Sexual Reproduction

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Sexual reproduction

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- Haploid and diploid phases in the life cycles of organisms.

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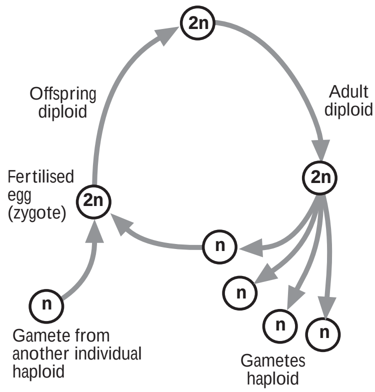
SEXUAL REPRODUCTION

The fusion of gametes results in a diploid zygote

Sexual reproduction involves the fusion of the nuclei of the sex cells, or **gametes**, from the male and female sex organs, to form a **zygote** in a process of **fertilisation**. Individual organisms can be either single sexed (**dioecious**), or **hermaphrodite** (**monoecious**) bearing both male and female organs. Hermaphrodite organisms may be self-fertilising, or they may have outbreeding mechanisms which favour or compel cross fertilisation with another hermaphrodite individual.

During gamete production (**gametogenesis**) in animals, and in spore formation which precedes gamete production in plants, the number of chromosomes in the nucleus is halved in a process known as **meiosis**, so that normal gametes have half the normal number of chromosomes, that is they are **haploid**. A **diploid** zygote, which has twice the haploid number of chromosomes, is formed by fertilisation. Certain genetic 'mixing' events, which occur during meiosis, and the random fusion of the gametes result in genetic variation in the offspring which may be of adaptive advantage.



Meiosis

Meiosis is a special type of cell division called a **reduction division** in which the number of chromosomes is halved from the diploid to the haploid number. The mechanisms of cell division are very similar to that already described for mitosis.

Meiosis involves two divisions referred to as the first and second divisions (Meiosis I and Meiosis II). Remember that the nucleus of each cell contains two sets of chromosomes; one maternal, from the female gamete and one paternal, from the male gamete. As a result, each chromosome has a partner in the other set which carries genes for the same characteristics. Two such chromosomes are said to form a **homologous pair**.

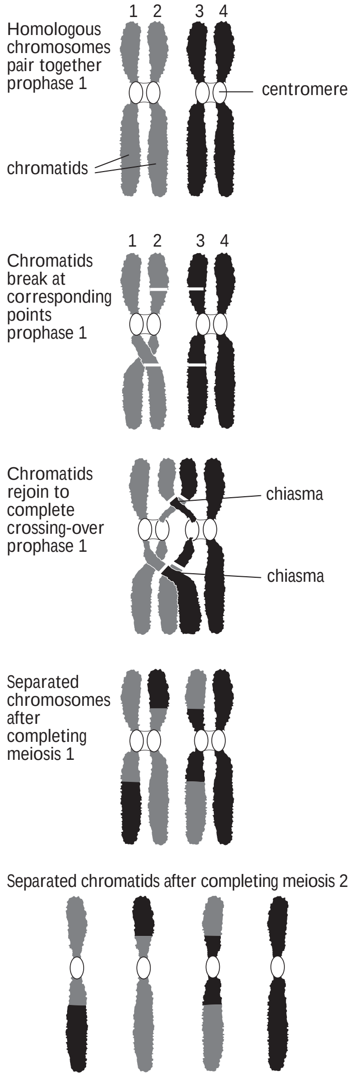
During interphase, before nuclear division by meiosis starts, the DNA replicates

During prophase I the chromosomes are formed as double structures of a pair of **sister chromatids**. They then pair up with their homologous partners to form structures called **bivalents**. They twist around each other, and breaks occur in the chromatids. A break in one chromatid is matched by another in the corresponding non-sister chromatid. The broken ends rejoin with the ends of the non-sister chromatid resulting in a **crossing over** between non-sister chromatids. The homologous chromosomes begin to repel each other, and the points where crossing over has occurred serve to slow the repulsion and appear as a cross shape (**chiasma pleural chiasmata**). These crossing over points occur in a random fashion serving to reshuffle the genetic pack, mixing the DNA of the maternal and paternal chromosomes. Crossing over during meiosis is an important source of genetic variation in organisms which reproduce sexually.

Prophase I may take several days to complete. In metaphase I the chromosomes are pulled to the equator of the cell, held only by the junction points of the chiasmata. They line up on the equator at random, with maternal and paternal chromosomes on either side. During anaphase I the homologous chromosomes pull apart from each other, separating towards the opposite poles of the cell, the completion of which is known as telophase 1.

Crossing over, and the random alignment and separation of maternal and paternal chromosomes, prevents any gametes being formed from being replicas of gametes that formed the original cell undergoing meiosis, and therefore introduces genetic variation into the gametes.

Two new spindles are formed at right angles to the first, one at each pole, and the chromosomes (each composed of two sister chromatids) move to the equator for a second metaphase (metaphase II). From here on, the events are similar to those of mitosis as the sister chromatids now move to opposite poles, i.e. anaphase II, and telophase II. Cytokinesis results in the formation of four new haploid daughter cells. Note that the result of meiosis is four cells (gametes) each containing half the original number of chromosomes with mixed up sections of maternal and paternal DNA sequences, as well as mixed up sets of maternal and paternal chromosomes.



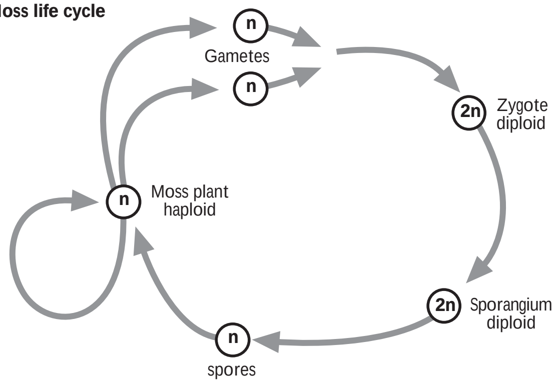
Usually 2 or 3 cross-overs affect each chromosome pair. Note cross-overs can occur between 1&3; 1&4; 2&3; 2&4, but not 1&2 or 3&4

The life cycle of plants involves haploid and diploid phases.

In all sexually reproducing plants there is an alternation of haploid and diploid phases in the life history. The cells of the haploid phase contain one set of chromosomes and the cells of the diploid phase contain two sets of chromosomes. This alternation is most clearly seen in the mosses in which a haploid, sexually-reproducing gamete producing plant (gametophyte) alternates with a diploid asexually-reproducing spore producing plant (sporophyte). Fertilisation is dependent upon the presence of a surface film of water. The gametophyte moss plant produces male gametes which swim in a surface film of water to the female organs. By contrast the process of spore dispersal depends on dry wind currents so it is important that the sporophyte lifts the spore cases so that they are exposed to air currents.

Although the life cycle of Flowering plants is so different from that of mosses, their reproductive structures and the sequence of events leading up to fertilisation reflects this alternation between haploid and diploid stages. In Flowering plants the main plant is the diploid sporophyte generation, and the haploid gametophyte generation is reduced to a few cells and nuclei within the pollen grains and ovum.

Moss life cycle



◆ CHECKPOINT SUMMARY

- Offspring result from the fusion of gametes, forming a zygote.
- This fusion of gametes involves various genetic mixing events and therefore leads to genetic variation in offspring.
- These genetic mixing events include events in the nuclear division (meiosis) involved in the production of gametes, and in the random fusion of gametic nuclei from different sexes.
- Meiosis is a reduction division in which the diploid number of chromosomes (two sets) is reduced to the haploid (one set).
- In the first phase of meiosis (Meiosis I) the two sets of chromosomes pair up, so that chromosomes occur in homologous pairs. Each chromosome is duplicated into two chromatids, so one pair of chromosomes is made up of four chromatids.
- The homologous chromosomes of a pair entwine, one chromatid of each pair breaks and rejoins with the broken chromatid of the other pair, in a process known as genetic recombination or crossing over.
- The chiasmata align on the equator of the nuclear spindle apparatus (NSA), before the homologous chromosomes repel each other to opposite poles.
- Cross overs are visible under the light microscope and are known as chiasmata (Greek for crosses), they result in the exchange of genes (alleles) between homologous chromosomes.
- Either chromosome of each pair can go to a particular pole, resulting in mixing of the original sets (independent assortment).
- Two daughter nuclei are thus formed, each with one (haploid) set of chromosomes, with each chromosome composed of two chromatids.
- The second phase of meiosis (Meiosis II) involves the centromeres of the chromosomes aligning on the equator of a each of two new NSA formed at right angles to the first.
- The chromatids then repel each other to form four new haploid nuclei.
- Animals and plants are typically diploid and have haploid gametes, but mosses have haploid plant bodies, produce gametes without meiosis which fuse to form a diploid sporophyte which produces haploid spores by meiosis to produce new haploid moss plants.

Pollination

Pollination is the process by which pollen is transferred from the anther lobes of the stamen to the stigma of the carpel. Flowers may be self-pollinating or cross-pollinating.

Self-pollination occurs when the stigma receives pollen from the stamens of the same flower. This is only possible in hermaphrodite flowers when the stamens and carpels mature at the same time. The stamens are often arranged so that the pollen can fall on to the stigma(s). Many self-pollinating flowers, e.g. the garden pea, self-pollinate in the bud stage before the flower opens. Indeed, in some the flower never opens and is eventually destroyed by the development of the fruit.

In **cross-pollination** the stigma receives pollen from the stamens of a different flower, which may either be on the same or on a different plant. It must be noted however that if a flower is cross pollinated by pollen from a flower on the same plant then, like self-pollination, this is still a case of **in-breeding**. It is only cross-pollination between flowers on different plants that results in true genetic **out-breeding**. There are a variety of devices which favour cross-pollination, but only some of these ensure out-breeding, that is cross-pollination between flowers on different plants.

Devices preventing self-pollination and favouring cross-pollination in hermaphrodite flowers

Hermaphrodite flowers can have their stamens and stigmas maturing at different times. In some plants, the anthers mature first (**protandry**) for example, Geranium spp., whilst in others (less commonly) the carpels mature first (**protogyny**), for example Luzula (woodrush). In many cases, however, there is an 'overlap' period when both anthers and stigmas are mature during which self-pollination could occur if the flowers have not been cross-pollinated for some reason.

Hermaphrodite flowers frequently have special arrangements of their parts to prevent self-pollination. For example, the iris has a flap on its style which prevents pollen on the back of a withdrawing insect from coming into contact with the stigma; similarly the viola has an arrangement by which the stigma is exposed to pollen on the incoming insect but is covered as the insect leaves.

Devices preventing in-breeding and favouring out-breeding

If a species has separate male plants and female plants, that is if it is dioecious, then clearly out-breeding must always occur. Some species, despite having hermaphrodite flowers, encourage out-breeding by means of genetically determined **incompatibility** by which pollen will not grow normally on the stigmas and styles of flowers on the same plant. In some cases the incompatibility is complete and pollen on the stigma of the same flower or on a different flower on the same plant never develops correctly, so that in-breeding never occurs. In others it is only partial. In these cases the pollen tube grows down the style of flowers on the same plant more slowly than pollen from another plant, but can eventually lead to fertilisation of the ovule. Partial incompatibility allows for in-breeding should out-breeding not occur.

◆ CHECKPOINT SUMMARY

- The structure of flowers is adapted to the mode of pollination, the two main ones being insect and wind pollination.
- Pollination is the transfer of pollen from the pollen sacs of the male stamens to the stigma of the female carpel.
- Insect pollinated flowers typically have bright coloured floral parts (espcially petals), nectar, and scent to attract insects.
- Petals may be modified as landing platforms for insects, stamens are designed to deposit pollen on visiting insects, and stigmas are arranged to have pollen grains deposited on them from visiting insects.
- Wind pollinated flowers have reduced floral parts, no nectar, prominent hanging stamens exposing, and large 'hairy' stigmas collecting, pollen carried on air currents.
- Wind pollinated plants typically flower before the emergence of the leaves in the spring of temperate climates.
- Various arrangements exist to reduce the possibility of pollen reaching the stigma of the same plant.
- Protandry (development of the stamens before the stigma of the carpel).
- Protogyny (development of the stigma before the stamens).
- Dioecious species with separate male and female plants.
- Pollen germinates on a compatible stigma, and the pollen tube grows down through the style, to reach the egg cell (ovum) nucleus in the ovule.
- The pollen tube nucleus degenerates, and the generative nucleus divides into two male gametic nuclei.
- One of the male gametic nuclei fuses with the ovum nucleus to form the diploid zygote nucleus, and the other fuses with the two polar nuclei to form the triploid endosperm nucleus.
- This double fertilisation is unique to flowering plants.

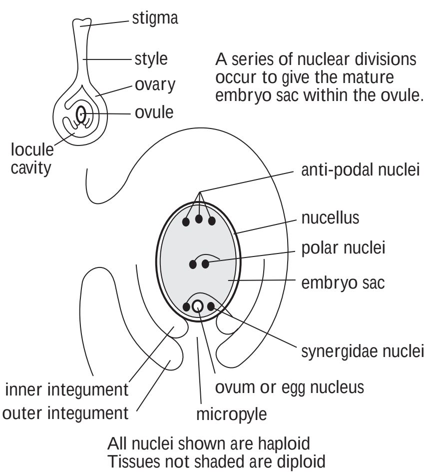
Fertilisation

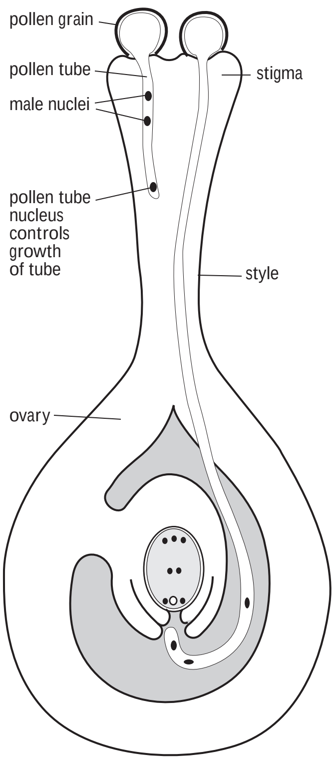
At an early stage in the development of the ovule, whilst the flower is still in bud, nuclear divisions, in which the chromosome number is halved by meiosis, occur to produce a haploid cell which divides and grows into a small structure called the **embryo sac**. This contains eight nuclei, only three of which are directly involved in the reproductive process, namely, the **egg nucleus** and the two **polar nuclei**. The embryo sac is surrounded by a nutrient-rich tissue called the **nucellus,** located within the ovule, the whole structure being surrounded by a double wall (inner and outer **integuments**). A small gap in the wall **(micropyle)** allows the entry of the pollen tube.

When a pollen grain lands on a receptive stigma, it germinates forming a pollen tube which grows through the tissues of the style and ovary until it reaches the ovule, absorbing energy-rich nutrients along the way. Growth of the pollen tube is under the control of the pollen tube nucleus, whilst the generative nucleus is carried along at the advancing tip. Before it reaches its destination, the generative nucleus divides to form two male gamete nuclei.

Fertilisation in flowering plants is a double event involving both of the male nuclei. One of these fuses with the egg nucleus to form a diploid zygote which will divide and grow into the plant embryo. The other fuses with both polar nuclei to form a triploid (triple fusion) nucleus.

After fertilisation, the ovule undergoes a number of changes to become a seed. The zygote develops into the embryo of the new plan; the triple fusion nucleus develops into the endosperm (food store) in endospermous seeds (mainly members of the grass family e.g. wheat and rice) and in others it degenerates; the integuments develop into the seed coat (testa). The wall of the ovary develops into the fruit.

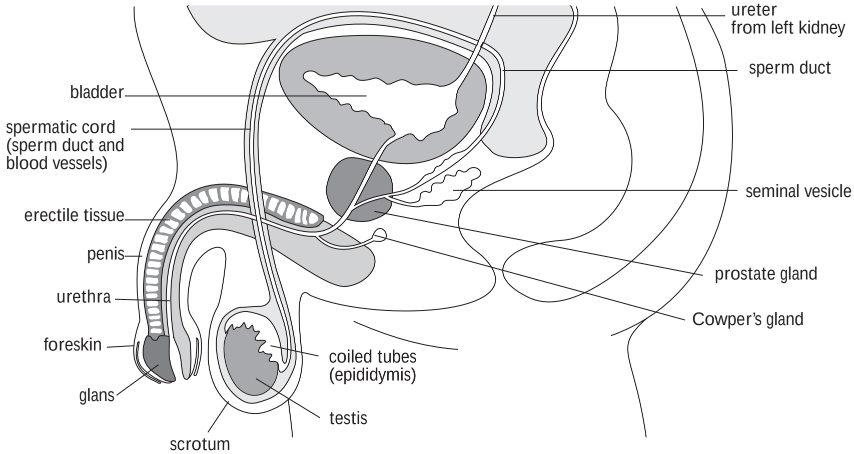




REPRODUCTION IN HUMANS

Structure and function of the male reproductive system

The male reproductive system



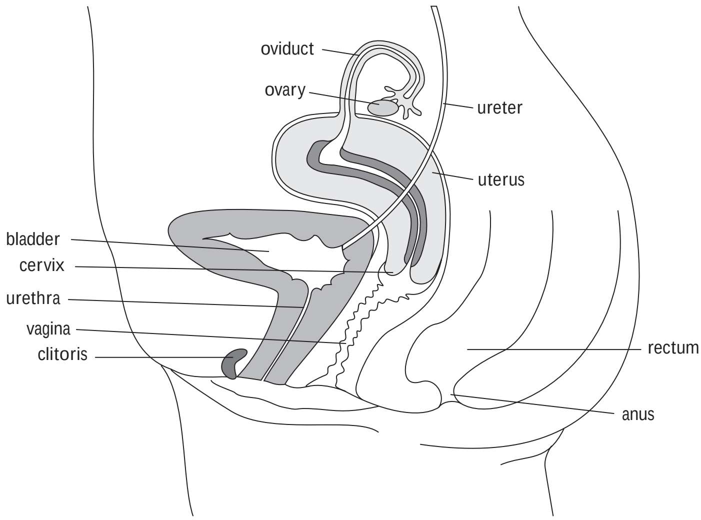
The male gamete producing organs (**testes**) have two functions. Firstly, the production of haploid male gametes (sperm) capable of fertilising an ovum and so passing on the male's genes into a new generation. Secondly, the production of male hormones, particularly testosterone. This allows the development of the secondary sexual characteristics of the male and is also needed for sperm production and sexual activity. Both functions are performed in the **semeniferous tubules** which are packed into lobules inside each testis. **Spermatogenesis** (the production of sperm discussed later) occurs in the walls of the tubules whilst testosterone is secreted by cells in between the tubules (interstitial cells). The testes lie outside the body in the **scrotum**. The function of this is to keep the testes slightly cooler than body temperature (about 35ºC) for optimal sperm production.

The remaining components of the reproductive system are all concerned with moving sperm from the testes to the **urethra** and into the female reproductive tract during sexual intercourse. The sperm are moved from the seminiferous tubules and transported to the **epididymis**, a long coiled tube where fluid is reabsorbed from the sperm and chemicals secreted which allow sperm to complete their maturation and develop the ability to swim. From here sperm are moved to the sperm ducts (vas deferens), which lead into the urethra just below the exit from the bladder.

In order to perform their functions, sperm are mixed with a variety of secretions to form **semen** before they leave the body during ejaculation (see below). The paired **seminal vesicles** secrete a watery alkaline fluid containing sugars (e.g. fructose) for nourishing the sperm. Mucus is also secreted. The **prostate gland** and **Cowper's glands** also secrete alkaline fluid and mucus. The alkaline fluid helps to neutralise any traces of urine present in the urethra and to neutralise the acid environment of the vagina, so providing more suitable conditions for the sperm to function.

The **penis** is used to convey sperm into the reproductive tract of the female during sexual intercourse. It contains **erectile tissue** and a central tube, the urethra through which semen from the sperm ducts pass. At other times this tube carries urine from the bladder. A system of **sphincter muscles** closes the exit from the **bladder** during sexual activity.

The female reproductive system



The female gamete producing organs (ovaries) lie inside the abdomen. As in the male these have two functions: the production of haploid female gametes (ova) containing genetic information from the female; and the production of female hormones, particularly oestrogen and progesterone.

These hormones control the development of secondary sexual characteristics and, along with hormones from the pituitary gland, control the events of the menstrual cycle.

Close to the border of each ovary is the **oviduct**. The oviducts are narrow tubes whose function is to transport ova released from the ovary to the uterus. The oviducts aid the movement of ova to uterus in two main ways. Firstly they have a fringed funnel which help to 'catch' the ova and guide them into the oviduct. Secondly they are lined with ciliated epithelial cells which beat and so move the ovum along towards the uterus. Fertilisation usually takes place in the oviduct.

The **uterus** is a muscular organ about 7 x 5 cm in size in a non-pregnant woman whose function is to house a developing embryo. Its wall consists of three layers: an outer covering; a thick middle layer of smooth muscle (the **myometrium**); and the inner **endometrium** containing a dense network of blood vessels and glands. The characteristics of the endometrium vary during the menstrual cycle as discussed below. During pregnancy the uterus can expand to up to 10 times its normal size.

The **cervix** or neck of the uterus is a ring of smooth muscle containing mucus secreting cells which help to provide optimum conditions for sperm survival at around the time of ovulation. The cervix is normally tightly closed but during birth will dilate to allow the baby's to emerge head first.

The **vagina** is a short muscular tube which receives the penis during sexual intercourse. It is lined with epithelial cells secreting vaginal fluids. Like the cervix it must stretch to several times its normal size during birth.

The external female genitalia or **vulva** consists of the **labia majora** and **labia minora** which surround the vaginal opening, opening of the **urethra** and the **clitoris**, a small erectile structure. The clitoris is similar in structure to the penis. Stimulation of the clitoris may result in orgasm.

Glands within the vulva secrete mucus to lubricate the penis during sexual intercourse.

Spermatogenesis and oogenesis

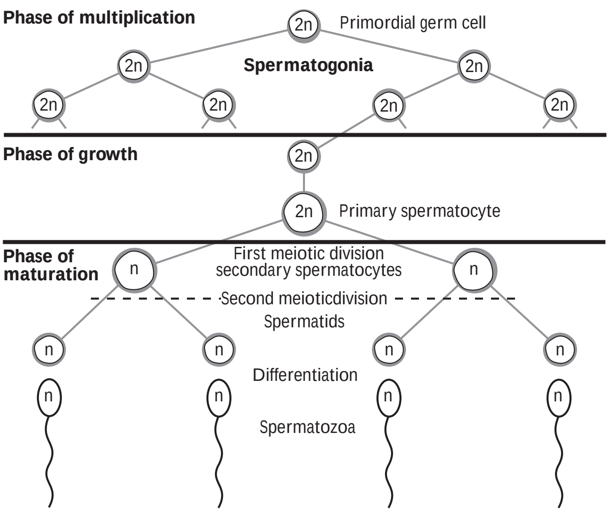
Spermatogenesis is the term used to describe the production of male gametes (sperm). Oogenesis is the production of female gametes (ova). These two processes share many essential similarities, such as the central role of meiosis in creating haploid gametes. There are however several differences in the timing and organisation of the processes. These can help to explain why adult males produce several million small sperm per day whilst women produce just one large, mature 'egg cell' per month.

Spermatogenesis

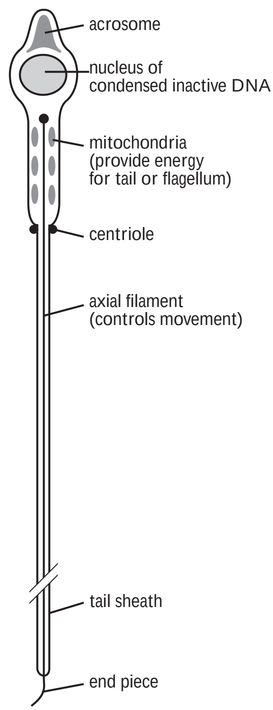
Sperm are produced in the seminiferous tubules within the testes of the adult male. The process of spermatogenesis is initiated by the hormone testosterone at the time of puberty. Epithelial germ cells in the outer layer of the seminiferous tubule divide by mitosis to form a population of diploid **spermatogonia**. These divide by mitosis and grow into **primary spermatocytes**. Each primary spermatocyte undergoes meiosis, forming two haploid **secondary spermatocytes** in Meiosis I and four **spermatids** in Meiosis II. In the final stage each spermatid develops from a round cell into a fully functional sperm cell (**spermatozoa**). This complete process of spermatogenesis takes about 70 days.

As spermatogenesis progresses, the developing sperm cells move towards the lumen of the seminiferous tubule into which they will eventually be released.The cells are attached to large **Sertoli cells** (nurse cells) until maturity. These cells provide oxygen and nutrients and remove waste products. They also play an essential role in remodelling the spermatid to form a sperm cell.

A mature sperm is approximately 20 µm in length and 2.5 µm in diameter, the smallest cell in the human body. It consists of a **head**, containing a haploid nucleus and a membrane bound sac of enzymes at the tip, (the **acrosome**), a **middle piece** containing many mitochondria to provide energy for swimming, and a **tail** containing microtubules.



Spermatozoon



Oogenesis

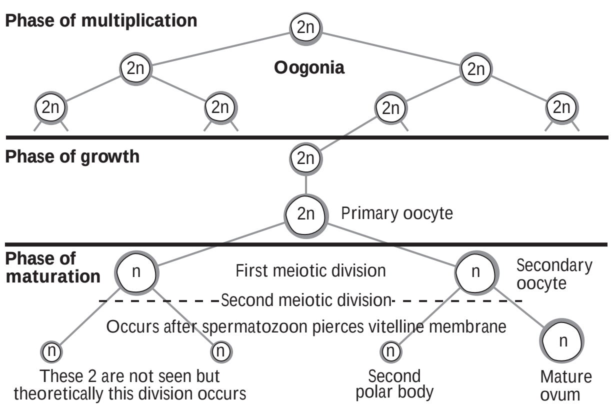
Unlike spermatogenesis, oogenesis does not begin at puberty, but in fetal life. Oogenesis begins in the germinal epithelium of the ovary where germ cells divide by mitosis to form **oogonia**. Further mitosis and growth of these cells produces **primary oocytes**. These cells begin Meiosis I but are halted during prophase. A layer of granular cells develops around each primary oocyte forming a **primary follicle**. Several million of these follicles are present at birth of which only a fraction will complete their development into gametes during the reproductive life span of the woman. From puberty onwards one follicle per month will complete its development into an **ovarian follicle** (Graafian follicle) containing a female gamete (secondary oocyte). The stages in the development of one follicle and the primary oocyte within it can be summarised as follows:

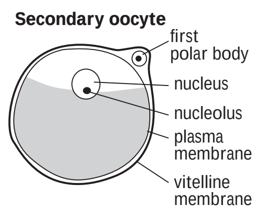
The primary oocyte inside the follicle enlarges whilst its surrounding granular cells increase in number, and are surrounded by an outer layer of cells (the **theca**) derived from the tissue of the ovary. Under the influence of **follicle stimulating hormone** (FSH) and **luteinising hormone** (LH) the follicle continues to grow into a secondary follicle, developing a central space filled with fluid secreted by the granular cells. Further enlargement, under the influence of oestrogen secreted by the granular cells, produces a mature Graafian follicle up to 1cm in diameter.

Meanwhile, inside the follicle the primary oocyte completes its first meiotic division, forming a haploid **secondary oocyte** and a small functionless **polar body** (containing the other half of the chromosomes). The second meiotic division begins but is halted in metaphase. At this point, mid way through the menstrual cycle, the Graafian follicle bursts to release the secondary oocyte. Meiosis II is not completed until the moment of fertilisation when a second polar body is formed. Strictly speaking the term **ovum** should not be used until that point.

The secondary oocyte which is released at ovulation is a large cell, about 140 μm in diameter. It contains a haploid nucleus and a large quantity of grainy cytoplasm. It is surrounded by a jelly like layer, the **zona pellucida**. The ovarian (Graafian) follicle after releasing the secondary oocyte becomes the **corpus luteum** which has an important role in the secretion of progesterone and oestrogen.

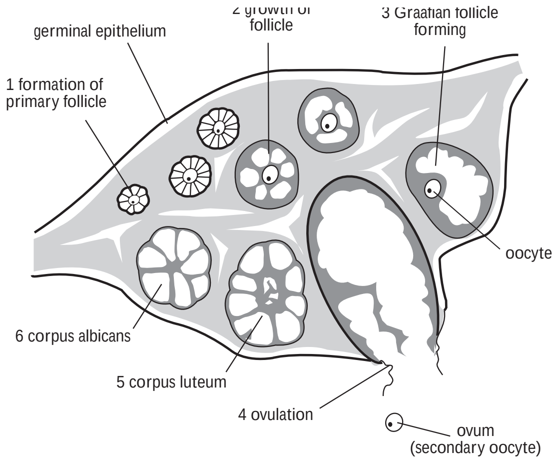
All of the changes described above occur during a single menstrual cycle. Further details of the menstrual cycle are given below.





Polar bodies take no part in reproduction and disappear, therefore only one functional cell is produced from the primary oocyte.

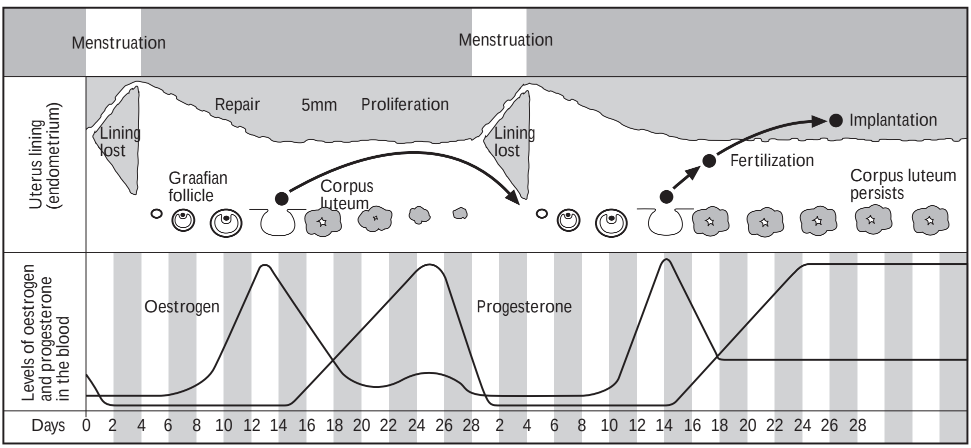
Mammalian ovary section



The menstrual cycle

Between puberty (average age 12) and the menopause (average age 45) human females experience regular sexual cycles, known as menstrual cycles. Each cycle is approximately 28 days long and involves a series of changes within the ovary and uterus. These can be considered as two separate but closely linked cycles: the **ovarian cycle** which is concerned with the development and release of an 'egg cell' around the mid point of the cycle, offering the chance of fertilisation if mating occurs; and the **uterine cycle** which is concerned with the development of the endometrium (uterus lining) to ensure the highest chance of implantation of a fertilised ovum or zygote.

Unless pregnancy occurs, one menstrual cycle will follow directly on from the next. (Therefore when interpreting graphs of the cycle note that day 28 is followed by day 1.)



The events of the menstrual cycle

The menstrual cycle relies on interactions between four main hormones: the ovarian hormones oestrogen and progesterone and the pituitary hormones Follicle Stimulating Hormone (FSH), and Luteinising hormone (LH). A further hormone, from the hypothalamus, Gonadotrophin Releasing Hormone (GnRH) is also involved. The events of the menstrual cycle are summarised below:

- Release of GnRH from the hypothalamus causes FSH to be released from the anterior pituitary. FSH travels in the bloodstream to the ovaries where it stimulates the development of several follicles (primary oocytes). One or more of these will eventually mature into an ovarian (Graafian) follicle containing the secondary oocyte.
- FSH stimulates the production of oestrogen from the follicles within the ovaries. This oestrogen in turn stimulates the growth of the endometrium, replacing cells lost during the previous menstrual period. At this point oestrogen has a negative feedback effect on FSH, reducing its production.
- Oestrogen levels increase until the mid point of the cycle when they bring about a peak of LH production from the anterior pituitary causing ovulation (the release of the secondary oocyte from the Graafian Follicle). A small peak of FSH production also occurs at the time of ovulation.
- LH causes the Graafian Follicle to develop into a corpus luteum which begins to secrete progesterone and oestrogen.
- Progesterone stimulates further development of the endometrium, in particular an increase in the density of spiral arteries and an increase in the secretion of mucus and fluid from glands in the endometrium. This is sometimes known as the secretory phase and its function is to prepare the uterus in case the newly released secondary oocyte ('egg' cell) is fertilised.
- The other function of progesterone is to inhibit the production of both FSH and LH and hence the development of further follicles. This is an example of negative feedback.
- If fertilisation does not occur, the corpus luteum degenerates and secretion of progesterone and oestrogen falls. This fall causes the uterine blood vessels to rupture and the uterus lining to degenerate and pass out of the body via the vagina. This is known as menstruation or the menstrual period and lasts for 4-5 days. Decline in progesterone levels causes the inhibition of FSH and LH to be removed and a new cycle can begin. Note that a new cycle begins whilst menstruation is still occurring.
- If fertilisation does occur then the corpus luteum does not degenerate but continues to secrete progesterone and oestrogen, maintaining the uterus lining and preventing further follicles from developing. After about 12 weeks of pregnancy in humans and corresponding times in other mammals the developing placenta takes over this hormonal (endocrine) role.

CHECKPOINT SUMMARY

- The male reproductive system consists of the testes which produce spermatozoa by meiosis.
- A system of tubes and erectile tissue transfer them to the female reproductive tract.
- Accessory glands are important in secreting substances essential for successful fertilisation of the female.
- The female system consists of ovaries which release egg cells (ova) into the abdominal cavity, from where they are swept down the oviducts by ciliated epithelium, into the uterus where they may or not be implanted.
- The uterus connects to the exterior by the vagina.
- The ova are produced (oogenesis) by meiosis in the germinal epithelium of the ovaries. Of the products of meiotic nuclear division, one accumulates all the cytoplasm to form the relatively large ovum, and the others are reduced to polar bodies.
- Spermatozoa are produced (spermatogenesis) by meiosis in the germinal epithelium of the testes. The four products of meiosis all develop into spermatozoa.
- The menstrual cycle is a monthly version of the ovarian cycle found in all mammals.
- A sequence of hormonal secretions from the brain, pituitary gland, and the ovaries themselves, coordinated by negative feedback loops control the events of the cycle.
- Luteinising hormone stimulates the release of the an ovum from an ovarian follicle, and the development of the corpus luteum. In the male it stimulates the secretion of testosterone by the testes.
- Follicle stimulating hormone initiates the development and growth of the ovarian follicles, and stimulates the ovary to secrete oestrogen. In males it stimulates spermatogenesis by the testes.
- Oestrogen stimulates the development of the primary and secondary sexual characteristics, the development of the uterus lining in the first half of the menstrual cycle.
- Progesterone stimulates the secretory phase of the uterus in the second half of the cycle, and maintains pregnancy whilst suppressing further ovulation

The transfer of male gametes and fertilisation

If fertilisation is to occur then male gametes must come into contact with the female gametes. Under natural circumstances male gametes are transferred into the reproductive tract of the female via the penis during sexual intercourse.

For sexual intercourse to occur, the male's penis must first become erect. This occurs following sexual stimulation and involves an increase of blood flow into the spongy erectile tissue of the penis. Movement of the erect penis inside the vagina during intercourse stimulates the sensory cells at the tip of the penis. A series of stages, co-ordinated by the sympathetic nervous system then follow, eventually leading to ejaculation: the release of semen containing sperm into the vagina. These stages include:

- contraction of the involuntary muscle lining the sperm duct and epididymis so forcing the sperm towards the urethra;
- contraction of the seminal vesicles, Cowper's and prostate glands which add their secretions to the sperm;
- closure of the bladder sphincter muscle; and reflex contractions of the muscles surrounding the urethra, forcing the semen out of the penis and high into the vagina of the female. Ejaculation is accompanied by the intense sensation of orgasm.

A single ejaculation can contain several hundred million sperm. Once in the vagina these sperm acquire the ability to swim and begin their journey through the cervix (first aligning themselves with long chains of mucus), across the uterus and up into the oviducts. The speed with which they may reach the oviducts suggests that muscular movements of the uterus and oviduct may in fact be more important than swimming at this stage. It has been suggested that chemicals called prostaglandins contained in seminal fluid could bring about this effect. If ovulation has occurred within 24 hours prior to this, a secondary oocyte should be present in one of the oviducts and it is here that fertilisation may take place.

Fertilisation

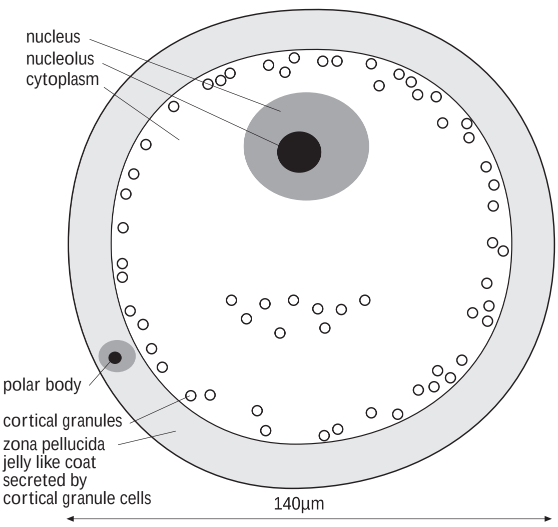
Fertilisation is the process by which the haploid nucleus of a single sperm cell fuses with the haploid nucleus of a single ovum creating a diploid zygote.

Before a sperm can fertilise the secondary oocyte it must undergo a process known as **capacitation** where it is 'primed' for the process by the acid environment of the uterus. The main feature of this involves changes in the cell membrane of the sperm in the region around the acrosome vesicle. Firstly the membrane is weakened and becomes more permeable, and the acrosome membrane fuses with the cell membrane.

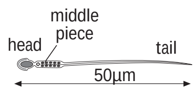
When a sperm comes into contact with the zona pellucida of a secondary oocyte the acrosome reaction occurs. This involves the acrosome splitting open and releasing the lytic enzymes contained within it. These begin to digest the zona pellucida, allowing the sperm to move through it to reach the cell membrane of the secondary oocyte. When it reaches the membrane it fuses with it and its head enters the cytoplasm. The tail is left behind. Entry of the sperm stimulates the nucleus of the secondary oocyte to complete its second meiotic division so that it can fuse with the nucleus of the sperm.

One of the surprising things about fertilisation is the mechanism which allows just one single sperm to penetrate the secondary oocyte when several hundred or thousand sperms are surrounding this cell. As the sperm enters the secondary oocyte a number of changes occur which result in the layer surrounding the egg cell (zona pelucida) becoming impermeable to other sperm.

Human female gamete (secondary oocyte) just before fertilisation



Human male gamete just before fertilisation



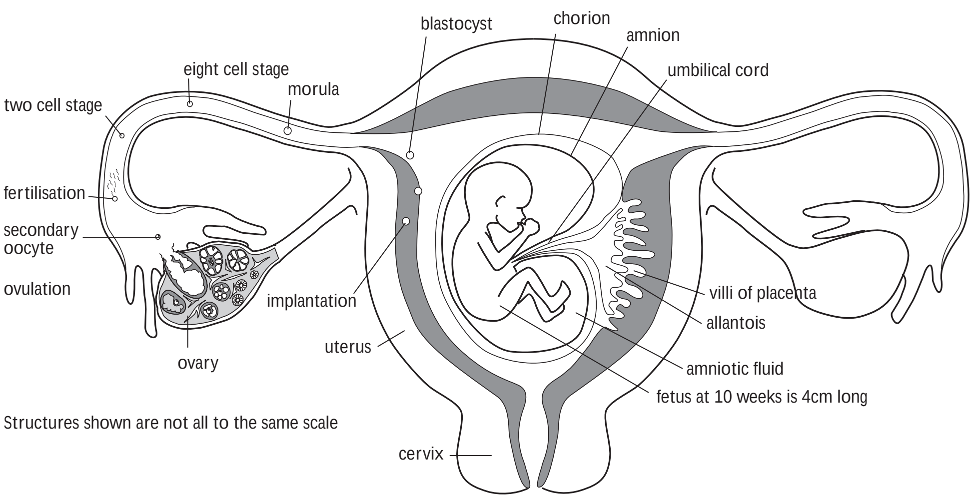
140µm is smaller than the smallest dot you can make with a fine ball point pen

Implantation

Following fertilisation the zygote undergoes cell division by mitosis forming a small ball of identical cells within a few days. Gradually the cells start to differentiate (become specialised for different tasks) and the ball of cells becomes a hollow sphere filled with fluid (blastocyst). The outer wall of the blastocyst is made of cells called **trophoblasts** which will form the villi which grow into the wall of the uterus at implantation. A small mass of cells inside this layer will form the embryo. As these changes occur, the zygote moves slowly down the oviduct and towards the uterus where it must implant in the uterine wall if further development is to take place. The cells secrete a hormone called **human chorionic gonadotrophin (hCG)** which maintains the corpus luteum, ensuring that it continues to secrete oestrogen and progesterone. (The presence of hCG in the urine is detected in a 'pregnancy test'.)

When the blastocyst arrives in the uterus it is still contained within the zona pellucida. As this breaks down the trophoblastic cells of the blastocyst come into contact with the endometrium of the uterus. They begin to invade the endometrium, secreting digestive enzymes and growing into the maternal tissues. This process, which results in the blastocyst becoming embedded in the endometrium, is known as implantation. It occurs as early as seven days after fertilisation.

Implantation is the first stage in the crucial association between maternal and fetal tissues and circulation which form the basis of mammalian development. As the trophoblastic cells become embedded in the endometrium of the uterus they differentiate to form finger like projections which penetrate deep into the endometrium. These are the **chorionic villi**. Enzymes secreted by the cells of the villi digest the walls of the spiral arteries and veins within the endometrium and create blood filled spaces around each villus. From here the maternal blood nutrients and oxygen diffuse into the villi and are delivered to the cells of the blastocyst. Carbon dioxide and other waste materials diffuse out of the blastocyst and into the maternal blood down their concentration gradients. The efficiency of these exchanges is improved by the large surface area of chorionic villi.



Over the following weeks rapid growth and development of both the chorionic region and the embryo occur. Within three to four weeks of fertilisation blood is circulating through embryo and villi. This improves the efficiency of exchange.

The structure and function of the placenta

The placenta is fully formed 12 weeks after fertilisation. On the maternal side it consists of projections of the endometrium between which lie a series of blood filled spaces. Blood from the maternal arteries enters the spaces where exchange is performed and then returns to the circulation in the maternal veins. On the fetal side, chorionic villi project into the blood filled spaces. Each villus contains branches of the umbilical artery and vein which form a dense network of capillaries. These join up to form the **umbilical artery** and **veins** which run through the umbilical cord to the embryo (at this stage called the fetus). It should be noted that the blood of mother and fetus are kept entirely separate. This helps to regulate exchanges between mother and fetus, protects the fetus from the effects of high maternal blood pressure which would damage its small blood vessels, prevents possible immune reactions which might occur if the fetus was of different blood group to the mother, and prevents the entry of mature female hormones which would be dangerous even for a female fetus.

The placenta has two main roles in relation to the development of the human embryo and fetus. Firstly it is the organ of exchange between mother and fetus, supplying the fetus with nutrients and oxygen and removing carbon dioxide and urea. Antibodies are also supplied to the fetus which protect it from infections in the first months of life. Secondly it is an endocrine organ producing several hormones throughout the gestation period (development time before birth).

In order to perform its exchange roles efficiently the placenta must provides a large surface area for exchange of nutrients and gases; a thin yet selectively permeable barrier between maternal and fetal blood; and a steep concentration gradient for each substance in the appropriate direction.

A large surface area is provided by the numerous villi and the highly branched capillaries within the villi between the fetal blood contained in vessels and the maternal blood in the large blood filled spaces of the placenta. Maternal and fetal blood are separated by just a few layers of cells creating a short diffusion distance. Small molecules (eg. oxygen, carbon dioxide, urea, water) move across by simple diffusion whilst amino acids and glucose cross by facilitated diffusion. Some vitamins and minerals move by active transport.

Oxygen, glucose, amino acids and other substances required by the fetus need to be at a much higher concentration in the maternal blood than they are in the fetal blood for efficient diffusion to occur. Similarly, carbon dioxide and urea must be at a low concentration in the maternal blood if they are to diffuse out of the fetal blood and be removed. Favourable gradients are maintained by the fact that the fetus has a small volume of blood but a high rate of blood flow whilst the mother has a slower rate of blood flow but a larger volume of blood in the spaces of the placenta, and by an overall counter-current system of blood flow in which the maternal and fetal blood flow in opposite directions maintaining steeper diffusion gradients. Just before birth about 10% of the mothers blood flows through the placenta on each circuit of the body, aiding rapid exchanges.

Hormones secreted by the placenta

The placenta secretes three main hormones:

▼ Human chorionic gonadotrophin (hCG)

▼ Progesterone

▼ Oestrogen.

Each has specific roles relating to fetal development and/or maternal changes associated with pregnancy, birth and lactation (milk production).

hCG is secreted in only small amounts by the placenta but is thought to have roles in suppressing FSH and LH from the pituitary and in stimulating development of some fetal systems.

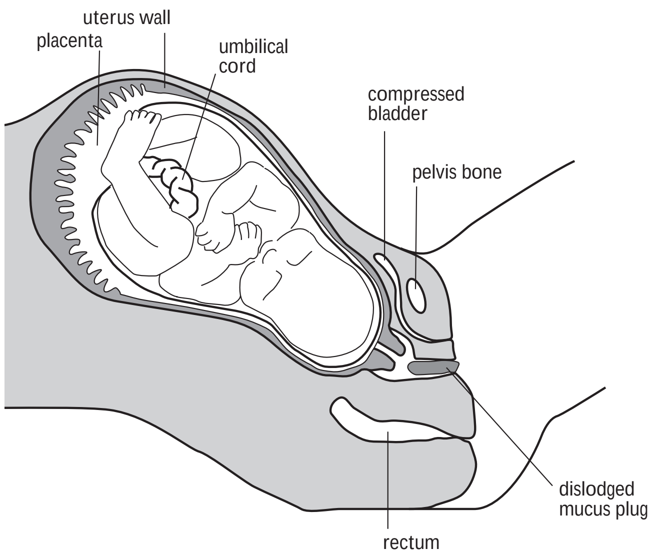
Progesterone is secreted in relatively large quantities (250-350mg/day). High levels prevent shedding of the endometrium, inhibit ovulation and may aid breast development.

Oestrogen is necessary for the maintenance of pregnancy (perhaps through inhibiting FSH) and is thought to be involved in preparing the body for birth and in breast development.

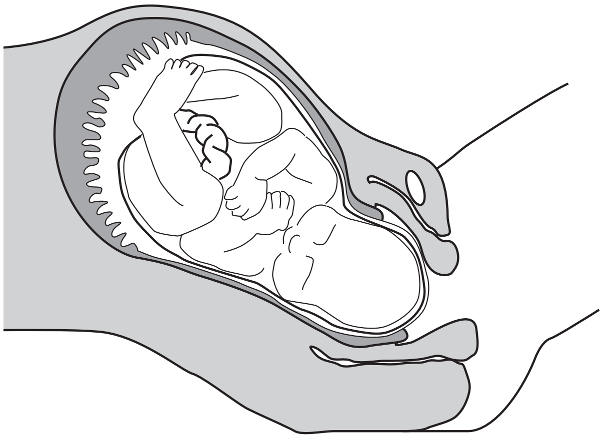
Birth

Approximately 38 weeks after fertilisation the fetus is ready to be born. At around this time the level of the hormone progesterone decreases rapidly and the level of oestrogen increases. The effect of this is to make the uterus wall more susceptible to the effects of **oxytocin**, a hormone produced by the posterior pituitary gland, which causes contraction of the muscle layer of the uterus (the myometrium). The exact signals which trigger these changes in hormone levels and hence initiate the birth process are not clear but are thought to involve a mixture of physical and hormonal signals from both mother and fetus.

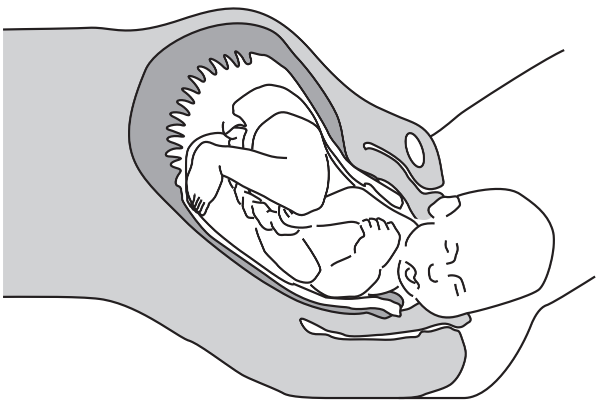
The birth process can be divided into several stages.

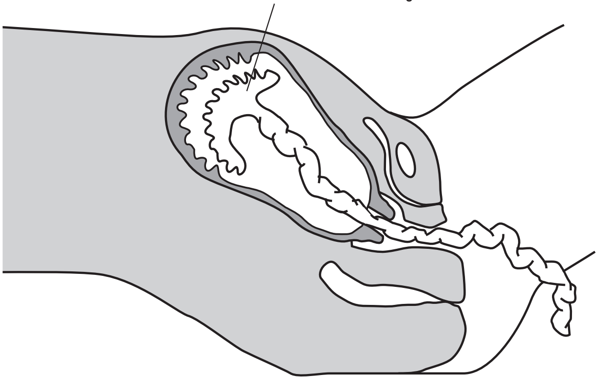


In the **first stage**, which may last 12 hours or more, the uterus begins to contract and the cervix begins to dilate. During, or sometimes before the main contractions begin the amniotic sac bursts and the fluid is released via the vagina. A plug of mucus which blocks the cervix during pregnancy also detaches and passes out of the vagina. Over time the force and frequency of the contractions increases under the control of oxytocin and they spread out through the muscle fibres of the uterus from top to bottom, gradually pushing the fetus downwards toward the cervix. By the end of this stage the cervix has dilated to about 10cm in diameter, wide enough to allow the fetal head to 'engage' and then pass through.



The **second stage** involves the actual birth of the baby which is pushed out of the uterus, through the cervix and down the vagina. The majority of babies are born head first, having moved into this position in the uterus in the weeks leading up to birth. The head and shoulders of the baby are the widest part so once these have passed through the cervix the rest of the body, still attached to the placenta via the umbilical cord, follows more easily. Once it emerges the baby begins to breathe. Since it no longer requires an oxygen supply via the placenta the umbilical cord is cut and tied/clipped.





The third stage involves the loss of the placenta from the body. Final contractions allow this structure to detach itself from the uterus wall and pass out of the vagina. Although a large loss of blood may be expected, muscle fibres around the blood vessels contract to limit this.

Lactation

In its first nine months of life before birth the fetus obtains all its nutritional requirements via the placenta. After birth it must ingest milk produced by the mammary glands of the mother and delivered via the nipple. Suckling begins soon after birth and a new born baby may spend several hours per day engaged in feeding. For the first four months of life babies are rarely given any other food or drink, and in many cultures breast feeding may continue to supplement other foods for several years. The production of milk is known as lactation.

Milk, is a watery fluid containing the sugar lactose along with fat, and proteins, some vitamins and minerals. It is produced in the milk glands of the breast and its secretion is stimulated by suckling. The substances contained in milk are easily digested in and absorbed from the baby's gut.

Milk production is controlled by the interaction of several hormones. During pregnancy, the hormones oestrogen and progesterone stimulate the development of breast tissue containing milk glands and milk ducts. However, milk is not produced and released at this stage as progesterone and oestrogen inhibit another hormone, **prolactin** which is also required. The fall in levels of progesterone and oestrogen after birth removes this inhibition and allows prolactin from the anterior pituitary gland to act on the breast tissue. It stimulates the milk glands of the breast which are lined with milk producing epithelial cells to secrete milk.

Milk is not released until the milk ejection reflex is initiated by the sucking action of a baby. The following steps are involved:

- nerve impulses from sensory receptors in the nipple are sent to the hypothalamus; this stimulates the posterior pituitary gland to produce **oxytocin**;