Gametogenesis: from Germ Cells to Functional Gametes

What is gametogenesis?

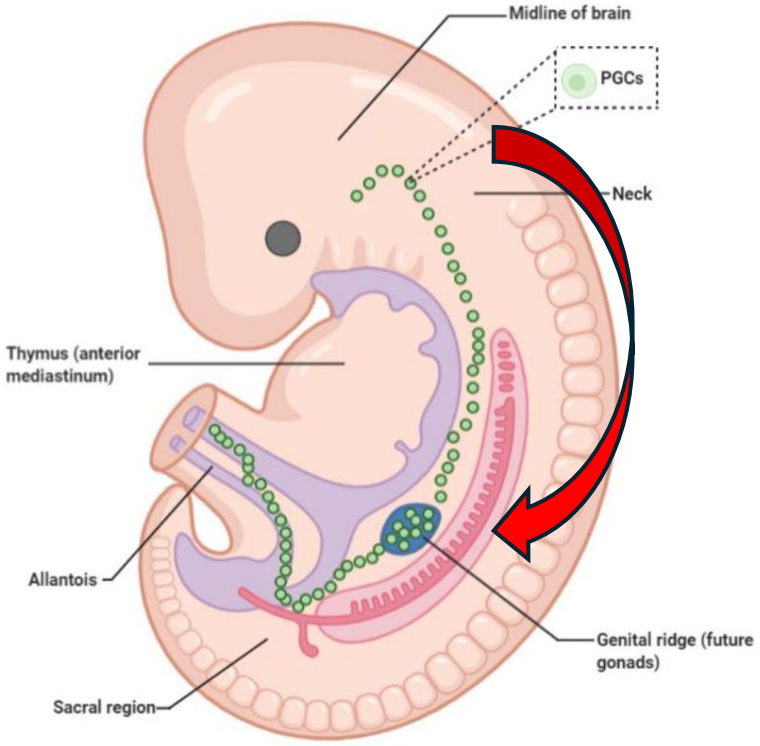
Gametogenesis is the developmental process through which diploid germ-line precursors generate mature haploid gametes able to fertilize and determine embryonic development.

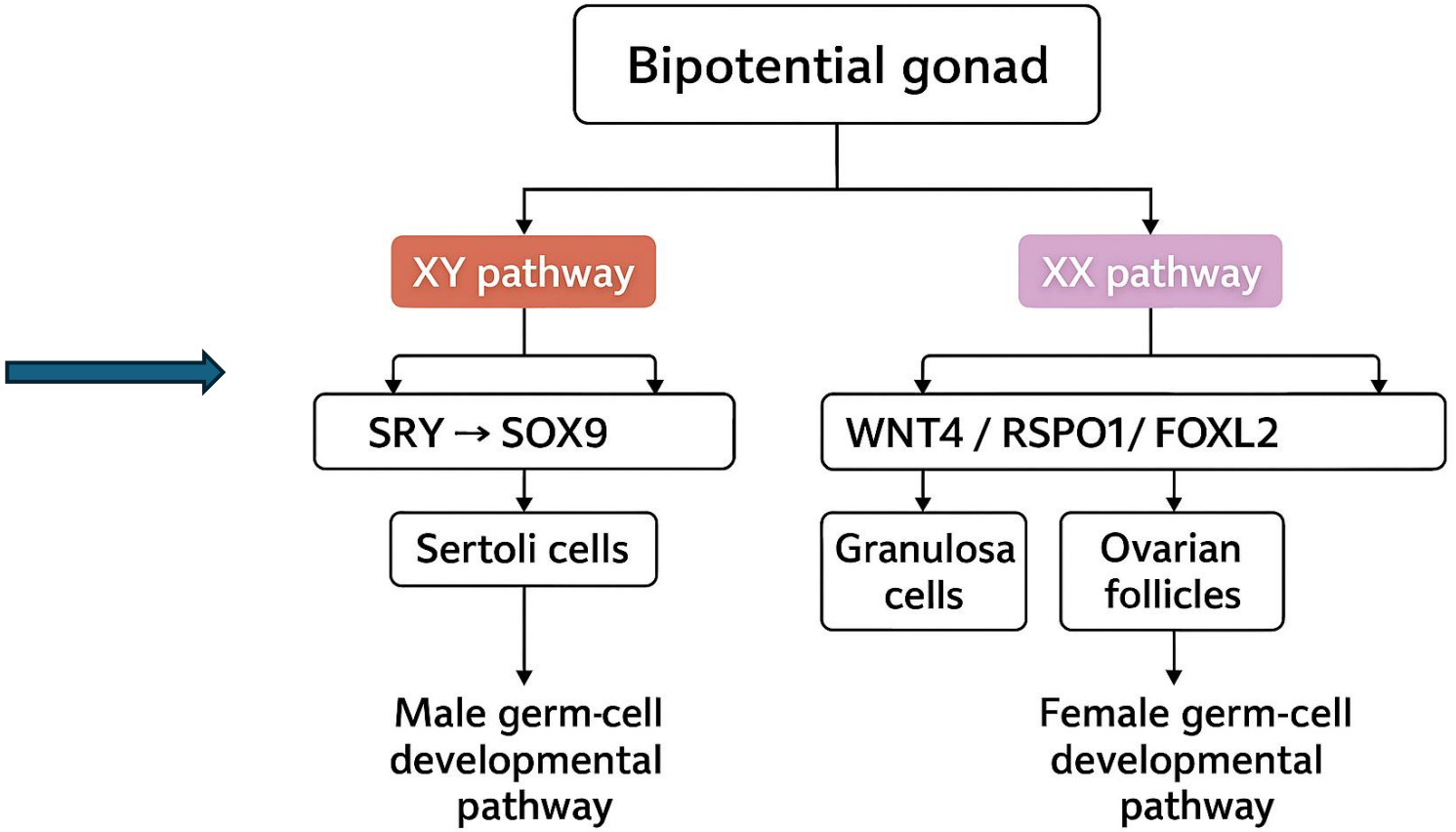
It is regulated by:

- Genetic programs
- Somatic cell signaling
- Endocrine regulation

From PGC Migration to Gonadal Differentiation

Primordial germ cells colonize the genital ridge, where the somatic environment directs gonadal and germ-cell fate.





Two different approaches

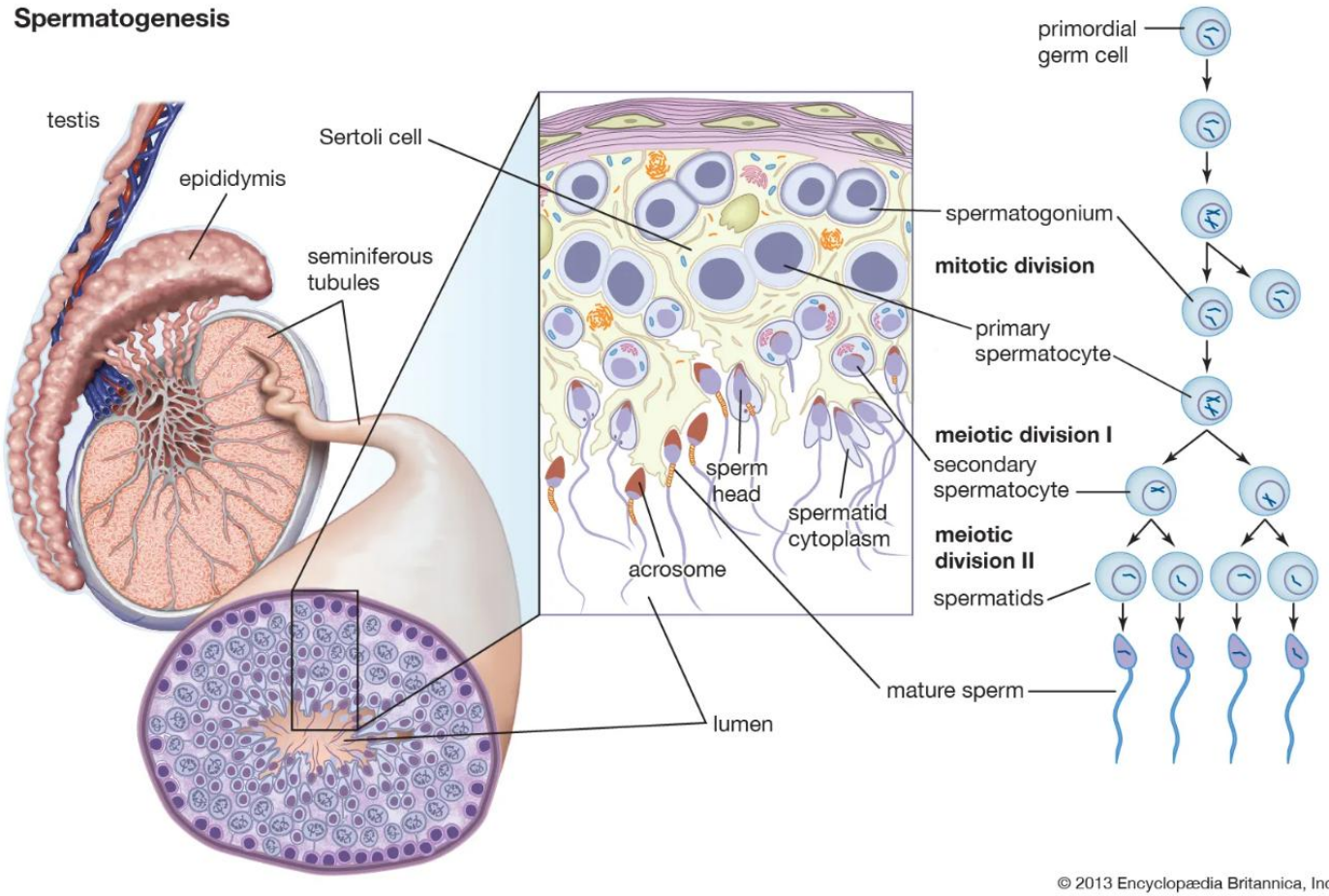
SPERMATOGENESIS

- Production and differentiation of male gametes within the seminiferous epithelium

OOGENESIS

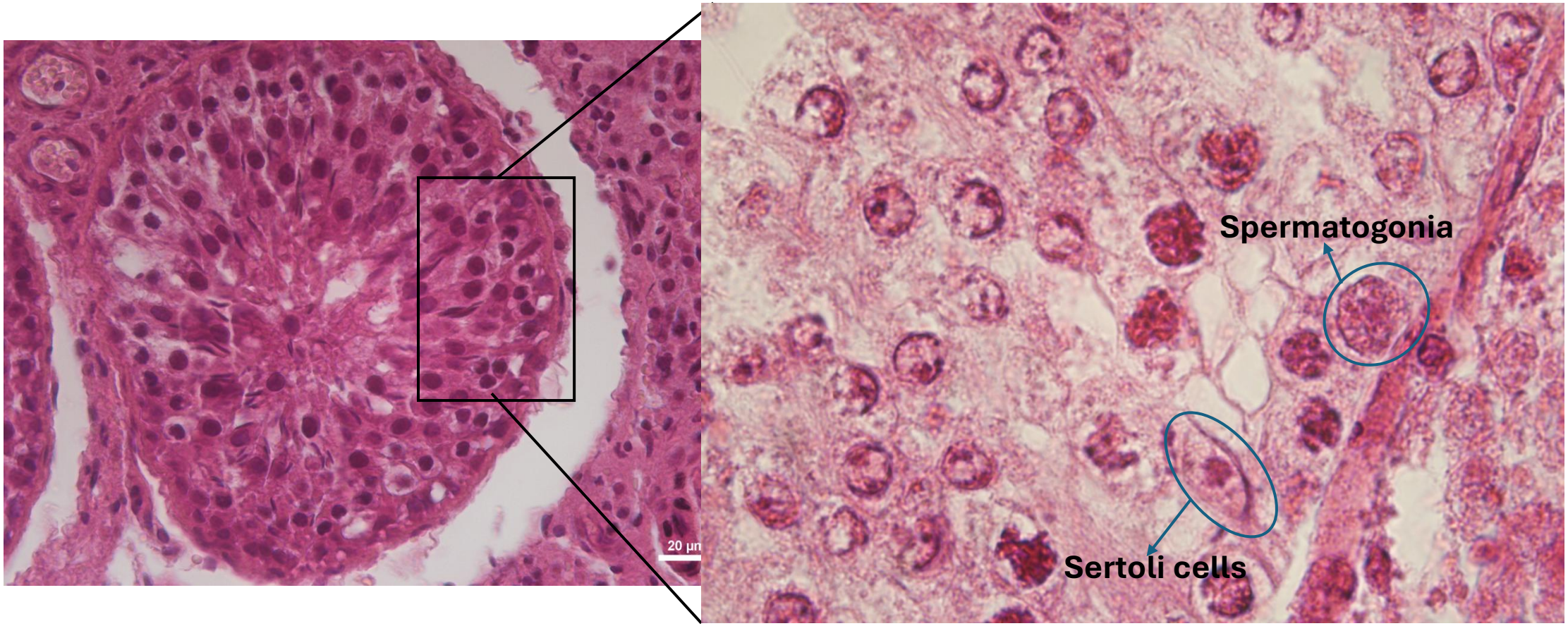
- Growth, meiotic maturation and developmental preparation of female gametes within ovarian follicles

SPERMATOGENESIS



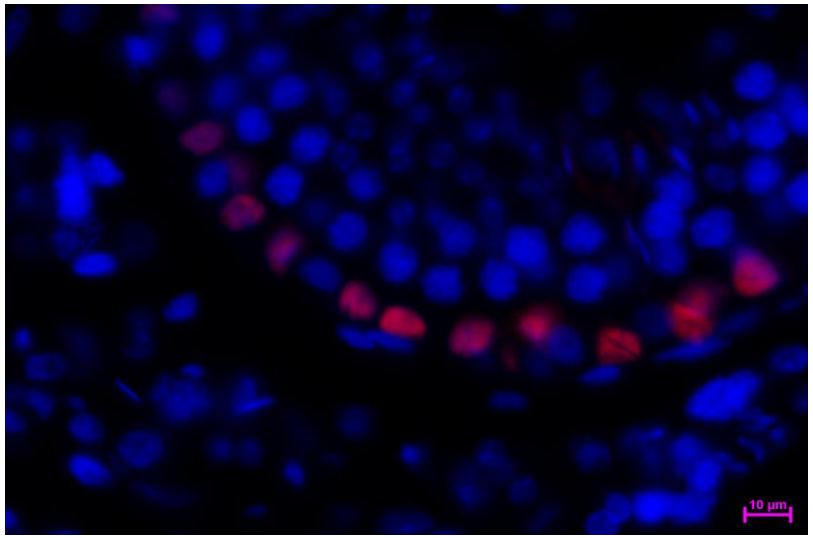
Spermatogenesis is a continuous, hormonally and locally regulated process in which spermatogonial stem cells give rise to functional spermatozoa through coordinated mitosis, meiosis, and spermiogenesis, supported by somatic Sertoli cells.

Functional organization of the seminiferous tubules

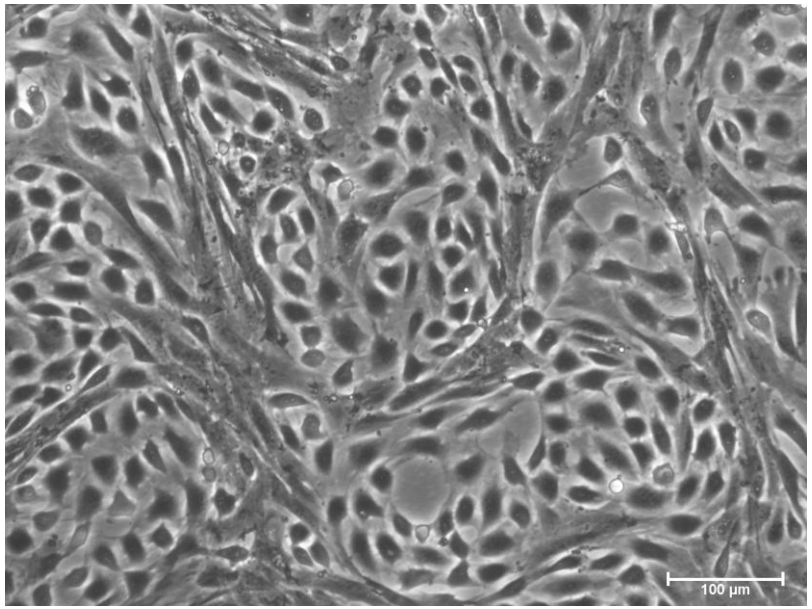


Sertoli cells: main functions

Native tissue



Isolated cells



Structural support

- Form the blood–testis barrier
- Define basal and adluminal compartments
- Support germ cell movement and organization

Nutritional and metabolic support

- Provide nutrients and survival signals to developing germ cells
- Phagocytose residual bodies

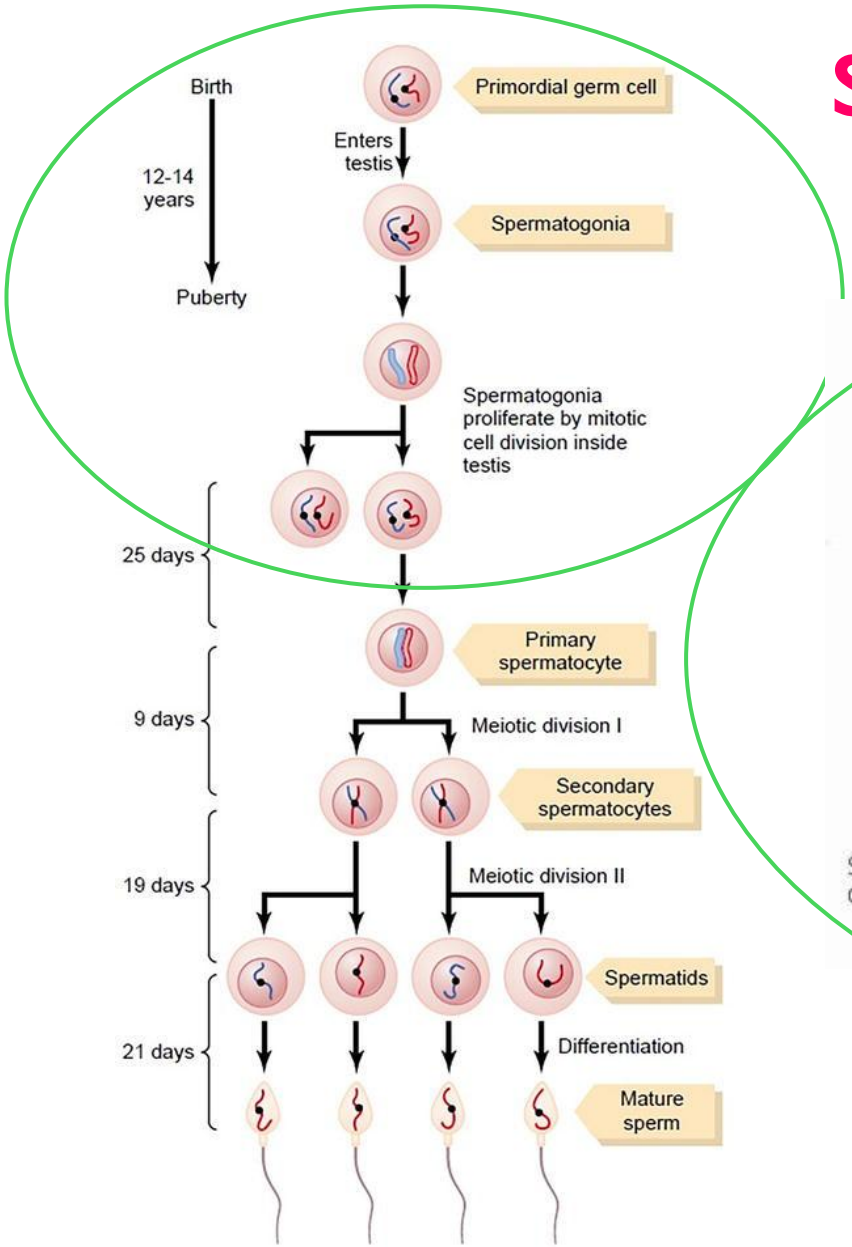
Endocrine and paracrine functions

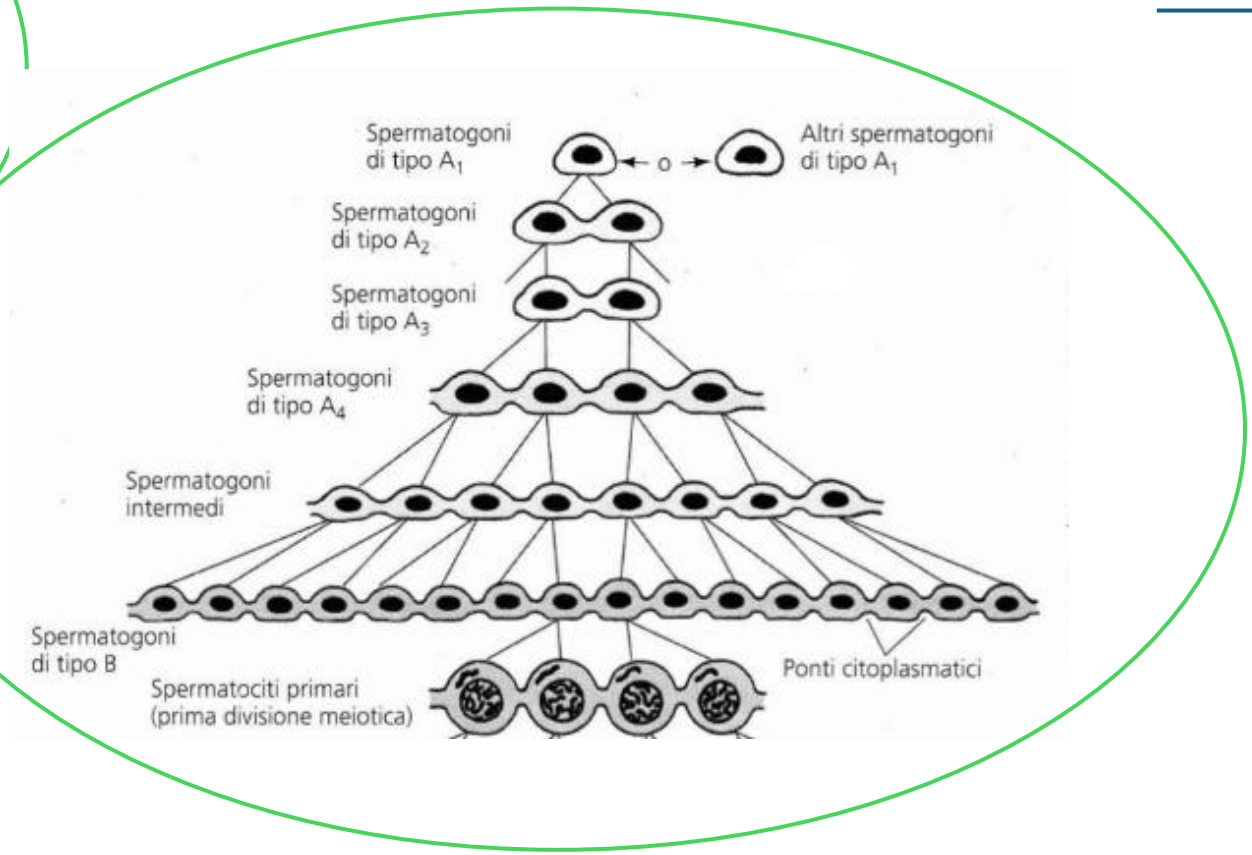
- Respond to FSH and testosterone
- Produce inhibin B, AMH, growth factors and cytokines
- Regulate germ cell differentiation

Spermiation

- Facilitate release of mature spermatids into the lumen

From Primordial germ cells (PGCs) to spermatogonia





Sertoli cells

↓

GDNF
(self-renewal / maintenance)

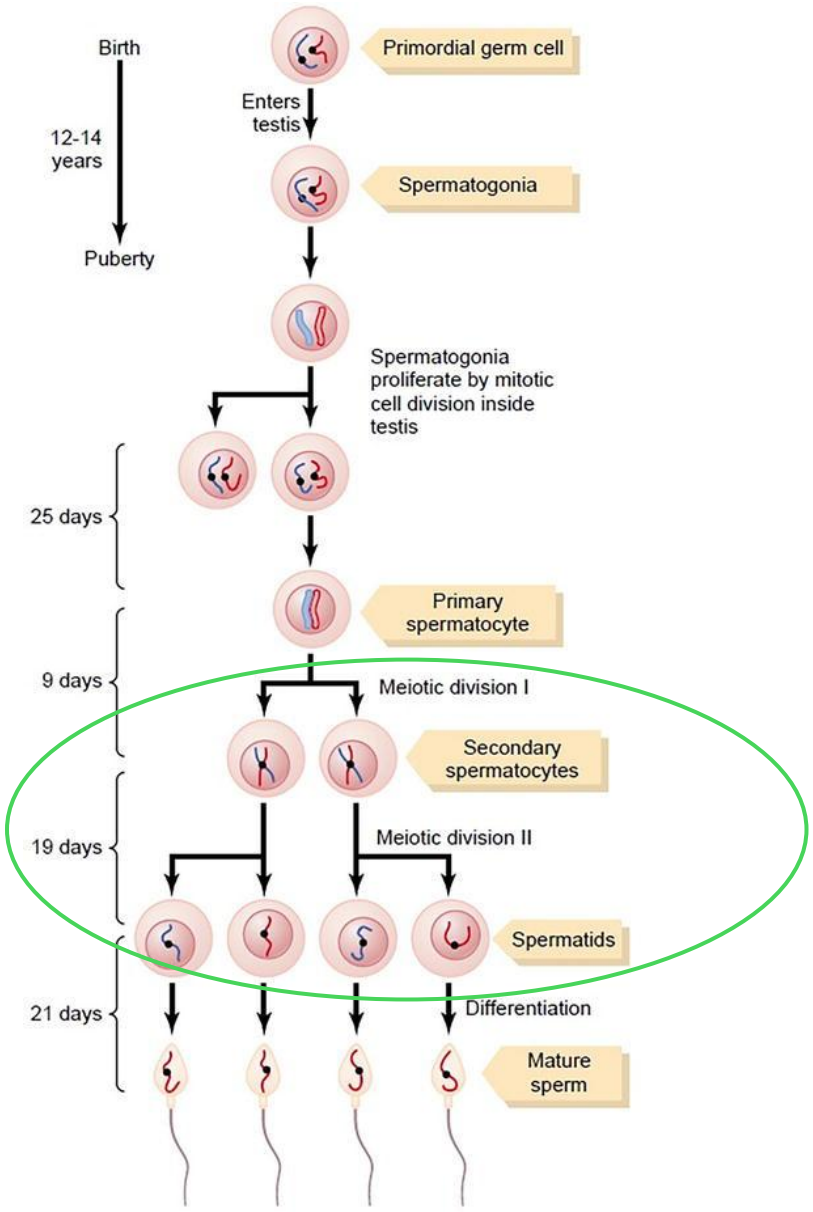
↓

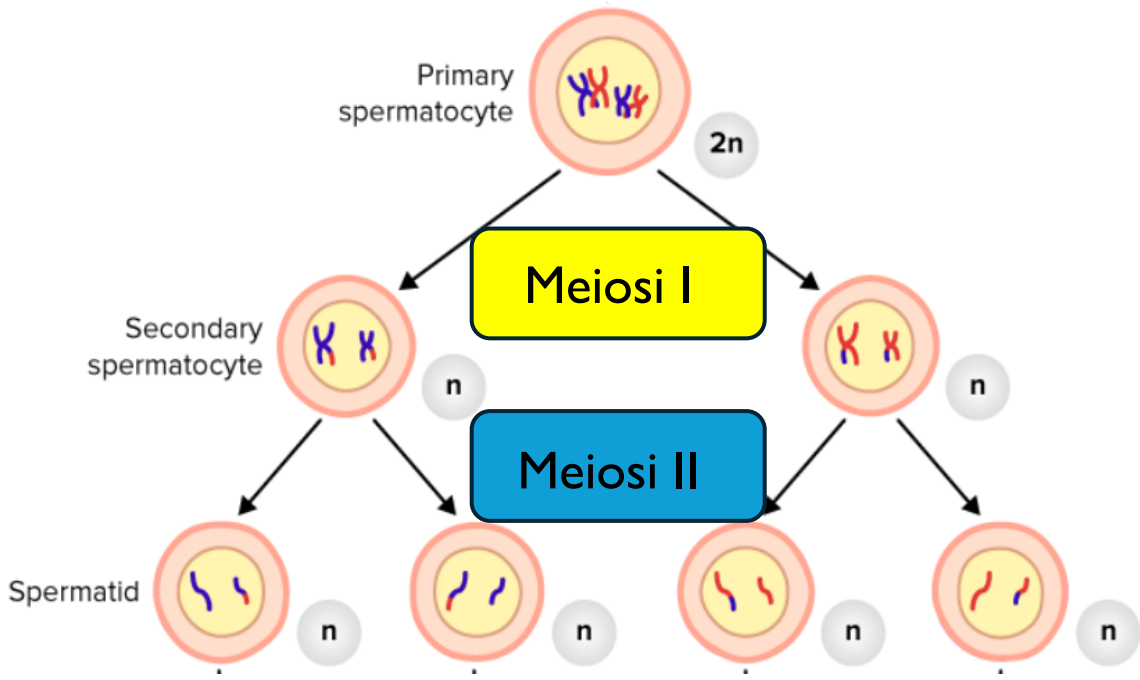
Reduced GDNF

↓

Differentiation

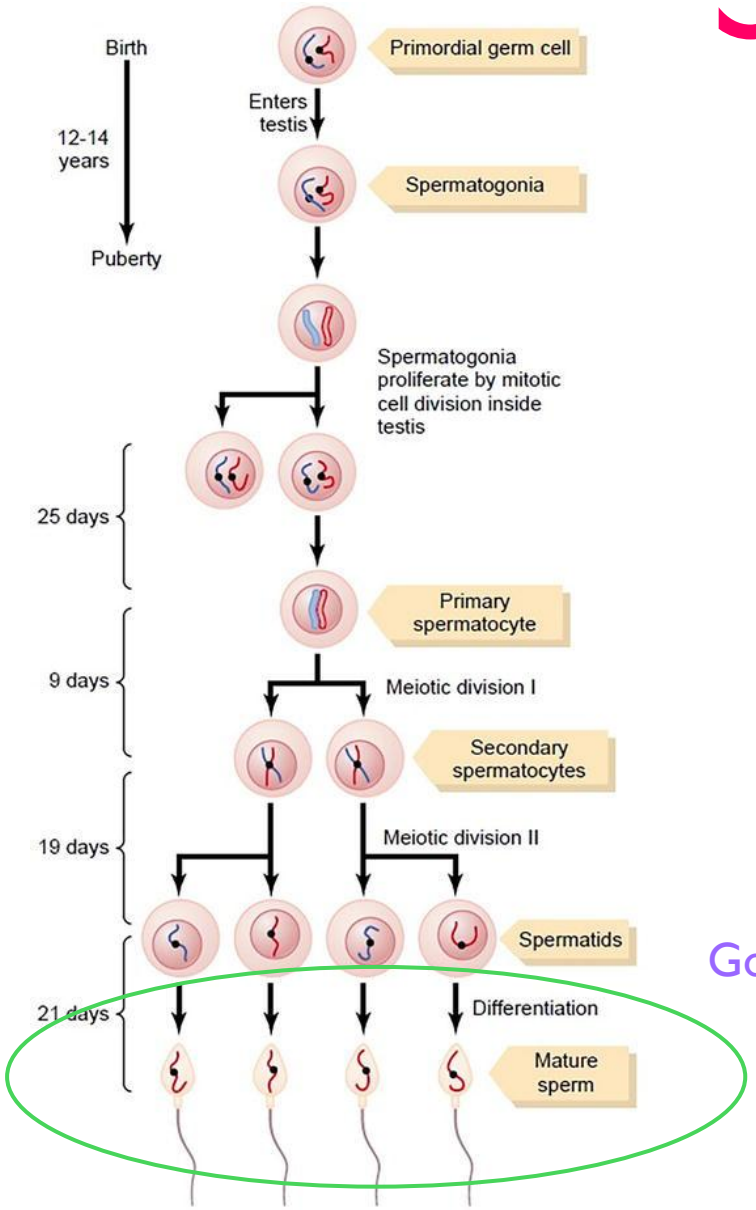
Meiotic divisions: from primary spermatocytes to haploid spermatids

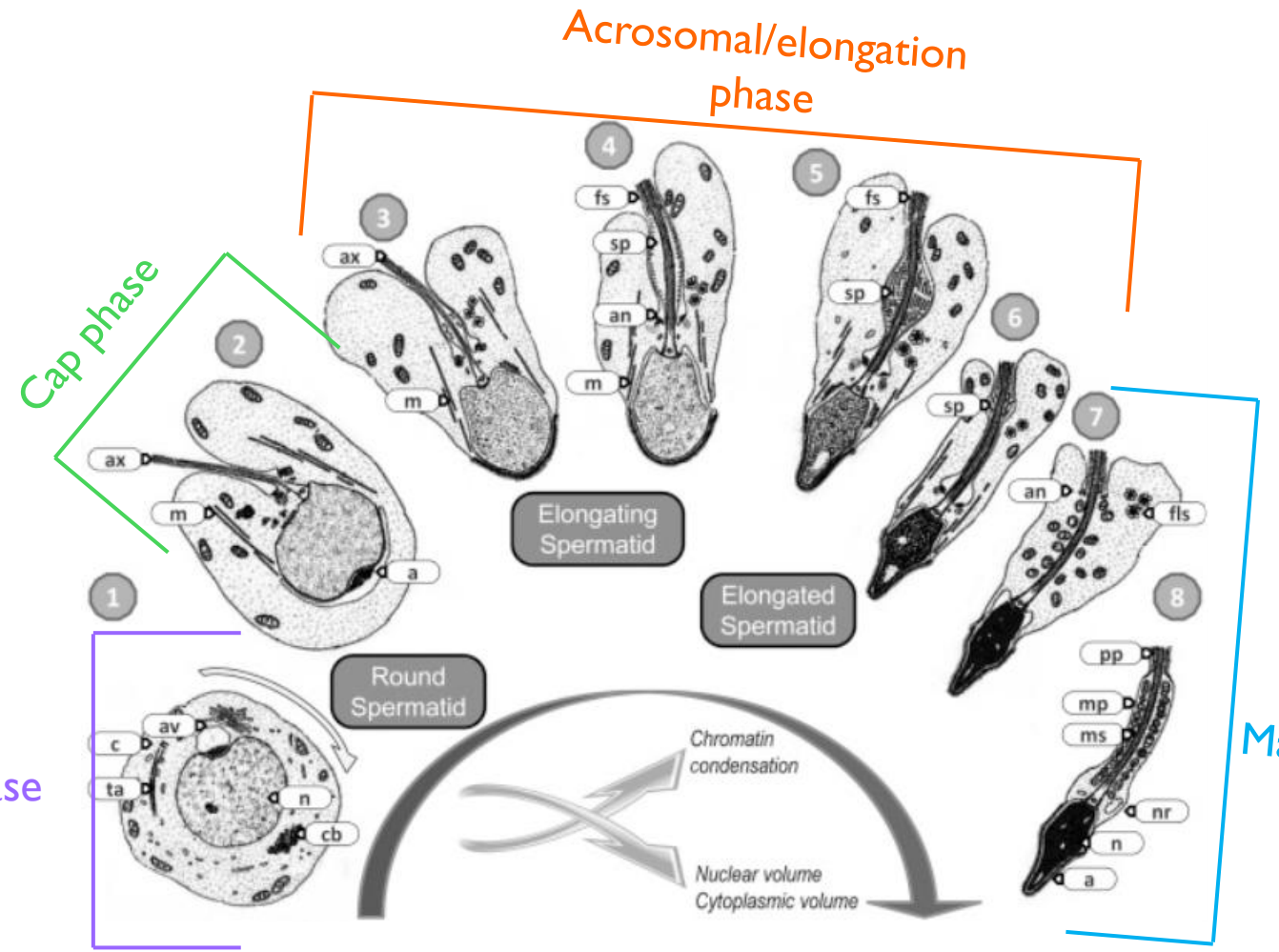




1 primary spermatocyte → 4 haploid spermatids

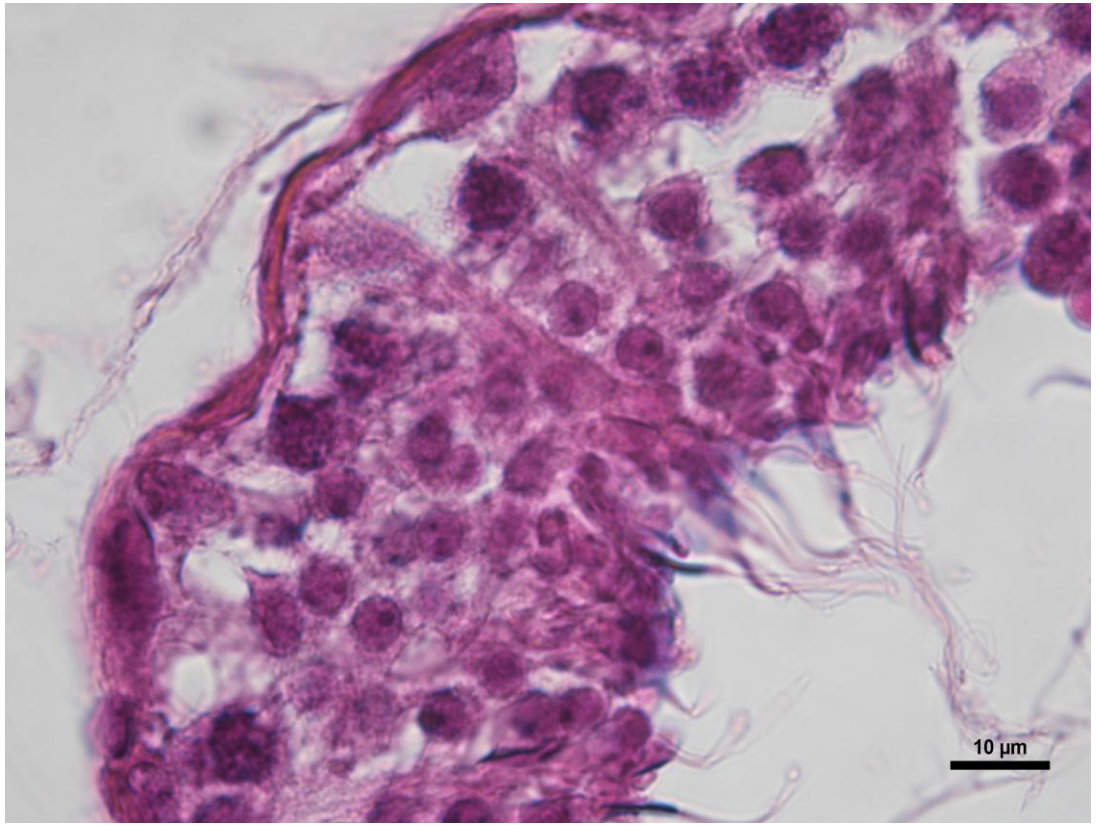
Spermiogenesis



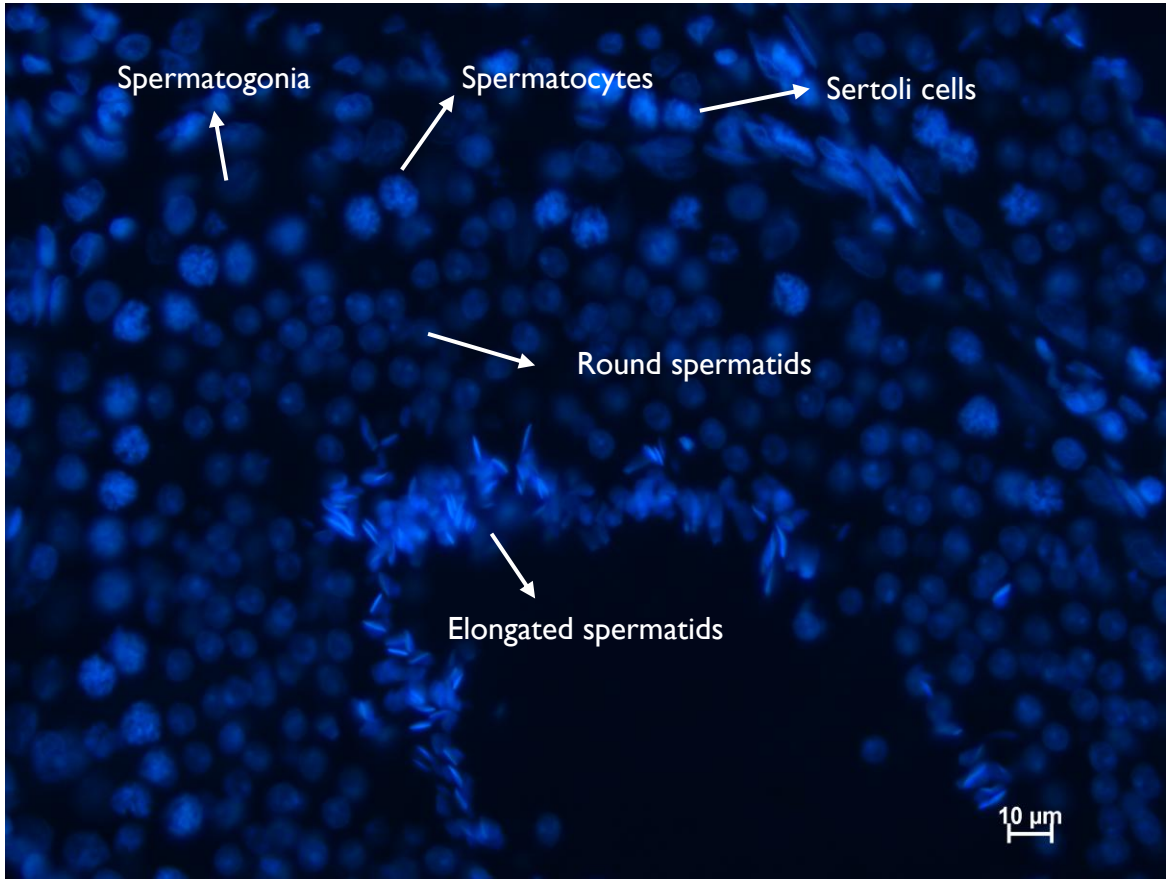


From schematic stages to tissue organization

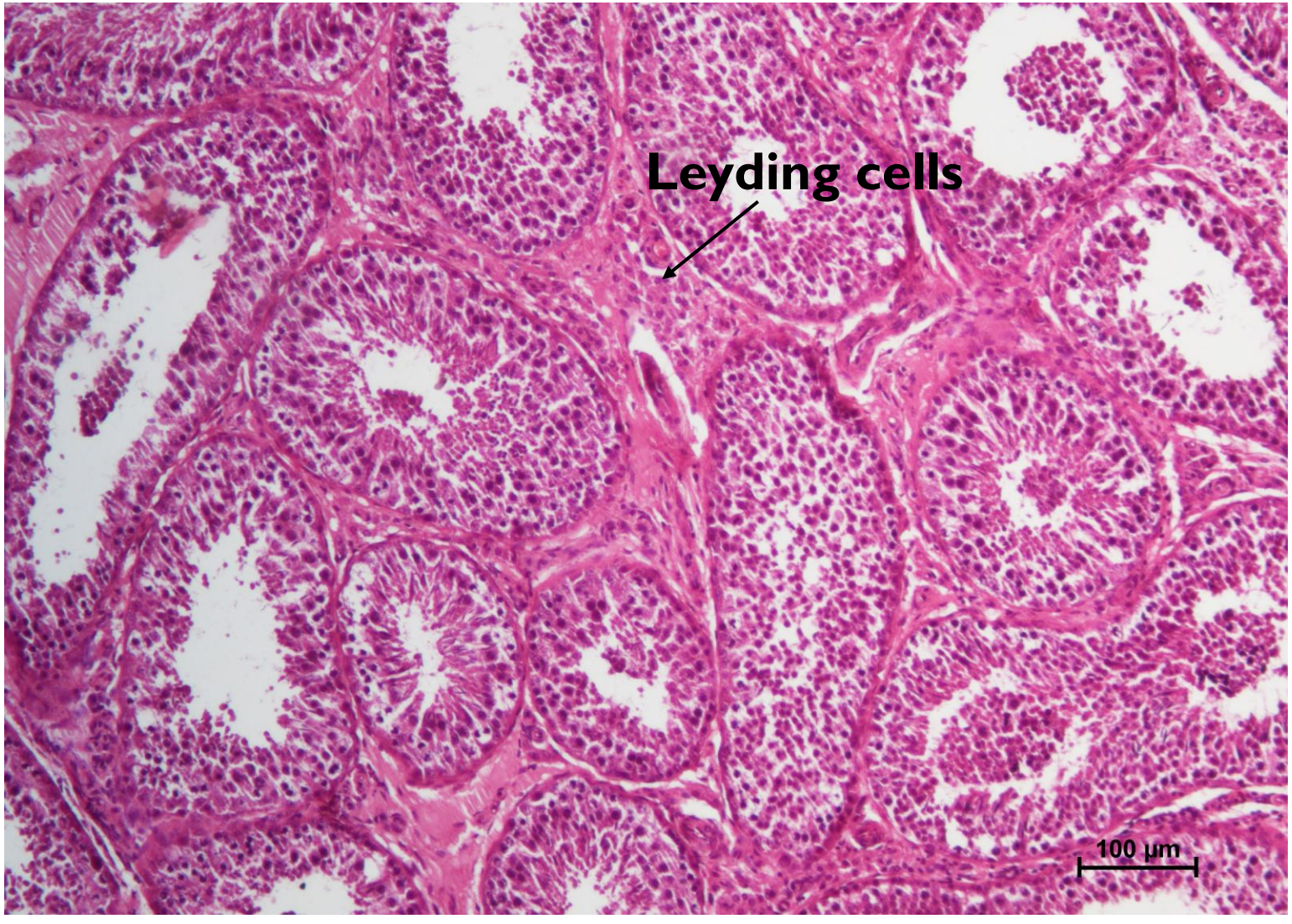
Histological morphology



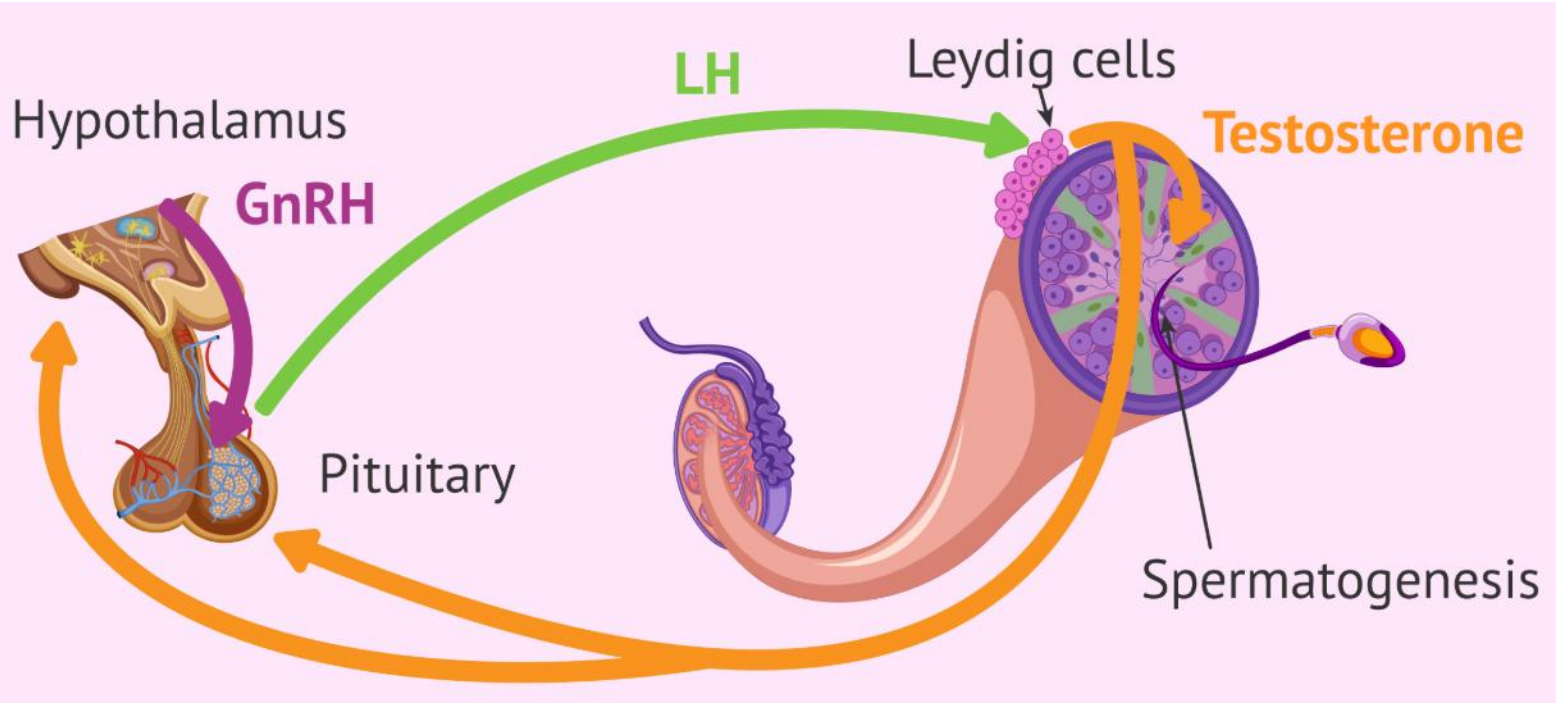
Nuclear morphology and cell identification



Endocrine support of spermatogenesis: Leyding cells



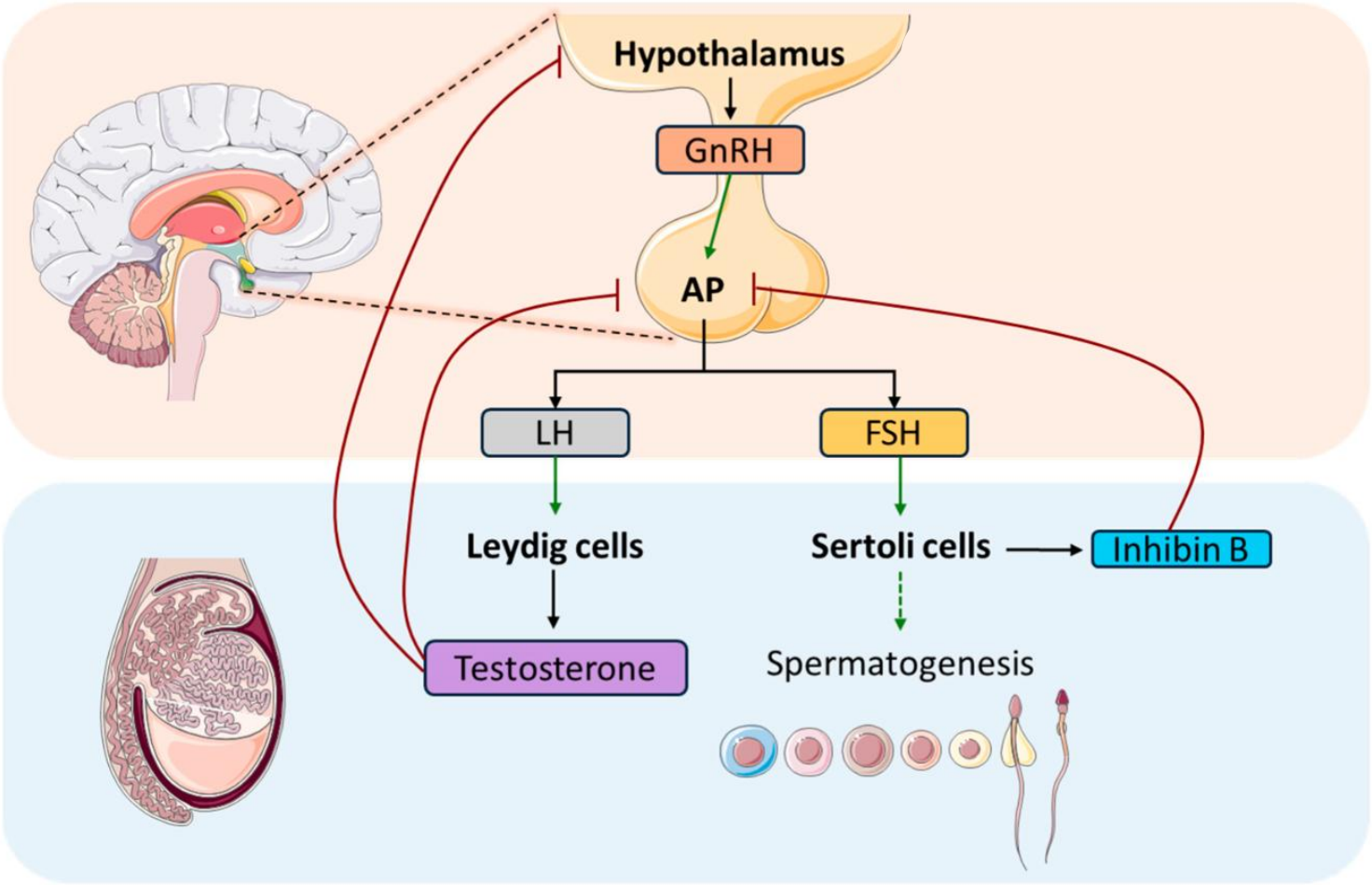
Endocrine support of spermatogenesis: Leyding cells



- Located in the interstitial compartment
- LH-responsive endocrine cells
- Induce testosterone production
- High intratesticular testosterone
- Action on Sertoli cells and reproductive tract

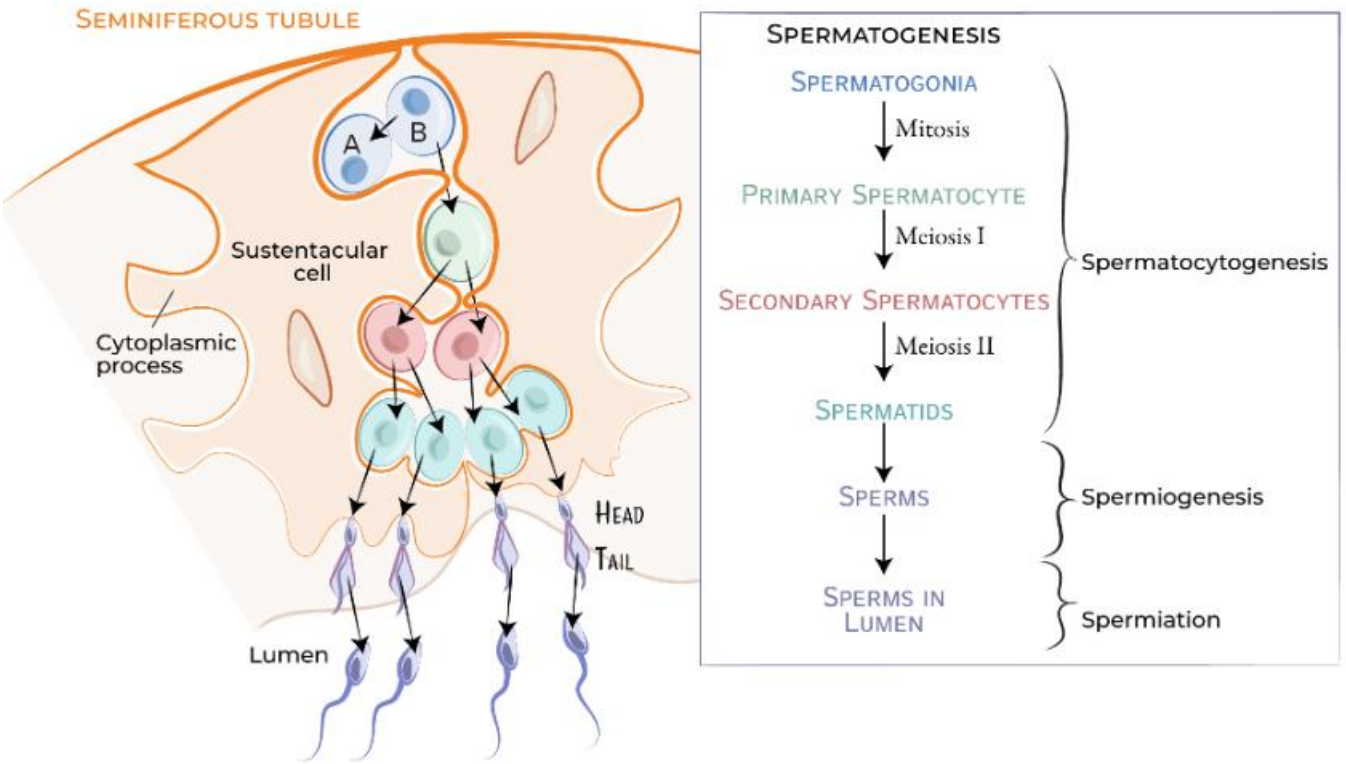
Leydig cells provide the androgenic environment required for normal spermatogenesis.

Endocrine regulation of spermatogenesis



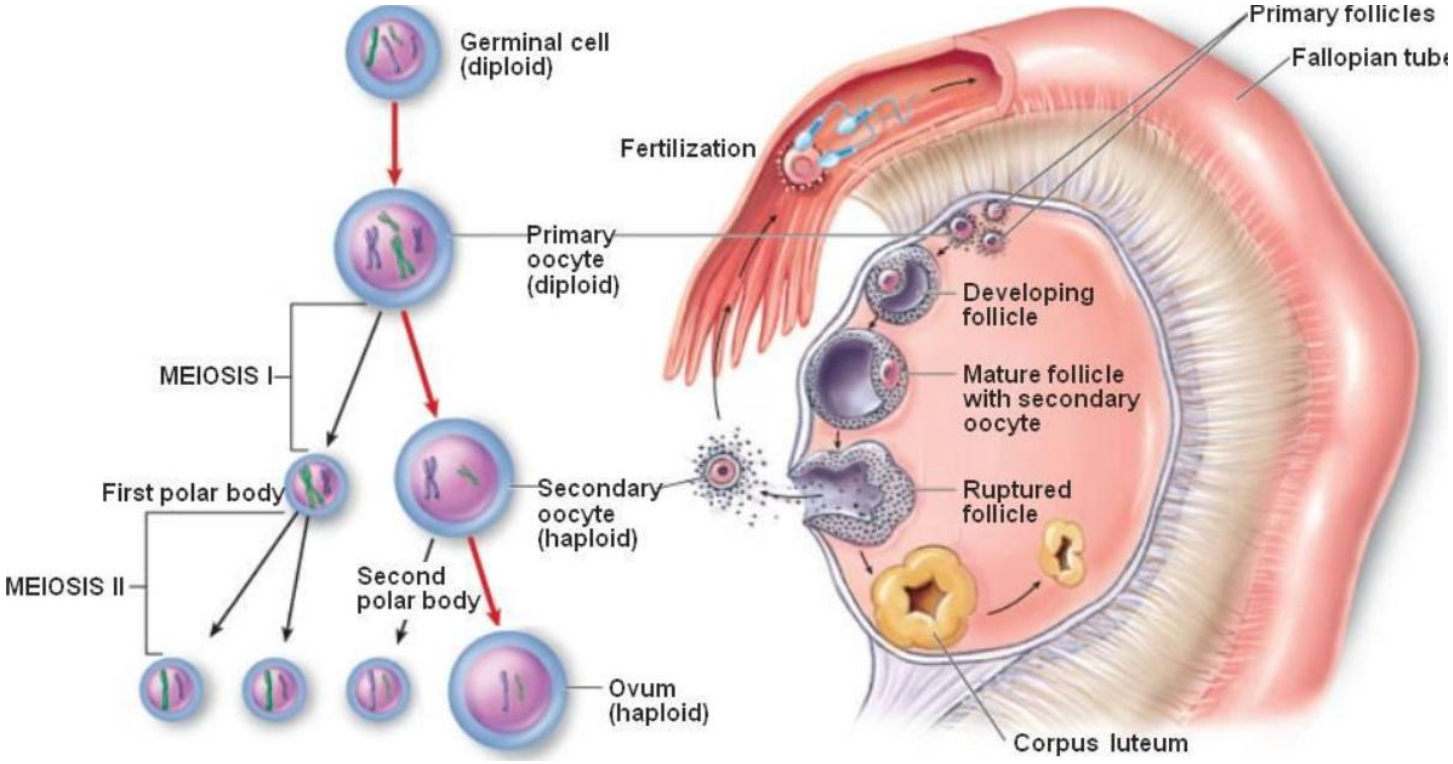
LH stimulates Leydig cells to produce testosterone, whereas FSH acts on Sertoli cells to support spermatogenesis and inhibin B secretion.
Normal spermatogenesis requires both endocrine stimulation and local somatic support.

Key Features of Spermatogenesis



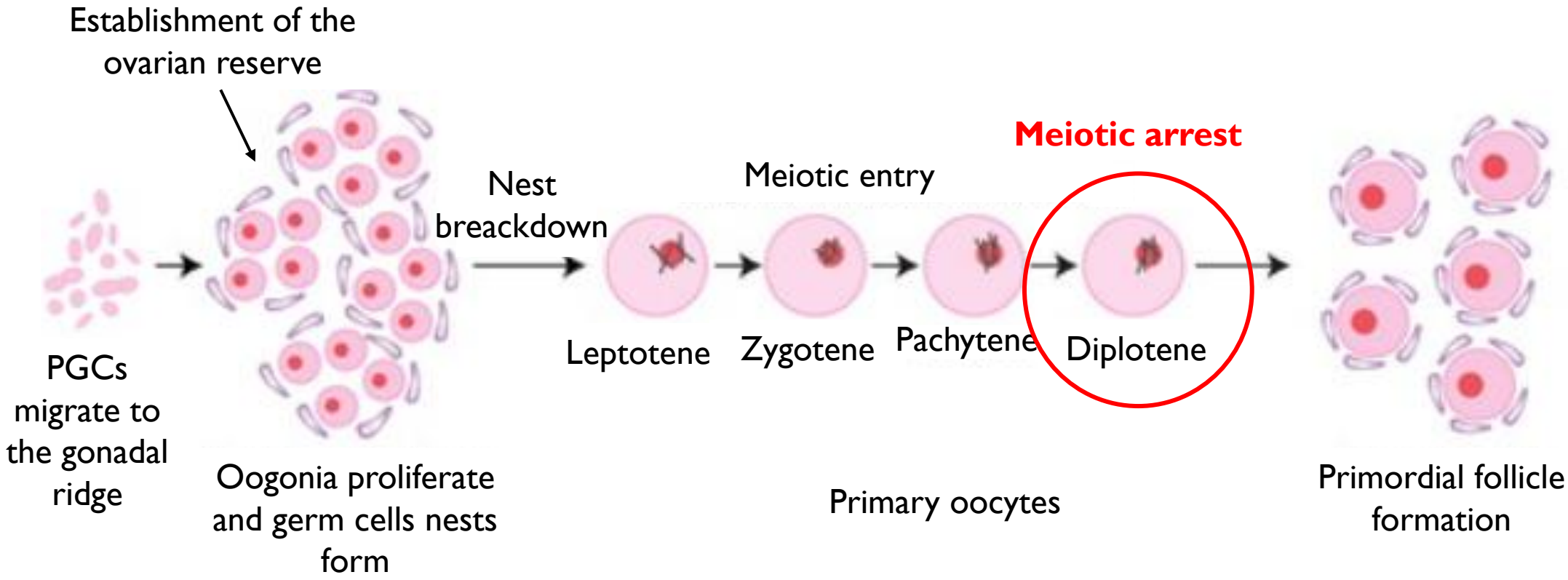
- Begins at puberty
- Continuous process
- High daily gamete output
- Four haploid speramtids per meiosis
- Requires high intratesticular testosterone
- Strong dependence on Sertoli cell support

OOGENESIS



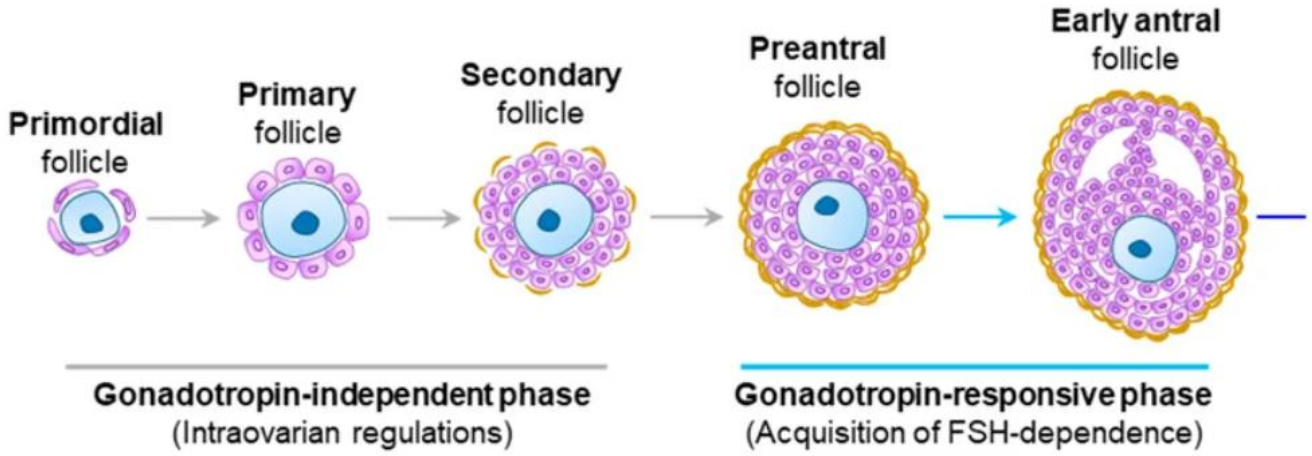
Oogenesis is the complex, highly regulated process by which primordial germ cells give rise to a mature, developmentally competent oocyte through mitotic proliferation, entry into meiosis, prolonged meiotic arrest, oocyte growth, nuclear and cytoplasmic maturation, and dynamic interactions with follicular somatic cells.

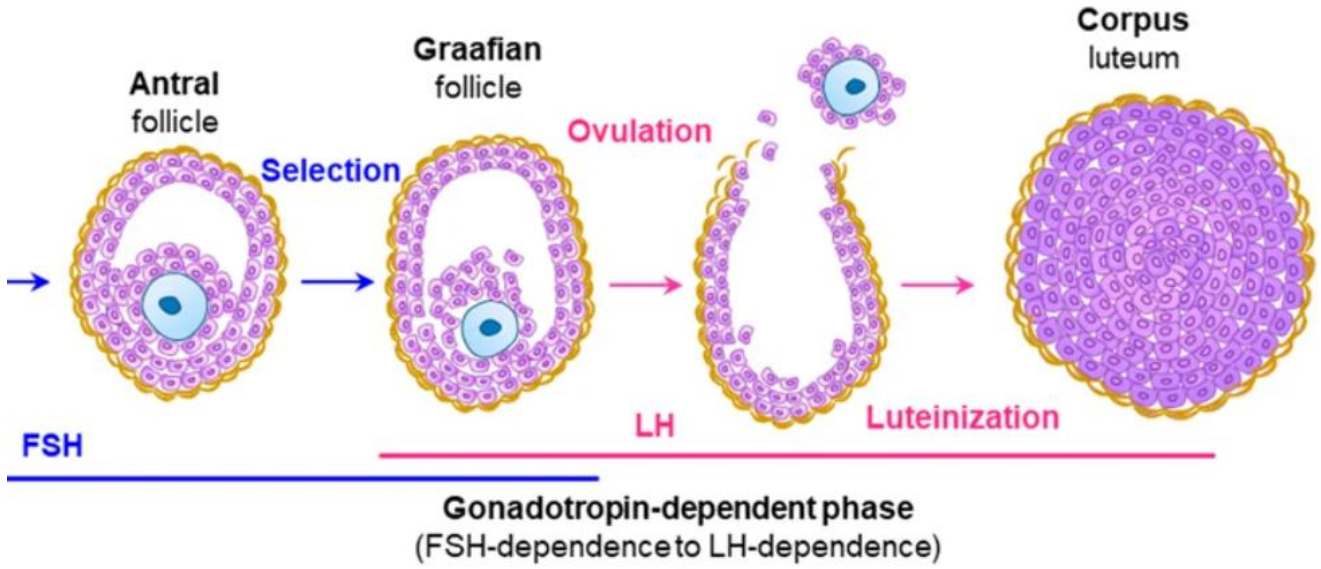
Establishment of the Ovarian Reserve



Key event: arrest at diplotene of prophase I precedes primordial follicle assembly.

Folliculogenesis

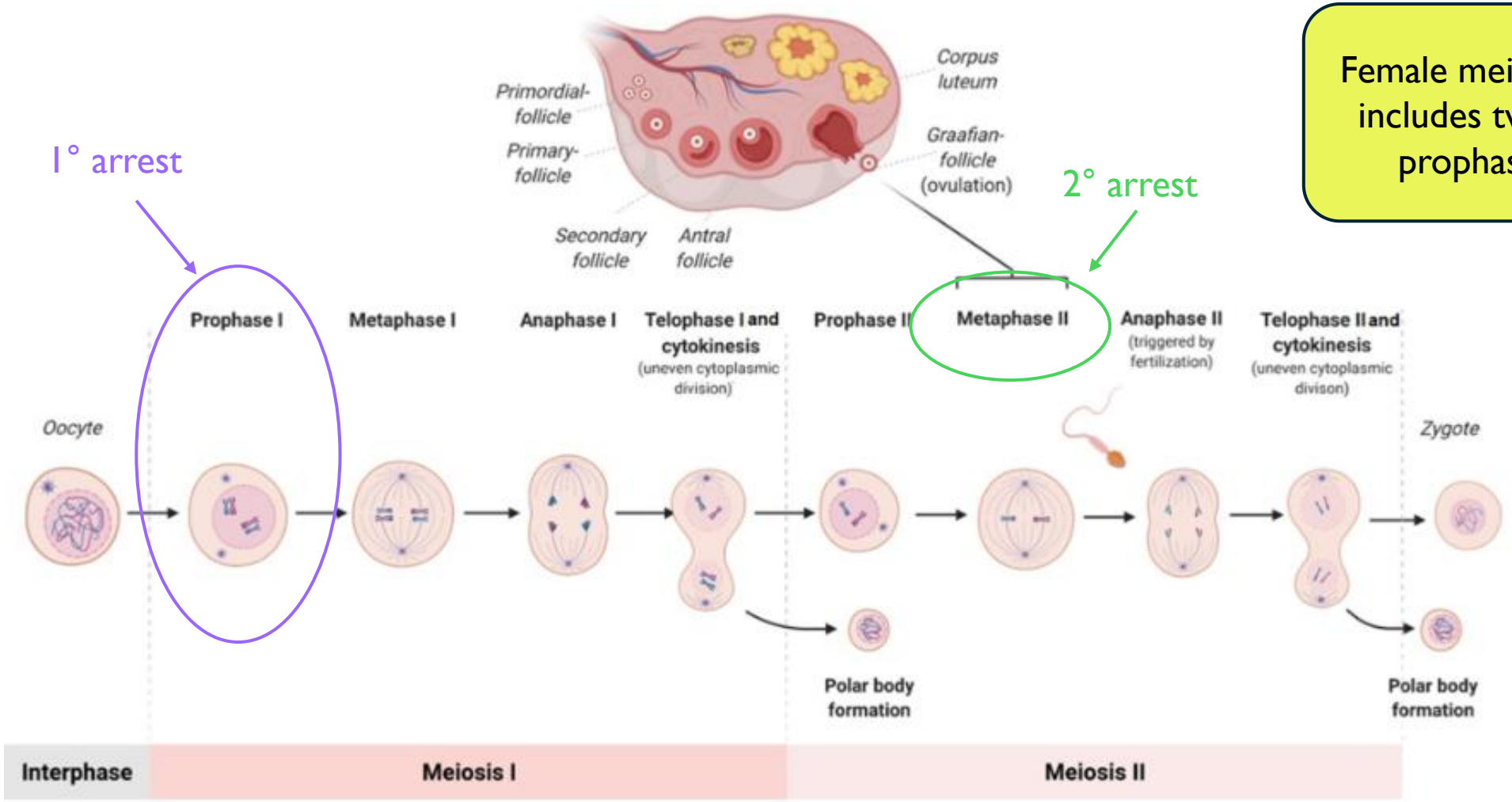




Folliculogenesis integrates oocyte growth, somatic-cell differentiation and endocrine regulation.

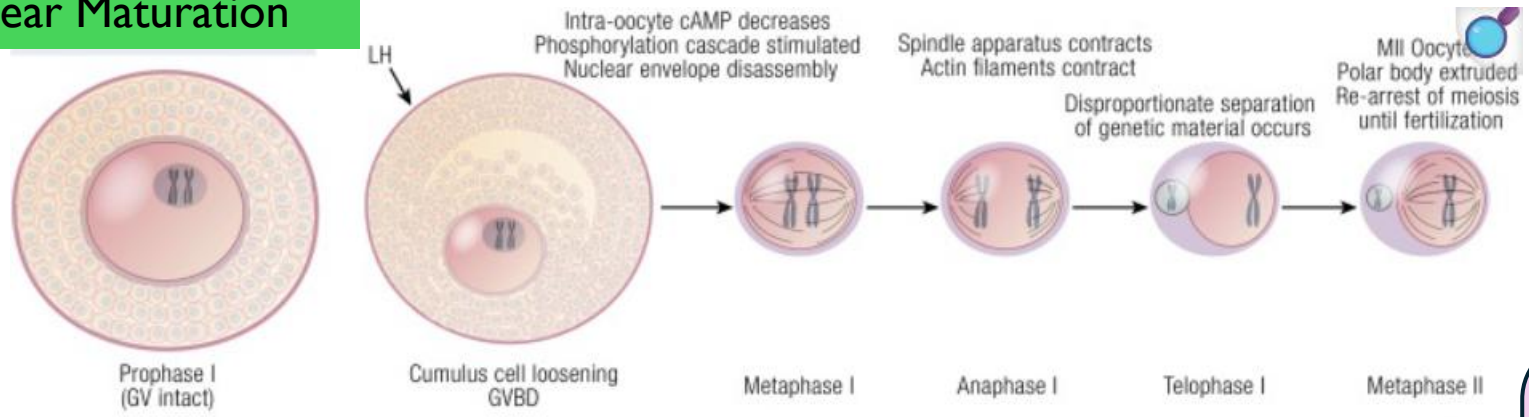
Meiotic arrest and Resumption

Female meiosis is discontinuous and includes two physiological arrests: prophase I and metaphase II.

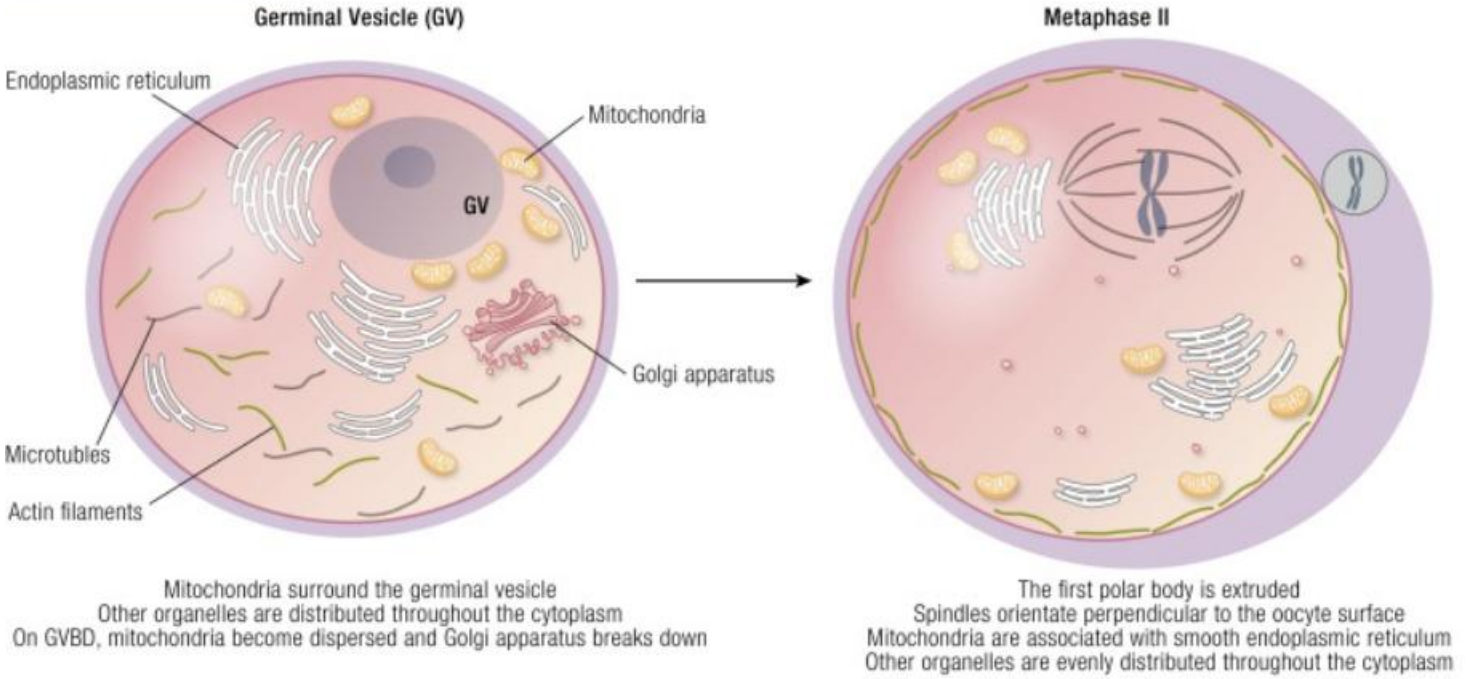


Oocyte maturation: Nuclear and Cytoplasmic events

Nuclear Maturation



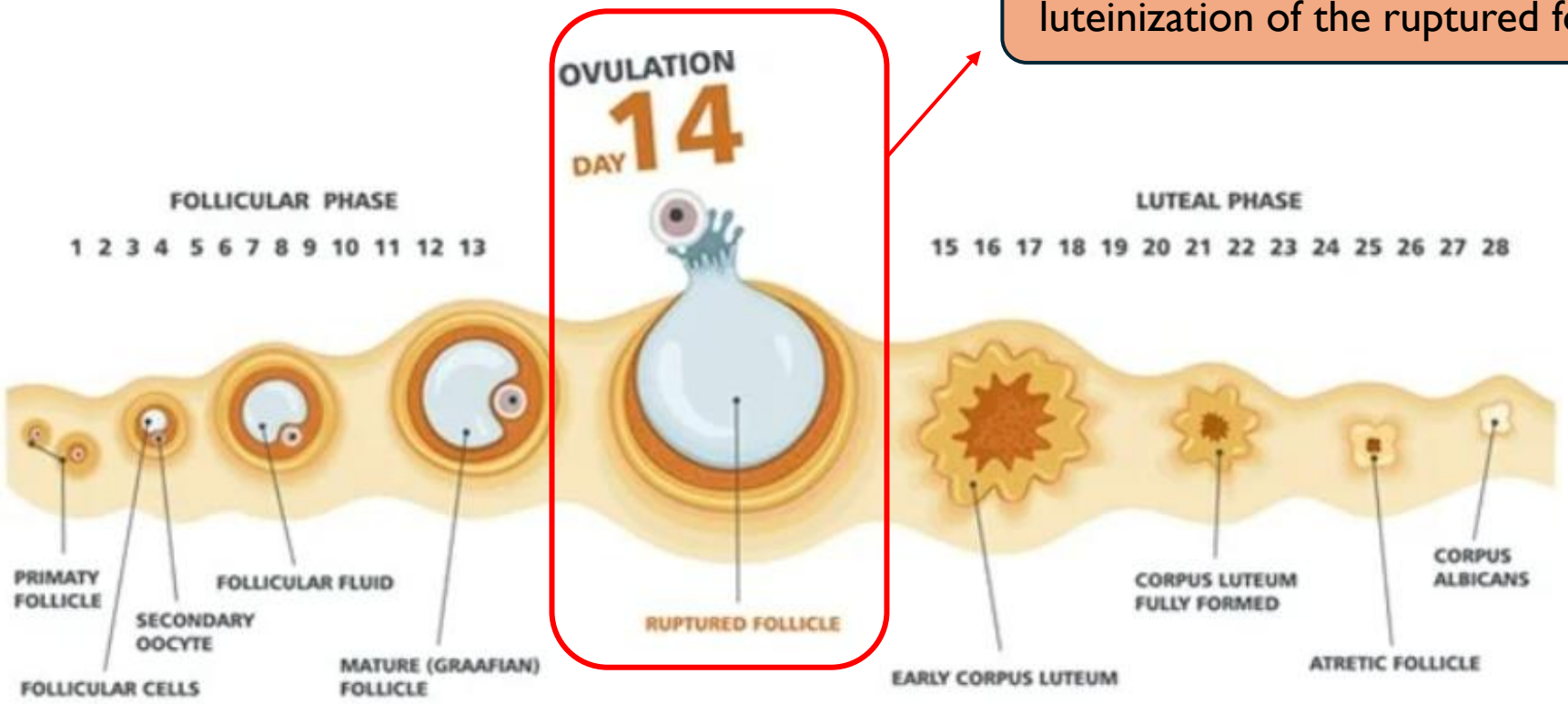
Cytoplasmic Maturation



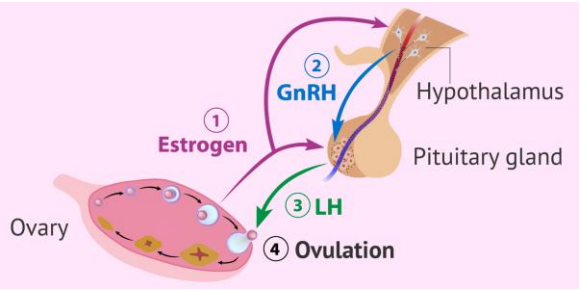
Developmental competence requires both meiotic progression and cytoplasmic remodeling.

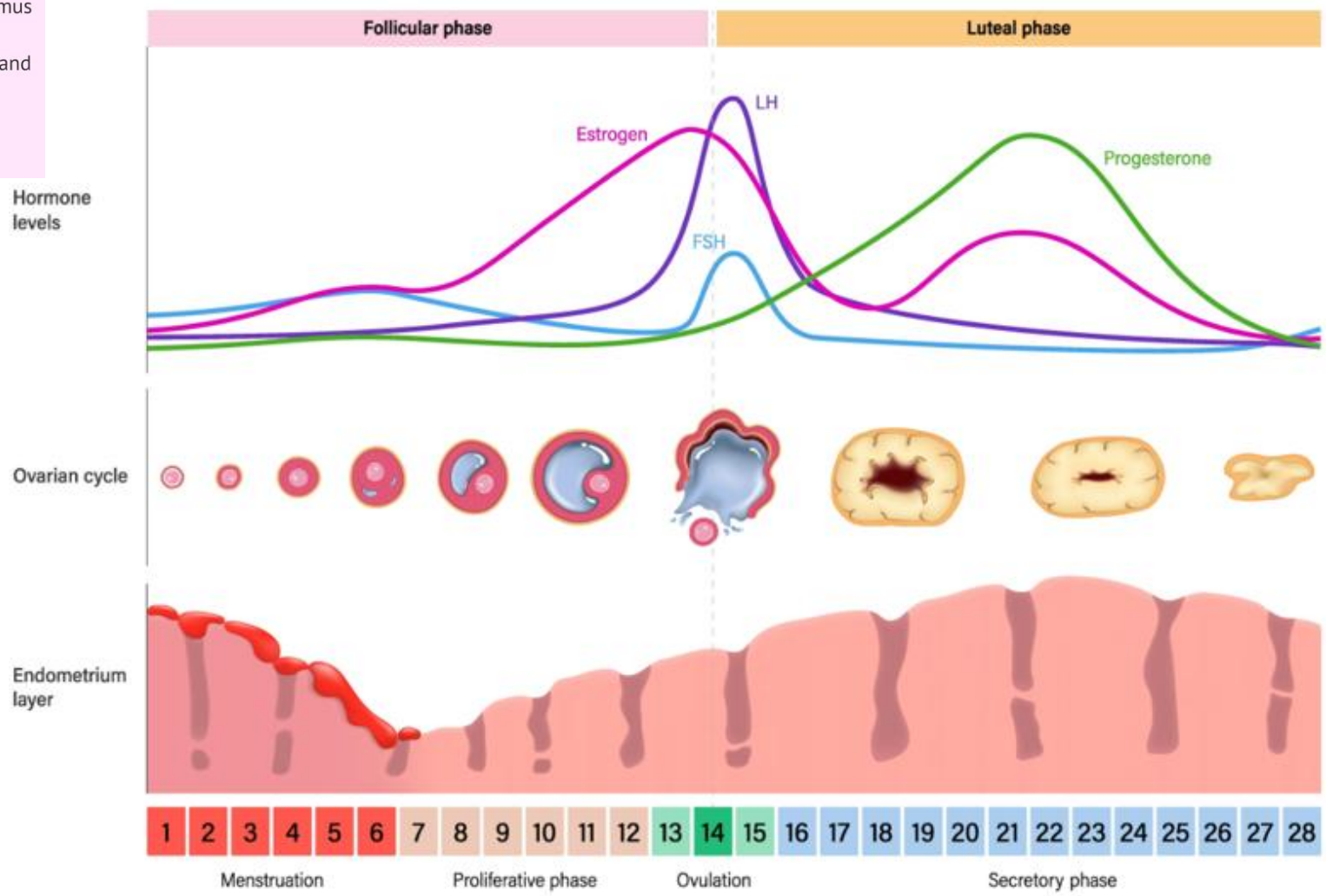
Ovulation and Corpus Luteum Formation

The LH surge triggers ovulation and luteinization of the ruptured follicle.



Hormonal Regulation of the Menstrual Cycle

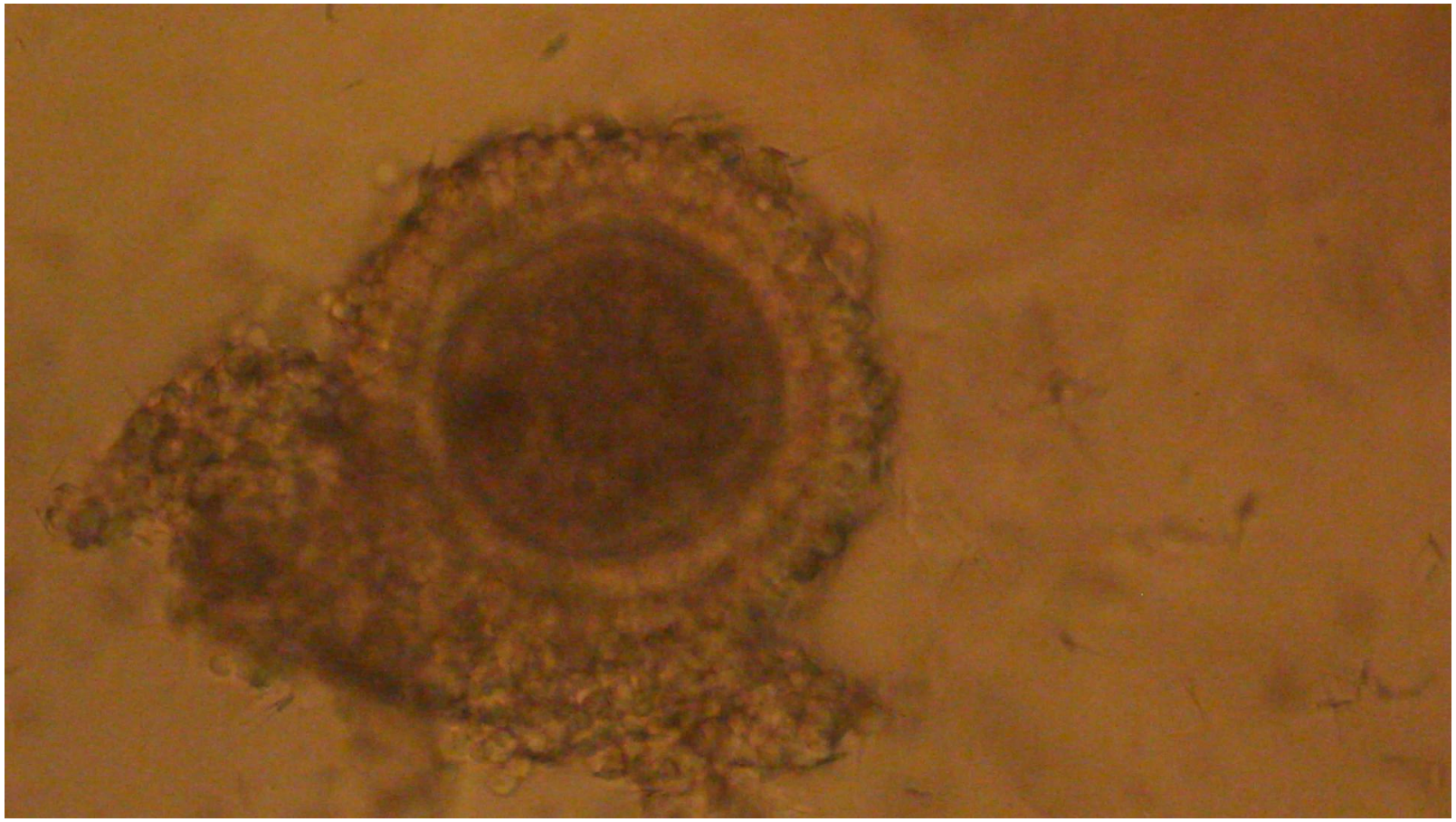




FSH supports follicular growth, sustained estradiol triggers the LH surge, and progesterone dominates the luteal phase.

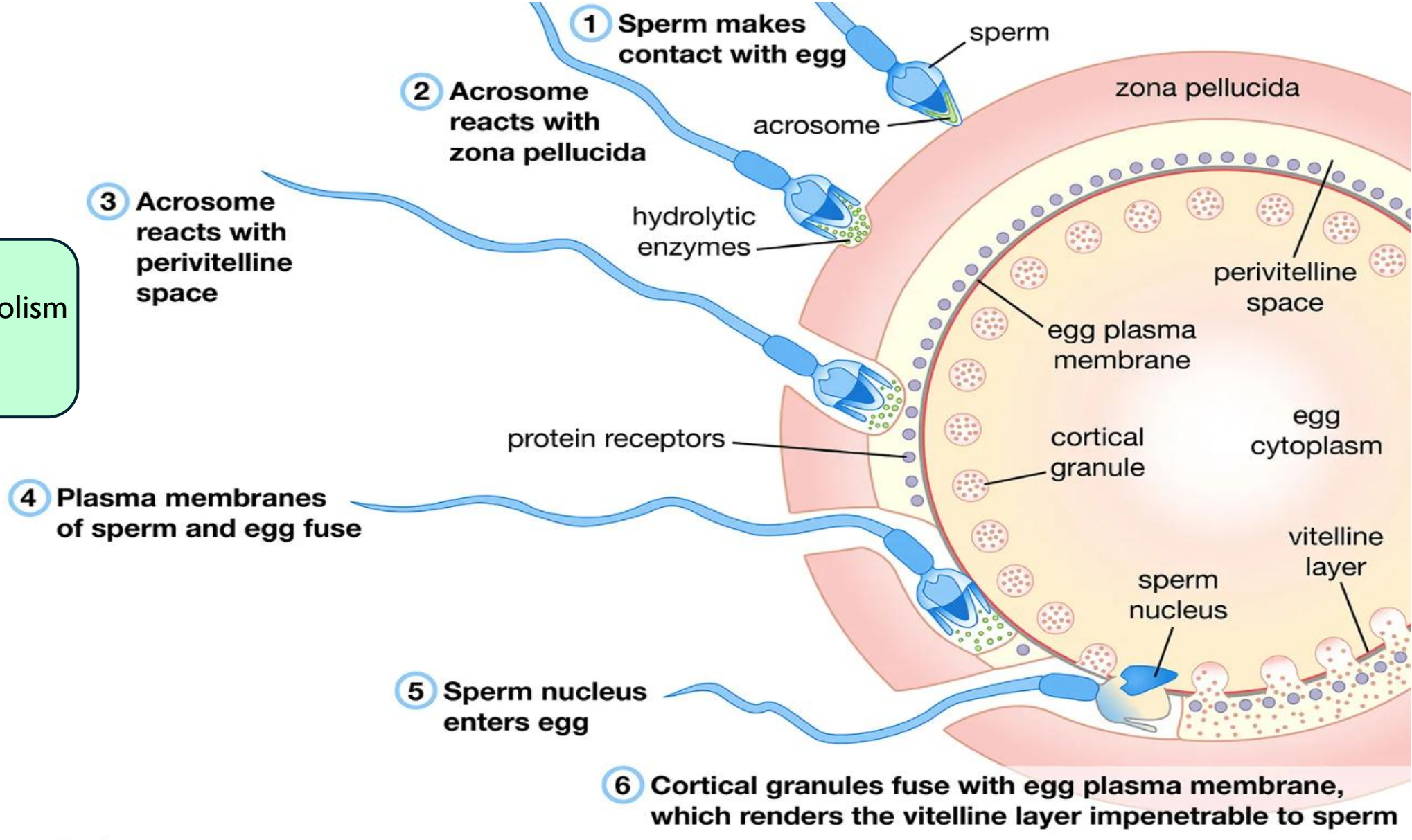
Fertilization

Fertilization occurs in the isthmus of the Fallopian tubes and is the process by which a spermatozoon interacts with and fuses with the oocyte, triggering oocyte activation, completion of meiosis II, and formation of the zygote.

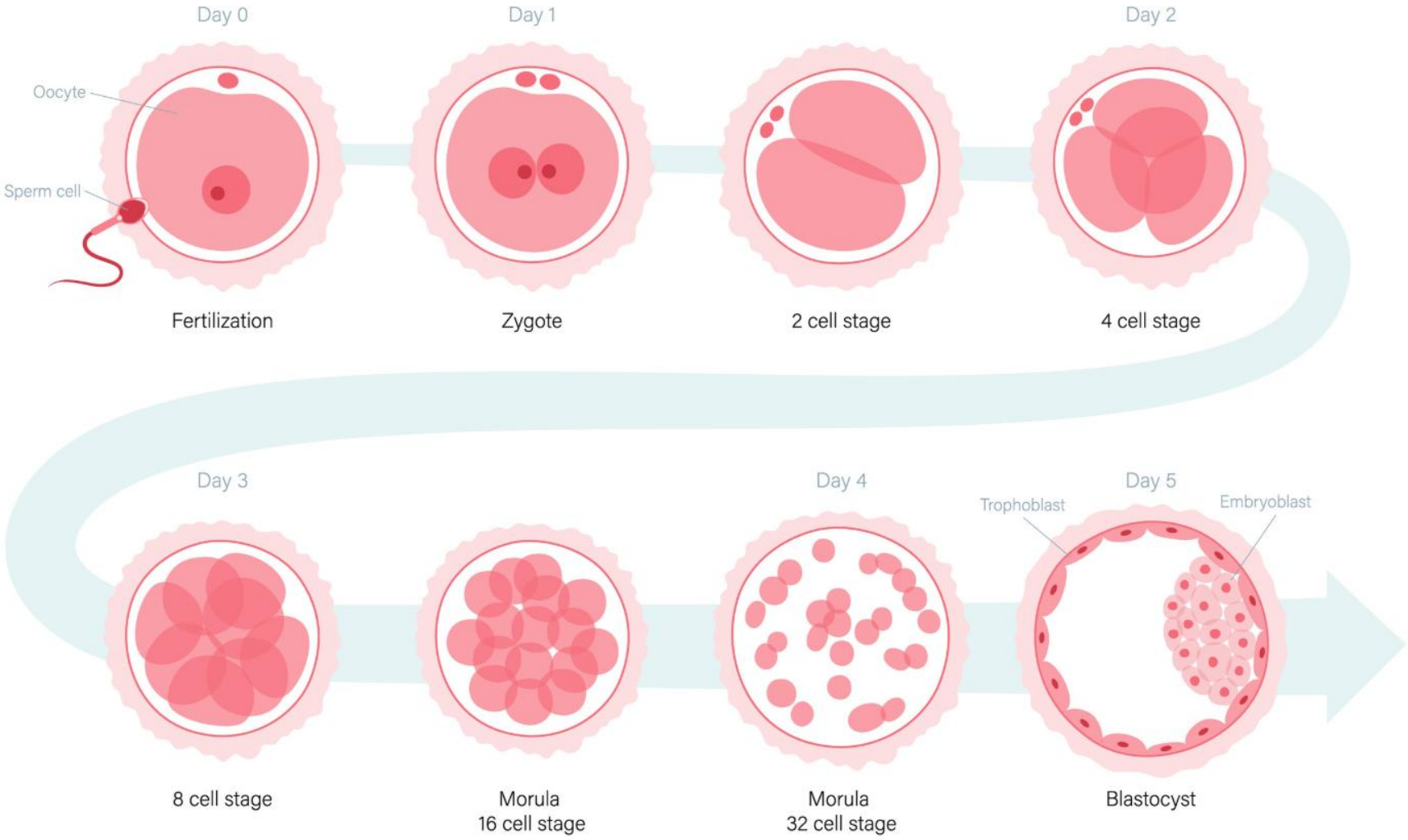


Fertilization: Sperm–Oocyte Interaction

Fertilization:
activates cellular metabolism of the oocyte;

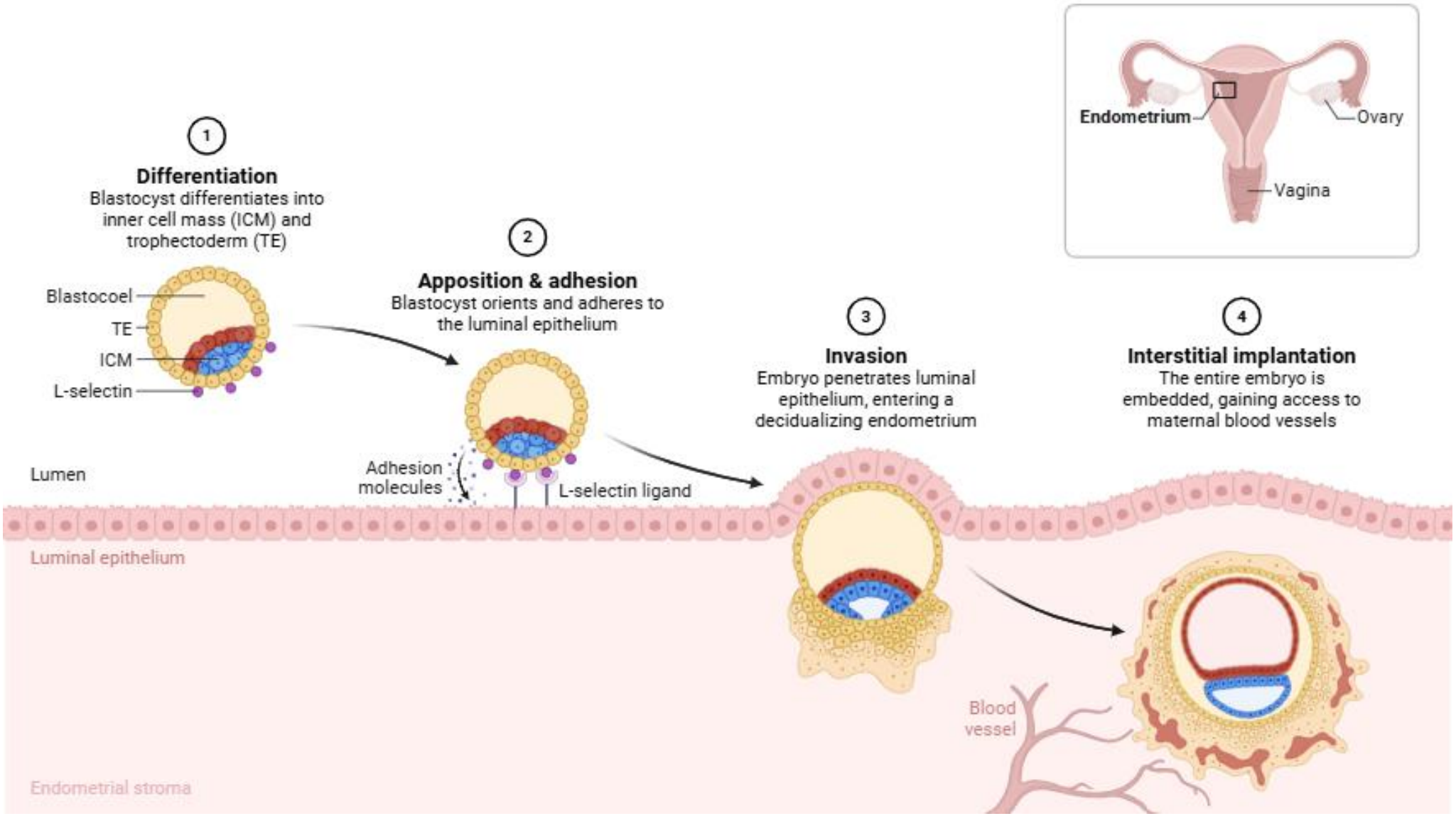


Early Embryonic Development

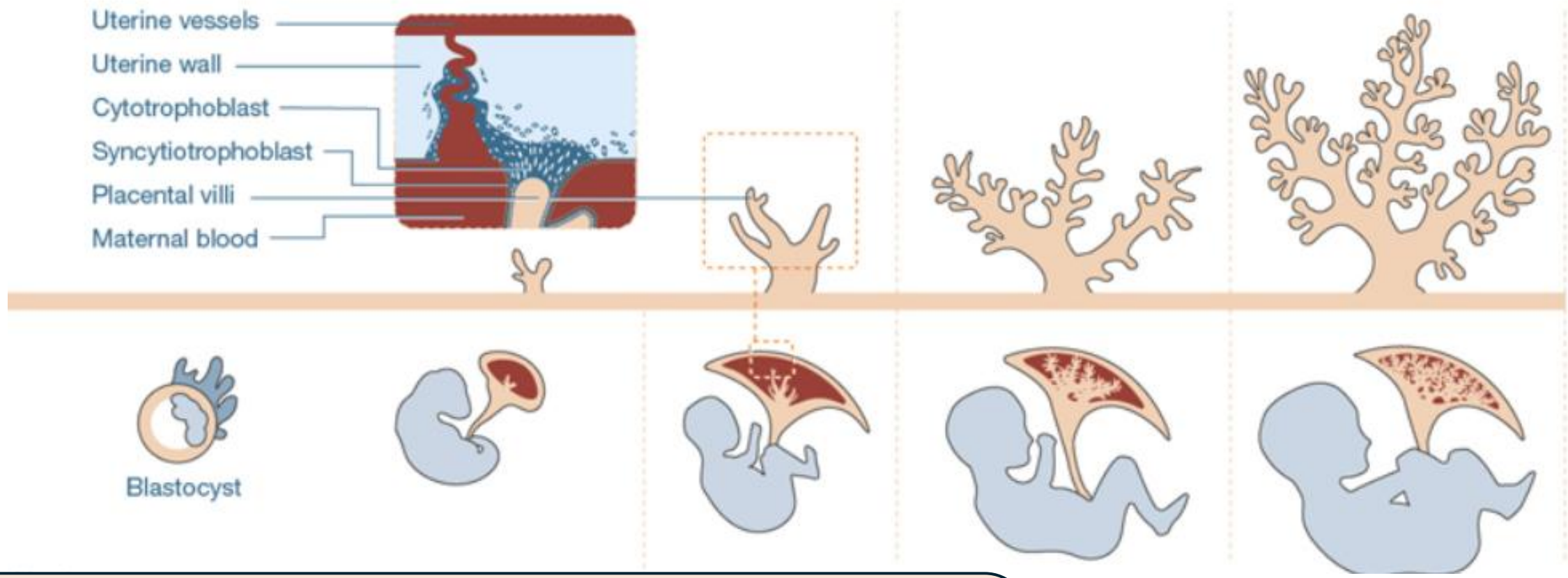


After fertilization, the zygote undergoes cleavage divisions, forming a morula and then a blastocyst.

Blastocyst implantation



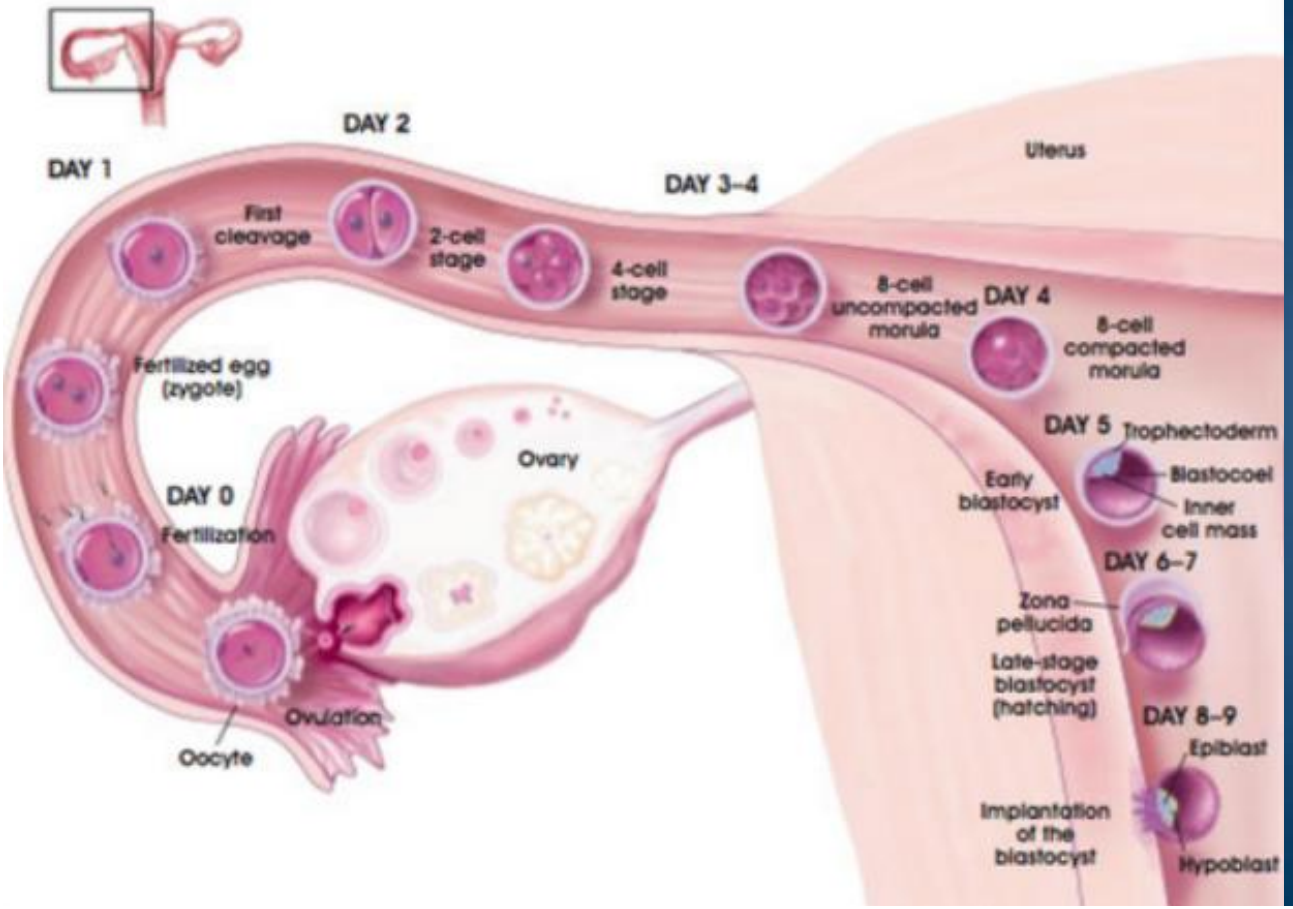
From Implantation to Placenta Formation

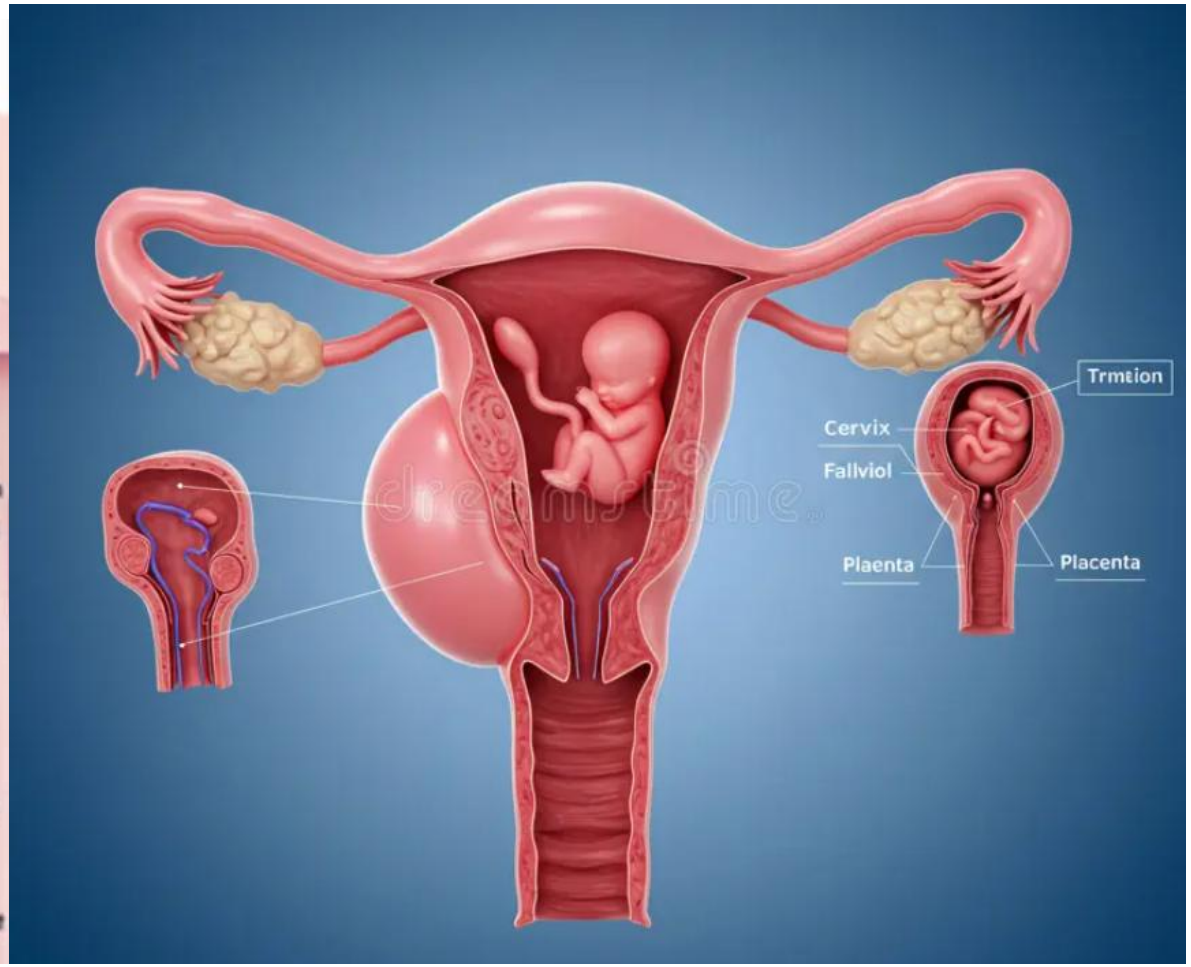


After implantation:

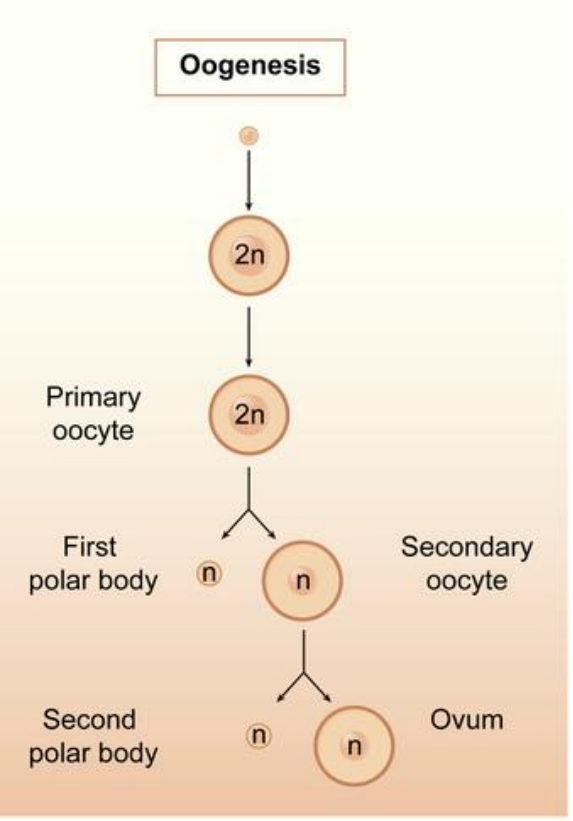
- Trophoblast cells proliferate and differentiate
- Cytotrophoblast and syncytiotrophoblast contribute to placental development
- Chorionic villi begin to form
- Maternal tissues and vessels are remodelled
- Nutrient and gas exchange are progressively established

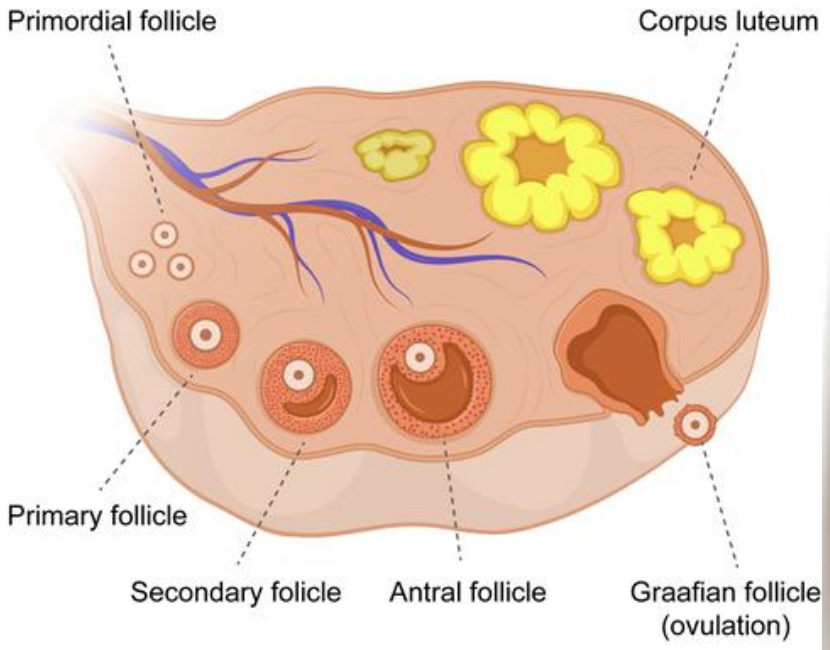
Embryo Journey Through the Female Reproductive Tract





Key Features of Oogenesis



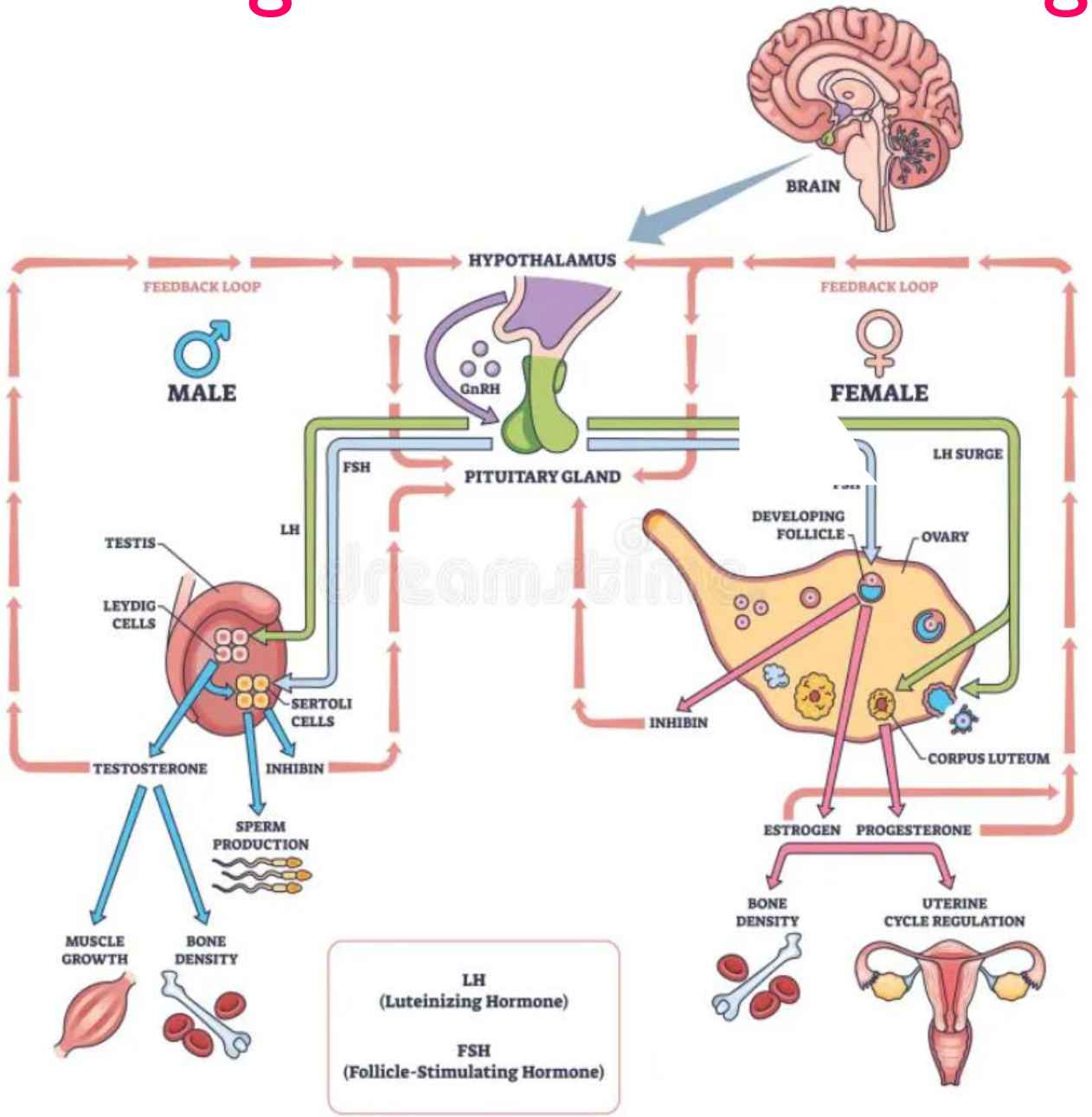


- Begins during fetal development
- Discontinuous meiotic process
- Finite ovarian reserve
- One functional gamete per meiosis
- Strong dependence on follicular microenvironment
- Oocyte quality declines with age
- Cytoplasmic maturation is essential for embryo development

Spermatogenesis vs Oogenesis

Feature	Spermatogenesis	Oogenesis
Onset	Puberty	Fetal life
Continuity	Continuous	Cyclic and discontinuous
Gamete output	Millions of spermatozoa per day	Usually one oocyte per cycle
Meiotic products	Four functional spermatozoa	One functional oocyte + polar bodies
Stem cell pool	Maintained throughout reproductive life	Finite ovarian reserve
Meiotic arrest	No prolonged arrest	Arrest at prophase I and metaphase II
Main support cells	Sertoli cells	Granulosa and cumulus cells
Cytoplasmic contribution	Minimal	Extensive
Gamete size	Small, highly specialized, motile	Large, non-motile, rich in cytoplasmic reserves
Biological strategy	Quantity and continuous production	Quality, developmental competence, and cyclic selection

Hormonal Regulation of Gametogenesis



Sex Determination and Sexual Differentiation

The three types of sex

Chromosomal sex

Determined at fertilization (XX or XY)

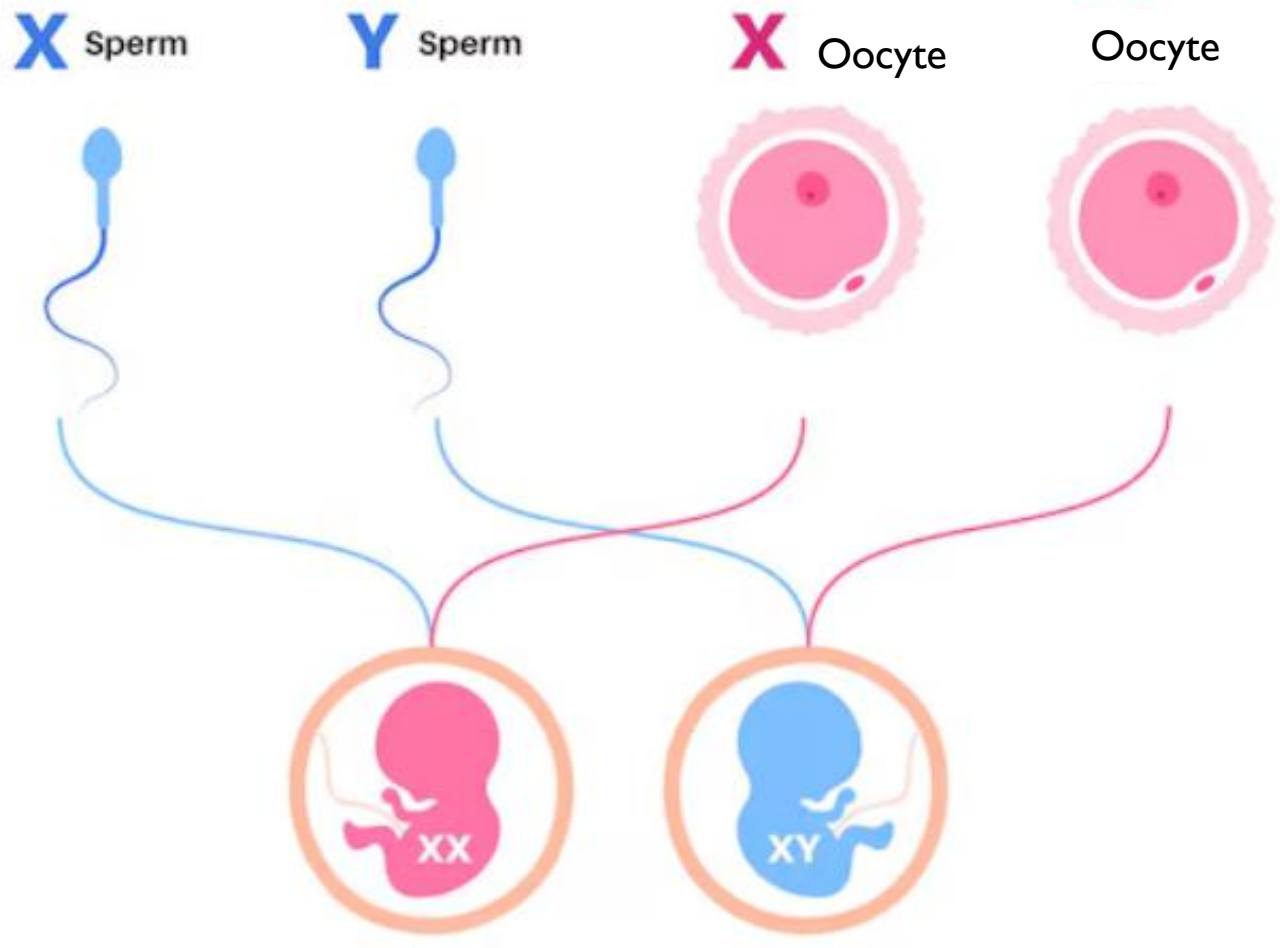
Gonadal sex

Differentiation of the bipotential gonad into ovary or testis

Phenotypic sex

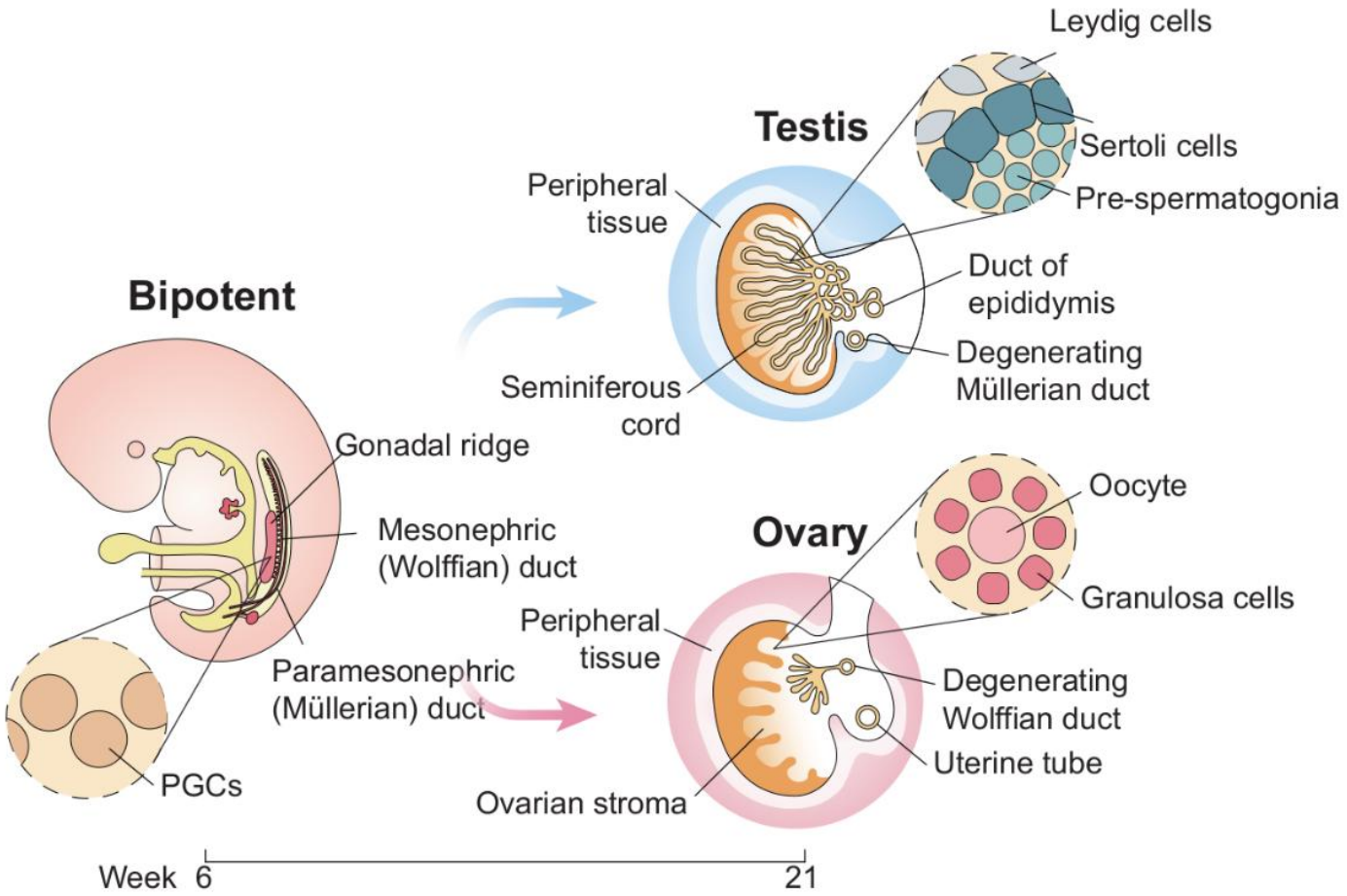
development of internal ducts, external genitalia and secondary sexual characteristics

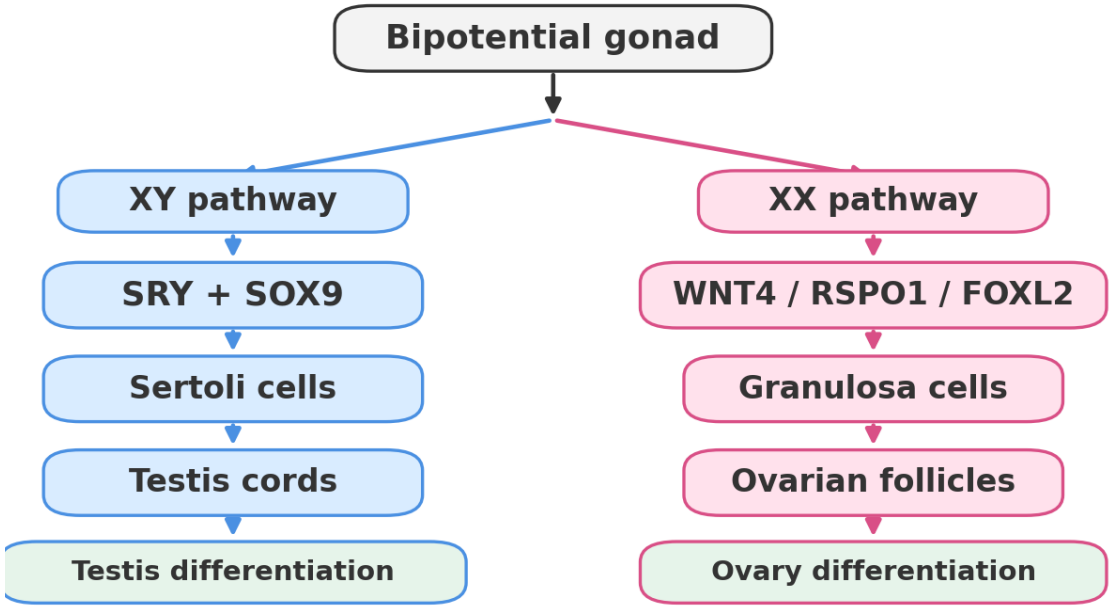
Chromosomal sex is established at fertilization



- ✓ The oocyte contributes one X chromosome
- ✓ The spermatozoon contributes either X or YXX and XY chromosomal complements are established at fertilization
- ✓ Chromosomal sex precedes gonadal and phenotypic differentiation

Gonadal Sex: from bipotential gonad to testis or ovary

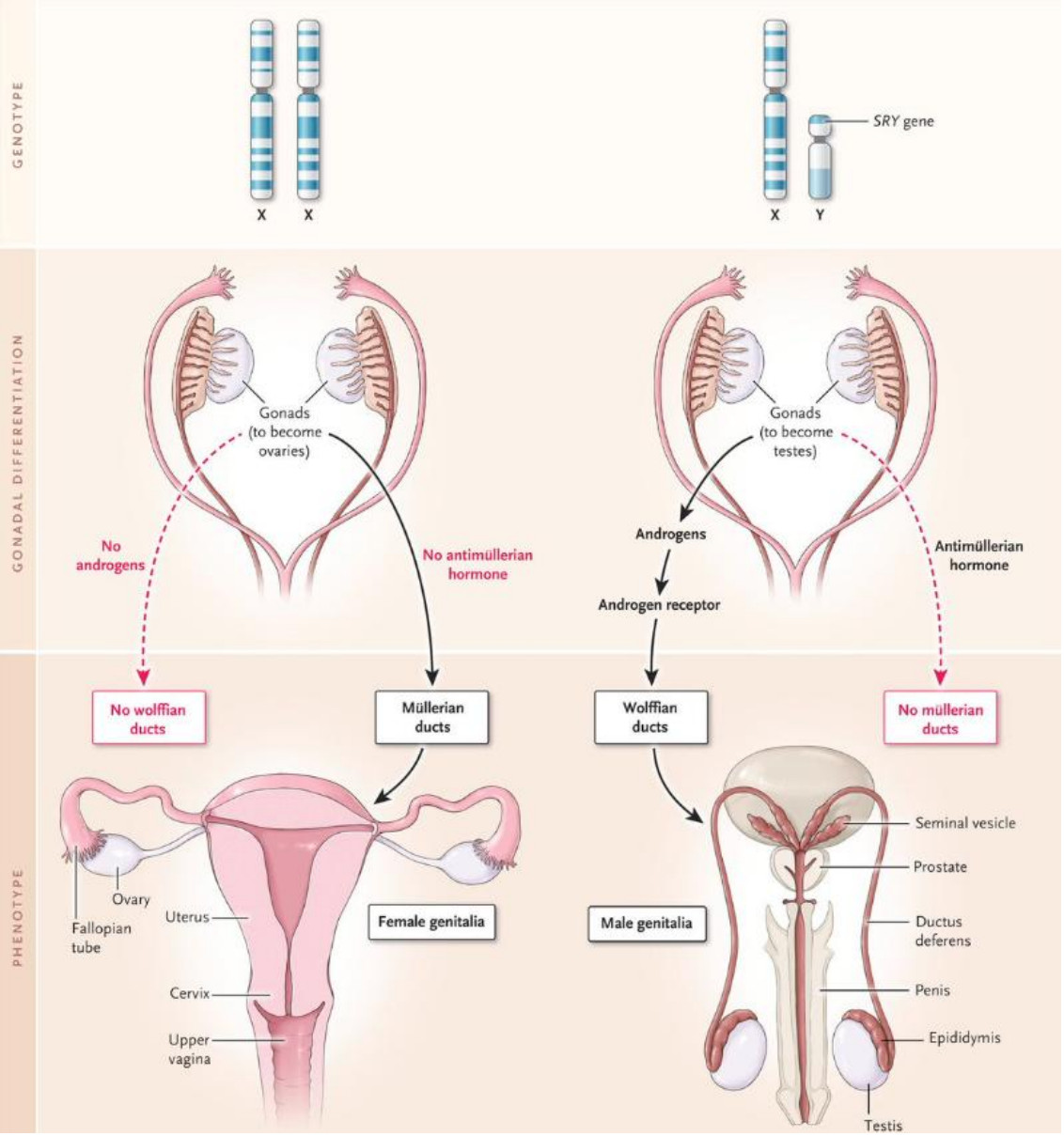




Gonadal sex is established by somatic supporting-cell fate decisions: Sertoli cells organize testis development, while granulosa cells support ovarian differentiation.

Phenotypic Sex Differentiation

From gonadal hormones to reproductive tract development



Testis pathway

- Sertoli cells → AMH → Müllerian duct regression
- Leydig cells → testosterone → Wolffian ducts maintenance
- Testosterone → DHT → external genital masculinization

Ovary / absence of testicular hormones

- No AMH → Müllerian ducts persist
- No high testosterone → Wolffian ducts regress
- No DHT → female-typical external genital development