Meiosis, Spermatogenesis, and Oogenesis

Each human cell has 46 chromosomes in its nucleus. More accurately, each has 23 pairs of homologous chromosomes (referred to as the diploid number), chromosomes that look alike and carry genes that code for the same traits. Eggs and sperm, however, carry only 23 chromosomes total, half the usual number. The original number of 46 is then reestablished when the egg and sperm unite in fertilization. This reduction in chromosome number takes place in the process of meiosis, a process that requires two cellular divisions. (Review Mitosis pp. 85 – 89)

In the male, meiosis takes place in the spermatogenic cells of the seminiferous tubules. During the S phase of the cell cycle the DNA is replicated. In prophase of the first meiotic division, the DNA condenses into chromosomes. Each of the 46 chromosomes will be attached to an exact replicate of itself called its sister chromatid. Each chromosome with its sister chromatid then comes to lie next to its homologous chromosome forming a tetrad. While a tetrad, crossing over takes place. This occurs when segments of the sister chromatids exchange pieces of chromosome with the sister chromatids of the corresponding homologous chromosomes. This results in a recombination of DNA and a mixing of genetic traits. During anaphase of the first meiotic division the homologous chromosomes, still attached to their sister chromatid, migrate to opposite ends of the cell. Telophase and cytokinesis follow. Each cell now has 46 chromosomes, one or the other of the homologous chromosomes plus its identical sister chromatid.

During anaphase of the second meiotic division, the sister chromatids separate and migrate to the opposite ends of the cell and cytokinesis follows. Note that no DNA synthesis preceded the second meiotic division and therefore the chromosome number is reduced from 46 to 23 (referred to as the haploid number). From each spermatogenic (spermatogonia) cell that undergoes meiosis, four sperm cells will result.

The newly formed haploid cells are called spermatids and will develop into mature sperm. The mature sperm consists of a head, containing the nucleus, a midpiece packed with mitochondria, and a motile tail (flagellum) to propel the sperm. In front of the nucleus is the acrosome containing enzymes which help the sperm penetrate the egg. Surrounding the maturing sperm are Sertoli cells which nourish the developing sperm and secrete testicular fluid, a transport medium.

Sperm development, spermatogenesis, begins at puberty. Gonadotropin-releasing Hormone (GnRH) from the hypothalamus stimulates the pituitary to release FSH and LH. The LH stimulates the interstitial cells to secrete testosterone. Testosterone then binds to the spermatogenic cells stimulating meiosis.

Oogenesis

In the male, gametogenesis begins at puberty but in the female the number of eggs is determined at birth. During fetal life, primary oocytes (over a million), surrounded by follicle cells, begin the first meiotic division but stop at prophase I. Beginning at puberty, one of these primary oocytes completes the first meiotic division. However there is unequal cytoplasmic division. One cell gets almost no cytoplasm and is called the first polar body. The other retains, by far, the greater amount of cytoplasm and becomes the secondary oocyte. The secondary oocyte is stopped again during the second meiotic division and is released in ovulation. If penetrated by sperm, it completes meiosis II and produces a second polar body, and becomes a fertilized egg or zygote.

During maturation, the primary oocyte and its surrounding follicle (or granulose) cells grow to about an inch in diameter and as a Graafian follicle can be seen as a bulge on the ovarian wall. As the primary follicle grows, fluid accumulates within the follicle (the antrum) enclosing the oocyte and some of the follicle cells, the latter called the corona radiata. After meiosis I is completed, the ovarian wall ruptures and the secondary oocyte with the corona radiata is released at ovulation.

Hormonal Control of Ovulation

At puberty, menarche is initiated. On day one of the menstrual cycle, rising levels gonadotropin-releasing hormone (GnRH) released by the hypothalamus stimulates the anterior pituitary to release follicle stimulating hormone (FSH) and luteinizing hormone (LH) which results in the rapid growth of follicular cells. As the follicle enlarges, estrogen is secreted. This estrogen causes a proliferation of the endometrium in anticipation of conception. At first, as estrogen levels rise in the plasma, the release of FSH and LH are inhibited (although the anterior pituitary continues to synthesize these hormones.) After a certain level of estrogen is reached, there is a sudden release of LH (and a little FSH) from the pituitary at about day 14. This burst of LH triggers the completion of the first meiotic division of the oocyte and subsequent ovulation. After ovulation the levels of estrogen decline but the LH stimulates the ruptured follicle to form the corpus luteum which immediately starts producing estrogen and progesterone. These inhibit pituitary release of FSH and LH and thus the inhibition of new follicle development. As LH levels decline the corpus luteum begins to degenerate and with it, the levels of estrogen and progesterone and as these last two hormones decline to a certain low level, at about day 28, FSH and LH are then again released by the anterior pituitary. If an egg is fertilized, however, the embryo releases a LH-like hormone (human chorionic gonadotropin or hCG) so that the corpus luteum continues to produce estrogen and progesterone. This function is later carried out by the placenta which eventually produces the estrogen and progesterone itself. This cycle continues until menopause when the estrogen produced by the ovaries begins to decline.

Oral contraceptives usually contain both estrogen and progesterone which inhibit ovulation by suppressing LH and FSH which in turn suppress follicle development.

Menstrual Cycle

Days 1 – 5: Low levels of estrogen and progesterone causes the functional layer of the uterine endometrium to slough. Blood and tissues are passed through the vagina as the menstrual flow. FSH levels begin to rise stimulating follicle growth and thus estrogen production.

Days 6 – 14: With rising estrogen levels, the functional layer of the endometrium is rebuilt. Rising estrogen levels also cause cervical mucus to thin allowing for the passage of sperm. The surge of LH release and ovulation occur at the end of this stage.

Days 15 – 28: Rising progesterone levels continue to prepare the endometrium for implantation. These levels also increase the viscosity of cervical mucus. Progesterone is also inhibiting LH release from the pituitary. At the end of this phase the corpus luteum degenerates causing the endometrium to again slough off.

Fertilization

Of the millions of sperm ejaculated, only a small percentage will reach the uterine tubes where fertilization normally occurs. Semen, the mixture of sperm and accessory gland secretions, contains the sugar fructose which provides fuel as the sperm has little cytoplasm. In order to penetrate the corona radiata and deep to the corona, the zona pellucida membrane, the acrosomal enzymes of many sperm are needed. Once a single sperm makes contact with the plasma membrane of the oocyte, the two plasma membranes fuse and nucleus of the sperm is pulled into the cytoplasm of the oocyte. As soon as fusion of the membranes occurs, sodium channels are opened and Na^+ diffuses into the space between the cell membrane and the zona pellucida. This causes a depolarization of the cell membrane preventing the fusion of another sperm cell. Enzymes are also released into this space destroying sperm receptors and detaching remaining sperm. Thus monospermy is assured.

The fertilized egg, or zygote, implants on the uterine wall on or about day four. The conceptus, the new life created by fertilization is called a pre-embryo until the third week, an embryo from weeks 3 to 8 and thereafter is referred to as a fetus. The zygote proceeds through a number of cell divisions forming a hollow, spherical blastocyst. Some of the outer cells of the sphere will form the embryo’s part of the placenta. The other part of the placenta is derived from maternal tissue. A small mass of cells, called the inner cell mass, is found within the sphere and will differentiate into the embryo. These undifferentiated cells are the embryonic stem cells.