Department of Zoology

U.G. 6TH SEM

COURSE-ZOOHC13

SPERMATOGENESIS

Spermatogenesis is the process by which spermatogonia develop into sperm.

Spermatogenesis, a process by which sperm are produced, involves a complex and unique series of events. It begins shortly before puberty, under the influence of rising levels of pituitary gonadotropins, and continues throughout life. It can be mainly divided into three distinct phases:

1. **Spermatogonial phase,** in which spermatogonia divide by mitosis to replace themselves as well as provide a population of committed spermatogonia that will eventually give rise to primary spermatocytes.
2. **Spermatocyte phase (meiosis),** in which primary spermatocytes undergo two meiotic divisions to reduce both the chromosome number and amount of DNA to produce haploid cells called spermatids.
3. **Spermatid phase (spermiogenesis),** in which spermatids differentiate into mature sperm cells.

At the end of spermatogenesis, spermatids undergo their final maturation and are released during a process called **spermiation** from the supporting Sertoli cells into the lumen of the seminiferous tubule.

A. Spermatogonial Phase

In the spermatogonial phase, stem cells divide to replace themselves and provide a population of committed spermatogonia.

Spermatogonial stem cells undergo multiple divisions and produce spermatogonial progeny that display differences in nuclear appearance in routine H&E preparations. **Human spermatogonia** are mainly of three types:

• **Type A dark (Ad) spermatogonia** have ovoid nuclei with intensely basophilic, finely granular chromatin. These spermatogonia are thought to be the stem cells of the seminiferous epithelium. They divide at irregular intervals to give rise to either a pair of type Ad spermatogonia that remain as **reserve stem cells** or to a pair of type Ap spermatogonia.

• **Type A pale (Ap) spermatogonia** have ovoid nuclei with lightly staining, finely granular chromatin. Ap spermatogonia are committed to the differentiation process that produces the sperm. They undergo several successive mitotic divisions, thereby increasing their number. Type Ap spermatogonia are also called **renewing stem cells.**

• **Type B spermatogonia** have generally spherical nuclei with chromatin that is condensed into large clumps along the nuclear envelope and around a central nucleolus.

B. Spermatocyte Phase (Meiosis)

In the spermatocyte phase, primary spermatocytes undergo meiosis to reduce both the chromosome number and the amount of DNA.

The mitotic division of type B spermatogonia produces **primary spermatocytes.** They replicate their DNA shortly after they form and before meiosis begins, so that each primary spermatocyte contains the normal chromosomal number (2n) and double the amount of DNA (4d).

Prophase of the first meiotic division, during which the chromatin condenses into visible chromosomes, lasts up to 22 days in human primary spermatocytes. At the end of prophase, 44 autosomes and an X and a Y chromosome, each having two chromatin strands (chromatids), can be identified. Homologous

chromosomes are paired as they line up on the metaphase plate. The **paired homologous chromosomes,** called **tetrads** because they consist of four chromatids, exchange genetic material in a process called **crossing-over.** During this exchange, the four chromatids rearrange into a tripartite structure called a **synaptonemal complex.** This process ensures genetic diversity. Through genetic exchange, the four spermatids produced from each spermatocyte differ from each other and from every other spermatid. After crossing-over is complete, the homologous chromosomes separate and move to the opposite poles of the meiotic spindle. Thus, the tetrads, which have been modified by crossing-over, separate and become dyads again. The two chromatids of each original chromosome (although modified by crossing-over) remain together. This is just the opposite of what happens in mitosis, in which the paired chromatids—one representing the "template" and the other, newly synthesized DNA—separate.

The movement of a particular chromosome of a homologous pair to either pole of the spindle is random (i.e., maternally derived chromosomes and paternally derived chromosomes do not sort themselves out at the metaphase plate). This random sorting is another source of genetic diversity in the resulting sperm.

The cells derived from the first meiotic division are called **secondary spermatocytes.** These cells immediately enter the prophase of the second meiotic division ***without synthesizing new DNA*** (i.e., without passing through an S phase.

The second meiotic division is short and lasts only several hours. Each secondary spermatocyte has a reduced number of chromosomes (1n), which is represented by 22 autosomes and an X or a Y chromosome. Each of these chromosomes consists of two sister chromatids. The secondary spermatocyte has the (2d) diploid amount of DNA. During metaphase of the second meiotic division, the chromosomes line up at the metaphase plate, and the sister chromatids separate and move to opposite poles of the spindle.

As the second meiotic division is completed and the nuclear membranes re-form, two haploid **spermatids,** each containing 23 single-stranded chromosomes (1n) and the 1d amount of DNA, are formed from each secondary spermatocyte.

C. Spermatid Phase (Spermiogenesis)

In the spermatid phase, spermatids undergo extensive cell remodeling as they differentiate into mature sperm.

The spermiogenic phase (spermiogenesis) involves morphologic and functional differentiation of newly formed spermatids into mature spermatozoa. Early in this transformation, the Golgi apparatus packages material that initiates acrosome formation. A flagellum forms from the centrioles and becomes associated with the nucleus. The nucleus progressively elongates as its chromatin condenses. These elongated spermatids are deeply embedded in the Sertoli cell cytoplasm.

During spermiogenesis the **genome is repackaged with protamines rather than histones**, which is necessary to reduce the volume of the genetic payload from the relatively bulky round spermatids to the streamlined spermatozoa (compare the size of the elongated spermatids Late spermatids are released (spermiation) almost simultaneously through the activity of the Sertoli cell. The release of spermatids is associated with the loss of the residual cytoplasm. The process of spermiogenesis occurs without cell divisions, is one of the most phenomenal cell transformations in the body, and can be subdivided into many characteristic steps. For example, this process can be divided into 16 steps in the mouse and 6 steps in the human.

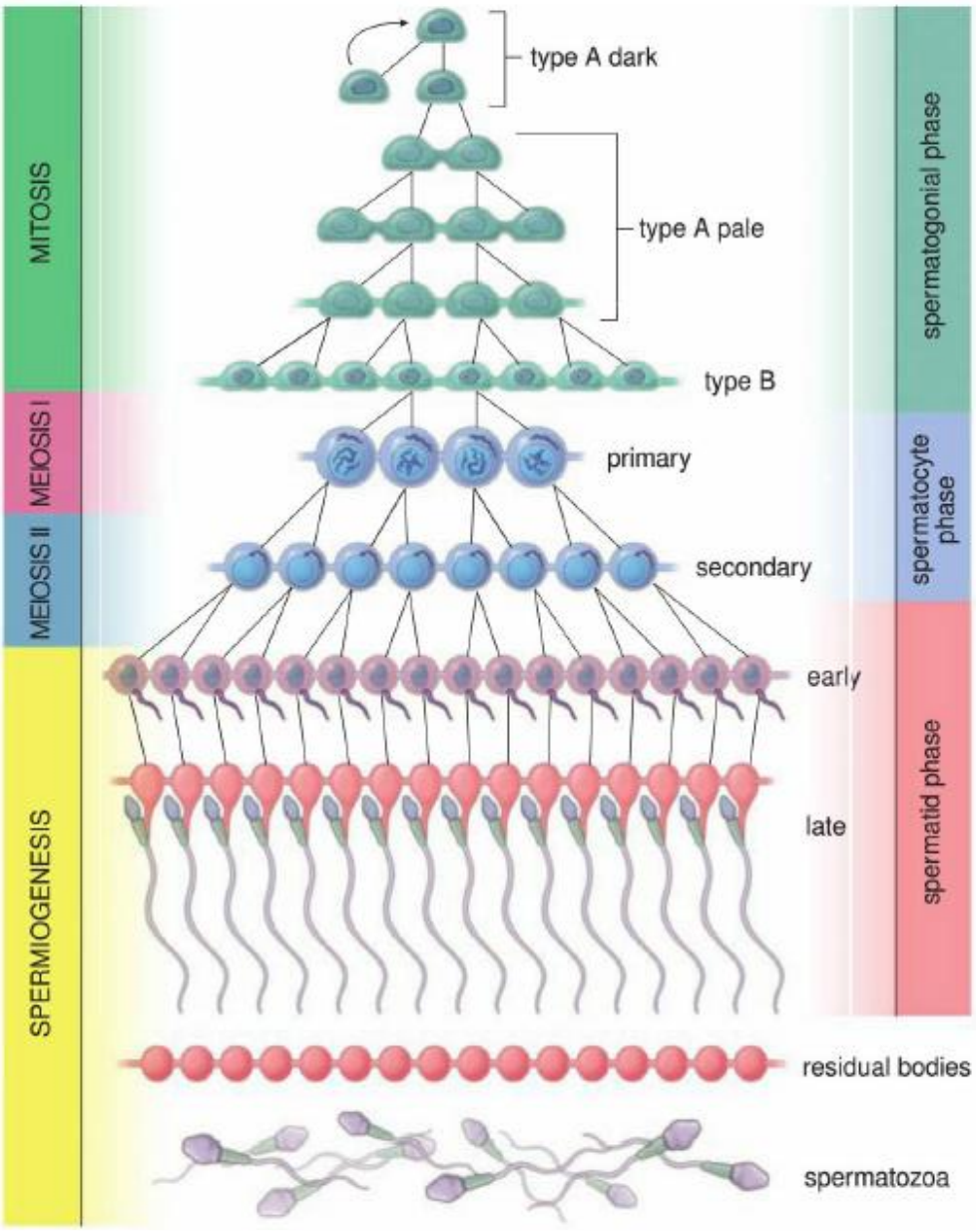

Figure- Schematic diagram illustrating the process of spermatogenesis

Hormonal Control of Spermatogenesis:

Spermatogenesis is initiated due to increase in gonadotropin-releasing hormone (GnRH) by the hypothalamus. GnRH acts on the anterior lobe of pituitary gland to secrete luteinizing hormone (LH) and follicle stimulating hormone (FSH). LH acts on the Leydig's cells of the testes to secrete testosterone.
FSH acts on Sertoli cells of the seminiferous tubules of the testes to secrete an androgen binding protein (ABP) and inhibin. ABP concentrates testosterone in the seminiferous tubules. Inhibin suppresses FSH synthesis. FSH acts on spermatogonia to stimulate sperm production.

Significance of Spermatogenesis:

(i) During spermatogenesis, one spermatogonium produces four sperm, (ii) sperm have half the number of chromosomes. After fertilization, the diploid chromosome number is restored in the zygote. It maintains the chromosome number of the species, (iii) during meiosis I crossing over takes place which brings about variation, (iv) spermatogenesis occurs in various organisms. Thus it supports the evidence of the basic relationship of the organisms.

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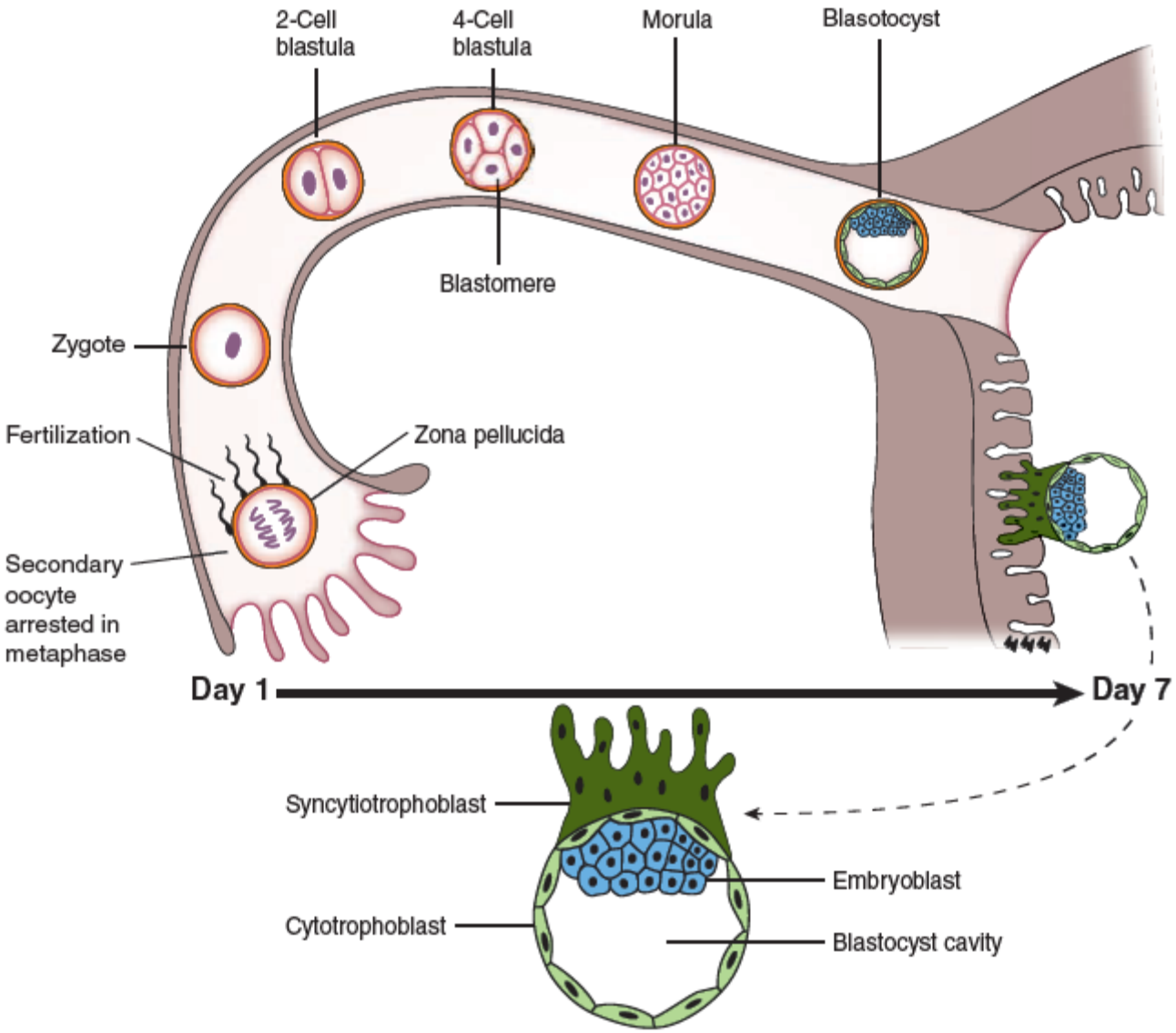
FERTILIZATION

a) Fertilization occurs in the ampulla of the uterine tube.
b) Male and female pronuclei fuse, forming a **zygote (a new cell whose genotype is a combination**
c) of maternal and paternal chromosomes).
d) **Syngamy** is a term that describes the successful completion of fertilization, that is, the formation of a zygote.
e) **Cleavage** is a series of mitotic divisions of the zygote.
f) The process of cleavage eventually forms a **blastula** consisting of cells called **blastomeres.**
g) A cluster of blastomeres (16–32 blastomeres) forms a **morula.**
h) Blastomeres are **totipotent** up to the eight-cell stage (i.e., each blastomere can form a complete embryo by itself). **Totipotency** refers to a stem cell that can differentiate into every cell within the organism, including extraembryonic tissues.
i) **Blastocyst** formation involves fluid secreted within the morula that forms the blastocyst cavity. The conceptus is now called a **blastocyst.**

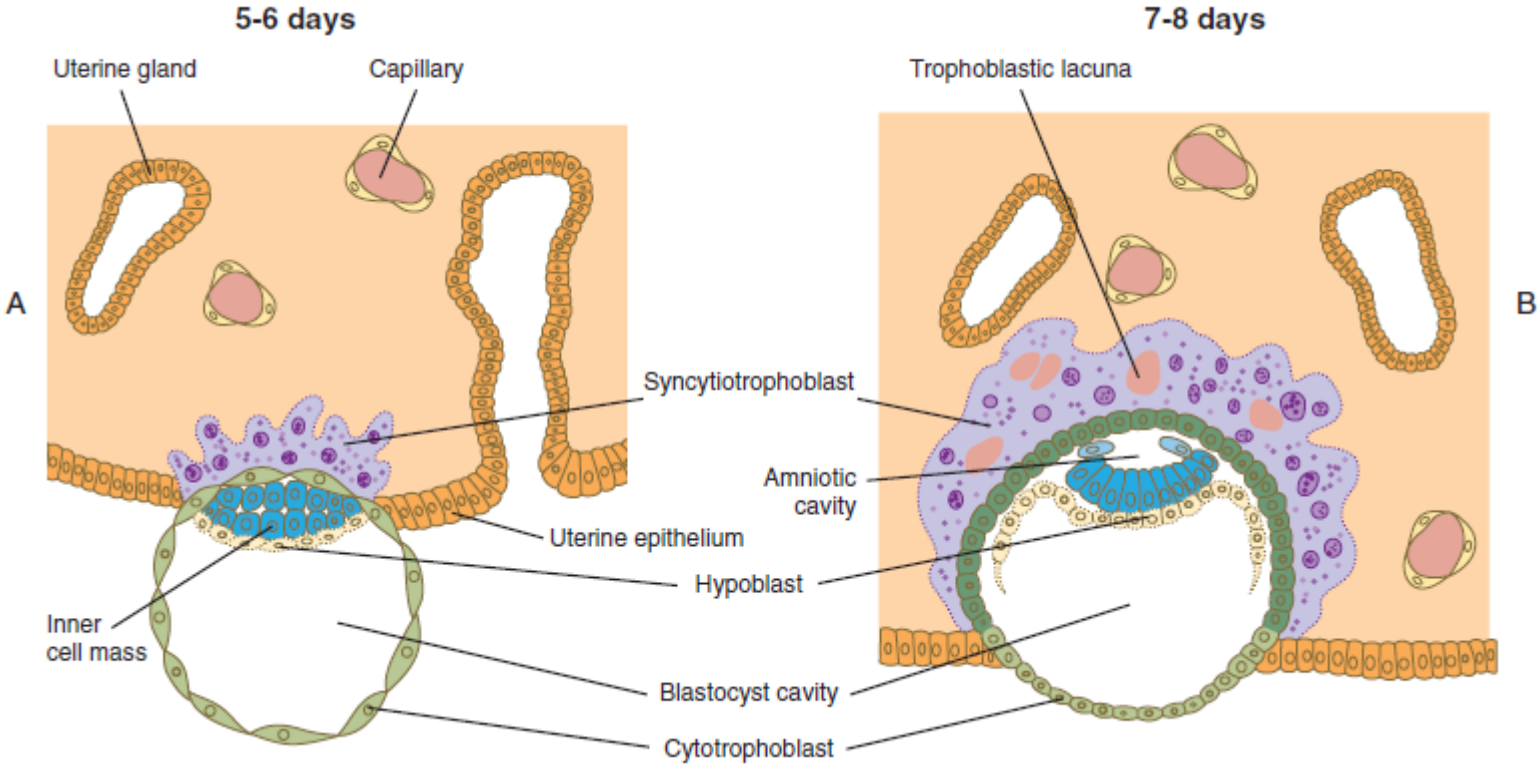
1. The inner cell mass of the blastocyst is called the **embryoblast (becomes the embryo**). The embryoblast cells are **pluripotent. Pluripotency** refers to a stem cell that can differentiate into ectoderm, mesoderm, and endoderm.

2. The outer cell mass of the blastocyst is called the trophoblast (becomes the fetal portion of the placenta).


2-Cell blastula
4-Cell blastula
Morula
Blasotocyst
Blastomere
Zygote
Fertilization
Zona pellucida
Secondary oocyte arrested in metaphase
Day 1
Day 7
Syncytiotrophoblast
Embryoblast
Cytotrophoblast
Blastocyst cavity

IMPLANTATION

1. The blastocyst usually implants within the **posterior superior wall of the uterus by day 6-7 after fertilization.**
2. Implantation occurs in the **functional layer of the endometrium** during the progestational (secretory) phase of the menstrual cycle. **The trophoblast** proliferates and differentiates into the **cytotrophoblast** and **syncytiotrophoblast.**



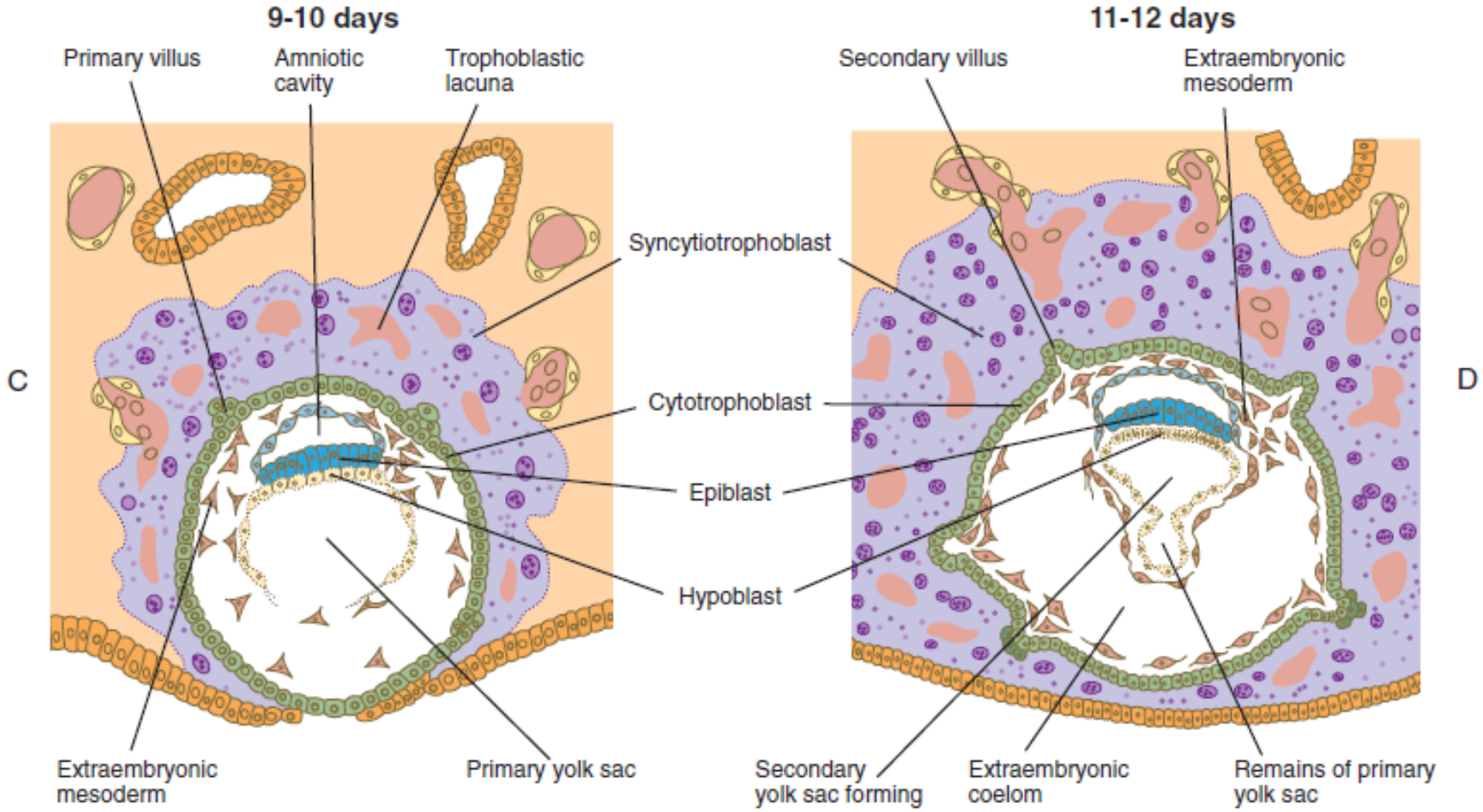


FIGURE . Major stages in implantation of a human embryo. A, The syncytiotrophoblast is just beginning to invade the endometrial stroma. B, Most of the embryo is embedded in the endometrium; there is early formation of the trophoblastic lacunae. The amniotic cavity and yolk sac are beginning to form. **C, Implantation is almost complete,** primary villi are forming, and the extraembryonic mesoderm is appearing. **D, Implantation is complete; secondary villi are forming.**

PLACENTA

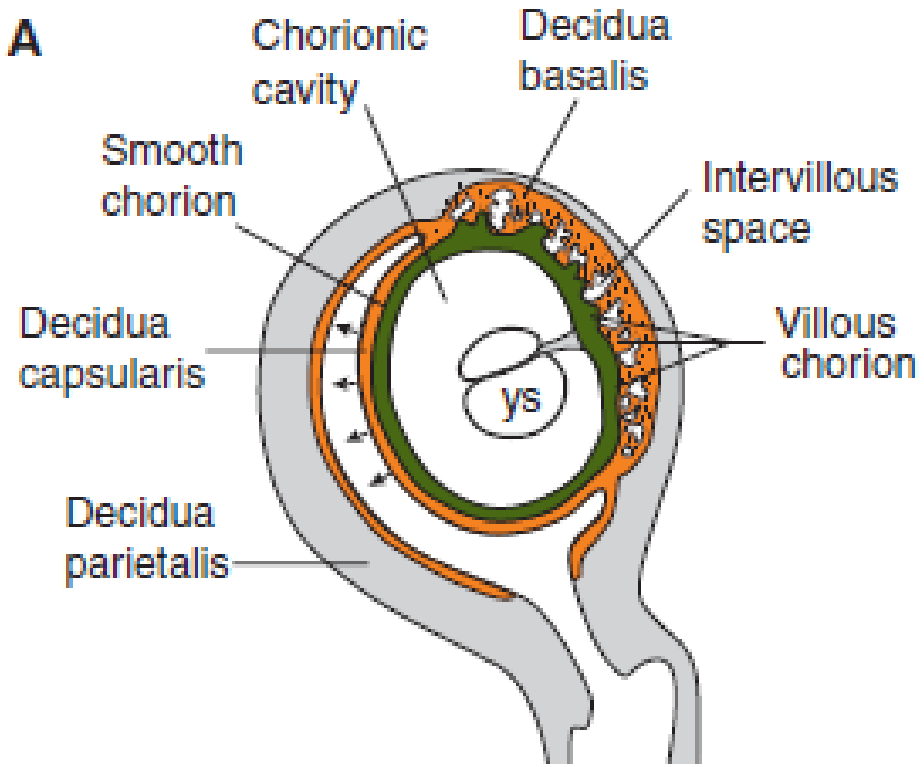
1. The placenta develops as the embryo invades the endometrium of the uterus and as the trophoblast forms the villous chorion. The formation of the villous chorion proceeds through three stages: **primary chorionic villi, secondary chorionic villi, and tertiary chorionic villi.**
2. The human placenta is **hemochorial** (i.e., maternal blood comes in direct contact with the chorion) and **discoid-shaped.**

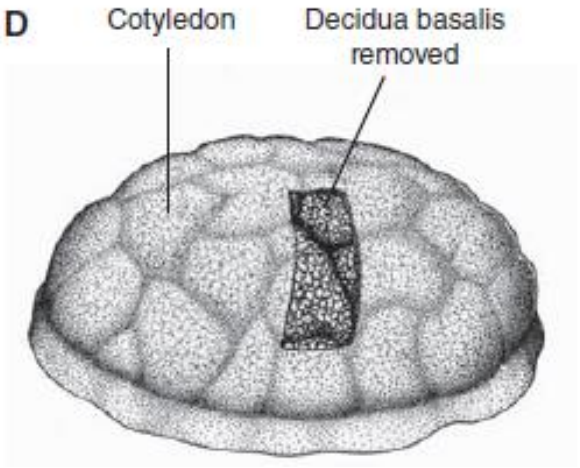
A. The maternal component

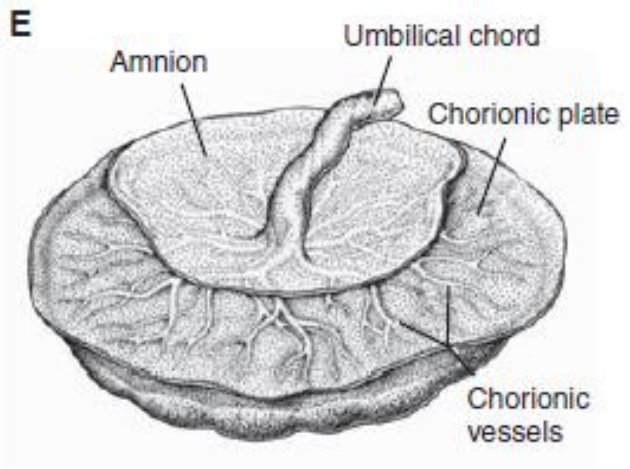
1. The maternal component of the placenta consists of the **decidua basalis**. The decidua basalis includes the portion of the endometrium located between the blastocyst and the myometrium (i.e., the site of implantation). The **decidua parietalis** includes all portions of the endometrium other than the site of implantation.
2. The decidua basalis and decidua parietalis shed as part of the afterbirth.
3. The **decidua capsularis** includes the portion of endometrium that covers the blastocyst and separates the blastocyst from the uterine cavity.
4. The term *decidua means "falling off," "shed," or "sloughed off."*
5. The maternal surface of the placenta is characterized by 8–10 compartments called **cotyledons**, which impart a cobblestone appearance to the maternal surface. The cotyledons are separated from each other by decidual (placental) septa.
6. The maternal surface is dark red and oozes blood due to torn maternal blood vessels.

B. The fetal component

1. The fetal component of the placenta consists of **tertiary chorionic villi** derived from both the trophoblast and extraembryonic mesoderm, which collectively are called the villous (bushy) chorion.
2. The villous chorion develops prolifically at the decidua basalis.
3. The villous chorion contrasts to an area of no villous development known as the smooth chorion. The smooth chorion contacts the decidua capsularis.







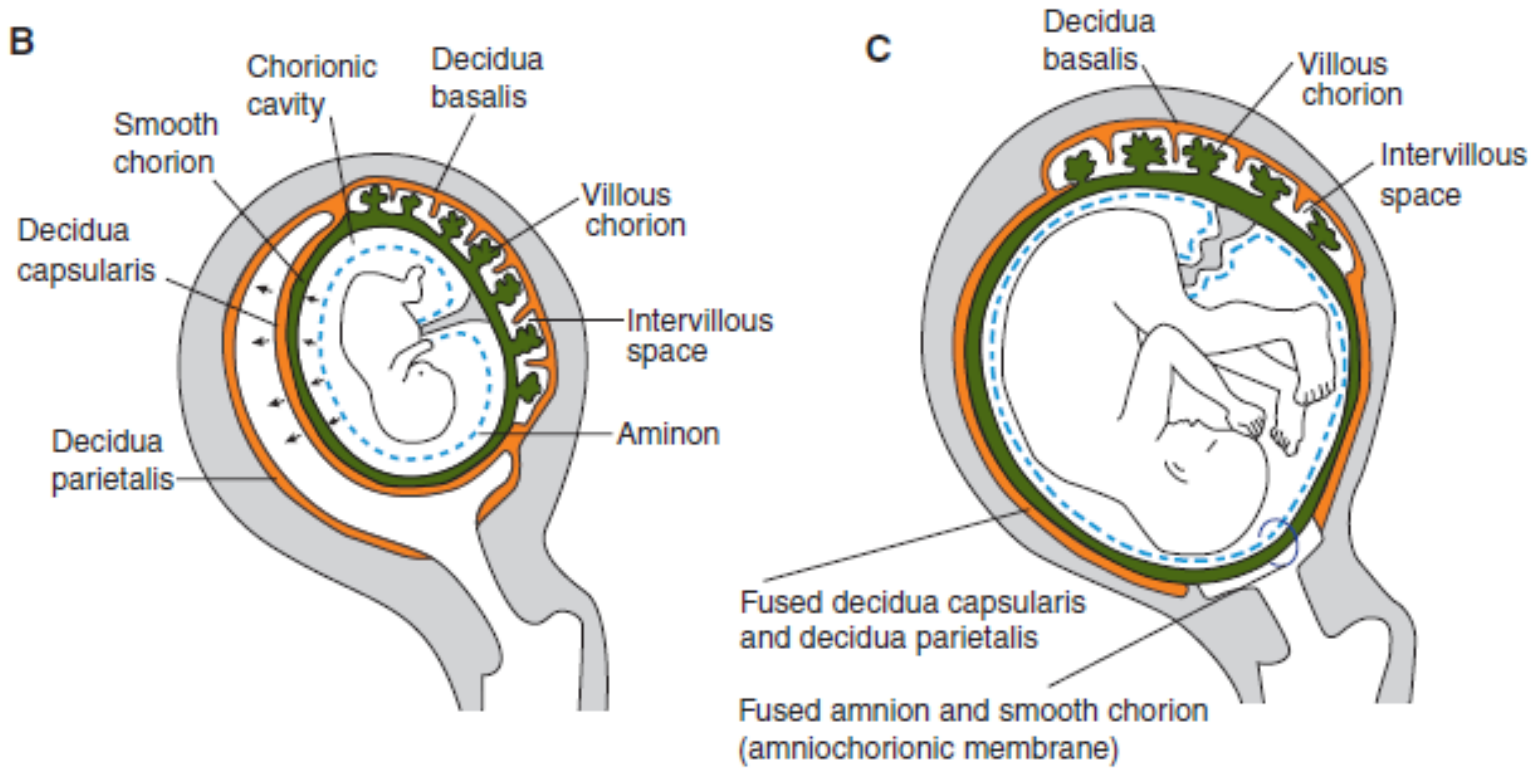


FIGURE. Diagram showing the relationship of the fetus, uterus, and placenta. A. Week 4. The diagram shows the early stages of placenta formation.. **B. Early fetal period. C. Late fetal period. D. Maternal surface** of the placenta**. E. Fetal** surface of the placenta.

Development of Chorionic villi

1. All elements (syncytium, cytotrophoblast and extraembryonic mesoderm) take part in formation of chorionic villi. Three stages in formation of chorionic villi are seen:

2. **Primary villus:** central core of cytotrophoblast covered by a layer of syncytiotrophoblast. Adjoining villi are separated by an intervillous space.

3. **Secondary Villus** (Early 3rd week): Central core of extraembryonic mesoderm covered successively by cyto and syncytiotrophoblasts.

4. **Tertiary Villus** (End of 3rd week): Appearance of blood vessels in the mesoderm forming core of each villus.

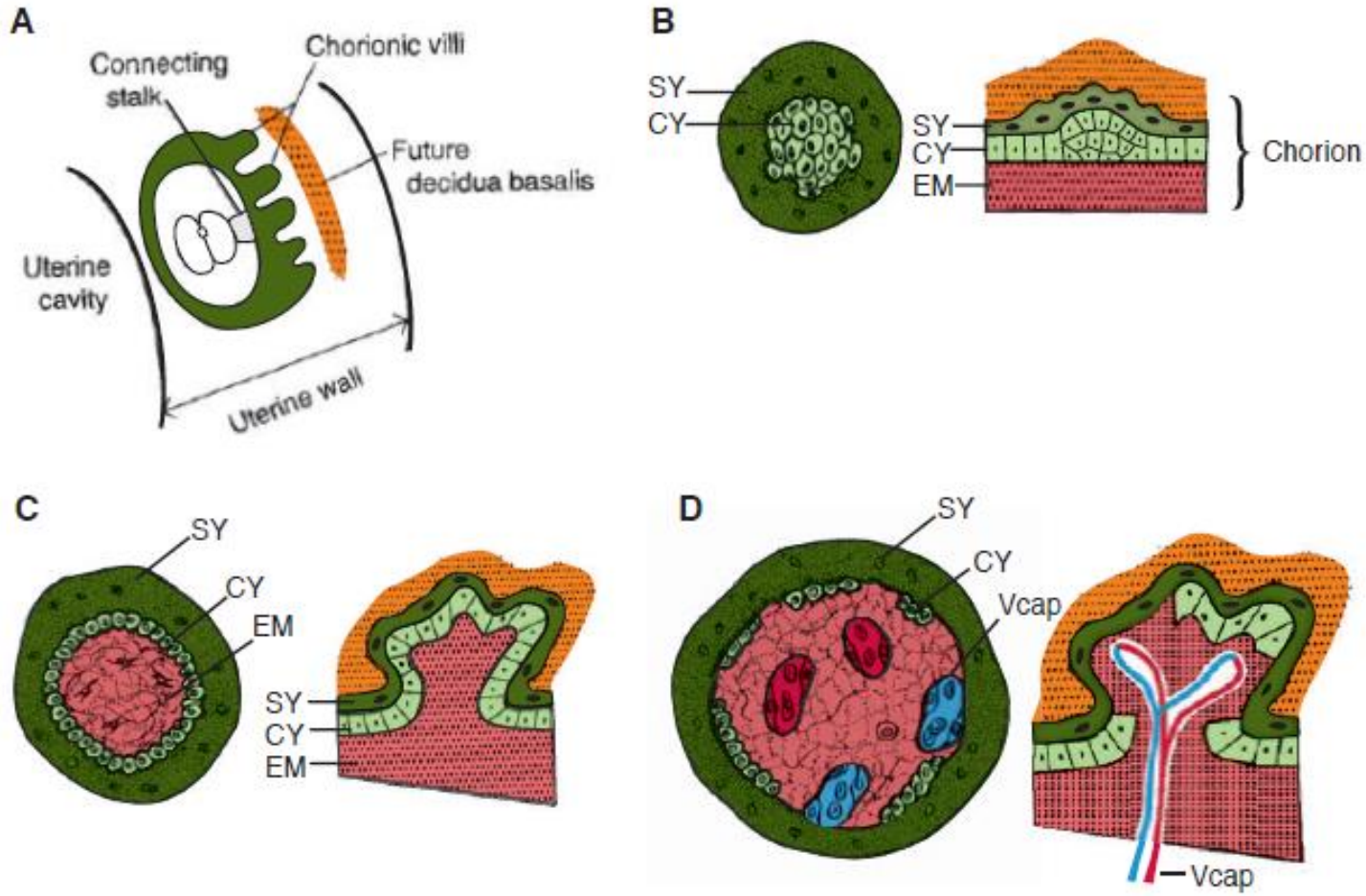
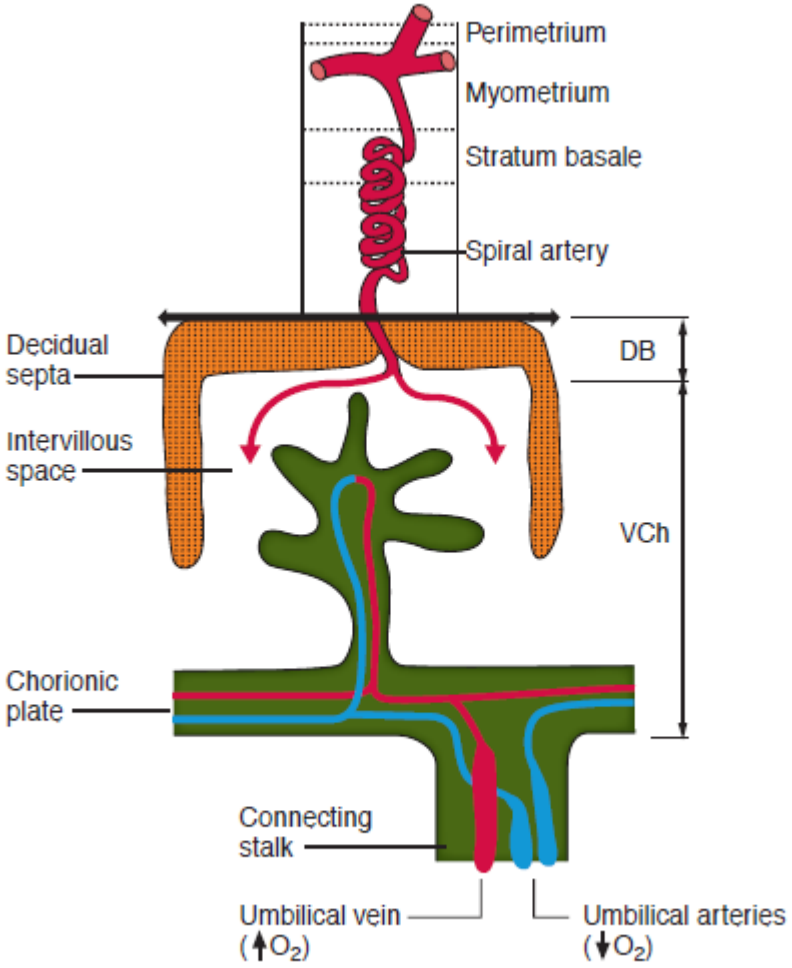


FIGURE. Diagram of the various stages of villous chorion formation. A. A week 2 embryo completely embedded in the wall of the uterus. **B. Primary chorionic villus during week 2. A primary villus consists of a core of cytotrophoblastic** cells (CY, light green) surrounded by syncytiotrophoblast (SY, dark green). **C. Secondary chorionic villus during the start** of week 3. A secondary villus consists of a core of extraembryonic mesoderm (EM, light red) surrounded by cytotrophoblastic cells (CY, light green) and syncytiotrophoblast (SY, dark green). **D. Tertiary chorionic villus at the end of week** 3. A tertiary villus consists of a core of villous (fetal) capillaries (Vcap, red and blue) surrounded by scattered cytotrophoblastic cells (CY, light green) and syncytiotrophoblast (SY, dark green).



The **villous chorion (VCh),** which consists of tertiary chorionic villi, and the decidua basalis (DB) constitute the definitive placenta. The thick, double-headed arrow indicates the plane of separation when the placenta is shed during the afterbirth. The cytotrophoblast penetrates the syncytiotrophoblast to make contact with the decidua basalis and form the outer cytotrophoblast shell, which secures the tertiary chorionic villus in an upright position.

PLACENTAL MEMBRANE

The placental membrane separates maternal blood from fetal blood. A common misperception is that the placental membrane acts as a strict "barrier." However, a wide variety of substances freely cross the placental membrane. Some substances that cross can be either beneficial or harmful. Some substances do not cross the placental membrane. The composition of the placental membrane changes during pregnancy.

A. **In early pregnancy,** the placental membrane has **four layers: syncytiotrophoblast, cytotrophoblast, connective tissue, and the endothelium of fetal capillaries.**
B. **In late pregnancy,** the placental membrane **has two layers: the syncytiotrophoblast and the endothelium of fetal capillaries.**