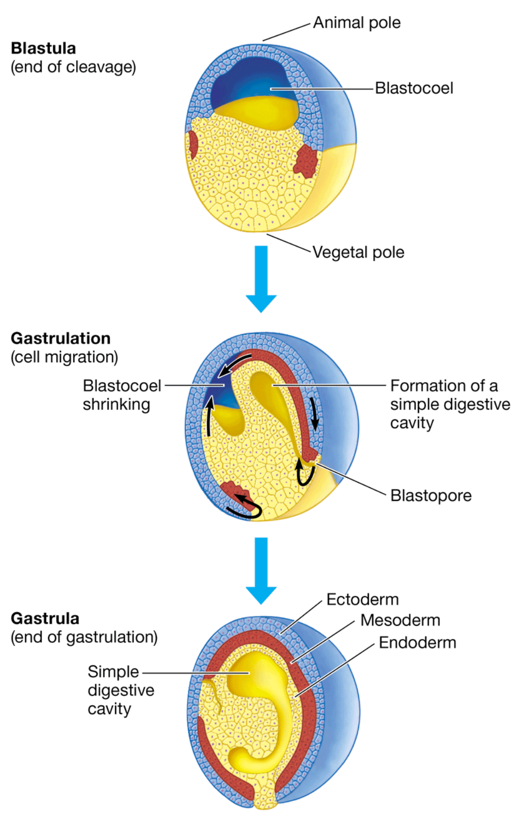

Figure 10: Gastrulation in a frog.

10 The mechanics of organ development

Following the "blueprinting" phase of embryonic development, several new organs will arise in the embryo:

- The **nortochord**

- The **neural folds**
- The **neural plate**

However, the distinction should be made that the aforementioned organs are not in and of themselves organs in the traditional sense of the word. The nortochord, for example, develops in the mesoderm, but does not serve any function other than of a glorified "play-doh" kit: it can be molded and fitted into any organ that arises in the same "section" of the embryonic stage: the nerve cord, for example, begins to form as a derivative structure of the nortochord at this point in maturation. Usually, a large part of this structure will dissolve before birth, though parts of the adult spine might bear composure from the nortochord.

As does the nortochord, both the neural folds and the neural plate eventually fade into the structural composition of the resultant embryo: the neural plate is "rolled" transformed by various rolling and sinking actions into what becomes the **neural tube**—the adult brain and spinal cord.

At this point, in various animals—frogs, for example—, the **coelom** will begin to form. In addition to the aforementioned structures, the body cavity or coelom represent some of the fundamental features of all chordates.

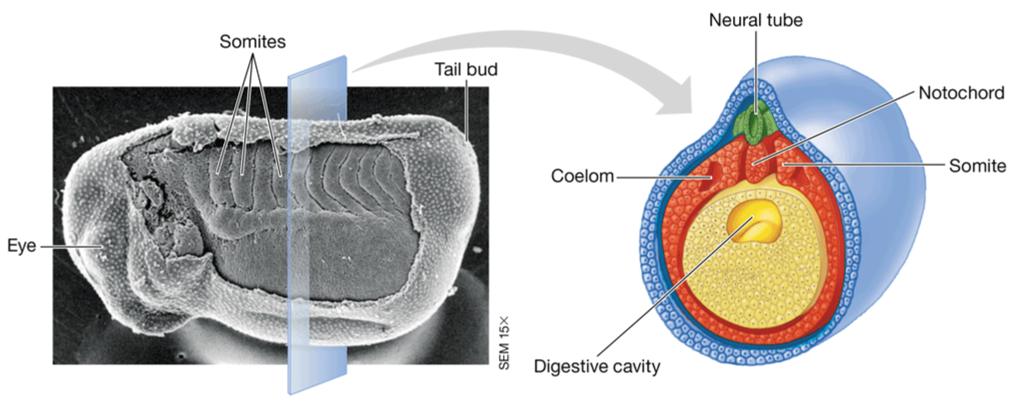

Figure 11: An embryo with completed neural tube, somites, and coelom shown in a side view (left) and in cross section (right)

11 The mechanics of animal development

So far, several stages in the development of an embryon have been discussed. Yet, the mechanism by which such coordination occcurs remains unclear. In practice, these developmental stages come about through the coordination of various, interconnected processes through **induction**—the influence of one group of cells on an adjacent group of cells. Of course, induction may be carried out through various kinds of communication. Cell-surface interaction is one such mode of communication.

In the development of organ cells, for example, the aforementioned coordination techniques are utilized: in order to be differentiated into specific types of tissues, a set of genes must be "switched on" through induction.

While induction does play a heavy role in various embryonic developmental processes, **cell migration** also plays a non-discountable role in gastrulation, for example: cells within the embryo "crawl" by extending and contracting in accordance with the aforementioned induction technique.

Finally, **apoptosis**, or cell suicide, allow "spaces" to be hollowed out in an organism, should the need arise.

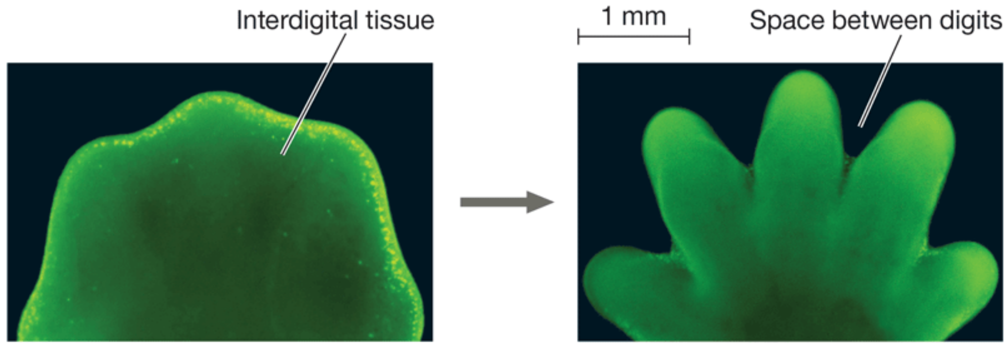

Figure 12: Apoptosis in a developing mouse paw

12 The mechanics of gestation

Approximately 24 hours after conception, a **blastocyst**, or sphere of undifferentiated cells, forms. This "ball" of cells is coated in a layer of outer cells that comprise the **trophoblast**, which secretes enzymes conducive to the implantation of the embryo in the uterine lining.

The process of implantation itself relies on the extension of trophoblast cells onto the endometrium. Having said so, these "extension" cells eventually form the **placenta**—a nourishing organ for the embryo. Alongside the placenta, various **extraembryonic membranes**—the amnion, the yolk sac, and the chorion—will form, each helping support the embryo.

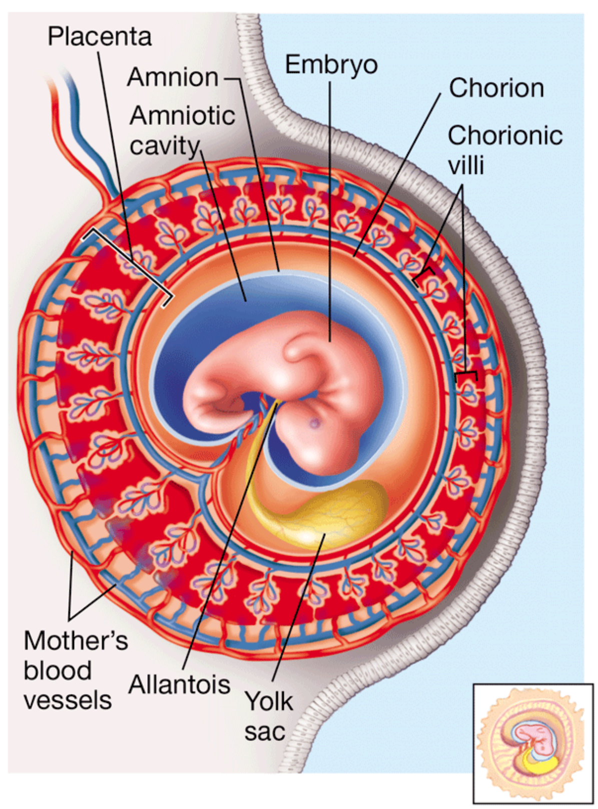

Figure 13: The embryo 31 days after conception.

13 The mechanics of childbirth

In order for **labor**, or the seris of events that expel an infant from the uterus to occur, various hormones must be present in the mother's body, in order to illicit their respective responses from the body:

- Estrogen: triggers the formation of oxytocin receptors inside the uterus, resulting in the rhythmic contractions associated with labor
- Prostaglandin: stimulate the contraction of the uterine muscle cells

With consideration to each of the aforementioned factors, the process of labor may begin:

1. **Dilation**: lasts 6-12 hours, from the initiation of the labor process until a maximum dilation of 10 cm
2. **Expulsion**: infant is forced down and out of the uterus and vagina
3. **"Afterbirth"**: umbilical cord is severed

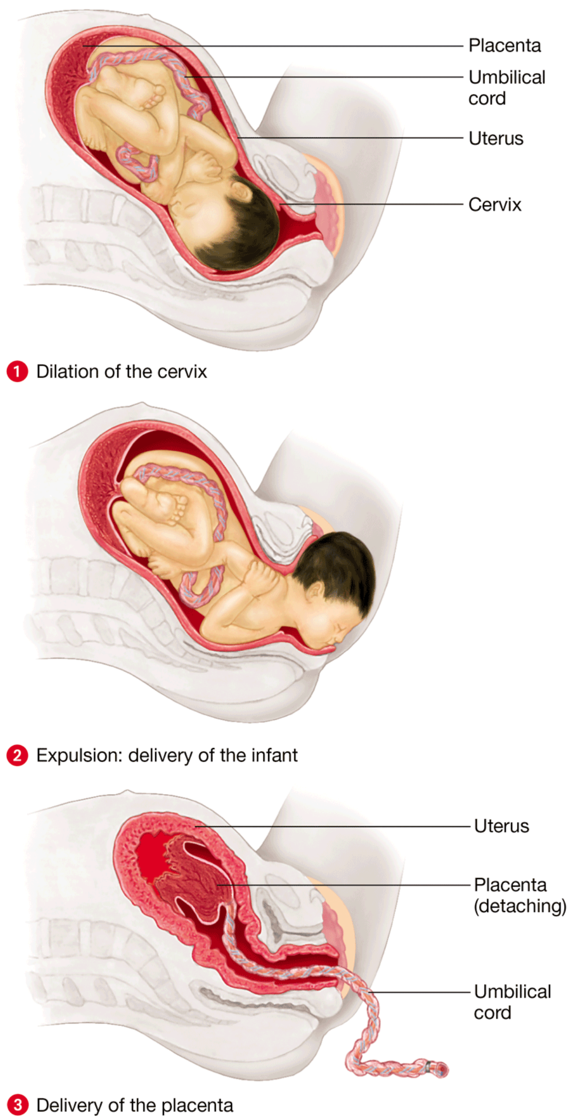

Figure 14: The three stages of labor