

GAMETOGENESIS

In the animal kingdom, and particularly within the class of mammals, the presence of a genital system is closely associated with sexual reproduction. During the embryonic and fetal phase, development takes place.

- a) The primitive sexual characteristics : testis and ovary.
- b) The primary sexual characteristics : genital ducts and external genital organs.

During the initial phase of embryonic development, the genital system is undifferentiated and shows a similar organization in both sexes. In this study, we will examine the development of the genital system, and in particular the phase during which, under the influence of chemical substances produced first by the sex genes and then by the gonads themselves, it begins to take on its definitive form.

Gametogenesis, or the formation of gametes, is a complex biological process that takes place in specific reproductive organs. These organs, called "genital glands" or "gonads," are present in the species studied and include the male structures, such as the testes, and the female structures, such as the ovaries.

Gametes are specialized cells that develop from stem cells known as "gonocytes" or "primordial germ cells." This process takes place during the embryonic development of the individual. These gonocytes undergo an early separation into three layers essential to the development of the embryo. These are recognized as follows :

The germen is the cell line responsible for producing the gametes.

The soma comprises all the somatic cells, that is, the cells of the organism that are not directly involved in forming the gametes.

In diploid species, gametes are haploid cells specialized for sexual fusion. These are specific to each species. It should also be noted that our domestic animals are classified as heterogametic, a classification that stands in contrast to isogametic species. This classification refers to the production of morphologically distinct gametes by the two sexes.

Among the elements studied, the female oocyte stands out for its size, immobility, and scarcity.

The spermatozoon, characterized by its small size, motility, and abundance, is the male reproductive element.

Their formation is governed by common fundamental mechanisms, the main process being chromatic reduction, or meiosis. This biological process involves halving the number of chromosomes, moving the cell from the diploid state to the haploid state.

1. Stages of Gametogenesis

1.1. Proliferation Phase (Multiplication)

During cell reproduction, this phase corresponds to the period of multiplication of the gonads (oogonia and spermatogonia) through equational mitoses, in the same way as somatic cells. These successive and numerous cell divisions preserve the integrity of the genetic material, thereby maintaining the diploid character of these cells. Initiated during migration, this phase continues actively for a period that varies more or less depending on the species. Throughout this process, the cells remain poorly differentiated until the last cells formed differentiate into "-cytes I." This final step marks the completion of proliferation: in females it coincides with the entry of the oogonia into meiosis, while in males it coincides with a slowing down, or even a complete halt, of spermatogonial mitoses (a state of quiescence notably observed in rodents).

1.2. Growth Phase (Meiotic Prophase)

During this phase, which corresponds to the prophase of the first meiotic division, the last generation of gonads stop dividing and increase in size (both nucleus and cytoplasm) to become first-order cells: primary spermatocytes in males and primary oocytes in females, thereby becoming auxocytes. The extent of this increase in volume depends on the cell type: it is very slight in the primary spermatocyte, but considerable in the primary oocyte, since it corresponds to the accumulation of cytoplasmic reserves needed for the first divisions of the embryo. At this stage, the -cytes I are still diploid cells. Their DNA consists of two sets (one paternal and one maternal), each made up of an identical series of n chromosomes (where n is a number characteristic of the species). Since each chromosome consists of a strand of DNA, the diploid cell therefore has $2n$ chromosomes. These are arranged into $(n-1)$ pairs of homologous chromosomes (or autosomes) and one pair of heterologous (sex) chromosomes.

Table 1 : Chromosome number in various domestic species (Moens, 2021)

Species Count ($2n =$)	Species Count ($2n =$)
Human 46	Rat 42
Cat 38	Pig 38
Cattle 60	Rabbit 44
Dog 78	Horse 64
Sheep 54	Donkey 62
Mouse 40	Chicken 78
Goat 60	

1.3. Maturation Phase

This is a relatively short step corresponding to the completion of meiosis. During this phase, the germ cells undergo two successive maturation divisions. First, a first-order -cyte divides to give two second-order -cytes. The second meiotic division then follows almost immediately, since it requires no further DNA synthesis ; each -cyte II then divides into two -tids. By the end of maturation, this process results in the formation of genuinely haploid cells, each containing n chromosomes.

1.4. Differentiation Phase

Specific to the male sex, this phase corresponds to the process of spermiogenesis. During this step, the spermatid undergoes differentiation to become a motile, highly specialized cell: the spermatozoon.

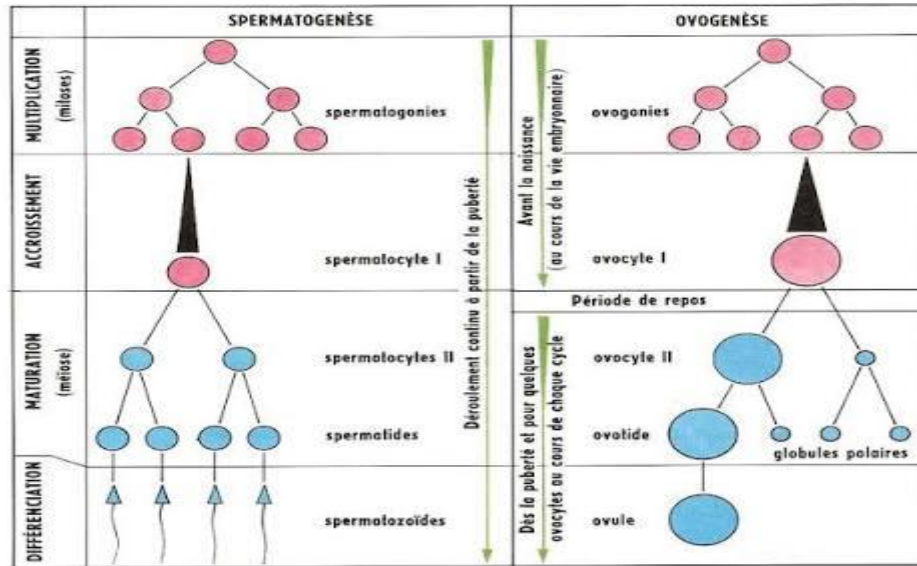


Figure 1. The stages of gametogenesis

2. Differences between Spermatogenesis and Oogenesis

Table 2: Comparison between spermatogenesis and oogenesis

Organ	Testis	Ovaries
Number of gametes produced	4 spermatozoa	1 egg + 2 polar bodies that degenerate
Chromosome type	Half of sperm→X Half of sperm→Y	All eggs →X
Motility	+ →flagellum	-
Gamete lifespan	About 4 days	About 24 hours
Production rate	Daily (millions/day) of sperm	Monthly (1 egg/month)
Production time	72 to 75 days	Decades, or more, for eggs maturing as menopause approaches
Duration of gamete production	From puberty to advanced age. Spermatogonia renew themselves by mitosis	Puberty→menopause (about 50 years). Oogonia do not renew themselves. The girl is born with her full reserve

SPERMATOGENESIS

Spermatogenesis is the continuous process of formation, growth, and maturation of haploid male gametes (spermatozoa) from diploid stem cells called spermatogonia. This slow process, whose complete cycle takes about 74 days in humans, begins at puberty, reaches its peak around 20-30 years of age, then gradually slows down while potentially continuing into advanced age. It takes place specifically in the seminiferous tubules of the testes, within the male genital system, which comprises all the organs responsible for producing semen and depositing it in the female genital tract.

The male reproductive system is made up of three sections (figure 3)

- ✓ The glandular section includes the two testes.
- ✓ The tubular section is made up of storage and transport pathways. These include the epididymis, the vas deferens, and the seminal vesicle gland.
- ✓ Urogenital section: the urethra, the prostate, and the bulbourethral (Cowper's) glands.

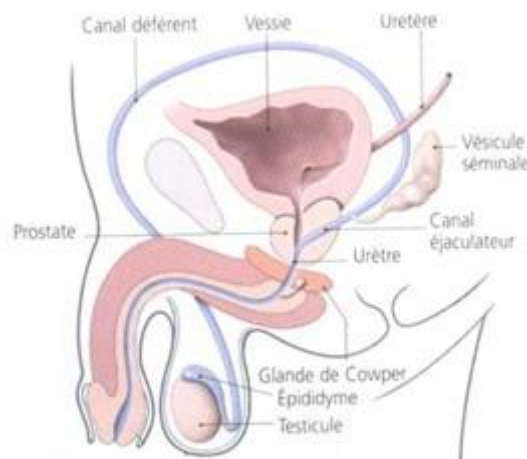


Figure 2 : Sagittal section of the male genital system

1. Male Genital System and Testicular Organization

The male genital system is made up of a set of anatomical structures that work together to carry out reproductive functions.

- The testis, generally oval in shape, is associated with an elongated structure called the epididymis, which forms a widening at one of its ends (figure 3)

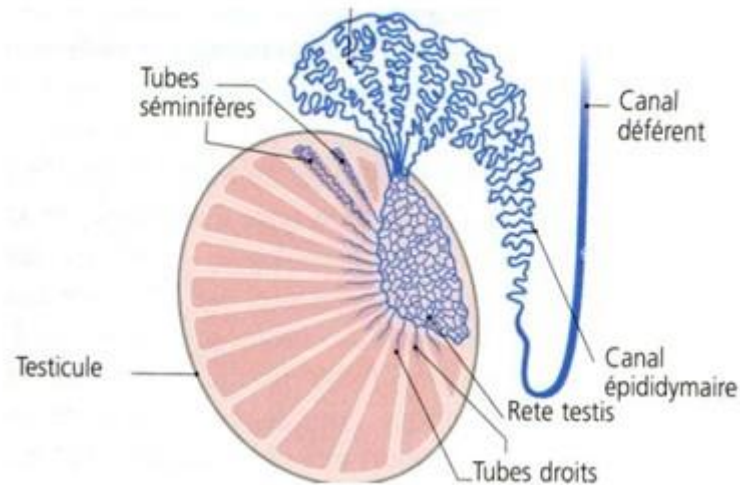


Figure 3 Sagittal section of a human testis (Poirier et al, 2005)

The seminiferous tubules are important for producing spermatozoa (see figure 4 a, b). They are organized in a manner similar to an epithelium, a layer of cells that develops in several layers on a base. These tubules are made up of somatic cells (Sertoli cells) and germ cells. During the production of spermatozoa, these cells move toward the center of the tubule, following a forward-moving progression.

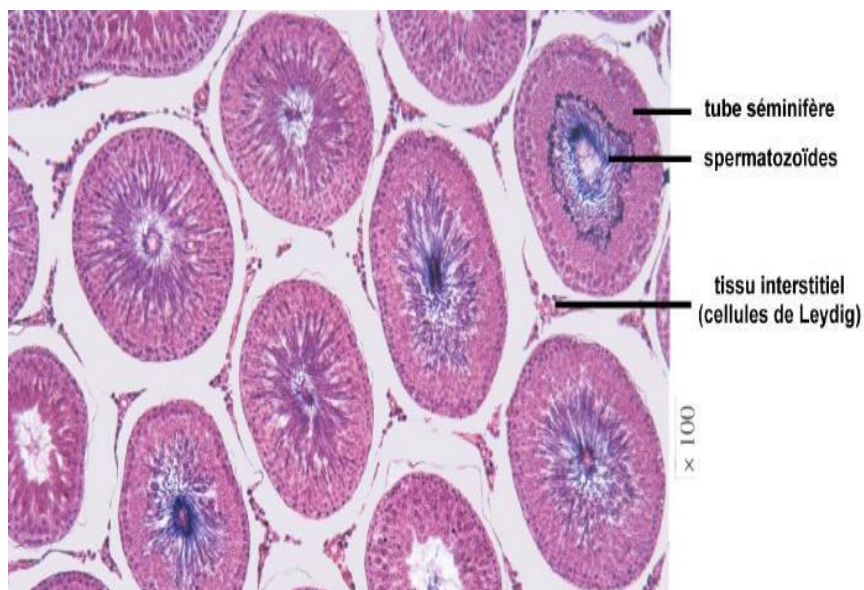


Figure 4 (a) Cross-section of seminiferous tubules (Poirier et al, 2005)

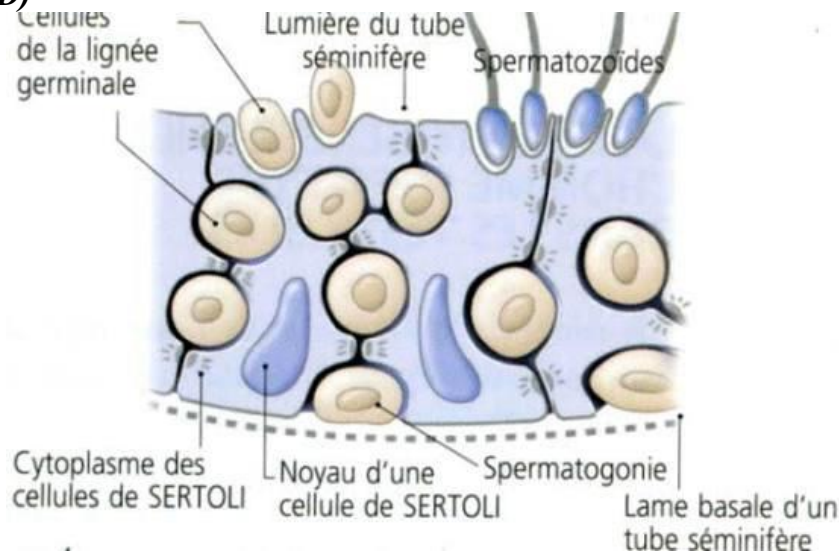


Figure 4 (b) Simplified diagram of the wall of a seminiferous tubule (Poirier et al, 2005)

The seminiferous tubules are surrounded by loose connective tissue. This tissue contains blood vessels and cells. These cells occur in clusters. They have an endocrine function. This is the case for **the Leydig cells**. These cells produce testosterone.

The spermatogonia and the Sertoli cells are in contact with the base. The "Sertoli cells" form cavities where the germ cells live. They play a role in their nutrition and maturation. They also consume the waste produced by the spermatozoa during their development.

They notably secrete ABP (Androgen-Binding Protein), which binds testosterone and maintains a high concentration of this hormone in the seminiferous tubules.

The Excretory Pathways and Accessory Glands

Beyond the testis itself, the male genital system includes a network of excretory ducts and accessory glands whose combined secretions transport, mature, and nourish the spermatozoa before ejaculation (Thibault & Levasseur, 2001).

- **The Epididymis:** A long, highly convoluted duct (several metres when uncoiled) applied against the posterior border of the testis. It is classically divided into three regions: the head (caput), closely connected to the efferent ducts leaving the testis; the body (corpus); and the tail (cauda), which continues into the vas deferens. Spermatozoa leaving the testis are immotile and incapable of fertilizing an oocyte; during their transit through the epididymis, which takes about 10 to 14 days, they acquire progressive motility and fertilizing capacity, a process supported by the secretory and absorptive activity of the epididymal epithelium (Poirier & Ribeiro, 2001). The cauda epididymidis also serves as the main storage site for mature spermatozoa between ejaculations.
- **The Vas Deferens (Ductus Deferens):** A thick-walled muscular duct, about 40 cm long, that continues the epididymis and carries spermatozoa toward the urethra. Its wall, rich in smooth muscle, undergoes powerful peristaltic contractions at the time of ejaculation, propelling the spermatozoa forward. It ascends within the spermatic cord,

crosses the pelvic cavity, and joins the duct of the seminal vesicle to form the ejaculatory duct, which opens into the urethra at the level of the prostate (Poirier & Ribeiro, 2001).

- **The Seminal Vesicles:** Two paired glandular pouches located behind the bladder. They secrete a viscous, alkaline fluid rich in fructose (the main energy substrate for spermatozoa), prostaglandins, and coagulation proteins. This secretion constitutes the largest fraction (about 60%) of the volume of seminal fluid (Thibault & Levasseur, 2001).
- **The Prostate:** An unpaired gland surrounding the first segment of the urethra, just below the bladder. It secretes a thin, slightly acidic fluid containing enzymes (notably prostate-specific antigen, PSA) that liquefies the seminal coagulum after ejaculation, facilitating spermatozoal motility. Its secretion contributes about 20 to 30% of seminal fluid volume (Poirier & Ribeiro, 2001).
- **The Bulbourethral (Cowper's) Glands:** Two small glands located below the prostate, on either side of the membranous urethra. Before ejaculation, they secrete a clear, viscous, alkaline mucus that lubricates the urethra and neutralizes residual acidity from urine, thereby protecting spermatozoa during their passage.
- **The Urethra:** The common terminal duct for both urine and semen. It is divided into three segments: the prostatic urethra, surrounded by the prostate and receiving the ejaculatory ducts; the membranous urethra, the shortest segment, which crosses the pelvic floor; and the penile (spongy) urethra, which runs the length of the penis and opens at the external urethral meatus.
- **The Scrotum:** The cutaneous and musculo-membranous pouch that contains the testes and epididymides outside the abdominal cavity. Its wall includes a thin layer of smooth muscle (the dartos) that contracts or relaxes in response to temperature, adjusting the distance between the testes and the body. This mechanism, together with the pampiniform venous plexus that cools arterial blood before it reaches the testis, maintains testicular temperature about 2 to 4°C below core body temperature — a condition essential for normal spermatogenesis (Thibault & Levasseur, 2001).

2. Stages of Spermatogenesis (Formation of Spermatozoa)

Process of formation of male gametes

Introduction Spermatogenesis comprises the set of cellular and morphological events which, within the seminiferous epithelium of the testes, lead to the formation of spermatozoa from diploid stem cells, the spermatogonia. This continuous physiological process begins at puberty under strict neuroendocrine control and spans approximately 74 days in humans (Clermont, 1972). It generates highly specialized, haploid, motile cells essential for sexual reproduction. This process takes place along a centripetal gradient (from the basement membrane toward the lumen of the tubule) and is divided into four successive phases (Perrard *et al.*, 2010) :

2.1. Multiplication Phase (Mitotic Proliferation)

Spermatogonia, diploid stem cells ($2n$ chromosomes and $2n$ DNA), multiply by mitosis. They are the most peripheral germ cells. They are located in the basal compartment of the tubule, in contact with the basement membrane and the Sertoli cells.

- ✓ Type A1 or Ad (dark) spermatogonia are the true stem cells.
- ✓ Type A2 or Ap (pale) spermatogonia represent the first cellular stage of spermatogenesis proper and have a lifespan of 18 days before dividing into 2 type B spermatogonia.
- ✓ Type B spermatogonia divide after 9 days to give 2 primary spermatocytes; the 2 primary spermatocytes do not separate completely, and cytoplasmic bridges persist until the end of spermatogenesis, allowing exchanges between all the cells derived from the same gonium and enabling synchronous development.

2.2. Growth Phase

This concerns the primary spermatocytes and corresponds roughly to the interphase and the beginning of the prophase of the first meiotic division. Cell size increases through the accumulation of synthesized material. When they reach their maximum size, of $25\text{ }\mu\text{m}$, they are referred to as auxocytes.

2.3. Maturation Phase (Meiosis)

This is the fundamental step in reducing the genetic material (Embryology.ch, 2023):

- **The reductional division (Meiosis I):** The primary spermatocyte completes its long prophase (leptotene, zygotene, pachytene, diplotene, diakinesis), during which genetic recombination (crossing-over) occurs. The division gives rise to two second-order spermatocytes (secondary spermatocytes), which are haploid (n chromosomes, $2n$ DNA).
- **The equational division (Meiosis II):** Very rapid, it splits each secondary spermatocyte to form a total of four haploid spermatids, each with n chromosomes.

2.4. Differentiation Phase (Spermiogenesis)

Spermiogenesis, a step specific to male gametogenesis, corresponds to the complex metamorphosis of spermatids (initially round, unremarkable cells) into mature spermatozoa. Lasting 23 days, this final phase involves no cell division, but is characterized by profound ultrastructural remodeling. It ends with spermiation, that is, the release of newly formed spermatozoa into the lumen of the seminiferous tubule.

This metamorphosis includes five major events:

- **Nuclear condensation and elongation:** nuclear changes begin around the middle of spermiogenesis: the nucleus elongates and becomes progressively denser. This condensation results from the replacement of histones by protamines, leading to extreme compaction of the chromatin. The anterior two-thirds of the nucleus are covered by the acrosome; the posterior third remains in contact with the cell's cytoplasm.

- **Formation of the acrosome from the Golgi apparatus:** the Golgi vesicles develop, become pro-acrosomal granules, and then fuse to form a single vesicle — the acrosomal vesicle — which spreads out and comes to cover two-thirds of the nucleus. It then takes the name acrosome, and its content becomes homogeneous. The acrosome, a true large lysosome located at the anterior pole of the future spermatozoon, contains hydrolytic enzymes (hyaluronidase, acrosin) essential for penetrating the oocyte's envelopes during fertilization.
- **Development of the flagellum:** the two centrioles migrate to the pole opposite the acrosome. The microtubules of the distal centriole elongate and organize into an axoneme, which extends and emerges from the cell by pushing back the plasma membrane, thereby providing the future motility of the spermatozoon.
- **Formation of the middle piece (mitochondrial sheath):** the mitochondria arrange themselves end to end in a spiral around the initial portion of the axoneme, forming the mitochondrial sheath of the middle piece — this structure will supply the ATP needed for flagellar movement. At its distal end, the sheath is bounded by a dense ring called the annulus.
- **Elimination of the cytoplasm:** most of the cytoplasm is phagocytosed by the Sertoli cells. Part of it detaches, forming residual bodies (of Regaud). The remainder is eliminated during the final phase of maturation, during passage through the epididymis.

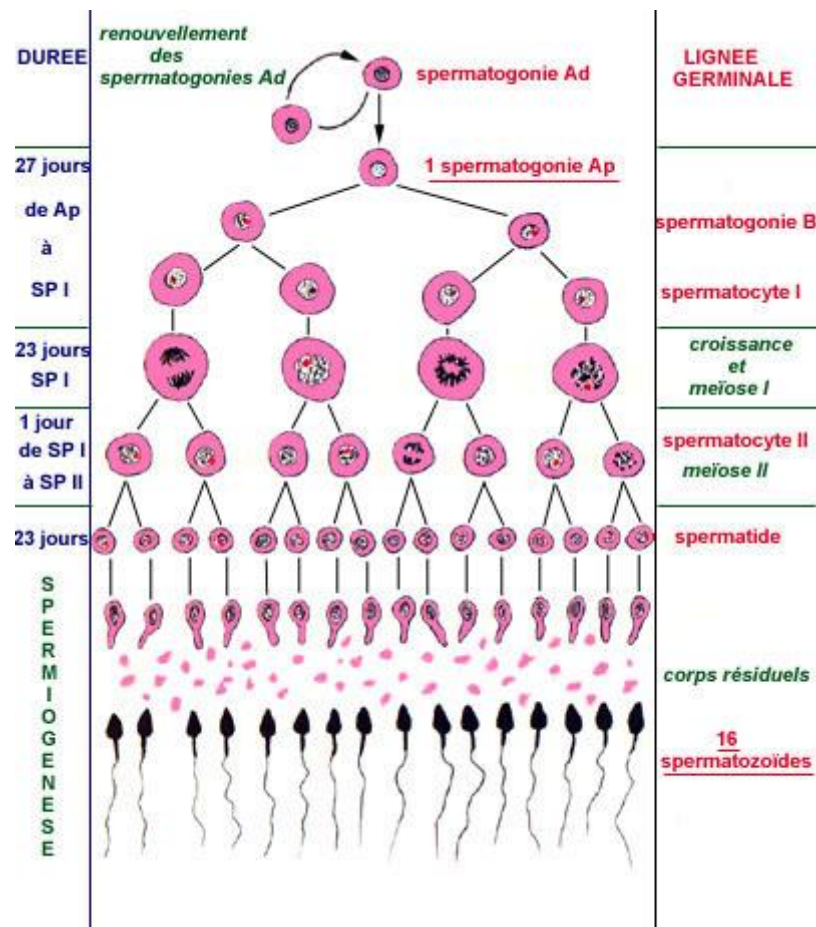


Figure 5 : General diagram of spermatogenesis

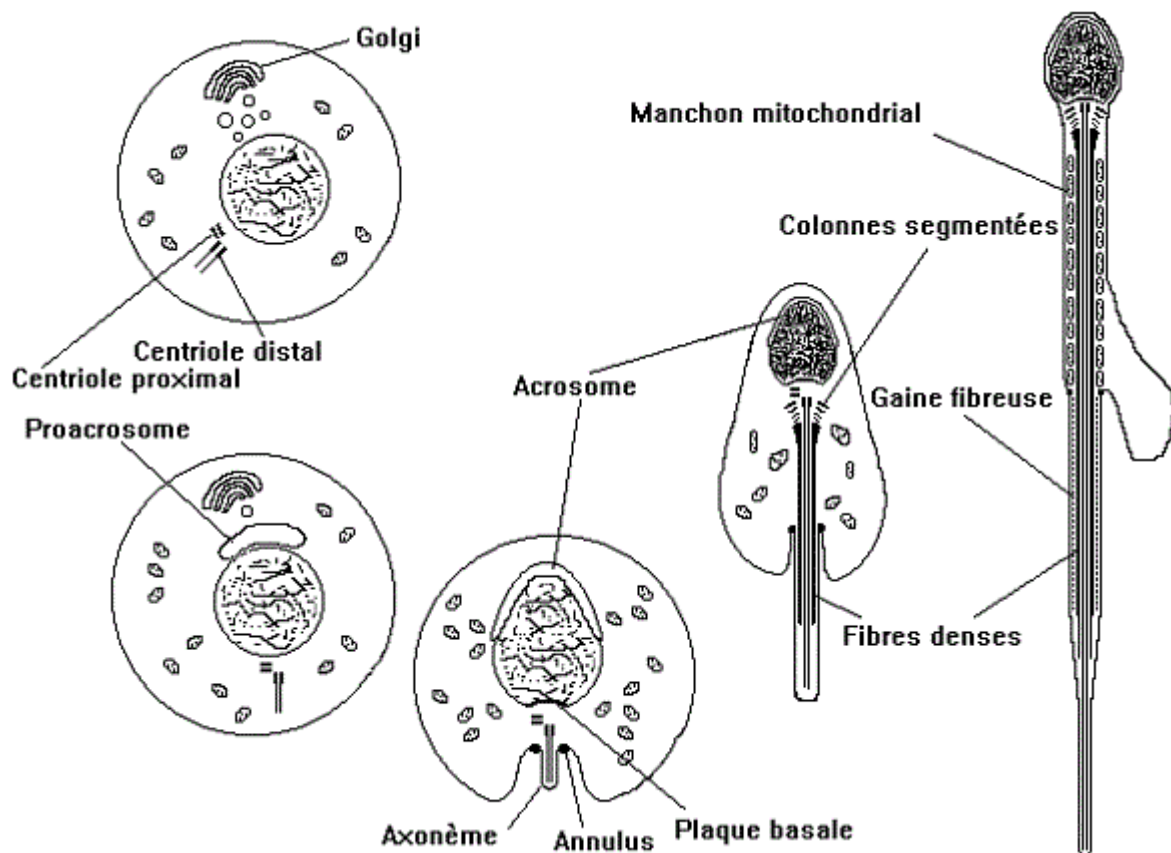


Figure 6 : The 5 stages of spermiogenesis

3. Structure of the Spermatozoon

The spermatozoon is a motile cell, very different from all others. It is organized in the same way in most mammals.

The spermatozoon is about 60 μm long. Under light microscopy, one can see:

- ✓ An elongated, flattened head (4 to 5 μm long and 2 μm thick). It contains the acrosome and the nucleus.
- ✓ The neck is short and narrow (1 μm by 1 μm). It corresponds to the space between the two centrioles.
- ✓ The flagellum consists of: the middle piece, the principal piece, and the end piece.

Components of the male gametocyte (spermatozoon)

The male gamete, or spermatozoon, is a cell with a single flagellum. Its length is 50 to 70 μm . It is very elongated and poor in cytoplasm. It has several segments (see figure 5).

The head: its shape and size vary according to species. Stallions and carnivores have an elliptical shape. Ruminants and pigs have a racquet shape. It measures between 4 and 5 μm long and 2 to 3 μm wide. The membrane is almost entirely occupied by the father's haploid nucleus. It is capped by the acrosome, bounded by two membranes: inner and outer. The acrosome is thinner and denser at the equator of the head. Behind the acrosome, the nucleus is separated from the plasma membrane by a thin layer of cytoplasm (the "post-acrosomal cap"). The spermatozoon attaches to the oocyte at the level of the post-acrosomal cap.

B) The Neck or collar: this is the narrowed part following the head. It is fragile and has two centrioles: one at the start and one at the end, which are perpendicular to each other. A connecting apparatus is also visible here: a basal plate against the base of the nucleus and a striated column around the two centrioles.

C) Tail or flagellum: it is traversed along its entire length by the filaments characteristic of flagellar structures (two central microtubules surrounded by nine pairs of peripheral microtubules).

The tail is divided into three parts:

- **The middle piece** is made up of axial filaments surrounded by nine thick fibers. These fibers extend the striated column and are themselves surrounded by a helical sheath of mitochondria. They meet only at this level and provide the energy needed for the cell's movement.
- **The principal piece** is the part that comes after the middle piece. It contains microtubular material reinforced by two thick longitudinal fibers from the middle piece.
- **The end piece:** the microtubules lose their symmetrical arrangement and are surrounded only by the plasma membrane.

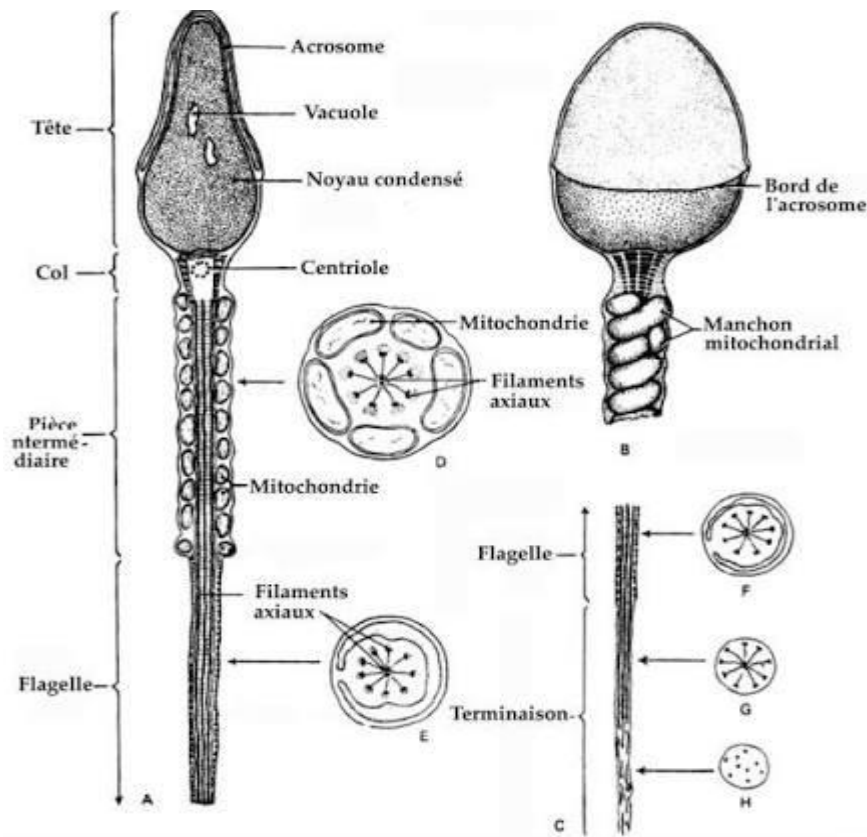


Figure 7 : Structure of a human spermatozoon (Moens, 2020)

4. Physiological Properties of the Spermatozoon

Motility The movements of the flagellum are wave-like and begin at the proximal part of the flagellum. The spermatozoon moves along a sinusoidal path, with a velocity that varies depending on the viscosity of the medium. This movement requires the hydrolysis of ATP.

Fertilizing capacity The spermatozoon only becomes capable of fertilizing after capacitation, which is characterized by:

- The loss of the glycoprotein coat from the spermatozoon's plasma membrane during passage through the female genital tract.

- An increase in velocity.

-Viability Seminal fluid is a poor medium for gamete survival. Only 20% of spermatozoa survive there for 24 hours at 37°C. In the female genital tract, however, survival can reach 2 to 3 days. After freezing in liquid nitrogen, the vitality and fertilizing capacity of some spermatozoa can be preserved.

-Metabolic activity The spermatozoon has no nuclear activity. It does not carry out DNA, RNA, or protein synthesis. Respiratory activity, however, is significant, since flagellar movement requires a large supply of ATP.

OOGENESIS

Oogenesis refers to the set of biological and cytological processes that allow the formation, growth, and differentiation of female gametes. It takes place within the gonads (the ovaries) and results in the production of a mature, fertilizable gamete: **the secondary oocyte** (arrested in metaphase II), from diploid germline stem cells called **oogonia**.

Unlike male germline development, oogenesis is fundamentally characterized by its **discontinuity** and its **limited duration**. It is a complex process spanning several decades, punctuated by long periods of dormancy. The oogenesis cycle unfolds in several key phases:

- **Early initiation:** Oogenesis begins as early as embryonic and fetal life. Oogonia multiply by mitosis and then differentiate into **primary oocytes**. These begin their first meiotic division but arrest prematurely at the end of prophase I, thereby constituting the initial germline reserve.
- **Continuous depletion of the reserve (atresia) :** A major feature of ovarian physiology is that the germ cell reserve is entirely fixed before birth and does not renew itself. On the contrary, it undergoes a massive, continuous decline. Estimated at around 700,000 primary oocytes at birth, this reserve falls to only about 250,000 oocytes by the time of puberty.
- **A cyclical resumption:** From puberty onward, the process resumes on a cyclical, regular basis under hormonal control. Reproductive activity will span 30 to 40 years, generating around 400 to 600 cycles of 28 days, until the germline reserve is fully depleted, marking menopause.

1. Female Genital System

L'appareil génital féminin (ou tractus reproducteur) est un système anatomique complexe dont la fonction principale est d'assurer la pérennité de l'espèce en permettant la reproduction sexuée (Beaumont & Cassier, 1998). Contrairement à l'appareil masculin, il est soumis à des variations cycliques majeures. Ses fonctions sont multiples : la production des gamètes (ovocytes), la sécrétion des hormones sexuelles, le transport des spermatozoïdes, l'accueil de l'embryon, et le maintien du développement fœtal jusqu'à la parturition (Thibault & Levasseur, 2001).

It is divided into three major functional units: the gonads (ovaries), the internal genital tract (tubes, uterus, vagina), and the external genital organs (vulva) (Figure 8 a, b).

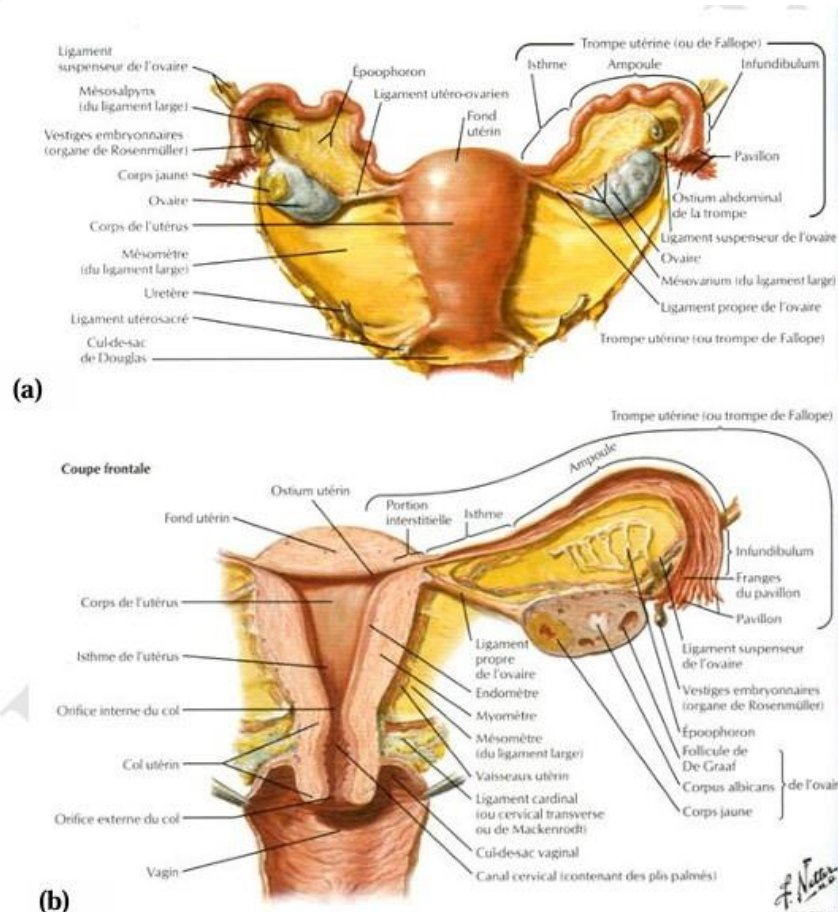


Figure 8 Female genital system, external appearance (a), frontal section (b) (Cochard, 2015)

The ovaries are paired, solid, oval-shaped organs (measuring about 3 cm long and 1 to 1.5 cm wide). They are held in the pelvic cavity by a system of ligaments (notably the suspensory ligament and the utero-ovarian ligament) and are covered by a dense connective tissue capsule: **the tunica albuginea** (Poirier & Ribeiro, 2001).

From puberty until menopause, the ovary fulfills a dual physiological role (Thibault & Levasseur, 2001) :

- **Exocrine function:** Oogenesis and folliculogenesis, leading to the maturation and cyclical release of a fertilizable gamete (the secondary oocyte).
- **Endocrine function:** The systemic secretion of steroid sex hormones (estrogens during the follicular phase, and progesterone during the luteal phase).

A longitudinal section of the ovary reveals a histological organization into two distinct zones (Poirier & Ribeiro, 2001) :

1. **The cortical zone (ovarian cortex):** This is the peripheral, wide, functional region. It is made up of a highly cellular connective stroma. It is within this cortex that the germ cells,

enclosed within somatic cells, are found, forming the ovarian follicles. Different stages of folliculogenesis (primordial, primary, secondary, and antral follicles) can be observed here simultaneously, along with post-ovulatory residual structures (corpus luteum and corpus albicans).

2. **The medullary zone (medulla):** Located at the center of the organ, it contains no follicles. It is made up of loose connective tissue that serves as a passageway. It is extremely rich in blood vessels (ovarian arteries and veins), lymphatic vessels, and nerve fibers, which enter through the hilum of the ovary to vascularize the cortex (**Figure 9**).

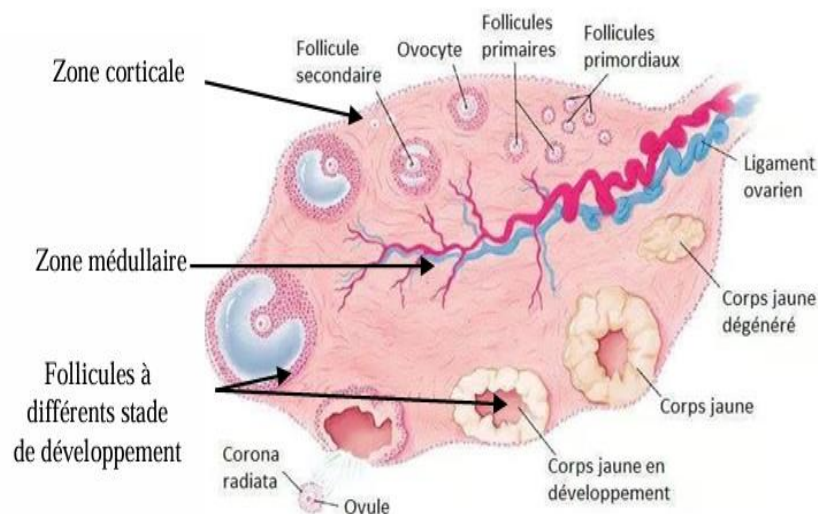


Figure 9 Longitudinal section of an ovary

3. II. The Internal Genital Tract

These musculo-membranous ducts are responsible for capturing and transporting the oocyte and for embryonic development.

1. The Fallopian Tubes (Oviducts or Uterine Tubes)

These are two paired ducts, about 10 to 12 cm long, connecting the ovarian region to the uterine cavity. Their wall has smooth musculature that allows active peristalsis. They are divided anatomically and functionally into three segments (Thibault & Levasseur, 2001):

- **The infundibulum:** This is the funnel-shaped distal end. It is bordered by highly mobile tissue folds called **fimbriae**. During ovulation, these fimbriae become engorged with blood, elongate, and sweep over the surface of the ovary to capture the oocyte and direct it into the tube, thereby preventing it from being lost in the peritoneal cavity.
- **The ampulla:** This is the longest and widest part of the tube. **It is the exclusive physiological site of fertilization.** Its mucosa is rich in ciliated cells (which guide the

oocyte toward the uterus) and secretory cells (which nourish the gametes) (Poirier & Ribeiro, 2001).

- **The isthmus:** A proximal segment, much narrower, with a thick muscular wall, which opens directly into the uterus.

2. The Uterus

This is a hollow, smooth muscular organ, triangular in shape (about 7 cm long outside pregnancy). It is the incubation chamber where implantation of the embryo and fetal development take place. It is divided into two main parts:

- **The uterine body:** It receives the two tubes at its upper borders (the uterine horns). Its wall is made up of three layers:
 - *The serosa:* the outer peritoneal layer.
 - *The myometrium:* an extremely thick smooth muscle layer, responsible for contractions during childbirth.
 - *The endometrium (uterine mucosa):* This is the innermost layer. It consists of a simple **columnar epithelium** (including ciliated and non-ciliated cells) resting on a basement membrane, and of a **lamina propria** (Poirier & Ribeiro, 2001). This lamina propria is loose connective tissue, richly vascularized by spiral arterioles and containing coiled tubular glands. The endometrium is itself divided into a *residual zone* (deep, stable) and a *functional zone* (superficial, very thick), which sheds and causes menstruation in the absence of fertilization.
- **The cervix:** The narrowest part, forming the transition between the uterus and the vagina.
 - *The endocervix (uterine side):* Lined by a simple invaginated epithelium forming the endocervical glands. These glands secrete **cervical mucus**, a network of glycoproteins. This mucus is alkaline (neutralizing vaginal acidity). Outside of ovulation, it forms a tight mesh (a viscous plug) that blocks bacteria and spermatozoa. At the time of ovulation, it becomes liquid and “stringy,” allowing only the most vigorous spermatozoa to pass through (Thibault & Levasseur, 2001).
 - *The exocervix (vaginal side):* Lined by a non-keratinized stratified squamous epithelium.

3. The Vagina

This is a highly extensible, tubular musculo-membranous organ, 10 to 15 cm long.

- **Physiological role:** It is the organ of copulation (the site where seminal plasma and spermatozoa are deposited) and represents the lower genital tract (the natural passage for the fetus during childbirth).
- **Histology:** The inner wall is lined by a **non-keratinized stratified squamous (Malpighian) epithelium** (Poirier & Ribeiro, 2001). This tissue notably lacks glands;

its lubrication depends on vascular exudation and secretions from the cervix. The vagina hosts a commensal bacterial flora that breaks down the glycogen from epithelial cells into lactic acid, thereby maintaining a strongly acidic pH (around 4) that protects the genital tract against infection.

III. The External Genital Organs (The Vulva)

The vulva comprises the external structures protecting the entrance to the genital tract (Beaumont & Cassier, 1998):

- **The labia majora and labia minora:** The labia majora are protective skin folds (pigmented and rich in sebaceous glands). The labia minora are highly vascularized mucosal folds located more internally, delimiting the vaginal vestibule.
- **The clitoris:** A small erectile organ located at the anterior junction of the labia minora. The embryological homolog of the male glans, it has a very high density of sensory nerve endings.

2. The Phases of Oogenesis

Oogenesis is a discontinuous physiological process that is classically divided into three major stages: **multiplication**, **growth** et la **maturation**.

Unlike spermatogenesis, oogenesis includes **no differentiation phase** (there is no equivalent to spermiogenesis). In addition, the growth phase and the beginning of maturation are closely dependent on the development of the protective structure surrounding the gamete: the ovarian follicle. Finally, maturation is a strongly delayed process, whose definitive completion is strictly conditional on an external event: fertilization (Thibault & Levasseur, 2001).

2.1. Multiplication Phase and Establishment of the Germline Reserve

This first phase concerns the **oogonia** (stem cells of the germ line). It is characterized by an intense succession of mitotic divisions, resulting in the formation of **first-order oocytes (primary oocytes)**.

Chronology and Cytological Dynamics (Human/Mammalian Model):

- **Period of activity:** This phase occurs transiently and exclusively during embryonic and fetal life, within the cortical zone of the ovary.
- **Morphological growth:** The oogonia are initially small spherical cells measuring about **15 µm** in diameter. Following their differentiation into primary oocytes (which remain diploid: 2n chromosomes, 2c DNA), their size increases significantly to reach **20 to 40 µm** in diameter.
- **Formation of the primordial follicle:** Immediately after their formation, the primary oocytes associate with the surrounding somatic cells. The oocyte becomes surrounded

by a layer of flattened follicular cells, the whole being isolated from the ovarian stroma by a thin peripheral membrane. This assembly constitutes the initial stage of folliculogenesis: the **primordial follicle** (Gilbert, 2004).

- **Entry into meiosis and quiescent state:** Primary oocytes immediately begin their first meiotic division (Meiosis I), but this process comes to an abrupt halt. The cell arrests at the stage of **prophase I**. The oocyte then enters a deep state of dormancy (quiescence) in which it will remain for many years (at least until puberty).
- **Fetal atresia:** At the same time as this process, the embryonic ovary is the site of massive cell degeneration (atresia). Around the **7th month** of intrauterine life, the majority of germ cells degenerate irreversibly (Larsen, 2001).

Status at birth: Due to the cessation of mitosis and massive atresia, the female newborn is born with a **fixed, non-renewable reserve** of about one million primary oocytes. Each of these is arrested in prophase I and carefully contained within a primordial follicle.

2.2. The Growth Phase

The growth phase is a fundamental and exceptionally long stage of oogenesis. It follows the multiplication phase when the oogonia stop their mitotic divisions to become **first-order oocytes (primary oocytes)**, still diploid ($2n$ chromosomes). This phase is closely linked to the development of the ovarian follicle.

1. A Spectacular Growth Dynamic

This step is characterized by a considerable increase in the cytoplasmic volume of the primary oocyte. The extent of this growth varies greatly depending on the reproductive strategies of different species (Houillon, 1967 ; Thibault & Levasseur, 2001) :

- **In mammals (including humans):** The diameter of the primary oocyte goes from about 20-30 μm to 120-140 μm , a roughly 4.5-fold increase.
- **In amphibians (e.g., the frog) :** The growth is enormous, with volume potentially multiplied by a factor of 27,000 due to massive accumulation of reserves (Houillon, 1967).

2. Intense Metabolic and Cellular Activity

This morphological growth is accompanied by major synthetic activity, intended to prepare for fertilization and support the very earliest stages of embryonic development, before the genome of the future zygote takes over (Gilbert, 2004). The following can be observed:

- **Synthesis of RNA and proteins** in very large quantities.
- **Vitellogenesis:** The accumulation of exogenous material forming nutrient reserves, called yolk (or vitellus), whose importance is directly related to the species' mode of embryonic development.

- **Formation of cortical granules:** Synthesized by the Golgi apparatus, these organelles migrate to position themselves beneath the plasma membrane (in the cortical cytoplasm). They will play a key role during fertilization in blocking polyspermy (Gilbert, 2004).

3. Chronology and Evolution of the Ovarian Reserve

In women, this phase is spread out over a particularly long time: it extends from fetal life to puberty, and is not truly completed until the final maturation of the pre-ovulatory follicle (Larsen, 2001).

In addition, this period is marked by massive cell death, known as **follicular atresia**. Between birth and puberty, large numbers of primordial follicles regress. Thus, of the initial reserve, only about **400,000 oocytes** remain at puberty. At each menstrual cycle, only a very small number of primary oocytes undergo major growth, and ultimately **fewer than 500 follicles** will reach the stage of ovulation over the course of a woman's entire reproductive life (Larsen, 2001; Thibault & Levasseur, 2001).

2.3. The Maturation Phase (Nuclear and Cytoplasmic)

The maturation phase is the final stage of oogenesis. It corresponds to the completion of the two meiotic divisions (reductional then equational). Unlike spermatogenesis, this oocyte meiosis has three fundamental particularities: it is discontinuous (marked by two long arrests), it is asymmetric (unequal cytoplasmic distribution), and its completion is strictly conditional on fertilization (Thibault & Levasseur, 2001).

1. Cytoplasmic Maturation: Acquiring Competence

Long before ovulation, while the primary oocyte is deeply dormant, a silent molecular maturation takes place. It is essential for the events that follow (Gilbert & Barresi, 2018):

- **Transcriptional activity:** During the long prophase I (at the diplotene stage), the primary oocyte massively synthesizes the three types of RNA (mRNA, rRNA, tRNA).
- **Protein translation:** This RNA is then translated into specific proteins. It is this protein accumulation that makes the oocyte "competent," that is, able to resume its meiosis twice (at the LH surge and then upon sperm penetration) and ensure the success of fertilization (Gilbert & Barresi, 2018).

2. Nuclear Dynamics: Chronology of the Meiotic Divisions

A. Completion of Meiosis I (Reductional Division)

- The primary oocyte (a diploid cell with $2n$ chromosomes and $4c$ DNA) begins its first division as early as fetal life, but remains **arrested in prophase I** for years.

- It is not until puberty, and cyclically at each ovulation, that the primary oocyte finally completes this first division under the effect of the hormonal surge.
- **The unequal division:** This division is highly asymmetric (Houillon, 1967). It gives rise to a large haploid cell that retains almost all of the cytoplasm (the **secondary oocyte**, with n chromosomes and $2q$ DNA), and to a small, abortive cell lacking cytoplasm, the **first polar body (PB1)** (Thibault & Levasseur, 2001).

B. The Onset of Meiosis II (Equational Division) and the Second Arrest

- Immediately after the release of PB1, the secondary oocyte begins the second meiotic division.
- However, the process undergoes a second sudden arrest: the oocyte **arrests in metaphase II**. It is in this exact form (arrested secondary oocyte) that the female gamete is expelled from the ovary at ovulation (Thibault & Levasseur, 2001).

C. The Conditional Completion of Maturation

The release of this second arrest depends exclusively on an external event (Larsen, 2001):

- **In the absence of fertilization:** The secondary oocyte remains frozen at this stage and degenerates in the tubes after about 24 hours.
- **If fertilization occurs:** Penetration of the spermatozoon activates the secondary oocyte, which instantly completes its division. It then transforms into the **ootid** (the mature, truly haploid egg) and expels a second abortive cell, the **second polar body (PB2)**.

Summary of Meiotic Output:

Because of the unequal cytoplasmic distribution, the output of oogenesis is very low compared to spermatogenesis. At the end of this maturation phase, **a single starting primary oocyte yields only one** functional gamete (the secondary oocyte, then the ootid), the other daughter cells (the polar bodies) being destined to degenerate (Houillon, 1967).

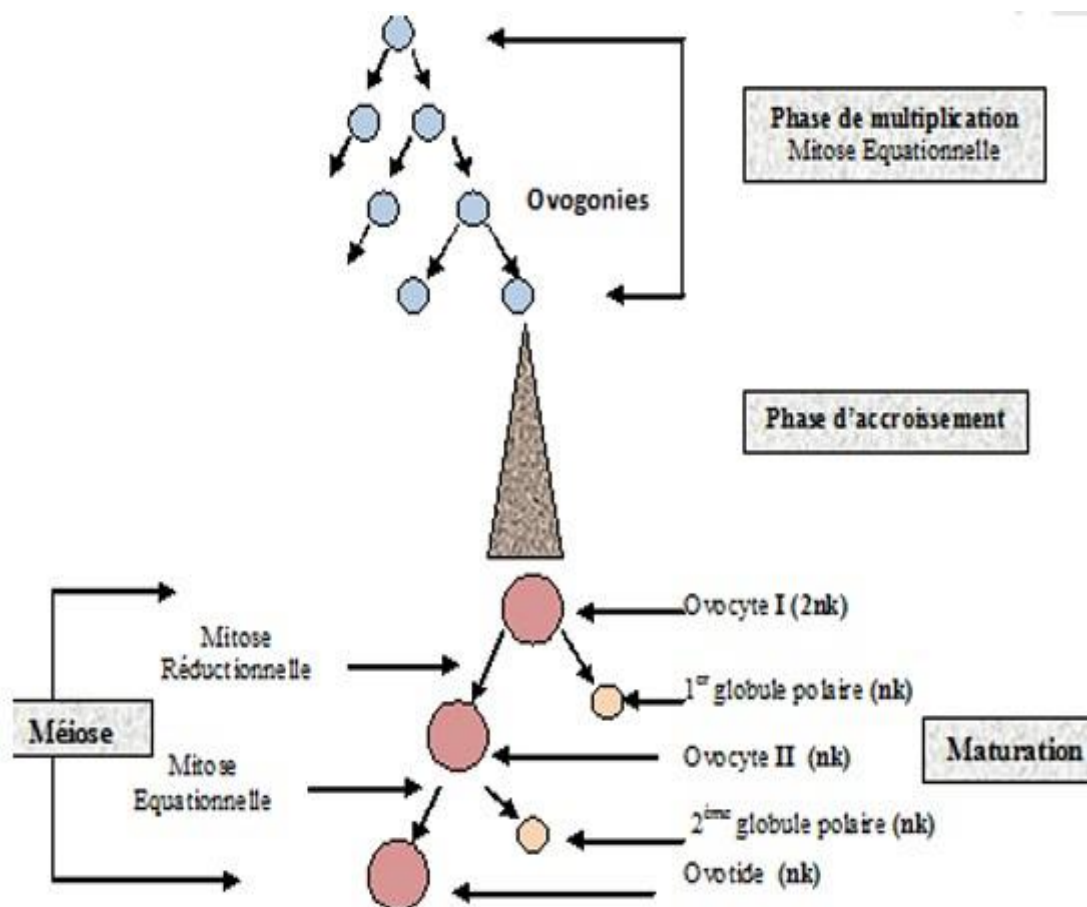


Figure 10 Diagram of oogenesis

Bibliographic references

1. Beaumont, A., & Cassier, P. (1998). *Biologie animale : des Protozoaires aux Métazoaires*. Paris : Dunod.
2. Clermont, Y. (1972). Kinetics of spermatogenesis in mammals: Seminiferous epithelium cycle and spermatogonial renewal. *Physiological Reviews*, 52(1), 198–236.
3. Cochard, L. R. (2015). *Netter's Atlas of Human Embryology* (2nd ed.). Philadelphia : Elsevier.
4. Embryology.ch. (2023). Stades du développement de la spermatogenèse. Universités de Fribourg, Lausanne et Berne. <https://embryology.ch>
5. Faculté de Médecine de Constantine 3. (2024). Cours 2 : La spermatogenèse. Support de cours d'histologie et de biologie de la reproduction.
6. Gilbert, S. F. (2004). *Biologie du développement*. Bruxelles : De Boeck Supérieur.
7. Gilbert, S. F., & Barresi, M. J. F. (2018). *Biologie du développement*. Bruxelles : De Boeck Supérieur.
8. Gilbert, S. F., & Barresi, M. J. F. (2020). *Developmental Biology* (12th ed.). New York : Oxford University Press.
9. Houillon, C. (1967). *Embryologie*. Paris : Hermann.
10. Larsen, W. J. (2001). *Human Embryology* (3rd ed.). Churchill Livingstone.
11. Moens, A. (2020). *Structure du spermatozoïde humain*. Support de cours.
12. Moens, A. (2021). *Notes et données sur la folliculogenèse, la dynamique ovarienne et les caryotypes d'espèces domestiques*. Support de cours.
13. Moore, K. L., Persaud, T. V. N., & Torchia, M. G. (2019). *The Developing Human: Clinically Oriented Embryology* (11th ed.). Philadelphia : Elsevier.
14. Perrard, M.-H., et al. (2010). Analyse de la spermatogenèse ex vivo. *Médecine/Sciences*, 26(4), 373–376.
15. Poirier, J., & Ribeiro, A. (2001). *Histologie : Les tissus*. Paris : Masson.
16. Poirier, J., et al. (2005). *Histologie et biologie cellulaire*. Paris : Masson.
17. Thibault, C., & Levasseur, M.-C. (2001). *La reproduction chez les mammifères et l'homme*. Paris : INRA Éditions.