Lecture 5. Gametogenesis: spermatogenesis and oogenesis

Lovinskaya Anna Vladimirovna,

PhD, Departure of Molecular Biology and Genetics

Gametogenesis

Gametogenesis is the process of formation and differentiation of haploid gametes (sperms and ova) from the diploid primary germ cells, gametogonia (spermatogonia and oogonia) present in primary sex organs called gonads (testes in male and ovaries in female respectively).

Gametogenesis

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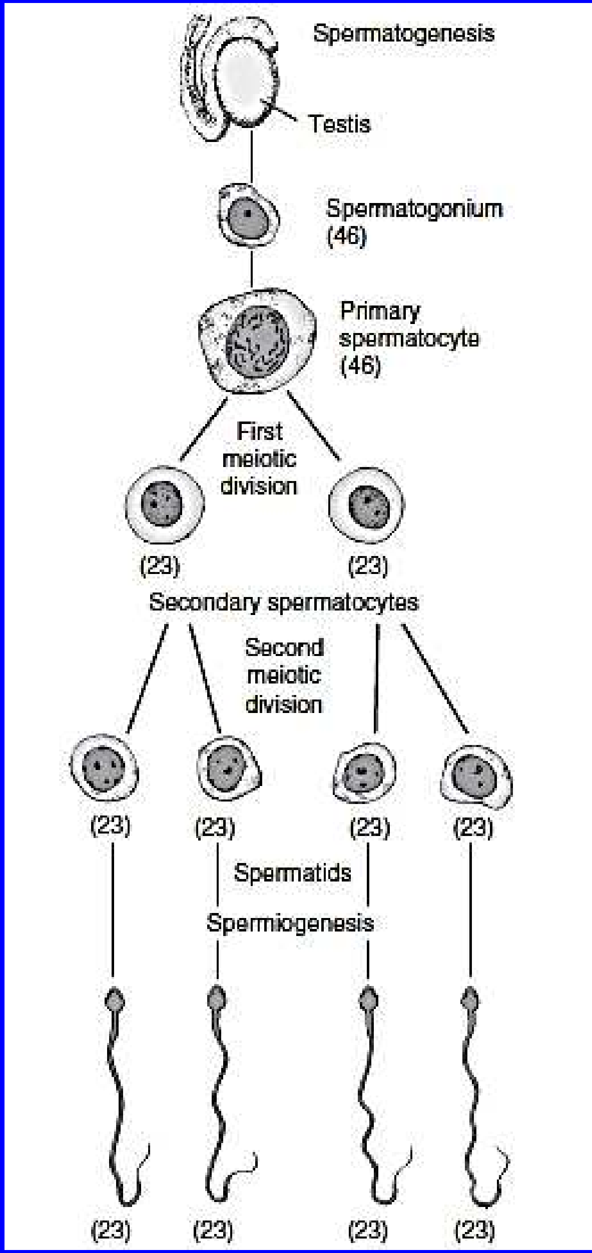
Spermatogenesis **Oogenesis**

Spermatogenesis



Spermatogenesis is the formation of haploid, microscopic and functional male gametes (spermatozoa) from the diploid reproductive cells (spermatogonia) present in the testes of male organism.

Spermatogenesis is divided into two parts:

A. Formation of Spermatid. It is divided into three phases:

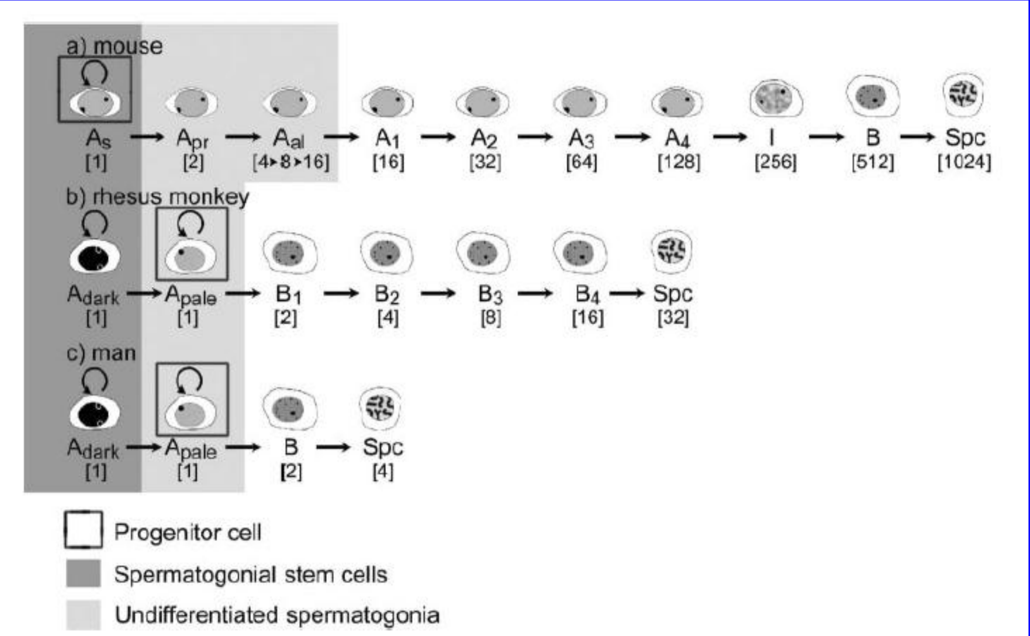
1. Multiplicative or Mitotic phase;
2. Growth phase;
3. Maturation or Meiotic phase

B. Spermiogenesis

Spermatogenesis: Formation of Spermatid

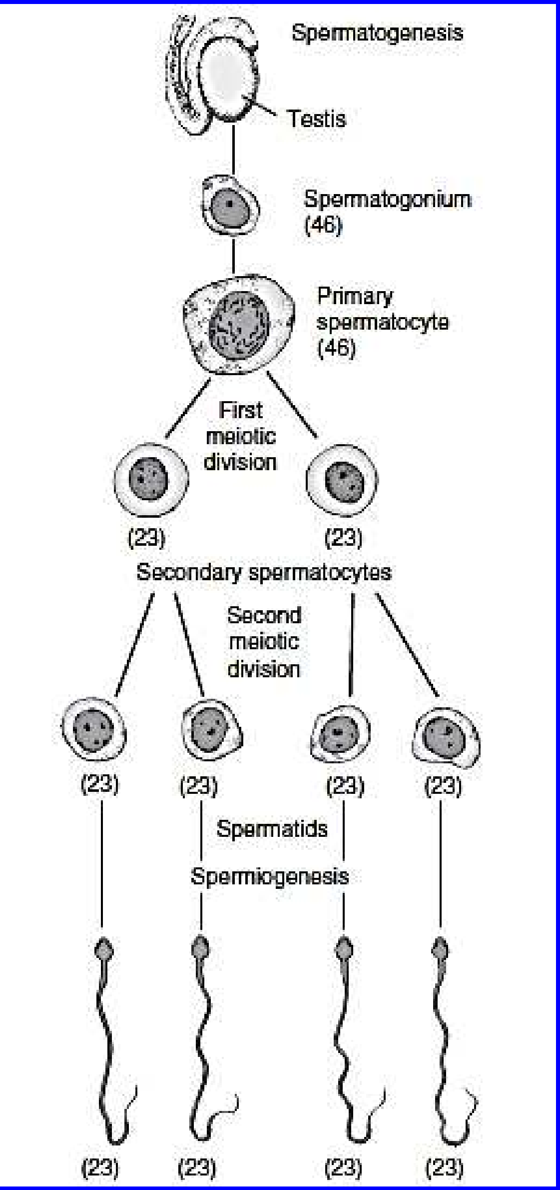
1. Multiplicative or Mitotic phase:

It involves the rapid mitotic division of diploid primary or primordial germ cells, called gonocytes, present in germinal epithelium of the seminiferous tubules of the testes. These cell are undifferentiated and have large and chromatin-rich nucleus. This forms large number of diploid and rounded sperm mother cells called ***spermatogonia*** (Gr. sperma = seed; gone = offspring). Each spermatogonial cell is about 12 pm in diameter and has a prominent nucleus. Some spermatogonia act as stem cells (called ***Type A spermatogonia***) and go on dividing and adding new cells by repeated mitotic divisions, so forming spermatogenic lineage, but some spermatogonia move inward and enter growth phase (called ***Type B spermatogonia***)



The premeiotic steps of spermatogenesis in different species of mammals. The number given in brackets underneath the cells indicates the total number of daughter cells derived from any one progenitor cell that enters differentiation.

Spermatogenesis: Formation of Spermatid



2. ***Growth phase*** is characterized by ***<u>spermatocytogenesis</u>*** in which a diploid spermatogonium increases in size (about twice) by the accumulation of nutritive materials (derived from germinal cells and not synthesized) in the cytoplasm and replication of DNA, and forms diploid primary spermatocyte. During this, the primary spermatocyte prepares itself to enter meiosis.

3. ***Maturation or Meiotic phas***e is characterized by meiosis. The diploid primary spermatocyte undergoes meiosis-I (reductional or heterotypical division) and forms two haploid cells called secondary spermatocytes, each containing 23 chromosomes. It is immediately followed by meiosis-II (equational or homotypical division) in each secondary spermatocyte to form two haploid spermatids, each of which has 23 chromosomes. So each diploid spermatogonium produces 4 haploid spermatids.

Table 1
Stages of male germ cell development and their duration in mice, rats and men. The duration is given in hours (days).

	Mice [a]	Rats [b]	Men [c]
Stem-cell spermatogonia: slow cycling, always present, DNA repair competent			
Differentiating spermatogonia: rapidly cycling, DNA repair competent			
A-spermatogonia	≅ 69 (3)	≅ 168 (7)	≅ 223 (9.5)
Intermediate spermatogonia	45.4 (2)	42.3 (1.8)	-
B-spermatogonia	*29.4 (1)*	*41.2 (1.7)*	*158.4 (6.5)*
	189.8 (6)	251.5 (10.5)	921.6 (16)
Spermatocytes: meiotic stages, DNA repair competent			
Prophase:			
Preleptotene (last S-phase)	20.6 (< 1.0)	84.1 (3.5)	62.4 (2.5)
Leptotene	44.0 (2.0)	21.3 (1.0)	134.4 (5.5)
Zygotene	32.7 (1.5)	49.9 (2.0)	26.4 (1.0)
Pachytene	193.7 (8.0)	270.1 (11)	355.2 (15)
Diplotene	21.4 (< 1.0)	17.6 (< 1.0)	-
MMI and MMII *	*20.8 (< 1.0)*	*14.1 (> 0.5)*	*26.4 (1.0)*
	333.2 (14)	457.1 (19)	604.8 (25)
Spermatids (postmeotic stages)			
Acrosomal stages * *	117.6 (5)	181.1 (7.5)	220.8 (9.2)
Elongated stages * * *	*97.5 (4)*	*106.6 (4.5)*	*160.8 (6.7)*
	215.1 (9)	287.7 (12)	381.6 (16)
Testicular sperm (no DNA repair competence)	146.4 (6)	202.4 (8.5)	158.4 (6.5)
Total spermatogenesis	35 d	50 d	64 d
After release from the testicular tubules, the sperm stay in the epididymis for about 1 week (at least in mice)			
Release of sperm in ejaculate	39–41 d	57 d	72–81 d

* First and second meiotic division (transition from primary to secondary spermatocytes, following each other rapidly with short interkinesis and no S-phase.
* * Also called early spermatids, DNA repair competent.
* * * Nuclear condensation, replacement of histones by protamines, DNA repair capacity ends during this stage
[a] Oakberg (1956a,b); [b] Clermont et al. (1959); [c] Heller and Clermont (1963).

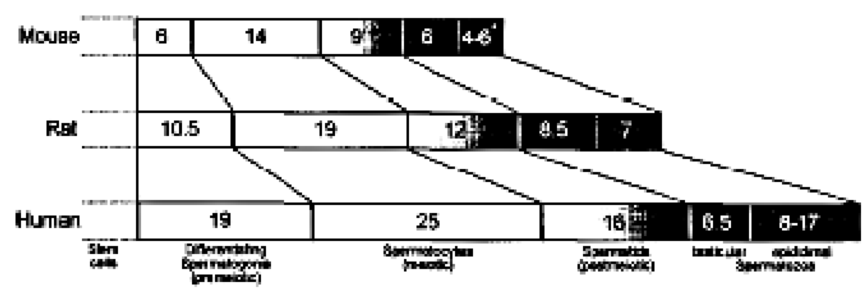


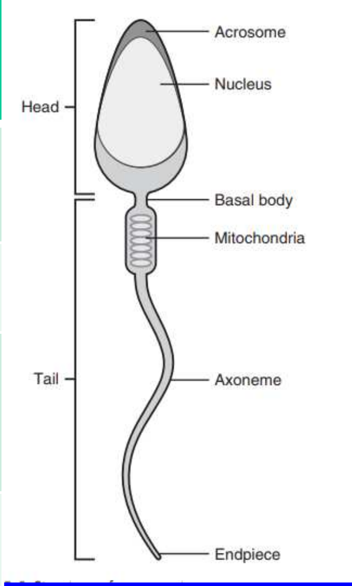
Fig. 1. Comparison of the duration (days) of male germ cell development in mice, rats and humans. DNA repair does not occur during the periods indicated by shading.

Spermiogenesis

The ***spermiogenesis*** or ***spermioteliosis*** is transformation of a non-motile, rounded and haploid spermatid into a functional and motile spermatozoan. The main aim is to increase the sperm motility by reducing weight and development of locomotory structure.

Changes in spermatid to form sperm during spermiogenesis:

Structure of spermatid	Changes in the sperm
Nucleus	Shrinks and elongated.
Golgi complex	Changes to acrosome
Distal centriole	Forms axial filament of sperm tail
Mitochondria	Form mitochondrial spiral of sheath called nebenkem
Cytoplasm	Generally lost except a thin sheath called manchette



SPERMATOGENESIS

In human male, spermatogenesis starts only at the age of puberty due to increased secretion of gonadotropin releasing hormone (GnRH) from the hypothalamus of brain. GnRH stimulates adenohypophysis to secrete two gonadotropins: FSH and ICSH. ICSH stimulates the Leydig's cells of testis to secrete male sex hormones, called *androgens*, most important of which is testosterone. *Testosterone* stimulates the spermatogenesis especially spermiogenesis. FSH stimulates the Sertoli cells of testis to secrete certain factors which helps in the process of spermatogenesis. It is called physiological control.

In man and a large number of other animals having XY mechanism in male, there are two types of sperms: 50% ***Gynosperms*** having X-Chromosome and 50% ***Androsperms*** having Y-Chromosome.

Sperm cells are the smallest cells in the body (egg cells are the largest). Men produce sperm continually. Between 300 and 600 sperm per gram of testis are produced every second. About 300 million sperm mature every day. Sperm can survive in the female reproductive tract for about 2 days and in the testes for several months.

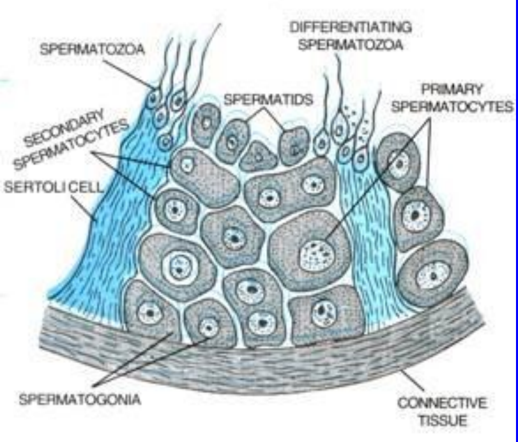
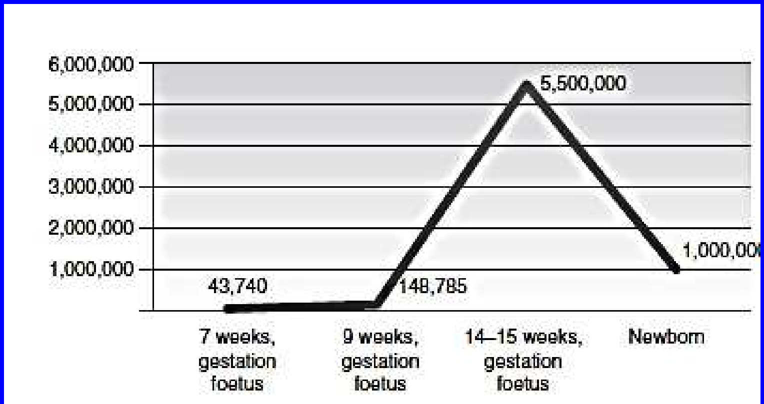


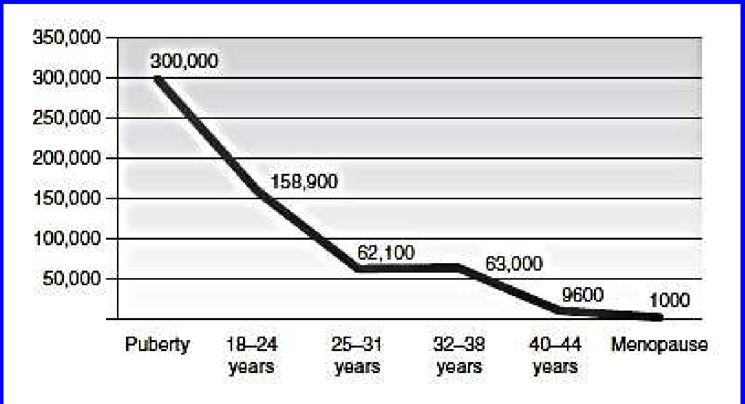
Fig. 3.14. T.S. A part of seminiferous tubule of testis showing spermatogenesis.

OOGENESIS

Oogenesis involves the formation of haploid female gametes (***ova***), from the diploid egg mother cells (***oogonia***) of ovary of female organism. It involves 2 biological processes: Genetical programming and packaging.

In human female, there are about 1,700 primary germ cells in the undifferentiated female gonad at one month of foetal development. These proliferate to form about 600,000 oogonia at two months of gestation period and by its 5th month, the ovaries contain over 7 million oogonia; however, many undergo ***atresia*** (degeneration of germ cells) before birth. At the time of birth, there are 2 million primary follicles, and at the time of puberty each ovary contains only 60,000-80,000 primary follicles. Oogenesis is completed only after the onset of puberty and only one out of 500 is stimulated by FSH to mature. So oogenesis is a discontinuous and wasteful process.

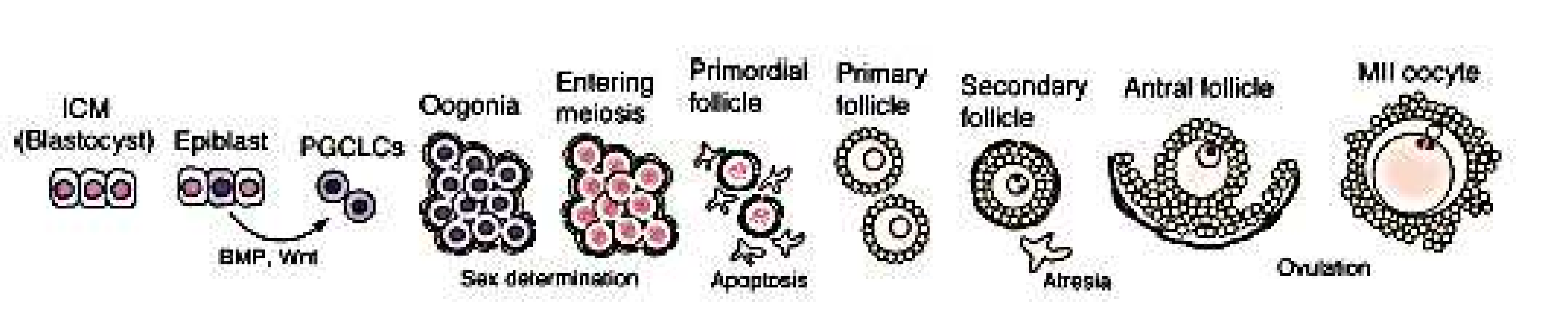




PHASES OF OOGENESIS:

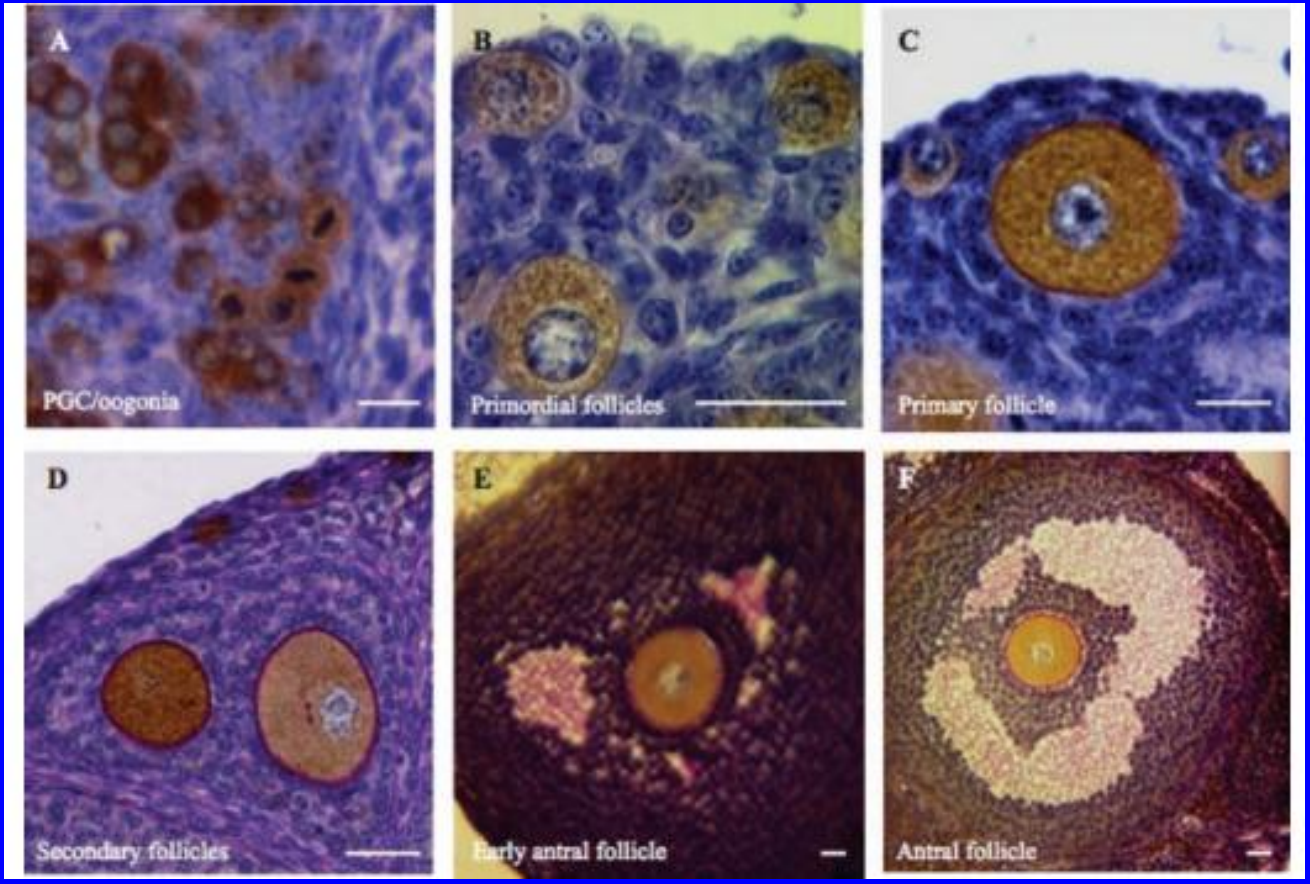
1. ***Multiplicative phase***: In this certain primary germ cells (larger in size and having large nuclei) of germinal epithelium of ovary undergo rapid mitotic divisions to form groups of diploid egg mother cells, oogonia. Each group is initially a chord and is called egg tube of pfluger which later forms a rounded mass, egg nest.

2. ***Growth phase*** of oogenesis is of very long duration (6-14 days in hen, 3 years in frog and 12-13 years in human female). During growth phase, one oogonium of egg nest is transformed into diploid primary oocyte while other oogonia of the egg nest form a single-layered nutritive follicular epithelium around it (*primary follicle*). Later, each primary follicle gets surrounded by more layers of granulosal cells and changes into *secondary follicle*. Soon secondary follicle develops a fluid-filled antral cavity (antrum) and is called *antral* (*tertiary) follicle*. It further changes to form *Graafian follicle*.



FOLLICULOGENESIS

The eggs (oocytes) develop within ovarian follicles (folliculus = little bag). The development of primordial (resting) follicles into preovulatory follicles is known as ***folliculogenesis***.



A–F: Examples of stages in follicle and oocyte growth from oogonia (A) to antral follicle (F). Oocyte cytoplasm is labeled with mouse vasa homolog (MVH) antibody, a specific oocyte factor; zona pellucida is stained with PAS reaction (pink). Note in C the onset of zona pellucida formation in the primary follicle. Scale bars 20 mm.

FOLLICULOGENESIS

Primordial follicles are seen on the foetal ovaries as early as 15 weeks' gestation. They surroundthe oocytes, which have completed the first stage of meiosis. The development of primordial follicles continues until all oocytes are surrounded; this takes place between 6 and 9 months' gestation.

The process of primordial follicle recruitment is continuous. It starts in the foetus, continues after birth, and runs until the ovarian reserve is depleted. Follicles up to 5 mm in size (class 5) are always present in ovaries, from infancy to menopause. This is because these follicles require only small amounts of gonadotrophins. However, class 5 or bigger follicles are dependent on larger quantities of hormones during the 20 days preceding ovulation.

Activity	Recruitment and initiation			Growth				Selection	Maturation			
Follicle category	Primordial	Primary	Secondary	Pre-antral	Early-antral			Antral		Early-ovulatory	Preovulatory	Ovulation
Follicle class	-	-	-	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	
Follicle diameter		0.03–0.06mm	0.06–0.12mm	0.12–0.2mm	0.2–0.4mm	0.4–0.9mm	0.9–2.0mm	2–5mm	6–10mm	10–16mm	16–20mm	
Duration		>150 days	~120 days	25 days	20 days	15 days	10 days	5 days	5 days	5 days	5 days	
Hormones	-	Gonadotrophin responsive			Gonadotrophin dependent (FSH)			Higher levels of hormones (FSH, LH and others)				
Blood supply	-		Hormones and nutrients delivered via blood supply in follicles >0.08mm									
TCM influences	Jing		Jing, Yin, Qi and Blood									

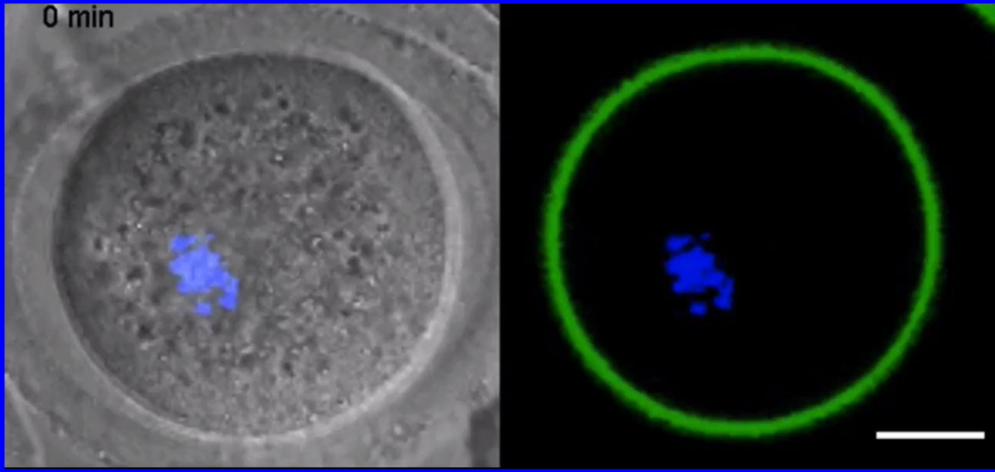
Figure 2.11 Follicular development in a human ovary with a conjectural overview of TCM influences.

PHASES OF OOGENESIS:

3. ***Maturation phase*** is characterized by meiosis. In this, the diploid and fully grown primary oocyte undergoes meiosis-I (reductional division) to form two unequal haploid cells. The smaller cell is called ***first polar body*** (***Polocyte***) and has very small amount of cytoplasm. The larger cell is called secondary oocyte and has bulk of nutrient-rich cytoplasm. Both of these are haploids and each has 23 chromosomes.

Secondary oocyte undergoes meiosis-II (equational division) to form two unequal haploid cells. The smaller cell is called ***second polar body*** and has very little of cytoplasm, while the larger cell is called ootid. It has almost whole of cytoplasm and differentiates into an ovum. Meanwhile, first polar body may divide into two.

The primary function of formation of polar bodies is to bring haploidy but to retain the whole of the cytoplasm in one ovum to provide food during the development of zygote to form an embryo.



Stages in oogenesis

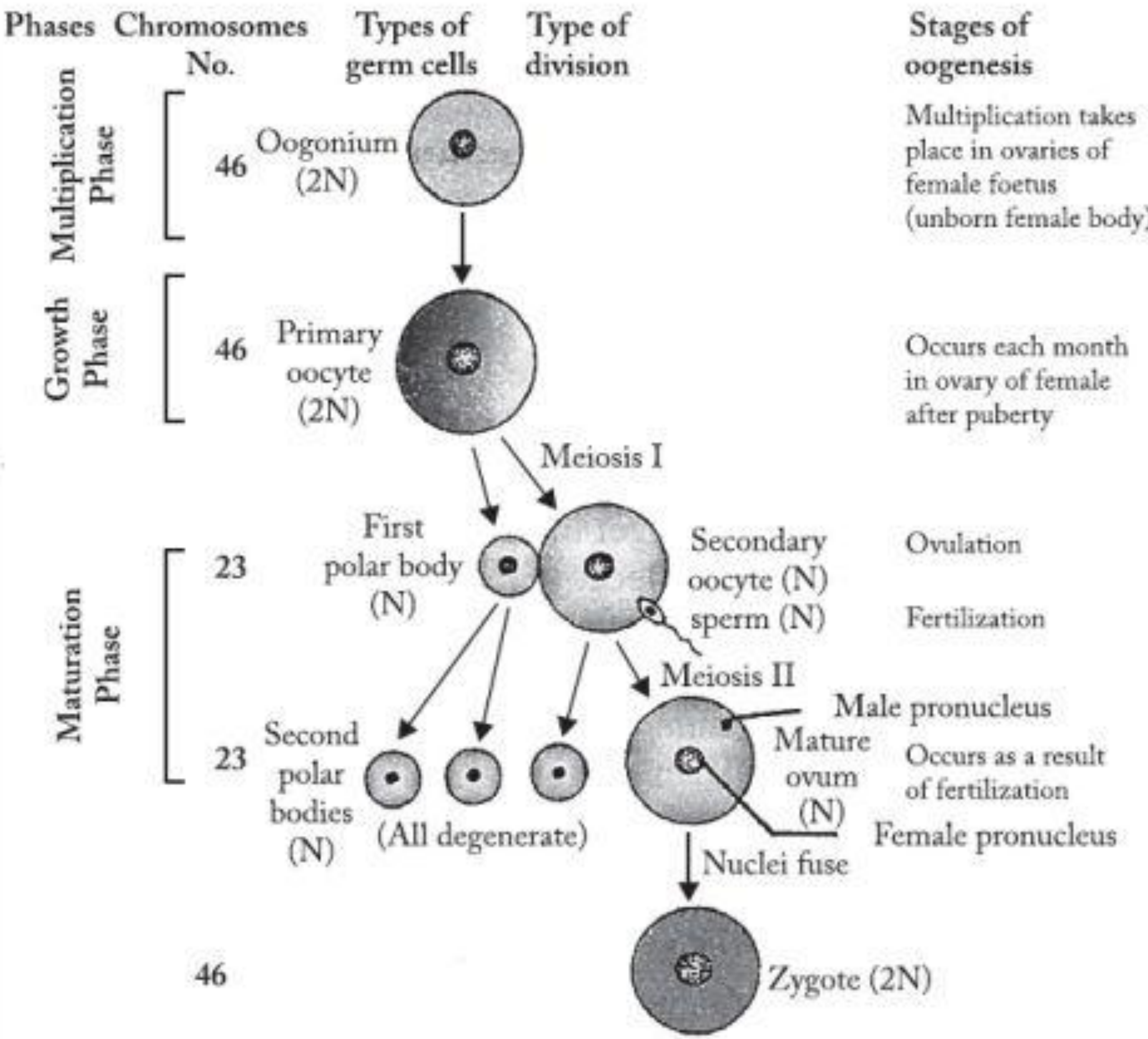
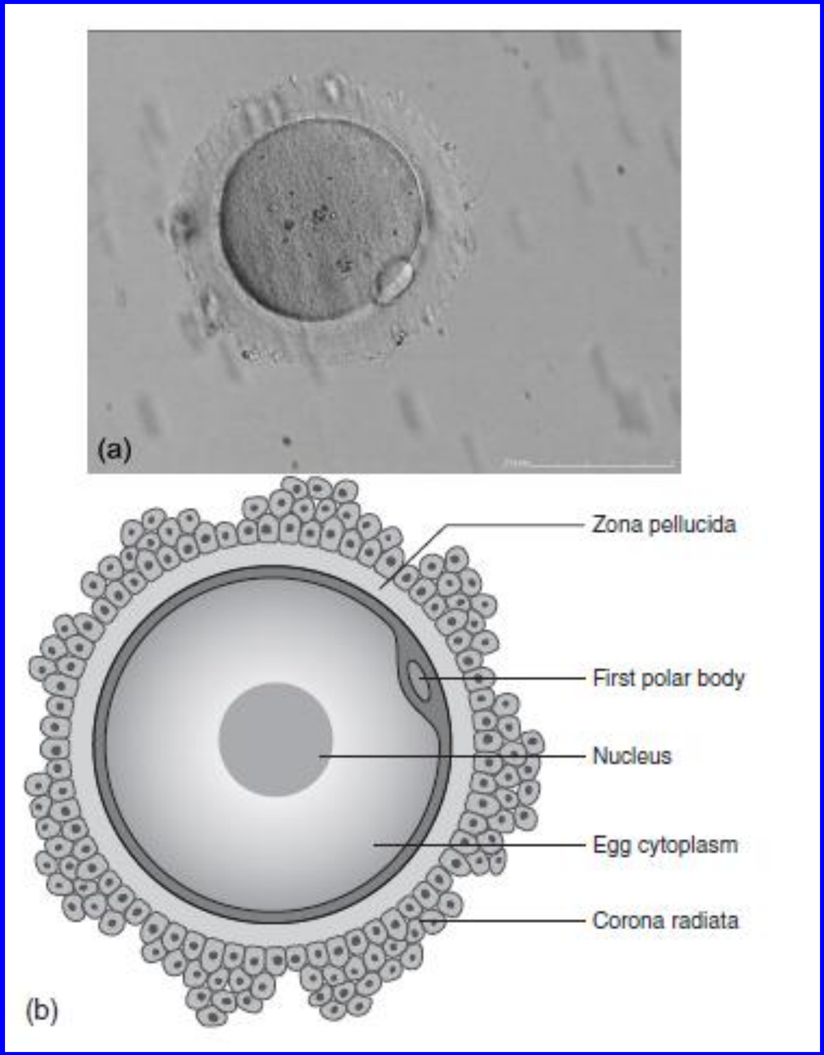


Fig.: Stages in oogenesis.

Meiosis II of the secondary oocyte follows immediately after meiosis 1 is completed but arrests in the metaphase and will remain in this phase until fertilization. The follicle ruptures, and the egg is released. If and when the egg is penetrated by a spermatozoon, this activates the egg, and meiosis II is completed (approximately 3 h later).

STRUCTURE OF THE EGG



A mature egg (ovum, oocyte) is the biggest cell in the body at 0.1 mm. It contains a large nucleus and within it the DNA material of the egg. The egg is surrounded by the corona radiata and the zona pellucida. They are protective layers of the egg, which a spermatozoon needs to penetrate during fertilization. The cytoplasm contains yolk granules that nourish the embryo early in development until it is nourished by its mother.

Egg quality is influenced by the nuclear and mitochondrial genome but also by the microenvironment provided by the ovary.

Summary of the Differences between Spermatogenesis and Oogenesis

	Spermatogenesis	Oogenesis
Process		
Location	Occurs *entirely* in testes	Occurs *mostly* in ovaries
Meiotic divisions	Equal division of cells	Unequal division of cytoplasm
Germ line epithelium	Is involved in gamete production	Is not involved in gamete production
Gametes		
Number produced	Four	One (plus 2 – 3 polar bodies)
Size of gametes	Sperm smaller than spermatocytes	Ova larger than oocytes
Timing		
Duration	Uninterrupted process	In arrested stages
Onset	Begins at puberty	Begins in foetus (pre-natal)
Release	Continuous	Monthly from puberty (menstrual cycle)
End	Lifelong (but reduces with age)	Terminates with menopause

Thank you for attention!